Comprehension of Time-Compressed Speech: Effects of Age and Speech Complexity

Tomasz Letowski*
Nancy Poch†

Abstract

The periodic sampling method of time compression is characterized by periodic removal of segments of speech according to predetermined compression rate (CR) and discard interval length (DIL). Fifteen middle-aged (42–54 years old) and 15 older (60–69 years old) adults participated in the study that assessed the combined effects of CR and DIL on the comprehension of time-compressed speech by aging adults. Three CRs (30, 45, and 60%), seven DILs (35 through 155 msec), and two types of speech materials were used. The subject's task was to report associations among the items mentioned in a time-compressed passage. In all cases, performance of the subjects deteriorated with increasing CR and DIL. The older adults were affected more by CR and DIL values than middle-aged adults. The difference in sentence complexity between the two speech materials affected both groups equally. In general, the results of the study indicated that (a) time-compressed speech differentiates between speech comprehension by middle-aged and older adults and (b) the effects of CR and DIL became more independent with increasing age of the listener and increasing complexity of the speech material. Reported results support the concept that time-compressed speech may be an effective signal in clinical assessment of adults whose auditory complaints are not explained by their peripheral hearing losses.

Key Words: Aging, speech perception, time compression

Abbreviations: ANSI = American National Standards Institute, CF = compression frequency, CR = compression rate, CHABA = Committee on Hearing, Bioacoustics, and Biomechanics, CID = Central Institute for the Deaf, DIL = discard interval length, HL = hearing level, M = arithmetic mean, SD = standard deviation, SOLA = Synchronized OverLap Add

Older adults frequently report more difficulties in speech understanding than can be explained on the basis of audiometric findings (Bergman, 1980; CHABA, 1988; Willott, 1991). Observed discrepancies between the results of audiometric tests and the person's self-report regarding speech comprehension are typically attributed to overall slowing of cognitive functions (Birren et al, 1980; Salthouse, 1985), age-related changes in central auditory processing (Jerger et al, 1989, 1991; Stach et al, 1990) or a combination of both (Pichora-Fuller et al, 1995). Although it is not clear what the relative contributions of perceptual, linguistic, and cognitive processes are to speech understanding, deficits in any of them may result in a slower speed of speech processing (Newman and Spitzer, 1983). The hypothesis that speech processing becomes slower with age is strongly supported by reports that speech understanding in older adults diminishes rapidly with increased rate of speech (Sticht and Gray, 1969; Konkle et al, 1977; Bergman, 1980; Kobrin et al, 1991) and that older adults prefer listening to slower rates of speech than younger listeners (Riensche et al, 1979).

Speech includes segments of repeated information, making it highly redundant. Similarly, the neural pathways have many parallel connections, making signal processing highly redundant. Both of these redundancies make speech perception highly robust. Therefore, in order to observe changes in speech processing due to minimal neural dysfunctions, it is necessary to use fairly

*U.S. Army Research Laboratory, Auditory Processes Group, Aberdeen Proving Ground, Maryland; †Washington State University, Department of Speech and Hearing Sciences, Pullman, Washington

Reprint requests: Tomasz Letowski, U.S. Army Research Laboratory, AMSRL-HR-SD/Building 520, Aberdeen Proving Ground, MD 21005-5425

difficult speech material, set a complex listener's task, or degrade the quality of the speech signal.

According to Fitzgibbons and Gordon-Salant (1994), tests based on the degradation of temporal properties of speech should be good predictors of speech comprehension in adverse listening conditions. One effective method of temporal degradation of speech is time compression. An important property of this method is that time-compressed speech preserves the pitch and prosody of original speech but increases the amount of information transmitted per unit of time. The basic time-compression technique used in audiology is the periodic sampling method, in which equal portions of the speech signal are regularly discarded and the remaining portions are abutted in time (Lee, 1972). The resulting temporal composition of the time-compressed speech depends on (1) compression rate (CR), which determines how much the overall length of the speech signal is shortened; (2) compression frequency (CF), which determines how often portions of the signal are discarded; and (3) the length of the discard interval (DIL). Any two of these parameters can be manipulated independently with the remaining one dependent on the other two.

An important characteristic of time-compressed speech is that a short segment of such speech can highly stress the performance of the central auditory nervous system without a serious involvement of long-term memory storage. This means that time-compressed speech can be used to assess information processing speed rather than the overall capacity of information-processing resources. This is an important factor in studying information processing since high demands for memory can overshadow the changes in information processing resulting from the changes in either the environment or listener characteristics. However, the answer to the question of whether time-compressed speech puts greater demand on auditory or cognitive/linguistic processing depends on the complexity of the speech signal and the listener's task.

Despite the theoretical potential of time-compressed speech, studies using such signals have not yet contributed much to our understanding of speech processing. Part of the reason may be that past research has primarily focused on the effect of CR on comprehension of speech while neglecting the effect of DIL almost entirely. As a matter of fact, DIL was not only kept constant in individual studies but normally not even reported. The analysis of instrumentation used in these studies seems to indicate that most of the authors used the same short DILs of approximately 30 msec, assuming that deletion of longer segments of speech would unacceptably affect the temporal pattern of speech (Heiman et al, 1986). Of the early studies examining perception of time-compressed speech, only two examined the effect of DIL on speech understanding (Garvey, 1953; Fairbanks and Kodman, 1957). In addition, both of these studies employed only isolated words and did not look into connected discourse material. The authors of those studies recommended that DILs should be short enough to avoid eliminating an entire phoneme if intelligibility is to be preserved. These critical values were less than 60 msec in Garvey's study and less than 80 msec in the Fairbanks and Kodman results, where the subjects were familiarized with the word lists prior to testing.

Recently, Poch (1992) and Letowski and Poch (1995) examined closely the effect of DIL on understanding time-compressed connected speech by young (mean = 32 years, SD = 6.7 years) and older adults (mean = 66.5 years, SD = 4.5 years) using a single CR of 50 percent. They reported that the subjects' performance in both groups deteriorated gradually until a certain critical DIL was reached, beyond which performance dropped sharply. The values of critical DILs were 135 msec and 75 msec for young and older adults, respectively. The longer DILs necessarily resulted in less frequent sampling of the speech signal. This means that older listeners needed to "sample" the in-coming message at higher rates than young listeners in order to understand the message's meaning. The authors also reported that they did not observe any consistent effect of hearing loss on subjects' performance. The last finding agrees with that of Sticht and Gray (1969), who found that older adults had poorer scores on time-compressed monosyllabic word tests than younger adults, regardless of their hearing loss. However, none of the reported studies investigated the combined effects of CR and DIL changes on speech perception. Moreover, the effect of sentence complexity on comprehension of time-compressed speech was never tested. It also is unclear how changes in CR and DIL affect understanding of time-compressed connected speech by middle-aged listeners. Thus, the purpose of the present study was to examine the combined effect of CR and DIL on the ability of middle-aged and older adults to understand time-compressed connected speech. An additional motivation for this study was to determine the effect of sentence length on the comprehension of time-compressed speech.

METHOD

Subjects

Two groups consisting of 15 subjects each participated in the study. The subjects in group 1 were middle-aged adults, 42 to 52 years old (13 females and 2 males), with a mean age of 47.6 years (SD = 2.9). The subjects in group 2 were older adults, 60 to 69 years old (12 females and 3 males), with a mean age of 66.9 years (SD = 2.9). Studies have shown that the changes in central processing may begin in the fifth decade (Bergman, 1980; McCroskey and Kasten, 1982; CHABA, 1988). Therefore, we have decided to explore in the present study the effects of time compression on subjects in the fifth and seventh decades of life and to determine whether there is a significant difference in speech comprehension between these two age groups. The subjects were recruited from the local community and were paid for their participation in the study. The subjects in group 1 had thresholds of hearing not worse than 20 dB HL in the 250- to 4000-Hz range, while the subjects in group 2 could have thresholds of hearing up to 25 dB at 3000 Hz and 40 dB at 4000 Hz. These values agree with the age-adjusted norms proposed by Rowland (1980). To be included in the study, each subject also had to score 90 percent or better on a 50-word recognition test (CID W-22), obtain a 100 percent score on an experimental task employing a passage with 0 percent time compression, and complete the general health

Table 1 Audiometric Data and the Digit Symbol Substitution Test Results (DS) for Middle-aged Adults (Group 1)

Subject	*Age*	*.5R*	*.5L*	*1R*	*1L*	*2R*	*2L*	*3R*	*3L*	*4R*	*4L*	*DS*
S1	42	5	5	−5	0	0	5	0	0	5	5	74
S2	49	−5	0	10	5	15	10	15	15	20	20	59
S3	47	0	5	15	15	15	10	0	10	0	0	58
S4	46	10	10	5	10	5	10	5	15	5	15	48
S5	49	0	10	10	15	5	5	15	15	15	20	56
S6	52	0	0	5	0	15	15	15	20	15	20	60
S7	46	5	5	5	0	0	0	−5	0	15	15	85
S8	45	0	5	0	0	−5	−5	5	5	5	5	64
S9	47	0	5	5	0	−5	0	5	15	10	15	69
S10	49	20	0	15	−5	10	0	5	0	0	-10	44
S11	48	5	5	5	5	0	0	5	5	5	5	47
S12	52	5	10	10	10	10	10	0	10	10	15	51
S13	47	5	5	0	5	-5	0	-5	10	10	10	61
S14	45	0	5	5	0	5	20	20	20	15	15	63
S15	48	5	5	0	0	10	5	20	10	30	30	57

L = left ear, R = right ear.

Table 2 Audiometric Data and the Digit Symbol Substitution Test Results (DS) for Older Adults (Group 2)

Subject	*Age*	*.5R*	*.5L*	*1R*	*1L*	*2R*	*2L*	*3R*	*3L*	*4R*	*4L*	*DS*
S16	65	15	10	10	15	0	0	10	15	15	10	63
S17	61	15	5	15	10	0	0	20	20	20	15	56
S18	61	15	5	5	15	0.	10	5	20	15	20	58
S19	62	0	5	0	5	5	10	5	10	5	10	62
S20	61	5	5	-10	5	5	10	10	15	15	20	71
S21	63	10	10	5	10	10	15	10	10	15	10	45
S22	64	0	15	5	10	20	20	15	25	20	40	51
S23	65	15	15	10	15	10	10	20	20	15	15	59
S24	67	15	15	15	20	15	15	15	20	15	25	48
S25	59	5	20	5	10	5	0	15	10	40	20	52
S26	65	0	5	5	5	5	5	15	20	10	30	63
S27	69	0	0	5	5	5	15	15	5	35	30	57
S28	68	5	5	10	5	10	10	5	10	10	10	44
S29	68	5	15	5	10	-5	5	5	25	10	25	41
S30	67	10	10	15	15	15	20	20	20	40	40	65

L = left ear, R = right ear.

Table 3 Results of the General Health Questionnaire

Category		*Middle-aged Adults*	*Older Adults*
Employment	Employed	15	4
	Retired	0	11
Profession	Clerical	2	6
	Coach	1	0
	Homemaker	1	2
	Laborer	1	0
	Manager	0	2
	Musician	0	1
	Nurse	1	2
	Scientist	1	1
	Teacher	8	1
Volunteer work	None	5	5
(hr per wk)	1–5 hr	8	7
	6–10 hr	2	3
Social activities	None	1	0
(hr per wk)	1–5 hr	11	7
	6–10 hr	2	4
Education	High school	2	4
	Undergraduate	5	4
	Graduate	7	2
	Other	2	5
Health problems	No	5	5
(other than hearing)	Yes	10	10
Hearing problems	No	8	8
(in noise)	Yes	7	7
Hearing	Good	15	15
Self-assessment	Fair	0	0
	Poor	0	0
Hearing	Good	10	12
Family assessment	Fair	1	3
	Poor	4	0

questionnaire (Appendix A). In addition, the Digit Symbol Substitution Test of the Weschler Adult Intelligence Scale was administered to each subject participating in this study. This test is considered a consistent and reliable measure of the decline in information processing due to aging (Birren and Morrison, 1961; Salthouse 1982, 1985). The results of this test were not used as a subject selection criterion but rather to assess general cognitive characteristics of the subjects for future data analysis. The hearing threshold levels and Digit Symbol Substitution Test scores for subjects in group 1 and group 2 are listed in Tables 1 and 2, respectively. The results of the general health questionnaire are shown in Table 3.

Test Material

The test material used in this study was comprised of two sets of 18 narrative paragraphs labeled respectively speech material A and speech material B. Fifteen basic paragraphs of each set were used for testing and the remaining three paragraphs were used for subject selection and training. The paragraphs in both sets, similar in overall length, differed in sentence length, and therefore were used as two separate speech materials to facilitate their direct comparison. The first set of passages was used in our two previous studies (Poch, 1992; Letowski and Poch, 1995). The second set has never been used before.

All 36 paragraphs were 85 to 95 words in length, had simple sentence structures, and used common words concerning everyday topics such as home, school, vehicles, weather, tools, etc. The structure of each paragraph involved two groups of four items each that constituted three related pairs and one unrelated pair (see Letowski and Poch, 1995). The readability level of each paragraph did not exceed the eighth-grade reading level as determined by the Flesch-Kincaid Reading Formula. The average length of paragraphs in speech material A was 89.1 words (SD = 3.3) and in speech material B was 90.9 words (SD = 3.4). However, the average numbers of words per sentence were 10.4 (SD = 1.4) and 13.0 (SD = 1.6), respectively. The corresponding average numbers of sentences per paragraph were 8.6 (SD = 1.1) and 7.1 (SD = 0.9). This difference was statistically significant at $p < .001$ ($t = 5.5$, $df = 17$). We hypothesized that the greater internal complexity of speech material B should produce poorer comprehension scores than those obtained with speech material A.

All paragraphs in speech material A and speech material B were read by the same female talker at a comfortable voice effort level and at an average rate of 172 words per minute. The paragraphs were digitally recorded using an ACO condenser microphone, Adcom GFP-555 preamplifier, Ariel DSP 16+ signal acquisition system, and Swan 386 computer. All recordings were made in identical conditions in an audiometric booth (Suttle B1) with background noise level complying with ANSI S3.1-1991 criteria for sound field testing (ANSI, 1991). The sampling rate was 50,000 Hz. The digitized sound files were used uncompressed or were time compressed by the periodic sampling method. Time compression was accomplished using custom-made software (Letowski and Poch, 1995), which regularly discarded intervals of 35, 55, 75, 95, 115, 135, and 155 msec and abutted the remaining segments of the speech in time. In order to reduce the occurrence of transients in the processed signal, the software varied the length of discard intervals slightly so that the beginning and ending of an interval remained within a specified range of the zero crossing. The compression rates used in this study were 30 percent, 45 percent, and 60 percent.

Procedure

The test signals were played from digital storage through the Ariel DSP - 16+ board, Adcom GFP-555 preamplifier, Hewlett-Packard 350D attenuator, and Macintosh 50 power amplifier to a set of matched Telephonics TDH-39 headphones. The speech samples were presented diotically to the listener at 50-dB sensation level. This level is routinely used in clinical testing as the level at which speech test scores reach their maximum. The level was set monaurally for the better ear and the subject adjusted the level in the other ear to match the loudness of sound in the first ear. The subjects were tested individually in the same audiometric booth that was previously used for making speech recordings.

The middle-aged (group 1) and older (group 2) subjects were tested with paragraphs that were time compressed using DILs from 75 to 155 msec and from 35 to 115 msec, respectively. Selection of DILs for both groups was based on the results of previous studies (Poch, 1992; Letowski and Poch, 1995) and informal pilot tests. For the CRs and speech materials used in this study, our older subjects (group 2) could not achieve any score if the DIL exceeded 115 msec while middle-aged adults (group 1) could still score when DILs were as long as 155 msec. For DILs shorter than 75 msec, the middle-aged subjects practically made no errors in speech comprehension.

The 30 basic test paragraphs, 15 from both speech material A and speech material B, were randomly assigned to 15 time-compression conditions (5 DILs × 3 CRs) for each group of subjects. The six remaining paragraphs were used for subject evaluation and training. During the test, the subjects were asked to listen to the time-compressed paragraphs and identify three pairs of related elements in each paragraph. The procedure used in this study followed closely the procedure used by Letowski and Poch (1995). Subjects were given a matrix for each paragraph. The matrix contained four rows and four columns (16 blocks). The subject's task was to place X's in 3 of the 16 blocks, which showed how the items listed on the matrix were connected in the context of the paragraph. One item in a row and one item in a column were mentioned but not connected in the context. The subjects' responses were coded from 0 to 3 according to the number of correctly identified elements. Subjects received written instructions and verbal direction during the practice session, which preceded the actual test session (see Letowski and Poch, 1995).

During the test session, each subject listened to 30 different time-compressed paragraphs repeating each CR 10 times and each DIL six times. The order of presentation of the three CRs was counterbalanced in three blocks of 10 paragraphs each. The order of presentation of the five DILs was counterbalanced in six blocks of five paragraphs each. In addition, the first five paragraphs presented in the test session were repeated for each subject at the end of the session in order to provide test–retest reliability data.

RESULTS AND DISCUSSION

The effects of DIL, CR, speech material, and group on perception of time-compressed speech were analyzed using a SYSTAT data analysis package (Wilkinson, 1988). Initial data analysis was performed separately for each group of listeners and the results for both groups were compared later. Two repeated measures analyses of variance (ANOVAs) on three factors were conducted. These factors included speech material (two levels), CR (3 levels), and DIL (five levels). All of the data were arcsine transformed before analysis. The ANOVA results for middle-aged adults showed significant effects of speech material ($F = 31.73$, $df = 1/14$, $p < .01$), CR ($F = 252.52$, $df = 2/28$, $p < 0.1$), DIL ($F = 25.93$, $df = 4/56$, $p < .01$), and CR × DIL interaction ($F = 3.33$, $df = 4/56$, $p < .02$). The ANOVA results for older adults show similar significant effects of speech material ($F = 42.05$, $df = 1/14$, $p < .01$), CR ($F = 299.95$, $df = 2/28$, $p < .01$) and DIL ($F = 20.31$, $df = 4/56$, $p < .01$) but no significant interaction between factors. In all tests, the Greenhouse-Geisser correction was applied (Greenhouse and Geisser, 1959).

The effects of CR and DIL and their interactions are illustrated on Figures 1 through 8

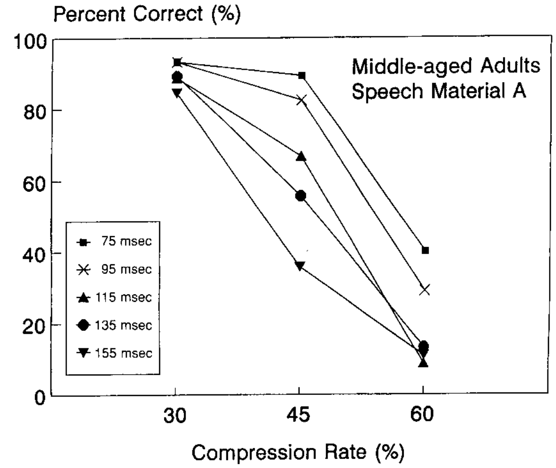

Figure 1 Percent of correct responses as a function of discard interval length. Average data for middle-aged adults and speech material A. Curves represent data for different compression rates.

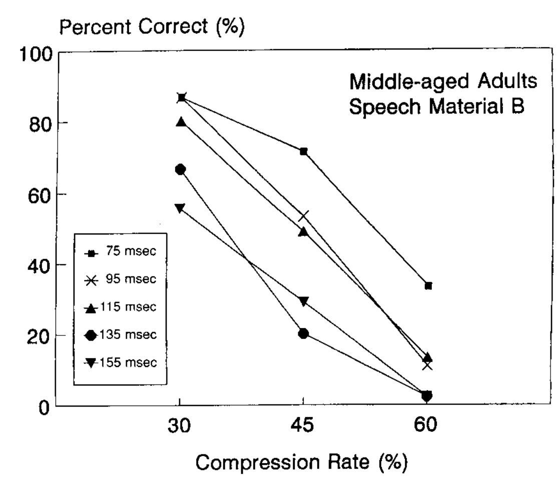

Figure 2 Percent of correct responses as a function of discard interval length. Average data for middle-aged adults and speech material B. Curves represent data for different compression rates.

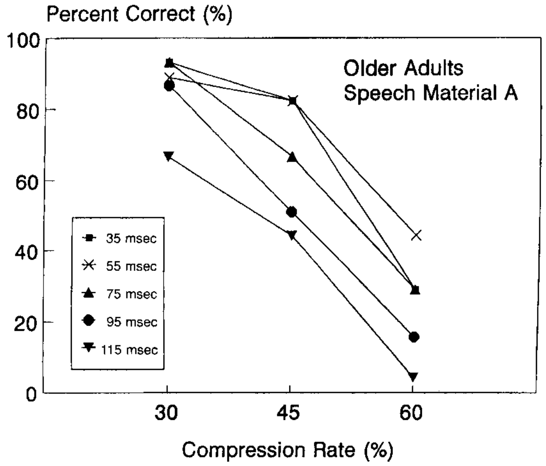

Figure 3 Percent of correct responses as a function of discard interval length. Average data for older adults and speech material A. Curves represent data for different compression rates.

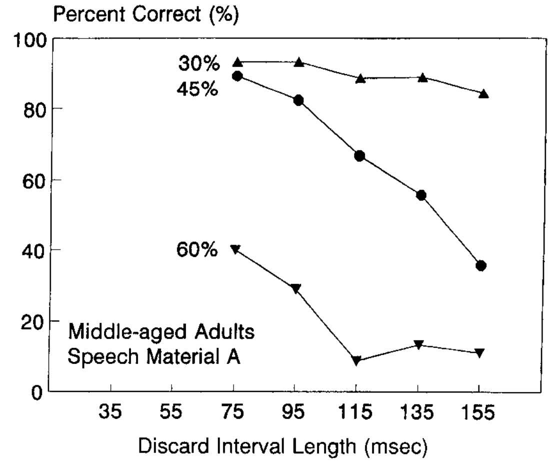

Figure 5 Percent of correct responses as a function of compression rate. Average data for middle-aged adults and speech material A. Curves represent data for different discard interval lengths.

showing percentages of correct responses as a function of CR (Figs. 1–4) and DIL (Figs. 5–8) for four combinations of group × speech material. Please note different DIL ranges in the figures for older and middle-aged subjects. Post hoc contrast analysis revealed that, for all combinations of group × speech material, the differences among the CRs were statistically significant. For older adults, significant differences between successive DILs were 95 msec and 115 msec for speech material A ($F = 8.53$, $df = 1/14$, $p < .01$) and between 75 msec and 95 msec for speech material B ($F = 10.72$, $df = 1/14$, $p < .01$). For middle-aged adults, there was a significant difference between DILs of 95 msec and 115 msec for speech material A compressed at CR = 45 percent ($F = 25.87$, $df = 1/14$, $p < .01$), but not for other CRs, and between DILs of 75 msec and 95 msec ($F = 5.31$, $df = 1/14$, $p < .04$) and 115 msec and 135 msec ($F = 32.53$, $df = 1/14$, $p < .01$) for speech material B.

Figures 1 and 3 and Figures 2 and 4 are relatively similar to each other, although they display DIL data that differ by 40 msec. This similarity is especially large for the middle curves in both respective graphs. This means that the average performance of the older adults for DILs of 55 and 75 msec is similar to that of

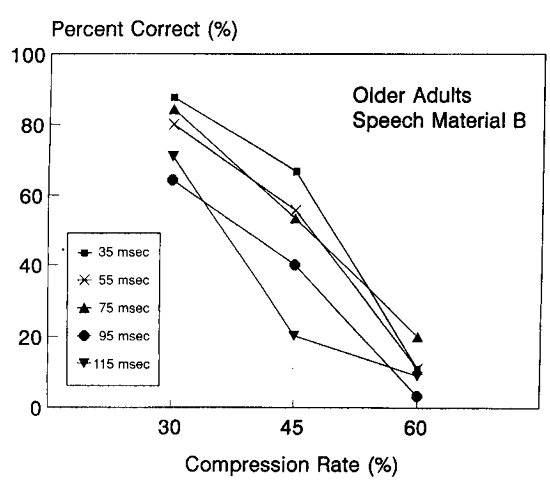

Figure 4 Percent of correct responses as a function of discard interval length. Average data for older adults and speech material B. Curves represent data for different compression rates.

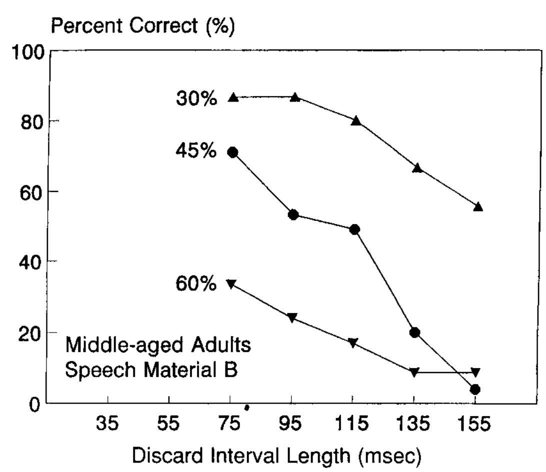

Figure 6 Percent of correct responses as a function of compression rate. Average data for middle-aged adults and speech material B. Curves represent data for different discard interval lengths.

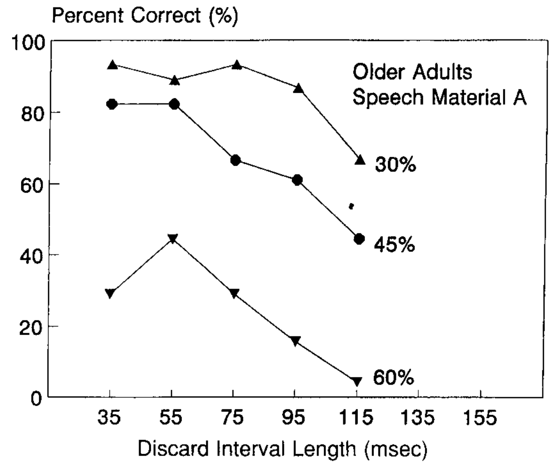

Figure 7 Percent of correct responses as a function of compression rate. Average data for older adults and speech material A. Curves represent data for different discard interval lengths.

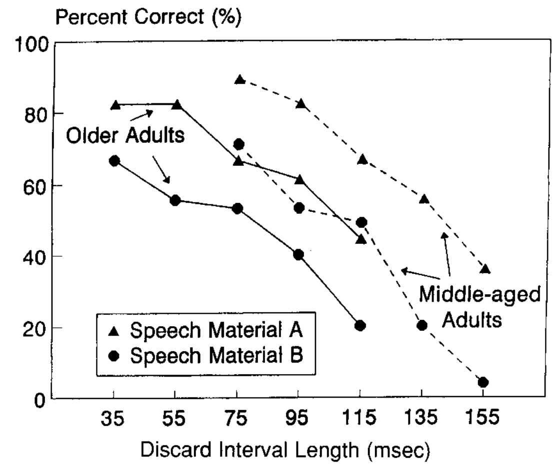

Figure 9 Percent of correct responses as a function of discard interval length. Data for middle-aged (broken lines) and older (solid lines) adults and speech materials A (triangles) and B (circles).

middle-aged adults for DILs of 95 and 115 msec. The same conclusion can be reached after inspecting Figures 5 through 9.

The subjects' understanding of speech material B was always poorer than that of speech material A when all other experimental conditions were the same. We hypothesized that this effect could be caused by the difference in the average sentence length between both speech materials. Assuming that older adults have greater difficulties in using semantic and syntactic clues than younger listeners (Newman, 1983; Newman and Spitzer, 1983), the reported difference in the average length of sentences used in both speech materials may be responsible for observed differences in subjects' performance. Separate ANOVAs for each of the speech materials and each of the subject groups confirmed similar significant effects of CR and DIL in all four cases (2 groups × 2 speech materials). The only exception was the nonsignificant effect of the CR × DIL interaction for speech material B and middle-aged adults.

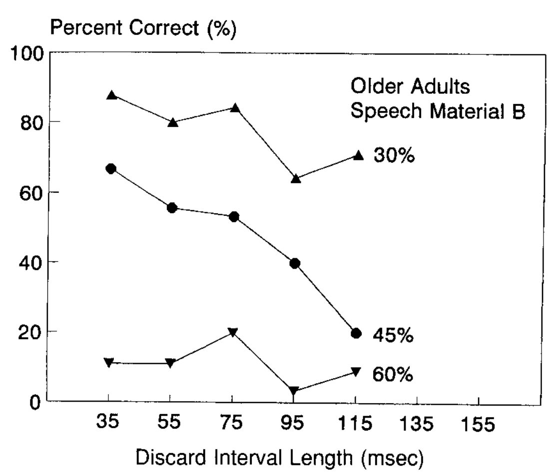

Figure 8 Percent of correct responses as a function of compression rate. Average data for older adults and speech material B. Curves represent data for different discard interval lengths.

To assess the differences between scores obtained by middle-aged and older adults, a separate mixed-design ANOVA was conducted. The analysis was similar to the two initial analyses except that an additional group factor (two levels) was included and that DILs were limited to three values (75, 95, and 115 msec), that is, to the values that were the same for both groups. The results showed a significant group effect ($F = 23.06$, $df = 1/28$, $p < .01$) and confirmed all other significant effects previously observed for each group of subjects separately. In general, the average difference in performance between groups of listeners for the same time-compression conditions and the same speech material was approximately 20 percent (see Fig. 9). It is coincidental that the same average difference of 20 percent can be observed for 45 percent CR in speech comprehension of both speech materials by the same group of listeners.

The comparison of test and retest data for speech material A did not reveal significant differences between both sets of data. This result indicated that perception of time-compressed speech did not significantly change within one test session. This is an important finding for future development of speech processing tests using time-compressed connected speech.

Individual differences among the listeners were assessed using both cluster and overall score analysis. The subjects were clustered according to their performance across the two speech materials, three CRs, and three DILs (75, 95, and 115 msec). Overall performance of older adults did not show any clear clustering. The subjects formed long, stringy clusters, indicating lack of well-defined subgroups. The overall scores of 12 older subjects were very similar and fell in the 40.1 to 48.2 percent range. One subject performed much poorer (35.2%) and two subjects much better (55.6% and 61.1%) than the rest of the group. The subject who performed the poorest (S20) had hearing thresholds in both ears of 20 dB HL or better at all test frequencies. Her difficulty with speech understanding cannot therefore be explained by peripheral hearing loss. It is also noteworthy that the best subject in this group (S17) was the only musician among the subjects. Her performance was better than that of most of the middle-aged subjects.

Intrasubject variability in the middle-aged adult group was greater than in the older adult group. The average performance of middle-aged adults varied from 46.3 percent to 74.1 percent. Again, however, no well-defined clustering could be found. Nevertheless, five subjects performed at a level comparable to that of older adults and one subject (S1) outperformed all other subjects by at least 5.6 percent. No relation of performance to hearing threshold configuration could be found. It is noteworthy, however, that S1 was the youngest of all of the subjects and the five subjects who experienced the greatest difficulties were the five oldest subjects in the middle-aged group.

Comparison of subjects' scores with their sociophysiologic profiles developed on the basis of the intake questionnaire did not reveal any patterns or dependencies. Profession, education, years in retirement, overall physical health, social activity, and hearing self-report did not correlate significantly with the subjects' performance. All of the subjects reported their hearing as "good" but eight of them—five middle-aged and three older adults—also reported that other people (family members, friends) thought to the contrary. These eight people did not perform significantly poorer than the other subjects in their respective groups but, at the same time, their scores were usually in the bottom halves of the respective groups.

The Spearman correlation coefficient between time-compressed speech comprehension score and listener age was –0.76 and between comprehension score and Digit Symbol Substitution Test score was 0.27. Both r's were significant at $p < .05$ level. The difference between average Digit Symbol Substitution Test scores for middle-aged adults (mean = 59.4, SD = 10.8) and older adults (mean = 55.7 and SD = 8.7) was not statistically significant ($p > .31$). These results seem to indicate that the listener's speech processing capabilities were negatively correlated with age and fairly independent of the listener's working memory storage capacity (Daneman and Carpenter, 1980). As regards the latter, it also is possible that the Digit Symbol Substitution Test is just not sensitive to the cognitive needs of speech processing.

In Figure 10, the data for the middle-aged (mean = 47.1 years) and older (mean = 66.9 years) adults obtained in the present study are compared with the data for the young (mean = 32 years) and older (mean = 66.5 years) listeners reported in our previous studies (Poch, 1992; Letowski and Poch, 1995). The comparison involves the same speech material (speech material A), the same subject task, and similar CRs (45% vs 50%). Scores for the young (Poch, 1992) and middle-aged (this study) adults were practically identical (93% vs 89.3%), indicating that, throughout the fifth decade of life, there is small if any change in speech processing capabilities. Speech comprehension scores for older (this study) and old (Letowski and Poch, 1995) adults

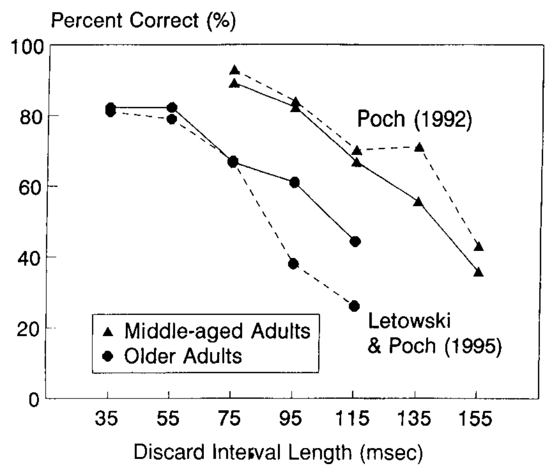

Figure 10 Percent of correct responses as a function of discard interval length. Data for middle-aged (triangles) and older (circles) adults. Comparison with the data for young adults (20–30 years old) reported by Poch (1992) and for old adults (60–75) reported by Letowski and Poch (1995).

were again very similar (66.6% vs 67%) but significantly poorer than those for both younger groups. This implies that the slowing of speech processing begins typically in the sixth decade of life. It is noteworthy that the data for older and old adults presented in Figure 10 do not differ for short DILs but become significantly different for longer DILs. This difference may be related to the wider age range of older subjects participating in the previous (60–75 years) than in the current (60–69 years) study.

Finally, it is important to stress that the periodic sampling method of time compression that was used in this and most of the other previous studies not only reduces the amount of information in the speech signal but also introduces a certain amount of nonlinear distortions resulting from periodic chopping. Both of these effects might have influenced presented data since it is known that older listeners are more affected by multiple distortion conditions (complexity hypothesis) than younger listeners (Carella et al, 1980). Thus, in future studies, the effects of time-compressed speech produced with the periodic sampling method should be compared against the effects caused by another method, which does not introduce audible secondary distortions. One such method is the Synchronized OverLap Add (SOLA) technique developed by Roucus and Wilgus (1985). The SOLA technique uses the redundancy of speech by overlapping and cross-correlating successive frames of the speech signal. The resulting time-compressed speech is produced without deletions of entire portions of the original signal and with no audible degradation of sound quality. This may be, however, a mixed blessing because such high-quality speech may not be as sensitive a measure of central auditory dysfunctions as periodically sampled time-compressed speech. It is plausible that multiple distortion of speech material may interact with reduced neural redundancy where there is pathology affecting the auditory system (Bornstein, 1994). Thus, speech processed with the periodic sampling method may be a more sensitive diagnostic indicator of auditory/cognitive dysfunction than speech processed with the SOLA algorithm.

CONCLUSIONS

1. Both DIL and CR affect comprehension of time-compressed speech. Interaction between DIL and CR becomes weaker with both increasing age of the listener and complexity of speech material.
2. Middle-aged and older adults differed in the comprehension of time-compressed speech. The change in age from the fifth (middle-aged adults) to the seventh decade (older adults) decreased the comprehension of the speech material used in this study by approximately 20 percent. This finding supports the hypothesis that there is an age-related decline in speech processing by aging adults.
3. No significant differences were observed in the comprehension of time-compressed speech by young (Poch, 1992) and middle-aged (this study) adults. This supports the notion that an age-related decline in the speed of central auditory processing and/or mental functions begins in the sixth decade.
4. Old adults (Letowski and Poch, 1995) and older adults (this study) performed similarly at low CRs and short DILs. The performance of old adults was, however, poorer at higher CRs and longer DILs. Since Letowski and Poch's (1995) subjects extended toward higher ages, this finding indicates that, at the age of 70+, difficulties in speech comprehension increase more rapidly with increased difficulty of the listener task or speech material than at younger ages.
5. Changes in the comprehension of time-compressed speech observed in this study seem to be affected primarily by the process of aging. The small differences in hearing loss among participating subjects did not affect comprehension in a systematic manner. In addition, no significant relationships between the listeners' scores and their responses to the general health questionnaire could be found.
6. Differences in the length and resulting complexity of individual sentences between speech materials A and B affected the comprehension of time-compressed passages. Greater sentence complexity of speech material B similarly affected both groups of listeners.
7. In order to make time-compressed speech a sensitive test material for comparing speech comprehension by people of various ages, the DIL value should be kept within a 60- to 70-msec range. The optimal time compression rate is about 50 percent, which agrees well with the assumption that about 50 percent of the natural speech is redundant (Fodor et al, 1974). The above conclusions are limited to

speech compression produced using the periodic sampling method. Further studies should define optimal parameters for other time-compression methods (e.g., SOLA method).

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APPENDIX A
General Health Questionnaire

NAME ______________________ D.O.B.______________________

ADDRESS______________________ S.S.N. ______________________

____

TELEPHONE ______________________

1. Are you retired? ____ If so, how long have you been retired?
2. In what type of work have you been employed for the majority of your working career?

   ____ Executive/Business ____ Executive/Industry ____ Clerical

   ____ Labor ____ Secretarial ____ Sales

   ____ Teaching: ____ K–6th ____ Jr./Sr. High; ____ College/University

   ____ Other: Please explain ______________________
3. Do you volunteer your time outside the home?

   ____ Over 10 hours per week

   ____ 5–10 hours per week

   ____ 1–5 hours per week

   ____ Less than 1 hour per week

   ____ Never
4. How much time do you spend outside of the home for social activities?

   ____ More than 10 hours per week

   ____ Between 5 and 10 hours per week

   ____ Between 1 and 5 hours per week

   ____ Less than 1 hour per week
5. What is your educational background?

   ____ Did not finish high school

   ____ High school diploma

   ____ Specialized training such as business school or voc. tech.

   ____ Associate degree

   ____ Bachelor's degree

   ____ Master's degree

   ____ Advanced degree such as Ph.D., M.D., Ed.D., etc.
6. Please report any health problems, current or past. These include surgery, chronic disorders (example: skin problems), acute illnesses. Please try to write down when these health disorders occurred and if they are ongoing.

   ____

   ____

   ____

   ____
7. Do you have problems hearing in any of the following situations? Check all that apply:

   ____ One-to-one conversation ____ Parties ____ Work

   ____ Restaurants ____ Movies ____ Radio

   ____ Television ____ Automobile ____ Telephone
8. In general, do you think your hearing is: ____ Good? ____ Fair? ____ Poor?
9. Do your family and/or friends think you have a hearing problem?