GIN (Gaps-In-Noise) Performance in the Pediatric Population

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Abstract

Background: The recently developed Gaps-In-Noise (GIN) test has provided a new diagnostic tool for the detection of temporal resolution deficits. Previous reports indicate that the GIN is a relatively sensitive tool for the diagnosis of central auditory processing disorder ([C]APD) in adult populations.

Purpose: The purpose of the present study was to determine the feasibility of the GIN test in the pediatric population.

Research Design: This was a prospective pseudorandomized investigation.

Study Sample: This investigation involved administration of the GIN to 72 participants divided into six groups of normal children ranging from 7 through 18 years of age.

Data Collection and Analysis: The approximate GIN threshold (the shortest gap duration for which at least four of six gaps were correctly identified) served as the dependent variable. Results were analyzed using an ANOVA to examine between- and within-group differences.

Results: No statistically significant differences were seen in GIN thresholds among age groups. In addition, within group analysis yielded no statistically significant differences between ears within each age group. No developmental effect was seen in GIN thresholds between the ages of 7 and 18 years. Children as young as age 7 are able to complete the GIN with no significant difficulty and perform at levels commensurate with normal adults. The absence of ear differences suggests that temporal resolution as measured by the GIN is an auditory process that develops relatively early and symmetrically (i.e., no laterality or ear dominance effects).

Conclusions: The GIN procedure appears to be a feasible measure of temporal resolution in both pediatric and adult populations.

Key Words: (central) auditory processing, Gaps-In-Noise, pediatrics, temporal resolution

Abbreviations: AFT-R = Auditory Fusion Test—Revised; ATh = approximate threshold; CANS = central auditory nervous system; (C)APD = (central) auditory processing disorder; FPT = Frequency Pattern Test; GD = gap detection; GDT = Gap Detection Test; GIN = Gaps-In-Noise; RGDT = Random Gap Detection Test

Auditory temporal processing may be defined as the perception of the temporal envelope or the alteration of durational characteristics of a sound within a restricted or defined time interval (Musiek et al, 2005). Auditory perception, which requires precise and accurate processing of the timing elements of sound, is crucial to the most basic processing at the neuronal level to complex higher-level speech perception and spoken language processing. In particular, temporal processing skills are critically important to phonemic distinctions (e.g., voice-onset time [VOT]), lexical and prosodic distinc-

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In the interest of full disclosure, Frank Musiek is associated with Audiology Illustrated, which distributes the GIN test.

tions, and auditory closure, as well as underlying many other auditory perceptual skills (Chermak and Musiek, 1997). In fact, as a result of the essential role that temporal processing plays in auditory perception, it likely underlies, at least in part, most other auditory processes such as localization, discrimination, pattern processing, binaural integration, and binaural separation. Several different, but related, dimensions of temporal processing may differentially support these other auditory processes, as discussed below.

Temporal processing may be conceptualized as four subprocesses including: (1) temporal resolution, (2) temporal patterning, (3) temporal integration, and (4) temporal masking (Shinn, 2007). Unfortunately, at the present time, no widely accepted clinical tools are available to assess temporal integration and temporal masking. As confirmed by Emanuel (2002), temporal ordering (i.e., patterning) is most often measured using the Frequency (Pitch) Pattern Test (FPT; Musiek, 1994). The FPT is sensitive to temporal processing deficits in adults and children (Musiek, 1994). Until recently, there were few tests of temporal resolution available for clinical use, especially those with documented sensitivity to deficits of the central auditory nervous system (CANS) in children and adults. Not surprisingly, few audiologists have incorporated assessment of temporal resolution in their test battery, despite its crucial role in auditory perception, speech perception, and language processing. Emanuel (2002) reported that while 76% of respondents indicated use of the FPT, only a quarter of the respondents reported using any measure of gap detection (i.e., the most commonly used measure of temporal resolution). This is of significant concern given the fact that temporal resolution is a component of the recommended minimal central auditory processing test battery, as outlined by both the consensus statement at the Bruton Conference (Jerger and Musiek, 2000), as well as the most recent technical report by the American Speech-Language-Hearing Association (2005).

Temporal resolution, particularly in the pediatric population, is a critical auditory skill necessary in accurate auditory processing. It may be defined as the auditory system's ability to respond to rapid changes in the envelope of a sound stimulus. Few studies have examined temporal resolution in the pediatric population. This is surprising given the fact that we know that this is an important skill in speech perception and its development. Temporal resolution is typically evaluated through a psychoacoustic measurement known as gap detection (GD). This paradigm generally involves the presentation of two stimuli that are separated in time by a "gap" or brief period of silence. The listener's task is to detect the presence of the gap, essentially discriminating sound from silence. Gaps vary in duration generally on the order of milliseconds, reflecting comparable interstimulus intervals between the tokens. The purpose of the procedure is to determine the smallest interval that a listener can detect. This is also known as the gap detection threshold (GDT). For highly trained individuals, GDTs are on the order of 2–3 msec (Phillips, 1999) and is slightly higher for naïve listeners (Phillips and Smith, 2004) for within-channel stimuli. Gap detection seems dependent on discontinuity in neural activity within the CANS. In order to process gaps, the auditory system must be able to detect a difference in the stimulus, thereby creating a detection of discontinuity (Phillips, 1999). Using these traditional psychometric approaches, GD has been studied as a function of age and hearing impairment. Although it is beyond the scope of this report to explore the entire body of GD literature, a brief review is warranted to contextualize the present investigation.

It has been demonstrated that temporal resolution ability varies as a function of age, with older adults demonstrating greater GDTs than younger adults (Strouse et al, 1998; Snell and Frisina, 2000; Bertoli et al, 2002; Lister and Tarver, 2004; Roberts and Lister, 2004; Lister and Roberts, 2005), although not all studies support these findings (He et al, 1999; Moore et al, 1992). Individuals with hearing loss also have been reported to demonstrate elevated GDTs (Fitzgibbons and Wightman, 1982; Florentine and Buus, 1984; Glasberg et al, 1987; Nelson and Thomas, 1997). Ablation and lesion studies suggest that impaired neurological functioning leads to elevated GDTs (Efron et al, 1985; Walton et al, 1997). The developmental time course of temporal resolution in children is unclear, with discrepancies across studies likely due to differences in age groups and experimental methodologies (Davis and McCroskey, 1980; Irwin et al, 1985; Grose et al, 1993; Jensen and Neff, 1993; Hall and Grose, 1994). One factor that is particularly relevant to the present study is the degree to which previous methodologies incorporated clinically viable measures of temporal resolution. In fact, previous methodologies for determining GDTs have clearly not been appropriate for children. Many of these methodologies employed abstract concepts and required long test sessions and high levels of concentration (Wightman et al, 1989).

Wightman and colleagues (1989) reported that children under the age of seven years demonstrate larger GD thresholds and greater variability than adults. It is difficult to determine whether this variability is due to auditory developmental issues or due, at least in part, to other intrinsic factors, such as attention and motivation, or perhaps to test methodology. The variability seen in GD thresholds in children younger than seven years may in part be the reason why definitive diagnosis of (central) auditory processing disorder ([C]APD) in children under the age of seven is quite difficult using behavioral tests alone.

Children with auditory neuropathy/dysynchrony also have been reported with abnormal temporal resolution (Rance et al, 2004). Rance and colleagues reported frequency resolution within normal limits; however, temporal resolution was abnormal (i.e., elevated) in a number of children with auditory neuropathy/dysynchrony. Temporal resolution deficit was positively correlated with the degree of speech reception deficit. Rance and colleagues (2007) reported more recently on both the receptive language skills and speech production in children with auditory dysynchrony. The authors examined children ranging in ages from 4 to approximately 14 years of age compared to their age-matched cohort with sensorineural hearing loss. They demonstrated that both receptive language and speech production were delayed in children with auditory dysynchrony compared to the children with sensorineural hearing loss. This link between temporal processing and impairment is not solely isolated to speech and language.

The relationship between temporal resolution and reading also has been investigated (Walker et al, 2002; Hautus et al, 2003). It has been clearly demonstrated that both children and young adults with reading impairment demonstrate deficits in the precise timing of auditory events. Although there is some discrepancy regarding the improvement of temporal processing deficits over time, it is apparent that it is present at least in early reading development (Hautus et al, 2003). We know that children with learning-related problems often have involvement of multiple systems, and it is likely that these temporal processing deficits might contribute to both language and reading impairment.

Regardless of the fact that GD has been proved to be a powerful tool in the assessment of a variety of experimental populations (Efron et al, 1985; Lister et al, 2002), it has not received the attention it should in the clinical arena. A limited number of studies has examined temporal resolution using the GD procedure in children with various disabilities. Hautus et al (2003) reported abnormal temporal resolution (i.e., elevated GDTs) in children (ages 6–9 years) with learning disabilities/dyslexia relative to age-matched controls. In contrast, the older children demonstrated normal GDTs, suggesting either developmental maturation or positive effects of their treatment programs.

Until recently, there had been only two commercially available tests of temporal resolution: (1) the Auditory Fusion Test—Revised (AFT-R) and (2) the Random Gap Detection Test (RGDT). Due to the nature of the task, it can be argued that the AFT-R is not truly a "gap detection" but, rather, a "fusion" task. Although the terms *gap detection* and *fusion* have been used interchangeably, they may not reflect the same underlying neurological process (Chermak and Lee, 2005). Gap detection requires the detection of silence, while fusion requires the detection of the presence of two versus one sound. Emanuel (2002) reported that the most frequently used measure of gap detection was the AFT-R, albeit with only 28% of respondents reporting using this measure. Less than 20% reported using an alternative measure of gap detection, presumably the RGDT. The RGDT is actually a revision of the AFT-R; however, the stimuli and manner of test presentation are slightly different (Keith, 2000). The RGDT is slightly different in that it employs both tonal and click stimuli. In addition, it has four as opposed to three subtests. As a result of the similarity to the AFT-R, particularly with respect to the response mode, the RGDT may also be a fusion, rather than a true gap detection, task.

Musiek et al (2005) introduced a new Gaps-In-Noise (GIN) test as a clinical measure of temporal resolution that could be used in the adult population. The GIN is easily administered and appears to yield good sensitivity and specificity to CANS dysfunction in adult populations while still demonstrating clinical feasibility (Musiek et al, 2005). Unlike other GD procedures, the GIN uses interrupted noise as opposed to tonal or click stimuli. The gaps are interspersed throughout the noise with gap durations ranging from 2 to 20 msec. Musiek et al (2005) reported a mean GDT derived from the GIN for naïve adult listeners as 4.9 msec with a standard deviation of 1 msec. Using a two standard deviation criteria (as is the criteria typically employed in establishing normative data), the GIN has been shown to yield a sensitivity of 67% and specificity of 94% for all subjects with known lesions of the CANS. If one examines its sensitivity for cortical versus brainstem involvement, the GIN demonstrates a sensitivity of nearly 80% for cortical lesions; however, its sensitivity for brainstem lesions is only 55%. This would suggest that although the brainstem must preserve the neural code in order for cortical processing of temporal resolution to occur, gap detection might be mediated at the level of the cortex. The GIN's test-retest reliability and equivalent forms reliability for adults were considered excellent ($r = 0.05$).

Given the importance of temporal resolution to auditory development and language processing, coupled with the infrequent use of GD measurement in clinical audiology, as reported by Emmanuel (2002) and Chermak et al (2007), a systematic study was undertaken to examine the feasibility of the GIN as a measure of temporal resolution in normal children. By collecting normative data across age groups, one can see the developmental time course of temporal resolution to maturity. The GIN has been proven to be a clinically feasible and sensitive measure of temporal resolution in the adult population (Musiek et al, 2005); therefore, the goals of the present study were to examine the clinical feasibility of the GIN with a normal pediatric population and to collect normative data for children ages 7–18.

METHODOLOGY

Subjects

Six groups of subjects (n = 72) participated in the present study. Subjects ranged from 7 to 18 years of age. Subjects recruited for this study were among the general clinical population as well as children of friends and colleagues, yielding a heterogeneous mix of children. All subjects volunteered for this research and met the institutional review board criteria for the enrollment of human subjects. There was a total of six groups of subjects (7–7.11 years, 8–8.11, 9, 10, 11, 12–18 year olds). Each of the five groups of subjects from ages 7 to 11 consisted of 10 subjects; the 12- to 18-year-old group consisted of 22 participants. All subjects presented normal pure tone thresholds (i.e., 20 dB HL or better for the octave frequencies 250 to 8000 Hz) bilaterally and all thresholds for each ear were within 10 dB across all frequencies tested. All children were free of active otologic disease on the day of testing based on otoscopy and tympanometry and reportedly had no neurologic or learning disabilities.

In order to determine the anticipated required number of subjects and the probability of obtaining a statistically significant result, a power analysis was performed. The level of significance employed for this analysis was p = .05. This analysis indicated that a sample size of 10 subjects per group would be required in order to obtain a power calculation of 0.935.

Procedures and Stimuli

All subjects were tested whiled seated in a sound-treated booth. The GIN stimuli were recorded on a compact disc and played through a calibrated audiometer (American National Standards Institute, 2004). The stimuli were presented at 50 dB SL with regard to pure tone average or speech recognition threshold to each ear independently. Stimuli were presented through calibrated supra-aural or insert earphones.

The GIN is composed of a series of 6 sec broadband noise segments containing zero to three silent intervals or gaps. The interstimulus interval between noise segments is 5 sec. Ten different gap durations (i.e., 2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 msec) are employed. Both gap duration and the location of gaps within the noise are pseudorandomized with regard to their occurrence. Variance in the number, duration, and placement of gaps is designed to decrease both the probability of guessing correctly and the number of trials needed to obtain statistically significant information.

The noise used in the GIN is a computer-generated white noise that is uniformly distributed. This distribution ranges from −32,000 to 32,000 with a root mean square value of 32,000/sqrt. That sampling rate occurs at 44,000 Hz. The noise of the GIN is turned on and off instantaneously. Figure 1 provides the spectral and time display of the GIN (Figure 1A) as well as an example of three possible GIN items (Figure 1B).

The GIN includes four lists of equivalent difficulty. Two lists, selected at random, were administered to each subject (one list to each ear). All subjects were given practice items, which were placed at the beginning of the CD to insure the task was understood. They were instructed to press the response button every time and as soon as they heard a gap or brief period of silence. If there was any confusion regarding the appropriateness of a response the examiner asked the subject how many gaps were detected in the previous noise segment to confirm the number of responses. During the practice session, subjects were checked to insure the response button could be easily handled and that they could respond verbally if needed. The score sheet used by the examiner provided the noise segment number, time interval in which the gap occurred, and duration of the gap (Figure 2A).

The approximate threshold (ATh) was used for analysis. The ATh was determined to be the shortest gap duration for which there were at least four of six correct (67%) identifications (Figure 2B). This level of performance had to be maintained (or improved) for gaps of greater duration. If a subject obtained a 67% performance but performance worsened for gaps that were longer, the initial level was not considered the ATh. Rather, the initial performance level that yielded a four of six correct performance level and was maintained for longer gap levels was considered the ATh. Although the GIN has two possible measures of analysis, the ATh and the overall percent correct, only the ATh was analyzed in the present study because it appears to yield better sensitivity and specificity than the percent correct index. The reader is referred to Musiek et al (2005) for a discussion of the percent correct analysis. Total test time is slightly longer than other temporal processing measures at approximately 20 minutes for practice and evaluation of both ears.

RESULTS

Mean ATh and standard deviations were computed for each age group. Means and 2 SD for each of the six groups, as well adult data previously published (Musiek et al, 2005), are presented in Figure 3.

ATh scores in milliseconds were analyzed using a two-way ANOVA. No statistically significant difference was found as a function of age for either the left ear ($F = 1.093$; $p = .372$) or the right ear ($F = .742$; $p = .595$). Paired sample comparisons were also made to determine if there were any maturational differences between ears within each of the six groups (Fig. 4). Using a significance value of $p < .01$, results (Table 1) demonstrated

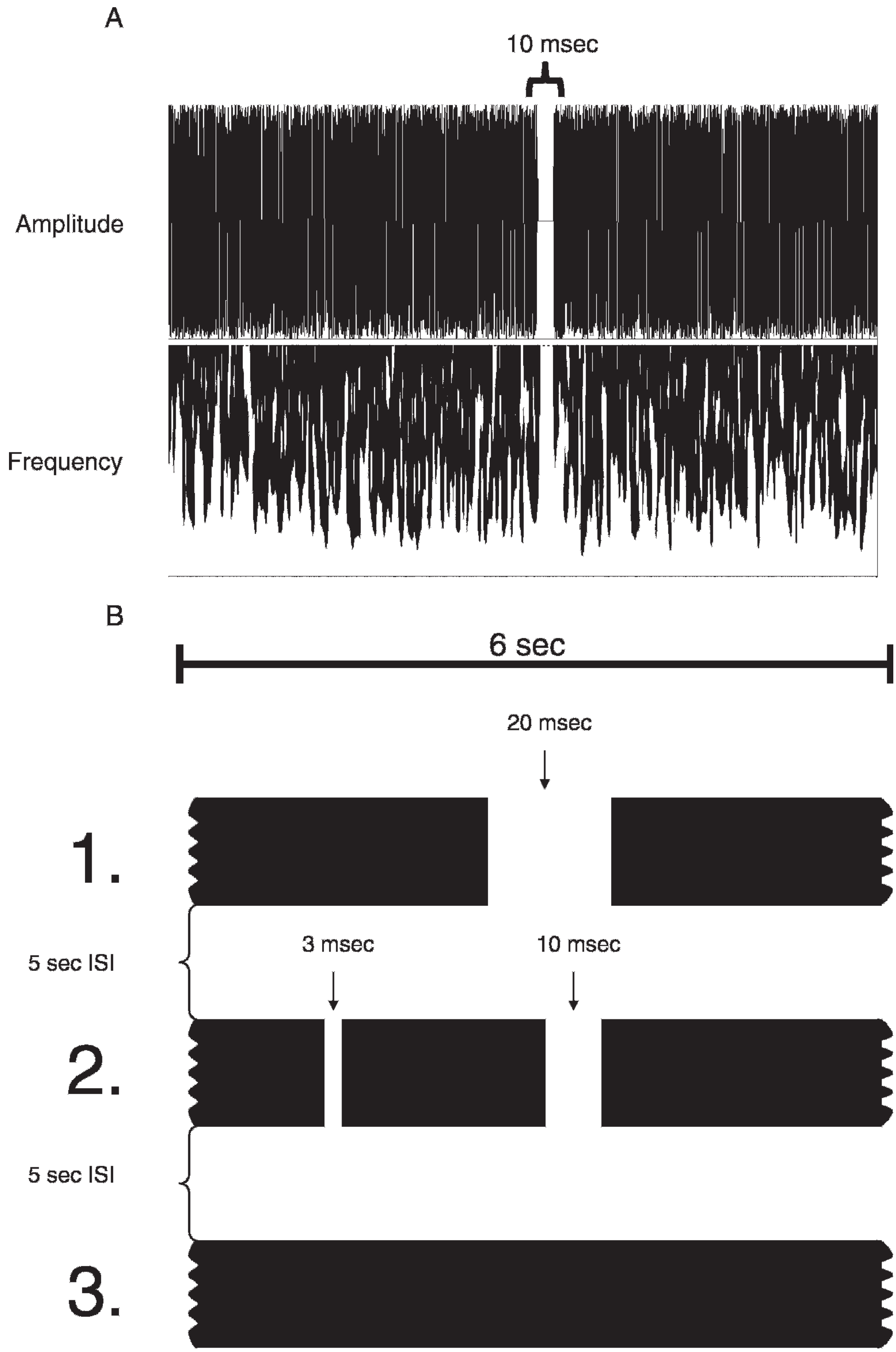

Figure 1. *(A)* Examples of GIN test items as well as spectral and time display of noise segment with representative gaps. *(B)* Sample of three GIN items demonstrating the duration of the stimuli, interstimulus intervals, and varying durations.

that there were no statistically significant differences between ears for any of the six groups. This suggests that maturation of the auditory system proceeded at the same rate for both the left and right aspects of the auditory system with respect to temporal resolution.

Visual inspection of the individual scatterplot data (Figure 5) reveals minimal ATh variability across groups. In addition, none of the subjects' ATh fell above the published adult mean plus 2 SDs of 8.0 msec, suggesting that temporal resolution is an auditory function that

A

Scoring

Location (msec)	Duration (msec)
1. 3870.3	20
2. 1303.2	~~2~~
4357.6	10
3.	

B

Scoring

Threshold	2 msec	3 msec	4 msec	5 msec	6 msec	8 msec	10 msec	12 msec	15 msec	20 msec	Total % Score
List 1	0 /6	1 /6	3 /6	4/6	6 /6	6 /6	6/6	6 /6	6 /6	6/6	39/60
Left Ear	0%	17%	50%	67%	100%	100%	100%	100%	100%	100%	65%

ATh = 5 msec

65% Correct

Figure 2. *(A)* Representation of a sample score sheet of three GIN test items. Shown is the location in elapsed time (in milliseconds) within the 6 sec noise segment where the gaps occurred and the duration of the segment. Segment 1 has one gap, segment 2 has two gaps, and segment 3 has no gaps. *(B)* The score sheet showing the ear tested, the proportion of correctly identified gaps and percentage of correctly identified gaps for each gap duration, and the ATh and total percentage of gaps detected.

matures early in life, and confirming that all subjects in the current study performed within normal limits.

DISCUSSION

The results reported here confirm the feasibility of the GIN for the assessment of temporal resolution in children. Given the role of temporal processing for auditory perception and speech perception (Phillips, 1999), language (Studdert-Kennedy and Mody, 1995; Wright et al, 1997; Musiek et al, 2005), and reading (Wolff, 1993; Hautus et al, 2003), it is essential that audiologists measure temporal resolution in children, as well as adults, referred for central auditory testing. Obtaining such information will improve the audiologist's ability to identify temporal resolution processing deficits and will increase the contribution to the multidisciplinary assessment of individuals referred for a variety of comorbid diagnoses. Early identification of temporal resolution deficiencies and subsequent remediation may preclude, or at least minimize, some of the educational obstacles that these children might otherwise encounter.

There appears to be a strong and important correlation between resolution deficits and some speech perception deficits. It has been clearly demonstrated that children and adults with auditory dysynchrony suffer from speech perception deficits (Rance, 2005;

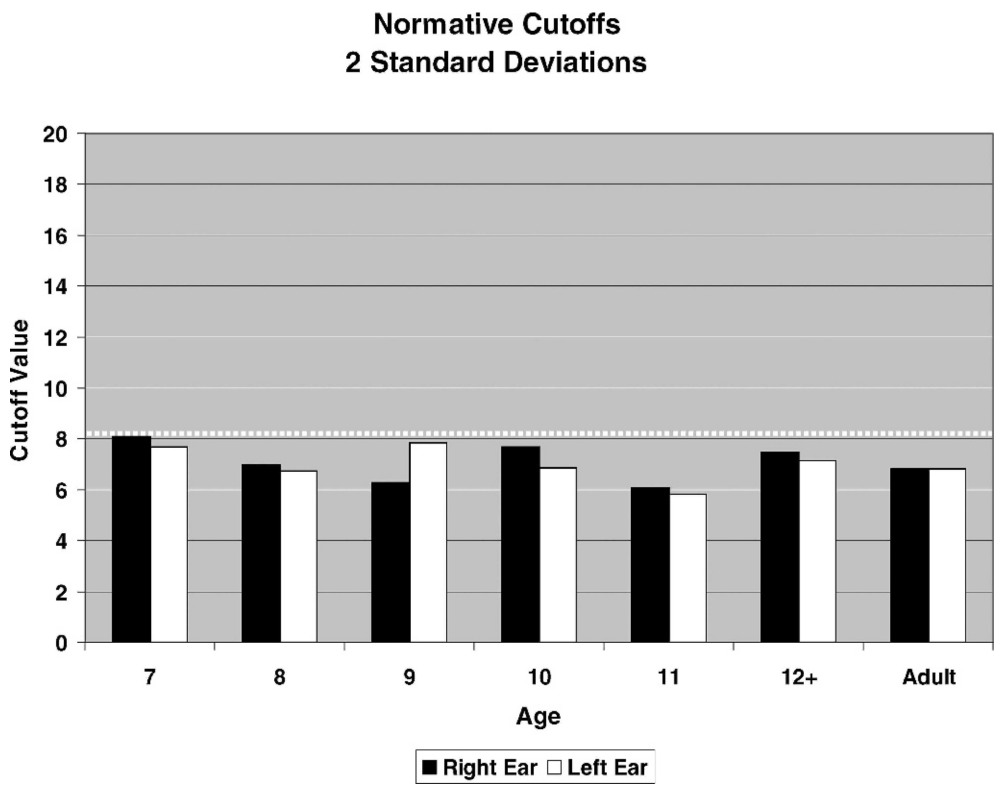

Figure 3. Recommended normative cutoff for each age group as a function of ear using a standard deviation normative criterion.

Gibson and Sanli, 2007). It has also been reported that speech perception abilities are highly dependent on temporal processing abilities (Zeng et al, 1999; Rance et al, 2004; Kumar and Jayaram, 2005). Zeng and colleagues (1999) were the first to report that impaired temporal processing in normal-hearing (nonauditory dysynchrony) subjects produces similar speech perception deficits as those with auditory dysynchrony. This further supports the evidence that demonstrates the critical role that temporal processing (specifically temporal resolution) plays in speech perception.

Although the exact developmental time course is still uncertain, it is clear that the entire auditory system is not fully mature at birth and that temporal resolution continues to develop during language acquisition (Wightman et al, 1989). The auditory cortex, which may mediate temporal resolution, does not mature until early adolescence (Sharma, 2007). The immaturity of the auditory system is observed even for the most basic auditory tasks. For example, infants' pure-tone thresholds are greater than adults, not reaching normal adult values until at least a year of age (Nozza and Wilson, 1984). Possible linkages between the development of temporal processing skills and that of pure tone sensitivity remain to be elucidated. Based on the evidence from the present investigation, it would appear that at least by age seven, if not sooner, the temporal resolution of children has reached adult values. Irwin and colleagues (1985) were the first to report that gap detection matures at around age ten years. However, Wightman and colleagues (1989) demonstrated that by five years of age, gap detection thresholds in children are similar to that seen in adults. Wightman et al (1989) reported adultlike gap detection thresholds in children as young as three to four years of age. The maturational time course observed by Wightman (1989) is similar to the values demonstrated in the present study. If it is demonstrated that children as young as three years of age are able to perform the task used in the GIN, it may be a promising tool in the early detection of (C)APD.

It has been demonstrated clearly that the temporal properties of sensory neurons within the CANS are highly trainable (Recanzone et al, 1992; Moore et al, 2003). If one can foster improvements in CANS function through auditory training and other (re)habilitative

Table 1. Within Subject Comparisons of Left versus Right Ears and Ranges in msec for Each Age Group

Group By Age	Mean Right Ear (SD)	Mean Left Ear (SD)	Range	p Value
7 yo	5.36 (1.36)	5.00 (1.34)	3–8	.167
8 yo	5.00 (1.00)	4.73 (1.00)	3–6	.465
9 yo	4.60 (0.84)	5.10 (1.37)	4–8	.052
10 yo	5.30 (1.25)	4.90 (0.99)	4–8	.269
11 yo	4.80 (0.63)	4.10 (0.87)	3–6	.011
12+ yo	4.87 (1.25)	5.00 (1.16)	3–8	.623

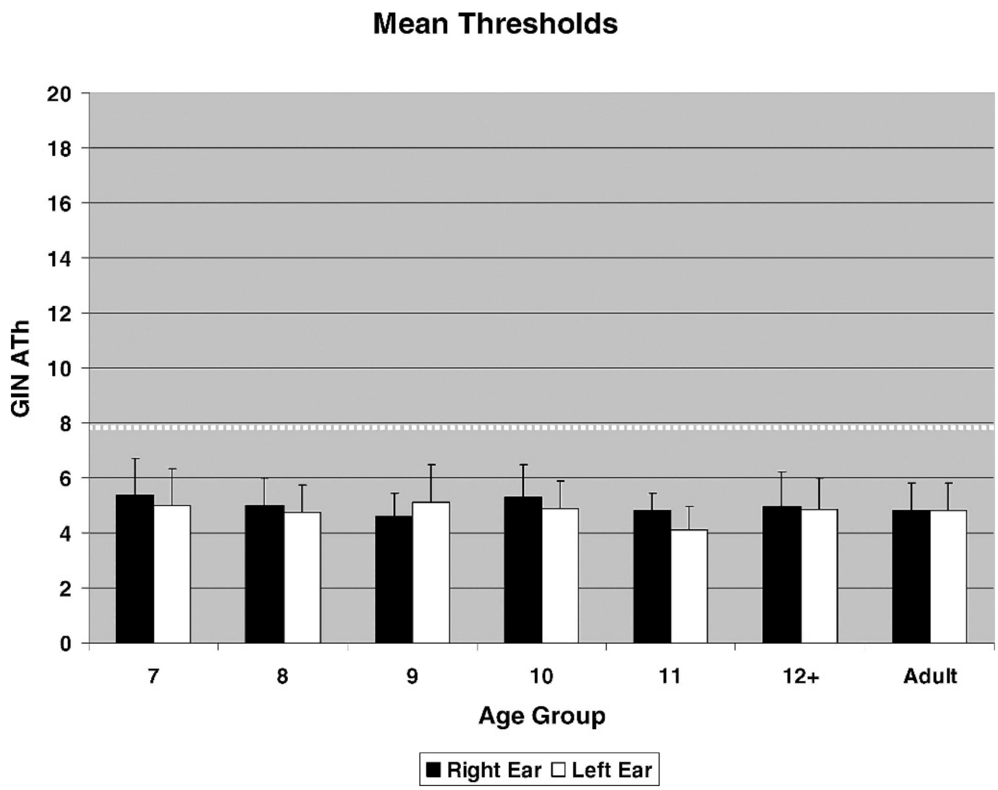

Figure 4. Mean gap detection thresholds as a function of age and ear across groups. The dotted line represents the normative adult values using a two standard deviation criterion.

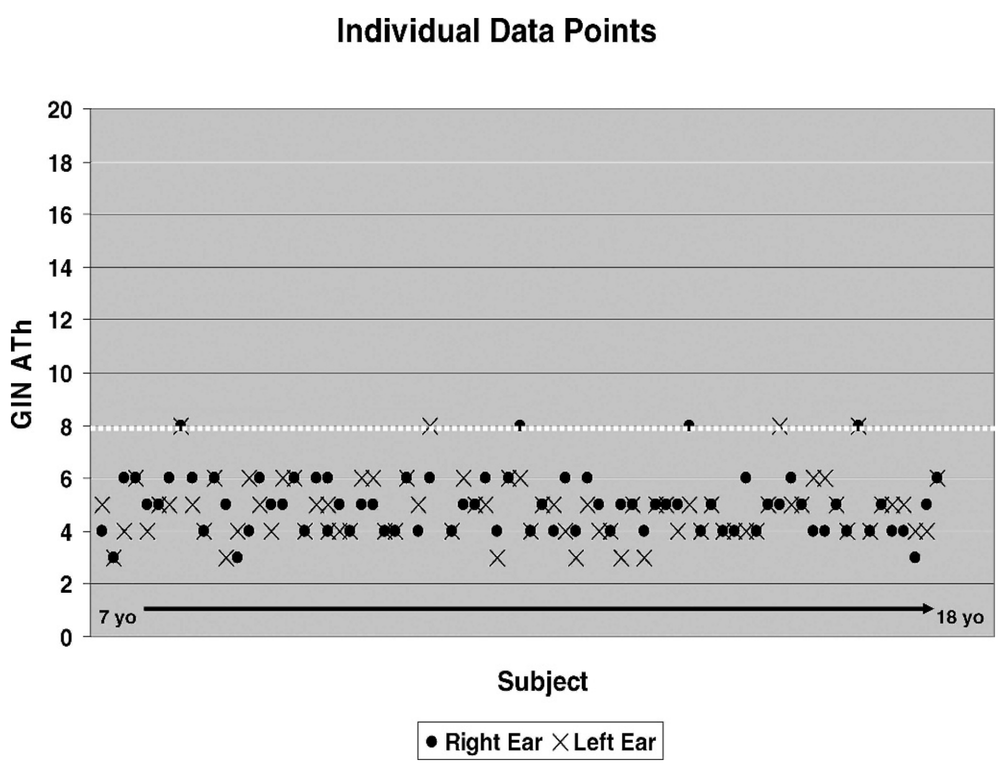

Figure 5. Individual data points for each subject as a function of ear across the age range. The dotted line represents the normative adult values using a two standard deviation criterion.

efforts for those individuals with central auditory processing deficits, we may expect to see improvements in related areas such as language and reading.

Results from the present investigation demonstrate not only early maturation of GD in children but symmetry between ears, which has also been seen in normal adults (Musiek et al, 2005). The absence of interaural differences has been reported in adults for a number of other temporal processes (e.g., frequency patterns) (Musiek and Pinheiro, 1987). In children, however, interaural differences have been reported for temporal resolution as measured through topographic brain maps, indicating greater activation with right ear stimulation (i.e., privileged access to the left hemisphere) but less activation in the left hemisphere. This asymmetrical processing could suggest an immaturity or inefficiency within the CANS, although behavioral measures of GD may not reflect underlying neurophysiologic asymmetry. Future research with the GIN should involve children with known (C)APD. Although no interaural differences in the GIN have been observed in normal adults and children, significant asymmetries on a temporal resolution task have been reported in pathological adult populations (Hammond, 1982). Unlike other temporal measures such as the Frequency Pattern or Duration Pattern Tests, which can be given either binaurally or in the soundfield, which in turn shortens test time, each ear must be evaluated independently with the GIN given ear asymmetries observed in the lesioned population (Musiek et al, 2005).

The authors propose two important future directions for the GIN. The first is to complete development of a screening version of the GIN for clinical use. Second, since temporal resolution appears to reach adult levels earlier than other temporal processes such as frequency patterns, we may be successful in evaluating children even younger than age seven. It would be ideal if a tool could be identified that evaluated children even at ages three, four, and five when reading and language development begins to flourish. In fact, some of our data collected on six-year-olds not presented in this report revealed similar ATh in the 4–6 msec range. The authors suggest that consideration should be given to further investigation of the GIN in children with a variety of language and learning disabilities.

SUMMARY AND CONCLUSIONS

The GIN procedure presents as a promising tool in the diagnosis of temporal resolution deficits in the pediatric population. The GIN appears to be a reliable and valid measure for the assessment and early identification of temporal resolution deficits down to the age of seven years. Children ages seven and older demonstrate an absence of significant ear asymmetries and ATh's similar to those seen in adults. The results of this study provide normative data for children between the ages of 7 and 18 years. Given the GIN's ability to detect lesions of the CANS, future studies are planned to determine the sensitivity of the GIN to (C)APD in pediatric populations. The GIN is an easy test to administer and is a simple concept for children to grasp. In addition, it is not an excessively long procedure like many traditional psychoacoustic measurements of gap detection. Also, the GIN is the only GD task that has four equivalent lists offering examiners alternative lists for repeat testing and monitoring the course of CANS disease and efficacy of treatment. Finally, the GIN is the only currently available nonlinguistic tool that is truly measuring temporal resolution and not auditory fusion. Given the GIN's documented sensitivity and specificity, as well as reliability with adult populations (Musiek et al, 2005), coupled with the present findings demonstrating the GIN's feasibility with children, the authors expect the GIN to provide clinicians another validated and reliable tool in the evaluation of (C)APD in children.

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