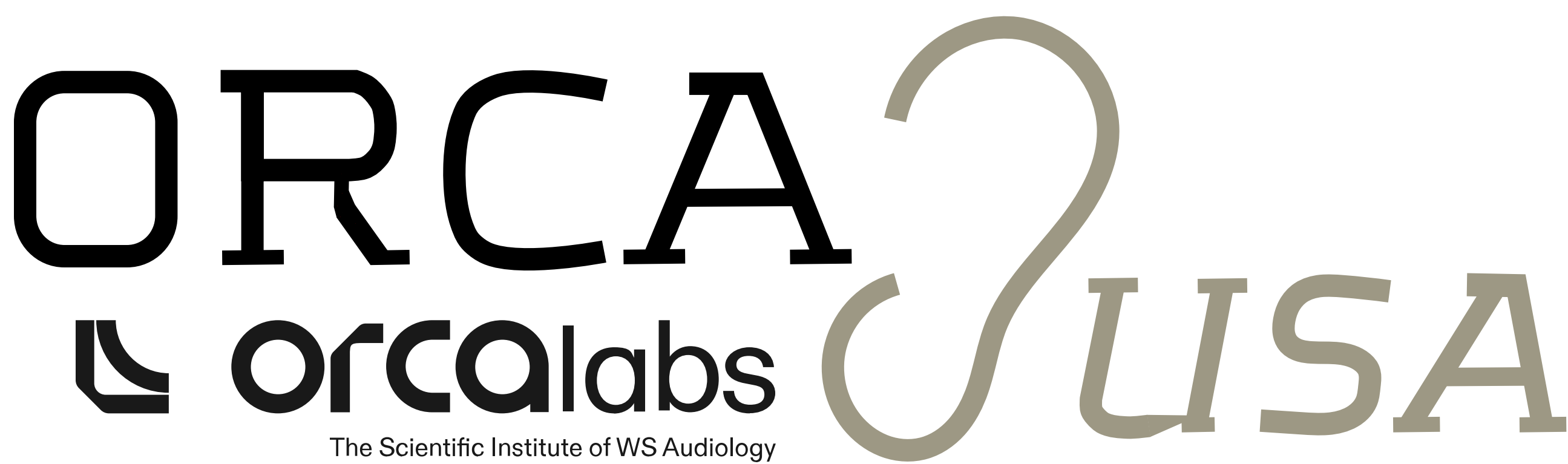


AUDIBILITY-BASED SPEECH INTELLIGIBILITY PREDICTION DURING TRACKING OF NOISE TOLERANCE (TNT)

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INTRODUCTION

A listener’s tolerance for background noise while listening to speech predicts their willingness to use hearing aids and their overall satisfaction with them^{1,2,3}. The Tracking of Noise Tolerance (TNT) test⁴ measures listeners’ noise acceptance while they listen to continuous speech. The TNT test instructs listeners to adjust background noise to a level they can tolerate while still understanding more than 90% of the speech. Although the TNT instructions include intelligibility criterion, the test does not measure speech identification performance directly. Determining how much speech a listener comprehends at this self-selected noise level would help clinicians confirm whether the listener is following test instructions and genuinely understanding the speech. The deviation from 90% criteria would also provide insight on whether the listener likely under- or overestimates their speech-in-noise performance. The subjective intelligibility, which can be estimated from the objective intelligibility⁵, can also inform us on the listener’s personal criteria for what constitutes a tolerable level of background noise. When subjective intelligibility is poor, the domains of speech interference and loudness are generally weighed the heaviest. As subjective intelligibility improves, the weightings on annoyance and distraction increase⁶.

This study examined whether audibility-based predictions could reliably estimate speech identification performance on the TNT test for listeners with hearing impairment. The method was based on the speech intelligibility index (SII)⁷. In the first phase, SII-to-intelligibility transfer functions were derived for the TNT materials based on the speech recognition performance of older adults with normal hearing. In the second phase, the TNT was administered to older adults with hearing impairment to determine each individual’s tolerable noise level range. Speech intelligibility at these levels was estimated using performance-intensity (P-I) functions measured individually for each listener. The intelligibility estimates obtained from the individualized P-I functions were then compared with those calculated using the SII-based method at the tolerable noise levels experienced during the TNT test.

METHODS

Participants

- NH GROUP**
- N = 20 (12 females) listeners with average four-frequency pure-tone average (4PTA; .5, 1, 2, 4 kHz) ≤ 20 dB HL.
 - Mean age = 63.3 (49 ... 84) yrs.

- HI GROUP**
- N = 19 (6 females) with bilaterally symmetrical hearing loss of sensorineural origin with 4PTA 48.2 dB HL (SD = 10.2 dB).
 - Mean age = 74.5 (66 ... 90) yrs.
 - Ten participants were experienced hearing aid wearers.

All participants were native speakers of American English and passed cognitive screening (MoCA).

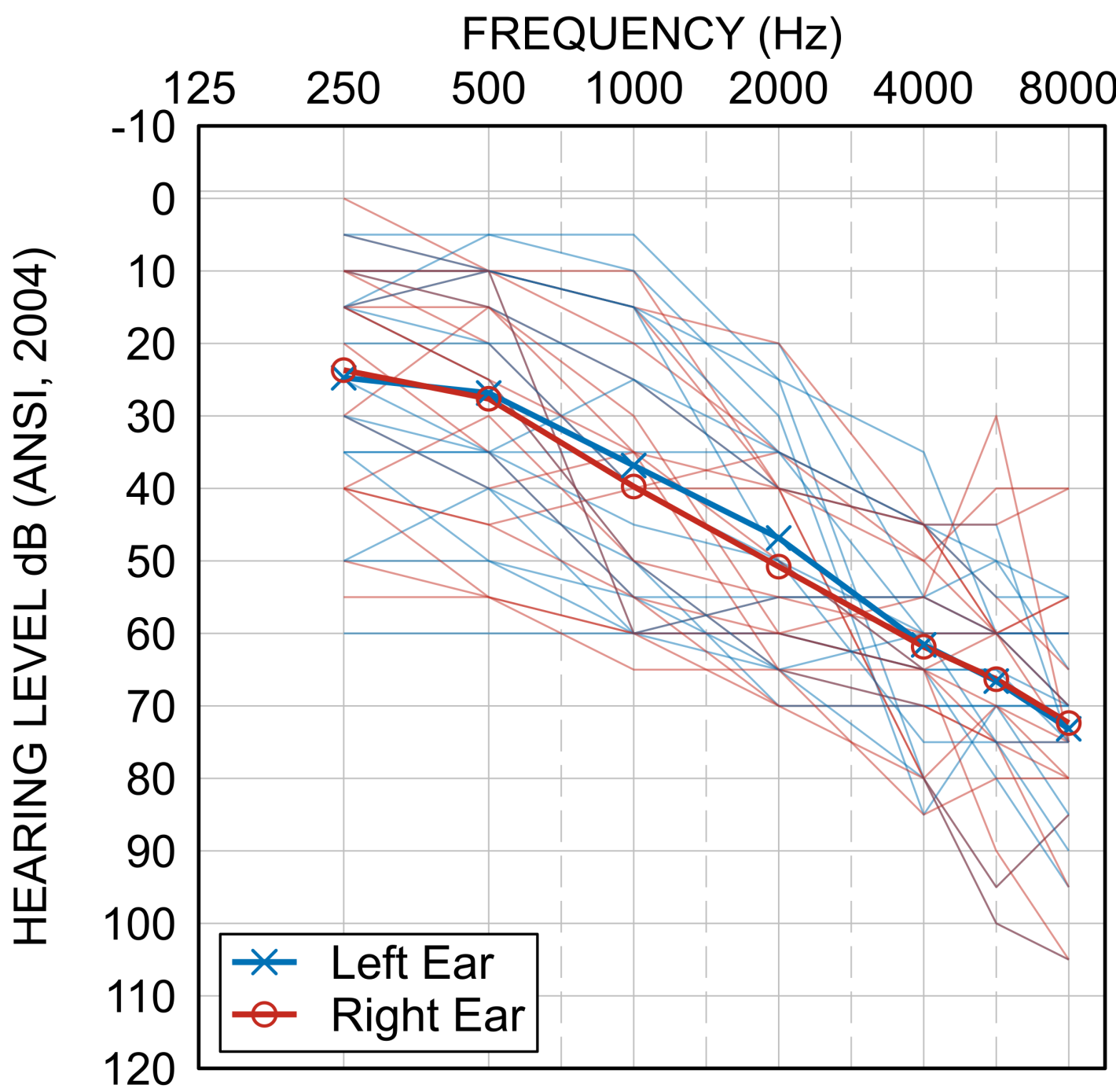


Figure 1. Individual (thin lines) and average (thick lines) pure-tone thresholds of the study participants in the HI group.

Tracking of noise tolerance (TNT) test

During the TNT test (Figure 2), the listener continuously adjusts the noise level while listening to a speech passage. The test starts with the noise level set below the speech level. The noise level then increases automatically at a rate of 1 dB/s until the noise is no longer tolerable according to the listener’s subjective criterion. The noise level is then reduced until the level satisfies their criterion. When the listener stops reducing the noise level, the noise level increases automatically again (i.e., Bekesy tracking). The rate of noise level change is reduced to 0.5 dB/s after 6 reversals. Total tracking duration is 2 minutes.

Listener instructions: “*You will hear some noise in the background while you listen to the male talker [...] monitor the noise level and maintain the loudest noise level you can put up with while still understanding 90% of the words in the story. If the noise becomes too loud, where you can no longer put up with it or understand, 90% of the words in the story, you can turn the noise down by pressing and holding the space bar [...]*”

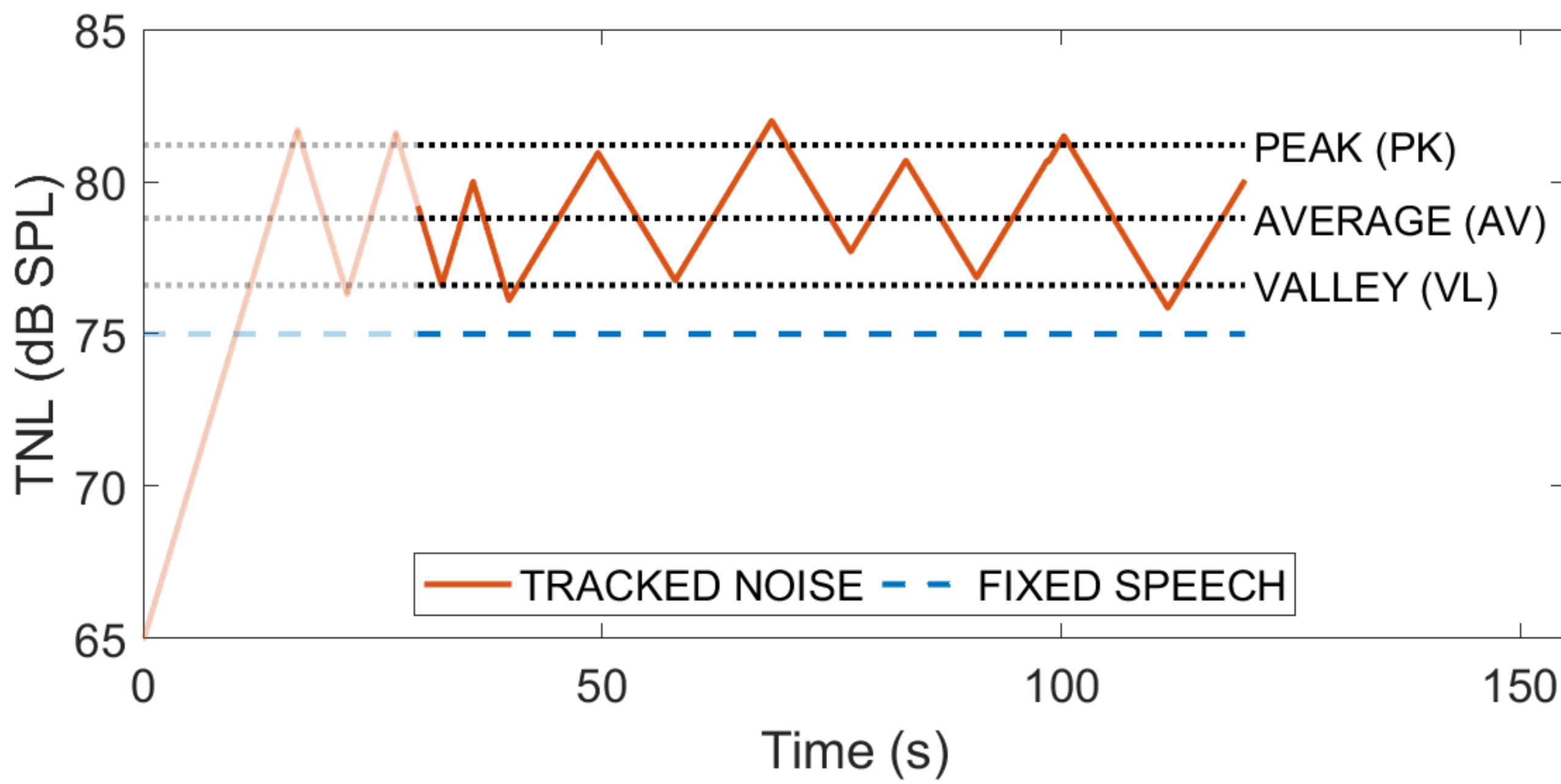


Figure 2. An example of the TNT tracing characterized by average (AV) Tolerable Noise Level (TNL), noise peaks (PK), and noise valleys (VL). Tracing from 30 to 120 sec is considered in the analysis. Peaks and valleys are defined as the 5th and 95th percentiles of the TNL trace.

Measuring the Intelligibility of TNT materials

- Materials from TNT were divided into seven passages each consisting of five equally difficult lists of three sentences each (10 keywords per list).
- Each list was presented at one SNR in randomized order.

	SNR (dB)
NH group	-9, -6, -3, 0 +3
HI group	Individualized SNR range to capture the whole P-I function.

Table 1: Signal-to-noise ratios (SNR) used in assessing individual speech-in-noise performance.

- **NH group** data were used to derive SII-to-intelligibility transfer functions.
- **HI group** data were transformed to individualized continuous P-I functions by fitting logistic functions (quickpsy; Linares & López-Moliner, 2016). These P-I functions were used to estimate speech intelligibility at SNRs experienced during the TNT tracking for each listener.

Predicting intelligibility during TNT tracking

The speech intelligibility index (SII) was used to estimate how much of a speech signal is audible and usable to a listener during TNT tracking.

- The hearing thresholds were defined based on the ear with the better 4PTA.
- The equivalent speech and noise spectrum levels of the TNT materials were calculated using MATLAB Audio Toolbox.
- The relative contribution of different frequency regions was determined using the average speech frequency weights specified in the SII standard.
- The transfer function mapping SII values (i.e., 0...1) to intelligibility percentages (i.e., 0 ... 100%) intelligibility was derived using speech intelligibility data from NH listeners using exponential functions of the form

$$s = \left(1 - 10^{\left(-\frac{SII}{Q}\right)}\right)^N$$

where S is the speech recognition score, and Q and N are fitting constants defining the slope and curvature of the transfer function.

Conditions

- Speech level was 75 dB SPL_{A,Eq}.
- Two noise types: speech shaped continuous noise (SSN), babble noise (BAB).
- All stimuli presented through insert earphones.
- NH group listeners were tested unaided.
- HI group listeners were tested using frequency shaped and amplified stimuli to compensate for the listeners’ audibility loss. Linear compensation gain was based on individual audiograms using NAL-NL2 recommendation.

RESULTS

- In the majority of trials, both estimated (from own P-I) and predicted (from SII) intelligibility levels remained bounded avoiding floor and ceiling effects (i.e., 0% or 100% intelligibility) (Figure 3).
- A notable exception was observed under the BAB noise condition, where individual P-I functions indicated near-floor speech intelligibility for six participants at TNT peaks, while SII indicated same for nine participants.

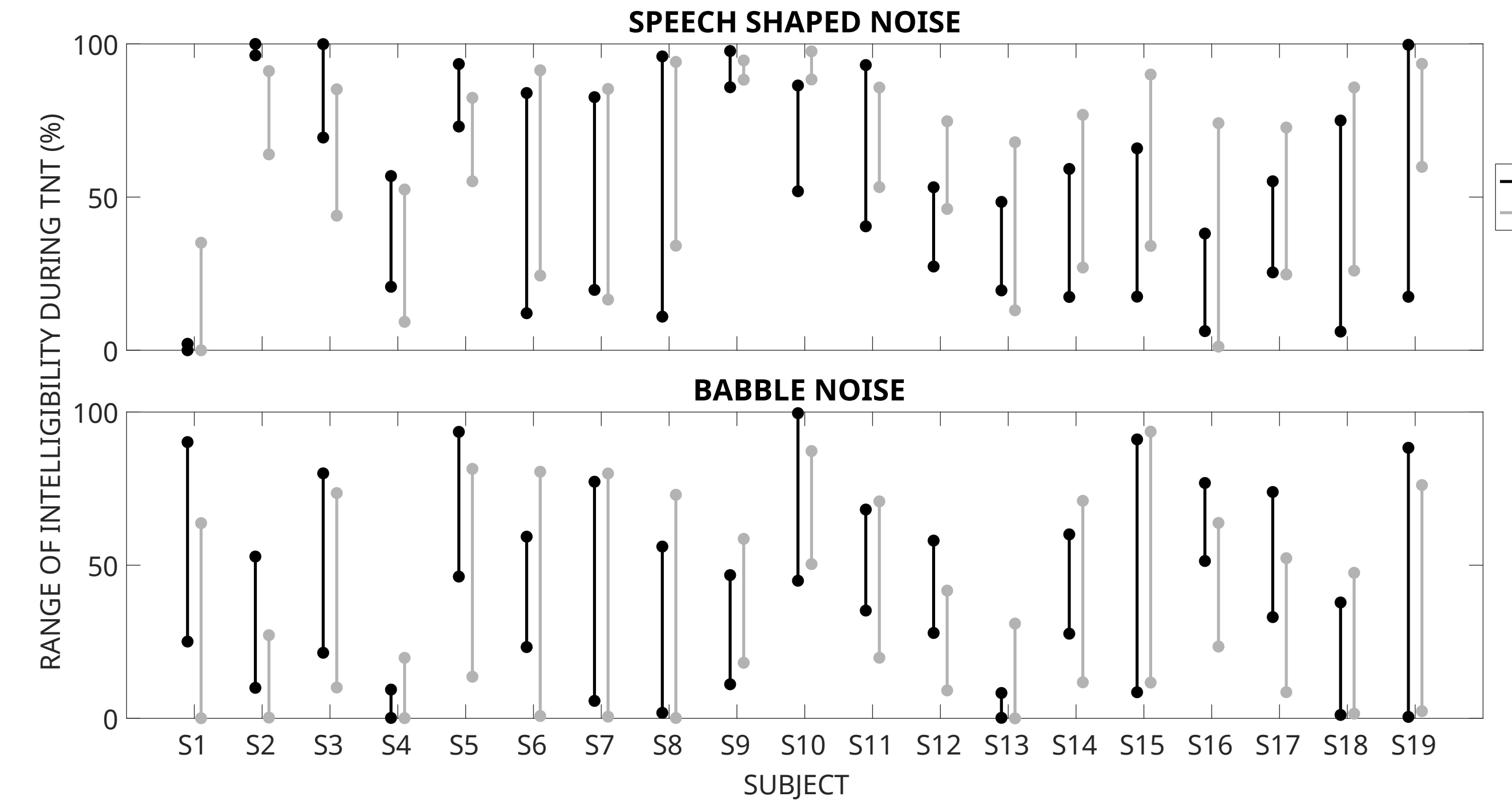


Figure 3: The ranges of speech intelligibility experienced by hearing-impaired (HI) listeners during the TNT test as estimated using each listener’s individualized performance-intensity (P-I) function (black) and predicted using the Speech Intelligibility Index (SII) calculation (gray). Results for speech-shaped noise (SSN) and babble noise (BAB) are presented in the upper and lower panels, respectively.

Accuracy of the intelligibility prediction

- Prediction error was defined as the difference between speech intelligibility (in %) estimated using the listeners own P-I function and the speech intelligibility predicted using the SII (Figure 4).
- On average, the SII-based method overpredicted speech intelligibility by 7.6% at VL and 4.8% at PK under the SSN condition. In contrast, under the BAB condition, the SII method underpredicted intelligibility by 1.8% at VL and 10.2% at PK.
- Figure 5 (right) showed the empirical cumulative distribution function (cdf) for the unsigned magnitude of the prediction error. The cdf showed that depending on the TNT index and the noise type the magnitude of the intelligibility prediction error was less than 20% in 74 to 79% of the trials, and less than 30% in 84 to 100% of the trials.

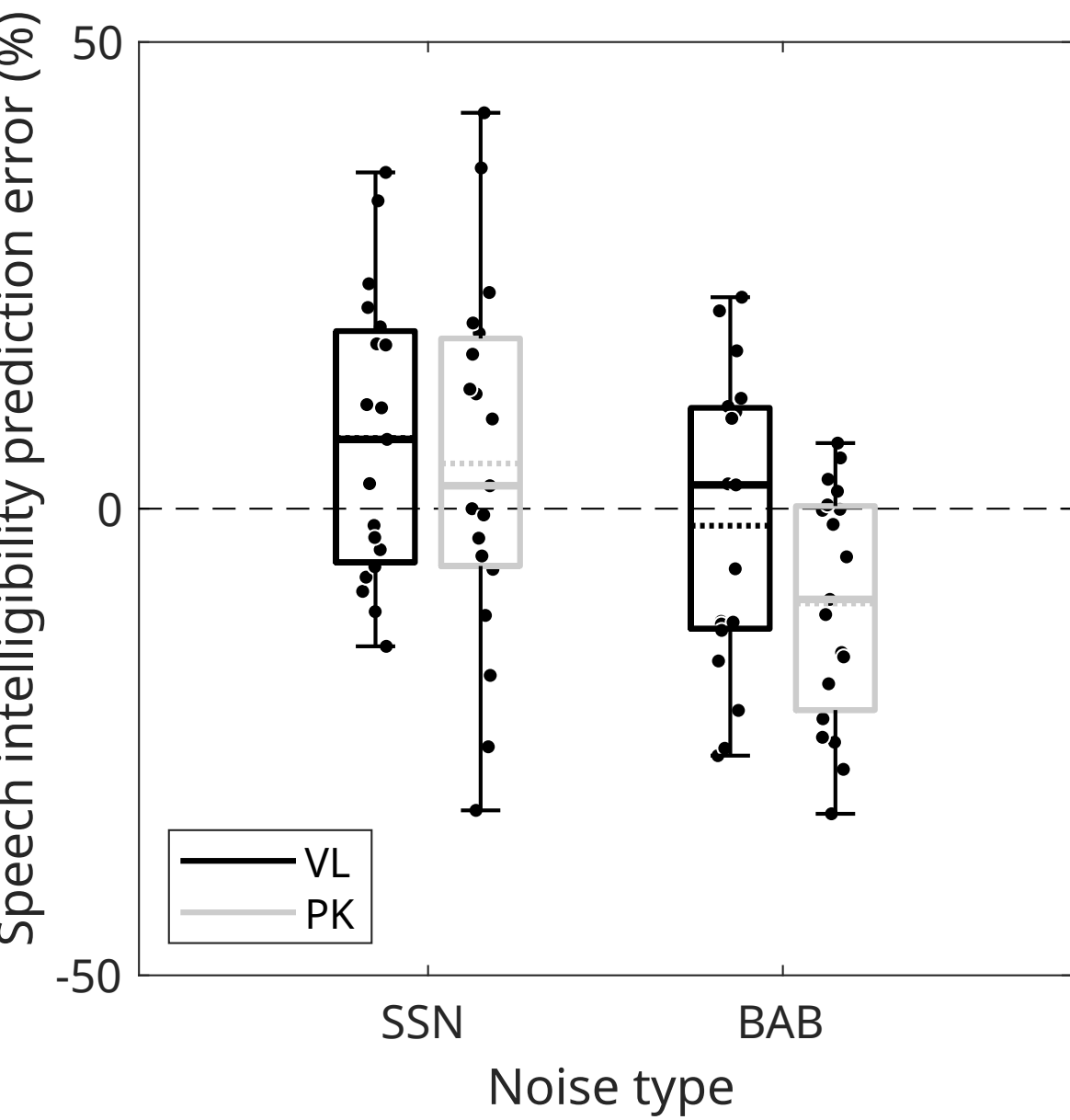


Figure 4: Distributions of speech intelligibility prediction errors at TNT valleys (black) and peaks (gray). Solid line: median. Dotted line: mean. Whiskers: 1.5 * IQR (inter-quartile range) from the hinges. Points: individual participant data.

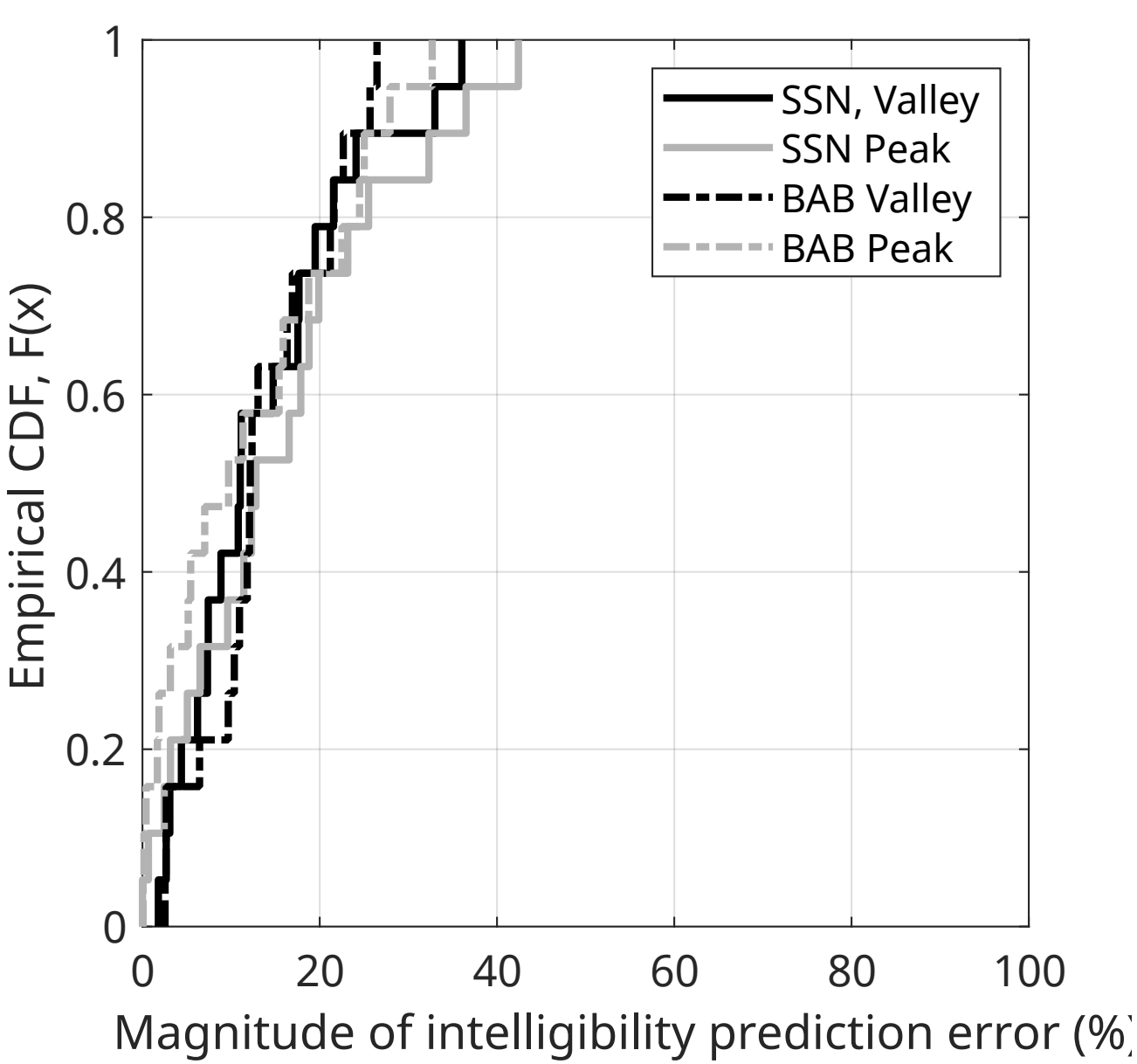


Figure 5: Empirical cumulative distribution function showing the frequency of unsigned magnitude of intelligibility prediction error.

SUMMARY

The audibility-based speech intelligibility prediction method provides a tool to supplement the TNT results. First, it provides a tool for the clinician to verify that the listener follows the intelligibility criterion included in the test instructions. Second, the speech intelligibility estimate can be used to assess whether the listener under- or overestimates their speech-in-noise abilities⁵. Third, an estimate of the range of intelligibilites experienced during the tracking of noise tolerance can provide insight into the individual factors that drive noise acceptance decisions. This may help profile the listener for more appropriate intervention.

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