Effects of Speech Rate, Background Noise, and Simulated Hearing Loss on Speech Rate Judgment and Speech Intelligibility in Young Listeners

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Abstract

**Purpose:** To study the effect of noise on speech rate judgment and signal-to-noise ratio threshold (SNR50) at different speech rates (slow, preferred, and fast).

**Research Design:** Speech rate judgment and SNR50 tasks were completed in a normal-hearing condition and a simulated hearing-loss condition.

**Study Sample:** Twenty-four female and six male young, normal-hearing participants.

**Results:** Speech rate judgment was not affected by background noise regardless of hearing condition. Results of the SNR50 task indicated that, as speech rate increased, performance decreased for both hearing conditions. There was a moderate correlation between speech rate judgment and SNR50 with the various speech rates, such that as judgment of speech rate increased from too slow to too fast, performance deteriorated.

**Conclusions:** These findings can be used to support the need for counseling patients and their families about the potential advantages to using average speech rates or rates that are slightly slowed while conversing in the presence of background noise.

**Key Words:** Background noise, signal-to-noise ratio threshold, simulated hearing loss, speech intelligibility, speech rate judgment

**Abbreviations:** HINT = Hearing in Noise Test; Quick SIN = Quick Speech-in-Noise test; SNR = signal-to-noise ratio; SNR50 = signal-to-noise ratio threshold

Adverse listening conditions, such as those with background noise or reverberation, frequently cause communication difficulty for listeners with normal hearing and for those with hearing impairment (Houtgast and Steeneken, 1973; Committee on Hearing, Bioacoustics, and Biomechanics, 1988; Peissig and Kollmeier, 1997; Killion et al, 2004). In order to reduce these negative effects, researchers have attempted to isolate what factors, if any, can be changed to improve an individual’s ability to understand speech in these conditions. One such variable that has been studied is an alteration of speech rate. It has been suggested that normal-hearing individuals perform better with and prefer speech rates that have been slightly slowed in comparison to average conversational speech rates, which typically fall between 140 and 180 words per minute (Wingfield, 1996; Wingfield and Ducharme, 1999; Wingfield et al, 1999; Wingfield et al, 2006). This preference for and improved performance with slightly slowed speech rates has been particularly documented in degraded listening conditions (Beasley et al, 1972; Konkle et al, 1977; Schmitt and McCroskey, 1981; Schmitt, 1983; Wingfield and Ducharme, 1999; Moore et al, 2007). A similar trend has been shown for listeners with hearing impairment, such that performance on speech understanding measures decreases with an increase in speech rate (Luterman et al, 1966; Sticht and Gray, 1969; Gordon-Salant and Fitzgibbons, 2001; Versfeld and Dreschler, 2002).

To isolate the effect of cochlear dysfunction on speech understanding abilities in the presence of noise,
simulated cochlear hearing losses have been used by some researchers (e.g., Baer and Moore, 1993, 1994; Moore et al, 1997; Nejime and Moore, 1997, 1998). One advantage of simulating a hearing loss, rather than using individuals with hearing impairment, is the opportunity to study different types of communication difficulties in a well-controlled setting (Gagné and Erber, 1987; Nejime and Moore, 1998). Second, all subjects are assumed to have a similar perceptual experience, as they have normal hearing sensitivity and presumably normal language processing skills (Baer and Moore, 1993; Nejime and Moore, 1998). This helps control for variations in central auditory function and ensures that participants receive similarly distorted signals. Third, the use of simulated hearing loss allows the distinction to be made between speech understanding difficulties caused by a peripheral hearing impairment and the effects of dysfunctional central processes (Gagné and Erber, 1987). An additional advantage for the present study is that all participants served as their own control.

Previous studies investigating speech rate effects on speech intelligibility have used percentage scores for speech understanding. In the present study, speech intelligibility was measured using a signal-to-noise ratio threshold (SNR50). SNR50 is the signal-to-noise ratio (SNR) that results in correct identification of presented speech 50 percent of the time by a listener (Nilsson et al, 1994; Etymotic Research, 2001). Two adaptive tests designed to evaluate speech intelligibility in noise are the Quick Speech-in-Noise test (Quick SIN [Etymotic Research, 2001]) and the Hearing in Noise Test (HINT [Nilsson et al, 1994]). In these test measures, the presentation level of either the speech stimuli or noise is altered in order to find the SNR at which the listener can correctly identify the target speech with 50 percent accuracy. The Quick SIN presents a number of advantages over use of the HINT. The primary advantage of the Quick SIN is the ease of use. All stimulus sentences and noise conditions are prerecorded; therefore, the examiner does not have to manipulate the level of either the sentences or the noise during test administration. Second, setup for the Quick SIN is straightforward and easy to accomplish. For these reasons, the Quick SIN was chosen as a measure of SNR50 for the present study.

Research to date has not examined the relation between participant preference for different speech rates and SNR50 at various speech rates. Because listening in degraded situations, such as background noise, is a frequent occurrence, further research is needed to help establish strategies for better speech understanding. The present study incorporated two types of tasks with rate-altered speech in the presence of background noise: a speech rate judgment task and an SNR50 task. The present study also incorporated two listening conditions: a normal-hearing condition and a simulated hearing-loss condition.

The purpose of the present study was threefold. First, the effect of background noise on speech rate judgment for listeners with normal hearing and with simulated hearing loss was investigated. Because the presence of background noise creates an adverse listening condition, and because this adverse listening condition could affect the processing of the speech stimuli, it was hypothesized that individuals would prefer speech rates that were slower than average conversational speech when in the presence of increasing background noise. Previous research has suggested that individuals do prefer slower rates of speech in some degraded listening conditions (Moore et al, 2007). Further, it was hypothesized that with a simulated hearing loss, individuals would prefer even slower speech rates than when listening with normal hearing. Second, the effect of speech rate on speech intelligibility in background noise for listeners with normal hearing and simulated hearing loss was examined. It was predicted that in the normal-hearing condition, individuals would have a lower SNR50 on an intelligibility measure than in the simulated mild high-frequency hearing-loss condition. Last, the relationship between speech rate judgment in background noise and speech intelligibility in background noise for listeners with normal hearing and simulated hearing loss was studied. A relationship between speech rate judgment and performance on the intelligibility measure was expected, such that as speech rate increased and was judged to be faster, SNR50 was expected to increase. Additionally, performance was expected to improve when a slower-than-average rate of speech was used.

**METHOD**

**Participants**

Thirty participants (6 males, 24 females) between the ages of 20 and 28 years ($M = 23.75$) were included in the present study. They were unpaid volunteers from the University of South Alabama and surrounding community. Informed consent was obtained from each participant in accordance with a protocol established by the university’s Institutional Review Board. Audiometric thresholds were obtained on all participants, and all participants had audiometric thresholds of 15 dB HL or less at 500, 1000, 2000, 4000, and 6000 Hz, bilaterally (American Speech-Language-Hearing Association, 2005). Additionally, all partici-
pants were native speakers of American English and had no significant history of speech/language or otologic disorders.

Instrumentation and Materials

Preliminary and experimental tasks were completed in a double-walled, sound-treated booth that met specifications for maximum permissible ambient noise levels for audiometric test rooms (American National Standards Institute [ANSI], 1991). The audiometric testing was performed using a Grason-Stadler Incorporated (GSI 16) audiometer and E-A-R TONE 5A insert earphones calibrated according to ANSI (1996) specifications for audiometers. Experimental speech stimuli were presented binaurally using a Tucker-Davis Technologies System 3 psychoacoustics workstation, through E-A-R TONE 5A insert earphones at a presentation level of 70 dB SPL. Prior to the study, the levels of the sentences and noise were calibrated in dB HL (ANSI, 1996) using a Quest Model 1800 sound level meter with a Brüel and Kjær DB138 2-cc coupler. Calibration was repeated at the conclusion of data collection.

The speech stimuli for both the speech rate judgment task and the speech intelligibility task were produced using sentences from the separated version of the Quick SIN test (Etymotic Research, 2001). Because the speech stimuli are recorded in one channel and a multitalker competing noise signal is recorded on the other channel, the speech and noise signals can be altered independently of each other. For the present study, the original speech and noise signals from the Quick SIN were digitally manipulated using Cool Edit Pro version 2.0 (Syntrillium Software Corporation), a multitrack sound-editing software system. Cool Edit Pro is no longer commercially available. Adobe Audition 3 is the most recent version of this software and is available from Adobe Systems Incorporated.

For the speech rate judgment task, one sentence (“The lake sparkled in the red hot sun”) was digitally modified for all experimental conditions. In order to alter this sentence for the task, the sentence was isolated from all other sentences in Track 21, Practice List A of the Quick SIN test. The noise was temporarily removed prior to any rate alteration manipulations. The time compression or expansion was accomplished by determining the duration needed to make the sentence the desired words per minute (wpm) rate and by using a “time stretch” function within Cool Edit. This function changes the speech rate while preserving the pitch of the target sentence.

The following formula was used:

\[
\text{duration needed to produce desired speech rate} = \frac{\text{(60 sec \times \# of words in sentence)}}{\text{wpm}}
\]

For example, if the desired rate was 130 wpm and there were eight words in the target sentence, the calculation was

\[
\frac{(60 \text{ sec} \times 8 \text{ words})}{130 \text{ wpm}} = 3.692 \text{ sec}
\]

This change in duration was entered into the “stretch” function of Cool Edit Pro to produce the desired speech rate (wpm). Cool Edit performs time compression (time expansion) by speeding up (or slowing down) the playback and bending the pitch of the resulting stimulus back to the original range.

The resulting speech rates ranged from 90 to 250 wpm, in 8 wpm steps. The stimuli created were rate-altered versions of the original sentence without any added distortion or change in pitch. The speech rate was altered in 8 wpm steps based on pilot data that indicated, on average, the just-noticeable difference in speech rate for a sentence of similar length to be 10 to 15 wpm. After the speech signal was rate altered, the competing noise signal was added back to the rate-altered speech stimuli at SNRs of +15 dB, +10 dB, and +5 dB. This mix of speech stimuli and noise was used to create a two-channel (stereo) recording with the same speech and noise signals in each channel. These stimuli were used in the normal-hearing condition of the speech rate judgment task.

For the speech intelligibility task, each track of the separated version of the Quick SIN test was independently manipulated. The block of interest was extracted from the compact disc with the speech signal in the first channel and the noise in the second channel. The rates of all of the sentences were altered so that each sentence had a rate of 130, 170, or 234 wpm. In previous research these rates have been judged by listeners with normal hearing to be slow, preferred, and fast, respectively (Moore et al., 2007). The speech rate was consistent within one block of experimental sentences. The noise signal in the second channel was then altered independently of the sentences to produce a different SNR for each sentence within one experimental block. This design was in keeping with the conventional administration of the Quick SIN, which involves a speech understanding measure with six sentences per block at six increasingly difficult SNRs (+25 dB, +20 dB, +15 dB, +10 dB, +5 dB, and 0 dB). The speech and noise signals were then mixed so that the two channels of the recording had identical samples of the combined speech and noise stimuli. These stimuli were used for the normal-hearing condition of the speech intelligibility task.

Further manipulations were then performed to create a simulated mild high-frequency hearing-loss condition for both experimental tasks. Using the stimuli previously created for each of the tasks in the normal-hearing condition, the speech and noise signals were filtered to create four bands, 1600 Hz wide, using a Chebyshev 1 bandpass filter. Similar to the procedures used by
previous researchers, these bands were composed of frequency components between approximately 62 and 6462 Hz and were filtered by a factor of six (i.e., sixth-order filters [Baer and Moore, 1993, 1994]). The amplitude of the acoustic energy in each of these bands was decreased by a specified amount to simulate the threshold elevation component of the hearing loss simulated in this study. Table 1 contains the average audiometric thresholds for all participants, the filtering levels used to simulate the hearing loss for the present study, and the average induced hearing loss, as calculated by subtracting the filtering levels from the average audiometric thresholds. On average, audiometric thresholds were below 10 dB HL, and all participants had audiometric thresholds less than 15 dB HL at 500, 1000, 2000, and 4000 Hz.

Loudness recruitment was then added to the bands of filtered speech and noise, in a similar manner to that done in previous research (Moore and Glasberg, 1993). The recruitment was simulated through digital manipulation of the stimulus input/output function, making it nonlinear (steep loudness growth) at low-intensity input levels and linear (change in input = change in output) at high input levels. These stimuli were used in the simulated hearing-loss condition within the task for which they were created (speech rate judgment task or speech intelligibility task).

Procedures

Practice exercises were completed prior to the speech rate judgment and speech intelligibility tasks. Participants were presented with verbal and written instructions regarding each task. For the speech rate judgment task, a block of rate-altered sentences from 90 to 250 wpm, in 16 wpm steps, with multitalker background noise at an SNR of 20 dB was used for practice. Participants were asked to judge the rate of the presented speech based on the response alternatives ranging from “too slow” to “too fast.” For the speech intelligibility task, participants were presented with a practice list from the Quick SIN in the conventional manner, such that one block of six sentences was presented with SNRs that decreased in 5 dB steps (+25 dB SNR to 0 dB SNR). Different sentences were used during the practice exercises than were used for the experimental tasks.

Two test sessions lasting approximately an hour and 15 minutes each were used for data collection. Participants were given breaks between the two experimental tasks and when requested. Each subject participated in all experimental conditions first for one hearing condition during the initial session and participated in all conditions for the other hearing condition in a separate session. The order of the two hearing conditions was counterbalanced across subjects. Because the stimulus items were the same for the two sessions, there was a minimum delay of two weeks between these experimental sessions.

Independent variables for the present study were speech rate, background noise level, and simulated hearing loss. Dependant variables were speech rate judgment and speech intelligibility.

Speech Rate Judgment Task

The procedures for this task were previously described in Moore et al (2007). For the speech rate judgment task, one sentence, at each of the 21 speech rates (from 90 to 250 wpm), was presented in four listening conditions (quiet, +15 dB SNR, +10 dB SNR, and +5 dB SNR). This task was completed in the normal-hearing condition and in the simulated hearing-loss condition. Participants were asked to listen to the target sentence and judge the presented speech rate based on five choices: too slow, slow but ok, preferred, fast but ok, too fast. Participants indicated their choice by selecting the appropriate descriptor on a computer monitor using a computer mouse. Responses were recorded by ECoS/Win Controller for Windows version 2.01 (Avaaz Innovations) for later review. The listening conditions (quiet and various levels of background noise) were randomly presented. Two runs of each listening condition were completed in both hearing conditions in order for test reliability measures to be completed.

Speech Intelligibility Task

For the speech intelligibility task, participants were asked to repeat, in its entirety, the sentence from the

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Average Threshold (dB HL)</th>
<th>Filtering Level (dB)</th>
<th>Average Induced Threshold (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>9.58 (4.04)</td>
<td>5</td>
<td>4.58</td>
</tr>
<tr>
<td>1000</td>
<td>7.08 (3.83)</td>
<td>10</td>
<td>2.92</td>
</tr>
<tr>
<td>2000</td>
<td>8.33 (4.18)</td>
<td>30</td>
<td>21.67</td>
</tr>
<tr>
<td>4000</td>
<td>6.92 (4.79)</td>
<td>40</td>
<td>33.08</td>
</tr>
<tr>
<td>6000</td>
<td>5.83 (4.80)</td>
<td>40</td>
<td>34.17</td>
</tr>
</tbody>
</table>
Quick SIN that was presented. Twelve blocks of sentences were used. Each block contained six sentences with SNRs of +25 dB, +20 dB, +15 dB, +10 dB, +5 dB, and 0 dB. Four of the 12 blocks were presented with a “slow” speech rate of 130 wpm, four blocks were presented with a “preferred” speech rate of 170 wpm, and four were presented with a “fast” speech rate of 234 wpm. Four blocks of each speech rate were completed for each hearing condition (normal hearing and simulated hearing loss), and results were averaged in order to reduce the amount of variability in the test results (Etymotic Research, 2001). After the experimental sentence was presented to the participant, each of five target words was scored, and an SNR50 was calculated for each speech rate within each hearing condition.

SNR50 was described by Killion et al (2004) as the SNR needed to achieve 50 percent accuracy in intelligibility. For the present study, SNR50 was calculated according to the protocol outlined by the Quick SIN instructions, such that the number of correctly identified words within one block of six sentences was subtracted from a constant (25.5). Because four blocks of sentences were completed for each of the three speech rates in each hearing condition, an average SNR loss was calculated for each condition so that statistical analyses could be carried out.

RESULTS

Speech Rate Judgment Task

Following the completion of data collection, participant responses to the stimuli were analyzed using the software-generated reports from the speech rate judgment task. For data analysis of the speech rate judgment task, each judgment category was assigned a number between 1 and 5 (1 = too slow; 2 = slow but ok, 3 = preferred, 4 = fast but ok, 5 = too fast). Each participant completed two trials for each speech rate in each noise condition (quiet, +15 dB SNR, +10 dB SNR, and +5 dB SNR) and for each hearing condition (normal hearing and simulated hearing loss). For each hearing condition and noise condition, data from the two trials were used to calculate an average speech rate judgment for each of the 21 speech rates. These averages were used for descriptive and analytic statistics.

Table 2 shows the mean speech rate judgments and standard deviations for each speech rate in each of the four listening conditions. Because subsequent statistical analyses showed that there was no difference in the speech rates given by participants listening with normal hearing or with the simulated hearing loss, the data were collapsed across hearing condition. The shaded area in Table 2 shows the range of speech rates that participants judged as “preferred.” As indicated by the table, the “preferred” range of speech rates fell between 162 and 210 wpm for all noise conditions. Overall, the difference between the speech rate judgments for all speech rates within each of the noise conditions was negligible.

Data were evaluated using both parametric and nonparametric statistical analyses. While the results were similar, only parametric results are presented in this article, as this is the more powerful analytical tool. A three-way repeated-measures analysis of variance (speech rate × hearing condition × noise condition) was conducted to evaluate the effect of the noise condition on the judgment of speech rate in two hearing conditions (normal hearing and simulated hearing loss). Significant main effects of noise \( (F[1.96, 56.89] = 7.425, p < .001) \) and speech rate \( (F[3.33, 96.69] = 817.90, p < .001) \) were found. The main effect of hearing condition was not significant. There was a significant interaction between speech rate and the noise condition \( (F[47.46, 1376.28] = 3.14, p < .001); \) however, there were no other significant interactions found.

Due to the significant interaction effect between speech rate and the noise condition found with the analysis of variance (ANOVA), a series of follow-up tests was conducted. Four one-way repeated-measures ANOVAs were completed in order to determine whether there were significant differences between the 21 speech rates within each noise condition. The results of the ANOVAs revealed a significant difference for speech rate within all four noise conditions (quiet condition, \( F[10, 20] = 90.97, p < .001; +15 \) dB SNR condition, \( F[10, 20] = 256.79, p < .001; +10 \) dB SNR condition, \( F[10, 20] = 164.23, p < .001; +5 \) dB SNR condition, \( F[10, 20] = 522.55, p < .001) \). With significant differences found within all four one-way ANOVAs completed, pairwise comparisons were used to determine which paired speech rates were significantly different within each noise condition. Bonferroni corrections were used to establish alpha level. Within each noise condition, paired comparisons of speech rates with at least a 16 wpm separation were typically significantly different with the exception of the extremely slow speech rates.

Additionally, to evaluate the significant interaction between speech rate and noise condition, 21 four-way repeated-measures ANOVAs were completed. The ANOVAs evaluated the presence of significant differences between the four noise conditions within each of the 21 speech rates (e.g., for a speech rate of 90 wpm, which noise conditions were significantly different). Of the 21 ANOVAs completed, there was only one statistically significant difference. This difference occurred at a speech rate of 234 wpm \( (F[3, 27] = \)
Subsequent pairwise comparisons were conducted for the 234 wpm speech rate and included the following comparisons: quiet and +5 dB SNR, quiet and +10 dB SNR, quiet and +15 dB SNR, +5 dB SNR and +10 dB SNR, +5 dB SNR and +15 dB SNR, +10 dB and +15 dB SNR. Holm’s sequential Bonferroni corrections were used to establish alpha level. Only the pairwise comparison of +5 dB SNR and +15 dB SNR was statistically significant ($t_{29} = 4.27, p < .001$).

For the speech rate judgment task, 20 percent of the participants were randomly selected for a calculation of intrasubject reliability using a correlation coefficient. Reliability was measured between the participants’ responses during the two experimental trials (i.e., the judgment given to a specific speech rate in the first trial and the judgment given to the speech rate in the second trial). The results of the correlational analysis were statistically significant ($r = 0.905, p < .001$).

**Speech Intelligibility Task**

For data analysis of the speech intelligibility task, the on-line recordings of participants’ responses were used to obtain an average SNR50 for each speech rate (130 wpm, 170 wpm, and 234 wpm) within each hearing condition (normal hearing and simulated hearing loss). From the four blocks of sentences presented at each of the three speech rates, four SNR50s were calculated for the 130 wpm speech rate, the 170 wpm speech rate, and the 234 wpm speech rate, within the normal-hearing and simulated hearing-loss conditions separately. These four SNR50 scores obtained with each speech rate were then averaged to obtain the “average SNR50” for each speech rate, within the appropriate hearing condition.

In the normal-hearing condition, a speech rate of 130 wpm resulted in a mean SNR50 of $2.04$ dB (SD $= 1.30$). A speech rate of 170 wpm resulted in a mean SNR50 of $2.70$ dB (SD $= 1.17$), and a speech rate of 234 wpm resulted in a mean SNR50 of $7.39$ dB (SD $= 2.27$) was found. While there was no difference in the mean SNR50s with speech rates of 130 and 170 wpm, there was a trend for a greater SNR50 with the faster speech rate of 234 wpm. Also of note are the standard deviations with each of these speech rates. The standard deviations with 130 and 170 wpm speech rates are very similar; however, there was more

**Table 2. Mean (and SD) Judgments for Each Speech Rate, Collapsed across Hearing Condition, in Four Noise Conditions**

<table>
<thead>
<tr>
<th>Speech Rate (wpm)</th>
<th>Quiet</th>
<th>15 dB Signal-to-Noise Ratio</th>
<th>10 dB Signal-to-Noise Ratio</th>
<th>5 dB Signal-to-Noise Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>1.01 (0.05)</td>
<td>1.01 (0.05)</td>
<td>1.04 (0.15)</td>
<td>1.01 (0.05)</td>
</tr>
<tr>
<td>98</td>
<td>1.01 (0.05)</td>
<td>1.02 (0.07)</td>
<td>1.03 (0.13)</td>
<td>1.03 (0.12)</td>
</tr>
<tr>
<td>106</td>
<td>1.06 (0.19)</td>
<td>1.09 (0.22)</td>
<td>1.18 (0.36)</td>
<td>1.24 (0.36)</td>
</tr>
<tr>
<td>114</td>
<td>1.15 (0.28)</td>
<td>1.22 (0.32)</td>
<td>1.38 (0.37)</td>
<td>1.39 (0.39)</td>
</tr>
<tr>
<td>122</td>
<td>1.85 (0.42)</td>
<td>1.68 (0.37)</td>
<td>1.63 (0.39)</td>
<td>1.65 (0.48)</td>
</tr>
<tr>
<td>130</td>
<td>1.60 (0.46)</td>
<td>1.76 (0.43)</td>
<td>1.86 (0.41)</td>
<td>1.87 (0.38)</td>
</tr>
<tr>
<td>138</td>
<td>1.90 (0.40)</td>
<td>2.02 (0.26)</td>
<td>2.08 (0.43)</td>
<td>2.16 (0.43)</td>
</tr>
<tr>
<td>146</td>
<td>2.11 (0.43)</td>
<td>2.20 (0.39)</td>
<td>2.29 (0.38)</td>
<td>2.32 (0.43)</td>
</tr>
<tr>
<td>154</td>
<td>2.23 (0.44)</td>
<td>2.30 (0.38)</td>
<td>2.45 (0.42)</td>
<td>2.43 (0.42)</td>
</tr>
<tr>
<td>162</td>
<td>2.50 (0.50)</td>
<td>2.52 (0.41)</td>
<td>2.58 (0.39)</td>
<td>2.60 (0.41)</td>
</tr>
<tr>
<td>170</td>
<td>2.70 (0.43)</td>
<td>2.77 (0.36)</td>
<td>2.78 (0.39)</td>
<td>2.86 (0.33)</td>
</tr>
<tr>
<td>178</td>
<td>2.89 (0.35)</td>
<td>2.92 (0.21)</td>
<td>2.96 (0.30)</td>
<td>3.05 (0.33)</td>
</tr>
<tr>
<td>186</td>
<td>2.98 (0.33)</td>
<td>3.01 (0.21)</td>
<td>3.13 (0.30)</td>
<td>3.10 (0.25)</td>
</tr>
<tr>
<td>194</td>
<td>3.14 (0.37)</td>
<td>3.23 (0.38)</td>
<td>3.11 (0.24)</td>
<td>3.25 (0.38)</td>
</tr>
<tr>
<td>202</td>
<td>3.39 (0.43)</td>
<td>3.28 (0.44)</td>
<td>3.33 (0.40)</td>
<td>3.34 (0.46)</td>
</tr>
<tr>
<td>210</td>
<td>3.55 (0.48)</td>
<td>3.38 (0.42)</td>
<td>3.46 (0.45)</td>
<td>3.49 (0.48)</td>
</tr>
<tr>
<td>218</td>
<td>3.79 (0.63)</td>
<td>3.79 (0.46)</td>
<td>3.80 (0.50)</td>
<td>3.97 (0.50)</td>
</tr>
<tr>
<td>226</td>
<td>3.98 (0.52)</td>
<td>3.83 (0.50)</td>
<td>3.94 (0.43)</td>
<td>4.01 (0.52)</td>
</tr>
<tr>
<td>234</td>
<td>4.12 (0.56)</td>
<td>4.00 (0.49)</td>
<td>4.04 (0.49)</td>
<td>4.20 (0.53)</td>
</tr>
<tr>
<td>242</td>
<td>4.36 (0.58)</td>
<td>4.26 (0.53)</td>
<td>4.38 (0.46)</td>
<td>4.39 (0.55)</td>
</tr>
<tr>
<td>250</td>
<td>4.45 (0.54)</td>
<td>4.41 (0.52)</td>
<td>4.53 (0.54)</td>
<td>4.44 (0.52)</td>
</tr>
</tbody>
</table>

Note: Speech rates: 1 = too slow, 2 = slow but ok, 3 = preferred, 4 = fast but ok, 5 = too fast. The shaded area shows the range of speech rates that participants judged as “preferred.”

8.97, $p < .001$).

For the speech rate judgment task, 20 percent of the participants were randomly selected for a calculation of intrasubject reliability using a correlation coefficient. Reliability was measured between the participants’ responses during the two experimental trials (i.e., the judgment given to a specific speech rate in the first trial and the judgment given to the speech rate in the second trial). The results of the correlational analysis were statistically significant ($r = 0.905, p < .001$).
variability with the faster speech rate of 234 wpm. Figure 1 depicts the mean SNR50 and standard deviations in decibels for each of the speech rates within both the normal-hearing and simulated hearing-loss conditions. As shown in Figure 1, the SNR50s for all three speech rates in the simulated hearing-loss condition were higher (or worse) than those for the normal-hearing condition.

A two-way repeated-measures ANOVA (speech rate \times hearing condition) was conducted in order to examine the effects of speech rate and hearing condition on SNR50. Significant main effects of speech rate \(F(2, 28) = 185.69, p < .001\) and hearing condition \(F(1, 29) = 235.16, p < .001\) were found. Additionally, there was a significant interaction between speech rate and hearing condition \(F(2, 28) = 28.61, p < .001\). Because there was a significant interaction between speech rate and hearing condition, pairwise comparisons via paired-samples t-tests were conducted. Nine paired comparisons were completed in order to compare participant performance with each speech rate within each hearing condition and between the hearing conditions. Table 3 contains a list of the paired comparisons completed, the degrees of freedom, \(t\) values, and the significance levels for each comparison. Using Holm’s sequential Bonferroni corrections to establish the alpha level, significant differences were found for all comparisons, with the exception of the 130 and 170 wpm speech rates in the simulated hearing-loss condition (see Figure 1 and Table 3).

Audio recordings of participant responses were made so that intertester and intratester reliability could be evaluated for the speech intelligibility task. Twenty percent of the participants were randomly selected for reliability measures. A second audiologist scored 20 percent of the participant responses in order to evaluate intertester reliability. These results were compared with the original scored results. The scores from the two testers were in 97 percent agreement. The principle investigator also randomly selected and rescored 20 percent of the participant responses on this task with 99 percent intratester reliability.

**Relationship between Speech Rate Judgment and Speech Intelligibility**

Pearson’s product-moment correlation coefficients \((r)\) were calculated to study the relationship between speech rate judgment and speech intelligibility. Speech rate judgments for each of the three speech rates (130, 170, and 234 wpm) used in the intelligibility task were correlated with SNR50 at the three speech rates. These correlations were carried out for each hearing condition, with the three noise conditions considered separately. The following measures were correlated for each hearing condition (normal hearing and simulated hearing loss, separately): (1) participant judgment of speech rate in a +5 dB SNR with SNR50 at all three speech rates, (2) participant judgment of speech rate in a +10 dB SNR with SNR50 at all three speech rates, and (3) participant judgment of speech rate in a +15 dB SNR with SNR50 at all three speech rates.

There were significant correlations between performance and speech rate judgment in the normal-hearing condition for all three SNRs: +15 dB SNR, \(r = 0.525, p < .001\); +10 dB SNR, \(r = 0.488, p < .001\); and +5 dB SNR, \(r = 0.487, p < .001\). Correlations for the simulated hearing-loss condition were also significant for all three SNRs: +15 dB SNR, \(r = 0.587, p < .001\); +10 dB SNR, \(r = 0.568, p < .001\); and +5 dB SNR, \(r = 0.527, p < .001\).

For the coefficient of determination in the normal-hearing condition, speech intelligibility and speech rate judgment in the +15 dB SNR had 28 percent shared variance \((r^2 = 0.28)\), +10 dB SNR had 24 percent shared variance \((r^2 = 0.24)\), and +5 dB SNR had 24 percent shared variance \((r^2 = 0.24)\). For the coefficient of determination in the simulated hearing-loss condition, speech intelligibility and speech rate judgment in the +15 dB SNR had 34 percent shared variance \((r^2 = 0.34)\), +10 dB SNR had 32 percent shared variance \((r^2 = 0.32)\), and +5 dB SNR had 28 percent shared variance \((r^2 = 0.28)\). This suggests that 24 to 34 percent of the variance in SNR50 can be attributed to a change in speech rate. Specifically, as speech rate increased, the speech was perceived as faster, and therefore an increase in speech rate judgment was recorded. Additionally, with the increase in speech rate, there was an increase in SNR50, demonstrating a decline in performance on the intelligibility task.
The purpose of the present study was to investigate the effects of speech rate and background noise on speech rate judgment and on speech intelligibility for listeners with and without a simulated hearing loss. An additional purpose was to determine whether a relationship existed between the preferred rate of speech in noise and the performance on a speech intelligibility measure in noise at three speech rates found to be “slow but ok,” “preferred,” and “fast but ok” by previous researchers (Moore et al, 2007). Three research questions were posed:

1. Does the presence of background noise affect speech rate judgment for listeners with normal hearing and with a simulated hearing loss?

2. Does speech rate have an impact on speech intelligibility in the presence of background noise, as measured by SNR50, for listeners with normal hearing and with simulated hearing loss?

3. Is there a correlation between speech rate judgment in background noise and speech intelligibility in background noise with various speech rates for listeners with normal hearing and with a simulated hearing loss?

Speech Rate Judgment Task

In agreement with previous research, speech rates that were judged as being the “preferred” rates by the participants in the present study fell between 162 and 210 wpm for all noise and hearing conditions (Foulke and Sticht, 1966; Cain and Lass, 1974; Lass and Fultz, 1976; Riensche et al, 1979; Sutton et al, 1995; Wingfield and Ducharme, 1999). For each speech rate, there were no significant differences in the judgments within any of the noise or hearing conditions. Statistical analyses revealed a significant interaction of speech rate and noise condition; however, subsequent statistics revealed that the only statistically significant difference for noise condition was within the 234 wpm speech rate. This finding was disregarded, as it was the only significant finding within appropriate analyses. Additionally, there was a significant difference between the judgments assigned to all speech rates that were separated by at least 16 wpm. Overall, these findings suggest that regardless of the level of background noise and the presence or absence of a simulated mild high-frequency hearing loss, there is no difference in the judgment of various speech rates or in the range of speech rates that are judged as “preferred.”

Previous research has suggested that individuals do prefer a slower-than-average rate of speech when in certain degraded listening situations, such as reverberation (Moore et al, 2007). Specifically, Moore et al concluded that the presence of reverberation causes distortion of the target speech by means of frequency smearing and spectral overlap. This distortion caused the listeners in the Moore et al study to perceive and judge the speech as faster than when presented in a quiet listening condition. The background noise used in the present study did not produce the same form of distortion, even when the SNR was relatively poor. Therefore, participants did not judge the speech as any faster or slower in the noise conditions than in the quiet condition.

The judgment of speech rate appears to be a central task that is not affected by the peripheral masker used in the present study (Leeper and Thomas, 1978; Sutton et al, 1995; Wingfield and Ducharme, 1999; Gordon-Salant and Fitzgibbons, 2004). Previous research suggested that the judgment of speech rate is affected by the addition of reverberation to the speech signal, and this may be due to the effect that reverberation has on this central task (Moore et al, 2007). The masking overlap and distortion caused by reverberation apparently have an effect on the processing that

<table>
<thead>
<tr>
<th>Paired Comparisons</th>
<th>df</th>
<th>t</th>
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<tr>
<td>NH 130–NH 170</td>
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<td>.001*</td>
</tr>
<tr>
<td>NH 130–NH 234</td>
<td>29</td>
<td>-9.44</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>NH 170–NH 234</td>
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<td>-5.47</td>
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<tr>
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<td>.792</td>
</tr>
<tr>
<td>SHL 130–SHL 234</td>
<td>29</td>
<td>-17.02</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>SHL 170–SHL 234</td>
<td>29</td>
<td>-15.53</td>
<td>&lt;.001*</td>
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<td>&lt;.001*</td>
</tr>
<tr>
<td>NH 234–SHL 234</td>
<td>29</td>
<td>-14.72</td>
<td>&lt;.001*</td>
</tr>
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</table>

*Indicates statistical significance based on Holm’s sequential Bonferroni procedure.
occurs during a speech rate judgment task. The noise used in the present study served as a peripheral masker, which, by definition, has no effect on the central processing of speech stimuli (Carhart et al., 1975). Therefore, it appears that speech rate judgment is not influenced by changes in hearing brought about by a simulated peripheral hearing loss and changes associated with the use of a peripheral masker, such as the four-talker babble used in the current study (Carhart et al., 1975). All factors used in the present study had a peripheral effect and therefore did not affect the central task of speech rate judgment. Further research in this area is needed to help delineate the role of the central auditory system in the judgment of speech rate.

Speech Intelligibility Task

On this task, there were consistent significant differences in SNR50 between the slow (130 wpm), preferred (170 wpm), and fast (234 wpm) speech rates in the normal-hearing condition. When listening to speech at a rate of 130 wpm, participants required the lowest SNR50 of any experimental condition. Therefore, as expected, the best speech intelligibility performance for listeners with normal hearing was achieved with the slowest rate of speech (130 wpm). Performance with the preferred rate of speech (170 wpm) was slightly deteriorated, and listeners required a slightly higher (better) SNR50. Performance deteriorated even further with the fastest rate of speech (234 wpm), and it was in this condition that listeners required the highest SNR (within the normal-hearing condition) to achieve 50 percent accuracy when repeating the target sentence. This result is in keeping with the findings of previous researchers (e.g., Luterman et al., 1966; Sticht and Gray, 1969; Beasley et al., 1972; Konkle et al., 1977; Wingfield and Ducharme, 1999), who all found that increases in speech rate led to more difficulty with speech understanding abilities.

With a simulated mild high-frequency hearing loss, there were significant differences in participant performance with the slow (130 wpm) and fast (234 wpm) speech rates and with the preferred (170 wpm) and fast (234 wpm) speech rates. However, there was not a significant difference between the SNR50s with the slow (130 wpm) and preferred (170 wpm) rates of speech. Lack of statistical significance between performance with these speech rates suggested that slowing the rate of speech for listeners with a simulated hearing loss did not improve performance. It has been previously reported that slowing speech rate does not result in increased speech intelligibility in some listeners (Picheny et al., 1989; Uchanski et al., 1996). In the present study a closer look at individual data from the simulated hearing-loss condition may be helpful in explaining the nonsignificant findings for SNR50 at these speech rates. One half of the participants actually performed better with the preferred speech rate (170 wpm) than with the slower-than-average speech rate (130 wpm). This group of participants had an average improvement in SNR50 of about 1.05 dB when listening to speech at the 170 wpm speech rate as compared to their performance at the slower 130 wpm speech rate.

Thirteen of the 30 participants showed better performance at the slower speech rate than with the preferred speech rate. These participants showed an average improvement in SNR50 of approximately 1.06 dB with the slower speech rate than with the preferred speech rate. Additionally, three participants showed the exact same SNR50 at both speech rates; therefore, there was no improvement in SNR50 at either the slow or the preferred speech rate for these three participants. Because half of the participants did better with the preferred speech rate and a little less than half of the participants did better with the slower speech rate, the statistical analyses were offset by the scores within each of these subgroups. Statistical significance between performance with the slow and preferred speech rates was, therefore, not reached for the simulated hearing-loss condition.

Based on these findings, there appears to be a great deal of variability in the effect of slowing speech rate on performance in noise, particularly when a hearing loss is present. This idea is strengthened by the fact that the same participants were used for both normal-hearing and simulated hearing-loss conditions in the present study. There was far less variability in performance at different speech rates in the normal-hearing condition than was seen in the simulated hearing-loss condition.

Differences in speech understanding abilities with normal hearing and with simulated hearing loss were evident when similar rates of speech were used (see Figure 1). Significant differences existed between the two hearing conditions when listening with speech rates of 130, 170, and 234 wpm. The differences in SNR50 with normal hearing and simulated hearing loss were approximately 4 dB with a speech rate of 130 wpm, 3 dB with a speech rate of 170 wpm, and 6 dB with a speech rate of 234 wpm. These findings are similar to those of Moore et al. (1995), who concluded that with a sloping high-frequency hearing loss, listeners needed an SNR approximately 4 dB higher than normal-hearing individuals.

These results show that, as predicted, when listening with a simulated hearing loss, individuals perform more poorly with all rates of speech than when listening with normal hearing and require a better SNR to achieve the same level of speech understanding (i.e., 50% accuracy). The simulated hearing loss used in
the present study incorporated the elements of threshold elevation of a mild degree at high frequencies, reduced frequency selectivity, and recruitment at frequencies at which a hearing loss was present. As suggested by researchers such as Moore and colleagues (e.g., Baer and Moore, 1993, 1994; Moore et al, 1995; Nejime and Moore, 1998), the distortions associated with the simulated hearing loss caused poorer perception of the target speech that participants were not able to compensate for when listening in situations in which background noise was present.

Using the criteria for "normal" speech understanding in noise abilities (less than a 2 dB SNR loss) suggested by the creators of the Quick SIN, the mean SNR losses for all three speech rates in the normal-hearing condition fell within the normal to near normal SNR loss category, suggesting (on average) little or no difficulty understanding speech in background noise. However, in the simulated hearing-loss condition, the mean SNR50 for all three speech rates fell outside this normal range.

It was more difficult for listeners in both hearing conditions to understand the presented speech as the speech rate became faster. Integral parts of the speech were masked by the higher levels of noise, which made understanding the target speech more difficult. For listeners with normal hearing, slowing the rate of speech (as compared to average speech rates) consistently resulted in better speech understanding performance, while slowing the rate of speech for listeners with a simulated hearing loss resulted in varying degrees of improvement in speech understanding abilities, as evidenced by the SNR50. Slowing the rate of speech in situations with background noise may allow the listener to use other cues about the speech content to decipher what is being said, while giving more time to process the incoming message. Because the listener has more time to process the speech and fill in information that was missed, listeners are more able to understand the target speech when a slower-than-average rate of speech is employed.

Overall, the results of the intelligibility task suggest that speech understanding in situations with background noise can be improved with slower rates of speech. This was more consistent for listeners with normal hearing; however, approximately half of the participants in the simulated hearing-loss condition showed improvement with the slower rate of speech. Almost one half of the remaining participants in this group showed improved performance with a speech rate considered to be a more average, or preferred, rate of speech. The average range of conversational speech is between approximately 140 and 180 wpm (Wingfield, 1996; Wingfield and Ducharme, 1999; Wingfield et al, 1999; Wingfield and Tun, 2001); therefore, the 170 wpm speech rate used in the present study was comparable to the average range of conversational speech found by other researchers. Additionally, as found by previous researchers (Stuart and Phillips, 1998), faster rates of speech were highly detrimental to speech understanding for those with normal hearing and those with whom a hearing loss had been simulated.

Relationship between Speech Rate Preference and Speech Intelligibility

Finally, the relationship between the judgment of speech rate and the participant’s performance with different rates of speech was evaluated. The speech rate judgments for each of the three speech rates used in the speech intelligibility task were correlated with the corresponding SNR50 for each hearing condition. The results of the correlation analysis reveal statistically significant relationships between speech rate judgment and SNR50 in both hearing conditions. The correlation coefficients indicate that these relationships were of moderate strength (Williams and Monge, 2001), suggesting that as speech rate increased, there was a corresponding increase in speech rate judgment and in the SNR needed to achieve 50 percent accuracy on the speech intelligibility measure. It can be concluded that as speech rate increases, there is a subjective change in speech rate judgment and a corresponding decrease in speech intelligibility performance. This is further emphasized by the coefficient of determination. In the normal-hearing condition, speech rate judgment in the +15 dB SNR accounted for 28 percent of the variance in speech intelligibility performance. Speech rate judgment in the +10 dB SNR accounted for 24 percent of the variance in speech intelligibility performance, and in the +5 dB SNR, speech rate judgment accounted for 24 percent of the variance in performance. In the simulated hearing-loss condition, speech rate judgment in the +15 dB SNR accounted for 34 percent of the variance in speech intelligibility performance. Speech rate judgment in the +10 dB SNR accounted for 32 percent of the variance in speech intelligibility performance, and in the +5 dB SNR, speech rate judgment accounted for 28 percent of the variance in performance.

Clearly, while other factors are involved, subjective speech rate plays an important role in speech intelligibility performance, particularly when a hearing loss is present. Individuals should be counseled regarding the potential benefit of speaking at an average speech rate or slightly slowed rate of speech, particularly when talking to individuals with a hearing loss. Extreme slowing of the speech rate may cause a deterioration in intelligibility in the presence of background noise (Picheny et al, 1989).
CONCLUSIONS

Based on the results of the present study, the following conclusions were drawn:

- In background noise participants did not give different preference ratings for different speech rates. This was true for the listeners in both the normal-hearing listening condition and the simulated mild high-frequency hearing-loss listening condition.

- Participants performed more poorly on a speech intelligibility task when a mild high-frequency hearing loss was simulated. Participants needed a better SNR to achieve 50 percent accuracy on the experimental speech intelligibility measure.

- As speech rate increased, those listening with normal hearing and with a simulated mild high-frequency hearing loss demonstrated a decrease in speech understanding abilities in the presence of background noise. This finding was more pronounced in the simulated hearing-loss condition, demonstrating that an increase in speech rate can have a greater effect on speech understanding abilities when a hearing loss is present. This implication can be generalized to those with true mild high-frequency hearing loss. Listeners should be counseled regarding the benefit of asking their communication partners to use average or slightly slowed rates of speech.

- Slowing the rate of speech for participants with a simulated hearing loss proved beneficial for approximately one half of the group. The remaining participants performed better with a speech rate that has been found to be “preferred” in the present study and by previous researchers (Moore et al., 2007). There was benefit observed for normal-hearing listeners when the rate of speech was slowed to 130 wpm.

- Finally, results from the present study suggest a relationship between speech rate judgment and speech understanding abilities, such that as speech rate increases, both speech rate judgment and SNR loss increase. There was more variability found in the performance of listeners with a simulated hearing loss than when the same group of participants listened in the normal-hearing condition, suggesting the heterogeneity associated with hearing loss.

REFERENCES


