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Comparison of clinical and traditional gap detection tests

Eric Hoover, **Lauren Pasquesi**, and **Pamela Souza**

Department of Communication Sciences and Disorders, Northwestern University, Evanston, IL

Abstract

Background—Temporal resolution is important for speech recognition and may contribute to variability in speech recognition among patients. Some clinical tests of temporal resolution are available, but it is not clear how closely results of those tests will correspond to traditional temporal resolution tests.

Purpose—The purpose of the study was to compare the Gaps-in-Noise (GIN) test to a traditional measure of gap detection.

Study Sample—Older adults with hearing loss and younger adults with normal hearing were included.

Data Collection and Analysis—Participants completed one practice and two test blocks of each gap detection test, and a measure of speech-in-noise recognition. Individual data were correlated to examine the relationship between the tests.

Results—The GIN and traditional gap detection were significantly, but not highly correlated. The traditional gap detection test contributed to variance in speech recognition in noise, while the GIN did not.

Conclusions—The brevity and ease of implementing the GIN in the clinic make it a viable test of temporal resolution. However, it differs from traditional measures in implementation, and as a result relies on different cognitive factors. GIN thresholds should be interpreted carefully and not presumed to represent an approximation of traditional gap detection thresholds.

Keywords

hearing loss; age; temporal resolution; gap detection

Temporal resolution refers to the ability of the auditory system to respond to rapid changes in a sound stimulus over time. This ability is important for speech recognition, where the listener must process temporal information at varying rates. For example, variations in the speech envelope contain lexical and syntactic information; segmental cues such as gap duration provide information about phoneme identity; and subsegmental information derived from the periodic vibrations of the vocal folds conveys voice pitch and sound quality. Good

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Corresponding author: Eric Hoover, University of South Florida, Auditory & Speech Science Laboratory, 3802 Spectrum Blvd. Ste. 210A, Tampa, FL 33612, Phone: (813) 974-4148, erichoover@usf.edu.

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temporal resolution may also support use of dips in the level of background noise to assemble segments of the target speech, a feature which has been shown to be important in speech-in-noise recognition (e.g., Bernstein and Grant, 2009; Rosen et al., 2013).

If temporal resolution is important for speech recognition, it may be one factor contributing to variability in communication ability among patients. Temporal resolution may decrease with sensorineural hearing loss and with age, but not every older patient with hearing loss demonstrates reduced temporal resolution (see Reed et al., 2009 for a recent review). Individual testing could ensure appropriate characterization of temporal abilities, which could then be used to guide auditory rehabilitation. For example, work by Gatehouse et al. (2006) found that temporal resolution ability influenced the benefits of fast- or slow-acting hearing aid compression. There is also evidence that therapy that focuses on improving temporal processing (for those listeners in which temporal processing is impaired) can improve speech recognition (Merzenich et al., 1996; Vatanabe et al., 2014). Accordingly, the ability to measure temporal resolution in a time-efficient way is necessary if those measures are to be considered in treatment decisions.

Various measures have been proposed to assess temporal resolution. We focus here on gap detection, which is relevant to speech recognition and relies on a well-validated paradigm. The listener’s task is to detect a brief temporal gap that separates two successive stimuli. The test is commonly within-channel, such that the stimulus that precedes the gap has the same spectrum and duration as the stimulus that follows the gap. Classic methodologies reported in the literature provide precise estimations of the shortest-perceivable gap, but can be time consuming compared to alternatives designed for a clinical environment. They also require specific equipment and software that must be set up and maintained, calibrated, and validated with reference to published norms.

To facilitate testing in a clinical environment, several tests have been developed. These include the Random Gap Detection Test (Keith, 2000), the Adaptive Test of Temporal Resolution (Lister et al., 2006), the Auditory Fusion Test (McCroskey and Keith, 1996), and the Gaps-In-Noise Test, or GIN (Musiek et. al., 2005). We focus here on the GIN, which has gained some acceptance in clinical use (e.g., Gilani et al., 2013; Sirow and Souza, 2013). The GIN consists of a compact disc recording administered via a clinical audiometer. Stimuli consist of a six-second burst of broadband noise which contains zero to three silent gaps. Gap durations range from 2-20 msec. The listener’s task is to press a button each time a gap is heard. A second track audible only to the audiologist uses brief tones to alert the audiologist to the gap points. The test is scored as the lowest gap duration where a listener correctly identifies at least 4 (out of 6) gaps, and in overall percent correct across all gap durations.

The GIN is a clinically feasible measure of temporal resolution in the adult population (John et al., 2012; Shinn et al., 2009). Somewhat surprisingly, there have been no published comparisons of gap thresholds from the GIN to those obtained from a psychophysical gap detection measure. Indeed, a common-sense view suggests that GIN thresholds might not reflect “pure” gap thresholds. The GIN must introduce some uncertainty, because the listener is unsure as to when to listen for each gap, and because scoring relies on audiologist judgment as to how close a response needs to be following the gap to be scored as a correct response. The participant also needs to have sufficient motor skills to press a button quickly in response when they perceive a gap. In contrast, the traditional gap detection paradigm allows for a higher level of certainty due to its use of a defined interval and typically an adaptive procedure. If the GIN is to be used to assess temporal resolution in the clinic, it would be useful to know how closely it approximates more traditional gap detection tests. Accordingly, we undertook a comparison of the GIN to a psychophysically-based measure. Speech-in-noise testing was included to explore its relationship to temporal resolution. Both younger and older adults were recruited to support generalization of findings to a clinical population. The GIN is considered both in terms of the data obtained, and in the practicality and usefulness of the test in a typical clinic.

Methods

Participants

Thirty adult participants were recruited via flyers and from a database of previous participants in our laboratory. Informed consent was obtained prior to testing. Inclusion criteria were as follows: symmetric pure-tone thresholds (<15 dB difference between ears at any frequency), no air-bone gaps (≤ 10 dB), normal acoustic immittance (Roup et al., 1998), and primary language being American English. No participant included in the analysis reported any history of auditory processing disorder. All participants completed a hearing case history, immittance testing, air- and bone-conduction pure-tone audiometry, speech recognition in quiet and noise, and two measures of gap detection. Testing was completed in 1 to 3 sessions each lasting 1.5-2 hours each.

Participants were divided into two groups based on age and hearing loss. The first group consisted of 19 young adults (12 female) with normal hearing (pure-tone thresholds ≤20 dB HL in both ears at octave frequencies from .25-8 kHz and at interoctave frequencies at 3 and 6 kHz, re: ANSI, 2009). This group had a mean age of 24.6 years (SD= 3.95 years). The second group consisted of 11 older adults (3 female) with mild to moderate sensorineural hearing loss (pure tone average ≥ 30 dB HL) with a mean age of 64.9 years (SD= 21.5 years). Group mean and standard error pure-tone thresholds in the test (right) ear are shown in Figure 1. Mean QuickSIN scores were −0.23 dB for the younger group and 3.56 dB for the older group. QuickSIN scores were different across the two groups (t_{29}=4.60, p<0.001).

Note that the groups differed in both age and hearing status. Our purpose was not to report effects of age and/or hearing loss on the GIN, which have been described elsewhere (e.g., John et al., 2012). However, both groups were included to consider typical patients as well as to report results from individuals expected to have normal temporal resolution.

Procedures and stimuli

Temporal resolution was tested using two methods, Gaps-in-Noise (GIN) and classical psychophysical gap detection thresholds. As described above, the GIN (Musiek et al. 2005) consists of a series of broadband noise trials each containing between zero and three silent gaps, where the duration of the silent gap varies from 2 to 20 ms. The bandwidth of the noise is 32 kHz but the bandwidth presented to the listener is attenuated below 100 Hz and above 4 kHz by the frequency response of the Etymotic Research ER-3A insert phones. The listener responds by pressing a response button each time a gap is detected, and a scorer marks a sheet when a response coincides with an audible cue on the non-test channel. GIN yields an approximate gap detection threshold (A.th.), defined as the shortest gap duration for which there were four out of six correct responses.

The GIN test was presented via a Grason-Stadler GSI-61 audiometer through Etymotic Research ER-3A insert phones. The GIN protocol states that the stimuli may be presented between 35-50 dB sensation level (SL) re: pure-tone average. Previous work found no effect of presentation level on GIN scores when tested within this range (Weihing et al, 2007). In the present study, stimuli were presented to listeners with normal hearing at 50 dB SL. For listeners with hearing loss, sensation level was adjusted per test instructions (range: 35-50 dB SL). Participants were instructed to press the response button immediately whenever they heard a gap in the noise. Each participant completed one practice list and two test lists in the right ear. Scoring was completed during testing by the experimenter, author L.P.

Psychophysical gap detection threshold (GDT) testing was completed for the same participants. An adaptive, three-alternative forced-choice procedure was used in which gap duration was tracked using a two-down, one-up rule to determine the gap duration identified correctly in 70.7% of presentations (Levitt, 1971), using locally-developed MATLAB scripts. Each trial consisted of a series of three 500-ms broadband noise segments with a frequency range of 100-10,000 Hz, one containing a silent gap. As with the GIN stimuli, the frequency range received by the listener was limited by the frequency response of the ER-3A phone. The gap duration varied by a factor of 1.4 for the first four reversals and then by a factor of 1.2 for ten subsequent reversals. Participants were asked to select the interval containing the gap. The participant’s gap detection threshold was the mean gap duration of the last ten reversals. Stimuli were presented at the same level as in GIN testing. Patients completed one training track and two test tracks in the right ear, and data were taken as the average of the two test blocks. The presentation order of the GIN and GDT tracks were randomized for each listener.

Results

Gap Detection Thresholds

For the GIN test, the gap detection threshold (A.th.) is the gap duration correctly identified in four out of six presentations. Individual (symbols) and mean thresholds (horizontal lines) are shown in Figure 2. For the younger group, the A.th. was 4.53 ms. The older group with hearing loss had a mean A.th. threshold of 8.60 ms. Thresholds for the two groups were significantly different ($t_{28}=10.26$, $p<0.001$). Figure 3 shows the group mean psychometric functions derived from the raw GIN test data. Group differences in gap detection are apparent throughout the psychometric functions.

For the GDT test, threshold is the result of adaptively tracking gap duration to obtain the 70.7% performance point. Individual (symbols) and mean thresholds (horizontal lines) are shown in Figure 4. Note that the individual responses are more tightly clustered than was the case for the GIN. Overall gap thresholds are lower and the mean difference between groups is smaller than for the GIN. The mean gap threshold was 2.99 ms for the younger group with normal hearing and 4.23 ms for the older group with hearing loss. Group thresholds were significantly different from each other (t=7.024, *d.f.*=28, p<0.001).

Comparison of Gap Detection Measures

A primary goal of the current study was to compare the GIN to traditional measures of gap detection. Figure 5 shows the correlation between GIN A.th. values and the GDT thresholds obtained using a traditional psychophysical method. Scores from each method were significantly correlated (r=0.70; p=0.02). However, there is also considerable scatter (especially for GIN scores), and the correlation is not high. Because gap thresholds obtained using adaptive tracking might be considered the “gold standard” measure of gap sensitivity, the pattern of the data suggests that effects other than simple perception of the gap may have influenced results.

Relationship between gap detection and speech recognition in noise

We also explored the extent to which gap detection scores were related to speech-in-noise recognition (measured via the QuickSIN). QuickSIN scores were correlated with GIN scores (r=0.645, p<.01) and with GDT thresholds (r=0.454, p=.01). As expected, QuickSIN scores were also correlated with amount of hearing loss, expressed as the three-frequency pure-tone average in the test ear (r=.751, p<.01) and with age (r=.737, p<.01).

A hierarchical regression model was used to analyze the relationships among speech-in-noise, gap detection as measured by the GIN or GDT, and patient factors of age and amount of hearing loss. The regression analysis used an alpha-level criteria of 0.05 for probability of entry into the model and 0.1 for probability for removal from the mode. Residual and scatter plots indicated that the assumptions of normality and linearity were satisfied (e.g., Hair et al., 2009). Although the independent variables were significantly correlated, collinearity within the model was acceptable (variance inflation factors <2.0, tolerances > .5). Accordingly, the independent variables were entered in two blocks. In the first block, we accounted for the expected effects of age and hearing loss on QuickSIN score. In the second block, we entered one of the gap thresholds (either GDT or GIN). In other words, we explored whether gap detection (measured by either test) accounted for variance in QuickSIN score, once the effects of age and hearing loss had been considered.

Results of the regression analysis are shown in Table 1 (for the GDT model) and Table 2 (for the GIN model). In each case, the initial model (Step 1) explained 63% of the variance ($F_{2,28}$=23.62, p<.01). When GDT was added (Step 2), the overall model was significant ($F_{3,27}$=19.87, p<.01) and the change in variance accounted for was significant. In contrast, the inclusion of GIN as a predictor did not account for any additional variance, although the overall model remained significant ($F_{3,27}$=15.21, p<.01).

Discussion

This study compared gap thresholds measured using the GIN to a traditional gap detection paradigm. Two groups were included to sample different populations: one typical of clinic patients (i.e., older listeners with hearing loss); and one comprising a group expected to have normal auditory systems.

The younger listeners with normal hearing demonstrated sensitivity to short-duration gaps, with results in good agreement with previous studies. For the GIN, the 4.5 ms threshold found in the present study corresponds to the 4.2 ms threshold reported by Samelli and Schochat (2008), 4.8 ms reported by Iliadou et al. (2014), and the 4.7 ms threshold reported by John et al. (2012). For the GDT, our 3-ms gap threshold is similar to that found over decades of similar paradigms (e.g., Plomp, 1964).

For both gap tests, older adults with hearing impairment had elevated gap thresholds compared to younger listeners with normal hearing. Those results are not surprising considering the wealth of evidence that some temporal processing abilities—including gap detection—decline with age (e.g., Gordon-Salant and Fitzgibbons, 1993; Snell and Frisina, 2000; Strouse et al., 1998). In addition, the audible bandwidth of the gap stimuli was reduced in older listeners with elevated pure-tone thresholds in the high frequencies and gap thresholds are dependent on audible bandwidth (Formby and Muir, 1988; Eddins et al., 1992). Note that some studies (Lister et al., 2002) suggest an even larger effect of age for across-frequency gap detection, a factor which could not be assessed with the iso-frequency GIN stimuli used in the present study. For the GIN, mean threshold for the older listeners with hearing loss was about 4 ms higher than for the younger listeners with normal hearing. This is consistent with results from John et al. (2012), who also reported a 4 ms between-group difference. Note however that the between-group difference for the traditional test was smaller—only 1 ms higher (on average) for our older listeners. Considered as a whole, these data suggest that the GIN may represent age-related factors other than poor gap detection, *per se*.

As a clinical measure of temporal processing, the GIN has several advantages: it can be administered quickly (less than 10 minutes per block) with equipment typically found in an audiology clinic; the task—to click a button when a break in the noise is perceived—is simple for the patient to comprehend; and it has convenient scoring for the audiologist. In the GIN, as in the GDT, the listener's task is to listen for a gap in noise. However, we can also consider how the GIN departs from traditional psychophysical measures. During the GIN, the listener listens to continuous noise segments interrupted by gaps near their threshold of gap detection, at which time they must quickly respond by clicking a button. In implementation, then, the GIN task is similar to pure-tone audiometry, except that the gaps occur in rapid succession. Patients must listen carefully and respond quickly; the audiologist must be vigilant for responses; there are relatively high chances for false positives (if the patient unintentionally or incorrectly pushes the response button) and false negatives (if the patient is inattentive to a perceived gap). Where the GDT interface used here alerts the listener when to listen and then waits for a response, the GIN has no visual cue to guide the listener and does not pause for the listener to consider their response. These effects may have important consequences for its interpretation as a measure of temporal resolution.

While both tasks likely incorporate task-independent cognitive factors that influence the threshold estimate, there are differences. We anticipate that the GDT includes a greater working memory component, because the listener must attend to subsequent noise intervals while remembering whether a gap was heard in previous intervals; GIN has a lesser memory component. The GIN also requires sustained auditory attention (vigilance), and a consistent rapid response (processing speed). Working memory, vigilance, and processing speed are task-independent cognitive factors relevant to speech communication but not specific to gap detection or auditory temporal processing. Although we did not measure those factors in our listeners, we would hypothesize that listeners with reduced working memory, lower processing speed or poorer sustained attention would show a greater discrepancy between GIN and GDT scores. This is generally supported by the closer agreement of GIN and GDT scores in the younger listeners, who might be expected to have higher working memory and faster processing speed (e.g., Park et al., 2002).

For clinicians who wish to consider gap detection as a component of speech-in-noise recognition, the GDT scores explained a small portion of the variability in QuickSIN scores. In contrast, the GIN scores failed to account for any variance in QuickSIN beyond that related to age and amount of hearing loss. This is consistent with the above interpretation of the GDT as a more focused measure of temporal resolution, and of the GIN as measuring temporal resolution overlaid by other factors (such as sustained attention or processing speed).

In summary, the GIN certainly measures temporal resolution (as evidenced by the significant correlation between the two tests). The brevity and ease of implementing the GIN in the clinic make it a viable test of temporal resolution, and support its use as a metric of auditory processing. However, GIN thresholds should be interpreted carefully and not presumed to represent the same temporal processing ability as measured in a traditional paradigm. Further exploration of the relationship between auditory temporal processing and cognition is needed to understand how task-independent factors relate to our interpretation of psychophysical measures.

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Abbreviations

HL	hearing level
dB	decibel
GDT	gap detection test
GIN	gaps in noise
SL	sensation level

ms	milliseconds

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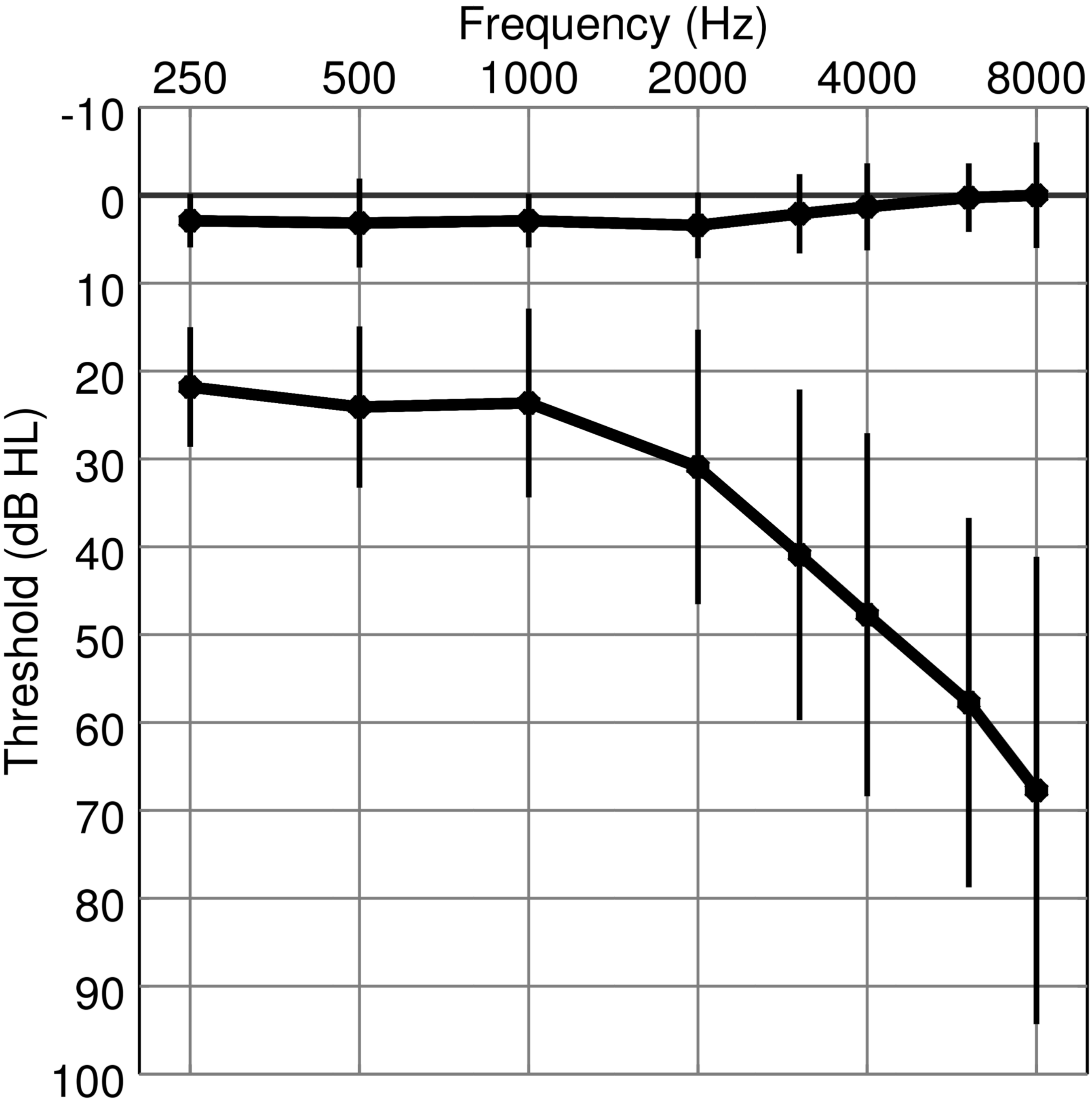

Figure 1.

Air-conduction thresholds averaged for the two groups, young listeners with normal hearing (N=19) and older listeners with impaired hearing (N=11). Error bars represent the standard deviation.

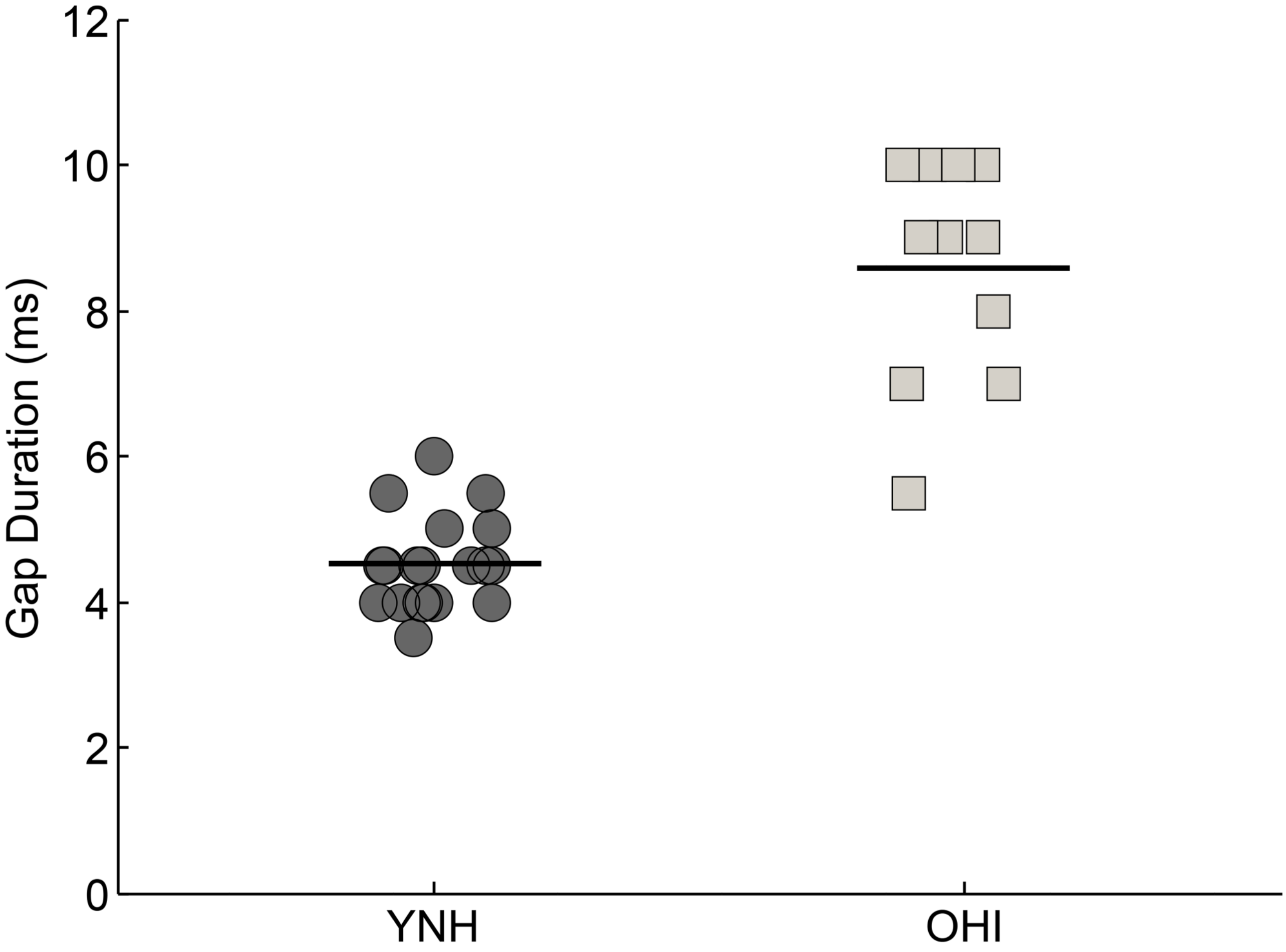

Figure 2.

Group mean GIN gap detection thresholds (A.th.) are shown for the YNH group (circles) and the OHI group (squares). Individual scores are scattered horizontally for clarity. Each point represents the score of one individual taken from the mean of two tests completed in the right ear.

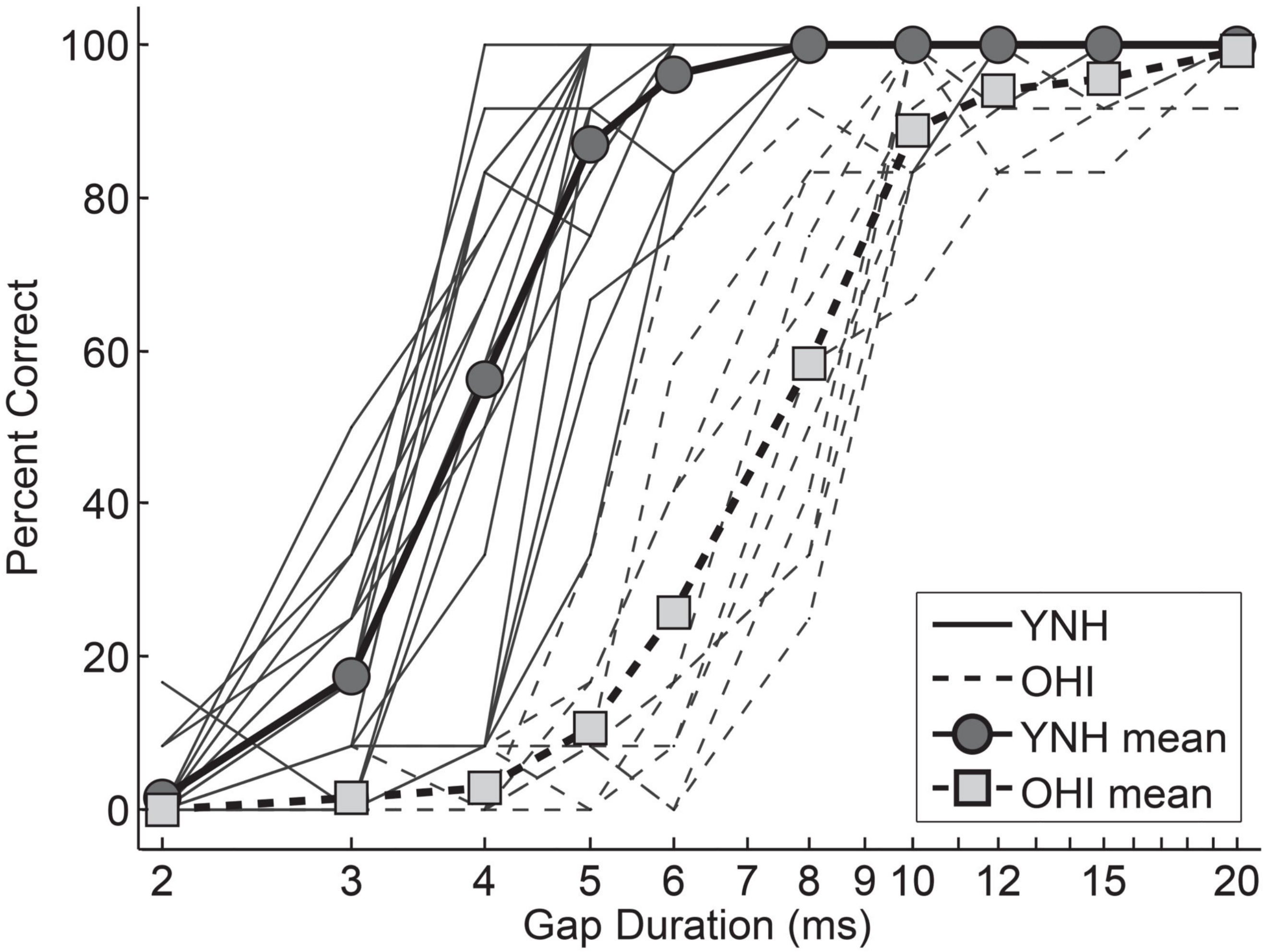

Figure 3.

Psychometric functions derived from the raw GIN test data are shown as the percent of gaps correctly identified as a function of gap duration. The abcissa shows the discrete gap durations presented in the GIN protocol on a log scale. Group mean (thick lines with markers) and individual (thin lines) psychometric functions are represented for YNH (solid lines, circles) and OHI (dashed lines, squares) groups.

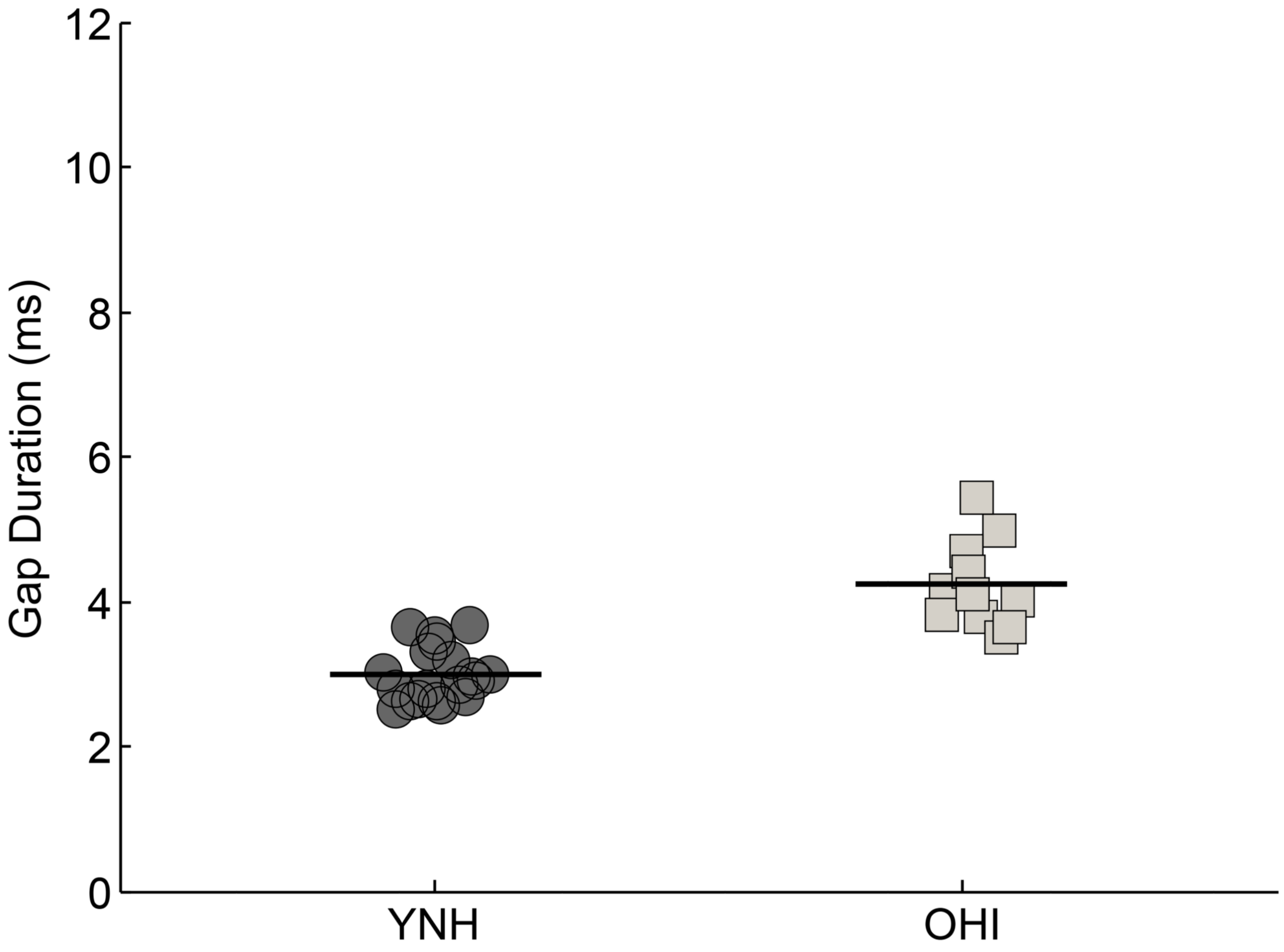

Figure 4.

Group mean GDT 70.7% gap detection thresholds are shown for the YNH group (circles) and the OHI group (squares). Individual scores are scattered horizontally for clarity. Each point represents the threshold of one individual taken from the mean of two test blocks completed in the right ear.

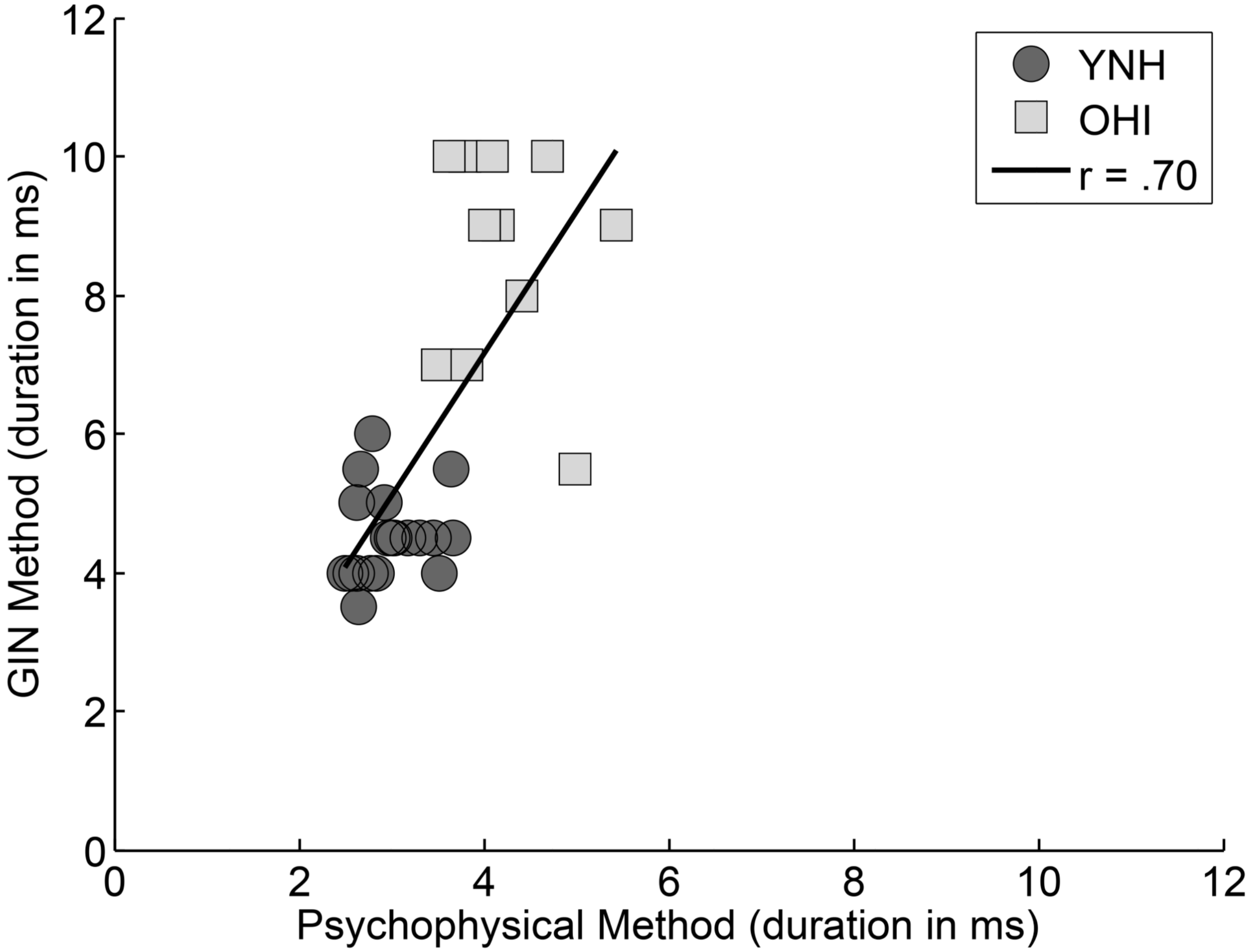

Figure 5.

Correlation between GIN A.th. and GDT gap detection thresholds for combined YNH (circles) and OHI (squares) listeners. Each point represents an individual's mean scores for each test.

Table 1

Summary of regression analysis for variables predicting speech recognition in noise, including the GDT scores. *F* and *p* values in this table refer to the effect of adding additional variables. *F* and *p* values for the overall models at each step are given in the text.

	Variable	β	t	R	R^2	ΔR^2	F	p
Step 1				**.79**	**.63**	**.63**	**23.62**	**<.01**
	Hearing	.46	2.52					.018
	Age	.39	2.19					.037
Step 2				**.83**	**.69**	**.06**	**5.23**	**.03**
	Hearing	.63	3.41					.002
	Age	.53	3.00					.006
	GDT	−.39	−2.29					.030

Table 2

Summary of regression analysis for variables predicting speech recognition in noise, including the GIN scores. *F* and *p* values in this table refer to the effect of adding additional variables. *F* and *p* values for the overall models at each step are given in the text.

	Variable	***β***	***t***	***R***	**R^2**	**ΔR^2**	***F***	***p***
Step 1				**.79**	**.63**	**.63**	**23.62**	**<.01**
	Hearing	.45	2.52					.018
	Age	.39	2.19					.037
Step 2				**.79**	**.63**	**.00**	**.03**	**.872**
	Hearing	.46	2.44					.021
	Age	.42	1.77					.088
	GIN	−.04	−.16					.872