RESEARCH ON SPOKEN LANGUAGE PROCESSING
Progress Report No. 19 (1993-1994)
Indiana University

The Effects of Speaking Rate and Stimulus Variability on Spoken Word Recognition by Young and Elderly Listeners[1]

Mitchell S. Sommers,[2] Larry Humes,[3] and David B. Pisoni

Speech Research Laboratory
Department of Psychology
Indiana University
Bloomington, Indiana 47405

[1]This work was supported by NIDCD Research Training Grant DC-00012 and NIA Research Grant DC-01694A to Indiana University, Bloomington, IN
[2]Now at the Department of Psychology, Washington University, St. Louis, MO 63130.
[3]Department of Speech and Hearing Sciences, Indiana University, Bloomington, IN

Abstract

These studies investigated the effects of increased speaking rate and greater speaking-rate variability on spoken-word recognition in older and younger listeners. For younger subjects, neither increased speaking rate nor greater rate variability produced significant changes in perceptual identification scores. Older listeners, in contrast, exhibited significantly poorer identification scores for fast, compared to medium or slow speaking rates. In addition, trial-to-trial variations in speaking rate produced a significant decrease in identification scores for elderly subjects listening to fast-rate items. These findings suggest that age-related declines in perceptual normalization and temporal processing may partially explain the poorer speech perception abilities of older listeners.

The Effects of Speaking Rate and Stimulus Variability on Spoken Word Recognition by Young and Elderly Listeners

Introduction

Studies comparing the speech perception abilities of young and elderly listeners have found that reduced audibility, due to presbycusic hearing loss, is one of the factors contributing to age-related declines in spoken-word recognition (Humes, et al., 1994; Humes, 1991). However, changes in absolute sensitivity cannot completely account for the speech perception deficits of older listeners. Several investigations have demonstrated reduced speech perception scores in elderly subjects with minimal hearing impairment in the frequency regions most important for processing spoken language (Committee on Hearing and Bioacoustics, 1988). The increased difficulty with speech for these older subjects, therefore, must be due to deficits in one or more additional capacities that decline with age.

One ability that exhibits considerable age-related declines is temporal processing (Gordon-Salant & Fitzgibbons, 1993). In spoken-word recognition, deficits in temporal processing may be reflected in a reduced capacity to recognize words produced at fast speaking rates or in an impaired ability to accommodate variations in speaking rate. The present investigations were therefore designed to examine the following questions: (1) does increasing speaking rate have differential effects on spoken-word recognition in older and younger listeners? and (2) do age-related differences exist in the ability to adjust to changes in articulation rate?

Although several studies have shown that faster speaking rates can reduce overall speech intelligibility for both older and younger subjects (Picheny, Durlach & Braida, 1989; Schon, 1970), these investigations were not designed to dissociate the effects of articulation rate, age, and absolute thresholds on spoken-word recognition. Therefore, little empirical evidence is available to indicate whether speaking rate has comparable effects on older and younger listeners with similar absolute sensitivity in the frequency regions most important for speech perception. Furthermore, most studies that have examined the effects of speaking rate on identification scores have altered speaking rate using digital compression algorithms that do not preserve the segment-level acoustic changes found with natural alterations in articulation rate. Little information is therefore available about how older and younger listeners are affected by naturally produced changes in speaking rate. Age-related differences in the ability to perceive speech produced at fast rates might reflect deficits in the mechanisms used to process the rapidly time-varying acoustic characteristics of speech signals. Declines in this type of temporal processing may be one of the factors responsible for the poorer speech perception abilities of older subjects.

A second factor associated with articulation rate that may differentially affect older and younger listeners is the ability to compensate for speaking rate variability. Speaking rates can vary substantially during normal discourse (Miller, Grosjean, & Lomanto, 1984) and such changes significantly alter the acoustic realization of speech sounds. To maintain perceptual constancy, listeners must therefore compensate or normalize for differences in speaking rate. Traditional accounts of perceptual normalization suggest that incoming speech signals are transformed to standardized representations and then matched to canonical forms stored in long-term memory. Thus, perceptual normalization is a resource-demanding process that may be substantially affected by age-related reductions in cognitive capacities (Salthouse, 1985). Deficits in the ability to normalize for speaking-rate variations may therefore partially account for the poorer speech performance of elderly listeners.

EXPERIMENT 1

Experiment 1 was designed to determine how increasing articulation rate affects spoken-word recognition in older and younger listeners. The stimuli were 150 monosyllabic words from phonetically-balanced word lists (House et al., 1965). Each word was produced in a carrier phrase at 3 different speaking rates (fast, medium and slow) and subjects were instructed to produce the entire phrase at the indicated rate. Average durations for the slow, medium and fast words edited from the carrier phrase were 905, 533, and 375 ms, respectively. We tested 10 elderly and 15 young listeners with absolute hearing thresholds of 20 dB HL or better for frequencies below 4 kHz. Subjects identified isolated words presented in quiet at an overall level of approximately 80 dB SPL.

The results of this experiment are shown in Figure 1. For young subjects, percent correct identification exceeded 90 percent at all three speaking rates and performance did not differ significantly as a function of rate. Thus, items produced at slow, medium and fast speaking rates were identified equally well by young listeners.

Insert Figure 1 about here

Older listeners, in contrast, exhibited a significant reduction in identification performance for items produced at fast speaking rates [$F(2,18) = 6.4$; $p < .01$]. Tukey HSD *post hoc* analyses revealed a significant difference between identification scores for the slow and fast speaking rates and between the medium and fast speaking rates ($p < .01$ for both comparisons) but no significant difference between scores for the slow- and medium-rate items. These findings agree with previous demonstrations of reduced spoken-word identification scores in older listeners for fast articulation rates (Picheny et al., 1989). Furthermore, they indicate that increasing speaking rate reduces identification scores for old, but not for young, listeners even when both groups have similar absolute sensitivity in the frequency regions most important for speech perception.

EXPERIMENT 2

Experiment 2 was designed to determine whether younger and older listeners are differentially affected by speaking-rate variability. As noted previously, listeners must normalize or adjust for changes in speaking rate because such alterations affect the acoustic characteristics of speech signals. A reduced capacity to compensate for speaking rate variations could therefore impair spoken-word recognition.

The stimuli for this experiment were 300 new monosyllabic words again taken from phonetically-balanced word lists. The same elderly and young listeners from Experiment 1 served as subjects. The words were presented in 2 different listening conditions. The first was identical to Experiment 1 in which all the words in a list were produced at the same speaking rate. In the second, or mixed-rate, condition, speaking rate was varied randomly from trial to trial. In both the single-and mixed-rate conditions, listeners heard fifty words produced at each of the three speaking rates.

Figure 2 shows the effects of trial-to-trial variations in speaking rate on younger and older listeners. The solid bars were taken from Experiment 1 and indicate percent correct identification when all the items in a list were presented at the same speaking rate. The hatched bars show identification scores for words presented at each speaking rate but within a mixed-rate context. Thus, data from the mixed-rate

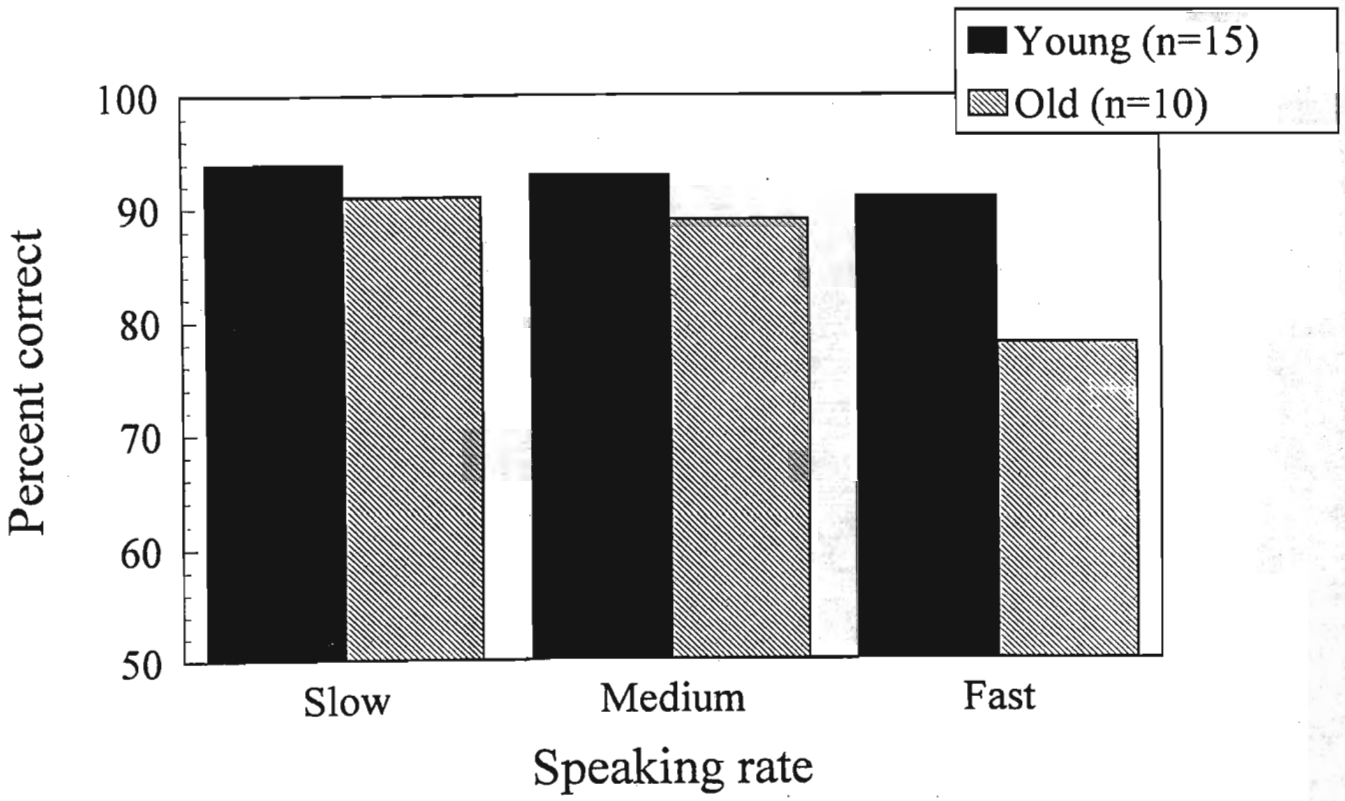

Figure 1: The effects of slow, medium and fast speaking rates on identification scores for young (<25) and old (> 65) listeners. Data for young subjects are shown in the solid bars, results from the elderly listeners are shown in the hatched bars.

slow conditions, for example, indicate identification scores for words produced at slow speaking rates in the mixed-rate context.

Insert Figure 2 about here

For young listeners identifying words in quiet, no significant effect of speaking rate variability was observed [$F(1,14) = 1.04$; $p > .1$]; at all three speaking rates, identification accuracy was not significantly different in the single- and mixed-rate contexts. Elderly listeners, in contrast, demonstrated a significant effect of speaking-rate variability [$F(1,9) = 34.2$; $p < .01$] and a significant variability x rate interaction [$F(2,18) = 54.6$; $p < .01$]. Tukey HSD *post hoc* analyses showed that the difference between single- and multiple talker conditions was significant only for fast-rate words. These findings indicate that, for elderly listeners, increased speaking-rate variability and faster articulation rates can combine to produce greater decrements in perceptual identification scores than either factor independently.

One explanation for elderly listeners' poorer identification of fast words in the mixed-rate condition is that perceptual normalization capacities may decline as function of age. Consequently, older adults may need to devote a greater percentage of limited cognitive resources to perceptual normalization. Under relatively easy listening conditions, such as slow or medium speaking rates, older individuals have sufficient resources for both normalization and identification. However, under difficult listening conditions, such as fast articulation rates, older listeners do not have sufficient cognitive resources for both normalization and identification and, as a result, identification performance is impaired.

An alternative explanation, however, is that rather than reflecting a specific age-related decrement in normalization abilities, the additional reduction in identification scores for mixed-talker fast-rate words may be due to differences in task demands for older and younger listeners. Specifically, the results of Experiment 1 demonstrated that older adults had greater difficulty identifying words produced at fast speaking rates while younger subjects did not. Thus, the older listeners' poorer recognition performance for fast words in the mixed-rate condition may be a result of greater encoding difficulty rather than age-related changes in normalization capacities. According to this hypothesis, increasing encoding difficulty for younger subjects should produce differences between single- and mixed-rate conditions that are comparable to those observed for the elderly with fast speaking rates.

EXPERIMENT 3

Experiment 3 was designed to assess whether older and younger listeners exhibit similar reductions in identification scores for mixed speaking rates when task difficulty is equivalent for the two groups. Task difficulty for young subjects was increased by having them identify words presented in a background masking noise. The signal-to-noise (SN) ratio for this masker was set such that identification performance in the single-rate condition was comparable to the single-rate scores of older subjects identifying fast-rate words. That is, single-rate performance for the young in noise and for the elderly with fast words was similar. If the decline in mixed-rate performance for the elderly that was observed in Experiment 2 was due to increased task difficulty, then young subjects should show a similar decline for mixed-rate contexts in noise. However, if younger subjects exhibit less of a decline in the mixed-rate condition than was observed for the elderly in Experiment 2, the findings would indicate age-related declines in perceptual normalization capacities.

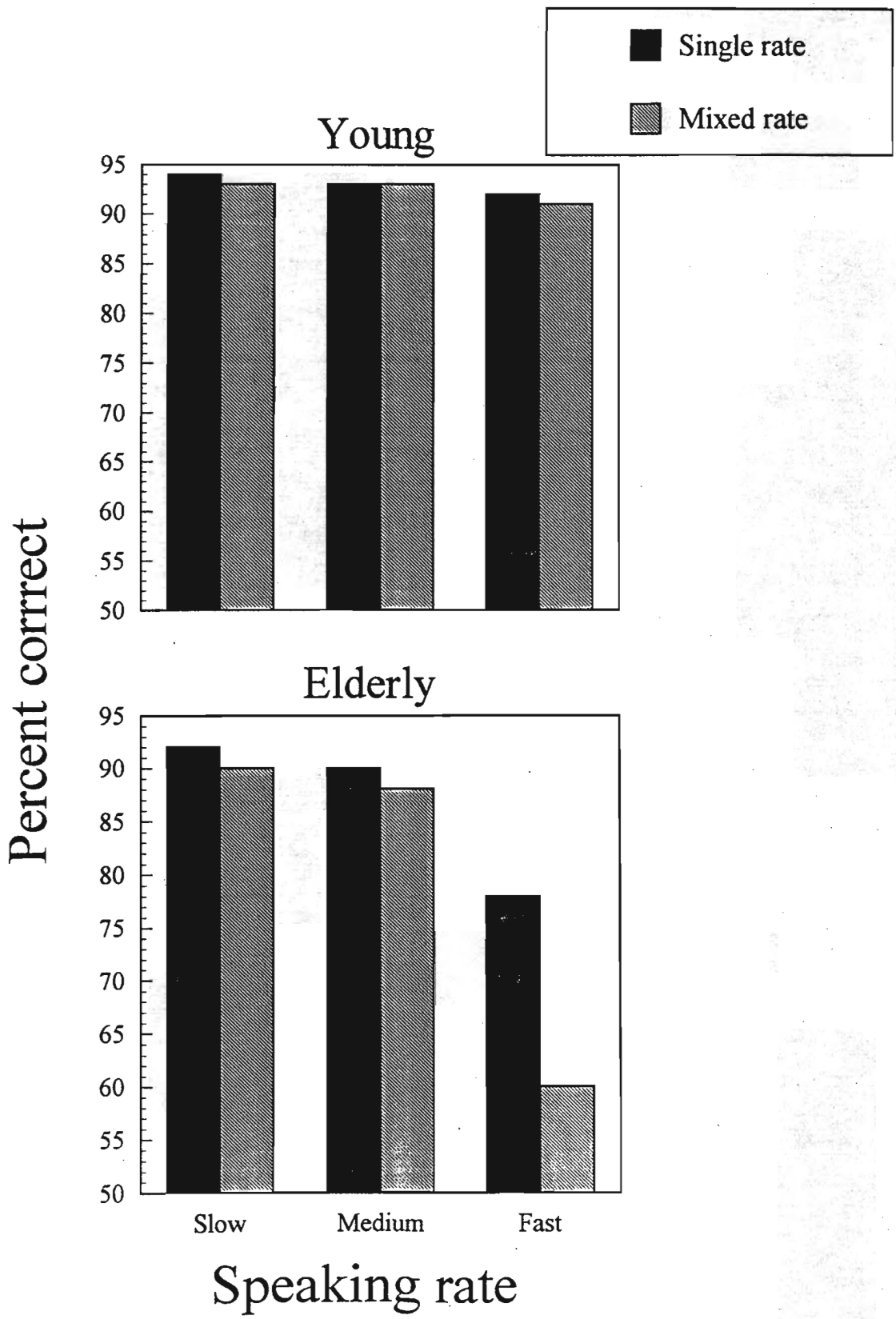

Figure 2: The effects of trial-to-trial variations in speaking rate on younger and older listeners. The solid bars were taken from experiment 1 and indicate percent correct identification when all the items in a list were presented at the same speaking rate. The hatched bars show identification scores for words presented at each speaking rate but within a mixed-rate context.

The same 300 monosyllabic words from Experiment 2 were used in this study. A new group of 15 young listeners identified the items in both the single and mixed-rate contexts in the presence of a background masking noise. Signal-to-noise ratio for both the single- and mixed-rate contexts was +5 dB.

Figure 3 shows the results of this experiment. The left set of data are from the elderly listeners in Experiment 2 and show spoken-word recognition scores for fast-rate items in single and mixed-rate contexts. The data on the right show results for young subjects tested at a signal-to-noise ratio of +5 dB. Adding the masking noise reduced identification scores for young subjects in the single-rate condition to approximately the same levels found for elderly listeners identifying fast-rate words in quiet. A mixed-design ANOVA on the data from all four conditions shown in Figure 3 with variability (single vs. mixed rate) as a within-subjects variable and age (young vs. old) as a between-subjects variable demonstrated a significant age x variability interaction [$F(1,23) = 36.69$; $p < .01$]; the difference between single and multiple speaking rates was significantly greater for the older subjects. This finding suggests that the decreased identification scores for fast-rate words in the mixed-rate context that was observed for elderly listeners in Experiment 2 cannot be completely attributed to task demands. When encoding difficulty is equated for young and elderly listeners, the older subjects still show significantly greater effects from the introduction of stimulus variability.

Insert Figure 3 about here

CONCLUSIONS

To summarize, first, despite similar absolute sensitivity, younger and older subjects are differentially affected by increased speaking rate. Compared to young subjects with comparable hearing abilities, older listeners exhibit poorer perceptual identification scores for words presented at fast speaking rates. This reduced intelligibility for faster articulation rates is consistent with recent findings of poorer temporal processing abilities in older listeners and may reflect deficits in the ability to follow the rapid time-varying characteristics of speech produced at fast rates. Second, under conditions of comparable encoding difficulty, older subjects exhibited reduced capacities for perceptual normalization compared to younger listeners. This finding suggests that one factor responsible for age-related changes in speech perception is that older listeners are less capable of accommodating acoustic-phonetic variability that results from changes in speaking rate.

Establishing how age affects the perceptual abilities necessary for the initial analysis of speech signals can provide important information about the factors contributing to poorer spoken-word recognition in older listeners. Such information is essential not only for understanding the linguistic deficits of older listeners but for developing effective rehabilitation strategies for this population. For example, deficits in spoken-language processing that result from reduced normalization capacities are unlikely to benefit from conventional audiologic treatments such as hearing aids. Future experiments in this area should therefore be directed at identifying other processing mechanisms necessary for the initial analysis of spoken words that may decline with age.

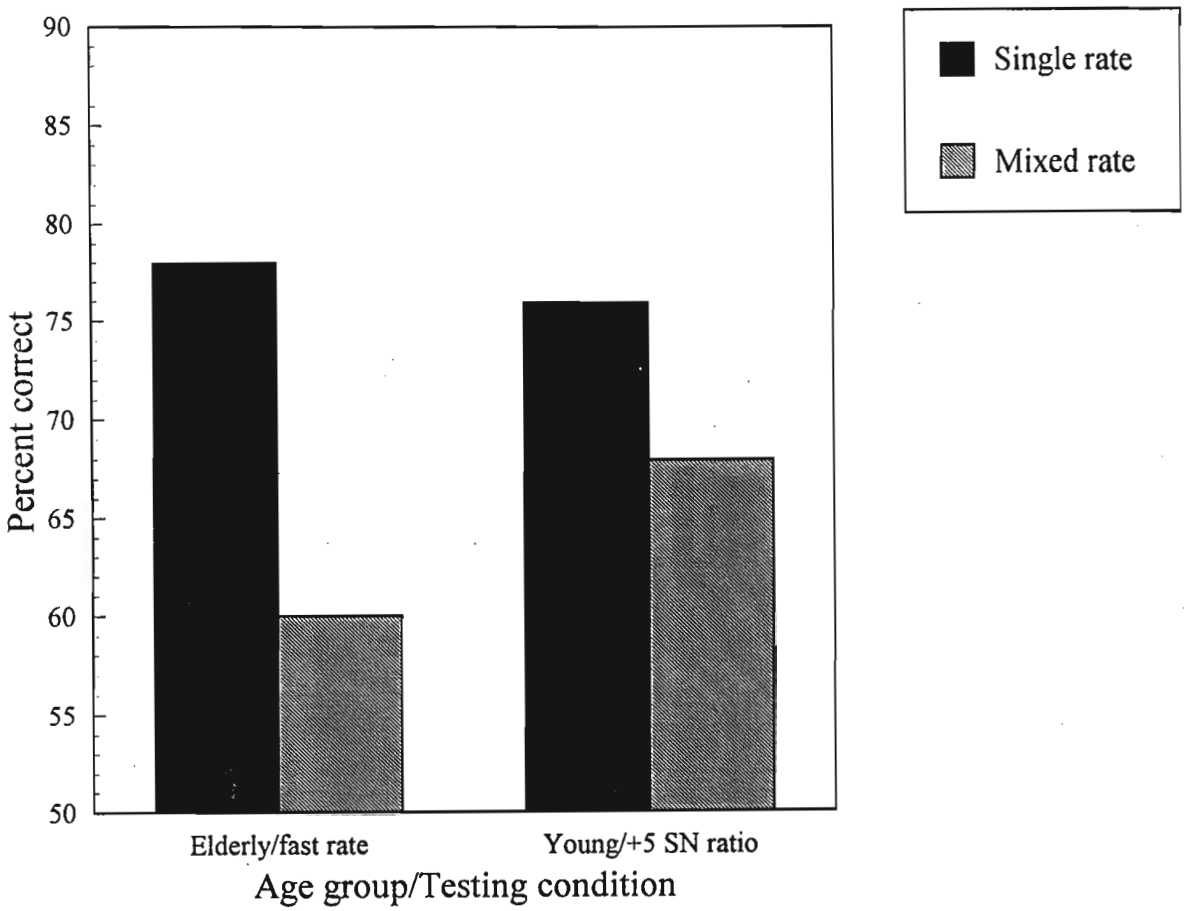

Figure 3: Comparison of identification scores for single- and mixed-rate contexts with single-rate performance equated for young and elderly listeners. The left set of data are from the elderly listeners in experiment 2 and show spoken-word recognition scores for fast-rate items in single and mixed-rate contexts. The data on the right show results for young subjects tested at a signal-to-noise ratio of +5 dB.

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