RESEARCH ON SPOKEN LANGUAGE PROCESSING
Progress Report No. 20 (1995)
Indiana University

The Relationship Between Stimulus Variability, Auditory Memory, and Spoken Word Recognition in Listeners with Hearing Impairment[1]

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[1]This research was supported by NIH-NIDCD Research Grant DC00111 and NIH-NIDCD Training Grant DC00012 to Indiana University, Bloomington, IN. We thank Michelle Wagner-Escobar, M.A., and Helena Saldaña, Ph.D., for their assistance.
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Abstract. This study examines the effects of stimulus variability on word recognition and immediate memory performance in normal-hearing and hearing-impaired listeners. Experimental subjects were adult hearing-aid users, while normal-hearing adults served as controls. Word recognition tests included a talker variability test and a speaking rate test. Immediate memory tests included an auditory digit span test and an auditory letter span test. Preliminary results indicate that normal-hearing listeners showed better word recognition and better recall of auditorily-presented signals than did hearing-impaired subjects, indicating a close relationship between phonetic coding and immediate memory.

Introduction

Speech perception is a complex process involving perceptual analysis and encoding of sensory information, retrieval of previously stored information from memory, and the interpretation, integration and assimilation of various knowledge sources. In listeners with normal hearing, both perceptual analysis and word retrieval are influenced by the presence of stimulus variability. For example, varying the talker's voice from trial-to-trial produces a decrease in both spoken word recognition scores and serial word recall performance when compared to a single-talker condition, presumably because the perceptual normalization process consumes common processing resources. This study examined the effects of stimulus variability on word recognition and immediate memory performance in normal-hearing and hearing-impaired listeners.

Purpose

The goals of this project were:

1) To compare the immediate memory spans of listeners with normal and impaired hearing.
2) To examine the effects of talker variability on immediate memory in listeners with normal or impaired hearing, and
3) To examine the relationship between immediate memory and word recognition performance in listeners with normal or impaired hearing.

Methods

Subjects

All subjects were between the ages of 18-65 years. Experimental subjects were selected from a group of hearing aid users seen at Indiana University Medical Center. Selection criteria included a bilateral mild-to-moderate hearing loss with speech discrimination scores of 75% or greater on the NU-6 (Tillman & Carhart, 1966), and a minimum of three months experience with their current hearing aid. Four males and three females participated as experimental subjects. Six adults with normal-hearing (i.e., $\leq$20 dB HL at octave frequencies from 250-4000 Hz) served as control subjects. They were recruited from students and staff at the Indiana University Medical Center.

Table 1

Subject Characteristics

		Age (yrs)	Auditory Thresholds (dB HL)				NU-6
			500 Hz	1000 Hz	2000 Hz	4000 Hz	
Hearing-Impaired Listeners	Mean	55.3	32.1	36.4	40	46.4	96.9%
	Range	40-64	25-45	20-60	30-55	35-65	88-100%
	SD	8.3	7.0	16.3	10.0	11.1	4.9%
Normal Hearing Listeners	Mean	39.7	5	-1.3	2.5	5	100%
	Range	29-51	-10-15	-10-5	0-10	0-10	-
	SD	11.8	12.3	6.3	5.0	4.1	-

Stimulus Materials

Word Recognition Tests. All stimulus materials were selected from computerized databases maintained at Indiana University Speech Research Laboratory. These databases contain tokens of spoken words, letters, and digits produced by multiple talkers, both male and female, that have been digitized and stored as individual computer files.

Talker Variability Test - From a digital database containing 6000 words (300 words from the Modified Rhyme Test [House et al., 1965] recorded by 10 male and 10 female talkers), 100 words were chosen based on computational analyses of their lexical properties. Half were "easy" (i.e., they occurred often in English, and contained few phonetically-similar words with which they could be confused), and half were "hard" (i.e., they occurred infrequently and were phonetically similar to many other words). The single-talker condition had 25 "easy" and 25 "hard" words produced by one male talker. The multiple-talker condition was similar except that the talker varied randomly from trial-to-trial. These materials were based on a previous study by Mullennix et al. (1989), using normal-hearing listeners.

Speaking Rate Test - Two hundred words were selected from a recorded database of 3000 PB words. The single-speaking-rate condition contained 50 words spoken by a single male talker at a medium speaking rate (mean word duration = 533 ms). The mixed-speaking-rate condition contained 150 words produced by the same male talker, but speaking rate varied from trial-to-trial, and included a total of 50 fast, 50 medium, and 50 slow tokens. The average duration for these tokens was 375 ms, 533 ms, and 905 ms, respectively. These stimuli were developed by Sommers et al. (1994).

Immediate Memory Tests. Two immediate memory tasks, an Auditory Digit Span test and an Auditory Letter Span test, were presented under two conditions: a single-talker condition in which one male talker produced all the items in a list, and a multiple-talker condition where a novel talker produced each item in a list. Table 2 summarizes the Digit Span and Letter Span tests. Nine different list lengths were constructed for each test. The lists ranged from two-to-10 items each and were drawn successively without replacement.

Table 2

Immediate Memory Span Stimulus Materials

Talker Condition	Letters (H B J K M R Q D F Z L)	Digits (0 1 2 3 4 5 6 7 8 9 10)
Single	45 lists	45 lists
Multiple	45 lists	45 lists

Procedures

All subjects were tested inside a sound-attenuated booth while seated at a table facing a loudspeaker. Stimuli were presented via free field at approximately 72 dB SPL. Hearing-impaired listeners used their hearing aids during testing. Stimulus presentation was blocked by test, but test order and the order of conditions within a test were randomized.

Word Recognition Tests

Subjects responded by repeating the word they heard and their responses were transcribed by the examiner. Only responses that exactly matched the target item were counted as correct (e.g., a plural response to a singular target was scored as an incorrect response).

Immediate Memory Span Tests

Prior to each memory test, subjects completed an identification task for the stimuli within that set. They were first given a written sheet containing the set of letters or digits from which the items could be drawn, and then asked to identify each item presented in isolation. In the single-talker conditions, each letter or digit was randomly presented three times. Because there were 121 stimuli to identify in the multiple-talker conditions, (a maximum of 11 list items X 11 different talkers), subjects heard each token only once. During each memory test, 45 lists were presented in a staircase fashion, increasing from two items to 10 items and then decreasing back from 10 items to two items. Following the presentation of each list, subjects responded by writing their responses on sheets of paper containing a blank space for each list item. Lists were scored as correct if and only if, all the items were recalled in their correct temporal order.

Results

Word Recognition Tests

A summary of the word recognition performance for the two groups of listeners is shown in Table 3 broken down by the four conditions in each listening test. Across the four talker-variability conditions, word recognition scores were consistently higher for the normal-hearing listeners than the hearing-impaired listeners ($p \leq .05$). This was true for both the lexically "easy" and "hard" words, and the single-talker and multiple-talker conditions. As expected, both groups had better word recognition performance in the single-talker than the multiple-talker conditions ($p \leq .04$). Easy words were identified with greater accuracy than the "hard" words, although the differences were significant only in the multiple-talker conditions ($p \leq .02$).

Normal-hearing listeners always identified words from the single-talker conditions better than the hearing-impaired listeners. These differences in performance between normal-hearing and hearing-impaired listeners increased even more in the multiple-talker conditions, which had increased stimulus variability.

Finally, the same pattern of results was observed for the speaking-rate tests. The normal-hearing listeners' word recognition performance was consistently better than that of the hearing impaired in all conditions ($p \leq .03$), except for slow words in the mixed-speaking-rate condition. The difference in performance between the two groups was largest at the fast speaking rate ($p \leq .008$).

Table 3

Mean percent of words correctly identified on the Talker test and the Speaking Rate tests for both subject groups.

		Talker Test				Speaking Rate Test			
		Single-Talker		Multiple-Talker		Multiple-Rate			
		Easy	Hard	Easy	Hard	Single	Fast	Med.	Slow
Normal-Hearing	Mean	85.6	86.0	79.8	70.0	82.7	71.2	83.7	85.8
	(SD)	(7.7)	(7.4)	(10.6)	(9.7)	(9.1)	(4.6)	(7.0)	(8.3)
Hearing-Impaired	Mean	65.2	60.1	50.9	37.1	64.5	50.0	63.7	70.5
	(SD)	(13.9)	(16.5)	(10.2)	(14.4)	(13.5)	(16.9)	(17.4)	(17.4)

Immediate Memory Span Tests

Figures 1 and 2 illustrate the percent of lists correctly recalled on the Digit Span Test by the two subject groups for the single-talker and multiple-talker conditions, respectively. Figures 3 and 4 present the results for the Letter Span test. A comparison of average memory spans (i.e., the maximum list length at which all five lists were correctly recalled) for the two groups is shown in Table 4.

The results of the Immediate Memory Span tests showed that both groups of listeners demonstrated reduced digit and letter recall as list length increased. In addition, the average memory span consistently was longer for the normal-hearing subjects than for the hearing-impaired subjects for all conditions except the multiple-talker condition on the Letter Span test, but these differences were significant only for letter recall in the single-talker condition ($p \leq .02$). Generally, introducing multiple talkers had little effect on either digit or letter recall. However, the hearing-impaired subjects had significantly longer memory spans for letter recall in the multiple-talker condition than in the single-talker condition ($p \leq .03$).

Insert Figures 1, 2, 3 and 4 about here.

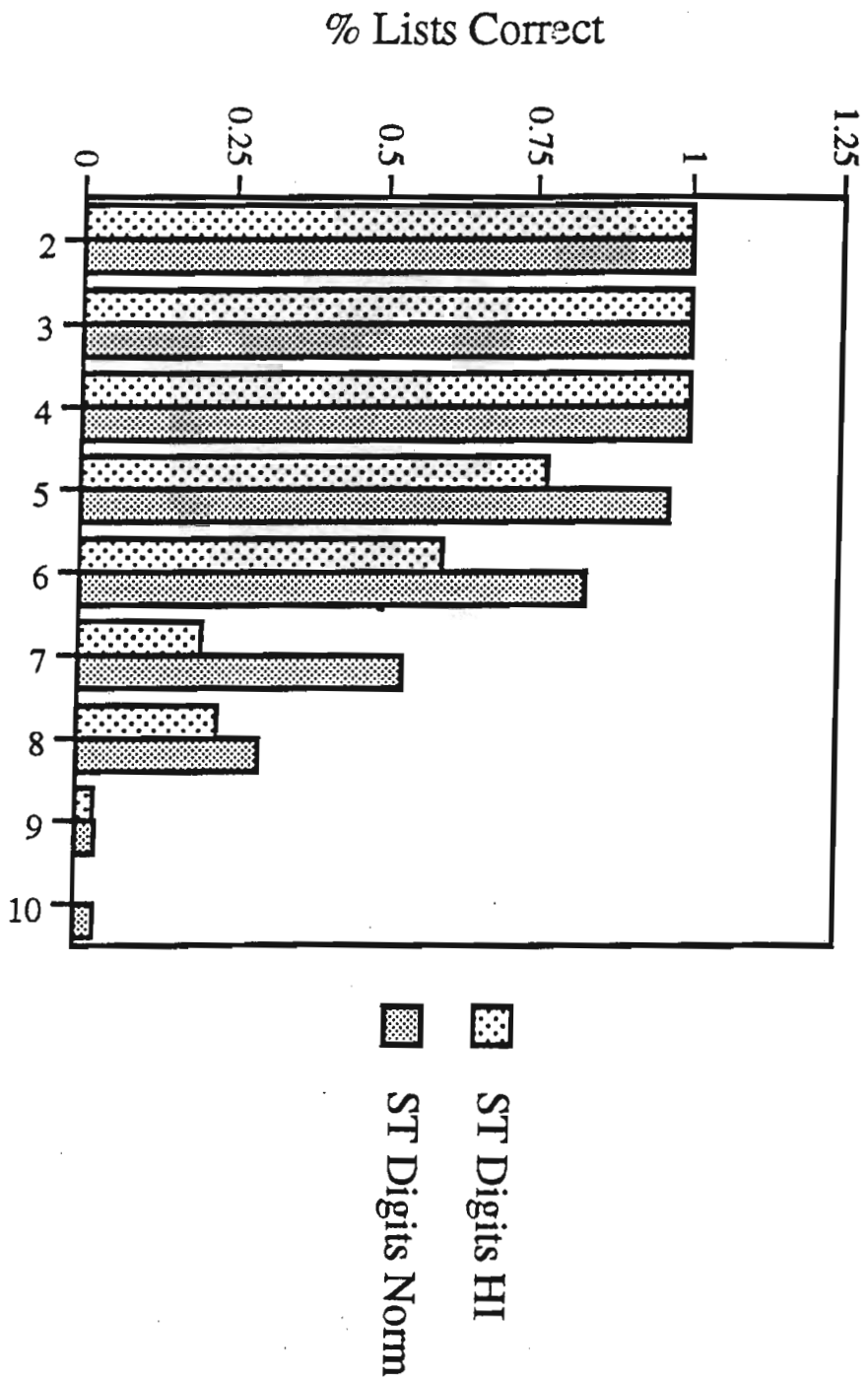

Figure 1. Performance of normal-hearing and hearing-impaired listeners in the single-talker digits condition.

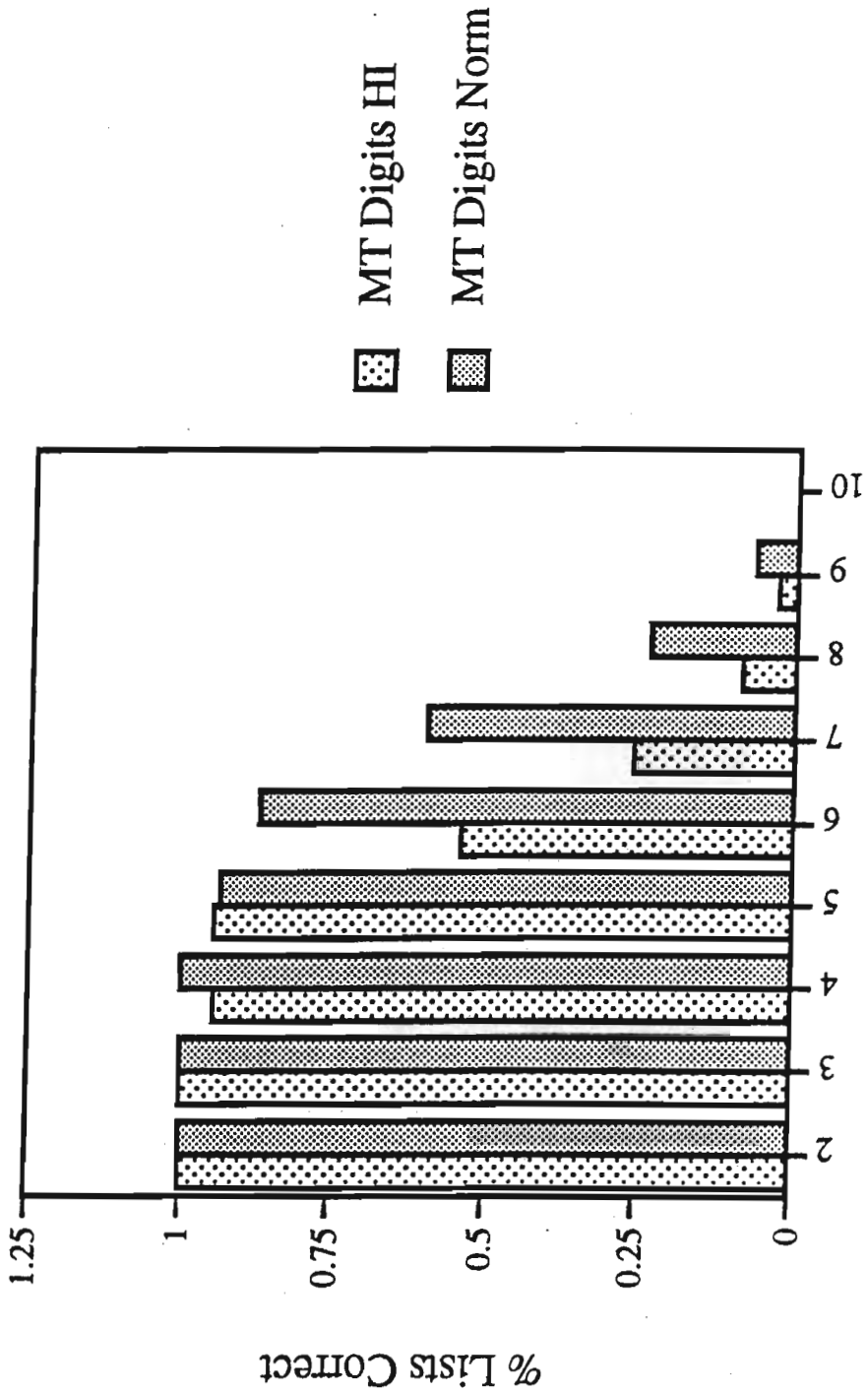

Figure 2. Performance of normal-hearing and hearing-impaired listeners in the multiple-talker digits condition.

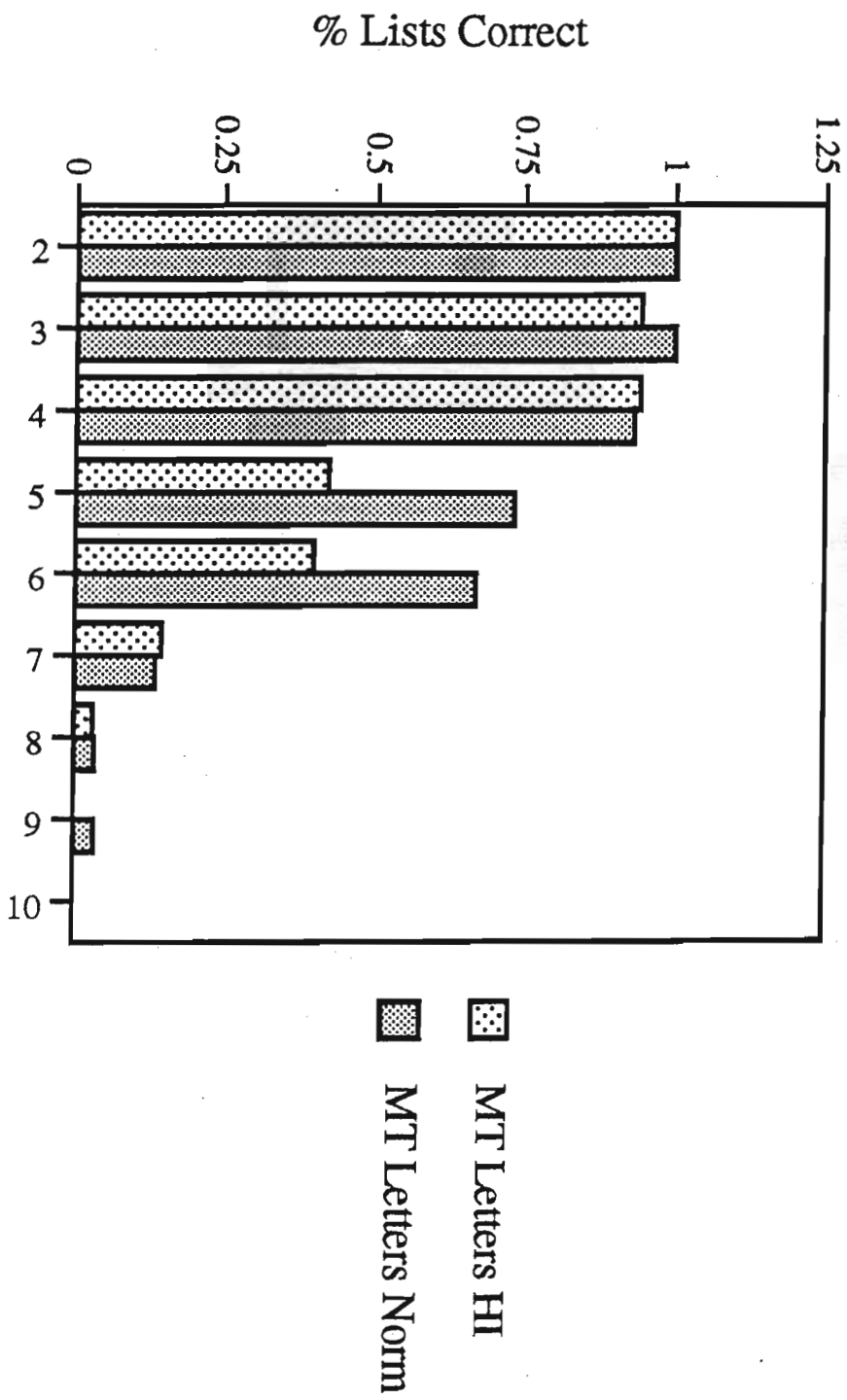

Figure 3. Performance of normal-hearing and hearing-impaired listeners in the single-talker letters condition.

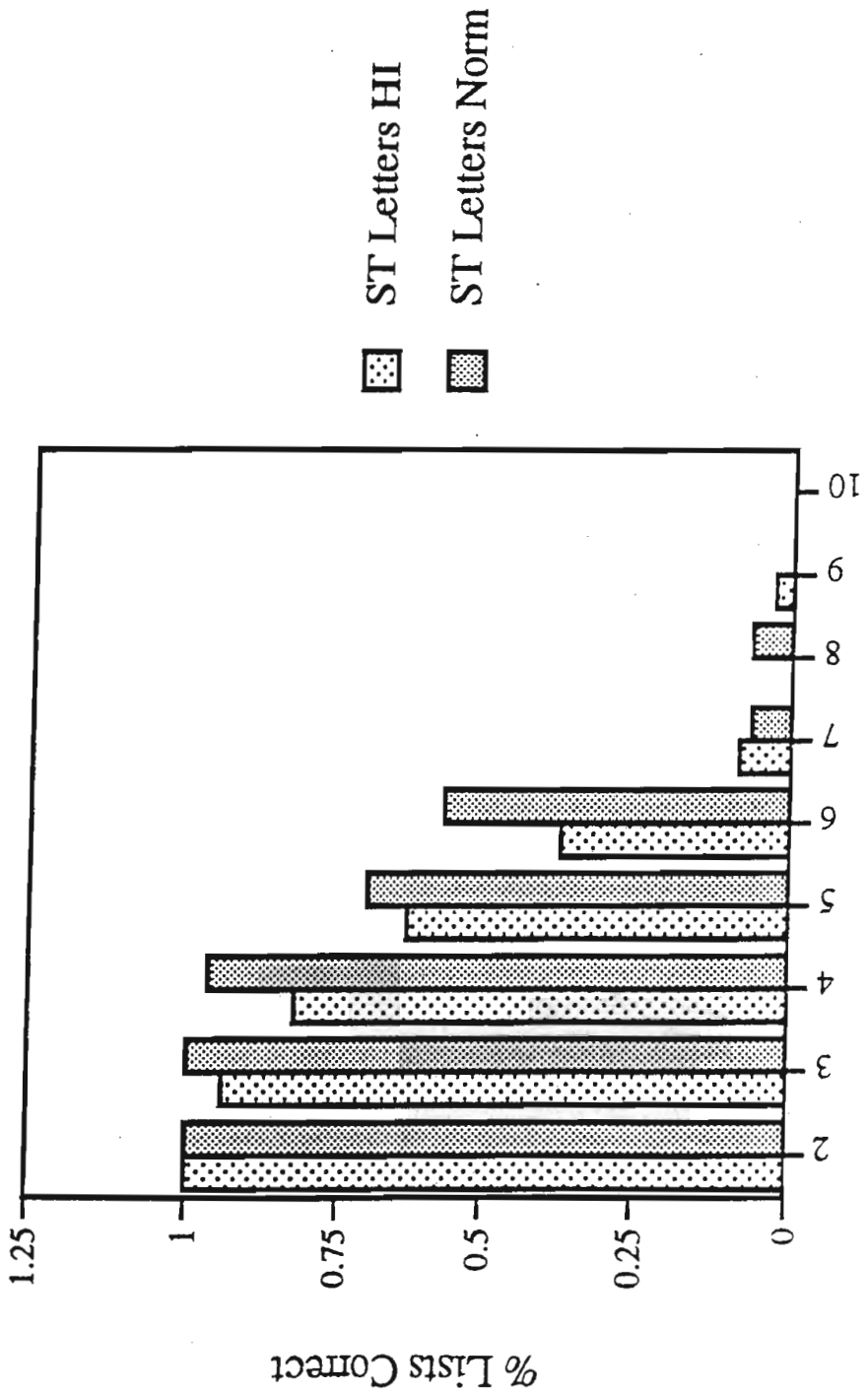

Figure 4. Performance of normal-hearing and hearing-impaired listeners in the multiple-talker letters condition.

Table 4

Average immediate memory span.

		Digit Span Test		Letter Span Test	
		Single-Talker	Multiple-Talker	Single-Talker	Multiple-Talker
Normal-Hearing	Mean	5.5	5.7	4.5*	3.7
	(SD)	(1.1)	(1.0)	(1.1)	(0.5)
Hearing-Impaired	Mean	4.4	4.9	3.0*	3.7
	(SD)	(0.8)	(1.1)	(0.6)	(0.5)

*$p \leq .02$

Correlations Between Word Recognition Scores and Immediate Memory Span

Tables 5 and 6 present the correlations for the normal-hearing and hearing-impaired listeners, respectively. Word recognition performance was significantly correlated ($p \leq .05$) only with memory span for letters in the multiple-talker condition, but the direction of the correlation differed for the two subject groups.

Normal-Hearing Subjects - Significant negative correlations were found between memory span for letters in the multiple-talker condition and performance on at least one condition in the Talker test and the Speaking-Rate test. Significant correlations were found with performance on the "easy" words in the single-talker condition ($r = -.88$), the single-speaking-rate condition ($r = -.85$), and the slow words in the multiple-speaking-rate condition ($r = -.90$).

Hearing-Impaired Subjects - Significant positive correlations were found between memory span for letters in the multiple-talker condition and performance on several conditions in the Talker test and the Speaking-Rate test. Significant correlations were found with performance on the "hard" words in the single-talker condition ($r = +.83$) and the multiple-talker condition ($r = +.76$). Significant correlations were also found with performance on the single-speaking-rate condition ($r = +.96$), the slow words in the mixed-speaking-rate condition ($r = +.90$), and the fast words in the mixed-speaking-rate condition ($r = +.91$).

Table 5

Correlations between word recognition scores and performance on the immediate memory span tests for normal-hearing listeners (N=6).

		Normal-Hearing Listeners			
		Digits		Letters	
		Single-Talker	Multiple-Talker	Single-Talker	Multiple-Talker
NU-6		--	--	--	--
Single-Talker	Easy	-.02	-.04	-.66	-.88*
	Hard	.23	.31	-.42	-.46
Multiple-Talker	Easy	.20	-.02	-.41	-.57
	Hard	.27	.24	-.04	-.10
Single Rate		.15	.15	-.64	-.85*
Mixed Speaking Rate	Slow	.18	-.09	-/38	-.90*
	Med.	.55	.30	-.09	-.70
	Fast	.09	-.10	-.19	-.60

*$p \leq .05$

Table 6

Correlations between word recognition scores and performance on the immediate memory span tests for hearing-impaired listeners (N=7).

		Hearing-Impaired Listeners			
		Digits		Letters	
		Single-Talker	Multiple-Talker	Single-Talker	Multiple-Talker
NU-6		.52	.34	-.18	.21
Single-Talker	Easy	.67	.59	-.04	.55
	Hard	.35	.27	.27	.83*
Multiple-Talker	Easy	.53	.47	.27	.65
	Hard	.46	.31	.16	.76*
Single Rate		.33	.39	.13	.96**
Mixed Speaking Rate	Slow	.05	.04	.35	.90**
	Medium	.06	-.13	.53	.74
	Fast	.29	.20	.20	.91**

*$p \leq .05$
**$p \leq .01$

Discussion

The present results should be considered preliminary and suggestive because of the small sample size. However, several interesting trends emerged. First, it appears that normal-hearing listeners displayed better word recognition *and* better recall of auditorily-presented signals than do hearing-impaired subjects. One possibility for this difference is that additional processing resources are required to analyze the degraded speech signal received by listeners with hearing impairment, and to match these signals to sound patterns stored in their mental lexicons. Secondly, the results showed that introducing stimulus variability yielded decreases in word recognition performance, but not in immediate memory span for letters or digits. The word recognition data replicate the earlier results of Kirk, Pisoni, & Miyamoto (1995). The only significant effect of introducing stimulus variability on immediate memory was an unexpected *increase* in memory span for letters for the hearing-impaired subjects. This finding was somewhat surprising. The reasons for this outcome are not clear and the findings need to be replicated in another group of hearing-impaired listeners. It is very possible that the items on the multiple-talker, letter-span lists were more perceptually discriminable than those in the single-talker, letter-span lists, and therefore could be encoded in such a way as to preserve their distinctiveness in memory. This would reduce the confusability among perceptually similar pairs of letters. This could be tested by selecting confusable and non-confusable letters in subsequent tests.

Only immediate memory span for letters was significantly correlated with word recognition performance. The letter recall task was more difficult than the digit recall, because the former requires the listener to make finer phonetic distinctions among confusable items in the list than the latter. It was not uncommon for hearing-impaired listeners to correctly identify phonetically-similar letters (e.g., /b/ and /d/) in isolation but then to confuse them once they appeared in a list in the memory span for letters task. Thus, hearing-impaired subjects who were best at identifying lexically "hard" words (i.e., those that have many phonetically similar words with which they can be confused) were also the same listeners who were best at letter recall, and showed increased memory spans.

Conclusions

These preliminary results looking at both perception and memory performance suggest a close relationship between phonetic coding and immediate memory. They also imply that hearing impairment may impact on cognitive tasks requiring access to short-term working memory. Further study with a larger subject population of both normal-hearing and hearing-impaired subjects is warranted to generalize these findings to other processing activities used in spoken language comprehension. If we assumed that spoken language processing makes use of a "limited-capacity" processing system requiring the use of short-term working memory, then impairments in perceptual analysis may propagate up the system and have an impact not only on speech perception performance, but on activities that make use of these neural/cognitive representations as well.

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