J Am Acad Audiol 28:68–79 (2017)

Interrupted Monosyllabic Words: The Effects of Ten Interruption Locations on Recognition Performance by Older Listeners with Sensorineural Hearing Loss

DOI: 10.3766/jaaa.15154

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Abstract

Background: Two previous experiments from our laboratory with 70 interrupted monosyllabic words demonstrated that recognition performance was influenced by the temporal location of the interruption pattern. The interruption pattern (10 interruptions/sec, 50% duty cycle) was always the same and referenced word onset; the only difference between the patterns was the temporal location of the on- and off-segments of the interruption cycle. In the first study, both young and older listeners obtained better recognition performances when the initial on-segment coincided with word onset than when the initial on-segment was delayed by 50 msec. The second experiment with 24 young listeners detailed recognition performance as the interruption pattern was incremented in 10-msec steps through the 0- to 90-msec onset range. Across the onset conditions, 95% of the functions were either flat or U-shaped.

Purpose: To define the effects that interruption pattern locations had on word recognition by older listeners with sensorineural hearing loss as the interruption pattern incremented, re: word onset, from 0 to 90 msec in 10-msec steps.

Research Design: A repeated-measures design with ten interruption patterns (onset conditions) and one uninterruption condition.

Study Sample: Twenty-four older males (mean = 69.6 yr) with sensorineural hearing loss participated in two 1-hour sessions. The three-frequency pure-tone average was 24.0 dB HL and word recognition was ≥80% correct.

Data Collection and Analyses: Seventy consonant-vowel nucleus-consonant words formed the corpus of materials with 25 additional words used for practice. For each participant, the 700 interrupted stimuli (70 words by 10 onset conditions), the 70 words uninterrupted, and two practice lists each were randomized and recorded on compact disc in 33 tracks of 25 words each.

Results: The data were analyzed at the participant and word levels and compared to the results obtained earlier on 24 young listeners with normal hearing. The mean recognition performance on the 70 words uninterrupted was 91.0% with an overall mean performance on the ten interruption conditions of 63.2% (range: 57.9–69.3%), compared to 80.4% (range: 73.0–87.7%) obtained earlier on the young adults. The best performances were at the extremes of the onset conditions. Standard deviations ranged from 22.1% to 28.1% (24 participants) and from 9.2% to 12.8% (70 words). An arithmetic algorithm categorized the shapes of the psychometric functions across the ten onset conditions. With the older participants in the current study, 40% of the functions were flat, 41.4% were U-shaped, and 18.6% were inverted U-shaped, which compared favorably to the function shapes by the young listeners in the earlier study of 50.0%, 41.4%, and 8.6%, respectively. There were two words on which the older listeners had 40% better performances.

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This work was supported in part by the Rehabilitation Research and Development Service, Department of Veterans Affairs through the Auditory and Vestibular Dysfunction Research Enhancement Award Program (REAP) at Mountain Home.

Portions of this work were presented at the annual convention of the American Auditory Society in Scottsdale, AZ, March 3–5, 2016.

The contents of this paper do not represent the views of the Department of Veterans Affairs or the U.S. Government.

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Conclusion: Collectively, the data are orderly, but at the individual word or participant level, the data are somewhat volatile, which may reflect auditory processing differences between the participant groups. The diversity of recognition performances by the older listeners on the ten interruption conditions with each of the 70 words supports the notion that the term *hearing loss* is inclusive of processes well beyond the filtering produced by end-organ sensitivity deficits.

Key Words: auditory perception, interrupted words, normal hearing for pure tones, sensorineural hearing loss, speech perception

Abbreviations: M = mean; SD = standard deviation

INTRODUCTION

Since the classic studies of Miller (1947) and Miller and Licklider (1950), numerous investigations have studied the effects that interruptions have on speech-recognition performance (e.g., Cherry, 1953; Dirks et al, 1969; Wilson and Carhart, 1969; Powers and Speaks, 1973; Howard-Jones and Rosen, 1993; Wang and Humes, 2010; Wilson et al, 2010; Kidd and Humes, 2012). Many variables have been investigated, including various combinations of interruption rate, duty cycle, regular versus irregular interruptions, and hearing status. One variable that has not been examined until recently is the manner in which the interruption pattern is temporally applied to the speech signal, which for a variety of reasons is best examined with single words. [Note: Huggins (1964) examined the recognition performance on complementary halves of light fiction passages that were delivered separately to 20 young listeners. The results indicated equivalent performances on the halves (Figure 4, p. 1061), which is understandable given the number of contextual cues available in each of the passages.] In this interrupted word paradigm and similar to Grosjean's (1980) gated speech protocol, the interruption pattern is synchronized digitally with the word onset and can be systematically varied with precision. The interruption paradigm (10 interruptions/sec and 50% duty cycle), which alternates 50-msec *on-segments* of the speech signal and 50-msec *off-segments* of silence, initially was used with 70 monosyllabic words to study the following set of complementary halves: (a) the first 50-msec segment was an *on-segment* that coincided with word onset, *0-msec onset condition*; and (b) the first 50-msec segment was an *off-segment* that coincided with word onset, *50-msec onset condition* (Wilson, 2014). For both young listeners with normal hearing for pure tones and older listeners with sensorineural hearing loss, the complementary halves produced significantly different results with 10–17% better recognition performance on the 0-msec condition than on the 50-msec condition. These findings substantiated the hypothesis that the temporal location of the interruption pattern influenced recognition performance. In a concurrent study but with a different set of monosyllabic words, the results were replicated with the complementary halves on young adult listeners but not on older listeners with sensorineural hearing loss, who produced equal performances on the two onset conditions (Wilson and Irish, 2015). The lack of a recognition-performance difference between the two onset conditions with the older listeners in the Wilson and Irish study was attributed to the use of only those words for which recognition performance by the younger listeners was >58% correct, which created a bias with the interrupted words.

Subsequently, the issue of interruption pattern location in the target word was explored in detail for 24 young adults with so-called *normal hearing* for pure tones by incrementing the temporal location of the interruption pattern in 10-msec steps, which produced ten onset conditions from 0 to 90 msec (Wilson and Hamm, 2015). From that study, two shapes of the psychometric functions across the ten sequential onset conditions emerged for 66 of the 70 words, flat (32 words) and U-shaped (34 words). The current study extended this protocol to 24 older listeners (>60 yr) with mild to moderate sensorineural hearing loss with the expectation of finding poorer overall performances by the older listeners, which is a relation typically observed with all speech perception tasks. The general question was, do older listeners with sensorineural hearing loss process interrupted words in the same manner as younger adults with normal hearing, but simply with a dc shift toward poorer performance, or does the older auditory system process words in a different manner from that used by younger adults? Beyond the poorer overall performance expected by the older listeners, the question was, in comparison to recognition performances by young adults with normal hearing on the individual words, how do older individuals with sensorineural hearing loss perform on the individual interrupted words? Specifically in comparison to the performances on the same materials by the younger listeners, are the shapes of psychometric functions across the ten onset conditions for the individual words by older listeners with sensorineural hearing loss (a) the same but displaced to lower performance levels, that is, a dc shift; (b) totally different; or (c) a combination of both. The latter two possibilities would support the notion that older individuals with sensorineural hearing loss have "hearing impairment" that extends beyond the cochlea.

METHODS

Materials

The stimuli were 70 monosyllabic words each of which was interrupted (10 interruptions/sec and 50% duty cycle) with ten interruption patterns referenced to the onset of the target word using 10-msec increments from 0 to 90 msec. With these interruption parameters, the interruption cycle is 100 msec with the signal alternately *on* 50 msec and *off* 50 msec. The development of these interrupted materials, which were from the Northwestern University Auditory Test No. 6 (Tillman and Carhart, 1966; Department of Veterans Affairs, 2010), is described in detail by Wilson and Hamm (2015). The mean word duration was 487 msec (standard deviation [SD] = 77 msec) that provided most words four to five glimpses when interrupted. A schematic of five of the ten interruption patterns, which are referenced to 0-, 20-, 40-, 60-, and 80-msec onset times, is shown in Figure 1. In the figure the initial on-segments of the interruption cycles coincide with the onsets of the target words. For the remaining onset conditions, the on-segment of the interruption cycle is offset from the word onset by a multiple of 10 msec. The onsets and offsets of the on-segments of the interruption cycle were not shaped, as in a previous study there was no significant difference in recognition performances on interrupted words with unshaped or shaped ($\cos^2$) on-segment onsets and offsets (Wilson, 2014). The test materials also included the 70 words uninterrupted and a list of 25 interrupted Northwestern University Auditory Test No. 6 words by the same speaker (0 msec onset condition) not included in the 70-word list, which were used as practice lists, one for each of the two test sessions. For each participant, a unique randomization of the 700 interrupted words (70 words by ten onset conditions) and the 70 uninterrupted words was made, along with two randomizations of the 25 interrupted words used for practice. The materials were recorded on compact discs as 33 tracks with 25 words/track. All stimuli used the carrier phrase *Say the word* ____, which was interrupted in synchrony with the interrupted target word.

Participants

The 24 older participants with sensorineural hearing loss met the following inclusion criteria: (a) males with English as the first language between 60 and 80 yr of age (mean [M] = 69.6 yr, SD = 5.2 yr), (b) 500-Hz threshold ≤30 dB HL (ANSI, 2010), (c) 1000-Hz threshold ≤40 dB HL, (d) a three-frequency (500, 1000, and 2000 Hz) pure-tone average between 20 and 40 dB HL (M = 24.0 dB HL, SD = 4.3 dB, range = 20–33 dB HL), and (e) clinic word recognition ≥80% correct (Department of Veterans Affairs, 2010). The mean high-frequency pure-tone average (1000, 2000, and 4000 Hz) was 37.6 dB HL (SD = 6.9 dB, range = 22–48 dB HL). The mean audiogram for the 24 test ears is given in Figure 2 with the individual audiometric data listed in Supplemental Table S1, supplemental to the online version of this article.

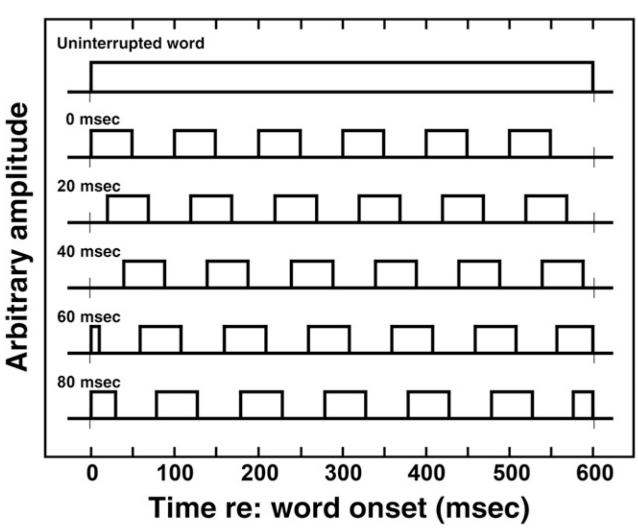

Figure 1. An abbreviated schematic of the interrupted word paradigm showing only the even onset conditions (i.e., 10-, 30-, 50-, 70-, and 90-msec conditions are not shown). The stimulus conditions are indicated along the left side of the figure with the onset and offset of the target word indicated by the short, thin, vertical lines on each baseline (modified from Wilson and Hamm, 2015, Figure 1, p. 672).

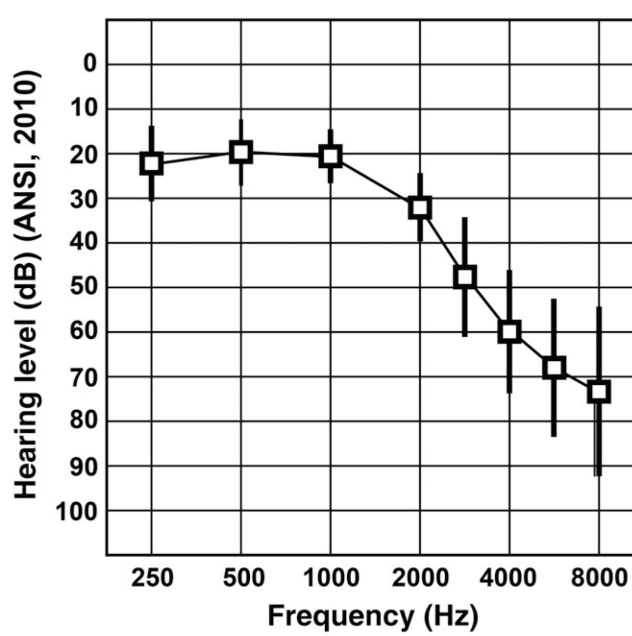

Figure 2. The mean audiogram for the test ear of the 24 older listeners with sensorineural hearing loss is shown along with ±1 SD.

Procedures

Each participant signed the IRB consent forms in the first of two 1-hr sessions that were separated by 1–14 days (M = 6.8 days, SD = 3.7 days). In Session 1, the participants had their pure-tone thresholds verified and were instructed on the test protocol, paying particular attention to the interrupted word paradigm that used a schematic as a visual aid (see Supplemental Figure S1). The first of the 25-word practice list randomizations was presented followed by fifteen 25-word lists of interrupted materials. Following the first 100 interrupted test words a brief break was provided and the participants whose mean recognition performance was <40% correct were terminated from the experiment; two participants failed to meet this final inclusion criterion even though both had word-recognition performance in quiet of ≥80% correct. The purpose of this additional inclusion criterion was to avoid subjecting those participants to the frustrations associated with the difficult listening task and prolonged periods of incorrect responses. An additional break was provided after the eighth word list. In Session 2, pure-tone thresholds at 500, 1000, and 2000 Hz were rechecked to ensure no change in hearing sensitivity and the second randomization of the 25-word practice list was given followed by 13 lists of interrupted words with breaks provided after the 7th and 13th test lists. Finally, the 70 words uninterrupted were presented.

The words were reproduced by a compact disc player (Sony Model CDP-CE375; Tokyo, Japan) and fed through an audiometer (Grason-Stadler Model 61; Eden Prairie, MN) to a TDH-50P earphone encased in a MX-41/AR cushion; the nontest ear was covered with a dummy earphone. The calibration of the interrupted words was the same as the calibration of the uninterrupted words, that is, no compensation was made for the silent segments of the interruption cycle. The words were presented in quiet at 80 dB SPL with the test ear alternated among the participants. Testing was conducted in a double-wall sound booth and the verbal responses from the participants were recorded in a spreadsheet.

RESULTS AND DISCUSSION

The mean overall recognition performance by the 24 older listeners with sensorineural hearing loss for the 700 interrupted words was 63.2% with SDs of 24.9% across words (n = 700 [70 words by ten onset conditions]) and 11.3% across participants (n = 240 [24 participants by ten onset conditions]). The mean recognition performances on the ten interruption conditions and on the uninterrupted condition are listed in Table 1 along with the SDs for both words and participants. In Figure 3A, the mean data and the SDs for the words are depicted (squares) with the dashed line representing the mean performance on the uninterrupted words. For comparison, the mean performances by 24 young listeners with normal hearing for pure tones are shown for the same onset conditions (gray circles; Wilson and Hamm, 2015). (Throughout the Results and Discussion section, unless otherwise noted, reference to interrupted word data on young adults with normal hearing is from Wilson and Hamm [2015].) In Figure 3B, the data for the individual participants in each onset condition are shown (small circles) against a backdrop of the mean data. Several relations can be noted from the data in the table and figure. First, the mean overall recognition performance by the older listeners on the ten interruption conditions (63.2%) was 27.8% poorer than on the uninterrupted condition (91.0%) with the difference ranging from 21.7% to 33.1% at the 80-msec and 40-msec onset conditions, respectively. Second, the older listener performances on the ten onset conditions (M = 63.2%; SD = 24.9%) were on average 17% poorer than the younger listener performances (M = 80.4%; SD = 22.8%) on the same materials and conditions, which was a significant difference [$t_{(9)}$ = 37.2, $p < 0.001$]. The earlier Wilson study (2014) with the 0- and 50-msec conditions of the same interrupted materials produced a 12% difference between groups of younger and older listeners. Third, variability was over twice as much among the 70 words (average SD = 24.6%) than among the 24 participants (average SD = 10.6%), which is similar to the variability observed among the younger listeners by Wilson and Hamm (words, SD = 22.2%;

Table 1. Mean % Correct Word Recognition Obtained from 24 Older Adults with Sensorineural Hearing Loss

	Onset Condition (msec)											
	0	10	20	30	40	50	60	70	80	90	Mean	Uninterrupted
Mean	68.1	62.1	58.3	60.1	57.9	58.0	63.1	66.3	69.3	68.6	63.2	91.0
SD (words)	23.2	24.6	26.2	25.5	28.1	26.6	23.8	23.9	22.1	22.6	24.6	16.1
SD (participants)	9.8	10.8	10.0	10.0	10.2	9.2	11.1	12.8	11.2	11.1	10.6	5.1
Maximum (words)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0		100.0
Minimum (words)	8.3	4.2	4.2	0.0	4.2	0.0	8.3	0.0	8.3	8.3		16.7
Range (words)	91.7	95.8	95.8	100.0	95.8	100.0	91.7	100.0	91.7	91.7		83.3
Mean (normal hearing)*	86.2	80.4	77.4	75.8	73.6	73.0	79.8	83.7	85.9	87.7	80.4	NA

Notes: NA = not available.

*From Wilson and Hamm, 2015 (Table 1, p. 673).

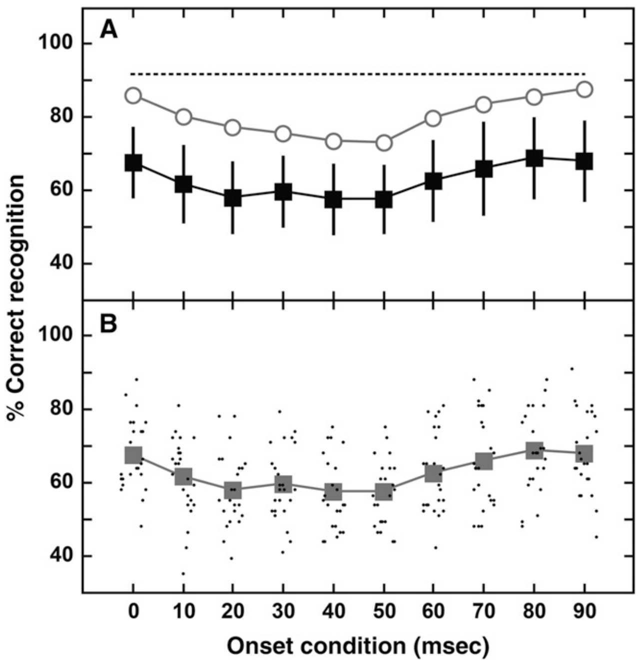

Figure 3. (A) The mean recognition performances on the ten onset conditions (squares) and on the uninterrupted condition (dashed line) obtained from the 24 older listeners with sensorineural hearing (squares). The vertical lines indicate ±1 SD for the 24 participants. The values for the individual words are listed in Supplemental Table S2. The mean data for the same materials obtained from 24 young listeners with normal hearing for pure tones also are shown (circles; Wilson and Hamm, 2015). (B) The mean recognition performances on the ten onset conditions by the 24 older listeners with sensorineural hearing (small filled circles) and the corresponding mean data shown in (A). Individual participant data are listed in Supplemental Table S7.

participants, SD = 7.8%). In Figure 3B, the mean performances by each of the 24 participants illustrate the variability in each of the ten onset conditions. Fourth, the mean functions for both groups of listeners, which are most easily observed in Figure 3, are characterized by better performances at the extremes of the onset conditions (0, 10, 80, and 90 msec) than at the middle onset conditions (30, 40, 50, and 60 msec). This finding, which is not as dramatic with the older listeners as with the younger listeners, supports the notion for a number of words that the information contained in the initial consonant is a major contributor to the intelligibility of that word.

Following an arcsine transformation of the data (Studebaker, 1985), a repeated-measures analysis of variance with one within-participants variable (0- to 90-msec onset conditions) was conducted. The analysis of variance indicated significant recognition performance differences among the ten onset conditions [$F_{(9,207)} = 26.80$, $p < 0.001$]. There were 45 possible pairs of onset conditions, the mean absolute differences between each pair are listed in the lower left triangle of data in Table 2 with the p values from the post hoc t-tests with Bonferroni corrections listed in the upper right triangle of data. In the table the numbers in bolded font indicate significant differences at the $p \leq 0.001$ level, of which there were 19 pairs (42% of the comparisons). At the $p \leq 0.01$ level the number of significant difference increases to 23 (51% of the comparisons). Whichever significance level is used, there are a number of significant pair differences among the performances on the ten onset conditions and the pattern of significant differences is similar to the pattern of differences observed on young normal listeners by Wilson and Hamm (2015, Table 2, p. 673). Although the mean function and the differences among the ten conditions provide a general overview of the underlying recognition performances, the main interest of the experiment was in the psychometric functions obtained on the individual 70 words in terms of the shape and location of the functions in the percent correct domain and how the individual functions for the 70 words compare with the functions for the same materials obtained earlier from young adults with normal hearing.

The shape of the psychometric function in which onset condition was the independent variable was evaluated further by examining the functions for each word, the means for which are listed in Supplemental Table S2, and illustrated in Supplemental Figures S2–S8. In the Wilson and Hamm (2015) study, categorizing the psychometric functions for each word into *flat* and *U-shaped* categories was accomplished visually as almost all of the functions were systematic. The word functions established on the listeners with sensorineural hearing loss in the current study were somewhat systematic but often compounded with a noise component. After several attempts, an arithmetic procedure evolved to categorize the shapes of the word functions that involved the difference between (a) the mean performance at the function extremes (0-, 10-, 80-, and 90-msec conditions) and (b) the mean performance in the middle of the function (30-, 40-, 50-, and 60-msec conditions). Based on the difference between these two means, three categories emerged: *flat functions* defined as a mean difference of ±8%, *U-shaped functions* defined as a mean difference of >8%, and *inverted U-shaped functions* defined as a mean difference of <−8%. The words in each of the three function shape categories are listed in Supplemental Tables S3–S5.

The mean functions for the words in each of the three shape categories are shown in Figure 4. In the figure the mean data for the older listeners with sensorineural hearing loss are shown in the right panels (filled circles) along with ±1 SDs (vertical lines), with the corresponding mean data from young adults with normal hearing shown in the left panels. For comparative purposes, (a) the mean data from the other group of listeners are depicted as gray circles without ±1 SD lines and (b) for the young listeners the mean data from the flat and U-shaped categories from the visual analyses in

Table 2. Absolute Differences between Mean % Correct Performances on 45 Pairs of Onset Conditions

	Onset Condition (msec)									
Onset Condition	0	10	20	30	40	50	60	70	80	90
0		**0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	0.010	0.999	0.999	0.999
10	6.01		0.854	0.999	0.486	0.425	0.999	0.801	0.002	**0.001**
20	**9.82**	3.81		0.999	0.999	0.999	0.026	0.003	**< 0.001**	**< 0.001**
30	**8.04**	2.02	1.79		0.999	0.999	0.859	0.024	**< 0.001**	**< 0.001**
40	**10.24**	4.23	0.42	2.20		0.999	**0.001**	**< 0.001**	**< 0.001**	**< 0.001**
50	**10.06**	4.05	0.24	2.02	0.18		0.004	**0.001**	**< 0.001**	**< 0.001**
60	5.00	1.01	4.82	3.07	**5.24**	5.06		0.999	**< 0.001**	**< 0.001**
70	1.79	4.23	8.04	6.25	**8.45**	**8.27**	3.21		0.763	0.999
80	1.19	7.20	**11.01**	**9.23**	**11.43**	**11.25**	**6.19**	2.98		0.999
90	0.48	**6.49**	**10.30**	**8.51**	**10.71**	**10.54**	**5.48**	2.26	0.71	

Note: Absolute differences are listed in the lower-left triangle of data, corresponding p values for the differences (arcsine transformed) from post hoc t tests with Bonferroni corrections are listed in the upper-right triangle of data. Values in boldface indicate significant differences of $p \leq 0.001$.

the Wilson and Hamm (2015) study are shown as shown as Xs in the two upper left panels. The numbers to the right of the various functions are the number of words that were included in that category for that particular group of listeners, e.g., there were 35 words in the flat category for the young adults with normal hearing. The mean functions for the two listener groups in each panel, though displaced, are remarkably similar in shape. A summary of the number of functions in the three shape categorizations is provided in Table 3, which includes the current data and the re-evaluation with the arithmetic algorithm of the Wilson and Hamm data from 24 young adults. In the table both the number (n) and percent (%) of words in each category and the number of words in each category that the two groups of listeners had in common are included. Seven relations in the table and in Figure 4 are noteworthy. First, 80–90% of the function shapes are categorized as either flat (50% and 40% for the two listener groups were flat) or U-shaped (41.4% for both groups). Second, for the young listeners with normal hearing, the number of words in the flat and U-shaped categories (35 and 29, respectively) are not substantially different from the previously used visual categorization (32 and 34, respectively) in the earlier study. Third, the young listeners with normal hearing had 35 flat functions, whereas the older listeners only had 28 flat functions; 17 words with flat functions were common to the two listener groups. Fourth, both participant groups had 29 words with U-shaped functions, 19 of which were common. Fifth, the new category function shape that emerged, the inverted U-shape, had 6 and 13 of the word function shapes for the younger and older listeners, respectively, of which five words were common. Sixth, overall 41 of the 70 words (58.6%) were in the same shape categories for both groups of listeners. Finally, the mean differences between the two functions in each of the three shape categories are substantially different (Table 4), varying from 9.1 dB (U-shaped) to 25.4 dB (flat) with the inverted U-shape in between the two at 13.5 dB. Except for ceiling effects that limit variability, the reasons for these differences are unclear.

It was insightful to examine the mean maximum, minimum, and range of performances that were observed across the ten onset conditions with each word. These data are listed in Supplemental Table S6, for the 24 young adults with normal hearing (leftmost data columns from Wilson and Hamm, 2015) and for the 24 older listeners with sensorineural hearing loss from the current study (rightmost columns). For the older group, the overall mean of the maximum performances on the 70 words was 81.3% correct, whereas the overall mean of the minimum performances was 41.4% correct. As a point of reference, these corresponding mean maximum and minimum on the 24 young adults with normal hearing were 93.8% and 61.4% correct, respectively. With the older adults in the current study, the range of mean recognition performances across the 700 interrupted word conditions was 100% with six words having 100% correct at one or more of the ten onset conditions (*chair*, *cool*, *dog*, *food*, *good*, and *red*) and three words having 0% correct at one of the ten onset conditions (*dab*, *shack*, and *sheep*). In comparison, the younger listeners had 43 words on which recognition performance was 100% correct at one or more of the ten conditions and two words (*date* and *deep*) with a 0% correct at one or more conditions; one word, *far*, had a performance range of 0% and one word, *date*, had a 100% range. With the data from the older listeners, the extremes of the performance ranges were 83.3% correct (*gun*) and 4.2% correct (*food*). These substantial ranges of recognition performance are directly related to the occurrence of the interruptions at different locations in the target words.

From these limited interrupted word data, which at best should be considered somewhat gross measures, one can only speculate on the reasons the words have the variety of psychometric function shapes that are exhibited. There are several scenarios that might

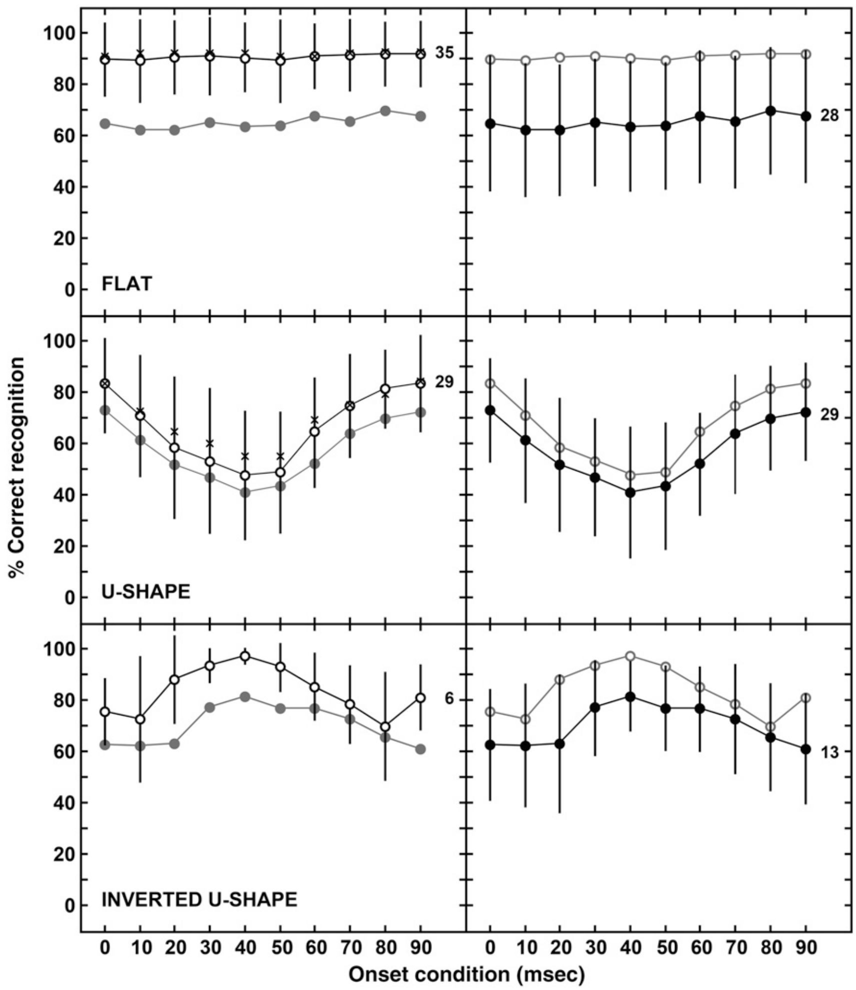

Figure 4. The mean functions across the onset conditions for the 70 words are shown for the three categories of function shapes (flat, U-shaped, and inverted U-shaped). Both the data from the current study with older listeners (filled circles) and from the earlier Wilson and Hamm study (2015) with young listeners (open circles) were established using the shape criteria described in this paper. The Wilson and Hamm study used a visual algorithm to define the flat and U-shaped functions, which are depicted with ×s (upper left panels). The horizontal adjacent panels show basically the same data with ±1 SD from the Wilson and Hamm study given in the left panels and ±1 SD from the current study in the right panels. The number of words involved in the mean calculation is noted to the right of the respective functions.

account for the intelligibility of these interrupted words. Throughout a word with a flat function there are cues that contribute uniformly to intelligibility, which make the word relatively immune to the effects of the interruption locations. Additionally, there are segments in the word from either the consonants or the vowel that are longer than 50 msec that singularly or collectively could provide ample cues to accomplish intelligibility. The words with U-shaped functions appear to be heavily dependent on the cues for intelligibility that are contained in the first 50 msec or so of the initial consonant. As less and less of the first critical 50 msec is available, recognition performance declines, then and as more and more of the first 50 msec becomes available

Table 3. Number and Percent of Words in Each Category of Function Shape from a Previous Study and from the Current Study, Both with 24 Listeners

Function Shape Category	Normal Hearing*		Hearing Loss		Common Words**
	n	%	*n*	%	
Flat	35	50.0	28	40.0	17
U-shape	29	41.4	29	41.4	19
Inverted U-shape	6	8.6	13	18.6	5

Notes: *From Wilson and Hamm (2015), Supplemental Table S1.
**Number of common words in the two groups of listeners.

Table 4. Overall Mean % Correct for Ten Onset Conditions in Three Function Shape Categories

Function Shape Category	Normal Hearing* Mean (dB HL)	Hearing Loss Mean (dB HL)	Difference (dB)
Flat	91.0	65.6	25.4
U-shape	66.8	57.7	9.1
Inverted U-shape	83.6	70.1	13.5

Note: These data are illustrated in Figure 4.
*From Wilson and Hamm (2015), Supplemental Table S1.

recognition performance improves. Finally, the words with the inverted U-shaped functions seem to be dependent more on either the latter segment of the initial consonant or the early segment of the vowel for improvement in intelligibility. Again, the issue is in determining what cues in each utterance of a word are critical in providing intelligibility.

It is instructive to examine the psychometric functions for the individual words, which are listed in Supplemental Table S2 and illustrated in Supplemental Figures S2–S8. A representative sample of ten of these functions is depicted in Figure 5 for the young listeners with normal hearing (open circles) and for the older listeners with sensorineural hearing loss (filled circles). The dashed line in each panel is the percent correct obtained by the older group on the uninterrupted words. In three of the panels, the function pairs are very similar both in terms of performance level and shape (*good*, *tire*, and *date*), five pairs were similar in shape but displaced from one another (*witch*, *gaze*, *beg*, *dab*, and *young*), one pair had different shape categories (*chair*), and one pair was totally different with performances by the older group better than performances by the younger group (*calm*). This reversal in performances by the two listener groups also occurred in one other word (*half*), which is shown in Supplemental Figure S8. The differences in performances on these two words are not just a few percent, but rather are on the order of about 40% across the ten onset conditions. In retrospect from the Wilson (2014) study, *calm* and *half* also exhibited 31% better performances by the listeners with hearing loss than by the younger listeners with normal hearing. Perhaps this relation between listener groups suggests that for some words older listeners with sensorineural hearing loss use different cues for word recognition than those cues used by younger listeners with normal hearing. As can be seen in Supplemental Figures S3–S8, several words had one or more datum points at which recognition performance was minimally better by the older listeners with sensorineural hearing loss. Of the 700 interruption word conditions, 546 conditions (78.0%) demonstrated on average 25.1% better performances by the young listeners with normal hearing than by the older listeners, 100 conditions (14.3%) had 17.7% better performances by the older listeners (20 of which were from two words, *calm* and *half*), and 54 conditions (7.7%) had equal performances. Although many of these reversals in recognition performances by the two groups of listeners are minimal and probably reflect "noise" in the data, for some unknown reasons, there are a few circumstances in which older individuals with hearing loss have substantially better word-recognition performances than younger individuals with normal hearing.

In addition to the similarities and differences in the word functions between the older listeners in the current study and the younger listeners in the previous study, there were similarities and differences between the psychometric functions for the individual listeners in the two groups. The psychometric functions for the 24 individual participants in the current study are depicted in Supplemental Figures S9–S11, with a representative sample of functions for four listeners shown in Figure 6. In each panel of the figures, the individual mean data for the ten onset conditions are given (circles) along with the mean recognition performance for the participant on the uninterrupted words (dashed line); for comparison, the mean data from the young adult listeners in the Wilson and Hamm (2015) study are indicated (gray squares). The individual performances by the older listeners ranged from equivalent to the mean performances by the younger listeners (e.g., Subject 4) to performances by the older listeners that were 20–25% below the mean performances by the younger listeners (e.g., Subject 1). To quantify the degree to which the recognition performances by the individuals in the two listener groups were intermingled, (a) the mean performances on the ten onset conditions by each individual were determined, and (b) ± 1 SD was used with each group distribution of the mean performances to define the "normal" ranges of performances for each of the two groups of listeners. For the younger listeners with normal hearing, ± 1 SD extended from 73.5% to 87.3% correct (M = 80.4%), whereas for the older listeners with sensorineural hearing, loss ± 1 SD was from 53.4% to 73.0% (M = 63.2%). There were three listeners in the younger group whose performances (61.1%, 68.6%, and 69.9%) were within the ± 1 SD range of performances by the older listeners and there were six listeners in the older group whose performances (73.9%, 75.6%, 76.0%, 76.1%, and 82.1%) were within the ± 1 SD range of performances by the younger listeners. Finding some older individuals with sensorineural hearing loss exhibiting performances similar to the performances by younger listeners with normal hearing on an interrupted speech task was somewhat of a surprise. Likewise, there were some younger listeners in the Wilson and Hamm study whose recognition performance on the same interrupted speech task was degraded just as it was with some of the older listeners in the current study. These relations simply illustrate the individual nature of what we term *normal hearing* and *hearing loss* and emphasize the importance of recognizing the different domains of auditory function and their manifestations/interactions with one another.

One other aspect of the data from the 24 older listeners is of interest, *viz*., the comparison of the individual performances on the words interrupted and the words uninterrupted. The relation between these two variables is presented as a bivariate plot in Figure 7 with the mean performance on the words in the ten

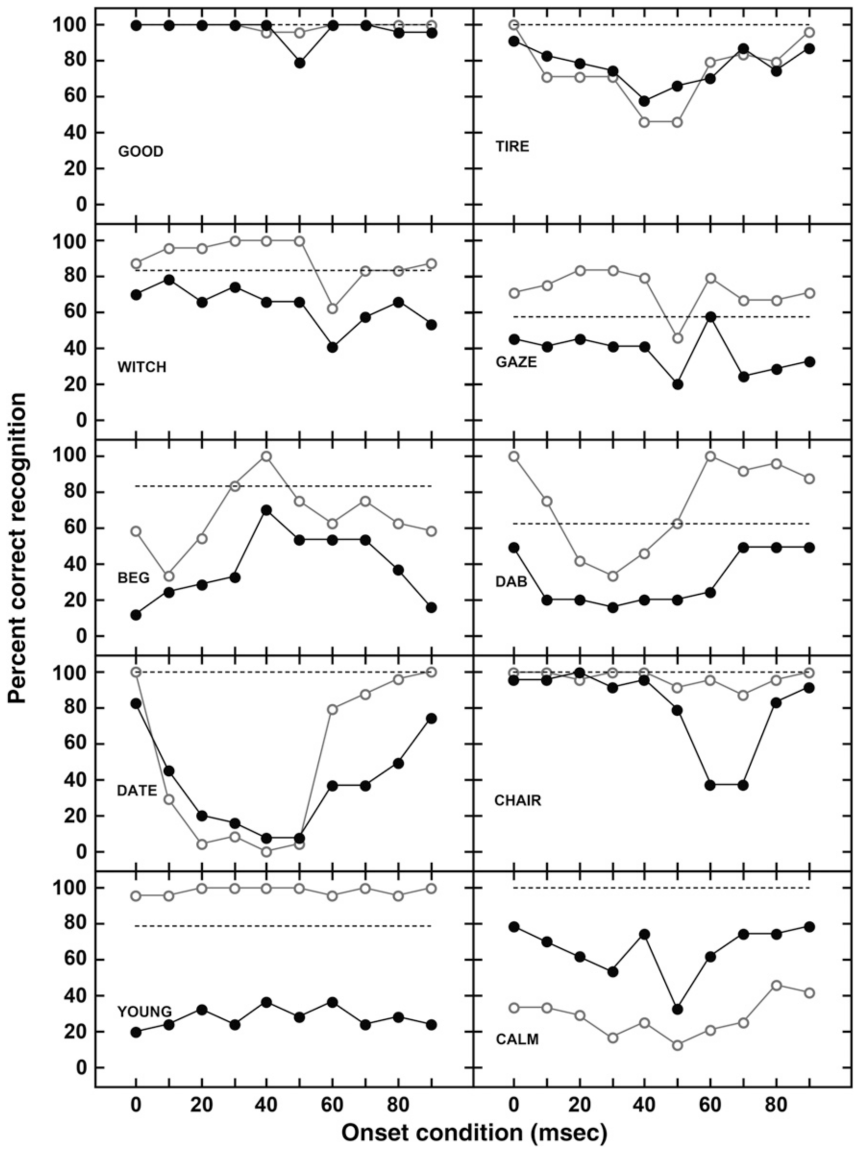

Figure 5. The mean recognition performance functions across the ten interrupted onset conditions of ten representative monosyllabic words obtained from 24 young listeners with normal hearing for pure tones (open circles; Wilson and Hamm, 2015) and from 24 older listeners with sensorineural hearing loss in the current study (filled circles). Dashed lines represent the mean recognition performance by the older listeners on the uninterrupted words. The % correct recognition for all 70 words is listed in Supplemental Table S2 and shown in Supplemental Figures S2–S8.

interruption conditions on the ordinate and the mean performance on the uninterrupted words on the abscissa for each participant (the individual participant data are listed in Supplemental Table S7). The group percent correct means, which are depicted with the large filled circle in Figure 7, were 63.2% (SD = 9.8%) and 91.0% (SD = 5.1%) for the interrupted and uninterrupted conditions, respectively, which is a 27.8% difference. The data indicate a direct relation between the recognition performances on the interrupted and uninterrupted conditions with better performance on the uninterrupted condition being reflected in better performance on the interruption conditions (r = 0.68). As recognition performance on the uninterrupted condition increases, the difference between performances on the uninterrupted and interrupted conditions decreases. This phenomenon is reflected in the larger ranges of performances on the interrupted condition (36.3%) than on the uninterrupted condition (17.1%). Because the range of recognition performances was much larger for the interrupted condition than for the uninterrupted condition, one interpretation is that interrupted words amplify minor recognition performance deficiencies observed in uninterrupted words presented in quiet, but this is a very individual matter.

In a previous study, two of the onset conditions used in the current study (0 and 50 msec) were evaluated on 12 older individuals with sensorineural hearing loss (Wilson, 2014). A comparison of the results from that

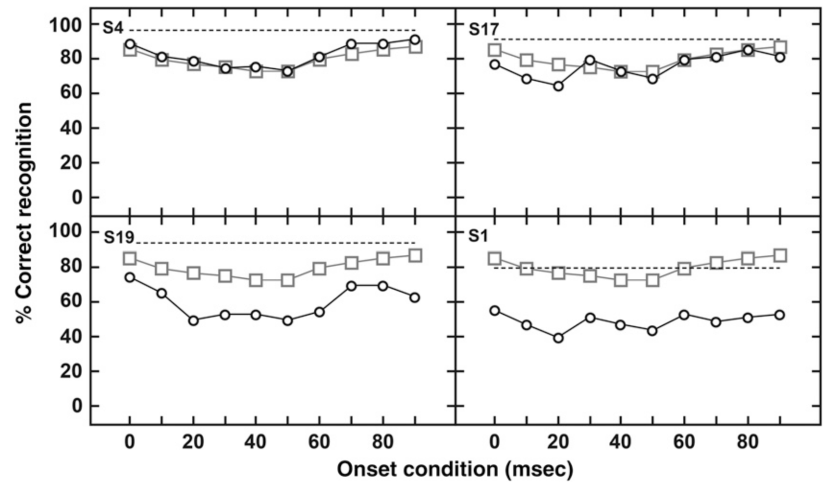

Figure 6. The mean recognition performance functions across the ten interrupted onset conditions by four representative listeners with sensorineural hearing loss (circles); the dashed line represents the mean recognition performance by the respective listeners on the 70 words uninterrupted. The mean function obtained from 24 young listeners with normal hearing for pure tones (squares; Wilson and Hamm, 2015) is shown for reference purposes. The % correct recognition for all 24 participants is listed in Supplemental Table S7 and shown in Supplemental Figures S9–S11.

study and the current study can be made in the two bivariate plots in Figure 8. The percent correct for the 12 listeners is on the ordinate and the percent correct for the 24 listeners is on the abscissa. The mean group performances on each of the two conditions were similar (0-msec condition [n = 12, 70.1% and n = 24, 68.1%, r = 0.63]; 50-msec condition [n = 12, 60.4% and n = 24, 58.0%, r = 0.65]) with better recognition performance (a) on the 0-msec condition than on the 50-msec condition, and (b) by the 12 listener group than by the 24 listener group, which simply reflects a small group difference of about 2%. Both of the correlation coefficients indicate a moderate linear relation. The relations shown in Figure 8 demonstrate good convergent validity of the test paradigm.

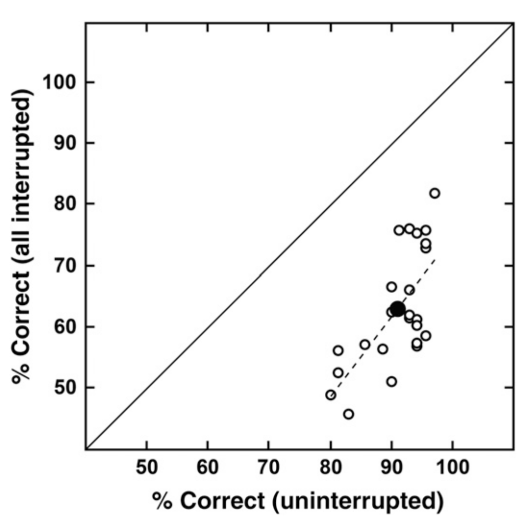

Figure 7. The % correct for each of the 24 older listeners with sensorineural hearing loss on the average of the ten interruption conditions (ordinate) and the uninterrupted condition (abscissa). The large filled circle represents the means and the dashed line is the linear regression used to describe the data (y = −55.3024 + 1.3017x; R^2 = 0.46). For graphic clarity, the data in the figure were jittered using a random, additive algorithm from −2.1 to 2.1 in 0.2 steps. The data for each participant are listed in Supplemental Table S7.

Oftentimes slight learning/practice effects can be observed in word-recognition performances when more than one test session is involved (Miller et al, 1951). In the current study, data collection involved two test sessions separated by 1–14 days, which provided an opportunity to see what, if any, changes occurred between test sessions with the anticipation that some improvement in performance would be observed in the second session. Here, the anticipation is that over time the participants learn to listen to the degraded speech signal, which is reflected in an improvement in performance. The current study provides two measures made over time, the practice lists of the same 25 words that were administered at the beginning of each session, and the mean performances for the interruption conditions given in each test session. The data for the two practice lists of 25 words are shown in Figure 9 with Session 1 on the ordinate and Session 2 on the abscissa (the practice data are listed in Supplemental Table S8). The data demonstrate consistency on the individual words between sessions with no appreciable change in performance between the two sessions. Overall, on the same practice words (large, filled circle), 56.0% were correct in Session 1 and 53.8% were correct in Session 2, with 12 words having better performances in Session 1 and eight words having better performances in Session 2. Performances were also compared on the interrupted materials presented in the two sessions. The

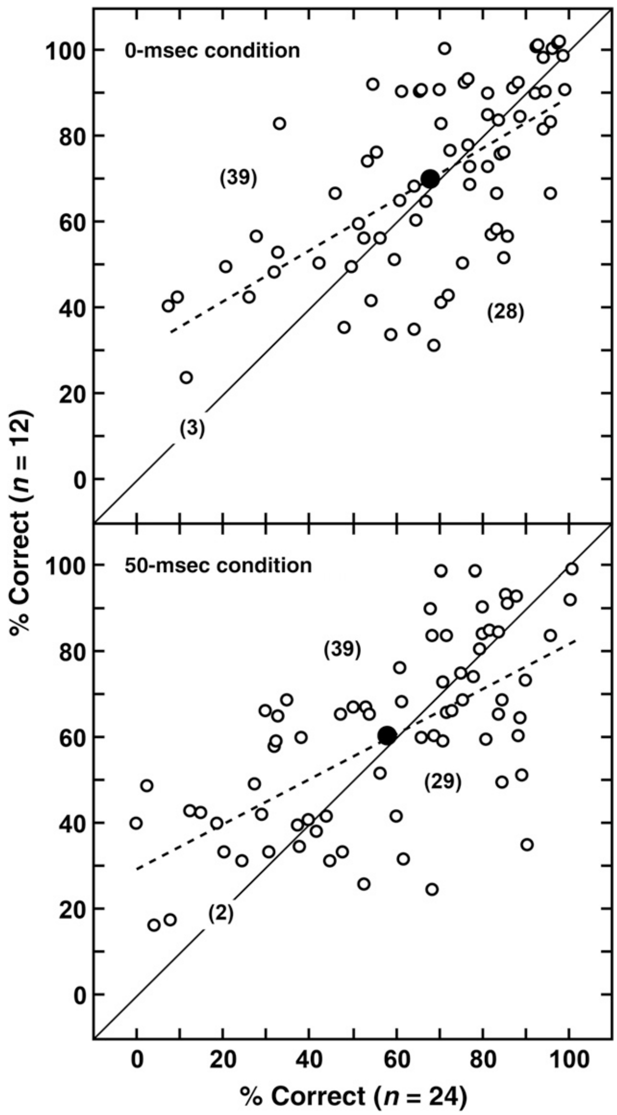

Figure 8. The mean recognition performances by older listeners with sensorineural hearing loss on the 70 interrupted words in the two onset conditions common to this study (n = 24) and in the Wilson (2014) study (n = 12). The large, filled symbols represent the mean performances, and dashed lines are the linear regressions used to describe the data (0 msec, $y = 30.778 + 0.581x$, $R^2 = 0.402$; 50 msec, $y = 29.697 + 0.528x$, $R^2 = 0.423$). The numbers in parentheses give the number of performances above, on, and below the line of equality. The data were jittered using a random, additive algorithm from −2.1 to 2.1 in 0.2 steps.

mean recognition performances on the interrupted materials were 61.3% (range across participants = 44.3–80.8%) and 65.3% (range across participants = 47.7–83.7%) for Sessions 1 and 2, respectively, which probably reflects a slight improvement in the ability of the listeners to process and recognize the interrupted words. These small differences between performances in the two sessions (2–4%) indicate fairly consistent performances between sessions.

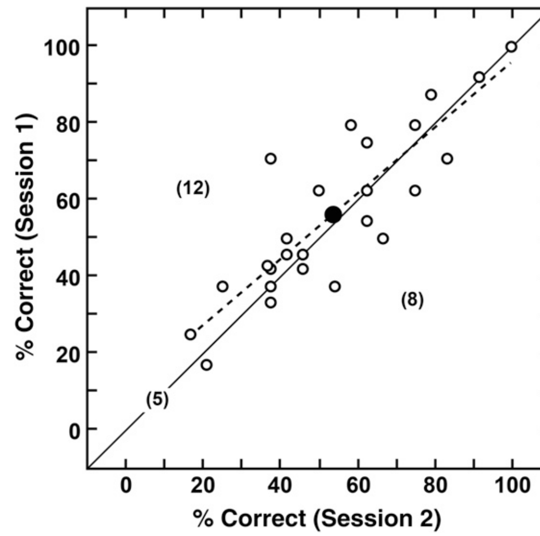

Figure 9. The mean recognition performances on the 25 interrupted words used as practice for each of the two test sessions with 24 older listeners with sensorineural hearing loss. The large, filled circle represents the mean performances and the dashed line is the linear regression used to describe the data ($y = 10.327 + 0.849x$, $R^2 = 0.74$). The numbers in parentheses give the number of performances above, on, and below the line of equality. The data were jittered using a random, additive algorithm. The data for the individual practice words are listed in Supplemental Table S8.

SUMMARY AND CONCLUSIONS

The current study examined the effects that the temporal placement of an interruption pattern had on word-recognition performances by 24 older listeners with sensorineural hearing loss and compared those performances with performances on the same materials by 24 younger listeners with normal hearing for pure tones (Wilson and Hamm, 2015). Overall, the older listeners performed 17% poorer on the interrupted words (63.2%) than did the younger listeners (80.4%), which confirmed one of the original assumptions. Variability among the 70 test words (24.6%) was over twice the variability among the 24 listeners (10.6%). The mean psychometric function across the ten onset conditions was broadly U-shaped with performances at the extremes of the onset conditions (68%) about 10% better than performances in the middle of the onset conditions (58%), which was similar in shape to the mean function obtained earlier from young listeners with normal hearing (Wilson and Hamm). The shapes of the psychometric functions for 41 words (58.6%) were the same for the two groups of listeners. Of the 41 functions, 17 were flat, 19 were U-shaped, and 5 were an inverted U-shape, which was a new shape category in this study. The functions for the remaining 29 words were in different shape categories for the two listener groups. Unexpectedly, two words (*calm* and *half*) produced substantially (39%) better recognition performances by the older listeners (70.8%) than by the younger listeners (31.1%). Collectively, the results from the current study and the Wilson and Hamm study are good examples of the orderliness and systematics exemplified by mean data (for 70 words in these studies), whereas underneath this seemingly tranquil statistic is a volatility that has a yet to be tapped plethora of information about the differential auditory processing by young individuals with so-called normal hearing and by older individuals with sensorineural hearing loss. The diversity of recognition performances by the older listeners on the ten interruption conditions with each of the 70 words supports the notion that the term *hearing loss* is inclusive of processes well beyond the filtering produced by end-organ sensitivity deficits.

Acknowledgments. The authors thank Rachel McArdle for her statistical contributions and Sherri Smith for the administrative assistance and guidance she provided.

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