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# Intelligibility of Clear Speech at Normal Rates

# For Older Adults with Hearing Loss

by

Billie Jo Shaw

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
Department of Communication Sciences and Disorders
College of Arts and Sciences
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speech processing, hearing aids

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# Intelligibility of Clear Speech at Normal Rates for Older Adults with Hearing Loss

Billie Jo Shaw

## ABSTRACT

Clear speech refers to a speaking style that is more intelligible than typical, conversational speaking styles. It is usually produced at a slower rate compared to conversational speech. Clear speech has been shown to be more intelligible than conversational speech for a large variety of populations, including both hearing impaired (Schum, 1996; Picheny, Durlach, & Braida, 1985; and Payton, Uchanski, & Braida, 1994) and normal hearing individuals (e.g. Uchanski, Choi, Braida, Reed, & Durlach, 1996) under a variety of conditions, including those in which presentation level, speaker, and environment are varied. Although clear speech is typically slower than normally produced conversational speech, recent studies have shown that it can be produced at normal rates with training (Krause & Braida, 2002). If clear speech at normal rates is shown to be as effective for individuals with hearing loss as clear speech at slow rates, it would have both clinical and research implications.

The purpose of this study was to determine the effectiveness of clear speech at normal rates for older individuals with hearing loss. It examined the way in which intelligibility, measured as percent correct keyword scores on nonsense sentences, varied as a result of speaking mode (clear versus conversational speech) and speaking rate (slow versus normal) in six adults aged 55-75 years old with moderate, sloping, hearing loss. Each listener was presented with nonsense sentences in four speech conditions: clear speech at slow rates (clear/slow), clear speech at normal rates (clear/normal), conversational speech at slow rates (conv/slow), and conversational speech at normal rates (conv/normal) read by four different talkers. Sentences were presented monaurally in quiet to the listeners via headphones.

Results indicated that clear/slow speech was the most intelligible condition overall. Neither conv/slow nor clear/normal provided an intelligibility benefit relative to conv/normal speech on average, suggesting that for older adults with moderate, sloping hearing loss, the combination of using clear speech and a slower speaking rate is more beneficial to intelligibility than the additive effects of altering either speaking rate or speaking mode alone. It has been suggested previously (Krause, 2001) that audiological characteristics may contribute to the lack of clear/normal benefit for certain listeners with hearing loss. Although clear/normal speech was not beneficial on average to listeners in this study, there were cases in which the clear/normal speech of a particular talker provided a benefit to a particular listener. Thus, severity and configuration of hearing loss alone cannot fully explain the degree to which listeners from hearing loss do (or do not) benefit from clear/normal speech.

More studies are needed to investigate the benefits of clear/normal speech for different audiological configurations, including individuals with flat losses. In addition, the listening tasks should include more difficult conditions in order to compensate for potential ceiling effects.

# Chapter 1

## Introduction

The purpose of this study was to determine the effectiveness of clear speech at normal rates for older individuals with hearing loss.  It examined the way in which intelligibility, measured as percent correct keyword scores on nonsense sentences presented in quiet, varies as a result of speaking mode (clear versus conversational speech) and speaking rate (slow versus normal) in adults aged 55-75 with moderate, sloping, hearing loss.

Clear speech refers to a speaking style that is more intelligible than typical, conversational speaking styles.  The term can also be used to describe the speaking style utilized by talkers when attempting to speak more clearly. Clear speech, which is typically produced at a slower rate of speech, has been shown to be more intelligible for a large variety of populations, including both hearing impaired (Schum, 1996; Picheny, Durlach, & Braida, 1985; and Payton, Uchanski, & Braida, 1994) and normal hearing individuals (e.g. Uchanski, Choi, Braida, Reed, & Durlach, 1996; Krause & Braida, 2002; Gagne, Rochette, & Charest, 2002). The results of these studies indicate that clear speech is effective for increasing overall intelligibility under a variety of conditions, including those in which presentation level, speaker, and environment are varied.

Although clear speech is typically slower than normally produced conversational speech, recent studies have shown that it can be produced at normal rates with training

(Krause & Braida, 2002). Since clear speech at normal rates is a relatively new breakthrough, it is necessary to test its effectiveness in various environments and with various populations. Because rate is a factor in intelligibility, one cannot assume that all of the previously established benefits of clear speech at slow rates will also extend to clear speech at normal rates.

There is particular interest in the intelligibility benefit of clear speech at normal rates for individuals with hearing loss. If clear speech at normal rates is shown to be as effective with this population as clear speech at slow rates, it would have both clinical and research implications. It is possible that caregivers and family members would be able to utilize clear speech at normal rates effectively when addressing individuals with hearing loss, enhancing communication efficiency and thereby increasing quality of life. In addition, future studies into the acoustic differences between clear and conversational speech at normal rates may result in a better understanding of acoustic-phonetic factors contributing to intelligibility. Such an understanding may also be applied to improving hearing aid technology. Furthermore, these studies may also identify common characteristics of individuals who benefit from the use of clear speech, as well as characteristics of those who do not benefit from its use.

# Chapter 2

# Literature Review

## *Intelligibility of Clear Speech*

Picheny et al. (1985) were the first to report that overall intelligibility increased significantly when speakers were instructed to speak clearly.  In that study, three male speakers were recorded utilizing both clear and conversational speech while reading nonsense sentences. Five listeners with moderate to severe sensorineural hearing loss (pure tone averages ranged from 45-74 dB SPL) were presented with sentences in quiet at three different levels:  most comfortable loudness level (MCL), maximum listening level (MAX), and MCL-10 dB.  In addition, two types of frequency-gain characteristics were utilized:  ORTH (orthotelephonic: stimuli presented with a relatively flat frequency-gain characteristic), and OMCL (octaves most comfortable level: stimuli were filtered into four octave bands, with each band adjusted to MCL). This resulted in a total of 36 experimental conditions (3 talkers x 2 modes x 3 listening levels x 2 frequency-gain characteristics).  Each listener was presented with 50 sentences for each experimental condition. Use of clear speech resulted in increased intelligibility of all phoneme classes studied for these listeners with sensorineural hearing loss.  The phoneme categories included:  fricatives, plosives, semivowels, nasals, and vowels.  In addition, the overall intelligibility of clear speech, averaged across speakers, was 17 percentage points higher than that of conversational speech.

Subsequent studies have shown that the intelligibility benefit obtained from clear speech is a very robust phenomenon. For example, Schum (1996) determined that unpracticed talkers were able to produce more intelligible speech when asked to speak clearly. This was true regardless of the speaker's age. Ten young speakers (aged 22-39 years old) and ten elderly speakers (aged 62-70 years old) participated in the study. All talkers produced clear speech which led to intelligibility scores greater than those obtained for conversational speech by listeners aged 60-77 years old with sensorineural hearing loss. Each listener had auditory thresholds (averaged over 500, 1000, 2000, and 4000 Hz) that fell between 20 and 70 dB HL in at least one ear. Percent-correct scores were converted to rationalized arcsine transform units (RAUs). This conversion equalizes the variance across performance levels, while producing numerical values in RAUs that are similar to the original percent-correct scores (Studebaker, 1985). The average increase in intelligibility for young talkers was 22 RAU, and 17 RAU for older talkers. These findings were consistent with earlier studies conducted by Picheny et al. (1985). Even though the speakers in Schum's (1996) study were not given specific instructions on how to produce clear speech, all were able to produce speech with improved intelligibility and all listeners benefited, indicating a very strong effect.

*Acoustical Factors*

Once large and consistent intelligibility benefits of clear speech had been established, researchers also began to focus on the acoustical differences between clear and conversational speech to determine which acoustic properties might be responsible for the improvement. In 1986, Picheny, Durlach, and Braida analyzed differences between clear and conversational speech. Their results can be classified into global, phonological, and phonetic differences. Significant global differences included differences in average speaking rates and pause distributions. The average speaking rate for clear speech was 90-100 words per minute (wpm), compared to 160-200 wpm for conversational speech. In addition, the number and duration of pauses increased during clear speech. Phonological differences between clear and conversational speech included frequency of occurrence for vowel reduction (vowels that became schwa-like), burst elimination (stop consonants that were produced without the burst), and sound insertions (schwa vowels that were inserted after voiced consonants). Vowel reduction decreased by approximately 50% in clear speech as compared to conversational speech. Burst elimination occurred in approximately 60% of opportunities in conversational speech, but only in approximately 15% of opportunities for clear speech (Picheny et al., 1986). Other phonological differences, including degemination (identical phonemes merging into one sound across word barriers), alveolar flap, and miscellaneous sound deletions were not as pervasive overall, and did not differ substantially between clear and conversational speech. Phonetic changes included differences in short-term RMS spectra, and segmental phone durations. Clear speech produced minimal changes to formant frequencies. Clear speech samples indicated increased segmental phone duration for tense vowels, and increased VOT for unvoiced plosives. Changes in vowel space were noted more frequently in lax vowels under clear speech conditions (Picheny et al., 1986).

In the studies conducted by Picheny et al., some speakers were naturally more clear than others regardless of speaking mode. Other studies aimed at identifying acoustic characteristics of highly intelligible speech therefore focused on determining why some speakers were more intelligible than others, even when all speakers were utilizing clear speech. Gagne, et al., (2002) noted significant intraspeaker differences in intelligibility for the same stimuli, produced in the same speaking style (57 occurrences of statistically significant differences out of 216 paired comparisons). In addition, not all speakers in this study produced consistent significant clear speech benefits. Bradlow, Torretta, and Pisoni (1995) also examined the acoustic characteristics that make some talkers more intelligible than others. Results from the study indicated that overall intelligibility was not correlated with mean fundamental frequency. However, clear speech tended toward a wider fundamental frequency range. In addition, there was a significant positive correlation between F1 range and intelligibility. There was no significant correlation between intelligibility and the range for F2.

*Rate*

After the initial findings of acoustic differences between clear and conversational speech, one hypothesis was that rate, and the number and duration of pauses, were the primary factors affecting intelligibility of speech. This hypothesis stemmed from the recognition of rate as the most obvious and consistent difference between clear and conversational speech. Therefore, early research focused on the role of rate in clear speech. For example, a study was conducted in which clear speech sentences were sped up using a uniform time-scaling process in which the duration of all elements of the clear speech sample were altered by the same amount. This procedure allowed researchers to alter the durations of sentences and produce sped clear speech sentences with the same overall duration as conversational speech (Picheny, Durlach, & Braida, 1989). In addition, conversational speech sentences were submitted to similar time-scale modifications to slow the speech, resulting in conversational speech sentences with the same overall duration as clear speech. The stimuli were presented to five listeners with sensorineural hearing loss. Both processed speech conditions (altered clear, altered conversational) resulted in reduced intelligibility scores. The average decrease in scores for processed conversational (i.e. slowed) speech was 15 percentage points. The average decrease for processed clear (i.e. sped) speech was 29.8 percentage points. In order to rule out the effect of processing as a factor, the stimuli were processed again in order to restore their original rates. This restored speech also resulted in scores lower than those of unprocessed speech for both clear and conversational stimuli. However, the differences were within an average of eight percentage points of the original speech. This indicates that signal processing had some adverse effect on intelligibility, but not enough to account for the sizeable decreases in intelligibility scores obtained for processed speech in both conversational and clear modes. Therefore, uniform changes in speaking rate alone are not responsible for differences in intelligibility.

Another study of the role of rate in clear speech was conducted using nonuniform time scaled speech (Uchanski, Choi, Braida, Reed, & Durlach, 1996). This study used the same speakers and nonsense sentences as the study conducted by Picheny et al. (1989) but differed from the earlier research in that nonuniform processing altered the rate phoneme by phoneme (Uchanski et al., 1996), rather than uniformly expanding or contracting the entire sentence (Picheny et al., 1989). Non-uniform processing was achieved by measuring the durations of matching segments in clear and conversational speech and inserting or deleting amplitude spectra within the spectrogram to achieve the desired change in duration. As in the previous time-scaling study (Picheny et al., 1989), the sentences were processed to achieve slowed conversational and accelerated clear speech, and reprocessed in order to return them to their original rates and control for processing of the stimuli as a potential intelligibility factor. The subjects consisted of four individuals with hearing loss, and two individuals with normal hearing. The results of this study were compared to those of Picheny et al. (1989). Overall, nonuniform time scaling had a less deleterious effect on intelligibility than uniform time scaling, but no benefit was found for slowing conversational speech in this manner. On average, processed (i.e. slowed) conversational speech resulted in a 5 percentage point decrease when nonuniform time scaling was utilized, as compared to the 15 percentage point decrease obtained for uniform time scaling. Similarly, the intelligibility of processed (i.e. accelerated) clear speech decreased by an average of six percentage points when nonuniform time scaling was employed, compared to 29.8 percentage points for uniform time scaling. Speeding up clear speech had a negative effect on intelligibility, while slowing down conversational speech also resulted in decreased intelligibility. Therefore, it can be concluded that clear speech intelligibility involves factors other than a simple decrease in speaking rate. These findings are supported by those of Bradlow et al. (1995), which showed no correlation between speaking rate and speech intelligibility.

After these failed attempts to produce clear speech at normal rates through signal processing, Krause and Braida (2002) conducted a study to determine whether clear speech at normal rates could be obtained naturally. Researchers were able to train speakers to produce clear speech at normal rates. A metronome was utilized during training to assist speakers in maintaining their individual normal rates. In addition, the speakers received continuous feedback on the intelligibility of their productions. Eight listeners (four male, four female), who were native English speakers with normal hearing, were presented with a variety of speech stimuli at a signal-to-noise ratio (SNR) of -2 dB. Intelligibility was measured in six different speech conditions: clear speech at slow (clear/slow), normal (clear/normal), and quick (clear/quick) rates; and conversational speech at slow (conv/slow), normal (conv/norm), and quick (conv/quick) rates. The results of the study indicate that clear speech at slow rates was the most intelligible condition, averaging 63% keywords correct. This was followed closely by clear speech at normal rates (59%), conversational speech at slow rates (51%), and clear speech at quick rates (46%). Findings from this study suggest that the intelligibility benefit of clear speech is mostly independent of rate, talker, and listener for normal hearing listeners in noise. Although cross-talker differences were noted, all talkers' intelligibility increased when utilizing clear speech as compared to conversational speech (Krause & Braida, 2002). Since normal hearing listeners obtained comparable benefits for clear/slow and clear/normal speech (compared to conv/normal), the question has been raised as to whether clear speech at normal rates has comparable benefits for other populations and environments that show benefit from clear speech produced at slow rates.

*Clear Speech at Slow Rates*

Clear speech at slow rates has been shown to be beneficial in several different environments and to have positive effects for a variety of populations. For example, Gagne et al. (2002) examined the benefits of clear speech in audio, visual, and audiovisual environments. The study consisted of 6 female talkers, and 12 listeners (11 female and 1 male) with hearing and vision within normal ranges. The primary language for all participants was French. The subjects were divided into small groups and presented with each of auditory, visual, and audiovisual stimuli. Scores were based on percent-correct syllable recognition tasks. Results indicated a positive clear speech effect for all three modalities. For the auditory-speech condition, six of six talkers produced significant improvements in intelligibility (13% on average) of clear speech, and five of six talkers produced significant clear speech results for both the visual-speech (9.6% on average) and audiovisual-speech (6.8% on average) conditions.

A similar study examined the effects of visual-only cues and auditory-only conditions in clear speech (Helfer, 1997). Results of that study indicated that the benefits of clear speech for visual-only cues and auditory-only conditions were additive for nine young, normal hearing individuals. Comparing auditory-only scores, clear speech produced an approximately 10 percentage point advantage over conversational speech. When visual cues were included, auditory-visual clear speech stimuli produced perceptual scores approximately 15 percentage points higher than auditory-visual conversational stimuli.

Additional research on listening environments has examined the intelligibility benefits for clear speech at slow rates presented in reverberation and background noise (Payton et al., 1994). Three individual experiments were conducted. Five normal hearing and two hearing impaired listeners were exposed to simulated acoustic environments featuring three levels of reverberation, three levels of noise, and three combinations of noise and reverberation. The results of the study indicate that clear speech was more intelligible in every environment for every listener, both normal hearing and hearing impaired. There was an overall difference of 21 percentage points between clear and conversational speech when scores were averaged across listeners, experiments and environments.

Krause and Braida (2003) examined the effectiveness of clear speech at slow rates in three types of signal degradation conditions: reverberation, low pass, and high pass environments. Five native English speakers with normal hearing were presented aurally with nonsense sentences. A different group of listeners was employed for each condition tested. The results of this study indicated that clear speech was consistently more intelligible than conversational speech across all environments.

In addition to these various environments, clear speech at normal rates has been shown to help speech perception in different populations. For example, one study (Helfer, 1998), indicated that older listeners (aged 61-88 years old) benefit from both visual cues and clear speech. Fifteen subjects within this age range were recruited for the study. There were no restrictions on hearing thresholds, thus ensuring a range of hearing loss among the subjects. According to Helfer's (1998) findings, hearing loss was not correlated with the size of clear speech benefit, indicating that clear speech should present some benefit to older listeners, regardless of audiological thresholds.

Working with a different population, Bradlow, Kraus, and Hayes, (2003) examined the perceptual effects of naturally produced clear speech at slow rates for 63 children diagnosed with learning disabilities. Results of that experiment indicated that the magnitude of the clear speech effect was 9.2 on the RAU scale for this population. In addition, pairwise comparisons of speech reception scores indicated that children with learning disabilities, when presented with clear speech stimuli, performed comparably to children without diagnosed learning disabilities who were presented with conversational speech stimuli. These results imply that clear speech has the potential to correct for decreased perceptual effects resulting from learning disabilities in children.

Bradlow and Bent (2002) examined the effects of naturally produced clear speech at slow rates on another population, non-native listeners. The subjects for this study consisted of a group of normal-hearing native English listeners, and a group of 32 normal-hearing non-native English listeners. Although two talkers produced stimuli sentences, each participant heard English sentences read by only one talker. Conditions included clear and conversational sentence productions at two different signal-to-noise ratios, -4 dB and -8 dB. The non-native listeners showed a clear speech benefit of 5 RAU overall. However, this benefit was smaller than that for native listeners, which was 16 RAU.

In a later study, Krause and Braida (2003) also examined the effects of clear speech on intelligibility for non-native listeners. In contrast to the results of Bradlow and Bent (2002), Krause and Braida found the clear speech benefit for non-native listeners (25.5 percentage points averaged across two talkers) to be comparable to the benefit for native listeners (27 percentage points averaged across two talkers). The discrepancy in the results from these two studies may be related to differences in amount and length of listeners' exposure to English or the nature of the speech materials utilized in the experiments. Bradlow and Bent (2002) used meaningful sentences, while Krause and Braida used nonsense sentences for their study.

*Clear Speech at Normal rates*

The finding that speakers can be trained to produce clear speech at normal rates (Krause, 2002) has led to studies aimed at determining whether clear speech at normal rates has comparable benefits for the same sets of populations and environments as clear/slow speech. Because this is a relatively new development, most of the work to date which focuses on clear speech at normal rates to date has concentrated on listeners with normal hearing. For example, Krause and Braida (2002) first demonstrated that clear speech at normal rates had a 14 point benefit in noise for eight individuals with normal hearing. In a subsequent study, this benefit was replicated with five normal hearing listeners. Results from this second study indicated clear/normal intelligibility averaging 51.3% across talkers, and conv/normal averaging 34.8%. This resulted in a 16.5 percentage point advantage for the clear/normal condition (Krause, 2001).

Continuing their examination of the effectiveness of clear speech at normal rates, Krause and Braida (2003) studied the effects of listening environment and population on clear speech at normal rates. Normal hearing listeners were presented with stimuli from two speakers in three different conditions: low pass (1/3 octave bands with center frequencies ranging 80Hz-1000Hz), high pass (1/3 octave band with a center frequency of 3150Hz), reverberant (sentences were convolved to produce effects similar to a room with 0.60 reverberation impulse response time). In addition, stimuli were presented to non-native listeners in speech shaped noise at a signal to noise ratio of 0 dB. Listeners in the non-native condition consisted of normal hearing listeners who learned English as a second language. For all conditions tested, results indicated a clear speech benefit for clear/slow speech. However, results for clear/normal speech varied with talker and condition (low pass, high pass, reverberation, non-native listener). One talker (T5) showed increased intelligibility for clear/normal speech in three out of four conditions, while the other talker (T4) showed increased intelligibility for clear/normal speech in only one out of four conditions.

With the completion of this preliminary work investigating the clear speech benefit at normal rates for listeners with normal hearing, a natural next question is whether or not clear speech produced at normal rates is beneficial to people with hearing loss. Krause (2001) conducted a preliminary study of intelligibility of speech presented in a variety of conditions for three listeners with stable sensorineural hearing losses. Three speaking modes were presented at a normal rate: clear, conversational, and processed conversational. In addition, two speaking modes were presented at a slow rate: conversational and processed conversational. The processed conditions were created by modifying formant frequencies, fundamental frequencies, and temporal envelopes in order to mimic the acoustic properties of clear speech. Results of this study indicated that clear/normal speech was the most intelligible condition at normal rates (69%), followed by conv/normal (62%). Processed conditions ranged from 61%-23% intelligibility. Although clear/normal speech produced an advantage of 7 percentage points over conv/normal, this benefit was not statistically significant. There are several factors that may be related to this lack of significance. These include the age of listeners, degree and audiological configuration of hearing loss, and the limited number of subjects in the study. More research is needed to examine these factors more thoroughly.

*Additional Factors*

While not specific to clear speech, much is known about the effects of age and audiological thresholds on speech perception. Dubno, Dirks, and Morgan (1984) examined the effects of mild sensorineural hearing loss and chronological age on speech recognition in noise. Four groups of listeners served as subjects for this study (young normal hearing, young hearing loss, older normal hearing, and older hearing loss).

Several measures were recorded for each listener. These included pure-tone thresholds, babble thresholds, loudness discomfort levels for babble, speech recognition scores in quiet, and signal to noise ratios required for 50% accuracy at each of 56, 72, and 88 dB SPL. In addition, researchers recorded speech levels for 50% performance on both high and low predictability sentences in quiet. Results for these tasks in quiet showed significant differences between the normal hearing and hearing loss groups. No significant differences were found between the young and older groups. Although older listeners consistently performed worse in noise than did younger listeners with equivalent audiological thresholds, these age effects were not observed in quiet. All subjects required more beneficial signal-to-noise ratios as the stimulus tasks became more difficult.

Differences between listener groups may be accounted for by factors in speech perception that can be associated with age or hearing loss. It has been suggested that elderly listeners' speech understanding abilities are influenced by memory factors and by the demands of the recognition task. Gordon-Salant and Fitzgibbons (1997) studied the effects of recall task, speech rate (manipulated through use of interword intervals), and contextual cues on speech recognition for young and elderly listeners. Four groups of subjects (young normal hearing, elderly normal hearing, young hearing impaired, and elderly hearing impaired) were presented with low and high context sentences. The sentences were presented in noise at five different speaking rates. Results indicated that elderly listeners performed better on final word recall tasks than on sentence recall tasks. This supports the theory that the memory demands of the recall task affect the performance of elderly listeners.

In a later study, Gordon-Salant and Fitzgibbons (1999) examined the effects of age and hearing status on performance during temporally based speech and nonspeech measures (temporal manipulation of acoustic signals and variation in stimulus complexity). The subject group configurations were similar to those of the 1997 study (young normal hearing, elderly normal hearing, young hearing impaired, and elderly hearing impaired). The hearing loss groups were matched on the basis of listeners' pure tone thresholds, thus minimizing the possibility of differences in audiological configurations as a between-groups factor. The hearing loss groups consistently performed more poorly than the normal hearing groups. However, none of the interactions involving hearing status were found to be statistically significant. The results of this study indicate that central processing factors may cause poorer psychoacoustic performance in older listeners. In addition, aging affects the ability to process rapid speech segments. This factor may have an adverse affect on intelligibility of clear speech when produced at normal rates.

Peters, Moore, and Baer (1998) conducted experiments to investigate the effects of temporal and spectral dips, which refer to changes in amplitude over time and in frequency, respectively, on speech intelligibility in background noise for individuals with normal hearing and those with hearing loss. Four groups of subjects (young normal hearing, elderly normal hearing, young hearing loss, and elderly hearing loss) were presented with 10 varying conditions of background noise. In one experiment, sentence lists were presented to all subjects without frequency response shaping. Researchers measured the decrease in listeners' speech reception thresholds (SRT) in noise as a result of spectral and temporal dips. Results of this experiment indicated that listeners with hearing loss received less benefit from spectral and temporal dips than did listeners with normal hearing. The young normal hearing (YNH) group received the most benefit, while the elderly hearing loss (EHL) group received the least benefit. The authors reported that the age difference in speech perception was most likely due to auditory factors, considering that the EHL group experienced a greater degree of hearing loss than that of the YHL (young hearing loss) group overall. In a second experiment, the two hearing loss groups (YHL, EHL) were tested with frequency-gain characteristics corresponding to NAL (National Acoustic Laboratory) procedures (Byrne & Dillon, 1986). NAL procedures provide the standard prescription for frequency shaping based on audiogram results. The results of this experiment indicated that the YHL group received greater benefit from spectral and temporal dips than did the EHL group and age was moderately correlated with SRTs for these conditions. The combined results of these experiments indicated that the overall performance of hearing loss groups was poorer than that of the normal hearing groups, even with amplification. One explanation for this difference in performance on speech perception tasks is related to the smaller dynamic range of people with hearing loss when compared to that of individuals with normal hearing. A limited dynamic range makes it difficult to supply enough linear gain to make the speech spectrum audible, without allowing noise to become uncomfortably loud. The masking effect of background noise had a substantial negative effect on the performance of listeners with hearing loss. These results imply that individuals with sensorineural hearing loss have less ability to utilize spectral and temporal dips in background noise than individuals with normal hearing. In addition, age was significantly correlated with

SRTs in background noise with spectral and/or temporal dips when amplification was utilized.

*Clear Speech and Hearing Loss*

There is some research to suggest that clear speech is less beneficial for hearing impaired listeners, possibly because hearing loss affects the way listeners utilize acoustic cues (e.g. Ferguson & Kewley-Port, 2002). For example, Ferguson and Kewley-Port (2002) compared the properties of clear and conversational vowels. Four experiments were performed in order to determine which acoustical cues were most important for vowel identification in normal hearing and hearing impaired listeners. The results of the first experiment indicated that clear speech vowels were more intelligible than conversational vowels by an average of 15 percentage points for young, normal hearing listeners. In contrast, speaking mode was not statistically significant for elderly, hearing impaired listeners. These subjects demonstrated the expected clear speech advantage for back vowels. However, the opposite effect occurred for front vowels, which resulted in an overall noneffect for clear vowels. The authors acknowledge that this may be attributed to the speaking style of the speaker, rather than being indicative of clear speech in general. However, the results suggest that hearing loss changes the way listeners use acoustic information to identify vowels.

In contrast to the results of Ferguson and Kewley-Port (2002), a number of other studies have shown that hearing impaired individuals generally benefit from clear speech at slow rates (Schum, 1996; Picheny et al., 1985; Payton et al., 1994). Studies which have shown clear speech advantage for individuals with hearing loss typically involve stimuli consisting of sentences, rather than individual words. Although sentence stimuli may be either nonsense or meaningful, additional acoustical context is provided that may be a factor in increased intelligibility scores for these materials. Additional research into clear speech at normal rates may lend insight into the role of other factors affecting speech intelligibility such as age and hearing loss.

*Hypothesis*

The body of previous research on clear speech intelligibility indicates that clear speech at slow rates is beneficial in a variety of environments and for many populations. The work of Krause and Braida (2002, 2003) also indicates that it is possible to obtain naturally produced clear speech at normal rates, while maintaining at least a portion of the intelligibility benefit, for some populations and environments. The task remains to test clear speech at normal rates with a variety of subject populations in order to determine whether the benefit of clear speech persists at normal rates for all populations. The work of Gordon-Salant and Fitzgibbons (1999) indicates that aging negatively affects an individual's ability to process rapid speech segments. In addition, Peters et al. (1998) found that elderly listeners with hearing loss had higher speech reception thresholds in noise than did young listeners with hearing loss, and that listeners with hearing loss performed worse than those with normal hearing on speech reception tasks overall, even when supplied with amplification. This leads to the question of whether clear speech will maintain its intelligibility benefit for older adults (both normal hearing and those with hearing loss) when spoken at normal rates. Panagiotopoulos (2005) found that older adults with normal hearing received a 21 percentage point advantage (relative to conv/normal speech) when listening to clear/slow speech, and a 14 percentage point advantage for clear/normal, indicating that clear/normal speech is advantageous for older listeners with normal hearing. The purpose of the current study was to ascertain how intelligibility, measured as percent correct keyword scores on nonsense sentences presented in quiet, varies as a result of speaking mode (clear vs. conversational speech), talker, and speaking rate (slow vs. normal) in adults over age 55 with moderate sloping hearing loss. Comparison of these results with those of Panagiotopoulos (2005) was conducted to obtain information concerning the effect of hearing loss alone.

In light of the information gathered at the beginning of the study on the effects of clear speech at both normal and slow rates, it is hypothesized that the intelligibility scores of clear speech at normal rates to exceed those of conversational speech at normal rates for older adults with hearing loss. In addition, I expected clear speech at slow rates to be more intelligible for this population than clear speech at normal rates.

## Chapter 3

## Methods

*Participants*

The participants in this study consisted of six listeners recruited from audiology clinics, hearing loss support groups, and retirement communities in the Tampa, FL area. Demographic information (age, gender, and years of education) for the six listeners is listed in Table A1 of Appendix A. In order to be included in the study, subjects were required to be native speakers of English between 55-75 years of age; pass a cognitive screening; and present with a moderate, bilaterally symmetric, sloping hearing loss.

The Mini Mental State Exam (MMSE) (Folstein, Folstein, & McHugh, 1975) was utilized as a cognitive screening tool. Listener's scores on this task were compared to normative data (Crum, Anthony, Bassett, & Folstein, 1993) based on age and educational level (see Appendix B). Participants were required to score within one standard deviation of the norm, or higher, to participate in the study. All potential listeners who were screened met this requirement. The MMSE scores for the six listeners who participated in the experiment are listed in Table A2 of Appendix A.

To qualify as having a moderate loss appropriate for inclusion in the study, each listener's pure tone average (average of thresholds at 500, 1000, and 2000 Hz) was required to fall between 35 and 60 dB. For the loss to be considered sloping for the purposes of the study, thresholds were required to increase (i.e. worsen) by at least 15 dB between 500 Hz and 2000 Hz. Listeners with thresholds that increased (worsened) by as little as 10 dB were also accepted if the difference between thresholds at 500 and 1000 Hz or between thresholds at 1000 and 2000 Hz met the 15 dB criteria. In addition, thresholds at 4000 Hz and 8000 Hz were required to be equal to or higher (i.e. poorer) than thresholds at 2000 Hz.

Audiograms dated within the last year were provided by subjects prior to their beginning the study. This was to ensure that all subjects met the inclusion criteria. Table 1 illustrates the participants' relevant audiological information for the ear which received stimuli during the experiment. Bilateral audiological thresholds are listed in Table A3 of Appendix A.

Table 1. Listeners' Audiological Configurations

| Listener | Age | Test Ear | PTA (dB) | Slope | Thresholds (dB) at Frequency (Hz) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 500 | 1000 | 2000 | 4000 | 8000 |
| L1 | 68 | R | 37 | 10 | 35 | 30 | 45 | 50 | 80 |
| L2 | 72 | R | 48 | 25 | 35 | 50 | 60 | 65 | 70 |
| L3 | 57 | L | 46 | 15 | 35 | 55 | 50 | 60 | 55 |
| L4 | 74 | L | 37 | 35 | 25 | 25 | 60 | 65 | 80 |
| L5 | 66 | L | 52 | 55 | 30 | 40 | 85 | 80 | 75 |
| L6 | 74 | L | 40 | 15 | 30 | 45 | 45 | 75 | 90 |

The original intention was for 8-10 listeners to participate in this study. In addition, the criteria for audiological configuration was initially more stringent, including pure tone averages between 40 and 60 dB, and a minimal 25 dB slope. Due to difficulty in finding persons who met this criteria despite extensive recruitment efforts, the number of participants was reduced to six, and the inclusion criteria was broadened. These changes were introduced in order to increase the rate at which subjects were recruited so that the timeline of the experiment could be maintained.

*Materials*

Sentences were drawn from a database compiled for a previous study involving clear and conversational speech at both slow and normal rates (Krause & Braida, 2002). Nonsense sentences were used in order to control for contextual cues as an intelligibility factor. The sentences are syntactically correct, but without semantic meaning, such as, "Our egg waits for his export" (Krause & Braida, 2002).

The stimuli consisted of eight unique lists of 50 nonsense sentences read by four different talkers (two lists per talker). These four talkers were chosen from a group of five, due to their ability to produce a clear speech intelligibility benefit (for young, normal hearing listeners) without slowing their speech rates. Each talker produced two lists of sentences. One list was dedicated to normal rate conditions, the other to slow rate conditions. Each list was read twice, once using clear speech, and once using conversational speech. Therefore, each talker produced 50 utterances in each of the following conditions: clear speech at normal rates (clear/normal), averaging 174 wpm; conversational speech at normal rates (conv/normal), averaging 178 wpm; clear speech at slow rates (clear/slow), averaging 89 wpm; and conversational speech at slow rates (conv/slow), averaging 103 wpm (Krause, 1995).

Table 2. Sentence Lists by Speaker and Condition

| List | Speaker | Condition | |
|---|---|---|---|
| 1 | T1 | conv/normal | clear/normal |
| 2 | | conv/slow | clear/slow |
| 3 | T3 | conv/normal | clear/normal |
| 4 | | conv/slow | clear/slow |
| 5 | T4 | conv/normal | clear/normal |
| 6 | | conv/slow | clear/slow |
| 7 | T5 | conv/normal | clear/normal |
| 8 | | conv/slow | clear/slow |

Instrumentation consisted of headphones connected to the output of a Lynx Audio sound card and a computer system utilizing Matlab software. Matlab is a signal processing software program that was used to control frequency-gain characteristics and presentation level of stimuli. All instrumentation was calibrated prior to the start of the experiment in order to ensure that the experimental system's output frequencies and levels were accurate. In addition to the speech stimuli, the Salthouse (1991) materials were utilized to assess participants' cognitive processing speed. These materials consist of letter and pattern comparison tasks, in which participants determined whether pairs of stimuli were the same or different.

*Procedures*

Each listener attended testing sessions roughly once a week for a minimum of four weeks. The sessions were 2-3 hours in duration. During each session, the listeners heard four lists, representing each of the four test conditions (clear/normal, conversational/normal, clear/slow, and conversational/slow). Test condition order was counterbalanced across sessions to control for sequencing and learning effects. In addition, a week long break at the midpoint of the study served to further reduce possible learning effects. Subjects in group 1 followed one schedule for weekly presentation of stimuli. Subjects in group 2 followed a different schedule. After the week-long break, subjects in group 1 were presented with the stimuli previously given to group 2, and vice versa. Each sentence list was repeated once in varying conditions.

Table 3. Presentation Order of Stimuli

| WEEK | GROUP 1 | GROUP 2 |
|---|---|---|
| 1 | T1 List 1 conv/normal<br>T1 List 2 clear/slow<br>T3 List 5 clear/normal<br>T3 List 6 conv/slow | T1 List 1 clear/normal<br>T1 List 2 conv/slow<br>T3 List 5 conv/normal<br>T3 List 6 clear/slow |
| 2 | T3 List 3 clear/normal<br>T3 List 4 conv/slow<br>T5 List 7 conv/normal<br>T5 List 8 clear/slow | T3 List 3 conv/normal<br>T3 List 4 clear/slow<br>T5 List 7 clear/normal<br>T5 List 8 conv/slow |
| 3 | BREAK | BREAK |
| 4 | T1 List 1 clear/normal<br>T1 List 2 conv/slow<br>T3 List 5 conv/normal<br>T3 List 6 clear/slow | T1 List 1 conv/normal<br>T1 List 2 clear/slow<br>T3 List 5 clear/normal<br>T3 List 6 conv/slow |
| 5 | T3 List 3 conv/normal<br>T3 List 4 clear/slow<br>T5 List 7 clear/normal<br>T5 List 8 conv/slow | T3 List 3 clear/normal<br>T3 List 4 conv/slow<br>T5 List 7 conv/normal<br>T5 List 8 clear/slow |

Stimuli were presented through headphones, without hearing aids. This allowed the examiner to better control the presentation level and frequency-gain characteristics of the stimuli. Each listener had their hearing corrected through the headphones. This correction was based on their individual audiograms, utilizing the National Acoustic Laboratory-Revised (NAL-R) procedure (Byrne & Dillon, 1986) and the Matlab software. This method of frequency-shaping allowed the evaluator to compensate for any possible differences in hearing aid types among the subjects. Stimuli were presented at the most comfortable loudness level (MCL) for each listener. The presentation levels that the listeners selected are listed in Table A4 of Appendix A.

In addition, the Matlab program was equipped with a user interface that allowed listeners to set their own pace for stimulus presentation. Listeners were asked to reproduce each sentence that was presented to them aurally. They were given a choice of writing or typing their responses.

The same scoring system established by Picheny et al. (1985) was used for this experiment. Intelligibility scores were based on percentages of correct keywords. Keywords included nouns, verbs, adverbs, and adjectives. Inserting, omitting, or misidentifying phonemes counted as errors. Inserting or omitting plurals or past tense suffixes did not count as errors.

*Data Analysis*

The data collected consisted of percentages of keywords correctly identified by listeners in each of the following conditions: clear/normal, clear/slow, conv/normal, and conv/slow. Data were recorded on an Excel spreadsheet and converted to graphs for visual analysis. A four-way analysis of variance (ANOVA) was applied to test significance of the results. In addition to analyzing intelligibility differences between conditions, data were examined for a relationship between cognitive processing ability and speech perception ability. Cognitive processing scores consisted of the number of Salthouse (1991) tasks correctly completed within 30 seconds.

# Chapter 4

## Results

The purpose of this study was to investigate how speech intelligibility, measured by percent keywords correct, varied with speaking mode, speaking rate, talker and listener for older listeners with moderate, sloping hearing loss. In addition to determining the relative intelligibility of each condition, the data collected were examined for a relationship between cognitive processing ability and speech perception ability. Specifically, cognitive processing scores were examined in relation to both the overall performance of listeners and to the clear speech benefit obtained. Visual inspection of the data suggested no relationship in either case. Nonparametric statistical analysis (Spearman's rho) also show no statistically significant correlations, although the analysis was underpowered and more subjects would be needed to confirm this result.

In order to assess intelligibility differences between conditions, keyword scores for each condition were examined. Keyword scores for each listener are presented in Appendix C, and Table 4 shows the average intelligibility of each condition. In analyzing the intelligibility benefit of each condition, the conv/normal condition was considered the baseline because it best represents typical speech. Clear/slow was the most intelligible condition overall and provided a 7.7 percentage point intelligibility benefit relative to conv/normal on average. However, neither conv/slow nor clear/normal provided any intelligibility benefit, suggesting that for older adults with moderate, sloping hearing loss, the combination of clear speech and slower rate on average is more beneficial than the additive effects of altering either speaking rate or speaking mode alone.

Table 4. Average Intelligibility

| Condition | Average Keyword Score (% correct) |
|---|---|
| clear/slow | 84 |
| clear/normal | 74 |
| conv/slow | 77 |
| conv/normal | 77 |

A four-way repeated measures analysis of variance (ANOVA) was performed on keyword scores after an arcsine transformation ($\sqrt{I_j/100}$) was applied to equalize the variances. The analysis included three within-subjects factors (rate, speaking mode, and talker) and one between subjects factor (listener). Table 5 lists F-ratios and significance levels for those effects and interactions that were statistically significant ($p<0.01$). Each of these will be discussed in detail in the sections below. A complete listing of all effects and interactions, including those that were not found to be significant, can be found in Appendix D.

Table 5. Significant Effects and Interactions at the 0.01 level

| Effect | F | df | Significance | Eta Squared |
|---|---|---|---|---|
| listener | 144.855 | 5 | .000 | 0.443 |
| talker | 58.075 | 3 | .000 | 0.107 |
| rate | 48.129 | 1 | .000 | 0.029 |
| mode | 10.814 | 1 | .001 | 0.007 |
| listener x talker | 2.238 | 15 | .005 | 0.021 |
| talker x rate | 24.832 | 3 | .000 | 0.046 |
| talker x mode | 6.540 | 3 | .000 | 0.012 |
| rate x mode | 41.652 | 1 | .000 | 0.025 |
| talker x rate x mode | 10.733 | 3 | .000 | 0.020 |
| listener x talker x rate x mode | 2.957 | 15 | .000 | 0.027 |

*Main Effects*

As shown in Table 5, all main effects were statistically significant. Of the four factors in this study, the effects of speaking mode and speaking rate were of primary interest since they show the degree to which the listeners in this study benefited from clear speech and slow speech, respectively. Regarding speaking mode, average keyword scores were 79.3% for clear speech and 76.6% for conversational speech. Although significant, the small difference in overall intelligibility (2.7 percentage points) between clear and conversational speaking modes indicates that this was not a large effect ($\eta^2 = 0.007$). Rather, the interaction of mode and rate had a larger effect on intelligibility than the main effect of mode. This interaction will be discussed in the next section. Regarding speaking rate, average keyword scores were 80.4% for slow rate speech and 75.4% for normal rate speech. The average benefit for slow speech was 5 percentage points overall, a somewhat larger effect ($\eta^2 = 0.029$), indicating that listeners benefited noticeably from slow rates as compared to normal rates on average.

The remaining factors, talker and listener, were both statistically significant in the ANOVA because some talkers were more intelligible than others and some listeners performed better than others. For instance, T5 was the most intelligible talker, producing an average intelligibility of 85.6%. The least intelligible talker, T4, produced an average intelligibility score of 73.9%. Similarly, average listener scores ranged from 61.7%-91.8%, indicating that the tasks were inherently more difficult for some listeners than others. Such intelligibility differences between talkers and performance differences between listeners were expected, and the more pertinent information to this study is the interaction between talker or listener and the mode and rate factors (i.e. the extent to which the benefit provided by clear speech or slow speech varies for different talkers or different listeners). These interactions will be discussed in detail later in the chapter.

*Interactions with Speaking Mode*

*Mode x Rate Interaction*

In order to examine the interaction of rate with speaking mode, Figure 1 shows the overall average across talker and listener for each condition tested. This figure allows for comparisons of the effect of rate within the two modes (clear and conversational). As shown in Figure 1, the clear/slow condition showed a 7.7 percentage point benefit over conv/normal overall. This supports the findings of Picheny et al. (1985), who found a clear (clear/slow) speech advantage over conversational speech for listeners with moderate to severe hearing loss. In addition, clear/slow speech exhibited a comparable intelligibility benefit over both conv/slow speech (7.7 percentage points) and clear/normal speech (10 percentage points). Conversational speech, regardless of rate, had similar intelligibility on average (77%). In other words, clear speech was beneficial to intelligibility at slow rates (clear/slow – conv/slow = +7 points) but not at normal rates (clear/normal – conv/normal = -3 points). These data indicate that for listeners with moderate, sloping losses in quiet conditions, the benefit of slow rate is dependent on speaking mode, and the benefit of clear speech is dependent upon rate. The ANOVA confirmed that the rate x mode interaction was significant and accounted for roughly the same amount of variance ($\eta^2 = 0.025$) as rate alone.

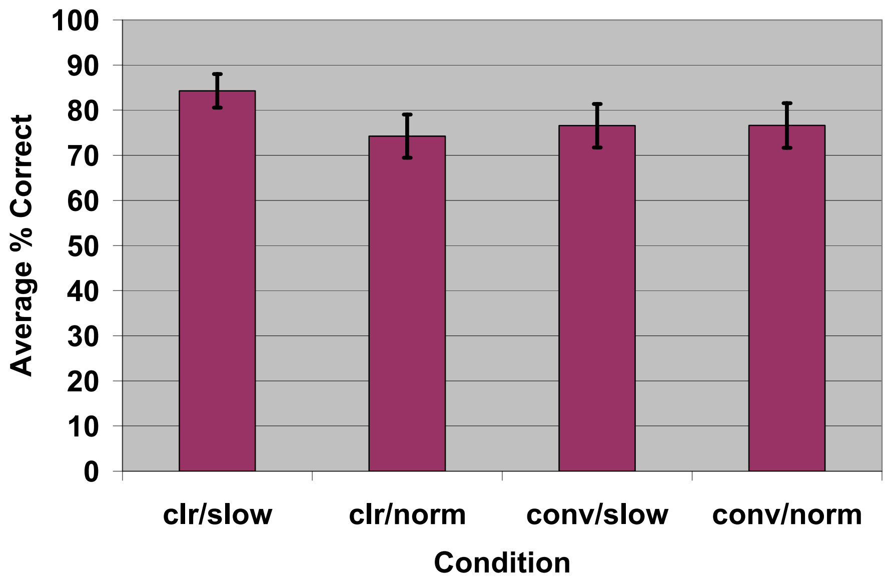


Figure 1. Average intelligibility, in percent keywords correct, for each test condition (rate x mode). Error bars indicate +/- 1 standard error from the mean.

Because the rate x mode interaction was shown to be significant in the ANOVA, post hoc t-tests were conducted to evaluate pairwise comparisons of the four conditions. These comparisons served to further evaluate differences that were observed between the conditions. A Bonferroni adjustment for multiple comparisons was implemented in the t-test results to compensate for the increased chance of Type I error associated with multiple comparisons. As shown in Table 6, results of the pairwise comparisons confirmed that clear/slow speech was significantly more intelligible than every other condition and that the other three conditions did not differ significantly from each other.

Table 6. Pairwise Comparisons

| (I) Condition | (J) Condition | Mean Difference (I-J) | Std. Error | Sig. | 99% Confidence Interval for Difference | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| conv/slow | clear/slow | -.098* | .011 | .000* | -.137 | -.060 |
| | conv/normal | .005 | .015 | 1.000 | -.049 | .059 |
| | clear/normal | .037 | .017 | .214 | -.022 | .095 |
| clear/slow | conv/slow | .098* | .011 | .000* | .060 | .137 |
| | conv/normal | .103* | .013 | .000* | .057 | .149 |
| | clear/normal | .135* | .013 | .000* | .088 | .183 |
| conv/norm | conv/slow | -.005 | .015 | 1.000 | -.059 | .049 |
| | clear/slow | -.103* | .013 | .000* | -.149 | -.057 |
| | clear/normal | .032 | .013 | .141 | -.015 | .079 |
| clear/norm | conv/slow | -.037 | .017 | .214 | -.095 | .022 |
| | clear/slow | -.135* | .013 | .000* | -.183 | -.088 |
| | conv/normal | -.032 | .013 | .141 | -.079 | .015 |

*Significant at the .01 level.

*Other Interactions with Speaking Mode*

Figure 2 shows the average intelligibility obtained by listeners in each speaking mode, which shows why the interaction of listener and mode was not statistically significant. Five out of six listeners showed increased scores on clear speech tasks (see

Figure 2). The remaining listener, L2, performed equally well for conversational and clear speech modes, averaging 91.8% for each. This may indicate a ceiling effect, in which her baseline performance (conversational speech conditions) was so high that improvement could not be shown. Thus, with the exception of those effected by ceiling effects, listeners generally benefited from clear speech.

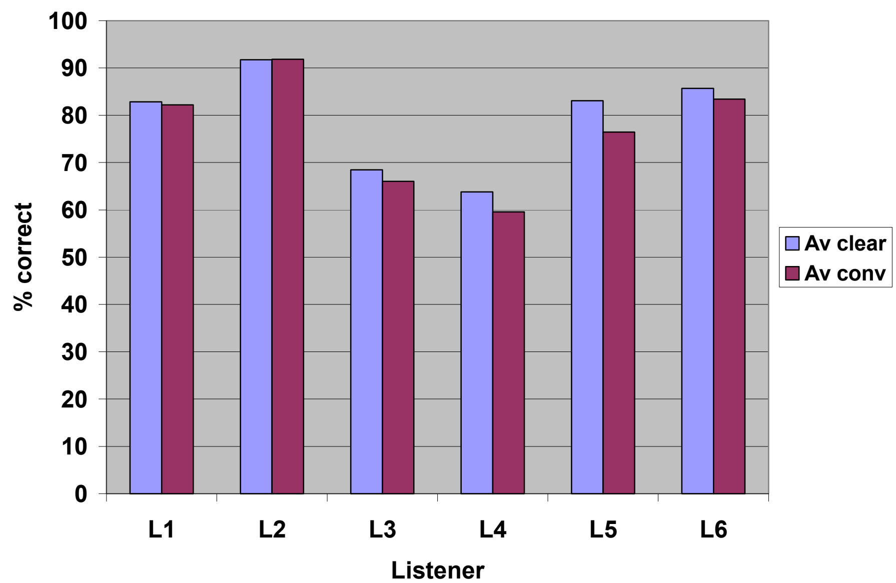


Figure 2. Average performance, in percent keywords correct, for each listener in each speaking mode.

Talkers, on the other hand, did not all achieve comparable benefits from speaking clearly when intelligibility was averaged across listeners. As shown in Figure 3, three of the four talkers did demonstrate increased overall intelligibility in clear speech conditions, as compared to conversational speech for listeners with hearing loss in quiet. In other words, most talkers were more intelligible when utilizing clear speech. This indicates that clear speech is beneficial for most talkers. However, the size of the clear speech benefit varied from 2.3% (T1) to 8.5% (T4), and one talker (T3) was actually less intelligible on average when utilizing clear speech. As a result of these talker differences, the interaction of talker and mode was statistically significant.

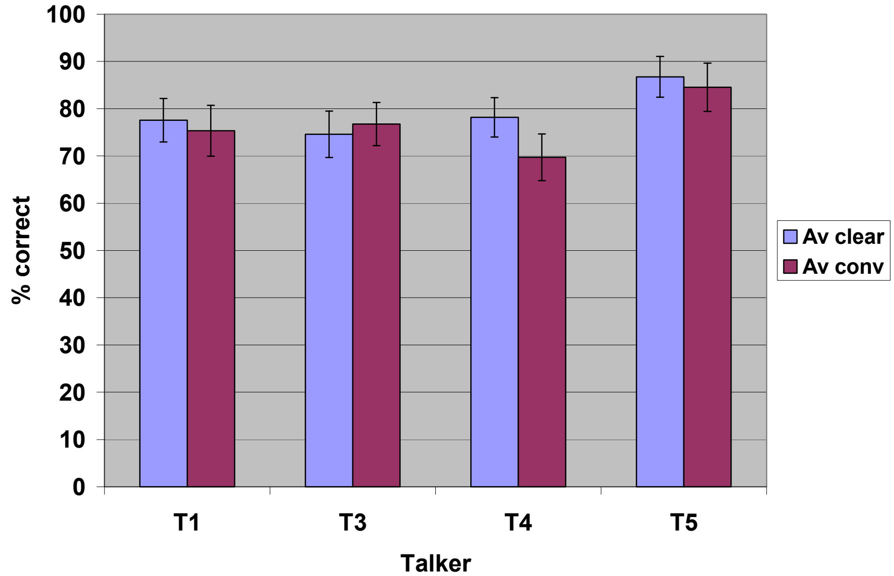


Figure 3. Average intelligibility, in percent keywords correct, for each talker in each mode. Error bars indicate +/- 1 standard error from the mean.

*Interactions with Rate*

Figure 4 shows the average intelligibility obtained by listeners at each speaking rate, which shows why the interaction of listener and rate was not significant. As shown in Figure 4, every listener performed better across talkers when presented with the slow rate.

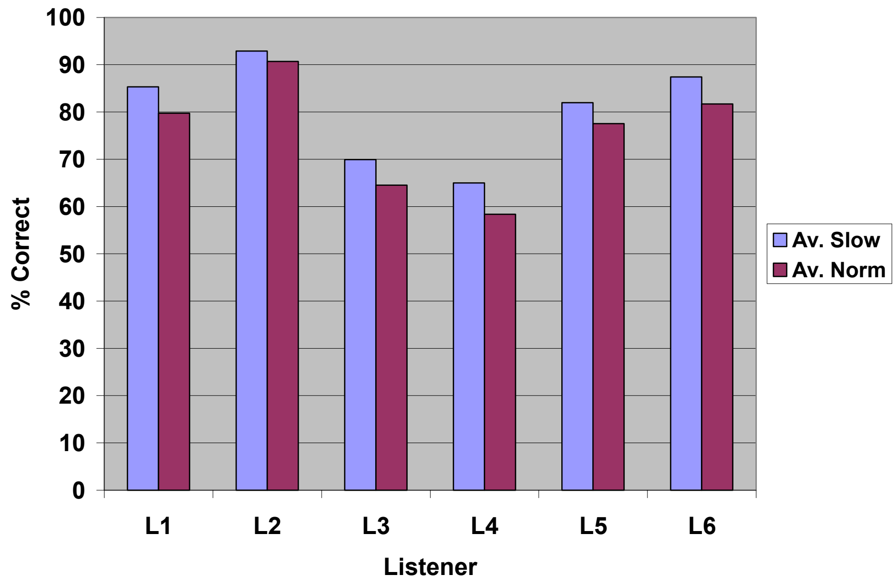


Figure 4. Average performance, in percent keywords correct, for each listener at each rate.

Every talker, however, did not perform similarly when speaking slowly. As Figure 5 illustrates, two of the four talkers achieved similar intelligibility benefits for slow speech conditions, as compared to normal rates. One talker, T4, showed a benefit for the normal rate relative to the slow rate, and the last talker, T5, exhibited comparable intelligibility in both slow (85.4%) and normal rate conditions (85.9%). These data indicate that it is not necessary for everyone to decrease speaking rate in order to improve intelligibility, as two of the four talkers did not exhibit a slow rate benefit. Because of these sizeable differences between talkers, the interaction of talker and rate was statistically significant, and the corresponding effect size was relatively large. In fact, this interaction accounted for more of the variance ($\eta^2 = 0.046$) in intelligibility scores than mode or rate alone as well as the other interactions with mode and rate.

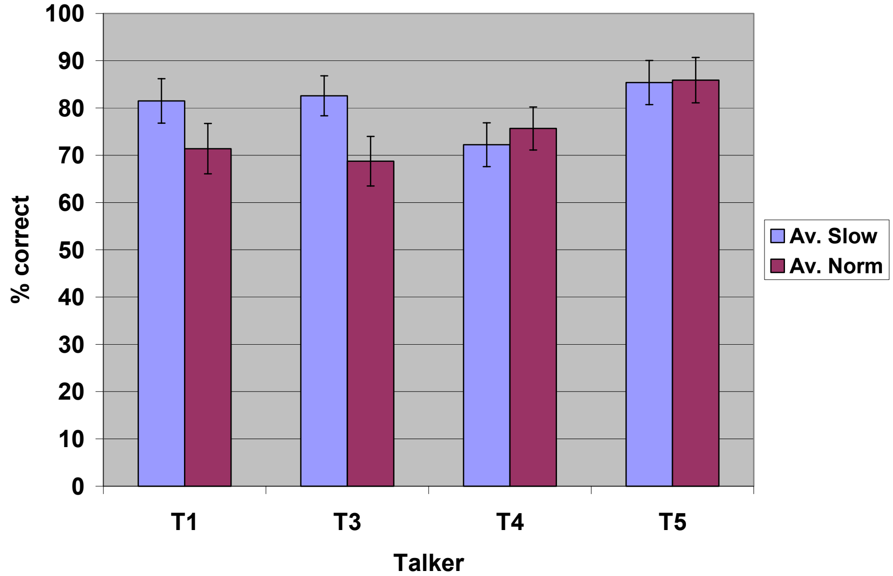


Figure 5. Average intelligibility, in percent keywords correct, for each talker at each rate. Error bars indicate +/- 1 standard error from the mean.

*Listener and Talker Interactions*

*Listener and Talker Interactions with Condition (Mode x Rate)*

The three-way interaction of listener, mode, and rate was not significant in the ANOVA. This is because all listeners followed the same general pattern when data were averaged across talkers. Specifically, clear/slow was the most intelligible condition on average for all listeners. In addition, the clear/normal condition did not show improvement over conv/normal on average for any of the listeners.

On the other hand, the relative intelligibility of the four conditions did not follow the same pattern for all talkers, and the interaction of talker, rate, and mode, shown in Figure 6, was statistically significant. Clear/slow was the most intelligible condition overall for three of the four talkers but for the remaining talker, T3, the conv/slow condition was most intelligible. Thus, T3's data alone would seem to indicate that a slower rate provides a benefit over speech at normal rates, regardless of speaking mode. However, as shown in Figure 6, only two of the talkers exhibited intelligibility benefits for both slow conditions (conv/slow, clear/slow) compared to conv/normal. For the remaining two talkers (T4, T5), one slow condition was the most intelligible, and the other was least intelligible. In other words, reduction of speaking rate alone was not sufficient to guarantee increased speech intelligibility for all talkers. However, when talkers spoke slowly and clearly, all achieved a benefit relative to conv/normal speech.

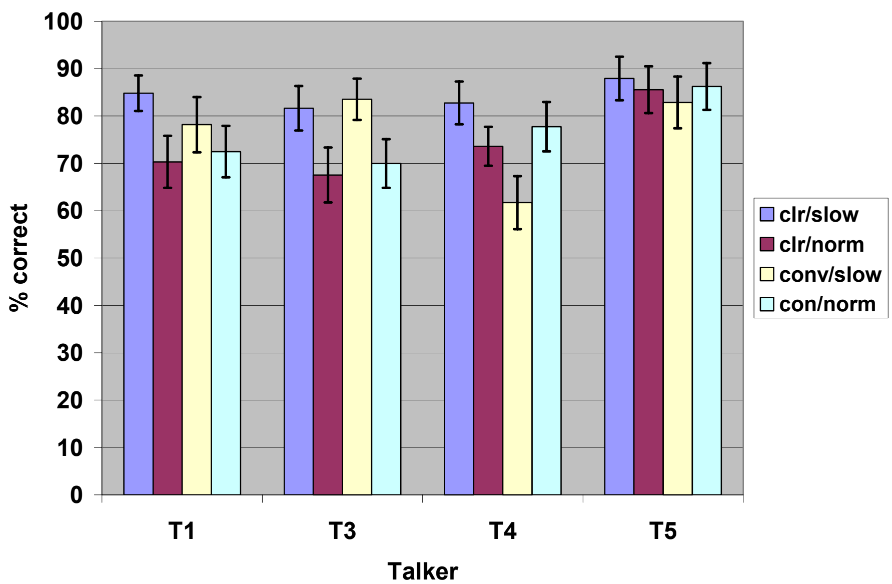


Figure 6. Average intelligibility, in percent keywords correct, for each talker at each rate and mode. Error bars indicate +/- 1 standard error from the mean.

*Other Listener and Talker Interactions*

Figure 7 shows the average intelligibility of each talker for the various listeners, which shows why the interaction of listener and talker was statistically significant in the ANOVA. Although T5 was the most intelligible talker for each listener, there was no discernible intelligibility pattern for the remaining talkers when compared across listeners. In other words, with the exception of T5, each listener found different talkers more intelligible.

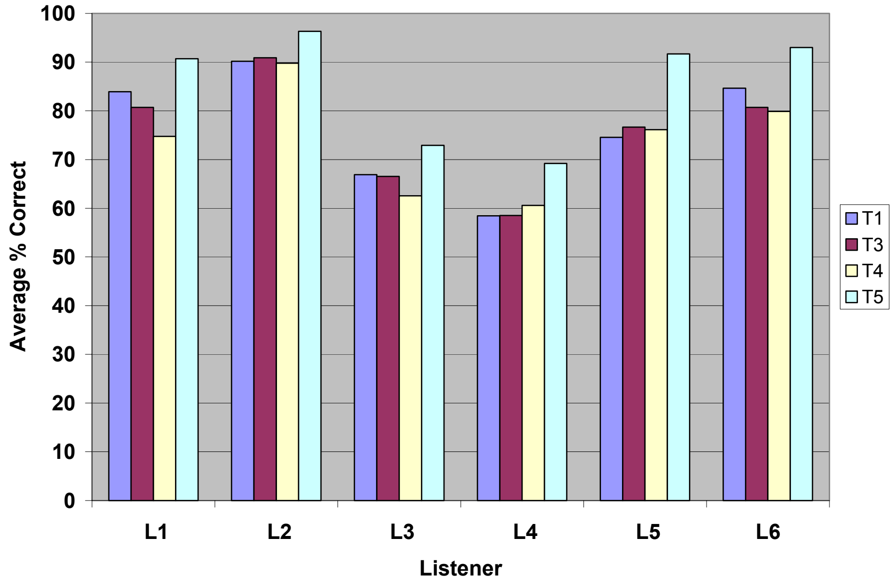


Figure 7. Average performances, in percent keywords correct, of every listener for each talker.

Each listener also showed different effects of condition, depending on the talker. Figure 8 shows the four-way interaction, talker x listener x mode x rate. All listeners benefited overall from the slow rate, and those listeners who showed any benefit from a speaking mode favored clear speech over conversational. However, the rate and mode that was most intelligible varied across talker and listener, and the talker x listener x mode x rate interaction was statistically significant. The effect size was $\eta^2 = 0.027$, which suggests that speaking mode and rate constituted a small but substantial impact on intelligibility for talker x listener interactions (about the same amount as rate alone or the rate x mode interaction).

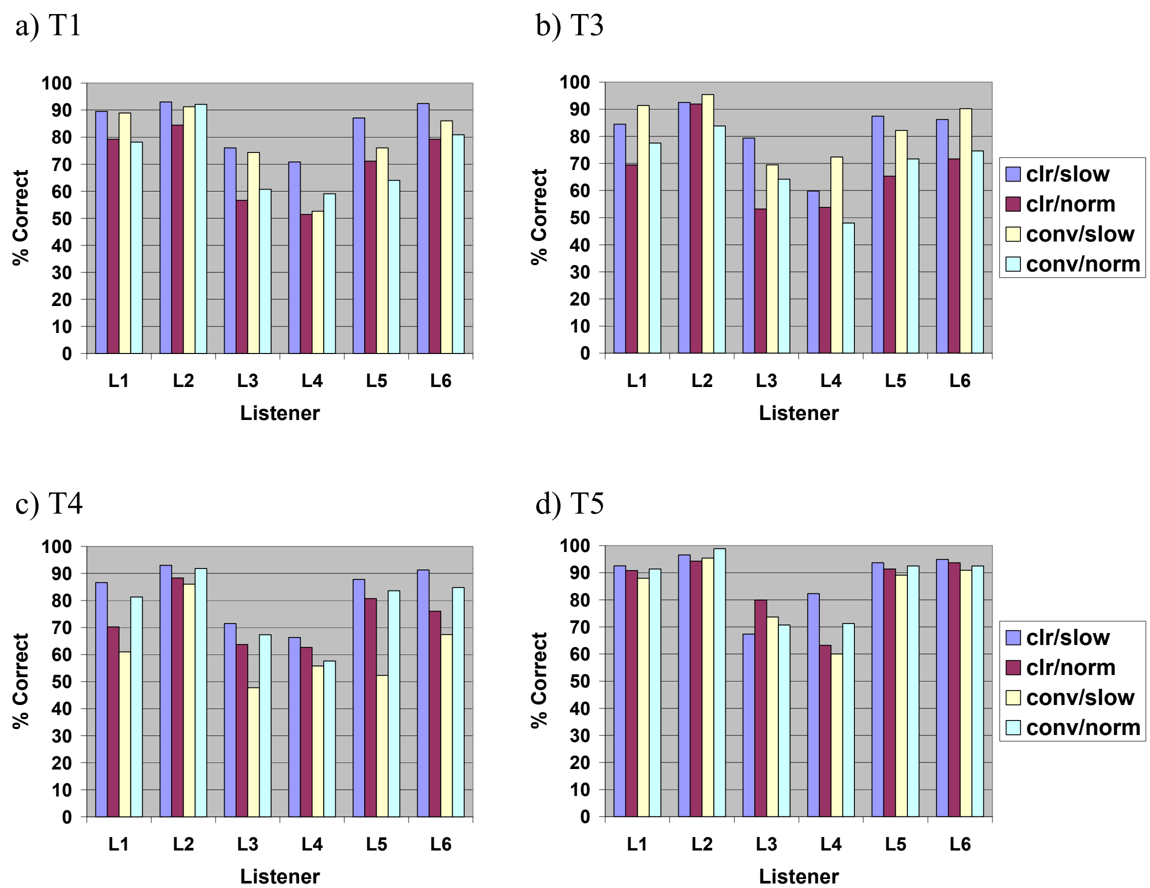


Figure 8. Average performance, in percent keywords correct, of every listener for each talker in each condition.  Panel a) shows data for T1, panel b) shows data for T3, panel c) shows data for T4, and panel d) shows data for T5.

Consistent with previous studies (e.g. Picheny et. al., 1985), the benefits of clear/slow speech were robust.  Not only was it the most intelligible condition on average, but the clear/slow speech of T1, T3, and T4 produced an intelligibility benefit over conv/normal speech for every listener, and T5 produced a clear/slow benefit for three of six listeners (L1, L5, and L6). Of the remaining three listeners, one constituted a potential ceiling effect. In other words, the listener performed so well in the conv/normal condition that there may not have been room to show improvement in the clear/slow condition. This resulted in a clear/slow benefit for 21 out of 24 talker/listener combinations.

In comparison of conv/slow and conv/normal conditions, 11 out of 24 talker/listener combinations showed a benefit for conv/slow over conv/normal. Of the 13 talker/listener interactions that did not benefit from conv/slow, two could have resulted from possible ceiling effects. Individual talkers differed considerably in this comparison. For example, T3 exhibited a conv/slow benefit for each listener, while T4 did not show a conv/slow benefit for any listeners. Although ceiling effects may account for some of the differences between the benefits of rate (conv/slow compared to conv/normal), and speech mode (clear/slow compared to conv/slow) the combination of slow rate and clear mode was more beneficial overall.

Finally, it should be noted that although clear/normal speech did not provide an intelligibility advantage over conv/normal speech on average, eight talker/listener combinations did exhibit a clear/normal benefit over conv/normal. Moreover, of the 16 talker/listener combinations that did not produce a clear/normal benefit, six were potential ceiling effects. T5 produced possible ceiling effects for four of the six listeners, while T3 did not produce any possible ceiling effects. All of these differences seem to indicate that some talkers have greater potential for producing clear speech at normal rates which provides an intelligibility advantage to older listeners with moderate, sloping hearing loss.

# Chapter 5

## Discussion

The results of this study indicate that older listeners with moderate, sloping losses benefit from clear/slow speech relative to conv/normal, which is similar to typical conversational speech. These findings support previous research (Picheny et al., 1985; Payton et al., 1994; Schum, 1996) on the benefits of clear speech at slow rates for listeners of various ages with various audiometric characteristics. Of note, however, is that slowing rate alone may provide a similar or greater benefit for some listeners in this population, while other listeners require both slow rate and clear mode to receive a benefit.

Although clear speech at normal rates has been shown to provide a benefit for young normal hearing listeners in noise (SNR = - 2 dB; Krause & Braida, 2002) and older normal hearing listeners in noise (SNR = 0 dB; Panagiotopoulos, 2005), this benefit was not widely seen in quiet for older listeners with sloping hearing loss. However, each listener did benefit from clear speech at normal rates from specific talkers. There was no apparent pattern as to which listener/talker interaction produced clear/normal benefit, although T4 exhibited a clear/normal benefit over conv/slow for each listener. This seems to indicate that the degree of benefit, if any, of clear speech at normal rates is dependent on both talker and listener for listeners with moderate, sloping losses in quiet.

To analyze the effect of hearing loss on the clear speech benefit, the results of this study were compared to those of Panagiotopoulous (2005). Panagiotopolous evaluated listeners with normal hearing, who were roughly the same age as the listeners with hearing loss in this study. Table 7 shows the comparison of percent keywords correct between the present study and the previous study. Again, the average percentages for conv/normal should be viewed as a baseline for comparison to the other conditions. In parentheses is the increase in percentage points of each condition compared to conv/normal.

Table 7. Average Listener Performance Across Studies

| | Current study: older listeners hearing loss SNR = ∞ dB ( quiet) | Panagiotopolous (2005): older listeners normal hearing SNR = 0 dB |
|---|---|---|
| Conv/normal | 77% | 45% |
| Conv/slow | 77% (+0) | 66% (+21) |
| Clear/normal | 74% (-3) | 59% (+14) |
| Clear/slow | 84% (+7) | 68% (+23) |

In Panagiotopolous' (2005) study, older listeners with normal hearing benefited from clear speech at normal rates (relative to conv/normal), but not at slow rates (relative to conv/slow). In the current study, older listeners with moderate, sloping losses showed the opposite effect, benefiting from the clear/slow condition (relative to conv/slow), but not clear/normal (relative to conv/normal). As shown in Table 7, the two slow conditions resulted in the highest average scores for Panagiotopolous' study, in which listeners were presented with stimuli in background noise. Because of the inherent difficulty of the listening tasks, it is possible that a ceiling effect limited the amount of clear/slow advantage obtainable during the study. Similarly, the average clear/normal performance in the current study was within three percentage points of conv/normal, indicating a possible ceiling effect for speech at normal rates.

Although the listeners with hearing loss in this study did not benefit from clear/normal speech, it cannot be concluded that no hearing-impaired listeners would benefit from clear/normal speech. Krause (2001) conducted a study of speech intelligibility for three listeners with sensorineural hearing losses. Test conditions included clear and conversational speech in quiet at both slow and normal rates, and utilized the same talkers and sentence lists as in the current study. Results of Krause's experiment indicated that two of the listeners, GI and GT, received a consistent benefit from clear speech at normal rates in comparison to conversational speech at normal rates. The audiometric characteristics of the three listeners in Krause's study are presented in Table 8. Visual inspection of the audiometric characteristics of these three listeners indicates that those who benefited from clear/normal speech presented with relatively flat hearing losses across thresholds. The listener who did not exhibit a clear/normal benefit on average, RK, presented with a sloping loss comparable to the listeners in the current study (L1-L6). As with the listeners in this study, RK did obtain a benefit from clear/normal speech from particular talkers, but not on average across all talkers.

Table 8. Audiometric Characteristics of Hearing-Impaired Listeners from Krause's (2001) Study

| Listener | Sex | Age | Test ear | PTA | Thresholds (dB) at Frequency (Hz) | | | | | Slope |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 500 | 1000 | 2000 | 4000 | 8000 | |
| GI | M | 65 | L | 50 | 60 | 45 | 45 | 55 | 85 | No |
| RK | M | 64 | L | 40 | 20 | 40 | 60 | 65 | NR | Yes |
| GT | M | 40 | R | 56.7 | 55 | 55 | 60 | 90 | 85 | No |

Given the small number of listeners in Krause's (2001) study and lack of clear/normal benefit for RK, the average benefit of clear/normal speech was not statistically significant. Krause suggested three possible explanations for this lack of expected clear/normal benefit. One possibility was that the clear/normal benefit did not extend to older listeners. This possibility is unlikely, based on the results of Panagiotopoulos (2005) who found a 14 percentage point clear/normal advantage for older listeners with normal hearing. Another possibility was that hearing-impaired listeners did not benefit from clear/normal speech. This possibility is also unlikely, due to Krause's (2001) results which indicated that two out of three hearing-impaired listeners exhibited an intelligibility benefit. Krause's third possible explanation was that audiometric characteristics may be factors in the potential benefits of clear/normal speech. This is the most likely explanation for the lack of overall clear/normal benefit exhibited by RK. RK's sloping hearing loss was consistent with the audiological configuration exhibited by the listeners in the current study (L1-L6). Like RK, these listeners did not benefit from clear/normal speech on average. However, there were talker/listener combinations from both studies in which listeners did benefit from clear/normal (T1 and L5; T3 and L4, L2; T4 and RK, L4; T5 and L3).

In a previous study of vowel intelligibility in clear speech, Ferguson and Kewley-Port (2002) found no significant difference between clear and conversational speech for elderly hearing impaired listeners.  Seven out of nine listeners in the Ferguson and Kewley-Port study met the criteria for sloping loss presented in the current study.  This supports the hypothesis that audiometric characteristics are factors in potential clear speech benefit, particularly if Ferguson and Kewley-Port's talkers were using a form of clear/normal speech.  Specifically, older adults with sloping hearing loss may not receive the same clear/normal speech benefit as older adults with normal hearing or flat hearing losses.  However, talkers in Ferguson and Kewley-Port's study most likely produced a form of clear/slow speech, because they were given no specific instructions or training to produce clear speech at normal rates.  In such a case, audiometric characteristics could not fully explain the lack of clear speech benefit in that study, because all listeners in this study received a benefit from clear/slow speech. It is possible, however, that listeners cannot fully benefit from clear/slow speech unless properly amplified, since listeners in this study were amplified and Ferguson and Kewley-Port's listeners were not.

*Difficulty of Tasks*

One difference that should be noted between the current study and Krause's (2001) study is that digital hearing aids are now more commonly used by listeners with hearing loss.  Because the NAL-R amplification provided via headphones in these experiments mimics a frequency-gain characteristic more likely to be produced by analog hearing aids, it is possible that the listeners were not acclimated to this type of signal processing and therefore, not able to take advantage of all the acoustic cues available to them during the experiment.  This possibility is not likely to explain the lack of clear/normal benefit, because all conditions would have been negatively affected to some extent. However, if the differences in amplification strategy primarily affected the acoustic cues which provide the clear speech advantage at normal rates, then this explanation could account for the lack of clear/normal benefit. To eliminate this potential confounding factor, one solution would be to allow time for training listeners to use the NAL-R amplification presented via headphones, providing them with extra practice sessions before recording data. However, this additional procedure would be cumbersome and not representative of real-world listening situations. Another solution would be to present the experimental stimuli in a sound field, allowing the listeners to utilize their own hearing aids. This adjustment to the procedures would eliminate the need for additional training time and provide more realistic data for real-world listening conditions.

Another issue that arose in the current study that was different from the Krause (2001) study is the presence of ceiling effects. As mentioned earlier, it is likely that L2's data exhibited a ceiling effect due to her consistently high scores on all listening tasks. T5's data may have also exhibited a ceiling effect in that all listeners showed greatest intelligibility for this talker, regardless of condition. In addition, some other talker/listener combinations resulted in high scores that may have reflected a ceiling effect (T1/L6, T1/L1, T4/L5). Ceiling effects may impact the data by limiting the amount of improvement that can be recorded between conditions. For example, if a listener scores high in the conv/normal condition, there is little room for an increased score in the clear speech conditions. To eliminate this problem in future experiments, one solution would be to increase the difficulty of the task, thus reducing the likelihood of high scores in the baseline condition. One way to increase task difficulty would be to recruit listeners with more severe pure-tone averages and/or more steeply sloping hearing losses. This would increase the difficulty of the task; however, listeners may feel frustrated at their lack of success and could become reluctant to complete the experiment. Another possibility would be to add background noise and manipulate the SNR so that the speech signal would be more ambiguous. Again, participant frustration levels would need to be monitored.

In the current experiment, most of the listeners expressed some frustration with the difficulty of the task, even those listeners whose performance indicated relatively high levels of success. This frustration was not reported for the older listeners with normal hearing in Panagiotopolous's (2005) study, which utilized the same talkers and sentence lists, even though the listeners in Panagiotopolous's study performed worse on average across all conditions than the listeners in this study. It is possible that this difference in reactions to the same stimuli is related to the listeners' hearing status, and that listeners with hearing loss are more susceptible to frustration for this type of listening task. Only one listener, L2, expressed enjoyment of the tasks in the current study. Her reaction to the listening tasks could have been influenced by two factors: 1) she was the only female participant, and 2) her performance scores were highest overall, indicating that she found the task easier than the other participants. It is likely that increasing the difficulty of this task would have resulted in more negative reactions by all listeners.

*Future Work*

Future research in this area should include increased numbers of subjects and presentation of stimuli in a sound field, as opposed to headphones, to provide more real-world data. Because audiological configuration appears to be a factor in performance levels for listeners with hearing loss, future studies should focus on these differences. One possible research focus would be to confirm Krause's (2001) findings of a clear speech benefit for listeners with flat hearing losses.

Due to the nature of the tasks presented in the current study, spelling errors, typographical errors, and poor handwriting created several situations in which judgment calls had to be made during the scoring process. Because all responses were scored by the same person, scoring was consistent across listeners, talkers, and conditions. However, if greater numbers of subjects in future studies result in the need for multiple scorers, it will be important to check inter-rater reliability.

An additional consideration for future research is increasing the difficulty of tasks to counteract the possibility of ceiling effects. Utilizing background noise is likely the most effective way to do this. Current research (Smart, 2006) is focusing on establishment of psychometric functions for clear/slow, clear/normal, conv/slow, and conv/normal speech for young normal hearing listeners in noise. Psychometric functions, which show variation in performance levels as a function of variations in SNR, would not only characterize the degree to which the clear speech benefit varies with difficulty of task, but would also facilitate pinpointing the most appropriate SNR to compensate for potential floor or ceiling effects in normal hearing listeners. Therefore, the results of this research may also provide insight into establishing the most appropriate SNRs for listeners with hearing loss. It may be necessary to provide unique SNRs for each listener participating in the study due to differing audiological configurations. Because adding noise to the stimuli will increase task difficulty, the following recommendations are offered to minimize listener frustration: 1) shorter experiments, in which each listener hears stimuli from only one talker, thus reducing the number of sessions to be attended and the amount of stimuli presented to each listener; 2) shorter duration for individual sessions, reducing the amount of frustration in each session; 3) group sessions, in which listeners will have an opportunity to interact with other participants and understand that the tasks are challenging for everyone; and 4) different speech materials, such as single words or meaningful sentences that may reduce the memory load inherent in the task, thereby allowing listeners to focus more cognitive effort on listening and to experience a reduction in any errors due to misremembering stimuli.

*Clinical Implications*

Older listeners with sloping hearing loss exhibited a benefit from slow speech relative to typical conversational speech. Clear/slow speech was the most intelligible condition overall, indicating that while slowing rate is effective, the use of clear speech is also valuable in increasing intelligibility.

Because clear/normal speech was not beneficial to this population on average, it would not be recommended for clinical use. Rather, clear/slow speech is likely the most effective mode of communication to be used in clinical settings with this population as it has been shown to be equally, if not more effective, for all listeners in this group. However, some individuals did benefit from the clear/normal speech of certain talkers. Therefore, some clients may request that normal rates be utilized during treatment sessions with certain clinicians or family members, and these requests should be considered valid.

Even though clear/normal speech is not the most effective tool for initiating therapy, it does have potential applications to hearing aids. Further research into the acoustic characteristics present in those talker/listener combinations which showed a clear/normal benefit may result in hearing aid technology that is able mimic this effect.

Although some individuals may ultimately show preference for normal speaking rates, clear/slow speech should be considered the most effective communication mode in which to initiate therapy.  It would be helpful for clinicians to practice clear speech and use it during therapy, as it has been shown to be effective for various populations, including those with a sloping hearing loss.

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Appendices

Appendix A:

Listener Demographics

Table A1. Listener age, gender, and years of education

| ***Listener*** | ***Age*** | ***Gender*** | ***Education*** |
|---|---|---|---|
| L1 | 68 | M | MBA |
| L2 | 72 | F | College (3 yrs) |
| L3 | 57 | M | High School |
| L4 | 74 | M | College (2 yrs) |
| L5 | 66 | M | B.A. |
| L6 | 74 | M | Tech College |

Table A2. Listeners' MMSE scores

| ***Listener*** | ***Score*** |
|---|---|
| L1 | 28 |
| L2 | 30 |
| L3 | 28 |
| L4 | 29 |
| L5 | 30 |
| L6 | 29 |

Appendix A (Continued)

Table A3. Listeners' Bilateral Audiological Thresholds

| Listener | Ear | Thresholds (dB) at Frequency (Hz) 250 | 500 | 1000 | 2000 | 4000 | 8000 |
|---|---|---|---|---|---|---|---|
| L1 | R | 40 | 35 | 30 | 45 | 50 | 80 |
| | L | 45 | 30 | 20 | 20 | 50 | 60 |
| L2 | R | 25 | 35 | 50 | 60 | 65 | 70 |
| | L | 30 | 35 | 40 | 50 | 70 | 80 |
| L3 | R | 30 | 40 | 55 | 50 | 55 | 60 |
| | L | 30 | 35 | 55 | 50 | 60 | 55 |
| L4 | R | 45 | 45 | 40 | 55 | 60 | 70 |
| | L | 25 | 25 | 25 | 60 | 65 | 80 |
| L5 | R | 25 | 30 | 45 | 85 | 75 | 70 |
| | L | 25 | 30 | 40 | 85 | 80 | 75 |
| L6 | R | 25 | 30 | 35 | 30 | 50 | 70 |
| | L | 15 | 30 | 45 | 45 | 75 | 90 |

Table A4. Stimulus Presentation Levels

| ***Listener*** | ***Presentation Level*** ***Pure Tone RMS*** | ***Peak*** |
|---|---|---|
| L1 | 88.5 dB SPL | 103.3 dB SPL |
| L2 | 96.3 dB SPL | 107.7 dB SPL |
| L3 | 98.6 dB SPL | 106.2 dB SPL |
| L4 | 89.9 dB SPL | 105.2 dB SPL |
| L5 | 96.1 dB SPL | 106.8 dB SPL |
| L6 | 95.5 dB SPL | 107.4 dB SPL |

Appendix B:

Norms for the Mini-Mental State Examination by Age and Education

| **Education** | | **Age Range** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **50-54** | **55-59** | **60-64** | **65-69** | **70-74** | **75-79** |
| 0-4 years | *Mean* | 23 | 22 | 23 | 22 | 22 | 21 |
| | *SD* | 2.6 | 2.7 | 1.9 | 1.7 | 2.0 | 2.2 |
| 5-8 years | *Mean* | 27 | 26 | 26 | 26 | 26 | 25 |
| | *SD* | 2.4 | 2.9 | 2.3 | 1.7 | 1.8 | 2.1 |
| 9-12 years | *Mean* | 28 | 28 | 28 | 28 | 27 | 27 |
| | *SD* | 2.2 | 2.2 | 1.7 | 1.4 | 1.6 | 1.5 |
| 13+ years | *Mean* | 29 | 29 | 29 | 29 | 28 | 28 |
| | *SD* | 1.9 | 1.5 | 1.3 | 1.0 | 1.6 | 1.6 |

*Adapted from Crum et al. (1993).

Appendix C:

Percentages of Keywords Correct

Table C1. Percentages for T1

| | L1 | L2 | L3 | L4 | L5 | L6 |
|---|---|---|---|---|---|---|
| **T1 conv/normal** | 65.71 | 82.86 | 57.14 | 57.14 | 57.14 | 74.29 |
| | 76.47 | 85.29 | 52.94 | 61.76 | 67.65 | 79.41 |
| | 77.78 | 97.22 | 61.11 | 52.78 | 63.89 | 75.00 |
| | 83.33 | 100.00 | 58.33 | 58.33 | 52.78 | 80.56 |
| | 86.49 | 94.59 | 72.97 | 64.86 | 78.38 | 94.59 |
| **Average** | **78.1** | **92.1** | **60.7** | **59.0** | **64.0** | **80.9** |
| | | | | | | |
| **T1 conv/slow** | 81.08 | 91.89 | 67.57 | 48.65 | 75.68 | 81.08 |
| | 93.94 | 90.91 | 81.82 | 51.52 | 81.82 | 90.91 |
| | 80.00 | 80.00 | 57.14 | 40.00 | 68.57 | 80.00 |
| | 100.00 | 97.06 | 82.35 | 70.59 | 79.41 | 94.12 |
| | 90.63 | 90.63 | 84.38 | 53.13 | 75.00 | 84.38 |
| **Average** | **88.9** | **90.1** | **74.3** | **52.6** | **76.0** | **86.0** |
| | | | | | | |
| **T1 clear/normal** | 78.79 | 81.82 | 72.73 | 45.45 | 69.70 | 87.88 |
| | 64.71 | 91.18 | 64.71 | 67.65 | 76.47 | 91.18 |
| | 88.24 | 91.18 | 58.82 | 44.12 | 61.76 | 73.53 |
| | 75.00 | 77.78 | 50.00 | 55.56 | 77.78 | 80.56 |
| | 88.89 | 80.56 | 38.89 | 44.44 | 69.44 | 63.89 |
| **Average** | **79.2** | **84.4** | **56.6** | **51.4** | **71.1** | **79.2** |
| | | | | | | |
| **T1 clear/slow** | 81.08 | 94.59 | 78.38 | 51.35 | 75.68 | 91.89 |
| | 90.91 | 96.97 | 75.76 | 72.73 | 90.91 | 100.00 |
| | 88.57 | 91.43 | 65.71 | 65.71 | 80.00 | 85.71 |
| | 91.18 | 85.29 | 79.41 | 79.41 | 94.12 | 94.12 |
| | 96.88 | 96.88 | 81.25 | 87.50 | 96.88 | 90.63 |
| **Average** | **89.5** | **93.0** | **76.0** | **70.8** | **87.1** | **92.4** |

Table C2. Percentages for T3

| | | | | | | |
|---|---|---|---|---|---|---|
| **T3 conv/normal** | 82.35 | 85.29 | 47.06 | 55.88 | 52.94 | 85.29 |
| | 68.57 | 82.86 | 74.29 | 48.57 | 74.29 | 74.29 |
| | 65.71 | 85.71 | 65.71 | 48.57 | 65.71 | 74.29 |
| | 77.14 | 80.00 | 62.86 | 40.00 | 80.00 | 68.57 |
| | 94.12 | 85.29 | 70.59 | 47.06 | 85.29 | 70.59 |
| **Average** | **77.5** | **83.8** | **64.2** | **48.0** | **71.7** | **74.6** |
| | | | | | | |
| **T3 conv/slow** | 78.13 | 100.00 | 68.75 | 65.63 | 84.38 | 93.75 |
| | 97.22 | 94.44 | 77.78 | 72.22 | 77.78 | 86.11 |
| | 91.67 | 94.44 | 80.56 | 80.56 | 77.78 | 91.67 |
| | 100.00 | 94.29 | 60.00 | 77.14 | 94.29 | 97.14 |
| | 88.57 | 94.29 | 60.00 | 65.71 | 77.14 | 82.86 |
| **Average** | **91.4** | **95.4** | **69.5** | **72.4** | **82.2** | **90.2** |
| | | | | | | |
| **T3 clear/normal** | 64.71 | 85.29 | 58.82 | 64.71 | 73.53 | 73.53 |
| | 77.14 | 97.14 | 45.71 | 68.57 | 71.43 | 85.71 |
| | 62.86 | 91.43 | 48.57 | 40.00 | 62.86 | 68.57 |
| | 62.86 | 88.57 | 51.43 | 42.86 | 60.00 | 62.86 |
| | 79.41 | 97.06 | 61.76 | 52.94 | 58.82 | 67.65 |
| **Average** | **69.4** | **91.9** | **53.2** | **53.8** | **65.3** | **71.7** |
| | | | | | | |
| **T3 clear/slow** | 81.25 | 100.00 | 87.50 | 59.38 | 87.50 | 90.63 |
| | 80.56 | 97.22 | 77.78 | 61.11 | 91.67 | 83.33 |
| | 75.00 | 83.33 | 69.44 | 55.56 | 86.11 | 80.56 |
| | 94.29 | 97.14 | 82.86 | 65.71 | 82.86 | 94.29 |
| | 91.43 | 85.71 | 80.00 | 57.14 | 88.57 | 82.86 |
| **Average** | **84.5** | **92.5** | **79.3** | **59.8** | **87.4** | **86.2** |

Table C3. Percentages for T4

| | | | | | | |
|---|---|---|---|---|---|---|
| **T4 conv/normal** | 82.86 | 97.14 | 77.14 | 71.43 | 91.43 | 88.57 |
| | 87.88 | 90.91 | 69.70 | 57.58 | 93.94 | 87.88 |
| | 80.00 | 94.29 | 68.57 | 40.00 | 82.86 | 94.29 |
| | 82.35 | 85.29 | 52.94 | 52.94 | 73.53 | 70.59 |
| | 73.53 | 91.18 | 67.65 | 64.71 | 76.47 | 82.35 |
| **Average** | **81.3** | **91.8** | **67.3** | **57.3** | **83.6** | **84.8** |
| **T4 conv/slow** | 51.43 | 82.86 | 48.57 | 54.29 | 31.43 | 65.71 |
| | 68.57 | 91.43 | 60.00 | 57.14 | 71.43 | 68.57 |
| | 61.76 | 82.35 | 47.06 | 58.82 | 55.88 | 79.41 |
| | 55.56 | 86.11 | 50.00 | 52.78 | 55.56 | 63.89 |
| | 68.75 | 87.50 | 31.25 | 56.25 | 46.88 | 59.38 |
| **Average** | **61.0** | **86.0** | **47.7** | **55.8** | **52.3** | **67.4** |
| **T4 clear/normal** | 68.57 | 91.43 | 71.43 | 71.43 | 91.43 | 77.14 |
| | 84.85 | 90.91 | 63.64 | 69.70 | 87.88 | 84.85 |
| | 51.43 | 88.57 | 65.71 | 65.71 | 68.57 | 88.57 |
| | 67.65 | 82.35 | 55.88 | 50.00 | 79.41 | 55.88 |
| | 79.41 | 88.24 | 61.76 | 55.88 | 76.47 | 73.53 |
| **Average** | **70.2** | **88.3** | **63.7** | **62.6** | **80.7** | **76.0** |
| **T4 clear/slow** | 88.57 | 97.14 | 82.86 | 77.14 | 94.29 | 94.29 |
| | 88.57 | 97.14 | 82.86 | 62.86 | 94.29 | 94.29 |
| | 85.29 | 91.18 | 64.71 | 67.65 | 82.35 | 97.06 |
| | 88.89 | 86.11 | 58.33 | 63.89 | 94.44 | 86.11 |
| | 81.25 | 93.75 | 68.75 | 59.38 | 71.88 | 84.38 |
| **Average** | **86.6** | **93.0** | **71.5** | **66.3** | **87.8** | **91.3** |

Table C4. Percentages for T5

| | | | | | | |
|---|---|---|---|---|---|---|
| **T5 conv/normal** | 100.00 | 100.00 | 84.21 | 78.95 | 92.11 | 94.74 |
| | 88.24 | 100.00 | 58.82 | 73.53 | 88.24 | 91.18 |
| | 87.10 | 96.77 | 83.87 | 64.52 | 93.55 | 90.32 |
| | 94.29 | 100.00 | 65.71 | 71.43 | 94.29 | 94.29 |
| | 86.11 | 97.22 | 61.11 | 66.67 | 94.44 | 91.67 |
| **Average** | **91.4** | **98.9** | **70.7** | **71.3** | **92.5** | **92.5** |
| | | | | | | |
| **T5 conv/slow** | 83.78 | 97.30 | 70.27 | 51.35 | 86.49 | 83.78 |
| | 93.94 | 100.00 | 78.79 | 63.64 | 100.00 | 96.97 |
| | 91.18 | 91.18 | 88.24 | 73.53 | 85.29 | 91.18 |
| | 79.41 | 100.00 | 61.76 | 50.00 | 79.41 | 88.24 |
| | 91.89 | 89.19 | 70.27 | 62.16 | 94.59 | 94.59 |
| **Average** | **88.0** | **95.4** | **73.7** | **60.0** | **89.1** | **90.9** |
| | | | | | | |
| **T5 clear/normal** | 89.47 | 100.00 | 78.95 | 60.53 | 97.37 | 100.00 |
| | 91.18 | 91.18 | 79.41 | 67.65 | 91.18 | 94.12 |
| | 93.55 | 90.32 | 90.32 | 70.97 | 93.55 | 93.55 |
| | 91.43 | 94.29 | 80.00 | 51.43 | 88.57 | 88.57 |
| | 88.89 | 94.44 | 72.22 | 66.67 | 86.11 | 91.67 |
| **Average** | **90.8** | **94.3** | **79.9** | **63.2** | **91.4** | **93.7** |
| | | | | | | |
| **T5 clear/slow** | 91.89 | 94.59 | 59.46 | 75.68 | 81.08 | 97.30 |
| | 96.97 | 100.00 | 66.67 | 78.79 | 100.00 | 100.00 |
| | 94.12 | 97.06 | 82.35 | 88.24 | 100.00 | 82.35 |
| | 85.29 | 97.06 | 64.71 | 82.35 | 91.18 | 94.12 |
| | 94.59 | 94.59 | 64.86 | 86.49 | 97.30 | 100.00 |
| **Average** | **92.6** | **96.6** | **67.4** | **82.3** | **93.7** | **94.9** |

Appendix D:

Within-subjects Effects and Interactions

Dependent Variable: rau

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 15.310(a) | 95 | 0.161 | 13.186 | 0.000 |
| Intercept | 593.874 | 1 | 593.874 | 48,591.382 | 0.000 |
| **listener** | **8.852** | **5** | **1.770** | **144.855** | **0.000** |
| **talker** | **2.129** | **3** | **0.710** | **58.075** | **0.000** |
| **rate** | **0.588** | **1** | **0.588** | **48.129** | **0.000** |
| **mode** | **0.132** | **1** | **0.132** | **10.814** | **0.001** |
| **listener * talker** | **0.410** | **15** | **0.027** | **2.238** | **0.005** |
| listener * rate | 0.036 | 5 | 0.007 | 0.582 | 0.714 |
| **talker * rate** | **0.910** | **3** | **0.303** | **24.832** | **0.000** |
| listener * talker * rate | 0.186 | 15 | 0.012 | 1.014 | 0.440 |
| listener * mode | 0.137 | 5 | 0.027 | 2.249 | 0.049 |
| **talker * mode** | **0.240** | **3** | **0.080** | **6.540** | **0.000** |
| listener * talker * mode | 0.199 | 15 | 0.013 | 1.083 | 0.370 |
| **rate * mode** | **0.509** | **1** | **0.509** | **41.652** | **0.000** |
| listener * rate * mode | 0.045 | 5 | 0.009 | 0.739 | 0.594 |
| **talker * rate * mode** | **0.394** | **3** | **0.131** | **10.733** | **0.000** |
| **listener * talker * rate * mode** | **0.542** | **15** | **0.036** | **2.957** | **0.000** |
| Error | 4.693 | 384 | 0.012 | | |
| Total | 613.876 | 480 | | | |
| Corrected Total | 20.003 | 479 | | | |

a. R Squared = .765 (Adjusted R Squared = .707)