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The Effect of Presentation Level on the Gaps-In-Noise (GIN©) Test

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Abstract

The Gaps-In-Noise (GIN©) test is a new procedure used in the diagnosis of central auditory processing disorders. Performance on the GIN is recorded as approximate gap detection threshold and percent correct. In order to utilize the GIN test clinically, it is important to know how presentation level influences performance on the GIN. To this end, ten normal-hearing adults were administered the GIN at 5, 10, 15, 20, 25, 30, 35, and 50 dB SL with regard to threshold to GIN noise. Results indicated that performance for both the approximate gap detection threshold (A.th) and percent correct improved with increasing presentation level. Performance at 35 dB SL was not significantly different from the standard clinical presentation level (50 dB SL). Gaps that were between 5 and 8 msec in duration tended to show more variation across presentation levels. Although an influence of presentation level was noted, this influence should not be manifested at the standard clinical presentation level.

Key Words: Central auditory processing, gap detection, intensity, temporal resolution

Abbreviations: A.th = approximate gap detection threshold; CANS = central auditory nervous system; GIN = Gaps-In-Noise Test; PTA = pure tone average

Sumario

La Prueba de Brechas en Ruido (GIN©) es un nuevo procedimiento utilizado en el diagnóstico de trastornos de procesamiento auditivo. El desempeño en el GIN es medido como umbrales aproximados de detección de brechas y porcentaje de respuestas correctas. Para utilizar la prueba de GIN clínicamente, es importante cómo los niveles de presentación influyen en el desempeño del GIN. Para este propósito, se aplicó el GIN a diez adultos normoyentes a 5, 10, 20, 25, 30, 35 y 50 dB SL en relación al umbral y al ruido GIN. Los resultados indicaron que el desempeño tanto del umbral aproximado de detección de brecha (A.th) como el porcentaje de respuestas correctas mejoró conforme aumentaron los niveles de presentación. El desempeño a 35 dB SL no fue significativamente diferente del nivel clínico estándar de presentación (50 dB SL). Las brechas entre 5 y 8 mseg de duración tendieron a mostrar más variaciones en los distintos niveles de presentación. Aunque se notó una influencia del nivel de presentación, éste no debe manifestarse en el nivel clínico estándar de presentación.

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Palabras Clave: Procesamiento auditivo central, detección de brecha, intensidad, resolución temporal

Abreviaturas: A.th = umbrales aproximados de detección de brecha; CANS = sistema nervioso central auditivo; GIN = Prueba de Brechas en Ruido; PTA = umbral tonal puro

The Gaps-In-Noise (GIN©) test is a new procedure developed for clinical assessment of central auditory processing disorders (CAPD). It is a measure of temporal resolution and is unique from other gap detection paradigms in its proposed clinical utility and feasibility. The GIN is comprised of four equivalent lists, although clinically only one of the four lists is administered per ear at 50 dB sensation level (SL) with regard to pure-tone average (PTA) or speech recognition threshold (SRT). Each list contains a series of four-second noise segments in which are embedded gaps. The spectrum of the noise is uniform in its distribution. Gap durations included in the test are 2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 msec. There are six instances of a gap in each list, which are randomly distributed among the trials. There are up to three gaps per noise segment, and some trials do not contain a gap. Participants are instructed to indicate by a button response when they hear the gaps embedded in noise. Typically, two GIN lists take approximately 17 minutes to administer.

Performance on the GIN is scored as approximate gap detection threshold (A.th) and percentage of the gaps that are correctly identified. The A.th is calculated, in part, as the smallest gap duration for which at least four of the six instances of the gap were correctly identified. Previous research has shown the GIN to be sensitive to central auditory nervous system (CANS) lesions (Musiek et al, 2005). The A.th measure was shown to have 67% sensitivity and 94% specificity when a >6 msec criterion was used to define beyond normal limits. Clinically, this criterion is utilized as 8 msec or greater, since there is no 7 msec gap in the test. The percentage correct measure was shown to have 44% sensitivity and 100% specificity when a <54% criterion was used to define beyond normal limits.

Previous studies, which have examined the effect of intensity on gap detection ability, have primarily used alternative forced-choice paradigms. For instance, Plomp (1964) asked participants to identify which interval contained a gap in white noise using a two-alternative forced-choice task. Results showed that the gap detection threshold from 35 to 75 dB SL with regard to threshold for a 200 msec noise pulse was approximately 3 msec, and this threshold doubled in value for each 5 dB decrement between 10 and 20 dB SL. Nelson and Thomas (1997) also used pseudorandom noise with a bandwidth of 2500 to 3150 Hz to examine the effect of intensity on gap detection ability. The gap detection thresholds for intensity levels of 16 and 64 dB SL with regard to threshold for the noise stimulus were 5.6 and 3.0 msec, respectively.

Other studies have used the alternative forced-choice paradigm to examine gap detection ability as a function of intensity using noise stimuli with different center frequencies. De Filippo and Snell (1986) used noise stimuli that were 50 Hz noise bands centered at 250, 500, and 1000 Hz. Averaged across all subjects and frequencies, the gap detection threshold was 105.2 msec at 5 dB SL, 38.3 msec at 15 dB SL, and 25.0 msec at 25 dB SL. No effect of frequency was reported at these sensation levels. Similar findings were reported by Hall et al (1996), who used stimuli that were 20 Hz noise bands centered at 1500, 2000, and 2500 Hz. For intensity levels of 15 and 30 dB SL with regard to detection threshold for the stimulus, no effect of noise band frequency was observed. However, effects of frequency were observed at much higher intensity levels (i.e., 78 dB SPL). Gap detection thresholds, averaged across all frequencies, were poorer at 15 dB SL (mean = 133.9 msec) than at 30 dB SL (84.6 msec).

In a variation on the above studies, Hall and Grose (1997) used an alternative forced-choice paradigm to examine the effect of noise that has a constant center frequency but different noise bandwidths on gap detection ability. The stimuli were 50 and 1000 Hz wide noise bands centered at 1000 Hz. Although they examined gap detection as a function of intensity in different levels of noise, one condition applied 0 dB SPL of background noise (i.e., very low level) and is relevant to the present review. Unlike the studies above, which found no effect of changing the noise center frequency, results of this study demonstrated a difference in performance across noise bandwidths. Gap detection thresholds tended to be poorer for 50 Hz wide noise bands than for 1000 Hz wide noise bands. For 1000 Hz wide noise bands, performance decreased from approximately 30 msec at 10 dB SL re: detection threshold for the stimulus to approximately 10 msec at 30 dB SL. For 50 Hz wide noise bands, the corresponding decrease in thresholds was from approximately 100 msec to approximately 60 msec.

The influence of presentation level on gap detection ability using pure-tone stimuli has also been investigated. For instance, Moore et al (1993) used an alternative forced-choice paradigm to determine gap detection thresholds to 100, 200, 400, 800, 1000, and 2000 Hz stimuli at 25, 40, 55, 70, and 85 dB SPL. At 25 dB SPL, gap detection threshold varied from 50 msec at 200 Hz to 10 msec at 1000 Hz. At higher intensities, thresholds were around 8 msec for 200 Hz and 6 msec for 1000 Hz in the 85 dB SPL condition.

Although the majority of studies that have examined the effect of intensity on gap detection ability have used an alternative forced-choice paradigm, other methods have been reported. Fitzgibbons (1983) used a Bekesy tracking procedure to measure these intensity effects. This procedure used an average of 25 midpoints for up-down intensity tracings to determine the gap detection threshold. The stimulus used was an unfiltered broadband noise stimulus that was only shaped by the transducer. The transducer had a flat response to 6000 Hz and was followed by a 10 dB reduction in the response at 7400 Hz. Gap durations were kept constant while intensity fluctuated, and multiple gap durations were measured in this way. Results indicated better performance at sensation levels above 30 dB (~4 msec threshold), with decreasing performance in the range of 25 to 10 dB SL with regard to quiet signal threshold (~6 to ~15 msec threshold, respectively).

Despite considerable research that has been conducted to examine the effects of intensity on gap detection ability, intensity effects have not yet been investigated on the GIN. Since presentation of the GIN at lower SLs may be necessary in a variety of clinical situations (e.g., cases of hearing loss), knowledge of these effects is important for clinical administration of the test. To this end, the present study sought to establish how performance on the GIN varied as a function of test presentation level in a normal-hearing population. Normal-hearing participants were selected as a baseline for comparison in future clinical studies.

METHODS

Participants

Ten normal-hearing female participants were included in the present study. The mean age of the group was 25 years of age (range = 20 to 47). Each participant had one ear tested, so five left and five right ears were included in the study. Due to the length of the study, participants did not have both ears tested. To qualify as having normal hearing, participants had to exhibit pure-tone air-conduction thresholds for the octave frequencies between 250 and 8000 Hz better than or equal to 20 dB HL and word-recognition scores on the Northwestern University Auditory Test No. 6 (Tillman and Carhart, 1966) greater than or equal to 90% correct, bilaterally. Additionally, participants had to have distortion product otoacoustic emissions above Dartmouth-Hitchcock Medical Center normative absolute amplitude values (Musiek and Baran, 1997) with a +10 signal to noise ratio at no fewer than five of six samples between 1187 and 3812 Hz, normal performance on the GIN at 50 dB SL with regard to threshold to GIN noise, and a negative history for neurological involvement.

Equipment

All participants were tested while seated in a double-walled IAC sound treated booth. The GIN stimuli were recorded on a compact disc. Noise stimuli used in the GIN were uniformally distributed with no rise-fall time. Stimuli were played on a Sony CDP XE 270 CD player and passed through a GSI 61 diagnostic audiometer to calibrated TDH-50 matched earphones or EAR-3A insert earphones. The interested reader should refer to Musiek et al (2005) for additional information regarding the GIN test.

Procedures

Prior to conducting the GIN procedure, participants' hearing thresholds to GIN noise was established using a Modified Hughson-Westlake procedure. The noise stimulus was presented for at least 200 msec on each presentation. The mean threshold to GIN noise was 3 dB HL (standard deviation = 2.74) for left ear participants and 6 dB HL (standard deviation = 2.24) for right ear participants. Testing was conducted in two sessions, which occurred on different days. In the first session, the GIN was presented at 5, 10, 15, 20, and 50 dB SL with regard to threshold to GIN noise. In the second session, the GIN was presented at 25, 30, and 35 dB SL. The threshold to GIN noise was used as a reference in the present study because it was assumed that it would be a more reliable reference for GIN tests presented at soft levels. However, there was no significant difference between threshold to GIN noise and PTA for the test ear ($t = [9] = -.293$, $p = .776$), indicating that using PTA as a reference may not have yielded very different results.

Standardized instructions (see Appendix A) were read to participants, and a short practice GIN list was administered at 50 dB SL before each session to ensure comprehension of the task. Presentation level and GIN list order were randomized in each session, with the exception of the 50 dB SL condition always initiating the first session. This randomization was identical for each ear.

For each presentation level, performance was recorded as A.th and percentage of gaps correctly identified. A.th was defined as the shortest gap duration that met the following two criteria: at least four out of six gaps were correctly identified, and performance for longer gap durations could not be worse than four out of six gaps. For instance, if a participant scored four of six correct for 3 msec gaps, three out of six for 4 msec, and then six out of six for 5 msec and every remaining gap duration, the A.th would be 5 msec and not 3 msec. When scoring the GIN, responses were measured in real time by hand. If a response was not noted within approximately one second after the gap occurred, then the gap was recorded as not identified. False positive responses were also recorded by hand but, as they were extremely rare and considered insignificant (mean number of errors across all lists = 6.20, standard deviation = 5.87), were not incorporated into any of the performance calculations.

RESULTS

Approximate Gap Detection Threshold (A.th) and Percent Correct

As will be described below, a value at 10 dB SL for the A.th measure had to be imputed for one subject in the left ear condition. This imputed value was used in statistics pertaining to the A.th measure only. The descriptive statistics for the two performance measures, along with corresponding 95th percentile for each presentation level, are presented in Table 1. These data are also

Table 1. Means (standard deviations) for A.th and Percent Correct by Presentation Level

dB SL	A.th Descriptive Statistics	A.th 95th Percentile	Percent Correct Descriptive Statistics	Percent Correct 95th Percentile
5	20.0 (-)*	-	6.0 (5.5)	16.67
10	16.1 (3.9)	20	26.8 (12.2)	53.33
15	9.4 (1.4)	12	44.2 (8.8)	58.33
20	8.2 (2.2)	10	55.5 (10.1)	78.33
25	6.5 (1.7)	10	61.8 (8.6)	78.33
30	6.1 (1.5)	8	66.0 (9.9)	83.33
35	4.9 (1.3)	8	71.3 (9.5)	80
50	3.9 (0.9)	5	83.0 (6.0)	91.67

Note: N = 10 for all cells except: *N = 1.

shown graphically in Figures 1 and 2. For A.th, performance at 5 dB SL was extremely poor, with only one participant obtaining a gap detection threshold at this level. Performance at 10 dB SL was still poor, and the variability across participants at this level was numerically much larger than the other conditions. At 15 dB SL, performance increased sharply, and then gradually improved as intensity increased to 50 dB SL. For percent correct, performance was poor at 5 and 10 dB SL, with the latter condition again showing the numerically greatest variability.

A repeated measures ANOVA was conducted for both A.th and percent correct with the within-subjects factor of presentation level (dB SL) and the between-subjects factor of ear. For the A.th measure, the 5 dB SL condition was excluded from the analyses because only one of the ten subjects had an A.th. Additionally, one subject in the left ear condition did not have an A.th at 10 dB SL. To prevent exclusion of this participant from the analysis by the statistical software, the value for that missing cell was imputed by taking the mean of all other left ear participant values in that condition (Little and Rubin, 2002).[1] For the percent correct measure, all presentation levels were included in the analysis because there were no missing values for any participant-condition cell.

For each within-subjects analysis, Huynh-Feldt corrected degrees of freedom were used to control for any potential violations of the sphericity assumption (Max and Onghena, 1999). The presentation level factor was significant for both the A.th ($F[2.83, 22.66] = 55.25$, $p < .001$) and the percent correct ($F[7, 56] = 147.78$, $p < .001$) measures. As presentation level increased, A.th decreased and percent correct increased. There was no significant ear effect for either the A.th ($F[1, 8] = .30$, $p = .60$) or the percent correct ($F[1,8] = .99$, $p = .35$) measures. Additionally, there was no significant interaction of presentation level and ear for either the A.th ($F[2.83, 22.66] = .36$, $p = .77$) or percent correct measures ($F[7, 56] = .80$, $p = .59$).

For the presentation level factor, paired t-tests were conducted to determine which conditions differed significantly. These comparisons were conducted separately for the A.th and percent correct measures. A Bonferroni adjustment was performed on the alpha level of .05 for each measure to control for the number of t-tests conducted, yielding an adjusted alpha level of .002 for analysis of A.th and .001 for percent correct. Results are displayed in Table 2. For A.th, at presentation levels between 10 and 50 dB SL, the nonadjacent conditions differed significantly, with the exception of 25 and 35 dB SL, which did not differ. For percent correct, all nonadjacent conditions differed significantly.

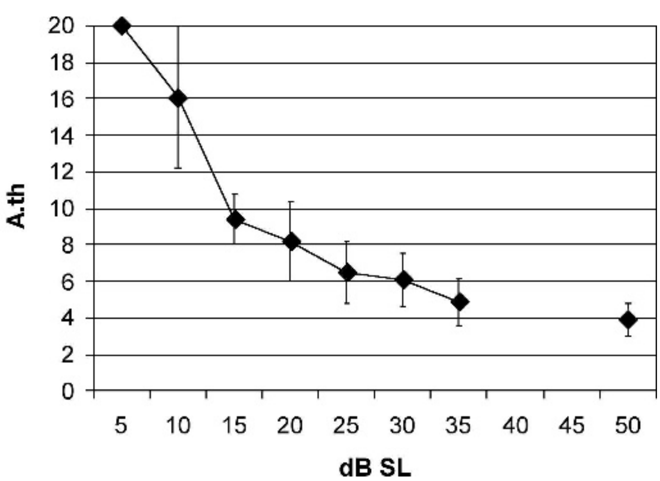

Figure 1. Mean values for A.th, with one standard deviation Y error bar, as a function of intensity.

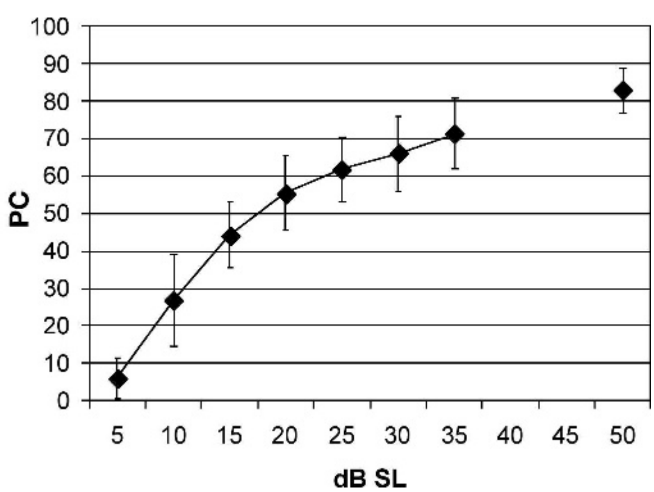

Figure 2. Mean values for percent correct, with one standard deviation Y error bar, as a function of intensity.

Table 2. Paired T-tests for Presentation Level Factor for A.th and Percent Correct Measures

		dB SL							
		5	10	15	20	25	30	35	50
dB SL	5	-	**	**	**	**	**	**	**
	10	-	-	*	*/**	*/**	*/**	*/**	*/**
	15	-	-	-	**	*/**	*/**	*/**	*/**
	20	-	-	-	-		*/**	*/**	*/**
	25	-	-	-	-	-		**	*/**
	30	-	-	-	-	-	-		*/**
	35	-	-	-	-	-	-	-	
	50	-	-	-	-	-	-	-	-

Note: A.th (*) and/or percent correct (**) significant at Bonferroni adjusted .05 alpha level. 5 dB SL conditions were not included in the A.th comparisons.

Psychometric Functions

For each gap duration, the mean number of gaps correct across all participants was computed for each presentation level. These values are presented in Table 3 and displayed as a psychometric function in Figure 3. The standard deviations across presentation levels for each gap duration were also calculated and are presented in Table 4.

DISCUSSION

Clinical Implications

The present study showed that A.th and percent correct performance on the GIN increase significantly with increasing intensity. There was no ear effect or interaction between ear and presentation level. Although nonadjacent intensity conditions tended to differ significantly for both measures, of greatest importance was the finding that 35 dB SL was the only condition that did not differ significantly from 50 dB SL. This suggests that, for individuals with normal hearing, the GIN can be presented as low as 35 dB SL without any significant decrease in performance. Once the level is decreased to 30 dB SL, performance is no longer equivalent to 50 dB SL.

Differences between A.th and percent correct were also observed in values of performance limit, or the lowest intensity level for which performance was within normal limits (i.e., less than or equal to 6 msec for A.th and greater than or equal to 54% for percent correct). For A.th and percent correct, the performance limit values were 35 and 20 dB SL, respectively.[2] These differences between performance limit in A.th and percent correct are consistent with the sensitivity and specificity data of Musiek et al (2005). In their study, sensitivity was approximately 20% poorer for the percent correct measure when compared to the A.th measure. As greater demands are placed on central auditory processing (CAP), whether by attenuating intensity as in the current study or the presence of a lesion in the Musiek et al study, gap detection ability decreases.

Table 3. Mean Number of Gaps Correct for Each Gap Duration by Presentation Level

		dB SL							
		5	10	15	20	25	30	35	50
Gap Duration	2	.00	.00	.20	.10	.10	.10	.10	.30
	3	.10	.00	.20	.20	.00	.60	.60	2.40
	4	.00	.20	.50	.50	1.20	1.70	3.10	4.40
	5	.10	.60	.30	1.60	2.40	3.10	4.50	5.80
	6	.20	.50	1.10	3.20	4.40	4.50	5.00	5.90
	8	.30	.50	2.60	4.00	5.20	5.70	5.60	6.00
	10	.40	2.00	4.80	5.80	5.90	6.00	5.90	6.00
	12	.40	3.40	5.20	5.90	5.90	5.90	6.00	6.00
	15	.90	3.80	5.60	5.90	6.00	6.00	6.00	6.00
	20	1.20	5.10	6.00	6.00	6.00	6.00	6.00	6.00

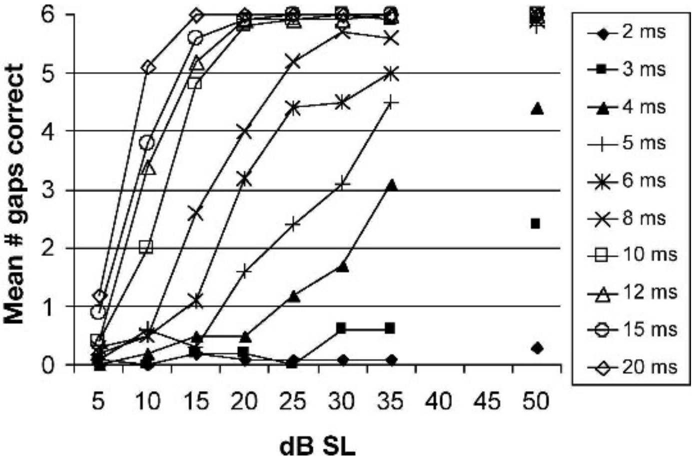

Figure 3. Mean number of gaps correct across all participants for each gap duration as a function of presentation level.

Table 4. Standard Deviations for Mean Number of Gaps Correct across All Presentation Levels for Each Gap Duration

Gap Duration	Standard Deviation
2	.10
3	.80
4	1.56
5	2.07
6	2.21
8	2.34
10	2.18
12	2.00
15	1.83
20	1.68

However, the participant might still be able to correctly identify some gaps below A.th. These responses will contribute to the percent correct score but not the A.th. As a result, percent correct performance will be better than A.th performance and will be more likely to fall within normal limits. The fact that percent correct performance tends to be better than A.th under demanding conditions may explain why it has a lower performance limit and decreased sensitivity.

In addition to indicating how low in intensity the GIN can be presented in the clinic without influencing performance, the results of this study may also allow us to predict GIN performance for certain types of hearing loss. A relatively flat conductive loss causes an attenuation of the test signal not unlike the presentation level changes utilized in the present study. In such situations, the values obtained in the present study for normal-hearing listeners could be used as preliminary normative values. The advantage of using these values to interpret performance as opposed to using 50 dB SL regardless of impairment is the elimination of crossover. For instance, if a conductive loss of 40 dB HL occurs, then presenting at 50 dB SL could potentially allow too much of the signal to cross over to the non-test ear, particularly if headphones are being used. However, using the values obtained in the present study, we can present the test at a lower SL and know what performance to expect.

Values obtained in the present study could also serve as basis of comparison for subsequent intensity functions obtained in other clinical populations. Although the sensitivity of A.th is quite high at 50 dB SL (Musiek et al, 2005), it is possible that reducing the presentation level of the test will allow for even greater sensitivity. Intensity functions obtained in clinical populations would help to answer this question.

Psychometric Functions

The psychometric functions created in the present study show, for each gap duration, the mean number of gaps correct across all participants at every presentation level. Points in Figure 3 that are equal to or greater than four gaps of six gaps correct fall within the criterion for meeting A.th and, therefore, contribute to normal performance on this measure.

Examination of the numerical trends of each function reveals important information about the contribution to clinically normal performance (i.e., four out of six gaps correctly identified) by each gap duration. For 10 to 20 msec gap durations, clinically normal performance was achieved at levels as low as 15 dB SL. At 10 dB SL, detection started to drop off sharply, and primarily 20 msec gaps contributed to normal performance. For 2 to 3 msec gap durations, there was generally little contribution to A.th. Two msec gaps in particular were extremely difficult to detect, as indicated by a mean correct value of less than 1 at 50 dB SL. The 4 msec gap durations appeared to be important to normal performance when the test was presented at 50 dB SL. However, performance dropped off quickly for this gap duration and reached a mean of 1 at 25 dB SL.

Functions created for the 5 to 8 msec gap durations tended to show the numerically largest variability across presentation levels, as shown in Table 3. As such, these gap durations may be the most diagnostically useful. If attempting to separate groups diagnostically, performance for the 10 to 20 msec gaps will be quite robust and will not be influenced as much by challenging auditory conditions. The 2 to 3 msec, and possibly 4 msec, gap durations will typically demonstrate low performance regardless of demands. Therefore, these very long and very short gap durations will not help separate groups. The 5 to 8 msec gap durations, however, tend toward showing the greatest variability and may be the most diagnostically useful.

This is consistent to some extent with results from Musiek et al (2005). In their study, 4 to 6 msec gap durations showed the largest difference between normal-hearing participants and participants with neurological involvement of the CANS. This range overlaps the 5 to 8 msec range described in the present study. To the extent that both studies are investigating situations in which increasing demands are placed on CAP, these results can be considered consistent. Gap durations that show the most variability as a function of intensity are similar to the gap durations that neurological patients have the most trouble detecting relative to normal-hearing listeners.

Comparison to Other Gap Detection Paradigms

It is of interest to compare the results of the present experiment to previously published studies that have utilized other gap detection paradigms. Figure 4 shows an intensity function for the present study, along with intensity functions from Plomp (1964) and Fitzgibbons (1983). These studies were used as a basis of comparison because the stimuli most closely matched the spectrum of the GIN. Although values from Plomp are raw data taken directly from reported tables, data from Fitzgibbons had to be estimated from figures. Compared to Plomp's results, performance on the GIN is better at presentation levels of 10 dB SL or less, equal at 15 dB SL, and poorer at presentation levels greater than 15 dB SL. Generalizations from performance at 5 and 10 dB SL should be drawn with caution, as most GIN participants did not have a threshold at 5 dB SL, and variability at 10 dB SL was great. Performance at presentation levels greater than 15 dB SL may be slightly better for Plomp's participants because they were well trained in gap detection tasks. Participants in the present study had no known prior training in gap detection tasks. Alternatively, Fitzgibbons's (1983) results appear more similar to GIN performance than to results seen in Plomp (1964). This is especially evident at 20 and 25 dB SL. This might be attributable to the fact that, similar to the participants of the present study, one of the three participants in Fitzgibbons (1983) was inexperienced in gap detection tasks . Taken as a whole, the intensity function for the GIN follows a similar pattern to that witnessed in other gap detection studies. In all paradigms presented in Figure 4 for which the data are available, performance is poor at or below 10 dB SL and then increases abruptly at 15 dB SL. Just as GIN performance plateaued at 35 dB SL, so does the performance of Plomp's (1964) participants appear to plateau at this level. Although performance may vary across studies, possibly as a function of experience with the task, the intensity functions that were observed speak to the similarity of the GIN to existing gap detection paradigms.

Physiological Correlate

We would like to discuss a pertinent physiological correlate for the results observed in the present study. This correlate is based on animal models and is not intended to be an exhaustive discussion. In these models, electrophysiological recordings during a gap detection task indicate that neurons in the CANS are typically more responsive to stimulus onsets than offsets. Responses to stimulus onset are characterized by synchronous neural responses that have high firing rates (Eggermont, 1997) and have been shown to decrease in magnitude as intensity decreases (Phillips et al, 2001).

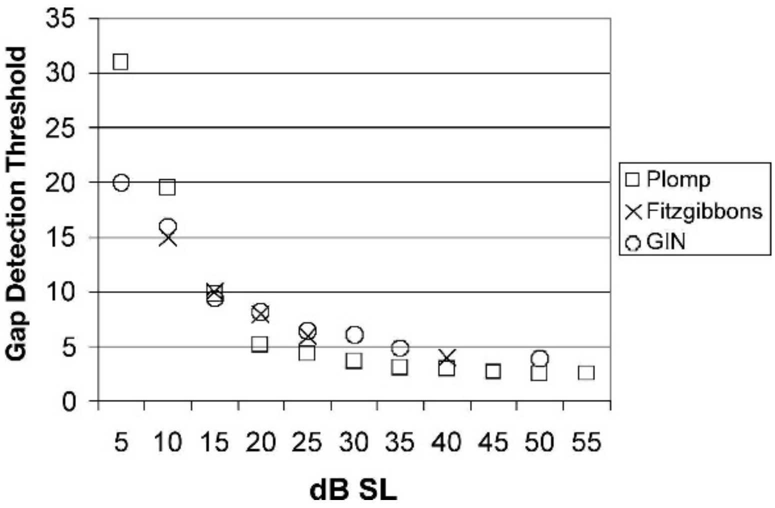

Figure 4. A.th intensity functions for Plomp (1964) and Fitzgibbons (1983), and the GIN.

Although offset responses may play a role in gap detection, this role may be less important than that of onset responses. Neurons that respond to offsets tend to differ from onset neurons in several important ways. In mice, Walton et al (1997) found that only 7% of 78 inferior colliculus (IC) neurons isolated in their study responded to offsets. This differs greatly from the number of onset neurons in the IC, which was 60% of their sample. Additionally, gap detection thresholds were greater for offset neurons (12.67 msec) than for onset neurons (2.03 msec).

At least at the level of the auditory nerve, neurons that code low-intensity signals tend to have higher spontaneous firing rates than neurons that code high-intensity signals (Lieberman, 1978). This suggests that neural responses to gaps might also be more detectable for high-intensity signals because the difference between the spontaneous firing rate and the response is larger. As the presentation level of a signal is decreased, the ratio of the neural response to the spontaneous firing rate becomes too small for gap detection to occur. Since offset responses are reduced relative to onset responses, this contamination of the response by the spontaneous firing rate may have a greater impact on these offset responses.

To the extent that these models can be generalized to the population in the present study, there are several tentative implications that can be drawn from these results. At the level of the CANS, the aspect of the response that may be most important for gap detection in the GIN is the onset response following the gap. At this onset, the firing rate of neurons and the synchronous manner in which they fire makes the response sufficiently large for gap detection. As the presentation level is lowered, both the net number of neurons recruited and their degree of synchronous firing may be decreased. Additionally, the spontaneous firing rate of the recruited neuron population may also become larger relative to the gap onset response. Therefore, these intensity effects may yield a poorer response to the onset of the gap, and GIN performance may become poorer as a result.

CONCLUSIONS

The present study established the effect of presentation level on the GIN test using 5, 10, 15, 20, 25, 30, 35, and 50 dB sensation level with regard to threshold to GIN noise. It was found that the GIN can be administered as low as 35 dB SL with no significant change in performance. The gap durations that were between 5 and 8 msec in length tended to show the greatest variability across presentation levels and may be most useful diagnostically. Future research will focus on the effects of intensity on GIN performance in clinical populations and compare the performance of these populations to the results of the present study. It is possible that the GIN may show increased sensitivity and specificity and lower presentation levels.

NOTES

1. A.th values obtained from the left ear subjects were 12, 15, 20, and 20. The imputed value for the subject with the empty cell was the simple average of these four values, or 16.75. The method of imputation did not appear to have much of an effect on the imputed value. Using a weighted average (Little and Rubin, 2002), where participants' scores contributing to the average are weighted based on how similar they are to the deviant subject, a value of 16.59 was obtained. Using a K-means approach (Little and Rubin, 2002), where participants are clustered together based on similarity of performance and only those participants who are most similar to the deviant subject are included in the average, a value of 17.50 was obtained. Inclusion of the simple average imputed value changed the left ear A.th mean (standard deviation) at 10 dB SL from 16.0 (4.1) to 16.1 (3.9).
2. It should be noted that this does not suggest performance at 20 dB SL and 50 dB SL are equivalent for percent correct since a significant difference was witnessed between the two conditions.

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Appendix A

In this test you are going to hear noise and within the noise there will be gaps of silence. The silent gaps will vary in length and occasionally there will not be a gap. Every time you hear the silent gap you should press the response button as quickly as you can. You should listen very carefully as some of the gaps are extremely small. Sometimes the noise level will vary in loudness.