Maturational changes in ear advantage for monaural word recognition in noise among listeners with central auditory processing disorders

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Abstract

This study aimed to investigate differences between ears in performance on a monaural word recognition in noise test among individuals across a broad range of ages assessed for (C)APD.

Word recognition scores in quiet and in speech noise were collected retrospectively from the medical files of 107 individuals between the ages of 7 and 30 years who were diagnosed with (C)APD. No ear advantage was found on the word recognition in noise task in groups less than ten years. Performance in both ears was equally poor. Right ear performance improved across age groups, with scores of individuals above age 10 years falling within the normal range. In contrast, left ear performance remained essentially stable and in the impaired range across all age groups. Findings indicate poor left hemispheric dominance for speech perception in noise in children below the age of 10 years with (C)APD. However, a right ear advantage on this monaural speech in noise task was observed for individuals 10 years and older.

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Introduction

Central auditory processing disorder, (C)APD, is a broad term that refers to a deficit in the neural processing of auditory stimuli within the central auditory nervous system (CANS). Individuals with (C)APD frequently report difficulty with speech perception in background noise, auditory discrimination, auditory localization, multiple direction commands (auditory memory), message comprehension, and auditory attention.[1] Because a broad range of symptoms defines (C)APD, the exact locations of the underlying neurological generators are complex and not clearly understood. In neonatal and pediatric cases, the etiology of (C)APD could be related to neuromaturational lag, neurological structural damage or a neurodevelopmental disorder.[2]

The human auditory system does not fully mature until adolescence,[3,4] and some auditory processes also do not mature until that time. Later developing auditory processes include the understanding of speech in noise and the ability to recognize degraded speech,[5] the ability to detect a small gap between two stimuli,[6] and the just noticeable difference in the localization of sound.[7] Among the broad range of (C)APD symptoms, difficulty understanding spoken language in noise is commonly reported due to underlying deficits in auditory closure, temporal processing, auditory discrimination, and binaural separation and/or integration.

Behavioral tests of (C)APD assess functioning of centers at various levels of the auditory pathway, including the auditory cortex, auditory association areas, and the corpus callosum. The maturation rate of these auditory centers may influence the outcome of (C)APD tests.[8,9] Although lower brainstem auditory fibers have been reported to play a role in processing speech in noise[10] and auditory brainstem responses are mature by age 2,[11,12] the ability to recognize and understand degraded speech in background noise does not become adult-like until adolescence.[5] This supports a role of higher auditory centers, such as the primary auditory cortex in the left hemisphere, in the development of auditory decoding skills.[8]

The corpus callosum and auditory association areas, the expression of cortical neurofilaments and the formation of the axonal skeleton all mature by age 10.[13,14] The late maturation of conduction pathways affects auditory processes, such as auditory temporal processing.[14] Dichotic listening, frequency pattern detection, and duration pattern detection do not reach adult-like values until approximately age 10.[9] However, auditory evoked potential (AEP) studies using late latency responses have shown that some cortical fibers continue to mature well into adolescence.[3,4,15,16] In typically developing children, myelination of the corpus callosum may not be complete until age 10, and neural maturation may take even longer in children with (C)APD.[17] Ten years of age seems to be a significant landmark in the maturation of auditory processes. Although various auditory processes mature at different times during development, whether the right and left ears show equal degrees of maturity for auditory processing tasks remains unclear. Individuals with (C)APD often show ear differences.

Ear advantage is defined as the relatively better performance of one ear over the other ear on listening tasks. Ear advantage scores are a powerful indicator of hemispheric dominance for language,[18] and a significantly larger ear advantage has implications for the diagnosis of (C)APD.[19] A slight right ear advantage for dichotic speech stimuli and a left ear advantage for non-speech sounds, such as sonar signals, has been reported in normal healthy adults.[20-22] Domitz and Schow[23] assessed 81 third-grade children (aged 8.8 to 9.9 years) using the Selective Auditory Attention Test, the Pitch Pattern Test, the Dichotic Digit Test, and the Competing Sentence Test and found that the mean right ear performance was greater than the mean left ear performance. Better right ear performance is an indicator of left hemispheric dominance for language. In contrast, poor right ear performance for dichotic stimuli is common among individuals with reading, language and learning disorders,[21,24] and a left ear advantage or no ear advantage for dichotic speech stimuli is an indicator of mixed or reversed language dominance.[24] Approximately 15-20% of individuals do not exhibit a right ear advantage, despite a right ear advantage being common among normal healthy adults.[25,26] The influences of attention and other supramodal processes, such as cognition, memory, and motivation, on the left ear advantage or on right hemispheric dominance in dichotic tasks cannot be ruled out.[27]

The right ear advantage is not specific to the dichotic condition and has been observed with monaural presentations in normal healthy adults.[28] Typically developing children generally exhibit similar right and left ear performance on tasks involving degraded acoustic stimuli and slightly better right ear scores than left ear scores on dichotic speech tasks.[19] Because language is processed predominantly in the left hemisphere, the right ear has an advantage for speech stimuli; the contralateral pathway from the right ear goes directly to the left hemisphere. However, for the left ear, the contralateral route for speech input travels through the right hemisphere and the corpus callosum before reaching the language centers in the left hemisphere.

A test of monaural word recognition in noise is one of the most frequently used tests in the (C)APD test battery. Words are presented to one ear (monaurally) with and without noise and the percent correct scores are compared between conditions and ears. Among healthy normal children and adults, the word recognition score (WRS) in the right ear has been reported to be slightly better than that of the left ear in the noise condition.[29] In contrast, it has been reported that children with (C)APD perform well in a quiet environment,[30] but have better left than right ear performance in noise.[8]

Maturational changes in ear advantage on monaural tasks have not been reported to date. However, a different rate of maturation for the left and right ear could disrupt the processing of auditory information consistent with a diagnosis of (C)APD. Therefore, the purpose of this study was to compare performance on a word recognition in noise task between ears in individuals of various ages diagnosed with (C)APD. No control group was included in this study; however, normative scores for word recognition in speech noise from the Central Test Battery were included.[29]

Materials and Methods

This was a retrospective medical records review study. The demographic and diagnostic records of pediatric and adult individuals assessed for (C)APD at the University of North Carolina at Greensboro (UNCG) Speech and Hearing Center were retrieved and analyzed retrospectively. Permission to access patient files for research was obtained through the Institutional Review Board (IRB) at UNCG. The demographic data obtained for 107 individuals with (C)APD included the patient case history, a questionnaire, and raw scores for audiological and (C)APD tests.

Participants

Data for 107 individuals between the ages of 7 and 30 years were extracted (Table 1). These individuals i) were referred by regional healthcare professionals, teachers and parents to the UNCG Speech and Hearing Center for a (C)APD evaluation; ii) had completed their (C)APD assessment between August 2003 and September 2011; iii) used English as their first language (reported by parents or guardians); iv) had normal hearing sensitivity, which was defined as a hearing threshold within 25 dB HL for the frequencies 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz; v) had normal middle ear function; and vi) no neurological deficits. For the purpose of this study, the individuals were divided into seven age groups (Table 1). The seven groups were mutually exclusive, and each participant was included in only one group.

Test battery used for diagnosis of (C)APD

The audiologic test information extracted from patient files included the results of pure tone and speech audiometry, otoscopy, and tympanometry. All of the tests were conducted in a sound-treated booth on calibrated audiometric equipment. These assessments were conducted by qualified, licensed audiologists. Tests from the UNCG (C)APD test battery included the word recognition score in noise, Staggered Spondaic Word, Dichotic Digit, Competing Sentence, Random Gap Detection, Duration Pattern Sequence, Phonemic Synthesis, and Pitch Pattern Sequence tests. Tests were administered as needed to target specific auditory processing skills; not all tests were administered to each patient. (C)APD was diagnosed if an individual scored below two standard deviations (SD) the mean on two or more tests or three SD below the mean on at least one test.[1,19] For this investigation, the results from the word recognition in noise test were used for analysis because difficulty listening in noise is a common symptom reported by individuals with (C)APD. For the word recognition in noise test, monosyllabic words from a recorded version of the W-22 word list (25 words) were presented at a comfortable listening level (40 dB SL re: SRT) in two listening conditions (*i.e.*, quiet and speech noise). Different 25-word W-22 lists were administered for the two conditions. Stimuli and noise were presented to the same ear at a signal-to-noise ratio (SNR) of +5.[29] The two conditions (quiet and speech noise) of the word recognition task were administered at the beginning of the test battery. Across the study participants, the right ear often was tested first; however, the *difference from normative score* (DNS, see below) was used to neutralize the order effect. Age normative scores from the Central Test Battery were utilized for the analysis and are a good reference for this investigation, as the current study used the same word lists, the same SNRs, and the same output levels.

Analysis of word recognition scores

In this study, three dependent measures were evaluated for each patient: i) The raw WRS was calculated as the percent correct in each ear for the two listening conditions (quiet and speech noise) for the seven age groups; ii) The difference scores between the quiet and noise conditions were computed using the raw WRS for each ear (*e.g.*, right-quiet minus right-noise, left-quiet minus left-noise); iii) The Difference from Normative Score (DNS) was calculated as the amount of deviation between the difference scores [see ii)] from the age norm (i.e., the value provided by the test manufacturer as two standard deviations below the mean). These DNS values were then analyzed using repeated measures analysis of variance (ANOVA) to test for significant differences due to age and ear as well as for interactions.

Results

For the purpose of the retrospective analysis, the 107 individuals with (C)APD were divided into seven groups, as shown in Table 1. Six groups reflected an age span of two years, while the seventh group included adults across a span of 12 years (19-30 years old).

Word recognition in quiet and noise

The mean and standard deviation of the WRS in the two listening conditions (quiet and speech noise) are shown in Table 2. As expected, for all seven age groups, WRSs were higher (better) in the quiet condition than in the noise condition for both the right and left ears. Differences in the left and right ear results for the quiet condition were analyzed. The repeated measures ANOVA indicated that the effects of ear, $F(1,100) = 0.01$, P=0.89, and age group, $F(6,100) = 1.26$, P=0.27, as well as the interaction between group and ear, $F(6,100) = 1.48$, P=0.19, were not significant. There were no significant differences between the right and left ear WRSs in the quiet condition. Additionally, scores for the quiet condition fell within the normal range for all seven age groups (90% correct and above). Scores for the noise condition fell 1.   below the normal range in both ears.

Difference from normative scores

The mean and standard error of the DNS for both ears across age groups are shown in Figure 1. Note that negative scores indicate impaired performance, while all positive scores (above zero) fell within the normal range. Results indicate that scores in left ear was abnormal across all age groups, while a different pattern was observed in the right ear. In the noise condition, individuals (below age 10) had mean scores that were below the normal range in the right ear. However, right ear scores of individuals above age 10, fell within the normal range.

Comparisons between the right and left ear scores were made for the seven age groups to investigate the presence of an ear advantage for word recognition in noise in (C)APD. A repeated measures ANOVA design included one between-subject (age group) and one within-subject (ear) variable.

The main effect of ear was significant, $F(1, 100) = 12.82$,

Table 1. Demographic data of individuals with (C)APD.

Age Groups	Number	Male	Female	Median age (years)
1. (7 and 8 years)	27	18	9	7.80
2. (9 and 10 years)	24	13	11	9.70
3. (11 and 12 years)	10	6	4	11.80
4. (13 and 14 years)	10	7	3	13.50
5. (15 and 16 years)	10	4	6	15.4
6. (17 and 18 years)	6	2	4	17.7
7. (19 to 30 years)	20	10	10	21.20
Total	107	60	47	

Table 2. Mean word recognition score (WRS) for the two listening conditions (quiet and speech noise) for the seven age groups.

Age group	WRS in quiet		WRS in noise	
	Right ear Mean (SD)	Left ear Mean (SD)	Right ear Mean (SD)	Left ear Mean (SD)
1. (7 and 8 years)	93.33 (4.96)	91.11 (5.69)	59.26 (15.76)	61.15 (12.46)
2. (9 and 10 years)	94.67 (4.95)	93.63 (4.46)	64.17 (11.15)	59.67 (15.46)
3. (11 and 12 years)	93.20 (4.23)	95.60 (2.95)	70.80 (16.97)	64.00 (17.68)
4. (13 and 14 years)	93.60 (4.69)	95.60 (4.40)	73.60 (8.68)	65.20 (14.85)
5. (15 and 16 years)	94.00 (4.71)	94.00 (3.88)	76.00 (8.64)	69.60 (16.02)
6. (17 and 18 years)	94.00 (2.19)	93.33 (5.46)	77.00 (9.44)	68.67 (8.16)
7. (19 to 30 years)	95.60 (3.40)	94.60 (5.07)	77.85 (7.37)	69.20 (15.47)

Note: Higher scores indicate better performance. SD, standard deviation

P<0.01, η^2 = 0.11(statistical power = 0.94). The effect of the *age group* variable was not significant, $F(6, 100) = 0.95$, P=0.46, η^2 = 0.05. However, a significant interaction between ear and age group was found, $F(6, 100) = 3.67$, P<0.01, η^2 = 0.18, indicating that ear-specific performance differed across the seven age groups (Figure 1). A follow-up univariate ANOVA was conducted to determine which ear's performance changed with age. For the speech noise condition, word recognition scores in the right ear differed significantly across the seven age groups, $F(6, 100) = 3.30$, P<0.01, η^2 = 0.16. However, left ear performance in speech noise did not significantly differ across the age groups, $F(6, 100) = 0.45$, P=0.84, η^2 = 0.02.

Discussion

The purpose of this retrospective study was to investigate the maturation of ear advantage for monaural speech perception in noise among individuals between the ages of 7 and 30 years diagnosed with (C)APD.

No maturational differences were found for word recognition in the quiet condition, as all age groups performed similarly, with scores falling within the normal range. This result suggests that individuals with (C)APD perform the same as those without the disorder under quiet conditions, displaying no ear advantage. These results are consistent with the findings of other investigations that report that individuals with (C)APD perform well on listening tasks in quiet.[30]

Performance in the noise condition was poorer than that in quiet for all age groups. Improvement in the WRS in noise due to maturation was observed only for the right ear; the left ear performance remained in the impaired range for the speech noise condition across age groups. Results from the current investigation also demonstrated an age-related shift in ear advantage for monaural word recognition in speech noise task. There was no clear ear advantage in groups of individuals below ten years of age. However, a shift in the right ear advantage was observed in the groups of individuals older than ten years of age, as right ear scores improved and left ear scores were essentially the same.

The findings of this study indicate that right ear performance appeared to shift and improve after ten years of age, falling within the normal range. The underlying neural generators behind this shift in ear performance remain unclear. However, auditory structures, such as thalamocortical fibers, the primary auditory cortex,[4,15,16] and the corpus callosum,[17] continues to mature up to age 10 and may play a role in speech perception in noise[4,8] and ear advantage. Observation of an apparent maturational shift in ear advantage for monaural word recognition across age groups provide additional evidence of the development of auditory processing skills and underlying neural centers.

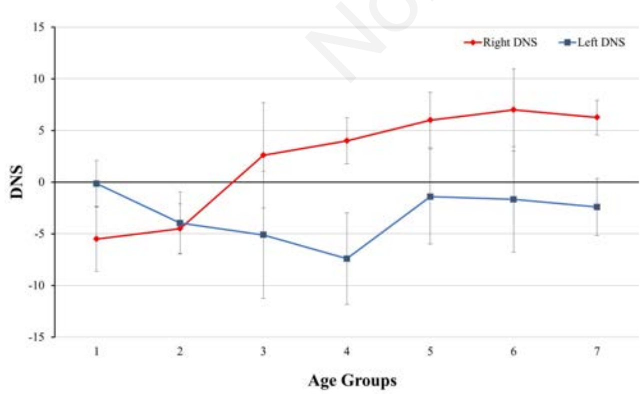

Figure 1. Difference from normative score for the WRS in speech noise among individuals with (C)APD. Note: In these graphs, zero indicates the age norm (2 SD below the mean) for the difference in WRS in noise and quiet.[29] Larger positive values indicate performance within the normal range, while negative values reflect poorer than expected performance. The error bars indicate the standard error. DNS, difference from normative score

Conclusions

Monaural speech tests can be used to measure the ear-specific maturation of the auditory system. Results of the present investigation indicate poor left ear performance on a word recognition in noise test in patients with (C)APD regardless of age. After age 10, a right ear advantage becomes apparent on this task. Findings also indicate that poor left ear performance could be a marker for (C)APD among individuals older than 10 years of age, whereas poor performance in both ears might be expected for children below age 10. Additionally, results of the current investigation revealed a shift in right ear performance, possibly due to the maturation of the CANS, with right ear performance of individuals with (C)APD who are older than 10 years of age falling within normal limits. These findings might indicate poor left hemispheric dominance for speech perception in noise in individuals (<10 years) with (C)APD.

Future research

Ear advantage for monaural word recognition in noise needs to be investigated longitudinally in individuals with (C)APD. Additionally, more research is needed concerning the maturation of the upper auditory pathway using middle and late AEPs in response to monaural speech stimuli and brain-mapping techniques that reveal developmental shifts in scalp topography.

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