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Spectral modulation detection in normal hearing children

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SPECTRAL MODULATION DETECTION IN NORMAL HEARING CHILDREN

by

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Abstract:* *This Capstone Project attempts to determine the ability of normal hearing children to resolve spectral information, and the relationship between spectral resolution ability and speech recognition ability in noise. This study also examines how these abilities develop with age.

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Background

For normal auditory perception a listener must recognize complex patterns of acoustic signals. Subtle differences in sounds that make up language, such as the /k/ and /b/ in “cat” versus “bat,” are represented by different patterns of energy across the audio frequencies sensitive to humans. Such patterns across frequency are often called ‘spectral shape’ or ‘spectral envelope.’ Formants, or resonant peaks of energy in the spectral envelope, are prominent acoustic characteristics for certain classes of speech sounds, and perceptually, spectral resonances allow differentiation amongst speech sounds. For example, the ability to resolve the first two or three formants of speech is imperative in the identification of vowels (Henry and Turner, 2003). The listener must perceive these spectral envelope characteristics to identify sounds and discern the intended message in speech.

Perception of the spectral envelope, or spectral cues in general, relies on underlying frequency-tuning abilities of the listener. Normal hearing listeners, who have sharply-tuned frequency selectivity, are able to easily and accurately make use of the spectral information in a speech signal. However, individuals with hearing impairment often have a “blurred” representation of the spectral envelope. Impaired frequency selectivity has been documented in hearing impaired listeners using both physiological and psychophysical measures (Henry and Turner, 2003). Compared to listeners with normal hearing, the bandwidths of auditory filters are much wider in individuals with cochlear hearing loss (Glasberg and Moore, 1986). Subjective self-reports from hearing impaired listeners, as well as objective measures of speech perception, indicate cochlear hearing impairment causes a “distortion” of speech and reduces speech intelligibility. This is verified by the enormous difficulty hearing impaired listeners have when trying to understand speech in noisy situations. This difficulty is believed to be due, in part, to the poor frequency selectivity in the impaired ear.

By definition, individuals with sensorineural hearing loss have damage to their sensory receptors, spiral ganglion neurons, and/or auditory nerve. However, two individuals with the same degree of sensorineural hearing loss, as determined by audiometric thresholds, may have quite different speech recognition scores with a hearing aid or cochlear implant device. Some researchers suggest that such differences in speech scores may be due to differing abilities of listeners to resolve spectral information, or due to their differing natural ability to differentiate spectral peaks in a sound spectrum (Henry and Turner, 2003). A hearing aid (HA) has the ability to amplify sound, but cannot "unblur" the blurry representation of spectral information created by a damaged auditory system. Cochlear implants (CIs), by design, process the sound spectrum in a drastically segmented manner that corresponds to the small number of electrodes on the internal electrode array. The ability of a cochlear implant user to utilize such severely-quantized frequency components, or relatively crude amounts of spectral information, may correspond to and predict that user's speech performance with the implant. Regardless of the primary limiting factor (a damaged auditory system for HA users, or quantized spectral encoding for CI users), some researchers suggest that spectral resolution ability may be a significant factor in determining how well hearing impaired listeners perceive speech, especially in noise (Henry and Turner, 2003; Henry, Turner, & Behrens, 2005).

Several research groups have measured spectral resolution abilities directly (Henry and Turner, 2003; Henry et al., 2005, Litvak, Spahr, Saoji, & Fridman, 2007). They asked listeners to discriminate spectra that differ in a specific spectral envelope parameter, related to either the width or depth of spectral peaks. Researchers believe that performance with these types of stimuli give vital information about the underlying frequency-resolving abilities of listeners and, more importantly, also about listeners' speech recognition abilities. In sum, spectral modulation tasks are hypothesized to measure spectral acuity "directly" while speech recognition in the presence of background noise may assess spectral acuity "indirectly."

Henry and Turner (2003) and Henry et al. (2005) attempted to relate psychoacoustic measures of spectral resolution ability with speech recognition performance, especially for listeners with impaired hearing. For a group of 21 cochlear implant users, Henry and Turner (2003) found a significant correlation between spectral-ripple thresholds and vowel identification scores. And, for groups of cochlear implant and hearing aid users, Henry et al. (2005) found significant correlations between their measure of spectral resolution (spectral-ripple thresholds), and both vowel and consonant recognition scores. Henry et al. (2005) suggests "that the ability to resolve spectral peaks in a complex acoustic spectrum may be associated with accurate speech recognition." Results from these two studies support the idea that speech recognition tests and tests of spectral resolution ability may assess the same underlying mechanism, namely frequency-tuning. However, in both these studies, speech recognition was assessed using isolated sounds, either vowels or consonants, and the tests were administered in quiet listening conditions.

More recently, Litvak et al. (2007), Saoji, Litvak, Spahr, & Eddins (2009) Spahr, Saoji, Litvak, & Dorman (2011), and Won, Drennan, & Rubinstein (2007) also found a strong correlation between performance on a spectral resolution task and speech recognition performance for CI users and normal-hearing subjects listening with a CI simulation. In these newer studies, spectral resolution ability was examined with a spectral modulation detection (SMD) task instead of the spectral-ripple discrimination task of Henry et al. In addition, in at least one study, speech recognition was tested in noise with sentence-length materials, instead of being tested in quiet with syllable-length materials. Saoji et al. (2009) found a significant correlation (-0.80 between low spectral modulation thresholds (superior performance) and consonant identification scores in twenty-five adult CI users. Using AzBio sentence materials, Spahr et al. (2011 found that SMD thresholds at low frequencies (e.g., 0.5 or 1.0 cyc/oct) accounted for a significant proportion of the variability in speech understanding scores in quiet and in noise for 11 adult CI users. Won et al., (2007) reported a similar finding in 14 adult cochlear implant users. These researchers found significant correlations between Speech Reception Thresholds (SRTs), in both two-talker babble and in steady-state noise, and spectral-ripple thresholds. They also report, for these same CI users, a significant correlation between CNC word recognition scores in quiet and spectral-ripple thresholds.

Zhang, Spahr, Dorman, & Saoji (2012). Studied individuals who use a cochlear implant at one ear and acoustic hearing at the opposite ear, often called “bimodal” stimulation or device-use. These researchers calculated “bimodal benefit,” defined as user performance with both electrical and acoustic inputs minus performance with just the implant alone (electrical). They found significant correlations between bimodal benefit on speech tasks and SMD thresholds (at 1.0 cyc/oct) for the non-implanted ear ($r = 0.79$ for CNCs in quiet, $r = .89$ for AZ-Bio sentences in noise). Zhang et al. (2012) state that SMD Thresholds may be a better predictor of bimodal benefit than either audiometric pure-tone averages or speech recognition scores using the non-implanted ear.

Litvak et al. (2007) and Saoji et al. (2009) also used “noise vocoders” or “cochlear implant simulations” (CI-simulations, sometimes called “noise vocoded”) to limit spectral information to a small number of bands, mimicking cochlear implant sound processors. These authors tried to determine if spectral smearing is, in fact, a primary determining factor in the speech recognition ability of CI users. This question was addressed by comparing performance of normal hearing adults listening to "noise vocoded" stimuli, created with varying amounts of spectral smearing, with the performance of actual cochlear implant users. The amount of spectral smearing was controlled by a parameter in the CI-simulation program that corresponds to the slope (or spectral spread) of the CI-analyzing filters, specified in dB per octave (dB/oct). Spectral modulation detection experiments and consonant recognition tests were then given to NH listeners, with the various CI-simulations, and to CI users. If spectral smearing is a primary limiting factor for CI users' performance, then normal hearing listeners should exhibit similar levels of performance on spectral resolution and speech tasks as CI users. Litvak et al., (2007) and Saoji et al., (2009) found this to be the case, and concluded that "this close correspondence between performance for normal hearing listeners using their CI simulation and actual CI listeners…is consistent with the notion that, in the absence of fine spectral details CI listeners may be relying on their ability to identify broad spectral patterns for speech identification" (Saoji et al., 2009).

Notably, these studies that relate spectral resolution ability to speech recognition performance have been performed exclusively with adult participants. It is unknown whether this type of result, a strong correlation between spectral modulation detection threshold and speech recognition performance, would be replicated in pediatric listeners of various ages and hearing status. And, yet, it could be quite informative to clinicians if such a strong relation were found in pediatric hearing impaired listeners. Specifically, if spectral resolution abilities and speech recognition scores for hearing-impaired pediatric patients are highly correlated, then performance on such a psychoacoustic spectral-resolution task could be a useful, non-linguistic predictor of speech recognition for children with various device configurations such as cochlear implants, hearing aids, or the two devices combined ('bimodal'). There is tremendous appeal to have a test that predicts ultimate speech-communication benefit with a device, or devices, that is not dependent on a child's current speech or language abilities.

The present study seeks to assess spectral resolution abilities in normal hearing children in two different ways: directly through a spectral modulation task and indirectly via a speech-recognition-in-noise task (Bamford-Kowal-Bench Speech in Noise, Etymotic Corp). The spectral modulation task uses stimuli similar to those in Litvak et al. (2007). In Litvak et al., the experimenter estimates the shallowest spectral-modulation depth at which a listener can distinguish a sinusoidally modulated spectrum from a flat spectrum. Spectral modulation tasks are practical due to the ease of administration and the relatively minimal amount of practice needed to learn the objective. However, since such spectral modulation tasks have been used exclusively with adult participants, it is not known whether children are able to understand and perform these types of task, or at which ages they develop performance similar to adults. Thus, a primary goal of this study is to determine whether normal hearing children are able to perform a spectral modulation detection task. Additionally, it is important to know whether there are any maturational effects. That is, does spectral acuity improve with age for normal-hearing children from 7 to 17 years old? Any change with age would be important to know if this type of task were used eventually with hearing impaired children. A second goal of this study is to determine whether a strong correlation between spectral modulation performance and speech recognition in noise obtains for a pediatric population as it does for adult listeners (Saoji et al., 2009, Spahr et al., 2011; Henry and Turner, 2003; Henry et al., 2005). And, a third goal is to determine whether pediatric participants listening with CI-simulation can perform these speech recognition and spectral modulation detection tasks. These results from pediatric listeners with a CI-simulation would serve as pilot data for future studies that would extend the research of Saoji et al. (2009) and Litvak et al. (2007) to young, child listeners.

The results of this study may eventually contribute to clinical procedures. First, if normal hearing children can perform this type of task, and if a correlation between SMD performance and speech recognition in noise exists, then these tests should be extended to pediatric listeners with hearing loss. Since many researchers indicate that limitations in spectral acuity can influence performance with a cochlear implant or hearing aid (Collins, Zwolen, & Wakefield, 1997; Donaldson and Nelson, 2000; Henry, McKay, McDermott, & Clark, 2000; Nelson, Van Tasell, Schroder, Soli, & Levine, 1995; Throckmorton and Collins, 1999), performance on a spectral resolution task could be a powerful predictor of device benefit in the pediatric hearing-impaired population. Additionally, with the growing number of cochlear implantations, and the increased use bimodal listening, it would be extremely beneficial to assess spectral acuity, clinically, as a way of predicting bimodal speech recognition performance. If spectral resolution performance is highly correlated with speech recognition performance for listeners of all ages and hearing-device use, then spectral resolutions tests could become a preferred alternative to current speech recognition testing. Spectral resolution tasks do not rely on speech or language abilities, and hence their performance results are not confounded by any speech/language delays, or by any cultural factors that could preclude the use of widely-used speech recognition tests.

Methods and Materials

Subjects

Participants were recruited through flyers posted around the Washington University Medical School Campus and community, as well as by word of mouth. Informed consent was obtained from parents of all the participants in the study, and the study was approved by the Washington University Institutional Review Board. Twenty normal hearing, pediatric subjects (11 female, 8 male) ranging in age from 7.3 to 17.8 years participated in this experiment (mean = 12.9, s.d. = 3.4). All subjects had normal hearing, defined as pure-tone air conduction thresholds ≤ 15 dB HL at octave frequencies from 250 to 8000 Hz at each ear. All subjects had normal middle ear function, as confirmed by tympanometric results, and all participants were native English speakers. Gender and age information for each participant are shown in Table 1.

Stimuli

For the spectral modulation detection experiment, spectrally modulated noises were provided by colleagues at Arizona State University (ASU) (Spahr, personal communication). These stimuli are similar to those described in Eddins & Bero (2007), and were generated by superimposing a specified spectral modulation on a random-noise magnitude spectrum spanning about four octaves (~ 300-5600 Hz). An inverse Fourier transform of a magnitude signal plus a random phase signal results in a spectrally-modulated noise waveform with the desired spectral shape. Multiple noise tokens with two spectral modulation frequencies, 0.5 and 1.0 cycles/octave, were provided by ASU. Multiple unmodulated noises, or reference sounds, with the same bandwidth (~300-5600 Hz) were also provided. Each stimulus was 350 ms in duration.

Sentence recognition was assessed using the Bamford-Kowal-Bench Speech in noise test (BKB-SIN). Lists 4-8, which are appropriate for normal-hearing listeners (BKB –SIN Manual), were used.

Additionally, to create the CI-processed stimuli for both the spectral modulation experiment and for the BKB-SIN test, all stimuli were processed by colleagues at Arizona State

University (Spahr, personal communication) using methods described in Litvak et al. (2007). For this study, only one value of the analyzing-filter slope was used in the CI-simulation vocoder, specifically, 40 dB per octave (see Litvak et al., 2007).

All stimuli were stored on a Dell laptop computer and were presented using the Windows Media Player program. Volume on the Media Player was set at “49” for all participants. Output from the laptop was then routed through a GSI-61 audiometer to a single loudspeaker in the sound booth. The audiometer dial was then adjusted to correspond to a 60 dB SPL level, as verified by a sound level meter (A-weighted, fast setting).

Procedure

All testing was completed in a single session, which lasted roughly 45-60 minutes. After informed consent was obtained, the examiner performed otoscopy, tympanometry and a hearing screening across octave frequencies from 250 to 8000 Hz (screened at 15 dB HL) using TDH circumaural headphones. Participants were administered the following four tests in the order: i) BKB-SIN with unprocessed stimuli, ii) spectral modulation detection (SMD) test with unprocessed stimuli, iii) BKB-SIN with CI-simulation-processed stimuli, and iv) SMD test with CI-simulation-processed stimuli.

BKB-SIN unprocessed: One paired list, twenty sentences total, of the BKB-SIN test was presented. The number of the BKB-SIN list (4, 5, 6, 7, or 8) for each participant, was chosen randomly. Sentence lists were presented at an overall level of 60 dBA SPL, and by design, the level of the sentences remains the same throughout the list, while the level of a multi-talker babble increases such that the SNR of the speech materials becomes progressively lower. The SNR for the first sentence is +21 dB, and the SNR decreases by 3 dB with each subsequent sentence. This progression of increasing difficulty (decreasing SNR) is replicated for the second group of ten sentences in the paired-list. The final sentence in each paired-list of ten has a SNR of -6 dB. Both the signal and the noise were presented in the sound field from the same loudspeaker positioned approximate three feet from the listener, at ear-level, at 0° azimuth. The subject was asked to repeat as much of the sentence as possible. The outcome measure is an SNR-50 level, that is, an estimate of the signal-to-noise ratio (in dB) at which the listener is expected to understand words with 50% accuracy. The SNR-50 level for unprocessed BKB-SIN stimuli was determined by averaging the SNR-50's for the individual paired lists (e.g., average the SNR-50 for list 4A with the SNR-50 for list 4B).

SMD unprocessed: Spectral modulation detection performance was obtained using the Method of Constant Stimuli, and a three-interval, three-alternative, forced-choice procedure with verbal feedback. Each trial consisted of three noise stimuli separated by 300 ms of silence (inter-stimulus interval). The spectrally modulated noise (the 'target' stimulus) was randomly assigned to the first, second or third intervals, while the unmodulated noises (the 'standard' or 'reference' stimuli) were assigned to other two remaining intervals. The participant was asked to tell the examiner "which 'noise' sounded different." The participant was presented with sixty total trials with equal representation, in random order, of two spectral modulation frequencies {0.5 and 1.0 cyc/oct}, and five modulation depths {10, 11, 13, 14, and 16 dB}. Every stimulus, both 'target' and 'standard' was created using different noise phase samples. Five "practice" trials were conducted to ensure that the task was understood. Following the practice trials, the test list was initiated, and responses were recorded by-hand by the experimenter. An overall 'unprocessed' Spectral Modulation Detection (SMD) score was determined by the overall percentage of correct responses for the sixty trials.

BKB-SIN CI-simulation: One paired list of the BKB-SIN, which had been processed with the CI-simulation program (ASU, Spahr, personal communication), was presented using the same procedures as described above for the BKB-SIN 'unprocessed' condition. A 'CI-simulation-processed' BKB-SIN SNR-50 level was determined by averaging, as before, the SNR-50s for the paired lists.

SMD CI-simulation: Spectral modulation detection performance, with CI-simulation-processed stimuli, was obtained using the same procedure as described above for SMD 'unprocessed' stimuli. A total of sixty trials were presented and a 'CI-simulation-processed' SMD score was determined by the percentage of correct responses.

Due to technical difficulties and a misunderstanding, subject #4 was not tested with CI-processed stimuli, and subjects #17 and #18 were tested with stimuli that were processed with a different CI-simulation program (Tiger/HEI, see Table 1). All other participants heard stimuli that had been processed with the Litvak CI-simulation program.

Results

All participants' data are included in statistical analyses for the "unprocessed" conditions (i.e., data from "unprocessed" BKB-SIN and SMD tests) for a total of 20 observations per condition. However, for analyses of results from "CI-processed" conditions, subjects #4, #17, and #18 are omitted for a total of 17 observations per CI-processed condition.

Spectral modulation detection (SMD) scores and BKB-SIN SNR-50 levels for each participant and for both "unprocessed" and "CI-processed" conditions are provided in Table 1. For the BKB-SIN data, a lower number (lower signal-to-noise ratio, or SNR) indicates better performance in noise. For the spectral modulation detection data, the higher the percentage correct score, the better the performance. Individual SNR-50 levels for the 'unprocessed' BKB-

SIN condition range from a -3.5 to a +3.0 dB, with an average SNR-50 level of 0.13 dB (s.d. = 1.9 dB). For the 'unprocessed' SMD condition, percent correct scores range from 75% to 100% (mean = 93%, s.d. = 8 percentage points). For the two listening conditions with CI-simulation processed stimuli, SNR-50 levels range from +9.5 to +23.5 dB (mean = 18.0, s.d. = 3.6), and the SMD scores range from 58% to 98% correct (mean = 75%, s.d. = 13 percentage points).

The Effect of Age

The effect of age, if any, on behavioral performance was examined by calculating Pearson correlations. The relation between "unprocessed" SNR-50 level and participant's age is shown in Figure 1. SNR-50 is significantly correlated with participant's age, with a Pearson correlation, r, of -0.66 (p = .0013). This trend indicates that as age increases, performance on the BKB-SIN test also increases (i.e., SNR-50 decreases). The relation between "CI-simulation processed" SNR-50 level and participant's age is not statistically significant, r = -0.41 (p = 0.056) (again, see Figure 1). The trend indicates, however, that as age increased, performance also increased. For the spectral modulation results, a statistically significant correlation was found between "unprocessed" SMD score and participant's age (r = 0.61, p = .0034) (see Figure 2). This relation indicates that SMD score increases as age increases. "CI-simulation processed" SMD scores and participant's age are also significantly correlated (r = 0.63, p = .0060) (again, see Figure 2). This relation indicates that performance on the SMD task, with CI-processed stimuli, increases as age increases.

Relation between Spectral Modulation Scores and Speech Recognition

The Pearson correlation between "unprocessed" SMD scores and "unprocessed" SNR-50 levels is -0.34, which is not statistically significant (p = .088) (see Figure 3). The Pearson correlation between "CI-simulation processed" SMD scores and "CI-simulation processed"

SNR-50 levels is -.57, which is statistically significant ($p = .014$), suggesting that higher scores on the "CI-simulation processed" SMD task are associated with better performance on the BKB-SIN task (see Figure 4).

Learning or Fatigue Effects

To examine the possible effects of learning or fatigue throughout the Spectral Modulation Detection task, number of incorrect responses on the first half (first 30 trials) was compared to number of incorrect responses on the second-half (last 30 trials). It was hypothesized that performance on the first versus second half of trials may vary by age. Younger children often have a more limited attention and hence may show a decrease in performance throughout the task. By contrast, older children may not fatigue and could exhibit learning as the task progresses. If this were the case, there might be significant differences in the number of errors in the first half versus the second half of the trials. One might expect younger children (≤ 12 years old) to exhibit significantly fewer errors in the first half compared to the second half due to loss of attention or fatigue. And, one might expect a decrease in the number of errors for the older children (≥ 13 years old) due to learning. A t-test was performed to assess any differences between the number of errors in the first half versus those in the second half for the spectral modulation detection task for these two listener age groups. There were no significant difference between the number of errors in the first half and in the second half for the younger children for the "unprocessed" SMD task, $t(9) = 0.947$, $p = 0.368$, nor for the "processed" SMD task, $t(8) = 0.491$, $p = 0.637$. For the older children, there also were no significant differences between number of errors in the first half and in the second half of the "unprocessed" SMD, $t(9) = 0.234$, $p = 0.802$) and "processed" SMD tasks, $t(7) = 0.832$, $p = 0.433$. Overall, then, there does not seem to be any change in performance throughout the course of the SMD task (Figure 5).

Discussion

The results reported in this study, firstly, demonstrate that children as young as seven years old are able to understand and complete a spectral modulation detection task. All children were able to complete the task with scores significantly higher than chance performance (approximately 33% correct). Thus, these results suggests that spectral modulation detection tasks are viable for testing the spectral resolution ability of children with normal hearing as young as seven years of age.

The significant correlation between "unprocessed" BKB-SIN SNR-50 levels and age suggests that as age increases, so does speech recognition ability in noise. This may be expected due to the higher level of attention and processing required for a speech in noise task, both of which may develop with age. "CI-simulation processed" SNR-50 levels showed a moderate, but insignificant, correlation with age.

Both "processed" and "unprocessed" SMD tasks revealed significant correlations with age. Since spectral modulation detection tasks are hypothesized to be a measure of underlying spectral resolution ability, these results suggest that spectral resolution ability progresses with age. This could be an important factor to consider if spectral resolution tasks are to be used clinically. However, whether this correlation with age truly reflects a developmental improvement in spectral-envelope-resolving ability or simply a developmental improvement in the ability to perform psychoacoustic tasks is, as yet, unknown. That is, an increased attention span could contribute to the increased performance of older children, since the SMD tasks required concentration for a somewhat extended period of time (approximately 30 minutes).

The relation between "unprocessed" SMD scores and "unprocessed" BKB-SIN SNR-50 levels is not significant. This insignificant correlation might be due to the small variation in scores (a ceiling effect) across the group of normal hearing children, especially for the SMD test. By contrast, there is a significant correlation between "processed" SMD scores and "processed" BKB-SIN SNR-50 levels, in which better performance on the SMD task is associated with better performance on the speech in noise task. This result supports findings by Saoji et al. (2009), Litvak et al. (2007), Spahr et al. (2011), and Won et al. (2007). All these studies have shown strong relations between an individual's spectral-resolving ability and speech recognition score. The "processed" tasks were much more difficult for the normal hearing children and their performance with the "processed" conditions may estimate how well hearing impaired children would perform on these tests.

Future studies may benefit from the findings of the current study. First, these results indicate that performance on speech-in-noise tasks as well as spectral resolution tasks improve with age. It would be imperative to establish norms for children of different ages if such results were to be compared to the performance of hearing impaired children. Secondly, it is encouraging that a significant correlation was found between spectral modulation detection scores and speech recognition in noise SNR-50 levels. This finding indicates that the pattern of results seen in the adult population may also be present in the pediatric population. It is possible that these correlations would be even stronger given a larger-scale study with a greater number of participants.

It would be worthwhile to also extend this study to the hearing impaired population, in particular to investigate the correlation between speech recognition with various device configurations (hearing aid, cochlear implant, bimodal use) and spectral resolution abilities. Depending on the correlations found from these types of studies, spectral resolution tasks could become an important clinical procedure for predicting device performance. Spectral resolution tests could become a non-linguistic substitute for, or complement to, speech recognition tests.

There are, however, limitations to the current study. Foremost is the relatively small sample size spread across a 10-year age range. A greater number of participants would have resulted in a more powerful study, and possibly stronger correlations. Furthermore, each age was represented by only one or two subjects. In addition, since the participants self-selected into the study, it is possible that these children are not representative of the abilities of the general population of children. Another limitation was the use of only one filter-slope for the cochlear implant simulation. Litvak et al. (2007) had NH participants listen to speech and spectral modulation stimuli that had been processed through multiple CI simulations, one for each of several filter-slopes (40 dB/oct, 30 dB/oct, 10 dB/oct, etc.). Use of multiple filter-slopes, which may represent spectral spread in a CI, would create a greater variation in the perceptual results of NH listeners for comparison to actual CI users.

Conclusion

This pilot study introduced a spectral resolution task to the pediatric population. Until now, studies including spectral resolution tests have been performed exclusively on the adult population. These studies on adults have found a strong relation between speech recognition ability and spectral resolution ability (Spahr et al., 2011; Saoji et al., 2009; Henry and Turner, 2003; Henry et al., 2005; Won et al., 2007). It is believed that these two types of assessments rely on the same underlying skill or mechanism: frequency tuning. The current study utilized a spectral modulation task to assess spectral resolution ability in children 7-17 years old, and found that children as young as seven can perform this spectral modulation task. Both sentence recognition in noise and spectral modulation detection ability are correlated with age, for both unprocessed stimuli and for stimuli that had been processed with a cochlear implant simulation. The findings of this study indicate that speech recognition in noise and spectral resolution may be related in the NH pediatric population, as has been found in the adult population. Spectral resolution performance should be examined in the pediatric hearing impaired population, and may eventually serve as a useful predictor of pediatric device benefit.

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Tables

Table 1: Demographic information and behavioral data for all participants.

Subject ID	Gender	Age	BKB-UNpro (dB)	SMD-UNpro (%)	CI-SIM Type	BKB-CI (dB)	SMD- CI (%)
1	Female	13.5	3	98	ASU/Litvak	19	72
2	Female	12.3	0	75	ASU/Litvak	20	63
3	Male	9.3	1.5	75	ASU/Litvak	21	70
4	Female	17.1	-3	96	N/A	N/A	N/A
5	Female	8.5	1.5	80	ASU/Litvak	9.5	58
6	Male	11.8	1	100	ASU/Litvak	17.5	95
7	Male	7.4	2.5	88	ASU/Litvak	14	67
8	Male	9.3	2.5	95	ASU/Litvak	23.5	62
9	Male	12.5	-0.5	100	ASU/Litvak	21.5	87
10	Female	13.6	-3.5	100	ASU/Litvak	15	73
11	Male	10	2	92	ASU/Litvak	16	62
12	Female	14.4	-0.5	88	ASU/Litvak	20	63
13	Female	12.4	-0.5	85	ASU/Litvak	20	62
14	Male	15.6	0.5	100	ASU/Litvak	18.5	80
15	Female	16.1	-1.5	100	ASU/Litvak	19.5	87
16	Female	16.5	-2	98	ASU/Litvak	17	88
17	Female	7.3	-1.5	95	Tiger/HEI	14.5	72
18	Male	17.8	2	88	Tiger/HEI	14	68
19	Male	14.4	-2	100	ASU/Litvak	23.5	92
20	Female	17.5	1	98	ASU/Litvak	15	98
Average		12.1	0.13	93		18	75
Standard Dev		3.3	1.9	0.1		3.6	0.1
Max		17	3	100		23.5	98
Min		7	-3.5	75		9.5	58

Figures

Figure 1

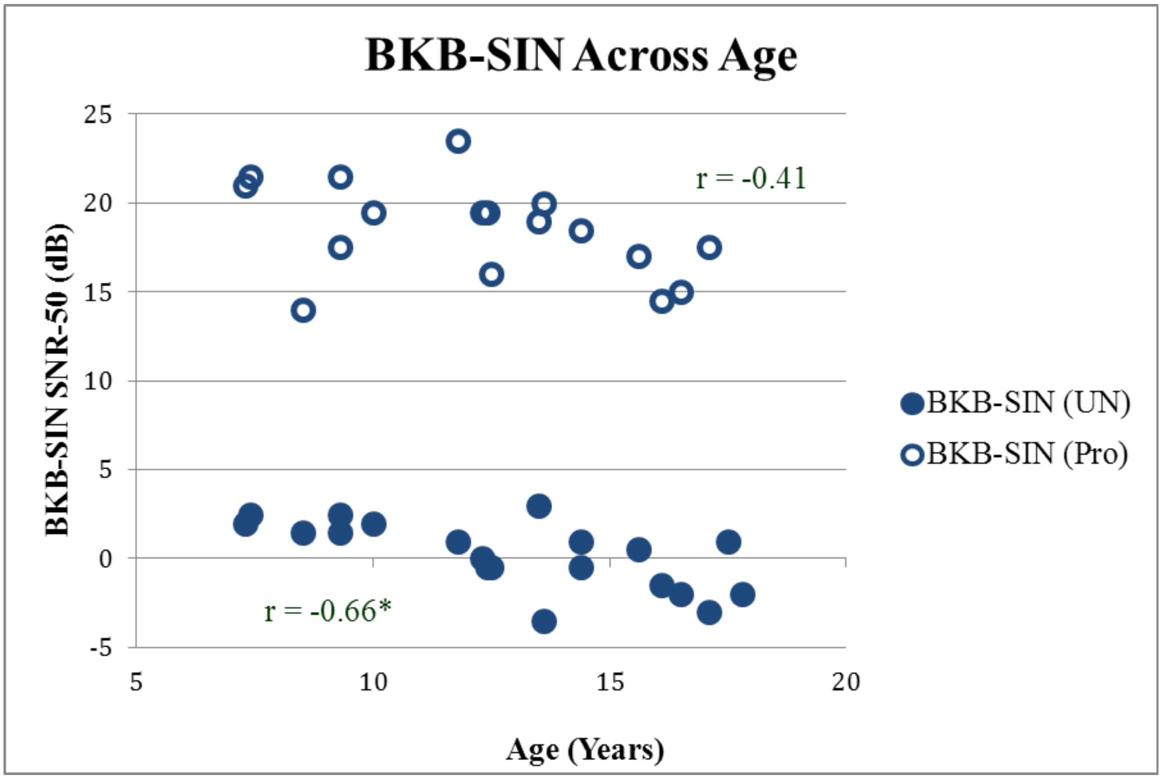

Figure 1: Individual BKB-SIN SNR-50 levels versus listener age. Unfilled circles represent SNR-50 levels for the "unprocessed" BKB-SIN test, and filled circles represent SNR-50 levels for the "processed" BKB-SIN test. Pearson correlations are also indicated, where an asterisk represents a statistically significant correlation.

Figure 2

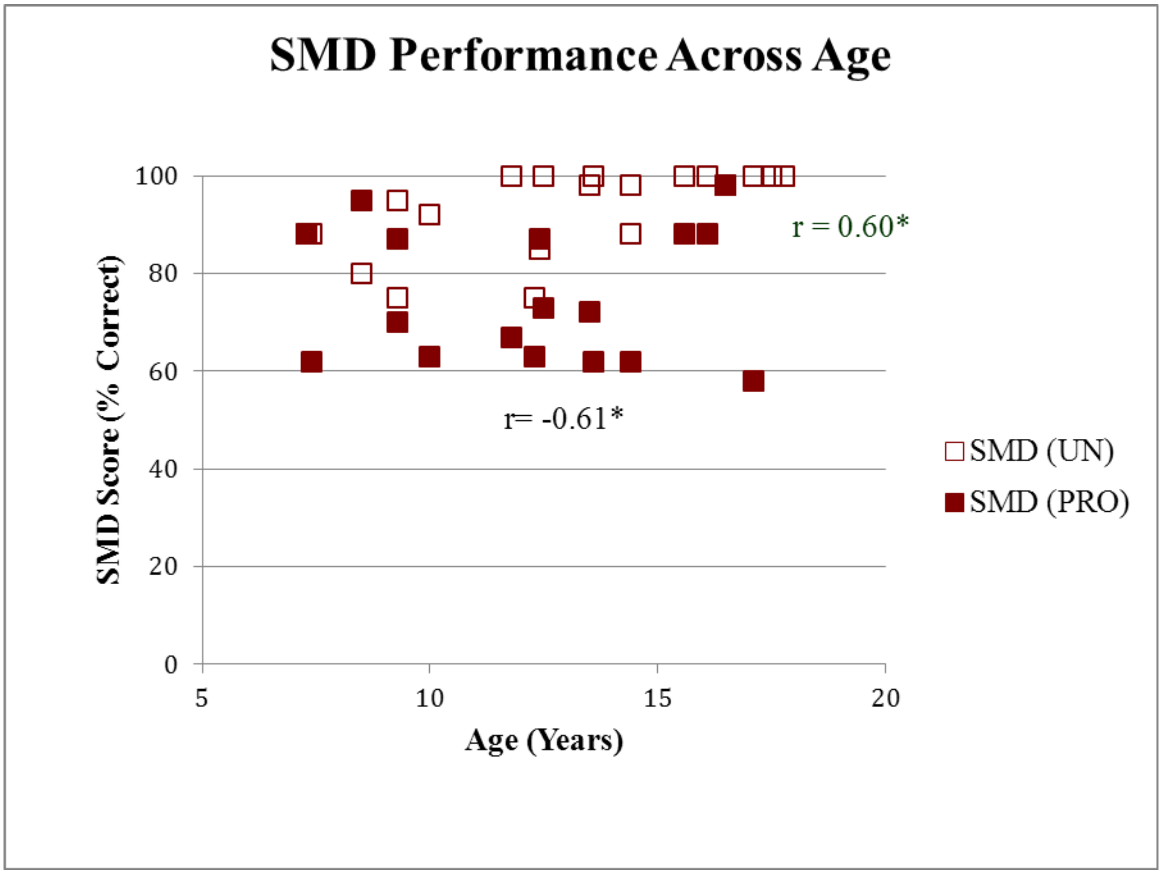

Figure 2: Individual Spectral Modulation Detection (SMD) scores versus listener age. Unfilled squares represent SMD scores for the "unprocessed" SMD test, and filled squares represent SMD scores for the "processed" SMD test. Pearson correlations are also indicated, where asterisks represent statistically significant correlations.

Figure 3

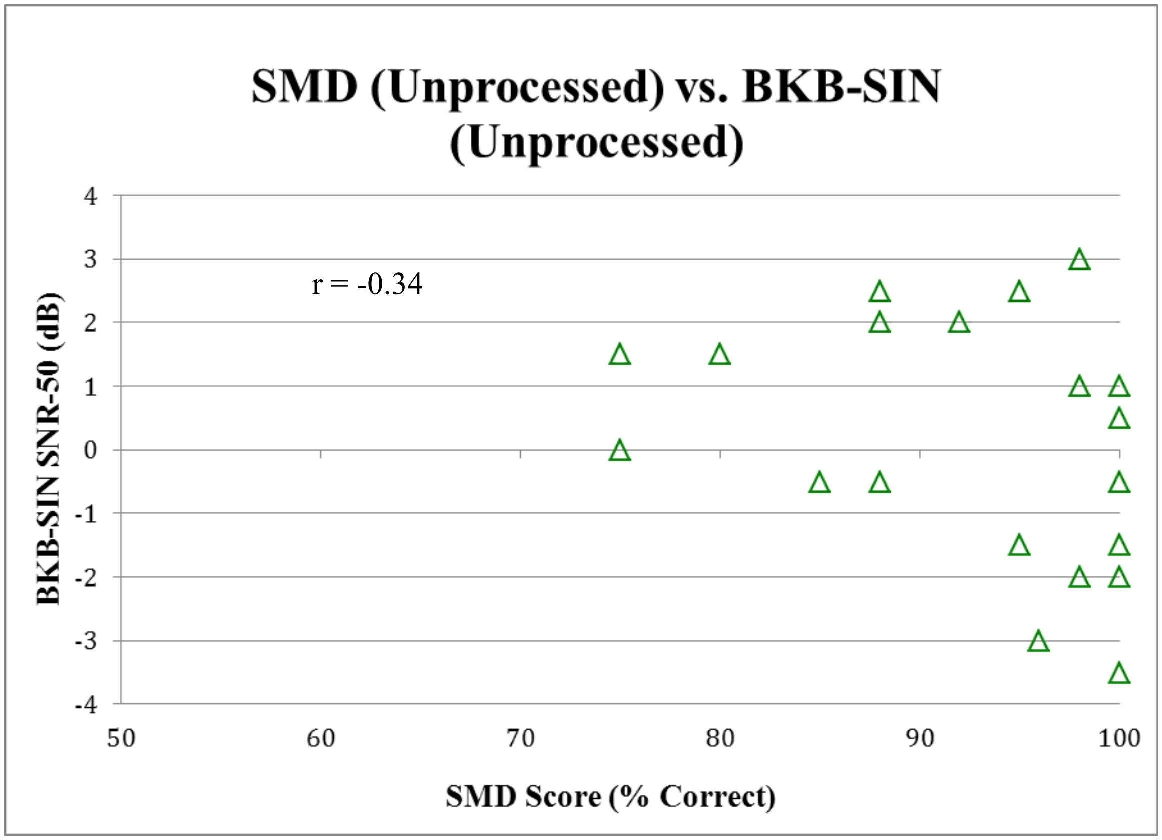

Figure 3: Individual "unprocessed" SMD scores vs. "unprocessed" BKB-SIN SNR-50 levels. Pearson correlation is also indicated, where an asterisk represents a statistically significant correlation.

Figure 4

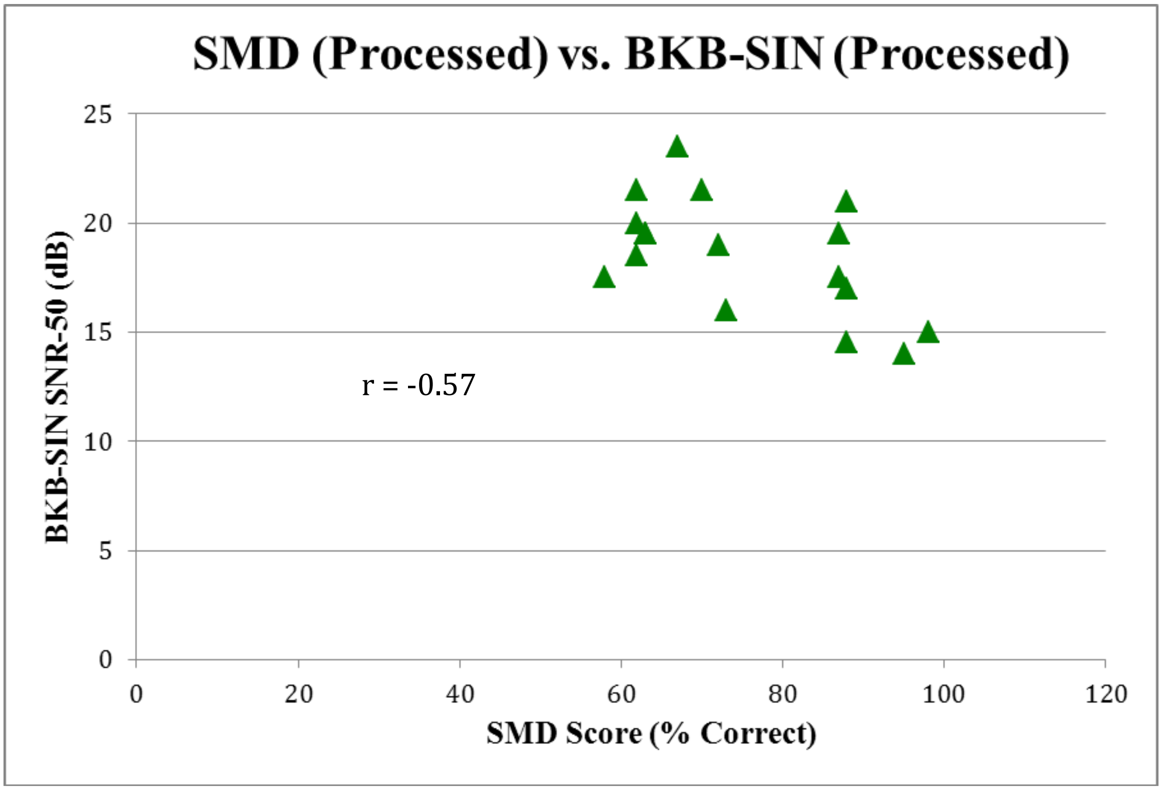

Figure 4: Individual "processed" SMD scores vs. "processed" BKB-SIN SNR-50 levels. Pearson correlation is also indicated, though is not statistically significant.

Figure 5

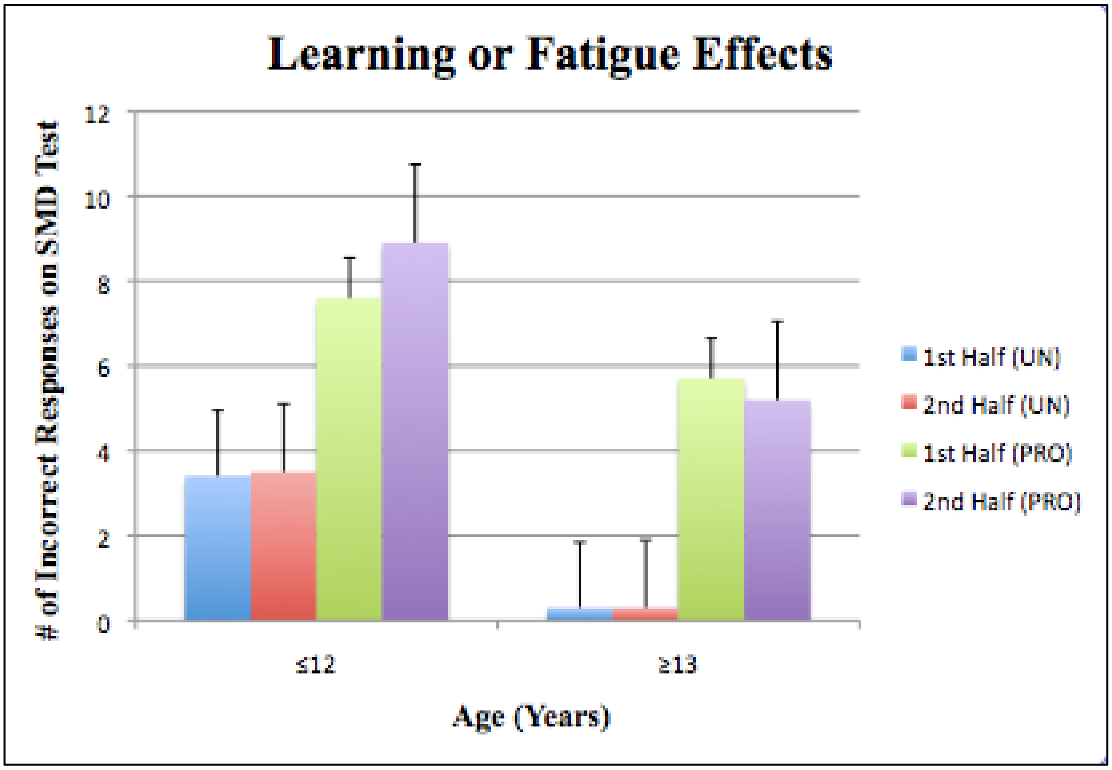

Figure 4: Group mean number of errors in the first half and the second half of the Spectral Modulation Detection Task for both "unprocessed" and "processed" stimuli. Groups are separated by age, ≤ 12 years and ≥ 13 years. Error bars represent +1 standard deviation.