

HEARING AIDS AND AURAL REHABILITATION

Age-Related Differences in Speech Recognition Performance as a Function of Test Format and Paradigm

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ABSTRACT

This study assessed speech recognition performance by young and elderly listeners with normal hearing and mild sensorineural hearing loss on a variety of speech recognition tasks. The tasks varied in terms of presence of noise, stimulus presentation level, test format, and test paradigm. The purpose was to identify a set of test conditions which is sensitive for revealing the effects of age, independent of hearing loss. The results showed that young and elderly listeners usually did not exhibit significant performance differences in quiet or fixed-noise conditions. However, an age effect was observed consistently for all conditions involving an adaptive noise paradigm. These findings imply that the important variables to consider for revealing effects of age are the use of noise coupled with an adaptive paradigm.

Speech processing in elderly listeners is a complex area of study. This is reflected in numerous conflicting reports in the literature regarding age effects on speech recognition tasks: some studies have shown that elderly subjects perform more poorly than young subjects (1-3); other studies have shown no differences in performance between young and elderly subjects (4-6). The reasons why age effects are observed in some studies but not in others are not immediately apparent. It has been suggested that a number of factors unrelated to peripheral hearing loss may contribute to speech-processing problems associated with age (7). These include physiologic changes in the central auditory pathways (8-10), poor attention span (11), auditory memory (12), and delayed speed of processing (13).

Given the complexity of factors that potentially contribute to performance in the elderly, it is not surprising that age effects are reported in some studies but not in others. For example, several early large-scale studies of speech recognition performance in quiet have shown significant reductions at age 60 yr and over for open-set monosyllabic word lists (3, 14, 15) and for closed-set monosyllabic rhyme tests (1). Most recent reports of speech recognition performance in quiet for monosyllabic word tests have shown no differences between young and elderly subjects matched for high frequency sensorineural hearing loss (4,

5, 16, 17), although age effects may exist for listeners with flat audiometric configurations and moderate or severe degrees of loss (18). For noise conditions, recent reports of speech recognition performance as a function of age have been inconsistent. Some studies did not observe significant differences in monosyllabic word-recognition scores between young and elderly listeners with matched audiograms (4, 5), whereas others (10) observed poorer performance by elderly listeners than by young listeners with matched losses. In addition, Dubno et al (2) reported that the signal-to-babble ratios (S/Bs) at which young listeners achieved a 50% criterion score for speech perception in noise (SPIN) test items (19) was lower (i.e., better) than those achieved by elderly listeners with matched mild sensorineural losses or normal hearing.

Methodological variations across studies probably contributed to some of these discrepant findings. One factor concerns subject selection. In some of the studies reporting age effects (1, 3, 14), young subjects had normal pure-tone sensitivity, whereas the elderly subjects had hearing thresholds typical for their age group [i.e., mild-to-moderate, gradually sloping sensorineural loss (20, 21)]. Deficits in speech recognition performance among elderly subjects in these studies may reflect the effects of hearing loss in addition to other nonauditory effects of age.

A second factor is stimulus presentation level. Most of the previous studies employed presentation levels of 40 dB SL re: spondee threshold (ST), or less. These levels may not have provided sufficient intensity for the elderly listeners to perform optimally, because high-frequency stimulus information could have been inaudible (22).

A third methodological variable is the presence or absence of background interference during testing. Jokinen (3) reported that age differences tend to be greater in noise conditions than in quiet conditions. This suggests that the more difficult listening condition incorporating noise may be more sensitive to age-related differences among subjects. In addition, the type of noise background used may be important. For example, the use of multitalker babble as the background interference may be more sensitive to age effects than a white noise background because it creates a greater masking effect than does a steady state noise (23).

The response format may also affect the difficulty of the task, and in turn may be sensitive to age effects. An open-set format usually is considered to be more difficult than a closed-set format because of the wider selection of possible responses (24). However, a multiple-choice format can be more difficult if the chosen response foils are highly confusable items for a particular listener group (25, 26).

Finally, the test paradigm may influence the difficulty of the task. The study that used the noise-adjust procedure revealed consistent effects of age (2), whereas studies that used fixed levels of signal and noise reported inconsistent age effects (4, 5, 16). It seems reasonable to infer that a more difficult listening situation is created by varying the noise level near the 50% point on the articulation function than by using a continuous level of noise.

In summary, the available data on age effects are equivocal due largely to experimental variations in subject selection, presentation level, presence of background noise, type of noise, response format, and test paradigm. Direct comparisons across studies are further complicated by the prevalent use of limited stimulus and response conditions in each study. Assuming that different test procedures place different task demands on the listener and that certain task demands are more sensitive than others to age effects, then it is necessary to evaluate the same populations of young and elderly listeners on a number of test conditions varying in task difficulty to determine which variables are sensitive to age effects. The purpose of the present study was to examine speech recognition performance of young and elderly listeners in a number of test conditions to identify a set of tasks that are minimally necessary for revealing speech processing deficits associated with age, independent of hearing loss.

METHOD

Subjects

Subjects were selected for the study on the basis of age and hearing status. Four groups of 10 subjects each with nearly equal numbers of males and females participated in the experiment. Group 1 (young normally hearing) was composed of 4 male and 6 female young adults (28 to 40, $M = 25.2$ years of age) whose air- and bone-conduction pure-tone thresholds were ≤ 15 dB HL (27) from 250 through 4 kHz. Group 2 (young hearing-impaired) consisted of 4 male and 6 female young adults (19 to 41, $M = 27.4$ years of age) with either gradually or sharply sloping sensorineural hearing losses. Their spondee thresholds were ≤ 40 dB HL, indicating a mild hearing loss. Subjects in groups 3 (elderly normally hearing; 4 males and 6 females) and 4 (elderly hearing-impaired; 5 males and 5 females) were senior citizens (65 to 75, $M = 67.5$ years of age) with pure-tone threshold sensitivity matched to that of the subjects in groups 1 and 2, respectively. Matching for hearing sensitivity among subjects in groups 2 and 4 was done on an individual basis. Figure 1 presents the mean pure-tone thresholds of the test ears of subjects in the four groups. The etiology of the loss for subjects in group 2 was heredity, noise exposure, or unknown in origin. Case history information for subjects in group 4 indicated that the losses were of late onset, 3 to 10 years' duration, and progressive in nature. Further, none of the subjects in group 4 reported a history of significant noise

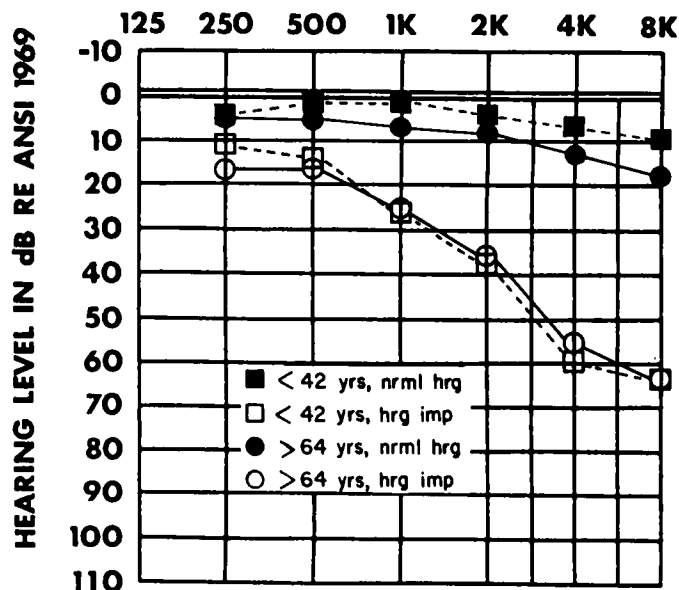


Figure 1. Mean pure-tone thresholds of 10 young normally hearing subjects, 10 young hearing-impaired subjects, 10 elderly normally hearing subjects, and 10 elderly hearing-impaired subjects.

exposure or otologic problems. Thus, presbycusis was the suspected etiology of the loss for subjects in group 4. All subjects exhibited normal tympanograms. In addition, acoustic reflex thresholds between 500 and 2000 Hz were elicited at levels below the 90th percentile upper limit established from subjects with different degrees of hearing loss and cochlear lesions (28). These results suggest that the losses of the hearing-impaired subjects were primarily cochlear in origin. All subjects were paid for their participation in the study.

Stimuli

Monosyllabic word materials with both open-set and closed-set formats were used to make direct comparison with other research. Materials were selected for their common usage in research and clinical testing, and for their similarity in test structure (e.g., number of items, number of lists, and use of a carrier phrase). The open-set materials consisted of standard Auditec of St. Louis recordings of Northwestern University Auditory Test No. 6 (NU6), 50-item lists 1A through 4A. In addition to the four standard lists, a recording of scrambled items from all four lists was prepared for the S/B-adjust procedure described later. A randomized list was used to minimize learning of word order effects, because the same words were used twice throughout the entire procedure.

The Modified Rhyme Test (MRT) (30) was used for the closed-set materials. Four lists of 50 words each were recorded on tape by a male speaker of General American dialect. The lists were recorded in an anechoic chamber, following procedures described by Krueger et al (30). A dubbing of scrambled items from the original recordings was prepared also.

Noise

A 12-talker babble consisting of three male and three female voices recorded and reproduced on a sound-on-sound recording was used as the background noise. The long-term average spectrum of the babble resembles the long-term average spectrum of speech.

Apparatus

Each set of stimuli and the noise were dubbed onto two separate channels of recording tape. During the experiment, the tapes were played back on a tape recorder (SONY TC-399). The output of the two channels was separately attenuated (Hewlett-Packard 350D attenuators), mixed (Colbourn audio-mixer amplifier No. S82-24), amplified (Crown D-75), and presented monaurally to a head-mounted earphone (TDH-49). The ear with better threshold sensitivity was the test ear for hearing-impaired subjects; the right ear was the test ear for the normally hearing subjects. The subject was seated in a double-walled, sound-isolated chamber during testing.

Calibration

A 1 kHz calibration tone equivalent to the peak VU-meter level of a designated word in the carrier phrase was recorded at the beginning of the MRT tapes and was prerecorded on the Auditec tapes of NU6. Stimulus levels were nominally assigned to the RMS-level of the calibration tone whose output at the earphones was either 80 or 95 dB SPL, as measured in a 6 cm³ coupler.

The overall level of the babble was adjusted to produce either 70 or 85 dB SPL at the earphones, to create a +10 dB S/B for the fixed noise conditions. This S/B was selected after pilot testing with normally hearing listeners as one that produced approximately 50 to 60% correct recognition scores.* For adaptive noise conditions, the overall level of the babble was adjusted as described below.

Procedures

Three procedures were used in the experiment. The first procedure was the determination of the S/B at which the listener achieved a 50% criterion recognition score. To that end, the scrambled items from the NU6 and the MRT were presented separately at fixed levels of 80 and 95 dB SPL for a total of four runs.† The listener was instructed to repeat the word perceived for the NU6 items, and to repeat the word from the six foils for the MRT items. The noise-adjustment procedure described by Dirks et al (31) was used to determine the S/B corresponding to the subject's estimated 50% criterion score for each run. Briefly, the starting level was a +30 dB S/B. Three stimulus items were presented for each noise level. Noise level was increased in 2 dB steps when the listener correctly recognized two of the three items presented and was decreased in 2 dB steps when the listener incorrectly identified two of the three items presented. This procedure continued until there were six reversals in the direction of noise-level adjustment. The S/B for the 50% criterion score was calculated as the mean of the final four excursion midpoints.

The second procedure was the presentation of full (50-item) lists of the two speech materials in quiet. The NU6 and the MRT were each presented at 80 and 95 dB SPL for a total of four runs. The noise channel was disconnected during the quiet conditions. The subject wrote the word heard for NU6 items, and circled one of six choices for MRT items.

The NU6 test and the MRT were presented in noise for the third procedure. Full lists of each test were presented separately

at 80 and 95 dB SPL. A fixed +10 dB S/B was used during these noise conditions. The subject's task was the same as that in the quiet procedure.

The order of listening conditions was selected to minimize possible learning effects. The more difficult S/B adjustment procedure containing the randomized items from the test lists was presented first. The remaining listening conditions were randomized across subjects. Random assignment was made of test list to listening condition, and each full list of test items was presented only once to each subject. The entire procedure was completed in two test sessions of 1.5 hr each, scheduled at a 1 week interval.

RESULTS

An analysis of variance (ANOVA) was conducted separately for the NU6 percent correct recognition scores in fixed (quiet and noise) conditions, for the MRT percent correct recognition scores in fixed (quiet and noise) conditions, and for the S/B scores obtained via the adaptive methods. A split-plot factorial design with two between-subjects factors and two within-subjects factors was used for each ANOVA (32). Percent correct recognition scores were arc-sine transformed prior to the ANOVA to remove the proportional relationship between treatment means and variances which can occur when the distribution has a binomial form (32).

Table 1 presents the average percent correct recognition scores obtained on the NU6 from the four subject groups in quiet and noise at 80 and 95 dB SPL. The 4-way ANOVA (age \times hearing \times level \times noise) revealed significant main effects of hearing [$F(1,36) = 19.80, p < 0.01$] and of noise [$F(1,36) = 628.92, p < 0.01$]. Significant interactions of hearing \times level [$F(1,36) = 5.11, p < 0.05$] and hearing \times noise [$F(1,36) = 9.89, p < 0.01$] also were observed. None of the main effects or interactions involved the age factor. The source of the hearing \times noise interaction was attributed to a larger difference in performance between the normally hearing and hearing-impaired groups in quiet than in noise. Thus, in terms of percent decrement from quiet to noise, the normally hearing subjects were more adversely affected by the noise than were the hearing-impaired subjects. In addition, the hearing \times level interaction arises from the fact that the normally hearing subjects' performance decreased as level was raised, whereas that for the hearing-impaired subjects improved as level was raised. This interaction confirms the value of multiple presentation levels in experiments employing hearing-impaired subjects or aging subjects.

Average percent correct recognition scores of the four subject groups on the MRT presented in quiet and noise are shown also in Table 1. The 4-way ANOVA (age \times hearing \times level \times noise) on the arc-sine transformed scores showed significant main effects of age [$F(1,36) = 4.81, p < 0.05$], hearing [$F(1,36) = 12.57, p < 0.01$], and noise [$F(1,36) = 251.11, p < 0.01$]. The ANOVA also revealed significant hearing \times noise [$F(1,36) = 18.08, p < 0.01$], hearing \times noise \times level [$F(1,36) = 6.91, p < 0.01$], and age \times hearing \times noise \times level [$F(1,36) = 6.20, p < 0.01$] interactions. The hearing \times noise interaction was compa-

* Dirks et al (31) observed 50 to 60% performance on NU6 at a 0 dB S/B by normal-hearing listeners. Differences between their measured S/B and that used on the current study can be attributed to the use of different recordings of NU6 (33) as well as to different methods of calibrating the babble (DD Dirks, personal communication).

† It should be noted that loudness-discomfort levels for speech, obtained prior to the test procedure, exceeded these presentation levels for each subject.

Table 1. Mean percent correct recognition scores from four subject groups on Northwestern University Test No. 6 (NU6) and on the Modified Rhyme Test (MRT) presented in quiet and noise. Standard deviations are in parentheses

Subject Group	Listening Condition							
	NU6				MRT			
	80 dB SPL		95 dB SPL		80 dB SPL		95 dB SPL	
	Quiet	Noise	Quiet	Noise	Quiet	Noise	Quiet	Noise
Young normally hearing	96.8 (3.01)	57.0 (9.80)	97.6 (2.07)	56.0 (12.22)	95.0 (3.40)	54.8 (6.70)	90.2 (4.54)	59.8 (7.91)
Elderly normally hearing	97.6 (3.75)	56.0 (5.78)	96.9 (2.23)	49.2 (10.17)	93.4 (6.50)	56.6 (8.49)	92.6 (5.15)	52.2 (9.82)
Young hearing impaired	79.2 (18.16)	48.4 (13.43)	86.8 (17.97)	45.8 (14.03)	83.6 (7.72)	59.4 (8.54)	88.2 (7.38)	58.2 (7.08)
Elderly hearing impaired	78.8 (16.58)	42.6 (15.54)	86.0 (10.71)	41.6 (13.70)	79.6 (11.43)	50.8 (6.48)	80.0 (7.07)	48.2 (10.52)

rable to that seen in the previous analysis. That is, larger differences were observed in mean performance between normally hearing and hearing-impaired listeners in quiet than in noise. However, the hearing \times noise \times level interaction indicates that the hearing \times noise interaction was somewhat different as a function of presentation level: the group difference in quiet was larger at 80 dB SPL than at 95 dB SPL. This finding is attributed to the fact that performance of normally hearing listeners decreased with increasing presentation level in quiet, whereas performance of hearing-impaired listeners increased with increasing presentation level. Finally, the 4-way interaction suggests that the 3-way interaction (hearing \times noise \times level) was different for young and elderly listeners. Indeed, the performance of elderly subjects demonstrated the hearing \times noise \times level interaction quite clearly, whereas the performance of the younger subjects showed only minor differences between hearing groups in all conditions except at 80 dB SPL in quiet. Further, the presence of noise at 80 dB SPL had a much more adverse effect on performance of young-normal listeners than on performance of young hearing-impaired listeners. In terms of age effects, simple main effects analyses showed that the younger hearing-impaired subjects exhibited higher scores than elderly hearing-impaired subjects in quiet at 95 dB SPL ($p < 0.05$) and in noise at both 80 dB SPL ($p < 0.05$) and at 95 dB SPL ($p < 0.05$). Age effects were not observed for the normally hearing listeners.

The average scores obtained by the four subject groups on the S/B-adjust procedures are shown in Table 2. Significant main effects of age [$F(1,36) = 8.14$, $p < 0.01$], hearing [$F(1,36) = 50.06$, $p < 0.01$], and test [$F(1,36) = 36.57$, $p < 0.01$] were revealed by the 4-way ANOVA (age \times hearing \times level \times test). An interaction between hearing and test [$F(1,36) = 17.07$, $p < 0.01$] also was significant. Tests of simple main effects showed that the hearing-impaired subjects obtained significantly lower S/Bs on the NU6 test than on the MRT [$F(1,72) = 27.24$, $p < 0.01$], whereas the normally hearing listeners did not obtain significantly different scores on the two measures. The significant main effect of the age variable reflects higher performance by younger subjects than by elderly subjects in all conditions.

Table 2. Mean signal-to-babble ratios required for 50% criterion scores from four subject groups on Northwestern University Test No. 6 and the Modified Rhyme Test. Standard deviations are in parentheses

Subject Group	Listening Condition			
	80 dB SPL		95 dB SPL	
	NU6	MRT	NU6	MRT
Young normally hearing	9.9 (2.13)	9.3 (2.31)	10.2 (3.49)	9.1 (3.35)
Elderly normally hearing	10.1 (1.45)	13.3 (1.64)	13.2 (2.53)	12.4 (3.13)
Young hearing impaired	16.3 (6.13)	20.1 (4.79)	15.9 (8.03)	24.0 (9.42)
Elderly hearing impaired	22.0 (6.80)	26.7 (9.06)	23.9 (9.43)	28.2 (9.16)

To summarize, age effects were not observed on the NU6 test when presented in quiet or fixed noise levels. Significant age effects were observed for hearing-impaired listeners on the MRT in three conditions (one quiet and two fixed noise). Finally, a consistent age effect was shown across all S/B adaptive measures.

DISCUSSION

The principle observation of this study was that age effects on speech recognition performance were task-dependent. Age effects usually were not observed for normal or hearing-impaired listeners in quiet conditions. Further, differential effects of age were not revealed when the NU6 test was presented in fixed noise conditions. Although an age effect among hearing-impaired listeners was evident on the MRT presented in three fixed listening conditions, scores were not different between young and elderly normally hearing subjects on this task. However, elderly listeners consistently exhibited significantly poorer performance than young listeners on the adaptive S/B procedure for both the MRT and the NU6 word tests at two presentation levels. This was observed for both normal and hearing-impaired listeners. Thus, age effects were observed for both subject groups in all conditions involving the S/B-adjust paradigm, but only for hearing-im-

paired subjects in a few conditions involving quiet and fixed-noise paradigms. This suggests that the test paradigm was primarily responsible for eliciting age effects. The response format (open- versus closed-set) was not an important variable because age effects were revealed with both formats on the S/B-adjust procedure.

The observation of age effects on the S/B-adjust paradigm was in agreement with results reported by Dubno et al (2) who found a constant age effect on scores obtained via the S/B-adjust procedure with SPIN test items. Thus, the present findings indicate that the earlier age effects on speech recognition performance reported by Dubno et al (2) were probably a consequence of their use of the S/B-adjust paradigm rather than their use of the SPIN test stimuli.

Also, generally consistent with earlier reports was the finding that age effects were not revealed for normal and hearing-impaired listeners when open-set word tests were presented in quiet and fixed-noise conditions. An absence of age effects was reported for open-set monosyllabic word tests presented in quiet (5, 16, 17) and in noise (4-6). However, Findlay and Denenberg (16) observed a significant age effect among hearing-impaired listeners on an open-set monosyllabic word test presented in multitalker babble. The discrepant findings may be associated with the extent to which young and elderly subjects were matched for threshold sensitivity. In the present investigation, audiograms of young and elderly hearing-impaired listeners were matched on an individual basis. In the study of Findlay and Denenberg (16), young and elderly hearing-impaired listeners all had normal hearing sensitivity through 2000 Hz, and thresholds of at least 40 dB HL at 4000 Hz. Thus, the absolute thresholds at 4000 Hz and above may have been different between the two age groups. Further, stimulus presentation level was 30 dB SL re: ST in Findlay and Denenberg's study, which may have been insufficient for the elderly listeners to achieve their maximum score (22). The present findings therefore indicate that open-set monosyllabic word tests presented in quiet and in fixed-noise conditions were insufficient to reveal age effects when appropriate controls were used, such as matching hearing sensitivity between young and elderly listeners and using favorably high stimulus presentation levels. The inadequacy of the quiet and fixed-noise procedures was shown despite the fact that the latter represented a difficult listening condition. The effects of age were subtle and were shown most clearly with specific tasks, such as the adaptive noise paradigm. The reason for the sensitivity of the S/B-adjust procedure for revealing age effects is unknown. However, the changing noise level near the 50% point on the articulation function associated with this paradigm may have placed greater stress on some nonauditory aspects of speech processing (e.g., attention or figure-ground perception) for elderly listeners than the use of a fixed-noise level.

There are several implications of the present results for the audiological assessment of the elderly person. The audiologist needs some way of differentiating the processing problems associated with age from those associated with the loss of hearing sensitivity alone. Toward that end,

assessment of speech recognition performance in the elderly should incorporate procedures that are sensitive to age-related processing problems. The present findings showed that age effects, independent of hearing loss, can be observed through speech recognition testing. However, the results clearly demonstrated that certain task demands must be placed on the elderly individual to reveal such effects. The present results suggest that the important variables necessary to reveal age effects are the presence of noise combined with the use of an adaptive noise paradigm. The results further indicate that the processing deficits associated with age are revealed consistently on speech recognition tasks in which monosyllabic words, S/B-adjust procedures, and noise babble are used, and listeners are matched for either normal hearing sensitivity or mild hearing loss. Additional investigation is necessary to determine whether such effects are present also for listeners having different degrees of hearing loss, and when different types of speech stimuli (such as nonsense syllable tests or sentence tests) and background interference are used. Presentation of open- or closed-set monosyllabic word tests in quiet or fixed-noise paradigms appeared to be of limited value for identifying age effects per se.

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