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The Words-in-Noise (WIN) Test with Multitalker Babble and Speech-Spectrum Noise Maskers

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Abstract

The Words-in-Noise (WIN) test uses monosyllabic words in seven signal-to-noise ratios of multitalker babble (MTB) to evaluate the ability of individuals to understand speech in background noise. The purpose of this study was to evaluate the criterion validity of the WIN by comparing recognition performances under MTB and speech-spectrum noise (SSN) using listeners with normal hearing and listeners with hearing loss. The MTB and SSN had identical rms and similar spectra but different amplitude-modulation characteristics. The performances by the listeners with normal hearing, which were 2 dB better in MTB than in SSN, were about 10 dB better than the performances by the listeners with hearing loss, which were about 0.5 dB better in MTB with 56% of the listeners better in MTB and 40% better in SSN. The slopes of the functions for the normal-hearing listeners (8–9%/dB) were steeper than the functions for the listeners with hearing loss (5–6%/dB). The data indicate that the WIN has good criterion validity.

Key Words: Auditory perception, hearing loss, multitalker babble, speech perception, speech-spectrum noise, word recognition in multitalker babble

Abbreviations: ANSI = American National Standards Institute; BBN = broadband noise; BKB-SIN™ = BKB-Speech-in-Noise test; HINT = Hearing in Noise Test; MTB = multitalker babble; QuickSIN™ = Quick Speech-in-Noise test; S/N = signal-to-noise ratio; SSN = speech-spectrum noise; WIN = Words-in-Noise test

Sumario

La prueba de Palabras en Ruido (WIN) utiliza palabras monosilábicas en siete tasas de señal/ruido de balbuceo de hablantes múltiples (MTB) para evaluar la capacidad de los individuos de entender lenguaje el medio de ruido de fondo. El propósito del estudio fue evaluar el criterio de validez del WIN comparando el desempeño en reconocimiento del lenguaje bajo ruido MTB y con ruido en el espectro del lenguaje (SSN), utilizando sujetos con audición normal y sujetos con hipoacusia. El MTB y el SSN tienen rms idénticos, y espectros similares, pero diferentes características de modulación de la amplitud. El desempeño de los normo-oyentes, que fue 2 dB mejor en MTB que en SSN, fue 10 dB mejor que el desempeño de los sujetos hipoacúsicos, resultando alrededor de 0.5 dB mejor para MTB, con 56% de los sujetos

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respondiendo mejor en MTB y 40% mejor en SSN. Las pendientes de la funciones para los sujetos normo-oyentes (8–9 %/dB) fueron más empinadas que las funciones de los sujetos hipoacúsicos (5–6 %/dB). Los datos indican que el WIN tiene un buen criterio de validez.

Palabras Clave: Percepción auditiva, hipoacusia, balbuceo de hablantes múltiples, percepción del lenguaje, ruido en el espectro del lenguaje, reconocimiento del lenguaje en balbuceo de hablantes múltiples

Abreviaturas: ANSI = Instituto Nacional Americano de Estándares; BBN = ruido de banca ancha; BKB-SIN™ = prueba de Lenguaje BKB en Ruido; HINT = Prueba de Audición en Ruido; MTB = balbuceo de hablante múltiples; QuickSIN™ = Prueba Rápida de Lenguaje en ruido; S/N = tasa señal/ruido; SSN = ruido en el espectro del lenguaje; WIN = prueba de Palabras en Ruido

The Words-in-Noise (WIN) materials were developed to evaluate the ability of listeners to understand words in multitalker babble (MTB; Wilson, 2003). The WIN involves a modified method of constants in which the level of the MTB is fixed and five or ten words are presented at seven signal-to-noise ratios from 24 to 0 dB in 4 dB decrements. The 70 words (ten words by seven levels) are from the Northwestern University Auditory Test No. 6 (Tillman and Carhart, 1966) spoken by a female speaker (Department of Veterans Affairs, 2006). The metric of interest is the signal-to-noise ratio (S/N) at which recognition performance is 50%, which is a value determined with the Spearman-Kärber equation (Finney, 1952). The 90th percentile on the WIN for young listeners with normal hearing is 6 dB S/N, which is used to define the normal range (Wilson et al, 2003). Studies from our laboratory demonstrate that the 50% points on the WIN observed from listeners with sensorineural hearing loss typically are in the 10 to 16 dB S/N range, which is a 4 to 10 dB hearing loss in terms of signal-to-noise ratio (McArdle et al, 2005; Wilson and Burks, 2005). Using the descriptor signal-to-noise loss or signal-to-noise hearing loss (Killion, 2002), then a 4 to 10 dB S/N hearing loss is substantial and, unfortunately, is an aspect of auditory function that routinely is evaluated by less than half the audiologists queried in a recent survey (Strom, 2006).

The concept of quantifying hearing loss in terms of signal-to-noise ratio is not new. In 1970, Carhart and Tillman observed that "it appears that by the time background talk reaches a level where it is just mildly disruptive to intelligibility for normal hearers it can become a serious masker for the sensorineural" (p. 279). They further indicated that audiologists are not "justified in assuming that the communication handicap imposed by that disorder [sensorineural hearing loss] can be specified in terms of the two traditional measures: namely, hearing loss as defined by [pure tone] threshold shift and discrimination loss [word-recognition performance] as defined by reduced intelligibility in quiet" (p. 279). There is an abundance of data that indicates speech-recognition performance in background noise can not be predicted with any degree of certainty by either pure-tone thresholds or by speech-recognition performance in quiet (Killion, 2002; Wilson and McArdle, 2005). Carhart and Tillman concluded that "in addition to these traditional measurements, one must also specify the increase in the masking efficiency of competing speech and of other background sounds that plague the patient when he is in complex listening environments." The same point was emphasized by Plomp and Duquesnoy (1982) when they remarked, "A hearing loss for speech in noise of 3 dB is more disturbing than a hearing loss for speech in quiet of 21 dB" (p. 101).

Wilson et al (2007) compared recognition performance on the WIN with recognition performances on the BKB-Speech-in-Noise test (BKB-SIN™; Niquette et al, 2003; Etymōtic Research, 2005), the Hearing in Noise Test (HINT; Nilsson et al, 1994), and the Quick Speech-in-Noise test (QuickSIN™; Killion et al, 2004) using both listeners with normal hearing and listeners with sensorineural hearing loss. Of the four instruments, the WIN was the most sensitive in discriminating between the two groups of listeners with only 1% of the listeners with hearing loss performing in the normal range. With the BKB-SIN, HINT, and QuickSIN, 22%, 28%, and 10% of the listeners with hearing loss, respectively, performed in the normal range. In an earlier study, the QuickSIN and WIN were found to produce recognition performances by listeners with hearing loss that were equivalent (McArdle et al, 2005).

The current study is a continuation of the examination of the various characteristics of the WIN. Because the WIN involves an MTB masker, which is somewhat variable in comparison to a random noise especially in the temporal domain (temporal continuity; Miller, 1947), it was of interest for comparative and criterion validity purposes to examine the masking characteristics that MTB and speech-spectrum noise (SSN) had on the stimulus words used in the WIN protocol. Based on previous data (Festen and Plomp, 1990; Takahashi and Bacon, 1992; Stuart and Phillips, 1996; Dubno et al, 2002; Summers and Molis, 2004; Turner, 2006), a couple of relations were expected between the masking characteristics of MTB and SSN. First, the two maskers were expected to produce similar overall masking because the rms levels were equivalent and because the spectra of the two maskers were similar (Miller, 1947). Second, the listeners with normal hearing were expected to obtain some release from masking in the MTB condition (re: SSN) that was not obtained from the listeners with hearing loss. This relation was expected because listeners with normal hearing are thought to take advantage of the improved signal-to-noise ratios that occur during the valleys of the amplitude modulations of the MTB, whereas listeners with hearing loss are not able to take advantage of the improved signal-to-noise ratio (Eisenberg et al, 1995; Holma et al, 1997; Bacon et al, 1998; Dubno et al, 2002; Turner, 2006). To define precisely the calibration of the two maskers, the maskers were equated in terms of rms measured during the course of each of the 70 carrier phrase, word segments that constitute the WIN.

METHODS

Materials

The Words-in-Noise (WIN) materials served as the basic experimental paradigm (Wilson, 2003). The WIN is a word-recognition protocol that uses multitalker babble as the background noise. The words and babble at the appropriate signal-to-babble ratio are mixed and recorded on one channel of the CD with the other channel, which is used for monitoring purposes, containing only the words. SSN was selected as the comparison masker because the spectrum reflects the long-term spectrum of speech in that it is flat to 1000 Hz above which there is a 12 dB/octave decrease (American National Standards Institute [ANSI], 1996). Figure 1 presents the spectra of the MTB and SSN maskers presented at equal rms through a TDH-50P earphone and measured in a 6 cm^3 coupler. To illustrate the frequency response of the earphone, the spectrum of a broadband noise (BBN) also is shown. The spectrum of the MTB closely approximates the spectrum of the SSN with only a 4–5 dB difference in the higher frequencies. A similar observation about the spectra of the two noises was made by Sperry et al (1997) with the same MTB and a SSN. The insert in Figure 1 shows 4 sec waveform samples of the MTB (top) and SSN (bottom) that were

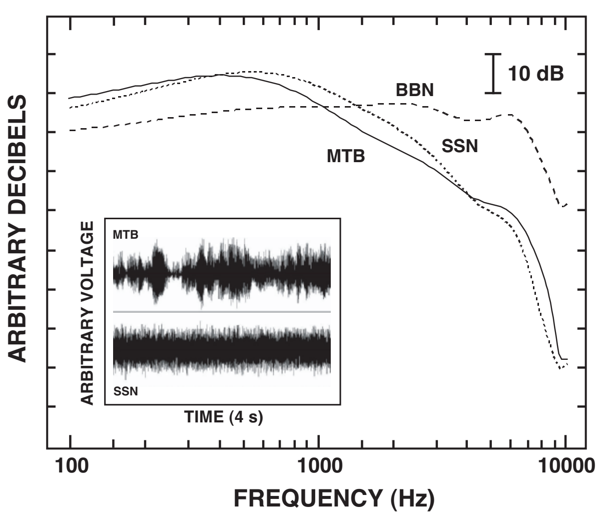

Figure 1. The spectra of the multitalker babble (MTB) and speech-spectrum noise (SSN) maskers presented at equal rms through a TDH-50P earphone and measured in a 6 cm^3 coupler are shown along with the spectra of a broadband noise (BBN) that reflects the frequency response of the earphone. The insert shows the MTB and SSN waveforms at equal rms for one carrier phrase/word segment.

randomly selected from one of the 70 words. Although the two noise samples had the same rms, a variety of amplitude modulations characterize the MTB, whereas amplitude modulations in the SSN waveform are minimal.

The following procedures were used to construct the test materials in SSN. SSN samples were digitized (44,100 samples/sec) from an audiometer (Grason-Stadler, Model 61). The rms of the MTB that coincided in the temporal domain with the carrier phrase and target word was measured for each of the 70 words. A second set of words was then compiled with the SSN replacing the MTB. The level of the SSN segments accompanying each word was then set to the same rms that was measured with the MTB that accompanied the word in the original recordings. Thus, the rms of the SSN segments varied over the same 1.5 dB range that the MTB varied over in the original WIN protocol (Wilson, 2003). To minimize the auditory effects of amplitude changes that occurred between adjacent SSN segments, the first 1000 msec of each SSN segment was ramped (plus or minus linearly) to equalize the segment amplitudes at the segment boundaries. Each word file was ~4 sec with 2 sec preceding the onset of the carrier phrase, ~1 sec for the carrier phrase and target word, and 1 sec following the target word. The 70-word WIN list was divided into two, 35-word lists (Lists 1 and 2) that included five words at each signal-to-babble ratio (Wilson and Burks, 2005).

Subjects

Twenty-four young adults (18–29 years, mean = 23.4 years) with normal hearing (≤20 dB HL [ANSI, 1996]) at the 250–8000 Hz octave frequencies participated. A group of 48 older adults (65–83 years, mean = 74.0 years) with high-frequency sensorineural hearing loss participated. Inclusion criteria included the following: ≥65 years of age, pure-tone thresholds of ≤30 dB HL at 500 Hz, ≤40 dB HL at 1000 Hz, and a pure-tone threshold average of ≤45 dB HL at 500, 1000, and 2000 Hz. Listeners with signs of conductive and retrocochlear hearing loss also were excluded. The average pure-tone thresholds (and standard deviations) for the 48 listeners are shown in Figure 2.

Procedures

Using a counterbalanced design, each listener was presented four 35-word lists, with two complementary lists for each of the two masker conditions. No practice on the task was provided. The presentation order of the four lists was alternated (e.g., MTB, SSN, MTB, SSN, or SSN, MTB, SSN, MTB) with randomizations of Lists 1 and 2 (or Lists 2 and 1) given to the first two conditions, followed by different randomizations of Lists 1 and 2 (or Lists 2 and 1) given to the last two conditions. For analysis, the results from the two 35-word lists for each condition were combined into the full list of 70 words. The left ears of the odd numbered listeners and the right ears of the even numbered listeners were used.

The stimuli were reproduced by a CD player (Sony, Model CDP-497) and routed through an audiometer (Grason-Stadler, Model 61) to a TDH-50P earphone encased in a Telephonics P/N 510C017-1 cushion. The non-test ear was covered with a dummy earphone. The presentation level of the noise was fixed at 70 dB SPL. The level of the speech was varied from 94 dB SPL (24 dB S/N) to 70 dB SPL (0 dB S/N) with five words presented at each of the signal-to-noise ratios. The data were collected during a single 30-minute session. All testing was

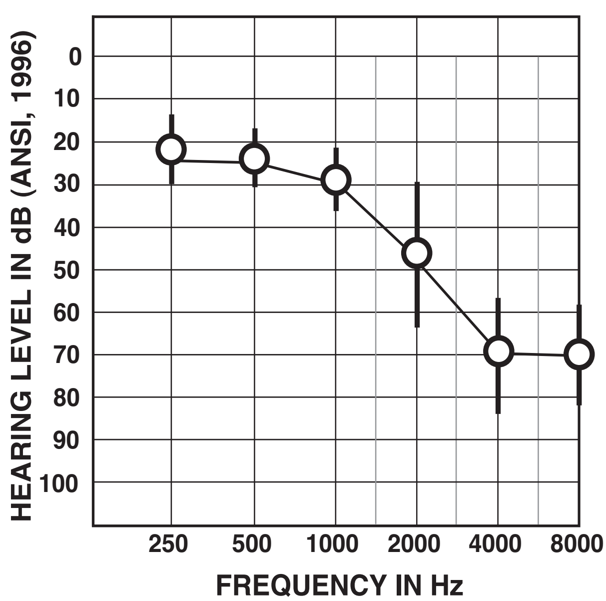

Figure 2. The average audiogram for the test ear of the 48 listeners with high-frequency sensorineural hearing loss is shown along with the standard deviations (vertical bars).

conducted in a double-wall sound booth. The listeners responded verbally with the responses recorded into a spreadsheet.

RESULTS AND DISCUSSION

Figure 3 depicts the psychometric functions generated with the mean MTB data (top panel) and the SSN data (bottom panel) from the listeners with normal hearing (open symbols) and for the listeners with hearing loss (filled symbols). The vertical lines represent the respective standard deviations. The lines connecting the datum points are the best-fit, third-degree polynomials used to describe the data. The 50% points calculated from the mean functions in Figure 3 and the slopes of the mean functions at the 50% point are listed in Table 1. The between group differences were 10.6 dB (MTB) and 9.0 dB (SSN). The slopes of the functions were steeper for the listeners with normal hearing (8.4 and 8.9%/dB) than for the listeners with hearing loss (5.3 and 5.7%/dB), both of which are slightly steeper than the slopes of functions for monosyllabic words in quiet. The relation between the slopes of functions for the two groups of listeners is typical and expected as the listeners with hearing loss exhibit larger variability than do listeners with normal hearing. Larger variability is reflected by a function with a more gradual slope.

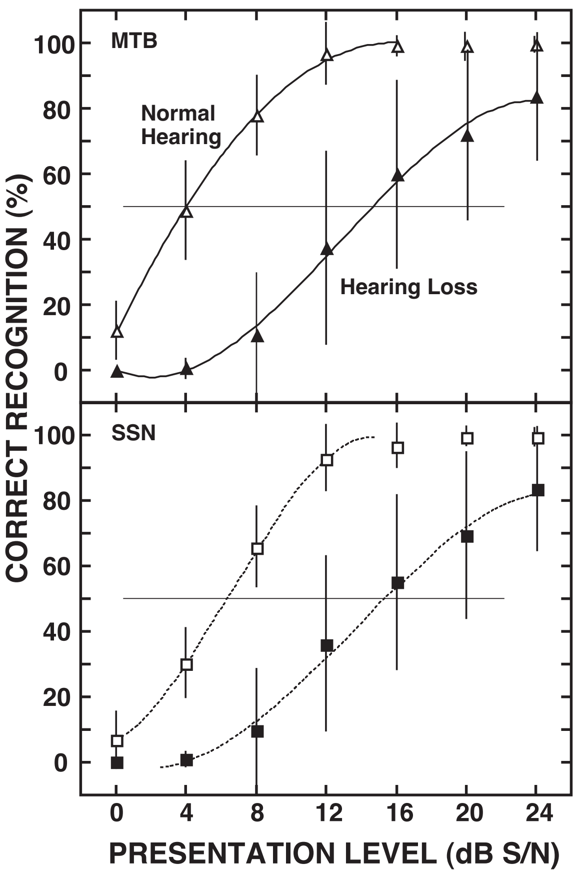

Figure 3. The psychometric functions for the multitalker babble (MTB—top panel) and speech-spectrum noise (SSN—bottom panel) maskers are shown for the listeners with normal hearing (open symbols) and the listeners with hearing loss (filled symbols). The vertical lines represent ±1 standard deviations.

The functions in Figure 3 are recast in Figure 4 to enable within-group comparison between the two masking functions for the listeners with normal hearing (top panel) and listeners with hearing loss (bottom panel). The mean 50% points (and standard deviations) calculated with the Spearman-Kärber equation are listed in Table 2. From Figure 4 and Table 2, the SSN was a more effective masker than MTB by 2.1 dB for the listeners with normal hearing and by 0.6 dB for the listeners with hearing loss. Similar differences between conditions are apparent in Figure 4.

Figure 5 is a bivariate plot of the individual 50% points for the MTB (abscissa) and SSN (ordinate) conditions. The diagonal line represents equal performance, and the large filled symbols depict the mean datum points for each group of listeners. Datum points above the diagonal line indicate higher thresholds in SSN in terms of the signal-to-noise ratio at which the 50% point occurred. For the listeners with normal hearing (triangles), the 96% of the datum points are clustered on or mostly above the diagonal line indicating that SSN was the more effective masker than was MTB for the majority of listeners even

Table 1. 50% Correct Points (dB S/N) and Slopes at the 50% Points (%/dB) Calculated from the Polynomials Used to Describe the Data in Figure 3 are Listed for the Two Groups of Listeners

	Normal Hearing		Hearing Loss		
Condition	50% Point (dB S/N)	Slope (%/dB)	50% Point (dB S/N)	Slope (%/dB)	Mean Difference
MTB	4.0	8.4	14.6	5.7	10.6
SSN	6.3	8.9	15.3	5.3	9.0

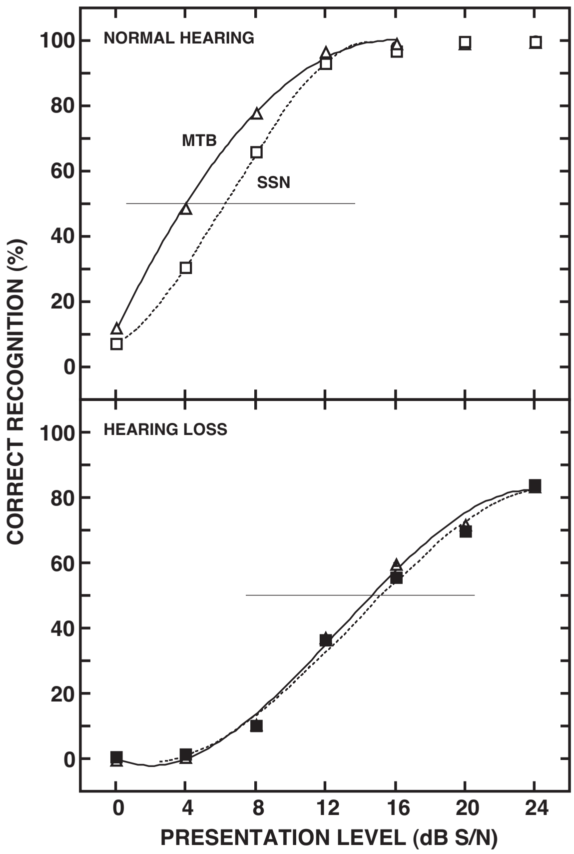

Figure 4. The mean functions for the multitalker babble (MTB) and speech-spectrum noise (SSN) maskers are shown for the listeners with normal hearing (top panel) and the listeners with hearing loss (bottom panel).

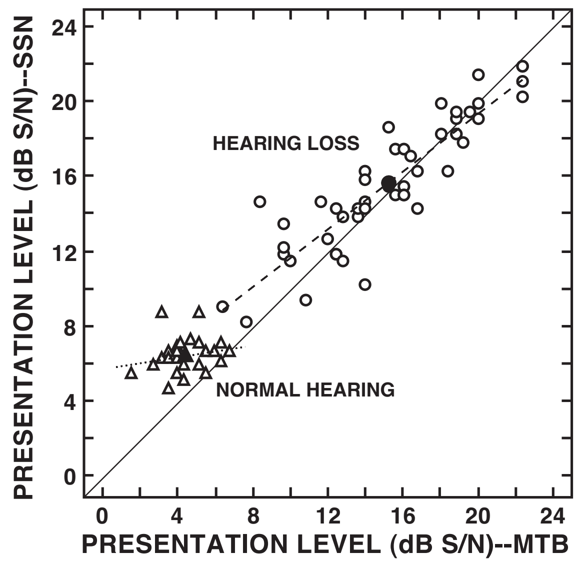

Figure 5. A bivariate plot of the 50% points calculated with the Spearman-Kärber equation for each of the 24 listeners with normal hearing (triangles) and the 48 listeners with hearing loss (circles) in the multitalker babble (MTB, abscissa) and in the speech-spectrum noise (SSN, ordinate). The large filled symbols depict the mean datum point for each group of listeners.

though the rms levels of the two maskers were the same. For this reason the correlation coefficient was 0.16 and the slope of the linear regression used to describe the data (dotted line) approximated zero. As indicated above in the introduction, these relations suggest that the valleys in the amplitude modulations of the MTB (see insert in Figure 1) provided the listeners with "windows of opportunity" during which the signal-to-noise ratio briefly is improved. An improved signal-to-noise ratio contributes to better recognition performance. Direct evidence of this type of release from masking is found in the studies of the effects of interrupted noise on speech-recognition performance (Miller and Licklider, 1950; Dirks et al, 1969; Wilson and Carhart, 1969). These studies demonstrated that listeners with normal hearing had better speech intelligibility when the masker was interrupted at certain rates and when the modulation depth of the masker was increased than when the masker was presented continuously.

In the current study, the data for the listeners with hearing loss are substantially more variable than the data for the listeners with normal hearing. The correlation coefficient, however, was 0.9, indicating a strong relationship between the MTB and SSN variables. As reflected by the mean 50% correct point (filled circle in Figure 5), the listeners with hearing loss as a group were not able to take advantage of the "windows of opportunity" that occurred during the amplitude modulations of the MTB. There were, however,

Table 2. Mean 50% Correct Points (dB S/N) and Standard Deviations (dB) Calculated with the Spearman-Kärber Equation from the 24 Listeners with Normal Hearing and the 48 Listeners with Hearing Loss

	Normal Hearing		Hearing Loss		
Condition	Mean (dB S/N)	SD (dB)	Mean (dB S/N)	SD (dB)	Mean Difference
MTB	4.5	1.3	15.2	4.1	10.7
SSN	6.6	1.0	15.8	3.5	9.2

56% of the listeners with hearing loss who had recognition performances that were better in MTB than in SSN (i.e., above the diagonal line), which indicates that many of the listeners with hearing loss obtained a similar release from masking in the MTB condition that was obtained by the listeners with normal hearing. In contrast to the listeners with normal hearing, 40% of the listeners with hearing loss had datum points below the diagonal line in Figure 5, which indicates better performance in SSN than in MTB. A similar mixed finding for listeners with hearing loss was observed by Summers and Molis (2004), who suggested that the distortion component of hearing loss (Plomp, 1978) also was a contributing factor to the performances that were observed.

One final relation is noteworthy in Figure 5. As reflected by the linear regression used to describe the data for the listeners with hearing loss (dashed line), which had a slope that approximated one, the 50% points that were lower in terms of signal-to-noise ratio tended to mimic the 50% points for the listeners with normal hearing in that the points were above the diagonal line (i.e., they demonstrated release from masking with the MTB condition). As the 50% points for the listeners with hearing loss increased in signal-to-noise ratio, the datum points migrated progressively to and then below the diagonal line, which indicated no release from masking was obtained with the MTB condition.

The 90th percentiles for the listeners with normal hearing were 6.3 and 7.2 dB S/N for MTB, and SSN, respectively. None of the listeners with hearing loss had 50% points below the 90th percentile values, which is consistent with the observation made in the Wilson et al (2007) report that the WIN provides good separation in recognition performances between listeners with normal hearing and listeners with hearing loss. Finally, the listeners with hearing loss were >65 years of age with mild-to-moderate, high-frequency sensorineural hearing losses. Younger listeners and listeners with more severe hearing losses perform slightly differently on the WIN task. Previous data indicate that age is a slight factor with hearing loss being the more influential factor (Wilson and Weakley, 2005).

CONCLUSIONS

When MTB and SSN of similar spectra and equal rms were used to mask the monosyllabic words in the WIN paradigm, several relations emerged. First, for listeners with normal hearing, mean recognition performance was 2.1 to 2.3 dB better in the MTB than in the SSN; that is, MTB was an easier listening condition. This finding was true for 88% of the listeners with normal hearing. Second, mean recognition performance for listeners with hearing loss was 0.6 to 0.7 dB better in the MTB than in the SSN. For these listeners, 56% performed better in MTB than in SSN, whereas 40% performed better in SSN than in MTB. Third, most of the performances by the listeners with normal hearing were in the 2 to 6 dB S/N range (MTB) and in the 4 to 8 dB S/N range (SSN), whereas most of the listeners with hearing loss performed in the 8 to 22 dB S/N range for both MTB and SSN. Fourth, the slopes of the mean functions were steeper for the listeners with normal hearing (8 to 9%/dB) than for the listeners with hearing loss (5 to 6%/dB). Fifth, none of the listeners with hearing loss had recognition performances that were in the normal range as defined by the 90th percentile in the listeners with normal hearing. Collectively, the findings of this investigation provide criterion validity to the clinical application of the WIN in the evaluation of the abilities of listeners with hearing loss to understand speech in background noise. Because the data from the listeners with hearing loss were essentially the same for the two types of maskers, the question is which masker is more appropriate? The MTB has more face validity in that listeners with hearing loss complain of difficulty understanding speech in noisy backgrounds, especially when the noise is composed of multiple speakers talking as in a restaurant or other social environments.

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