GIN (Gaps-In-Noise) Test Performance in Subjects with Confirmed Central Auditory Nervous System Involvement

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Objective: **The purpose of the present study was to investigate the value of a new gap detection procedure called Gaps-In-Noise (GIN) for assessment of temporal resolution in a clinical population.**

Design: **The test consists of 0 to 3 silent intervals ranging from 2 to 20 msec embedded in 6-sec segments of white noise. The location, number, and duration of the gaps per noise segment vary throughout the test for a total of 60 gaps presented in each of four lists. The GIN procedure was administered to 50 normal-hearing listeners (group I) and 18 subjects with confirmed neurological involvement of the central auditory nervous system (group II).**

Results: **Results showed mean approximated gap detection thresholds of 4.8 msec for the left ear and 4.9 msec for the right ear for group I. In comparison, results for group II demonstrated a statistically significant increase in gap detection thresholds, with approximated thresholds of 7.8 msec and 8.5 msec being noted for the left and right ears, respectively. Significant mean differences were also observed in the overall performance scores (i.e., the identification of the presence of the gaps within the noise segments) of the two groups of subjects. Finally, psychometric functions, although similar for short and long duration gaps, were highly different for gaps in the 4- to 10-msec range for the two groups.**

Conclusions: **A variety of psychoacoustic procedures are available to assess temporal resolution; however, the clinical use of these procedures is minimal at best. Results of the present study show that the GIN test holds promise as a clinically useful tool in the assessment of temporal resolution in the clinical arena.**

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Auditory temporal processing can be defined as the perception of the temporal characteristics of a sound or the alteration of durational characteristics within a restricted or defined time interval. It can also be viewed as the processing of the temporal features of sounds that unfold over time. Therefore, auditory perception requires an accurate processing of the sound time structure of the signal. Hence, it can be argued that temporal processing may be the underlying component of many auditory processing capabilities, including the processing of both verbal and nonverbal acoustic signals. This notion can be observed at many levels ranging from the neuronal sensitivity of first-order neurons to the effects of time on the processing of complex auditory information, such as speech, at the cortical level.

For present purposes, it may be useful to consider four primary subcategorizations of temporal processing. These include (1) temporal masking, (2) temporal ordering or sequencing, (3) temporal integration or summation, and (4) temporal resolution or discrimination. Currently, clinical tools available to assess these separate areas of temporal processing are limited. The frequency and duration pattern tests (Musiek, 1994) are currently the most commonly used measures of temporal processing during auditory processing evaluations (Emanuel, 2002). Although widely accepted as diagnostic measures of auditory processing, these tests primarily assess temporal ordering only as it exists in a pattern paradigm. As presented by Emanuel in her 2002 survey of typical practices with respect to auditory processing batteries, it was reported that the most commonly used temporal test was the frequency (pitch) pattern test. In fact, the majority of the respondents in her survey reported incorporating this particular test in their auditory processing batteries. One of the few commercially available tests of gap detection is the Auditory Fusion Test-Revised (AFT-R), which was developed by McCroskey and Keith (1996). The findings of the survey conducted by Emanuel, however, revealed that this test was administered by only 28% of the audiologists who responded to an online version of the survey and by only 4% of the audiologists in Maryland who responded to mailed copies of the survey.

Temporal resolution, a component of temporal processing, refers to the ability of the auditory

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system to respond to rapid changes in the envelope of a sound stimulus over time (Plack & Viemeister, 1993). Although there are methods of assessing other areas of temporal processing, there is a paucity of clinically feasible procedures available to measure temporal resolution. One of the issues surrounding the incorporation of temporal resolution measures into clinical practice is that the assessment of temporal resolution abilities has traditionally been accomplished with classic psychoacoustic gap detection (GD) procedures. The outcome of administering such a procedure is the assessment of an individual's gap-detection threshold (GDT), which is determined as the shortest-duration gap within a sound that a person can detect. Such measures are often not feasible in a clinical setting for a variety of reasons. Classic methodologies for GD may be time consuming, making them difficult to use within a test battery for patients who cannot tolerate long periods of testing. Lengthy testing is also a factor in testing children in the clinic. A greater difficulty, however, is that classic GD paradigms are often not readily available to clinicians. Additionally, interfacing the necessary psychoacoustic instrumentation in the standard audiologic clinic is likely to be a challenging factor.

The Gaps-In-Noise (GIN) test was developed to provide a clinically feasible means for evaluating GD abilities in a variety of clinical populations, with a special focus on patients with central auditory disorders. It has been recommended by a number of experts that the assessment of temporal resolution abilities be completed during clinical evaluations of individuals at risk for auditory processing disorders (Jerger & Musiek, 2002). These authors, who were reporting on the consensus achieved by an expert panel convened to address assessment needs for children considered to be at risk for auditory processing disorders, noted that this type of assessment was important because measures of GD abilities can provide insights into the integrity of the central auditory system. In addition, the identification of deficits in temporal resolution abilities can provide meaningful direction for rehabilitative planning.

The investigation of temporal resolution through the use of GD paradigms is not a novel approach, having been first introduced by Garner in 1947. Numerous researchers (e.g., Bertoli, Smurzynski, & Probst, 2002; Fitzgibbons & Wightman, 1982; Florentine, Buus, & Geng, 2000; Green, 1971; Green & Forrest, 1989; He et al., 1999; Nelson & Thomas, 1997; Phillips, 1999; Phillips & Hall, 2000; Plomp, 1964; Rupp et al., 2002; Sek & Moore, 2002; Shailer & Moore, 1983; Snell, 1997; Sulakhe, Elias, & Lejbak, 2003; Trehub, Schneider, & Henderson, 1995; Williams & Elfner, 1976; Williams, Elfner, & Howse, 1978) have investigated the phenomenon of temporal resolution through the use of GD. It is beyond the scope of this study to cover all of the available literature on the use of GD in the investigation of the temporal resolution abilities of normal and disordered subject populations. However, a review of a few of these investigations is important to set the context for the present investigation.

Phillips (1999) obtained GDTs in normal-hearing subjects on the order of 2 to 3 msec when traditional psychoacoustic methods involving extensive training were used. Other evidence suggests, however, that increased GDTs are often observed in less well-trained subjects (Phillips & Smith, 2004).

Many investigators have explored the effects of a variety of variables (e.g., age, hearing impairment) on temporal resolution abilities. It has been demonstrated that older subjects may present with increased GDTs in comparison to younger control subjects (Bertoli et al., 2002; He et al., 1999; Snell, 1997; Snell & Frisina, 2000; Strouse et al., 1998). However, other studies place into question the effects of aging on GDT measures (He et al., 1999; Moore, Peters, & Glasberg, 1992). The discrepancy noted among these studies with respect to aging effects probably is caused by the presence of significant interactions between stimulus complexity and age in several of these investigations. A broadband stimulus (such as in the type used in the present investigation) probably is the simplest type of stimulus that can be used in GDT paradigms. As a result, procedures that incorporate use of this stimulus type are less likely to produce significant age effects.

The application of GD paradigms with pediatric populations has received less attention with respect to temporal resolution. Although the research is very limited, there does appear to be a maturational effect found in children for GD tasks (Trehub et al., 1995). In addition, there is evidence that children with learning disabilities may demonstrate abnormal temporal resolution abilities based on GD procedures (Hautus et al., 2003).

The effects of hearing impairment on temporal resolution have been studied with results indicating that those individuals with hearing loss tend to demonstrate increased GDTs (Fitzgibbons & Wightman, 1982; Florentine & Buus, 1984; Glasberg, Moore, & Bacon, 1987; Nelson & Thomas, 1997). Most recently, the relation between behavioral and electrophysiological GDT has been investigated (Bertoli et al., 2001; Bertoli et al., 2002; Poth et al., 2001; Werner et al., 2001). Interestingly, it has been demonstrated that the correlation between behavioral and electrophysiological thresholds is not always strong. In particular, electrophysiological thresh-

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TABLE 1. Means and ranges (in parentheses) for subject age, PTA, A.th. (in msec), and percent correct scores for the right and left ears for group I (control) and group II (neurological)

Group	Age	Ear	PTA	A.th.	Percent correct
Group I	24.6 (13–43)	Right ear	3.1 (0–20)	4.9 (4–8)	70.3 (45–85)
		Left ear	4.1 (0–20)	4.8 (3–8)	70.2 (48–85)
Group II	46.6 (20–65)	Right ear	13.6 (7–18)	8.5 (5–20)	59.6 (15–80)
		Left ear	15.4 (6–20)	7.7 (5–15)	58.1 (37–80)

olds observed in the elderly have a tendency to be increased as compared with behavioral thresholds.

Gap detection in the assessment of temporal resolution has been shown to be a very powerful assessment tool for a variety of populations (Efron et al., 1985; Lister, Besing & Koehnke, 2002; Walton et al., 1997). However, to date, there are no procedures that are adopted universally by clinicians to assess temporal processing by GD (Emanuel, 2002). Perhaps this is why there are very few data on the temporal resolution abilities of individuals with neurological involvement of the central auditory nervous system (CANS). Research suggests, however, that impaired neurological functioning can adversely affect temporal resolution (Efron et al., 1985; Syka et al., 2002). Ablation studies in the animal model have demonstrated that adult rats presented with elevated GDTs after bilateral ablation of the auditory cortex (Walton et al., 1997). In addition, Efron et al. (1985) demonstrated increased GDTs in humans for the ear contralateral to the hemisphere with unilateral anterior temporal lobectomy.

This investigation examines a GD procedure that has been specifically designed for the clinical evaluation of temporal processing by using a GD paradigm. Also presented is information regarding the validity of this procedure as it relates to the assessment of patients with central auditory disorders.

METHODS

Subjects

Two groups of subjects participated in this study. The first group was composed of 50 control subjects (group I). The second group included 18 subjects with CANS involvement (group II). All subjects volunteered for this research and met the institutional review board criteria for the enrollment of human subjects for the University of Connecticut, Southern Connecticut State University, the University of Massachusetts Amherst, and the National Hospital for Neurology and Neurosurgery, London, England.

Group I was composed of 14 men and 36 women, ranging in age from 13 to 46 yrs, with a mean age of 24.6 yrs. All subjects in this group demonstrated pure-tone thresholds of 20 dB HL or better for the octave frequencies of 250 to 8000 Hz bilaterally. In addition, the thresholds at each frequency tested were within ±10 dB of each other. Mean pure-tone averages (PTAs) and ranges for both the right and left ears are presented in Table 1. Subject inclusion criteria also included negative histories for audiologic, otologic, and neurologic involvement.

Group II was composed of 14 men and 4 women who ranged in age from 20 to 65 yrs of age (mean age, 46.4 yrs). All subjects demonstrated normal pure-tone audiograms, using the same criteria as was applied to subjects in group I (Table 1). Subjects in this group had lesions involving but not limited to the CANS as defined by Galaburda & Sanides (1980) and Musiek & Baran (1986). Involvement of the CANS was confirmed by neurological evaluation and magnetic resonance imaging using T_1- and T_2-weighted images with contrast enhancement when needed. As shown in Table 2, nine subjects had lesions confined to the brain stem (all with involvement of auditory brain stem structures caudal to the medial geniculate body) and nine had lesions in the auditory cerebrum (auditory structures rostral to the medial geniculate body). Of the subjects with brain stem involvement, three had lesions that lateralized to the right, four had lesions that lateralized to the left, and two presented with bilateral involvement. In the subjects with cerebral involvement, two had lesions of the right hemisphere, six had lesions of the left hemisphere, and one had a diffuse lesion affecting both hemispheres.

Procedures and Stimuli

All subjects were tested while seated in a sound-treated booth. The GIN stimuli, which were previously recorded on a compact disc, were played on a Sony XE 270 CD player and passed through a GSI 61 diagnostic audiometer to TDH-50 matched earphones. The stimuli were presented at 50 dB sensation level re: PTA to each ear independently.

The GIN is a new test composed of a series of 6-sec segments of broadband noise containing 0 to 3 silent intervals or gaps per noise segment. The interstimulus interval between successive noise tokens (segments) is 5 secs and the gap durations presented are 2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 msec. Both gap

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TABLE 2. Age, site of lesion, disorder type, and laterality information for the 18 subjects in the neurological group

	Subject	Age	Site of lesion	Disorder	Laterality
Brain stem	1	39	Pons	Adenoleukrodystrophy	Midline
	2	38	Cerebellopontine angle	Aneurysm	Left
	3	54	Pons	Stroke	Right
	4	46	Pons	Stroke	Left
	5	43	Pons	Stroke	Right
	6	36	Pons	Undetermined	Midline
	7	59	Superior olivary complex	Stroke	Left
	8	51	Cerebellum	Tumor	Left
	9	51	Pons	Stroke	Right
Cerebrum	10	33	Heschl's temporal gyrus, posterior temporal lobe and insula	Stroke	Right
	11	39	Temporal lobe, insula, posterior internal capsule	Congenital cavernoma	Left
	12	49	Cortical	Trauma	-
	13	65	Fronto-temporal junction, insula	Stroke	Left
	14	53	Internal capsule	Stroke	Left
	15	51	Posterior temporal lobe	Stroke	Left
	16	57	Insula, temporal lobe, frontal lobe	Stroke	Left
	17	20	Temporal lobe (superior temporal gyrus)	Stroke	Right
	18	56	Heschl's gyrus, posterior insula	Stroke	Right

duration and the location of gaps within the noise segments are pseudorandomized in regard to their occurrences. In addition, the number of gaps per noise segment is varied. These variances in the number, duration, and placement of the gaps were incorporated as a test feature in the GIN to decrease both the probability of guessing correctly and the number of trials needed to obtain statistically significant information. Ten practice items precede the administration of the test items.

The noise used in the test was a computer-generated white noise that was uniformly distributed between −32,000 and 32,000 with an RMS value of 32,000/sqrt(2). The sampling rate was 44,100 Hz. Therefore, the limits of the noise were defined by the transducer used in this study (TDH-50). The noise was turned on and off instantaneously; hence, the gap durations reported above specify the durations of the silent intervals that were interspersed in the noise segments. The shortest interval between two consecutive gaps always exceeded 500 msec. Figure 1 provides the spectral and time displays of a noise segment with representative gaps shown (Fig. 1a), as well as a example of three GIN items (Fig. 1b). There were six tokens for each gap duration in each list, and four lists were available for testing.

Each list was administered to a subgroup of 36 control subjects to determine inter-list equivalency. The presentations of the lists were randomized across subjects, and all 36 subjects received all four lists. In addition, test-retest reliability was measured on 10 control subjects who were added to the study for this specific purpose. These subjects ranged in age from 22 to 40 yrs and met all of the previously presented

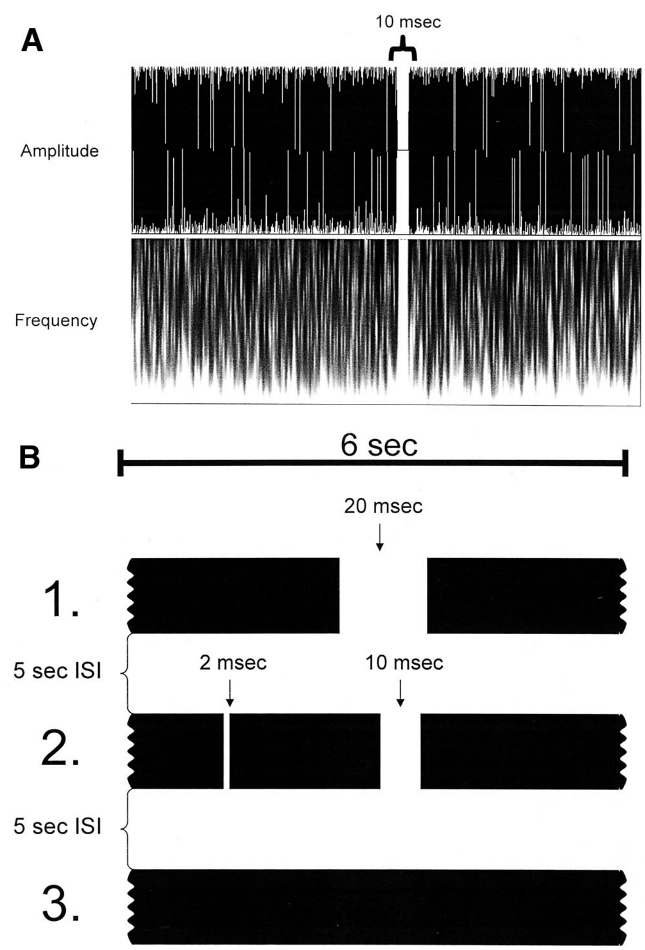

Fig. 1. a, Spectral and time displays of a noise segment with representative gaps. b, Samples of three GIN items demonstrating the duration of the stimuli, inter-stimulus intervals, and varying durations.

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A

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

Scoring

B

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
	0%	17%	50%	67%	100%	100%	100%	100%	100%	100%	65%

A.Th = 5 msec
65% Correct

Fig. 2. a, Representation of a sample score sheet of three GIN test items. Shown is the location or elapsed time (in msecs) within the 6-sec noise segment where the gaps occurred and the duration of the gaps segments. Example 1 has one gap, example 2 has two gaps, and example 3 has no gaps. b, Example of a completed score sheet showing the ear tested, the numbers and percentages of correctly identified gaps at each gap duration, the combined number and percentages of correct responses across all gap durations, and the approximate threshold (A.th.).

criteria. After initial testing, these 10 subjects were tested again 7 to 15 days later.

The subjects were instructed to press the response button as soon as they heard a gap. If the response button was not pressed when a gap occurred it was counted as an error. If a button was pressed and no gap occurred it was counted as a false-positive. 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. A number of practice items were presented before the experimental stimuli to ensure that the subjects understood the task and that they were comfortable with use of the response switch.

A score sheet used by the examiner provided the noise segment number, the time interval at which the gap occurred, and the duration of the gap for each noise segment (Figure 2). Two measures were derived for each ear during the procedure. These included an approximated GDT (referred to as the approximate threshold) and a combined percent correct identification score across all gap durations. The approximate threshold (A.th.) was defined as the shortest gap duration for which there were at least "four of six" correct identifications. This level of performance had to be maintained (or improved) for gaps of greater duration to be considered the subject's threshold. If a subject obtained a four of six level of performance at one gap duration but their performance slipped for gaps that were longer in duration, the initial level was not considered the A.th. Rather, the initial performance level that yielded a four of six correct performance level that was maintained for longer gap levels was considered the A.th. As mentioned above, in addition to the A.th., the percentage of correct responses of the total number of gaps presented in the test was determined for each ear. Therefore, the GIN test has two indices to measure temporal performance, the A.th. and the percentage of correct responses.

RESULTS

Approximate Threshold and Percentage of Identification Measures

Individual and mean A.th. for both groups of subjects are displayed in Figure 3 and Figure 4. Inspection of the data presented in these figures reveals longer A.th. measures for the neurological subjects than for the control subjects. Results of Student's two-tailed independent *t*-tests showed the mean A.th. for GD to be significantly smaller for the control group than for

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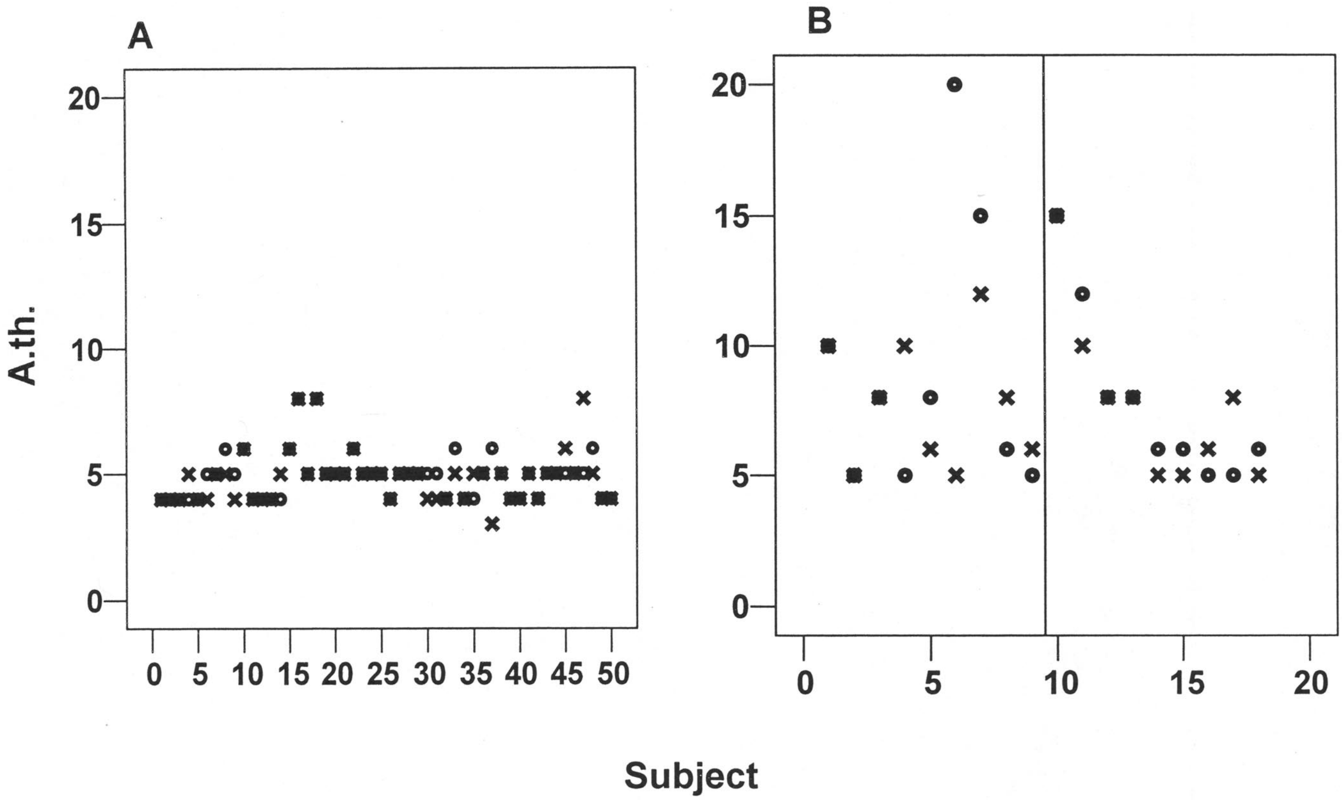

Fig. 3. Individual GIN approximate thresholds (A.th.) for the control (A) and neurological groups (B) for the left (X) and right (O) ears.

the neurological group for both the left ($p \leq 0.001$) and right ears ($p = 0.003$).

Figure 5 shows the mean percentage of correct identification scores for group I and group II. Review of these data shows higher percentages of correct identifications for both the left and right ears for group I when compared with the performance of group II for the total number of percent correct responses on the GIN test. This observation was supported by statistical testing using Student's two-tailed independent t-tests ($p = 0.024$ for the right ear and $p < 0.001$ for the left ear).

Additional analyses included the generation of psychometric functions for the mean percent correct identification by gap duration for both groups and individual ears. As can be seen in Figure 6, the psychometric functions for the control group are steeper than those for the neurological group, with the greatest separation between the two functions occurring in the 4- to 6-msec gap duration region. Note that there were no within-group significant differences for the left versus right ear found for the A.th. or percent correct indices for either group I or group II ($p = 0.583$ and 0.866, respectively). Quadratic functions were used to quantify the steepness of each psychometric contour. Coefficients of these functions verified that contours were steeper for

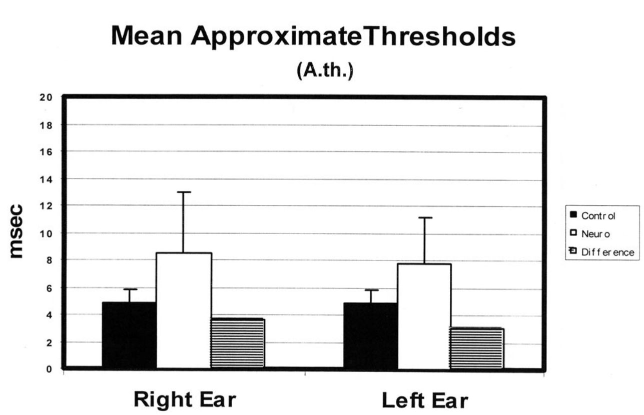

Fig. 4. Mean GIN approximate thresholds (A.th.) for the control and neurological groups (1 SD is shown).

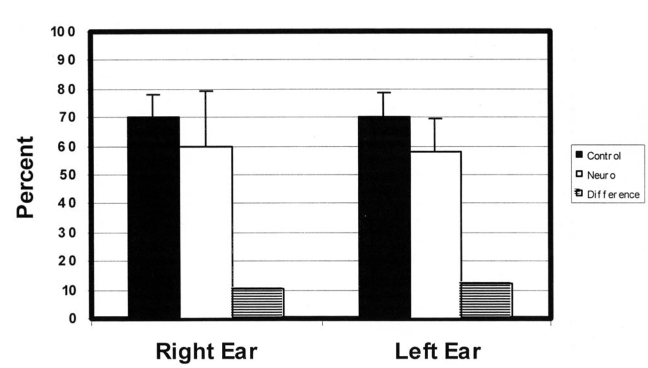

Fig. 5. Mean percent correct for the GIN test for the control and neurological groups (1 SD is shown).

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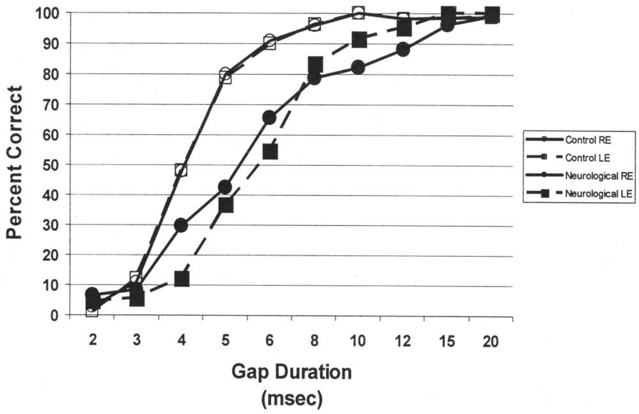

Fig. 6. Psychometric functions for each gap duration and each ear for both control and central auditory disorders (neurological) groups of subjects.

neurological subjects than for control subjects. Also, functions were more different across ears for the neurological subjects than for the control subjects (neurological subjects: left ear, $y = -0.59x^2 + 18.61x - 39.54$; right ear, $y = -0.49x^2 + 15.83x - 24.37$; control subjects: left ear, $y = -0.71x^2 + 19.82x - 23.46$; right ear, $y = -0.71x^2 + 19.76x - 22.89$).

If the cutoff criterion between normal and abnormal performance was established by adding 2 SD to the mean as is typically done clinically, the cutoff for a normal A.th. measure would be 7.0 msec. Applying this criterion, 12 of 18 subjects (67% sensitivity) in the neurological group would have failed the test in at least one ear (five of nine with brain stem and seven of nine with cerebral involvement). If this same A.th. criterion were applied to the control group, however, only three of the 50 subjects (94% specificity) would have failed the test (Figure 7).

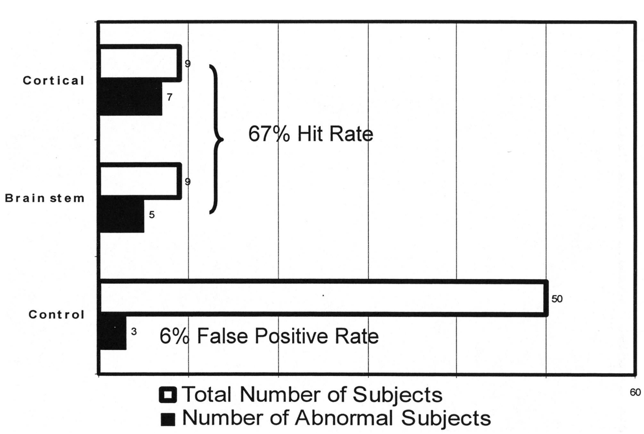

Fig. 7. Hit and false-positive rates for neurological and control groups using 2 SD from the mean approximate thresholds (A.th.) as the cutoff criterion. The central auditory disorders (neurological) group is divided into brain stem and cortically lesioned subjects.

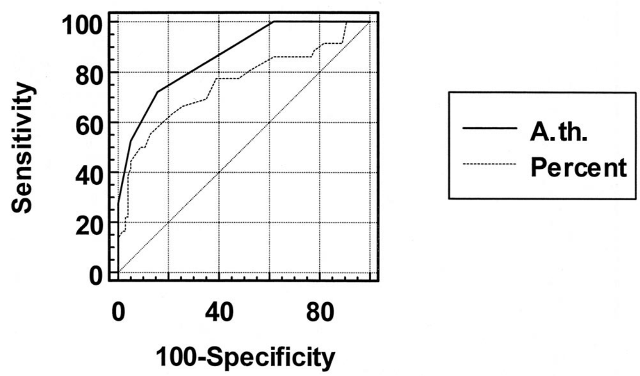

Fig. 8. Receiver operating characteristic curves for both the A.th. and percent correct indices.

In regard to total percentage of correct responses for the right and left ears, the mean scores were 70% bilaterally. Hence, 2 SD (approximately 16%) below the mean would yield a cutoff score of 54% for each ear. Applying this criterion for either ear score, eight of 18 neurological subjects (44% sensitivity) would have failed the test in at least one ear, whereas none of the control subjects would have performed outside the normal limits for either ear (100% specificity). If the total number of correct responses was used as the diagnostic index, a significant difference between groups I and II was achieved for both left and right ears ($p < 0.01$).

Often clinical indices are combined in an attempt to improve on the efficiency of a test. In this study, if either an abnormal A.th. or an abnormal total correct response measure was used as the diagnostic index of abnormality, 12 of 18 neurological subjects (67% sensitivity) and three (94% specificity) of the control subjects would have failed the GIN.

Receiver operating characteristic curves were formulated to determine which criteria would yield the best sensitivity and specificity for both the A.th. and percent correct indices (Fig. 8). Using a 5-msec cutoff criteria for the A.th. yielded a 73% sensitivity and 84% specificity, with an area under the curve of 0.87%. With respect to the percent correct measure, a 62% cutoff for the percent correct index demonstrated a 56% sensitivity and 87% specificity with an area under the curve of 0.75%. It should be noted that in the case of the A.th. index, sensitivity can certainly be improved; however, specificity is somewhat compromised if divergence from the typical clinical protocol for establishing cutoff criteria (i.e., 2 SD from the mean) is used. According to Hanley & McNeil (1984), a receiver operating characteristic curve with an area of the curve falling between 0.7 and 0.9 is associated with a "good" test. Therefore, based on the area under the curve measures noted in the present analysis, either index or measure (A.th.

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TABLE 3. Mean approximate threshold measures (in msec) and standard deviations for the right and left ears of 10 normal-hearing subjects on two different test dates

Ear tested	Test session	Mean	Standard deviation
Right ear	Initial	4.2	0.63
	Retest	4.1	0.74
Left ear	Initial	4.0	0.67
	Retest	3.9	0.57

and percent correct identification) constitutes a good test with respect to sensitivity and specificity.

Inter-List Comparisons

Four lists of 60 GIN items per list were used in the present investigation. Thirty-four control subjects were administered all four lists in random order to establish inter-list equivalency. A one-way analysis of variance demonstrated no significant differences across lists for either ear ($p = 0.792$).

Test-Retest Reliability

To establish a measure of test-retest reliability of the A.th. measure, the GIN test was administered to 10 young normal-hearing adults on two different test dates separated by at least 1 wk. Mean A.th. data and standard deviations for the initial and retest administrations of the test are presented in Table 3. These data reveal essentially equivalent test performance for the 10 subjects as a group on the initial and second test administrations for both ears. An inspection of the test results for the individual subjects showed no differences in performance between the two test administrations for nine of 10 subjects on each independent ear comparison. One subject showed a -1-msec change in the right ear score on retest, whereas a second subject showed a similar change in the left ear on retest. Pearson product-moment correlations for right ear and left ears confirmed test-retest reliability ($r = 0.95$ and 0.88, $p \leq 0.01$).

The time that was required to administer the GIN test to adult subjects was also measured. For this analysis, the same 10 subjects used for the test-retest reliability measures were used. The elapsed time was computed by starting a stopwatch when instructions and practice items were presented to the subject and stopping the watch at the end of the subject's response to the last item. Included in the elapsed time for each subject was the testing of both ears independently, the time spent switching from one ear to the other, and also all practice items. The elapsed times ranged between 16 minutes and 49 seconds and 17 minutes and 15 secs.

Discussion

This study reports the results of an investigation of a new clinical GD procedure (the GIN). Although there is a relatively long history of GD investigation, this procedure has not been used widely for clinical applications even though basic research has shown the procedure to be valuable in measuring temporal resolution abilities. There are currently two gap detection tests that are available on a commercial basis. These include the Random Gap Detection Test (RGDT) developed by Keith (2000) and the AFT-R developed by McCroskey and Keith (1996). The AFT-R procedure is more of a fusion task than a true GD task and is different from the one that is used in the GIN test. The AFT-R presents a series of stimuli that consist of two clicks that are separated by gaps of varying durations. The test requires individuals to determine whether they perceive one or two clicks as the interval between the clicks is varied. At some interval, patients will perceive only one rather than two clicks (fusion). The RGDT also differs from the GIN as it uses methods similar to the AFT-R. In addition, the normative cutoff for the RGDT is significantly higher at 20 msec with a mean GD value of 8 msec.

The focus of the present investigation was to determine if the GIN test was sensitive to confirmed lesions of the CANS. If this was the case, then it would be reasonable to conclude that this test has a place in test batteries designed to measure central auditory dysfunction. The GIN test in the present study did show relatively good sensitivity to CANS lesions. This finding is similar to others that have shown that humans and animals with damage to the CANS show abnormal GD performance (Efron et al., 1985; Syka et al., 2002). Efron et al. (1985) reported that increases in GDTs were generally (but not always) observed in the ear contralateral to the hemisphere with the insult. In the present study, four subjects did show similar contralateral findings; however, this was not a consistent finding for all of the neurological subjects.

The sensitivity and specificity indices in the present study showed the GIN test to be more sensitive to cortical compromise as opposed to brain stem involvement. It is difficult to explain this finding but some possibilities have been entertained. First, this finding could be due to variances in the subjects tested. That is, perhaps the patients in the current study with cortical lesions had relatively more involvement than those with brain stem involvement. It is also possible that the differences in these test measures would have become less obvious if additional neurological subjects were tested.

The GD studies previously reported evaluated only individuals with cortical lesions; hence, there

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are few data with which to compare the results of the present study in regard to the findings for patients with brain stem involvement. Efron et al. (1985) tested humans with anterior temporal lobectomies on a GD paradigm. The investigators in that study concluded that there was poorer GD performance in the ear contralateral to the lesioned hemisphere. This asymmetry, however, only occurred at one gap interval. Other gap intervals showed a similar performance for left and right ears, although both ears appeared to perform below the level of performance achieved by the control group.

Animal data on GD tests also indicated an effect from ablations of the auditory cortex. Syka et al. (2002) showed an increase in GDTs for rats with bilateral auditory cortex lesions. Interestingly, several days after surgery the rats appeared to recover some of their temporal processing ability; however, the improvement in GD never reached presurgical levels. Kelly, Rooney, & Phillips (1996) also showed that destruction of both auditory cortices in the ferret degraded the GDTs. The GDTs in this study were twice as large for the animals with cortical ablations compared with the control animals.

An additional factor in the interpretation of the results of this study is the age difference between the neurological and control groups. The control group is younger than the neurological group, but this difference, in our opinion, is not sufficient to significantly influence our results. It is true that a number of studies show greater GDTs for elderly listeners when compared with younger listeners (Lister et al., 2002; Schneider et al., 1994; Snell, 1997; Snell & Frisina, 2000). However, in these studies the "elderly groups," with mean ages in the seventh decade, were considerably older than those in our neurological group. Even with the large mean age difference between subjects in groups I and II, there was considerable overlap in the GDTs of the younger and older adults in the present study. In addition, the studies referenced above used either tonal stimuli or bands of noise, whereas in the present study the stimulus was a broadband noise. As evidenced by the work of Lister et al. (2002), comparisons of GDTs between young and middle-aged individuals is not significant. As reflected in Table 1, there probably is not a large enough discrepancy to reflect any age-related differences in the two groups. Therefore, the age discrepancy was not a significant concern in the present investigation.

He et al. (1999) showed that when broadband noise was used, no significant differences were found between old and young listeners. It is of interest to note that the slopes of He et al. (1999) the psychometric functions reported by for their young group of subjects were similar to those of our control group. Bertoli et al. (2002), using psychoacoustic and electrophysiological measures of gap detection, found differences between old and young subjects only for the electrophysiological measure but not for the psychoacoustic index. Moore et al. (1992) found most of their elderly subjects had GDTs that were within normal limits. Although these studies varied in their approaches and analyses, they support the possibility that there may little or no difference in the performances of young and old listeners in regard to GDT. This supports our opinion that given the stimulus used in the present study that the older mean age of our neurological group would have had only a minimal effect at best on test performance and therefore would not have significantly influenced our results. Finally, our belief that age was not a significant factor in producing increased GDTs and poorer overall identification performance is supported by our finding that the majority of our neurological subjects demonstrated increased A.th. and/or reduced identification scores in only one ear. If age had been a significant factor, then bilateral and symmetrical ear deficits should have been a more common finding among the neurological group.

Another factor that may influence performance on GDT measures is the time intervals between gap presentations. In a few instances in the present investigation, two gap items had intervals of less than 1 sec between them. In retrospect, this was of concern in that it may have affected response accuracy. However, no difficulty was noted in this regard during the testing of subjects. To ensure that closely placed items did not affect response accuracy, a subgroup of the normal-hearing subjects' responses were analyzed for errors on test items placed temporally close together. There was no increase in number of errors noted for intervals of less than 1 sec compared with other intervals of longer durations.

At this time, three indices of the GIN can be used in clinical evaluation: the A.th., or approximate threshold, the total correct score, and the psychometric function. The psychometric function indicates that gap durations of 4, 5, and 6 msec seem to best differentiate the two groups. This information may be useful for the development of a temporal processing screening procedure. Testing only at gap durations of 4 to 6 msec, for example, would take little time. If the individual performed poorly on the screening test, the entire test could be completed; however, if the individual performed well on the "screening procedure," the clinician could move on to another test. The A.th. and total percent correct measures are easy indices to derive, and both may be worthy of analyzing for clinical purposes. In the present study, little additional benefit was gained in regard to test sensitivity by using both measures. However, it is possible that in other popu-

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lations, these two test measures may provide differential information that would not be available if only one of the two indices were derived. Clearly, additional research is needed before a definitive recommendation as to the best clinical approach to the use of these indices for diagnostic purposes can be rendered.

Test-retest and inter-list consistency was high for the GIN test. As previously stated, test-retest measures for 10 individuals who were evaluated separately from the normative portion of this study were within 1 msec approximately 90% of the time for both ears. These data speak to a commonly perceived problem of lack of reliability data for central auditory tests. Additionally, the four available lists yielded essentially the same performance for control subjects. Hence, the equivalency across lists allows, when needed, comparisons for follow-up testing, retesting, and various types of monitoring.

The comparison of the GIN procedure with more traditional psychoacoustic procedures for GD in broadband noise deserves comment. Most psychoacoustic findings for GDTs in broadband noise have shown that the thresholds are approximately 2 to 3 msec for humans (Moore, 2003; Phillips, 1999). The mean A.th. in the present investigation were 4.8 and 4.9 msec for the left and right ears, respectively. However, because our subjects were not trained extensively, the gap intervals were larger than those used in most traditional psychoacoustic experiments and the procedure was different from those traditionally used. These factors, separately or in combination, could explain the differences between our data and data in the psychoacoustic literature as well as the difference noted between the present thresholds and those reported in the normative data for the RGDT test (Keith, 2000). Our control subjects' gap thresholds (A.th.) were similar, however, to the mean GDT noted by Phillips & Smith (2004) for untrained listeners tested in an within channel condition for narrowband noise centered at 4 kHz (i.e., 5 msec) and slightly lower than the mean value for a narrowband noise centered at 1 kHz noise (i.e., 8 msec). It should be noted that our mean values are also lower than the 8-msec mean values as reported by Keith (2000).

Future research should include the effect of intensity on the GIN test and the influence of cochlear hearing loss on the test's indices. In addition, the investigation of the test performance (e.g., the sensitivity/specificity) that would be obtained if tonal stimuli instead of white noise were used may also yield valuable information. An added benefit of the use of tonal stimuli is that it would readily allow for the investigation of within-channel and between-channel performance comparisons (Phillips & Smith, 2004). It is possible that these types of comparisons may provide important differential diagnostic information for clinical populations. It has been suggested that temporal resolution is important to speech perception, and its assessment provides insight to the neural integrity of the CANS (Gordon–Salant & Fitzgibbons, 1993; Walton et al., 1997). Clearly, additional research into this important measure of temporal resolution is warranted.

Currently, in the clinical domain, there is a need for this kind of procedure (Jerger & Musiek, 2000). It therefore seems reasonable to include a test of temporal resolution in a test battery designed to evaluate the CANS. The GIN is a test of temporal resolution that may fill a void in current auditory processing assessment.

Conclusions

Test performance on a GIN (detection) procedure that has been specifically designed for clinical application was compared for two subject groups; i.e., a group of normal-hearing subjects and a group of subjects with confirmed lesions of the central auditory nervous system. The results of this analysis revealed that the application of this procedure to the two groups resulted in significant differences between the groups for both gap threshold and gap identification measures across durations. Moreover, the procedure demonstrated good test-retest reliability, and it was found that the test could be administered and scored in a period of time that would be appropriate for clinical use.

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