Gaps-In-Noise Test Performance in Children with Speech Sound Disorder and Cognitive Difficulty

Yu Kyung Jung[1,2] and Jae Hee Lee[1,3]

[1]Department of Audiology and Speech-Language Pathology, Hallym University of Graduate Studies, Seoul, Korea
[2]Yonsei Speech-Language Institute, Seoul, Korea
[3]HUGS Center for Hearing and Speech Research, Seoul, Korea

Background and Objectives: The Gaps-In-Noise (GIN) test is a clinically effective measure of the integrity of the central auditory nervous system. The GIN procedure can be applied to a pediatric population above 7 years of age. The present study conducted the GIN test to compare the abilities of auditory temporal resolution among typically developing children, children with speech sound disorder (SSD), and children with cognitive difficulty (CD). **Subjects and Methods**: Children aged 8 to 11 years-(total n=30) participated in this study. There were 10 children in each of the following three groups: typically developing children, children with SSD, and children with CD. The Urimal Test of Articulation and Phonology was conducted as a clinical assessment of the children's articulation and phonology. The Korean version of the Wechsler Intelligence Scale for Children-III (K-WISC-III) was administered as a screening test for general cognitive function. According to the procedure of Musiek, the pre-recorded stimuli of the GIN test were presented at 50 dB SL. The results were scored by the approximated threshold and the overall percent correct score (%). **Results**: All the typically developing children had normal auditory temporal resolution based on the clinical cutoff criteria of the GIN test. The children with SSD or CD had significantly reduced gap detection performance compared to age-matched typically developing children. The children's intelligence score measured by the K-WISC-III test explained 37% of the variance in the percent-correct score. **Conclusions**: Children with SSD or CD exhibited poorer ability to resolve rapid temporal acoustic cues over time compared to the age-matched typically developing children. The ability to detect a brief temporal gap embedded in a stimulus may be related to the general cognitive ability or phonological processing. **J Audiol Otol 2020;24(3):133-139**

KEY WORDS: Gaps-In-Noise · Auditory temporal resolution · Auditory temporal processing.

Introduction

Auditory temporal processing involves the ability of the auditory system to represent the variations in intensity over time. Auditory temporal processing skills are considered crucial for speech intelligibility as speech contains temporal elements that differentiate various speech sounds [1]. Among the different aspects of temporal processing such as auditory temporal resolution, temporal masking, and temporal integration, auditory temporal resolution is one of the essential aspects of temporal processing. It requires following and resolving rapid changes in the envelope of sound over time [2].

Gap detection is a common and well-studied measure of auditory temporal resolution. In the traditional gap detection task, the listener needs to detect a brief temporal gap embedded in a stimulus. The shortest detectable gap has been estimated as the gap detection threshold using either speech or non-speech stimuli [3]. The gap detection threshold is known to depend on a variety of stimulus characteristics such as stimulus level, stimulus bandwidth, modulation features, spectral and temporal complexity, and uncertainty [1]. Several evidences suggest that gap detection performance is related to cognitive demand or attentional resources [4-5]. For example, Leung, et al. [4] measured auditory event-related potentials

during active and passive listening and found that gap detection performance was associated with attentional processing, possibly related to divided attention. Günel, et al. [5] suggested that the poorer performance of gap detection could be explained, in part, by associations with sustained attention, or cognitive ability, as speech input should be sustained in the memory for a sufficient duration.

The classic psychoacoustic procedures for gap detection often include time-consuming experimental procedures [6]. The long run-time measure of gap detection would be inappropriate, particularly in the pediatric population [7]. As an adaptive test of temporal resolution, the Gaps-In-Noise (GIN) test has been recommended as a reliable and straightforward method to measure gap detection thresholds in adults as well as in the pediatric population [7-8]. Shinn, et al. [7] verified that the GIN test could be clinically feasible and reliable to assess the temporal resolution of children as young as 7 years of age. Chermak and Lee [9] reported that the GIN test had several advantages compared to other auditory temporal resolution tests; such as, ease of use, short administration time, and firm face validity.

Auditory temporal resolution is critical for speech perception and successful language development in children, because difficulty in recognizing rapid temporal acoustic cues influences phoneme identification and aspects related to speech recognition [10,11]. To understand the impact of auditory temporal resolution on language and reading development, researchers have conducted the GIN test in children with deficits of learning in reading, and phonological processing [11,12]. Zaidan and Baran [11] administered the GIN test and found reduced auditory temporal resolution in children with dyslexia and phonological processing deficits than in typically developing children (8 to 11 years of age). Chaubet, et al. [12] reported that the auditory temporal resolution in children with dyslexia and phonological processing disorders was much lower than the performance of typically developing children (10 to 15 years of age).

Given that temporal resolution contributes to the ability to differentiate small characteristics of speech sounds, several studies determined the relationship between auditory temporal processing and speech sound disorder (SSD). For example, Sayyahi, et al. [13] reported a significant relationship between gap detection threshold and speech error consistency in children with SSD, which is a common developmental speech disorder. Muluk, et al. [14] found poorer gap detection performance in children with previous language delay and SSD. Similarly, Vilela, et al. [15] reported reduced auditory processing performance in children with SSD. Moreover, children with SSD performed poorly in auditory and visual sus-

tained-attention tasks, as well as in gap detection and frequency pattern tasks [16]. Moore, et al. [17] tested 1,469 children with normal hearing (aged 6 to 11 years). The authors found that auditory processing abilities were related to cognitive, communication, and speech-in-noise performance, and revealed that cognitive performance was one of the best predictors of auditory processing disorder. Moore, et al. [17] concluded that auditory processing disorder is primarily an attention problem, suggesting that children with cognitive difficulty (CD) would perform worse than typically developing children. Considering these facts, the present study aimed to compare the auditory temporal resolution performance measured by the GIN test among children with SSD, children with CD (borderline intelligence), and typically developing children. We hypothesized that children with SSD or CD would process temporal cues in speech differently, than would typically developing children.

Subjects and Methods

Participants

The age criteria for the present study was 8 to 11 years of age, as the GIN test is clinically feasible for children as young as 7 years of age [7, 18]. All children had pure tone thresholds of less than 15 dB HL in the frequency range from 250 to 8,000 Hz in the octave scale and had no middle-ear dysfunction or otologic disease.

Altogether 30 children between 8 and 11 years of age, native Korean and right-handed, participated in this study. The inclusion criteria common to all groups were as follows: 1) aged between 8 and 11 years, 2) ≤20 dB HL of hearing thresholds at octave frequencies from 250 to 4,000 Hz, and 3) ≥92% word recognition score in quiet from the Korean speech audiometry [19], confirming that each child had no distinct speech-understanding problem in quiet. Among the 30 children, 10 children were typically developing (5 males, 5 females) with no reports of reading, speech and language difficulties (mean age: 9.1 years), 10 children (5 males, 5 females) were identified as having a SSD; (mean age: 9.3 years), and 10 children (5 males, 5 females) had CD; (mean age: 10.3 years) which could be categorized as borderline intellectual functioning. Children with SSD or CD had speech therapy experience from 1 to 20 months.

To evaluate the articulation and phonological skills and/or general intelligence in the typically developing (TD), SSD, and CD groups, we conducted two evaluations: 1) the Urimal Test of Articulation and Phonology (U-TAP) and 2) the Korean version of Wechsler Intelligence Scale for Children-III (K-WISC-III). The U-TAP [20] is a Korean clinical, comprehensive evaluation that can be administered to children of preschool

age. The U-TAP is a widely used articulation and phonation test at the word or sentence level. The K-WISC-III [21] is a valid and standardized measure of intellectual function for children aged 6−16 years. Table 1 shows the mean scores of the U-TAP, and a full-scale intelligence quotient according to the K-WISC-III for the TD, SSD, and CD groups. Based on a full-scale intelligence quotient (IQ) according to the K-WISC-III, intelligence is divided into seven categories as follows: mentally retarded (IQ≤69), borderline (IQ: 70−79), low-average (IQ: 80−89), average (IQ: 90−109), high-average (IQ: 110−119), superior (IQ: 120−129), and very superior (IQ≥130).

As displayed in Table 1, the three groups of children differed in their articulation, phonology skills, and intelligence. Ten TD children had scores of articulation and phonology skills within normal range (mean U-TAP: 99.3±1.4, range: 97−100) and each had average intelligence (mean IQ: 99± 5.2, range: 91−109). Ten SSD children had lower-than-normal scores of articulation and phonology skills according to their chronological age based on ±2 standard deviations (mean U-TAP: 81.4±3.8, range: 75−87), indicating a significant delay in the acquisition of articulated speech sounds. Each child with SSD had average intelligence (mean IQ: 99.4±5.0, range: 90−109). Ten CD children had an intelligence categorized as "borderline" (mean IQ: 76.4±3.3, range: 70−79) without SSD (mean U-TAP: 92.4±3.9, range: 90−100). The present study was approved by the Research Ethics Committee (#0000627541). All subjects met the Institutional Review Board criteria for the recruitment of human subjects. Informed consent was signed by the parent or guardian of each child.

Stimuli and procedure

Test of auditory temporal resolution (Gaps-In-Noise test)

The GIN test [8] was administered by a commercially available compact disc via a clinical two-channel audiometer (Madsen Obiter OB-922, GN Otometrics, Taastrup, Denmark). The GIN test consists of one practice track and four testing tracks. As stimuli, 0 to 3 silenced gaps are embedded within 6-second white noise. There are ten different gap durations (2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 ms), and the duration or location of the gaps within the noise is pseudorandomized. As each gap appears six times in each track, a total of 60 gaps were presented. The stimuli were presented using a loudspeaker at a 50-dB SL relative to the pure tone threshold average across 0.5, 1, and 2 kHz for each subject. Whenever the subjects identified the silence gap, they were instructed to press a button.

Before the experimental test, a practice session (training track) included in the GIN test was conducted to ensure that each subject understood the task correctly. Each child could have breaks during the GIN and other tests. Approximately 40−60 min were required to complete the tests. The GIN test scores auditory temporal resolution in two ways: 1) an approximated threshold defined as the shortest detectable gap where a listener correctly identifies at least 4 out of 6 presentations of the same gaps and 2) percent-correct score (percentage of correct detection).

In a previous finding [22], the normality cutoff criteria of the GIN were reported based on the data of 75 typically developing children and a 95% confidence interval. For children aged 8-10 years, the clinical cutoff criteria were 6.1 ms for the GIN threshold and 60% for the percent-correct score. The present study applied these criteria to the data to deter-

Table 1. Mean scores of the U-TAP, full-scale IQ obtained by the K-WISC-III, duration of speech therapy, and WRS (%) for the three groups of children

	TD group	SSD group	CD group
Score of U-TAP	Mean U-TAP: 99.3±1.4 (range: 97−100, all were within normal range)	Mean U-TAP: 81.4±3.8 (range: 75−87, all were lower-than-normal range)	Mean U-TAP: 92.4±3.9 (range: 90−100, all were within normal range)
Full-scale IQ according to the K-WISC-III	Mean IQ: 99.0±5.2 (range: 91−109, all had average intelligence)	Mean IQ: 99.4±5.0 (range: 90−109, all had average intelligence)	Mean IQ: 76.4±3.3 (range: 70−79, all had borderline intelligence
Duration of speech therapy (month)	N/A	Mean: 6.3±3.1 (range: 1−12)	Mean: 13.7±3.6 (range: 9−20)
WRS (%) obtained from individually determined most comfortable level	Mean WRS: 100±0 (all had score of 100%)	Mean WRS: 97.8±1.5 (range: 92−100%)	Mean WRS: 96.8±1.1 (range: 92−100%)

U-TAP: Urimal Test of Articulation and Phonology, IQ: intelligence quotient, TD: typically developing, SSD: speech sound disorder, CD: cognitive difficulty, K-WISC- III: the Korean version of Wechsler Intelligence Scale for Children-III, N/A: not applicable, WRS: word recognition score

mine whether the gap detection performance of TD, SSD, and CD children surpassed the thresholds.

Analysis

All the statistical analyses were performed using SPSS version 20.0 (IBM Corp., Armonk, NY, USA). Due to the violation of the assumption of normality from the Shapiro-Wilk test, non-parametric tests of Kruskal-Wallis were conducted to compare the U-TAP score, the full-scale IQ assessed by K-WISC-III, and the GIN performance among the three groups. If needed, the non-parametric Mann-Whitney U test was followed for the multiple comparisons on each pair of the group. The Spearman's rank-order correlational analyses were also administered to examine the correlation between the results. Linear regression analysis was used to examine any significant predictor accounting for the variance in GIN performance. The statistical significance level adopted was 0.05. However, the α level was adjusted for multiple comparisons.

Results

Table 2 displays the descriptive statistics for the approximated threshold and percent-correct score obtained from the GIN test. As shown, the mean approximated threshold was 5.4 ms $\pm$ 0.4, 6.1 ms $\pm$ 0.7, and 7.1 ms $\pm$ 1.6 for the TD, SSD, and CD groups, respectively. The median value of approximated threshold was 5.5, 6.1, and 6.6 ms for the TD, SSD, and CD groups, respectively. The mean percent-correct score was 64.0% $\pm$ 3.1, 54.2% $\pm$ 3.3, and 48.9% $\pm$ 4.6 for the TD, SSD, and CD groups, respectively. The median value of the percent-correct score was 65.0%, 54.0%, and 49.0% for the TD, SSD, and CD groups, respectively. The results of the Kruskal-Wallis H test showed a significant main effect of the group on the approximated threshold and percent-correct score. The results of the Mann-Whitney tests showed that the threshold of

the TD group was significantly shorter (better) than the SSD or CD group, and the threshold of the SSD group was lower (better) than that of the CD group. Similar to the approximated threshold, the mean percent-correct score of the TD group was higher than the other two groups, and the SSD group performed better than the CD group.

As mentioned above, the clinical cutoff criteria for the normal gap detection threshold and percent-correct score would be 6.1 ms and 60%, at least for children aged 8–10 years [12]. Applying these criteria, all the TD children should have normal auditory temporal resolution (range of approximated threshold: 4.9–6.0 ms; percent-correct score range: 60.0–68.0%), as shown in Table 1. Among the 10 children with SSD, 5 children had a higher gap detection threshold (range of approximated threshold: 4.9–7.3 ms) compared to a cutoff threshold of 6.1 ms, and 9 SSD children had a lower percent-correct score compared to a cutoff score of 60% (score range: 49.0–60.0%). Among the 10 children with CD, 7 children had a higher gap detection threshold (range of approximated threshold: 5.4–11.0 ms) compared to a cutoff threshold of 6.1 ms. All the CD children had a lower percent-correct score than the cutoff score of 60% (score range: 40.0–57.0%).

We explored the relationship between the results of the GIN, U-TAP, and K-WISC-III tests to determine whether the gap detection scores were related to individual articulation and phonological skills or intellectual function. As plotted in Fig. 1, the percent-correct scores were significantly and positively correlated with the scores of the U-TAP (rho=0.44, $p<0.05$) and K-WISC-III (rho=0.67, $p<0.05$). As shown in Fig. 2, the percent-correct scores were negatively correlated with the approximated threshold (rho=-0.78, $p<0.05$); however, the U-TAP score was not related to the K-WISC-III results (rho=-0.05, $p>0.05$). A linear regression analysis was performed on the percent-correct scores of the SSD and CD subjects to examine whether the U-TAP or the K-WISC-III score accounted for the variance in the GIN score. Based on an alpha-level

Table 2. Descriptive statistics and Kruskal-Wallis H test results for the approximated threshold and the percent-correct score (%) for three groups of children

Variable	Group	Mean	Standard deviation	Minimum	Maximum	25th percentile	50th percentile	75th percentile	Significance p-value
Approximated threshold (ms)	TD	5.4	0.4	4.9	6.0	4.9	5.5	5.7	<0.01
	SSD	6.1	0.7	4.9	7.3	5.5	6.1	6.6	
	CD	7.1	1.6	5.4	11.0	6.0	6.6	7.9	
	Total	6.2	1.2	4.9	11.0	5.5	6.0	6.6	
Percent-correct score (%)	TD	64.0	3.1	60.0	68.0	60.0	65.0	67.0	<0.01
	SSD	54.2	3.3	49.0	60.0	52.3	54.0	57.0	
	CD	48.9	4.6	40.0	57.0	47.0	49.0	52.0	
	Total	55.7	7.3	40.0	68.0	49.8	54.5	60.8	

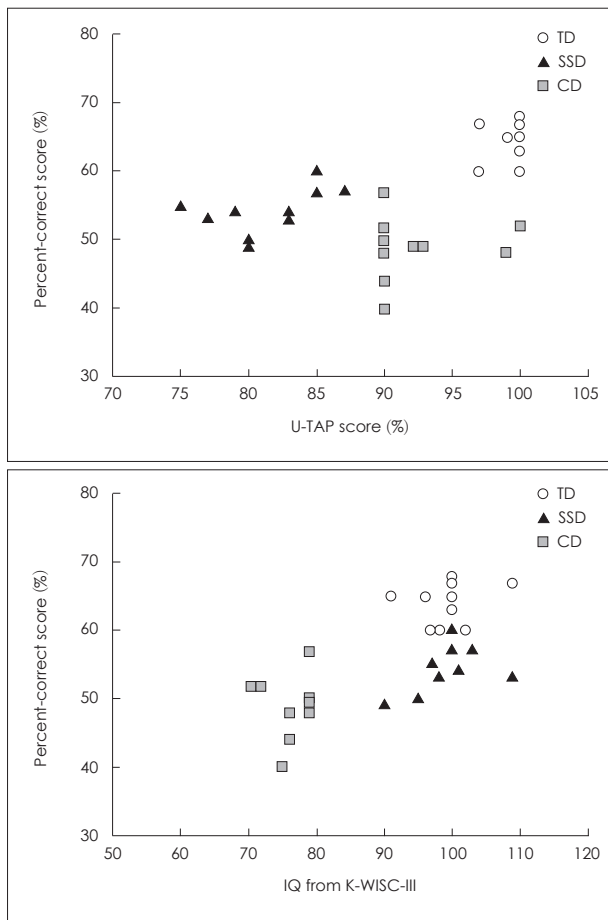TD: typically developing, SSD: speech sound disorder, CD: cognitive difficulty

Fig. 1. Scatterplots for the relationship between the percent-correct score (%) of GIN and the U-TAP score (top panel) and between the percent-correct score (%) of GIN and the IQ obtained by the K-WISC-III (bottom panel) for three groups of children. TD: typically developing, SSD: speech sound disorder, CD: cognitive difficulty, U-TAP: Urimal Test of Articulation and Phonology, GIN: Gaps-In Noise, IQ: intelligence quotient, K-WISC-III: the Korean version of Wechsler Intelligence Scale for Children-III.
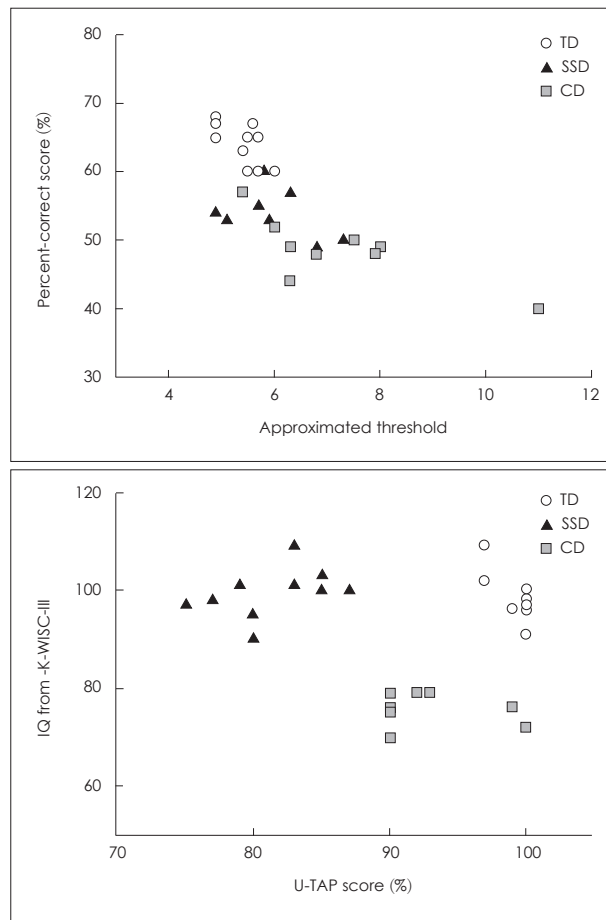

Fig. 2. Scatterplots for the relationship between the percent-correct score (%) of the GIN and the approximated threshold (top panel) and between the U-TAP score and the IQ obtained by the K-WISC-III (bottom panel) for three groups of children. TD: typically developing, SSD: speech sound disorder, CD: cognitive difficulty, GIN: Gaps-In Noise, U-TAP: Urimal Test of Articulation and Phonology, IQ: intelligence quotient, K-WISC-III: the Korean version of Wechsler Intelligence Scale for Children-III.

of 0.05, the results of the K-WISC-III explained 37% of the individual differences in the GIN performance (adjusted R square: 0.72, $p<0.05$), while the U-TAP score did not account for the variance in the GIN performance.

Discussion

In daily listening, speech naturally fluctuates over time such that listeners often need to encode, contrast, and perceive the temporal features of speech. The ability to recognize rapid temporal acoustic cues may be critical for speech perception and successful language development in the pediatric population. If children have deficient processing of rapid temporal cues in speech sound, their reduced temporal resolution may worsen their processing of phonological and phonemic information. Although the neurophysiologic mecha-

nisms underlying the association between temporal processing and phonological processing are not fully understood, previous findings reported that children with language and reading deficits or CD had poorer performance in temporal resolution tasks than age matched controls [12-15].

The present study administered the GIN test to compare the temporal resolution abilities of children with SSD (articulation and phonological processing deficits) and children with CD (borderline intelligence) relative to the performance of age-matched typically developing children. Our data revealed that children with SSD or CD detected gaps poorly than did typically developing children. Similarly, Marculino, et al. [18] reported that 9-year-old children with reading and learning difficulties detected the gaps poorly than the age-matched typically developing children. Zaidan and Baran [11] revealed that children diagnosed with dyslexia and phonological

awareness deficits showed poorer gap detection performance than a control group with normal reading skills. Chaubet, et al. [12] also found that pediatric groups with dyslexia or reading and writing disorders performed worse on the GIN test than normal-hearing typically developing children did. Similarly, other previous studies reported the lower auditory temporal processing in children with dyslexia or word reading difficulties [23-25].

This supports the assumption that gap detection performance could be used to clinically assess the phoneme-specific speech perception of students with SSD. Zhao and Kuhl [26] reported that music intervention focusing on the learning of temporal structure could improve infants' abilities to extract temporal structure in music as well as speech. Considering the benefit from interventions focused on temporal information, evaluation of temporal processing may be beneficial in clinical diagnosis. It may also assist in planning non-linguistic auditory interventions focused on the processing of temporal information. Murphy, et al. [27] revealed the efficacy of non-linguistic auditory interventions in children with SSD.

The present study determined that the IQ data obtained from the K-WISC-III score accounted for 37% of the variance in the GIN score. Similarly, Moore, et al. [17] found that the score of a cognitive test was the best predictor explaining the individual variability in poor communication and listening. Harris, et al. [28] also suggested an influence of listeners' cognitive ability and task difficulty on the gap detection task performance. As our study includes a small sample in each group, it has a limitation with regard to generalizing this finding. Additional research with a larger sample is required to clarify the relationship between auditory temporal resolution and general intellectual function in children with developmental deficits.

In conclusion, the present study compared the GIN performance of TD children, children with SSD, and children with CD (borderline intelligence). All children had normal hearing and excellent speech recognition in quiet. Our findings support the previous findings [13,17,29,30] that the children with SSD or CD may have a poorer auditory temporal resolution than the age-matched typically developing children have. The results of our study indicate that children from 8 to 11 years of age could attend to a subsequent gap detection task, and their temporal resolution performance may be related to phonological skills and intellectual functioning, consequently contributing to their poorer speech perception in various communication situations.

Author Contributions

Conceptualization, Data curation, Methodology, and Writing—original drift: Yu Kung Jung. Formal analysis, Supervision, and Writing—review & editing: Jae Hee Lee.

ORCID iDs

Yu Kyung Jung https://orcid.org/0000-0002-9147-0053
Jae Hee Lee https://orcid.org/0000-0002-4152-6434

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