Spectro-temporal modulation detection in children

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Abstract: Children's performance on psychophysical tasks improves with age. The relationship of spectro-temporal modulation detection to age, particularly in children who are hard of hearing, is not well-established. In this study, children with normal hearing ($N = 22$) and with sensorineural hearing loss ($N = 15$) completed measures of spectro-temporal modulation detection. Measures of aided audibility were completed in the children who are hard of hearing. Pearson product-moment correlations were completed with listener age and aided audibility as parameters. Spectro-temporal modulation detection performance increased with listener age and with greater aided audibility.

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1. Introduction

The audibility provided by amplification supports speech recognition. Even when audibility is considered optimal, substantial variability in speech recognition performance can be observed, particularly in children. Other factors, including the ability to encode and process time-varying spectral cues, might support speech understanding once the signal is audible. Spectral resolution can be assessed by testing a listener's ability to discriminate broadband noises with contrasting distributions of spectral peaks and valleys (Supin *et al.*, 1994). Ripple discrimination threshold has been found to correlate with speech perception in quiet and in noise for adult listeners with varying degrees of hearing loss, including hearing aid and cochlear implant users (Henry *et al.*, 2005; Won *et al.*, 2007). The number of spectral ripples per octave (RPO) that can be discriminated tends to decrease with greater hearing loss. Psychoacoustic thresholds tend to improve over time in children, and the age where adult-like performance emerges differs among tasks (Maxon and Hochberg, 1982; Jensen and Neff, 1993). Unlike speech recognition measures, ripple thresholds could have clinical relevance as an indicator of supra-threshold hearing that is not dependent on language ability. Establishing a range of age-appropriate performance on spectral ripple tasks would be a necessary step before they could be considered for clinical use with children with hearing loss.

Allen and Wightman (1992) measured the performance of children with normal hearing on a task similar to the spectral ripple threshold procedure. Specifically, they measured discrimination thresholds in 5-, 7-, and 9-year olds with normal hearing for ripple stimuli with fixed, contrasting spectral densities (expressed in critical bands/cycle). They found that 5- and 7-year olds performed significantly poorer than 9-year olds. The 9-year olds demonstrated adult-like performance on this task. These results indicate that ripple discrimination ability, like other auditory discrimination abilities, increases with age in children with normal hearing.

Some have expressed concerns that acoustic cues present in static spectral ripple tasks confound interpretation of measured thresholds (Azadpour and McKay, 2012). One recently introduced threshold procedure includes simultaneous spectral and

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temporal modulations of the ripple stimuli (Aronoff and Landsberger, 2013), with the goal of minimizing these cues. However, it is unclear, with the inclusion of temporal changes in the stimuli, whether relationships of performance to listener age are similar to that of static ripple discrimination and detection threshold procedures. In addition, the relationship of spectral-temporal detection with aided audibility in children who use hearing aids has not been established.

The purpose of this study was to characterize the relationship of spectro-temporal modulation detection with listener age and audibility in children who are hard of hearing (CHH). Children with normal hearing (CNH) were included in this study in order to identify the contribution of developmental changes in a population where individual differences in cochlear function are minimal. It was hypothesized that greater age and aided audibility in children who are hard of hearing would be associated with better spectro-temporal modulation detection performance.

2. Methods

2.1 Participants

Twenty-two CNH (11 male, 11 female), ages 6–12 (mean = 8.9 years, SD = 2.0 years) and 15 CHH (5 male, 10 female), ages 6–16 (mean = 11.3 years, SD = 3.0 years) participated in this study. Hearing status in the CNH was established by pure tone screening at 15 dB hearing level (HL) with TDH-39 earphones at octave intervals from 500 to 8000 Hz in the right and left ear. Pure tone thresholds for CHH were measured using standard audiometric procedures and insert earphones at octave intervals from 250 to 8000 Hz and also at 3000 and 6000 Hz. Figure 1 shows audiometric thresholds for the CHH. Real-ear measures of aided audibility for a 65 dB sound pressure level (SPL) calibrated speech signal (SII; ANSI S3.5-1997) were completed for each CHH participant for each ear. No changes were made to their hearing aids. All participants were native speakers of American English. Informed consent was obtained prior to participation. All procedures were approved by the Institutional Review Board of Boys Town National Research Hospital.

2.2 Ripple threshold

Procedure. Spectro-temporal modulation detection performance was measured using the Spectral-Temporally Modulated Ripple Threshold (SMRT) test (Aronoff and Landsberger, 2013). In this task, the listener must discriminate between a broadband reference noise and a spectrally modulated target noise that has dynamically changing distributions of spectral peaks and nulls. The difficulty of this perceptual task increases with increasing density of spectral peaks and nulls of the target, quantified as ripples per octave. The SMRT uses an adaptive procedure in which the ripple density of the target stimulus is varied to estimate the 50% discrimination threshold. Testing consisted of a three-interval, three alternative forced-choice task in which two of the intervals contained a reference stimulus of 20 RPO. The beginning RPO for the target interval was 0.5 RPO and the step size was 0.2 RPO using a 1-up/1-down stepping rule. Ten reversals were obtained and threshold was calculated using the last six

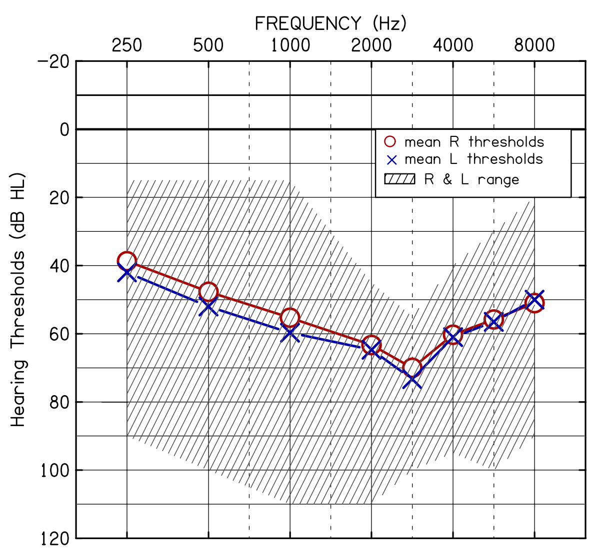

Fig. 1. (Color online) Mean and range of pure tone thresholds of children who are hard of hearing.

reversals. Multiple practice trials were completed with the participants prior to threshold procedures to familiarize them with the task. Each participant then completed two runs and the final threshold was determined by averaging the two threshold estimates. Stimuli were presented at 65 dB SPL via a JBL Bi-Amplified Studio Monitor loudspeaker at 45° azimuth. Children with NH were tested without amplification and children with SNHL were tested with their own hearing aids.

Analyses. Statistical analyses included a Pearson product-moment correlation of listener age with spectro-temporal ripple detection threshold in CNH. In addition, a multiple linear regression fit of listener age and better ear SII with ripple threshold was completed for CHH. All statistical analyses were performed using the R software interface (version 3.0.2; R Core Development Team, 2014). All effects are reported as significant at $p < 0.05$.

3. Results

Figure 2 shows spectro-temporal modulation detection thresholds for both CNH and CHH. Improvements in spectral ripple threshold with age are evident in the CNH, with performance reaching a peak at approximately age 9 years. To better capture the non-linear relationship of age and performance, listener age was log-transformed for subsequent statistical analyses in both groups of listeners. Older CNH had significantly better spectral ripple discrimination thresholds ($r = 0.47$, $t = 2.38$, df $= 20$, $p = 0.028$). In CHH the regression model was statistically significant [F(2,12) $= 4.01$, $p = 0.046$, adjusted $R^2 = 0.3$], and both greater listener age ($\beta = 2.86$, SE $= 1.11$, $t = 2.58$, $p = 0.024$) and greater SII ($\beta = 0.049$, SE $= 0.022$, $t = 2.22$, $p = 0.046$) were associated with better spectro-temporal modulation detection thresholds.

4. Discussion

The results confirmed that children age 6 years and older are capable of completing spectro-temporal modulation detection threshold tasks. The finding of poorer thresholds in younger children was consistent with previous reports on spectral discrimination tasks with children (Allen and Wightman, 1992). Performance reached a peak at approximately 9 years of age in the CNH, with mean thresholds approaching 8 RPO, consistent with average performance on this task reported for adults with normal hearing (Aronoff and Landsberger, 2013). Both age and aided audibility were significant predictors of ripple threshold in CHH. Individual variability of performance in children of similar age was also evident in each group of listeners. It is possible that general cognitive abilities such as sustained attention and executive function contributed to this variability, and developmental differences in these areas may have contributed to the better thresholds in older listeners.

While spectro-temporal modulation detection performance improved with age and audibility, similar to static ripple discrimination and detection tasks, the relationship of SMRT to speech perception remains to be established. Also, given the availability of both temporal and spectral cues in the SMRT, it would be informative to determine the respective contributions of temporal and spectral acuity to performance on this task. Regardless, these findings suggest that spectro-temporal modulation threshold procedures like the SMRT could be an informative clinical indicator of supra-threshold spectro-temporal acuity in children across a range of ages and aided audibility that complements standard speech perception measures.

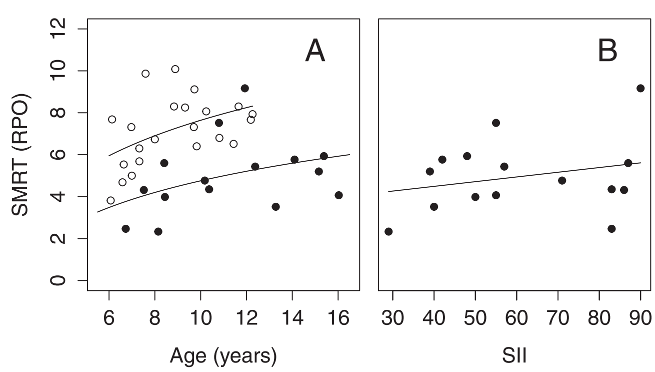

Fig. 2. (A) Ripple thresholds for children with normal hearing (open circles) and children who are hard of hearing (filled circles) vs age, (B) ripple thresholds vs better ear SII of children who are hard of hearing.

Acknowledgments

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References and links

Allen, P., and Wightman, F. (**1992**). "Spectral pattern discrimination by children," J. Speech Lang. Hear. Res. **35**(1), 222–233.

ANSI, A. (**1997**). S3. 5-1997, *Methods for the Calculation of the Speech Intelligibility Index* (American National Standards Institute, New York).

Aronoff, J. M., and Landsberger, D. M. (**2013**). "The development of a modified spectral ripple test," J. Acoust. Soc. Am. **134**(2), EL217–EL222.

Azadpour, M., and McKay, C. M. (**2012**). "A psychophysical method for measuring spatial resolution in cochlear implants," J. Assoc. Res. Otolaryngol. **13**, 145–157.

Henry, B. A., Turner, C. W., and Behrens, A. (**2005**). "Spectral peak resolution and speech recognition in quiet: Normal hearing, hearing impaired, and cochlear implant listeners," J. Acoust. Soc. Am. **118**(2), 1111–1121.

Jensen, J. K., and Neff, D. L. (**1993**). "Development of basic auditory discrimination in preschool children," Psychol. Sci. **4**(2), 104–107.

Maxon, A. B., and Hochberg, I. (**1982**). "Development of psychoacoustic behavior: Sensitivity and discrimination," Ear Hear. **3**(6), 301–308.

R Core Development Team (**2014**). "R: A language and environment for statistical computing," [computer software], available from www.R-project.org (Last viewed June 17, 2015).

Supin, A. Y., Popov, V. V., Milekhina, O. N., and Tarakanov, M. B. (**1994**). "Frequency resolving power measured by rippled noise," Hear. Res. **78**(1), 31–40.

Won, J. H., Drennan, W. R., and Rubinstein, J. T. (**2007**). "Spectral-ripple resolution correlates with speech reception in noise in cochlear implant users," J. Assoc. Res. Otolaryngol. **8**(3), 384–392.