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A comparison of word-recognition abilities assessed with digit pairs and digit triplets in multitalker babble

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Abstract—This study compares, for listeners with normal hearing and listeners with hearing loss, the recognition performances obtained with digit-pair and digit-triplet stimulus sets presented in multitalker babble. Digits 1 through 10 (excluding 7) were mixed in approximately 1,000 ms segments of babble from 4 to –20 dB signal-to-babble (S/B) ratios, concatenated to form the pairs and triplets, and recorded on compact disc. Nine and eight digits were presented at each level for the digit-triplet and digit-pair paradigms, respectively. For the listeners with normal hearing and the listeners with hearing loss, the recognition performances were 3 dB and 1.2 dB better, respectively, on digit pairs than on digit triplets. For equal intelligibility, the listeners with hearing loss required an approximately 10 dB more favorable S/B than the listeners with normal hearing. The distributions of the 50% points for the two groups had no overlap.

Key words: auditory perception, background noise, digital perception, hearing loss, monaural, monosyllabic words, normal hearing, signal-to-babble ratio, speech perception, word recognition in multitalker babble.

INTRODUCTION

The major complaint that most adults with hearing loss have is that they can hear but they cannot understand speech, especially in background noise. The importance of evaluating the ability of adults to understand speech in background noise has been emphasized in the past [1–9] and recently has received revived attention, especially for use with adults in determining the appropriate amplification strategy and assisting in establishing expectations of amplification [10–12]. Several speech stimuli have been proposed for evaluating the ability of patients to understand speech in background noise, including most notably sentences [13–17], words [12], and digits [18].

Monosyllabic digits in multitalker babble potentially offer audiologists a simple protocol that can be clinically used to evaluate the ability of patients to understand speech in background noise. Digits in noise are attractive as a screening instrument, especially in noisy environments in which pure-tone testing is precluded. The simplicity of the digit protocol is related to two factors. First, digits provide a closed-set response paradigm in that only eight or nine potential responses exist. Digits were reported to have a steeper psychometric function than other equivalent numbers of monosyllabic words. Second,

Abbreviations: ANOVA = analysis of variance, ANSI = American National Standards Institute, HL = hearing level, SD = standard deviation, S/B = signal to babble (ratio), SPL = sound-pressure level, rms = root-mean-square.

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to most individuals, digits are very familiar tokens, which minimize the learning effects associated with a word-recognition task.

Digits 1 through 10 (excluding 7) are a special case of monosyllabic words that have been used in auditory testing since the development of the Western Electric 4A audiometer in the 1920s [19]. Initially with the 4A audiometer, seven digits (1, 2, 3, 4, 5, 6, 8) were used in a digit-triplet format that later was changed to a digit-pair format [20]. The classic article by Miller et al. compared recognition performances obtained on digits and monosyllabic words from various set sizes [21]. As the number of possible responses to monosyllabic words increased, the psychometric function was moved to higher presentation levels and the slope of the function became more gradual. Performance on the digits was about 18 dB better than performance on an open-set word condition, and the psychometric function for digits was steeper than for the word condition. Subsequently, Broadbent and later Kimura popularized the use of digit triplets in their studies of diotic and dichotic listening [22–23]. In a recent article, Smits et al. proposed the use of Dutch digit triplets in speech-spectrum noise as a screening protocol for use over the telephone [18]. Wilson and Weakley [24] developed a similar paradigm using English digit triplets in multitalker babble.

Two problems were apparent in the Wilson and Weakley study with digit triplets in multitalker babble [24]. First, recognition performance on the digit “5” was noticeably poorer than performance on the other digits. Second, some older listeners had difficulty repeating the three-digit sequence because the task was too difficult, especially at the poorer signal-to-noise ratios. The difficulty of the task with older listeners probably was prompted by several cumulative factors, including hearing loss, listening in noise, and memory limitations.

This study compares recognition performances on digit pairs and digit triplets at various signal-to-babble (S/B) ratios in multitalker babble. Both listeners with normal hearing and listeners with hearing loss were studied. The data from the listeners with normal hearing provide a baseline with which we could compare recognition performances by listeners with hearing loss. The design of the study included measures of pure-tone sensitivity and subjective measures of understanding speech in background noise, both of which we evaluated with respect to the digit-in-babble data.

METHODS

Materials

An earlier report described the methods used to develop digit triplets in multitalker babble [24]. We used the same procedures to construct the digit-pair materials. Multitalker babble was selected as the background noise because it is the most common background noise experienced by listeners [25]. The multitalker babble, which was recorded by Causey,* consisted of three female and three male speakers who read passages that were recorded independently and subsequently electronically mixed [26]. A male recording of digits 1 through 10, excluding 7, was used (Tonal and Speech Materials for Auditory Perceptual Assessment, Disc 2.0). Briefly, the digits were paired with and time locked to unique segments of the babble. The digits were preceded and succeeded by 300 ms of the babble, thereby producing digit/babble segments from 665 ms (digit 5) to 1,160 ms (digit 9). We provided interstimulus intervals of 3.3 s and 3.8 s between the digit pairs and digit triplets, respectively. Each list of digit pairs consisted of 56 digits (8 at each of 7 S/B ratios), whereas each list of digit triplets consisted of digits 63 digits (9 at each of 7 S/B ratios). No digit was repeated at a given S/B ratio. The mean root-mean-square (rms) for the digits was –13.1 dB (re: maximum digitization range) and a 0.6 dB SD, whereas the mean rms value for the babble segments paired with each digit was –17.6 ± 0.2 dB. To avoid acoustic or perceptual distractions at the boundaries of the babble segments, we edited the segments at the negative-going-zero crossings, which produced a seamless transition between babble segments. Because brief, random segments of babble were concatenated, no intelligibility existed in the babble stream.

In the original experiment with digit triplets [24], the recognition performance by both listeners with normal hearing and listeners with hearing loss indicated that the digit “5” was an outlier that required a substantially more favorable S/B ratio for performance that was equivalent to the performances achieved on the other digits. For this reason, the digit “5” was excluded from the digit pairs, leaving eight digits, which was a convenient, even number. The digit triplets retained the “5” digit. The digits were adjusted

*Personal communication, Donald Causey, PhD (now retired from the VA Medical Center, Washington, DC, and the University of Maryland); 1988.

digitally in amplitude (4 dB steps) and then digitally mixed with their unique segment of babble. For the quiet and the 7 S/B ratios from 4 to –20 dB, two randomizations of the digits were generated, with each randomization grouped into four pair sets at each S/B ratio. We made no attempt to counterbalance or in any way equate the presentation position of each digit. We formed each digit pair by concatenating two-digit/babble segments, with an additional 500 ms segment of babble added before the first digit and a 300 ms segment of babble added after the second digit. The segments at the beginning and end of the digit pair and triplet sets had 25 ms rise and fall times. Finally, a practice set of digit pairs was constructed in which two digit pairs presented at each presentation level. The practice set (1.5 min), the two randomizations of digit pairs (3 min), and two randomizations of digit triplets (3 min) were recorded on an audio compact disc (CD) (Hewlett-Packard, Model DVD200i).

Subjects

Participants in the study included 16 young adults (aged 20 to 29 yr, with a mean age of 23.5 yr) with normal hearing (≤20 dB hearing level [HL] at 250 to 8,000 Hz [27]) and 32 older listeners (age 46 to 85 yr, with a mean age of 67.8 yr) with sensorineural hearing loss. The listeners with hearing loss met the following inclusion criteria: (1) threshold at 500 Hz ≤ 30 dB HL, (2) threshold at 1,000 Hz ≤ 40 dB HL, (3) thresholds in the frequencies above 1,000 Hz ≥ 35 dB HL, and (4) word recognition on the female speaker version of the Northwestern University Auditory Test No. 6 [28] in quiet at any level of >50 percent correct (mean = 81.6% correct, SD = 16.3%). The mean audiogram of the test ear of the listeners with hearing loss is shown in **Figure 1**, ± the SDs in parenthesis just below the threshold symbols.

Procedures

The listeners with normal hearing were recruited from East Tennessee State University, whereas the listeners with hearing loss were recruited from the ongoing audiology clinics at Mountain Home, TN, following an audiological evaluation. Following the informed-consent process, the listeners were asked to rate on a scale of 1 to 10 their ability to understand speech in quiet and in noise (**Appendix**, available in online version only www.vard.org/jour/jourindx.html). We then presented each listener with five conditions: one practice list, two digit-pair lists, and two digit-triplet lists. The duplicate presentations provided test (Trial 1) and retest (Trial 2) data. To avoid the same presentations on each trial, we alternately used two randomizations of each set of materials. The practice was to familiarize the listener with the listening/response tasks. After the practice list, one randomization of the digit pairs and one randomization of the digit triplets were presented, followed by a second list of the digit pairs and triplets. We counterbalanced the presentation order of the four conditions so that each randomization was presented an equal number of times in each of the four possible positions. The presentations in babble for both the practice and the four experimental conditions were made with the babble presented at 80 dB sound-pressure level (SPL) that yielded digit presentation levels from 84 to 60 dB SPL (4 to –20 dB S/B ratios). The presentations in quiet were made at 80 dB SPL. For each condition, the digits in quiet were presented first, followed by the conditions in babble, descending from 4 dB S/B ratios. We terminated testing for each condition when all digits at one level were incorrect.

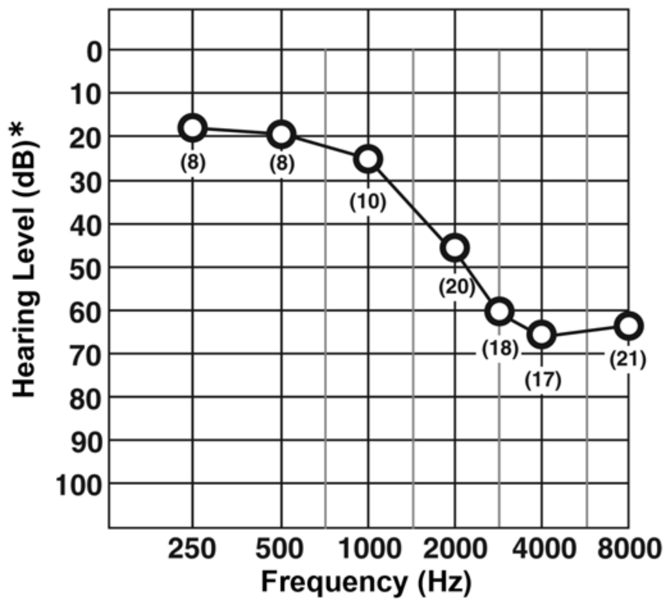

Figure 1.
Mean audiogram for 32 listeners with hearing loss is shown ± standard deviations (in parentheses).*American National Standards Institute (ANSI). Specification for audiometers (ANSI S3.6-1996). New York (NY): ANSI; 1996. p. 1–33.

The materials were reproduced on a CD player (Sony, Model CDP-497), fed through an audiometer (Grason-Stadler, Model 61), and monaurally delivered to a TDH-50P earphone encased in a Telephonics P/N 510C017-1 cushion. Half the subjects used the right ear, and the other half used the left ear. All testing was conducted in a sound booth, and the verbal responses of the listeners to each digit in a pair or in a triplet were recorded into a spreadsheet. We instructed the listeners to repeat the digits that they heard. Guessing was neither encouraged nor discouraged. Data collection took about 15 minutes.

RESULTS AND DISCUSSION

Recognition performance by both groups was excellent on the digits presented in the quiet condition. The listeners with normal hearing responded correctly to 100 percent of the digits in quiet, whereas the listeners with hearing loss responded correctly to 99.4 percent of the digits in quiet. These performances in quiet demonstrated that all the listeners were able to recognize the digits presented consecutively as two- or three-digit combinations.

The data in multitalker babble were evaluated in two ways. First, we used the Spearman-Kärber equation [29] to calculate the 50 percent points for each listener on each of the four data sets. This analysis of the four data sets enabled comparisons between (1) trials (1 and 2), (2) randomizations (1 and 2 for digit pairs; 1 and 2 for digit triplets), and (3) stimulus paradigms (pairs and triplets). We used both graphic and numeric analyses to evaluate the data. The graphic analyses permit observation of the individual subject and group data, whereas the numeric analyses use static procedures to describe group behavior. As will be demonstrated, no overlap existed in the distribution of the data between the listeners with normal hearing and the listeners with hearing loss; therefore, we used repeated-measures analyses of variance (ANOVA) on the data from each group. Second, we plotted the mean percent-correct performances for various conditions as a function of the presentation level with polynomials used to describe the data in terms of the 50 percent point of the mean function and the slope of the mean function at the 50 percent point. Finally, we compared the objective data from the digits-in-babble task with the subjective data obtained from the estimates on the scale of 1 to 10 that the listeners gave about their ability to understand speech in quiet and in background noise.

Randomization Effects

We used two randomizations of each digit paradigm. The four right columns of **Table 1** list the mean S/B ratios (in decibels) at which the 50 percent points were determined from the individual subject data (± SDs). With the listeners with normal hearing, the differences between randomizations were 0.2 to 0.3 dB, whereas with the listeners with hearing loss, the differences were 0.2 dB and 1.1 dB with the digit pairs and digit triplets, respectively. For both groups of listeners, the differences between the data for the randomizations were not significant.

Trial Effects

The mean S/B ratios (± SDs) (in decibels) at which the 50 percent points were determined for the digit pairs and digit triplets are listed in **Table 1** by both trial and randomization. The most obvious relation among the data in **Table 1** is that the listeners with hearing loss had mean recognition-performance levels that were 9 to 10 dB poorer than the levels achieved by the listeners with normal hearing. The mean 50 percent correct points for the listeners with normal hearing were –16 dB S/B and –13 dB S/B ratios for the digit pairs and triplets, respectively, with corresponding mean 50 percent points at –6 dB S/B and –5 dB S/B ratios for the listeners with hearing loss. These 50 percent points are almost identical to the 50 percent points that we observed with the same recorded version of the digit triplets in two other studies that included listeners with normal hearing and listeners with hearing loss [24,30]. Smits et al. reported a similar disparity between listeners with normal hearing and listeners with hearing loss [18]. This generalized relation, which is

Table 1.
Mean ± standard deviation (SD) for signal-to-babble ratios (in decibels) for 50% points that were calculated with Spearman-Kärber equation for listeners with normal hearing (n = 16) and listeners with hearing loss (n = 32). Data are listed by trial and by randomization.

Stimuli	Digit Pairs Trial		Digit Triplets Trial		Digit Pairs Randomization		Digit Triplets Randomization	
	1	2	1	2	1	2	1	2
Normal Hearing	–15.6 ± 2.5	–15.8 ± 2.1	–12.3 ± 2.3	–13.1 ± 2.1	–15.6 ± 2.4	–15.8 ± 2.2	–12.6 ± 1.7	–12.9 ± 2.7
Hearing Loss	–4.7 ± 3.6	–6.7 ± 2.8	–4.0 ± 2.9	–5.1 ± 2.5	–5.8 ± 3.4	–5.6 ± 3.4	–5.1 ± 2.5	–4.0 ± 2.9

referred to as a signal-to-noise hearing loss, is consistent with numerous previous studies that have examined the word recognition of word or sentence materials in background noise [1,3–9,11,31–37]. Finally, as shown in **Table 1**, the SDs for both digit pairs and digit triplets were larger in Trial 1 than in Trial 2. Although this statistic was systematic, the effect was small, ranging from 0.2 to 0.8 dB.

Figure 2 shows the 50 percent points for the individual subjects on Trial 1 (abscissa) and Trial 2 (ordinate) with the digit-pair data (**Figure 2(a)**) and the digit-triplet data (**Figure 2(b)**). The locations of the data points for the two groups of listeners in each panel emphasize the independence of the two distributions. An ANOVA indicated that the differences between the mean 50 percent points on Trials 1 and 2 for the listeners with normal hearing, which were <1 dB, were not significant. This relation can be observed from the pattern of individual 50 percent points in both panels of **Figure 2** (circles). In contrast to the trial data from the listeners with normal hearing, an ANOVA on the trial data for the listeners with hearing loss indicated a significant difference between trials, with performance on Trial 2 better than performance on Trial 1 ($F_{1, 31} = 11.039$, $p < 0.05$). The mean differences were 2.0 dB and 1.1 dB for the digit pairs and digit triplets, respectively. This relation can be observed in both panels of **Figure 2** in which 44 of the 64 data points from the listeners with hearing loss (69%) were below the diagonal line, representing equal performance, whereas 16 of the 64 data points (25%) were above the line. Thus, the majority of listeners with hearing loss performed better on Trial 2 than on Trial 1, which is the relation one would expect because of the contributions made by practice or learning effects. Because of the response patterns of the data depicted in **Figure 2** and because the differences between trials are less than half of the 4 dB measurement interval in the protocol, the interpretation of the significance differences from the numeric analysis must be tempered.

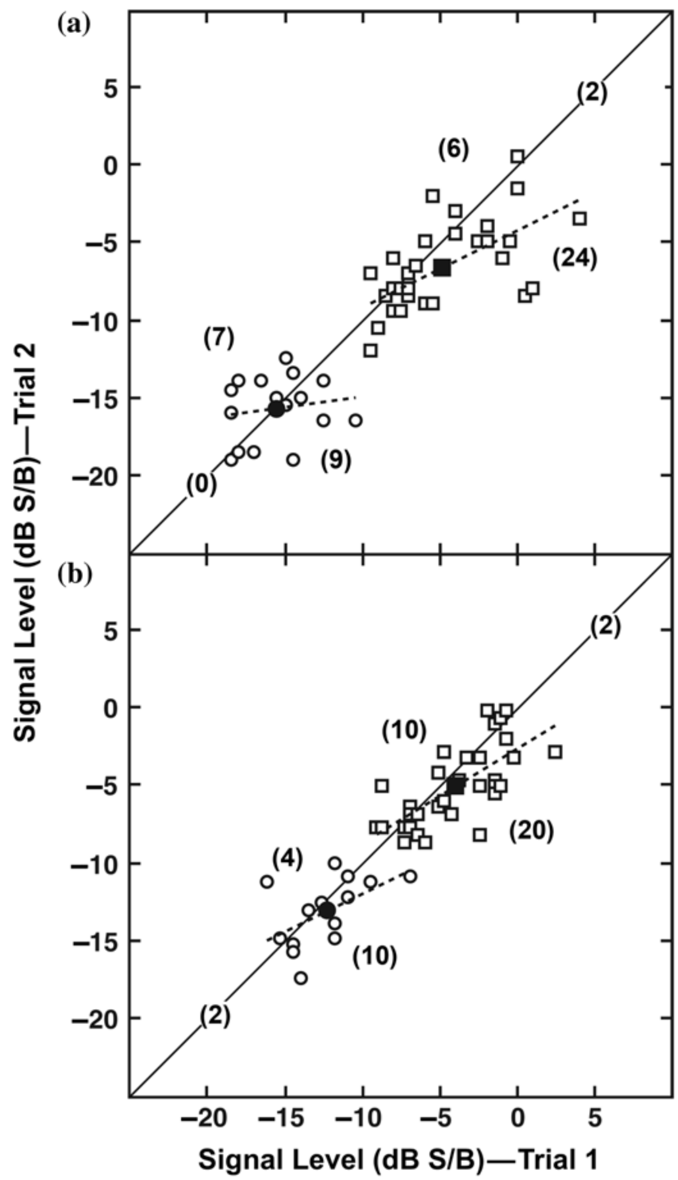

Figure 2.
Bivariate plot of Trial 1 (abscissa) and Trial 2 (ordinate) 50% points (decibel signal-to-babble [S/B] ratio) computed with Spearman-Kärber equation for listeners with normal hearing (○) and listeners with hearing loss (□): (**a**) data for digit pairs and (**b**) data for digit triplets. Filled symbols = mean data; dashed lines = linear regressions used to fit data; and numbers in parentheses = number of data points above, on, and below diagonal line, which represents equal performance. S/B = signal-to-babble ratio.

Digit Pairs Versus Digit Triplets

Repeated-measures ANOVAs indicated that the differences between the data for the digit pairs and digit triplets were significant (listeners with normal hearing: $F_{1, 15} = 32.609$, $p \leq 0.001$; listeners with hearing loss: $F_{1, 31} = 19.633$, $p < 0.001$). The left four data columns of **Table 1** provide the differences between the mean data for the digit pairs and digit triplets by trial. The performance by the listeners with normal hearing was ~3 dB better on the digit pairs than on the digit triplets. The performances by the listeners with hearing loss were smaller (0.7 to 1.6 dB), again with the performance on the digit pairs better than the performance on the digit triplets. **Figure 3** shows the bivariate plots of the data for the two trials in which performance on the digit pairs is shown on the abscissa and performance on the digit triplets is shown on the ordinate. Again, if one considers the data collectively, 76 of the 96 data points (79%) in **Figure 3(a)** and **(b)** are above the diagonal line, indicating better performance on the digit pairs than on the digit triplets. In contrast, only 20 data points (21%) are below the diagonal line, indicating better performance on the digit triplets than on the digit pairs.

The minimal 0.7 to 1.6 dB difference between performance on the digit pairs and digit triplets that we observed for the older listeners with hearing loss suggests that (1) any difficulty that listeners encountered in responding to digit triplets at the poorer S/B ratios they also encountered with the digit pairs and/or (2) the listeners used in this study had no specific difficulty responding to either digit pairs or digit triplets. That the listeners with normal hearing had a 3 dB better performance on the digit pairs than on the digit triplets was an unexpected finding, which we consider in the next section.

The shaded areas in the lower left corner of **Figure 3(a)** and **(b)** represent the 90th percentile for the listeners with normal hearing computed from the data on both trials of the two variables (–12.6 dB S/B ratios for digit pairs and –10.9 dB S/B ratios for digit triplets). None of the listeners with hearing loss were included in the 90th percentile ranges of performances by the listeners with normal hearing. On a digit-in-noise recognition task, Smits et al. [18, Figure 9] reported a similar dichotomy between listeners with normal hearing and listeners with hearing loss. As indicated earlier, in numerous previous studies involving word and sentence materials presented in background noise, the ability of listeners with hearing loss to understand speech in background noise is substantially reduced compared with that of listeners with normal hearing [1,3–5,7–9,11,31,33,37]. Again, measures of this inability constitute a hearing loss in terms of signal-to-noise ratio. As Plomp and Stephens suggested [25,38], hearing loss should be thought of in terms of audibility and distortion components. Simplified, the pure-tone audiogram is a measure of the audibility component of hearing loss, whereas measures like a speech-in-noise paradigm reflect the distortion component of hearing loss. Individuals with hearing loss typically have hearing loss in terms of both of these components. Presently, hearing aids can overcome much of the audibility hearing loss, but are less successful in overcoming the distortion hearing loss. Measures of the distortion component provide audiologists with information that they can (1) use to select an amplification strategy and (2) incorporate into the expectation aspect of audiologic rehabilitation.

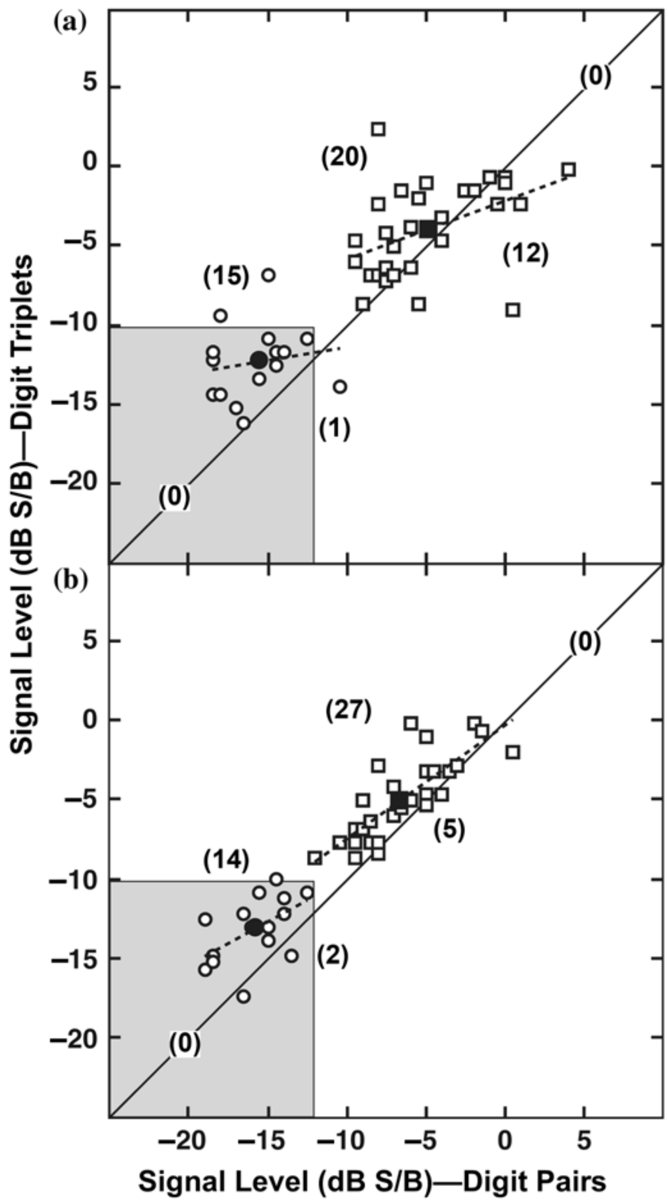

Figure 3.
Bivariate plot of digit-pair data (abscissa) and digit-triplet 50% points (decibel S/B) computed with Spearman-Kärber equation (ordinate) for listeners with normal hearing (○) and the listeners with hearing loss (□): (**a**) data for Trial 1 and (**b**) data for Trial 2. Filled symbols = mean data; dashed lines = linear regressions used to fit data; and numbers in parentheses = number of data points above, on, and below diagonal line, which represents equal performance. Shaded region in each panel represents the 90th percentile based on both trials for listeners with normal hearing. S/B = signal-to-babble ratio.

Psychometric Functions

Figure 4 plots the percent-correct data for the nine digits and the mean of the nine digits (lower right graph) combined from both trials as a function of the presentation level along with the recognition performance in quiet (Q). The numbers at the 50 percent point in each graph indicate the decibel difference between the data from the digit-pair and digit-triplet conditions for the respective groups.

Table 2 lists the 50 percent points (decibel S/B ratios) and the slopes of the functions (in percentage per decibel) at the 50 percent points, which were calculated from the polynomials used to describe the data sets in **Figure 4**. Several features are noteworthy:

- First, the striking feature of the data in the figure and in the table is the heterogeneity of the functions for the various digits both in the locations in the Cartesian coordinates and the slopes of the functions. The heterogeneity, which is observed even with the data for the digit "5" excluded, is similar to that observed in an earlier report [24]. For the listeners with normal hearing, the absolute differences between the functions at the 50 percent points for the digit pairs and digit triplets ranged from 3.1 dB (digit 6) to 0.2 dB (digit 10), with a 2.7 dB difference between the mean functions. Except for the digit "10," the digit pairs required a lower level than the digit triplets for equal recognition performance.
- Second, for the listeners with hearing loss, the differences between the functions for the digit pairs and digit triplets are smaller than the corresponding differences observed with the listeners with normal hearing, ranging from 1.4 dB (digit 8) to 0.1 dB (digit 6), with a 1.1 dB difference between the mean functions.
- Third, the interdigit SDs listed in **Table 2** are smaller for the listeners with hearing loss (1.4 dB and 2.7 dB) than for the listeners with normal hearing (3.5 dB and 4.9 dB), which indicates that the interdigit comparisons are more homogeneous for the listeners with hearing loss. The difference in variability is reflected in the mean functions depicted in **Figure 4** (lower right graph). The more homogeneous data from the listeners with hearing loss produced mean functions that were steeper (8.2%/dB and 7.9%/dB) than the corresponding mean functions for the listeners with normal hearing (6.8%/dB and 6.2%/dB). Perhaps the listeners with normal hearing had more perceptual cues available than the listeners with hearing loss had. The wide "perceptual-cue filter" available to the listeners with normal hearing produced more response options than the narrower perceptual-cue filter available to the listeners with hearing loss. More response options produce more variability. Typically, more variability on a

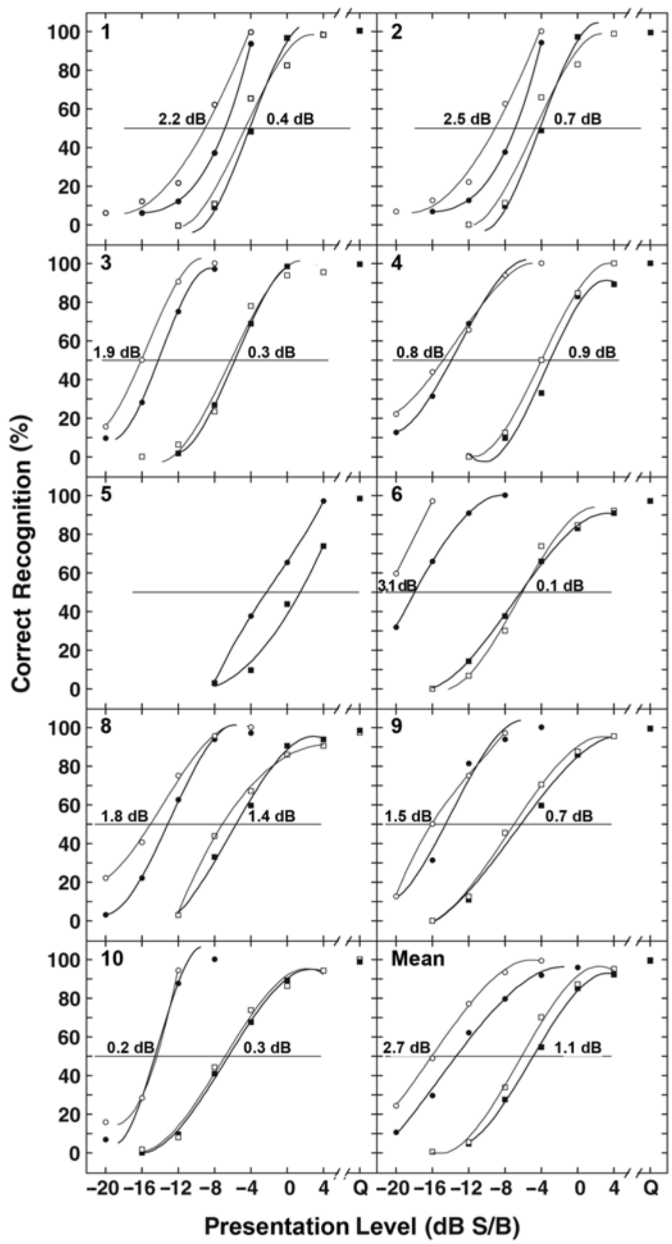

Figure 4.
Psychometric functions for 9 individual digits and for mean data (lower right) derived from data from both trials. Circles = data from listeners with normal hearing, squares = data from listeners with hearing loss, open symbols and light lines = digit-pair data, whereas filled symbols and darker lines = digit-triplet data. Lines through datum points are best-fit, third-degree polynomials used to describe data. Decibel values in each panel = difference between functions for pair and triplet conditions for two groups of listeners. Data for presentations in quiet (Q) also are depicted. S/B = signal to babble ratio.

JRRD, Volume 42, Number 4, 2005

Table 2.
Decibel signal-to-babble ratios at which 50% point was achieved and slopes (%/dB) at 50% points as calculated from polynomials used to describe data in **Figure 5**. Data for each digit (and mean function) are listed for digit pairs and digit triplets for two groups of listeners. Mean ± standard deviation (SD) for various metrics are listed.

Digit	Listeners with Normal Hearing				Listeners with Hearing Loss			
	Digit Pairs		Digit Triplets		Digit Pairs		Digit Triplets	
	50%	Slope	50%	Slope	50%	Slope	50%	Slope
1	–9.0	8.7	–6.8	12.1	–4.5	10.0	–4.1	12.5
2	–18.5	7.0	–16.0	8.4	–8.1	8.2	–7.4	9.9
3	–16.0	10.9	–14.1	12.3	–6.1	9.8	–5.8	10.9
4	–14.7	6.7	–13.9	8.7	–3.9	9.9	–3.0	10.3
5	—	—	–2.2	7.0	—	—	1.4	8.6
6	21.0	9.4	–17.9	8.6	–6.0	8.4	–6.2	6.6
8	–14.9	7.4	–13.1	10.2	–7.0	7.4	–5.6	8.2
9	–16.0	7.4	–14.5	9.1	–6.9	7.0	–6.2	6.4
10	–14.3	15.6	–14.5	15.7	–6.7	7.7	–6.4	7.6
Mean ± SD	–15.6 ± 3.5	9.1 ± 3.0	–12.6 ± 4.9	10.2 ± 2.7	–6.2 ± 1.4	8.6 ± 1.2	–4.8 ± 2.7	9.0 ± 2.1
Mean Function	–16.0	6.8	–13.3	6.2	–6.0	8.2	–4.9	7.9

speech-recognition task is associated with recognition performances by listeners with hearing loss than with performances by listeners with normal hearing, but the variability in this context is intersubject variability, which as expected, was larger for the listeners with hearing loss than for the listeners with normal hearing (**Table 1**). Regardless of the direction of homogeneity (or heterogeneity), the compelling generalization is that word-recognition materials that are equivalent for one group of listeners (hearing loss in this case) are not necessarily equivalent for another group of listeners (normal hearing).

- Fourth, as discussed by Wilson and Margolis [39], the best estimate of a mean slope is determined by averaging the slopes of the individual functions under consideration. The results of this analysis can be seen in **Table 2**, where the mean slopes of the functions are somewhat steeper than the slope of the mean function. With digit triplets, the mean slope of the individual functions for the listeners with normal hearing (10.2%/dB) is 4.0%/dB steeper than the slope of the mean function (6.2%/dB). Similar relations are observed with the other conditions, but to a lesser extent with the listeners with hearing loss. This relation is understandable because the functions for the individual digits from the listeners with hearing loss are more homogeneous than the comparable functions from the listeners with normal hearing. The more homogeneous the underlying functions, the closer the agreement between the mean slopes of the functions and the slope of the mean function.
- Fifth, when we analyzed the data for the digit triplets, omitting the data for the digit "5," the differences between the mean functions for the digit pairs and digit triplets were reduced in half. Thus for the listeners with normal hearing, the 3 dB difference between the digit-pair and digit-triplet functions was reduced to 1.5 dB, with a proportional reduction between the two functions from the listeners with hearing loss. Even a 1.5 dB better performance by the listeners with normal hearing on the digit-pair materials than on the digit-triplet materials was unexpected. One may only speculate about the underlying mechanism. Recall that the listeners with normal hearing had a recognition performance that was equal to the performance of the listeners with hearing loss but at 9 to 10 dB poorer S/B ratios. This result suggests that the listeners with normal hearing were able to take advantage of informational cues that were not available to the listeners with hearing loss, which was discussed previously in terms of perceptual-cue filters. Listening at the poorer S/B ratios as the listeners with normal hearing did was a difficult perceptual/cognitive task. Having to respond to three-digit sequences as opposed to two-digit sequences was an additional cognitive load that resulted in the 1.5 dB difference between performances on the two-digit paradigms.

Digit Position

We evaluated the mean percent correct by presentation position for each group of listeners, which **Table 3** lists. We avoided the influences of ceiling and floor effects in the analysis by only including data from the –8 to –20 dB S/B ratio conditions for the listeners with normal hearing and from the 4 to –12 dB S/B ratio conditions for the listeners with hearing loss. Both groups had equal performance (~60%) on the two positions in the digit-pair paradigm. The data from the digit triplets are more interesting in that presentation position appears to influence performance. As can be seen in **Table 3**, performance by the listeners with normal hearing progressed from 31.6 percent in the first position of a triplet to 55.7 percent in the third position. Likewise, performance for the listeners with hearing loss ranged from 42.8 percent correct in the first position to 58.6 percent in the third position.

Our examination of the circumstances involved with this apparent improvement in performance revealed that the “5” digit was the first digit of the triplet 25 percent of the time, which means that the remaining eight digits accounted for the remaining 75 percent. Thus, the occurrence of “5” in the first position was disproportionate. Recall from **Figure 4** that performance on the “5” digit was poorer than the performances on the other digits, especially by the listeners with normal hearing. When the data for the “5” digit were excluded from the analysis, the performance of the listeners with normal hearing progressed from 40.7 percent in the first position to 55.7 percent in the third position. Similarly, the listeners with hearing loss received the “5” digit 22 percent of the time in the first position of a triplet. The listeners with hearing loss experienced a change in performance from 42.8 percent correct with the “5” data included to 50.2 percent correct with the “5” data excluded. Thus, the performances of both groups improved 8 to 10 percent when the data for the “5” digit were excluded. Even with the data from the “5” digit absent, performance by both groups on the digit presented first in the triplet sequence was 8 to 10 percent poorer than performance on the last digit in the triplet sequence. For both groups of listeners, the linear relation of recognition performances across the three-digit presentation positions did not reflect the “serial-position curve,” which is a “U-shaped curve” [40–42]. Performance on the first stimulus of a sequence (primacy) and on the last stimulus of a sequence (recency) typically is better than performance(s) on presentations between the extremes, which is the U-shaped curve. Perhaps because of the short sequence of three digits, the serial-position curve was not observed; however, a recency effect was observed. More data points and more randomizations of the digits would be helpful in clarifying the differences in performance observed in the three digit positions of the triplets. Any future study involving digit triplets in multitalker babble should use a counterbalance scheme to distribute more evenly the occurrence of the various digits in the three digit positions.

Table 3.
Mean percent correct by digit position obtained by two groups of listeners over indicated signal-to-babble (S/B) ratio ranges, which avoided ceiling and floor data. Data from two trials were combined. Digit triplet data were analyzed both with and without digit “5” included.

Listener Group	Normal Hearing (–8 to –20 dB S/B) Digit Position			Hearing Loss (4 to –12 dB S/B) Digit Position		
	1	**2**	**3**	**1**	**2**	**3**
Digit Pairs	63.7	58.0	—	58.4	59.3	—
Digit Triplets						
With “5”	31.6	49.0	55.7	42.8	57.1	58.6
Without “5”	40.7	50.6	55.7	50.2	58.4	58.6

Objective and Subjective Data

Past attempts to establish a relation between objective and subjective measures of the ability of listeners to understand speech in background noise have not met with much success [43–46]. The data from the current study continue that trend. The median scores on the quiet question were 1 and 3 for the listeners with normal hearing and the listeners with hearing loss, respectively. With the noise question, the median scores were 3.5 and 7.0, respectively. As one would expect, the listeners with normal hearing had less difficulty understanding speech than the listeners with hearing loss. Both groups of listeners reported more trouble understanding speech in noise than in quiet. The responses to the two questions differentiate the two groups of listeners in terms of their perceived ability to understand speech in quiet and in background noise.

Figure 5 presents a bivariate plot of the score on the quiet question (**Figure 5(a)**) and on the noise question (**Figure 5(b)**) compared with the 50 percent points computed with the Spearman-Kärber equation for the digit pairs (open symbols) and the digit triplets (filled symbols) from the listeners with normal hearing (circles) and the listeners with hearing loss (squares). First, the bimodal distribution of the datum points for the two groups of listeners indicates that the individuals with hearing loss do recognize that they have trouble understanding speech both in quiet and in noise. Second, the only organized locus of datum points is for the listeners with normal hearing in association with the quiet question (**Figure 5(a)** lower left). For the remaining conditions (noise question for both listener groups and quiet question for the listeners with hearing loss), the pattern of datum points is unorganized or random, meaning that the subjective scores on the questions are independent of the objective recognition performance obtained on the digits-in-noise task. Although the answers to the two questions differentiate the two groups of listeners, within the group of listeners with hearing loss, the relation between subjective and objective measures of speech understanding in background noise is not substantial.

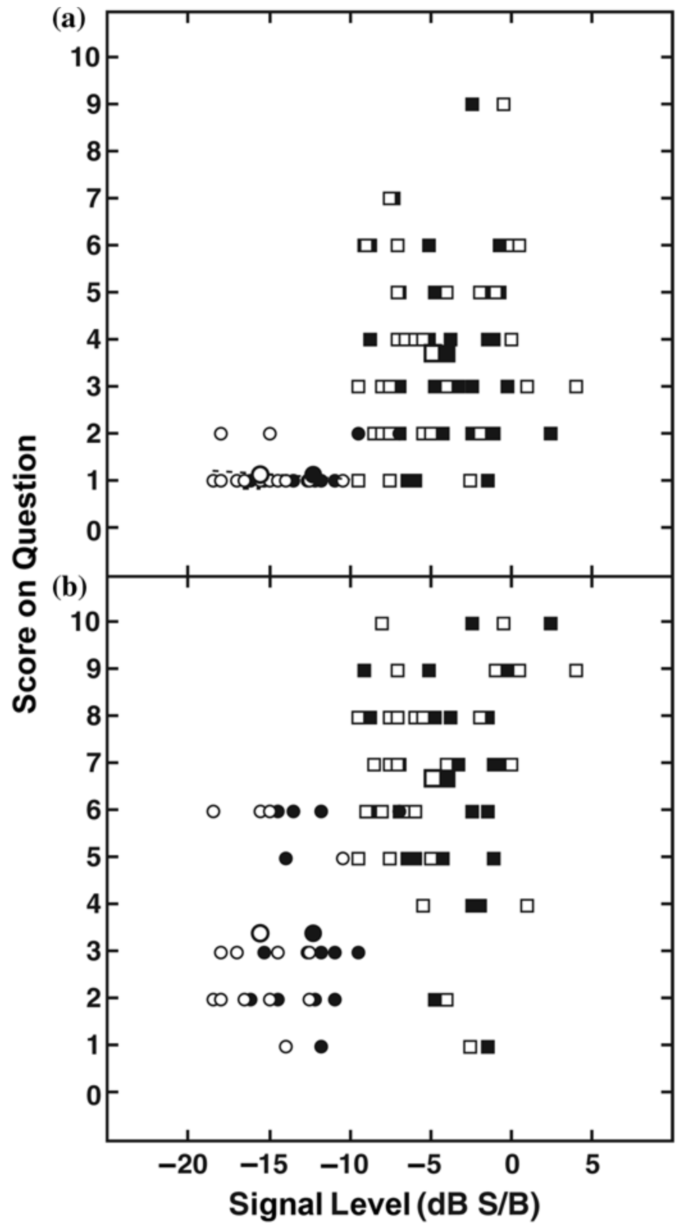

Figure 5.
Bivariate plot of 50% points (dB S/B) computed with Spearman-Kärber equation (abscissa) and scores on (**a**) quiet and (**b**) noise questions (ordinate) for listeners with normal hearing (○) and listeners with hearing loss (□). Open symbols = digit-pair data, filled symbols = digit-triplet data, and S/B = signal-to-babble ratio.

CONCLUSIONS

The digits-in-multitalker babble paradigms are sensitive to the problem that listeners with hearing loss have in understanding speech, especially in background noise. For both digit-pair and digit-triplet paradigms, no overlap existed in the distributions of the 50 percent points for the listeners with normal hearing and the listeners with hearing loss. To achieve equal intelligibility, the listeners with hearing loss required an ~10 dB more favorable S/B ratio than the listeners with normal hearing. For listeners with hearing loss, digit pairs provided essentially the same results that digit triplets provided. Because no appreciable difference exists between performances by the listeners with hearing loss on the digit pairs and digit triplets, either paradigm is appropriate, but clinically the use of the simpler digit-pairs paradigm is suggested.

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