J Am Acad Audiol 29:596–608 (2018)

The Influence of Speech Rate on Acceptable Noise Levels

DOI: 10.3766/jaaa.16159

Shelby Tiffin*
Susan Gordon-Hickey*

Abstract

Background: Older adults often struggle with accurate perception of rate-altered speech and have difficulty understanding speech in noise. The acceptable noise level (ANL) quantifies a listener's willingness to listen to speech in background noise and has been found to accurately predict hearing aid success. Based on the difficulty older adults experience with rapid speech, we were interested in how older adults may change the amount of background noise they willingly accept in a variety of speech rate conditions.

Purpose: To determine the effects of age and speech rate on the ANL.

Research Design: A quasi-experimental mixed design was employed.

Study Sample: Fifteen young adults (19–27 yr) and fifteen older adults (55–73 yr) with audiometrically normal hearing or hearing loss within age-normed limits served as participants.

Data Collection and Analysis: Most comfortable listening levels (MCLs) and background noise levels (BNLs) were measured using three different speech rates (slow, normal, and fast). The ANL was calculated by subtracting BNL from MCL. Repeated measures analysis of variances were used to analyze the effects of age and speech rate on ANL.

Results: A significant main effect of speech rate was observed; however, a significant main effect of age was not found. Results indicated that as speech rate increased the ANLs increased. This suggests that participants became less accepting of background noise as speech rates increased.

Conclusions: The findings of the present study provide support for communication strategies that recommend slowing an individual's speaking rate and/or reducing background noise, if possible. Participants in the present study were better able to cope with background noise when the primary stimulus was presented at slow and normal speaking rates.

Key Words: acceptable noise level, background noise level, most comfortable listening level, speech rate, temporal processing

Abbreviations: ANL = acceptable noise level; ANOVA = analysis of variance; BNL = background noise level; CSL = Computerized Speech Laboratory; MCL = most comfortable listening level; MoCA = Montreal Cognitive Assessment; SLP = Speech Language Pathologist; TC = time compression

INTRODUCTION

Auditory temporal processing has been described as the perception of temporal aspects of a sound or the alteration of the duration of a sound within a defined time interval (Musiek et al, 2005). The ability to process temporal aspects of speech is critical for everyday listening activities because it serves as the foundation for many auditory processing capabilities. Accurate processing of temporal structures of sound allows individuals to discriminate voicing of consonants as well as discriminate similar words.

Temporal processing abilities have been studied using different methodological approaches and measurements such as detection of gaps or accurate perception of sound patterns. Temporal processing abilities have also been measured using temporally distorted speech. Speech can be temporally distorted through rate-alteration

---

*University of South Alabama, Mobile, AL

Corresponding author: Shelby Tiffin, Department of Communication Sciences and Disorders, Missouri State University, Springfield, MO 65897; Email: shelbytiffin@missouristate.edu

of speech (time compressed or expanded) or the addition of reverberation. Speech perception and speech understanding (in quiet and in noise) have been measured using rate-altered speech in younger and older adults (Gordon-Salant and Fitzgibbons, 1993; Vaughn and Letowski, 1997; Gordon-Salant and Fitzgibbons, 1999; 2004; Adams and Moore, 2009; Adams et al, 2012). Several studies have demonstrated that older adults struggle with understanding rapid speech (Wingfield et al, 1985; Gordon-Salant and Fitzgibbons, 1993; 1999; Wingfield et al, 1994; Wingfield, 1996; Vaughan and Letwoski, 1997; Gordon-Salant et al, 2007); however, slowed speech has been demonstrated to benefit older adults (Gordon-Salant et al, 2007; Adams et al, 2012). The reported difficulties older adults encounter with rapid speech may be due to an underlying auditory temporal processing deficit or a result of age-related cognitive slowing (Wingfield et al, 1999).

Gordon-Salant and Fitzgibbons (1993) studied speech recognition performance and the effect of altered temporal factors in younger and older adults with and without hearing loss. To assess speech recognition, the authors used temporally degraded speech measures [time compression (TC), reverberation, and interrupted speech]. Independent of hearing sensitivity, significant differences were found across groups for TC, reverberation, and interrupted speech. The older adults performed more poorly than the younger adults on the temporally distorted speech measures. Thus, the authors concluded that age-related factors other than hearing loss contributed to the speech recognition difficulties found for older adults.

Further research was conducted to determine if the difficulties encountered by older adults when listening to rapid speech were due to speed of information processing or a decline in processing brief acoustic cues. Gordon-Salant and Fitzgibbons (2001) examined younger and older adults with and without hearing loss. The stimuli were sentences, phrases, and random word strings that were either undistorted, time-compressed uniformly by 50%, or were selectively time compressed (i.e., reduction in time of pauses, vowels, or consonants). A significant age effect was found for time-compressed sentences and phrases. Older listeners had the most difficulty with the uniform time-compression condition and the selective time-compression of consonants. Significant effects of hearing loss were also found for most of the listening conditions; however, these findings were once again independent of the aging effects. The authors concluded that the difficulties older listeners encounter when listening to rapid speech is due, in part, to a decline in processing brief acoustic cues (consonants) that is common to rapid speech.

Naturally fast speech has been shown to be more difficult to understand than digitally time-compressed speech. Gordon-Salant et al (2014) investigated whether recognition of time-compressed speech could predict speech recognition for naturally fast speech. A group of young normal hearing adults ranging in age from 19 to 22 yr (n = 13) and a group of older normal hearing adults ranging in age from 66 to 76 yr (n = 12) participated. Twelve test lists were recorded for this experiment with three rates (natural normal rate, natural fast rate, and 40% TC). The authors chose to use 40% TC because the natural fast rate was roughly the equivalent to a 40% TC speech rate. The twelve test lists contained six high predictability sentences and six low predictability sentences from the Revised Speech Perception in Noise (R-SPIN) test (Bilger et al, 1984). Each participant was tested under a total of 12 conditions that varied by speech rate (natural normal, natural fast, and 40% TC), environmental condition (quiet, noise), and context (high predictability, low predictability). Regardless of group, in noise, the natural normal speech rate produced the best scores of speech understanding, and the naturally fast speech condition produced the poorest scores of speech understanding. Both age groups performed similarly for the natural normal rate speech condition; however, the younger adults had better scores of speech understanding for the 40% TC and naturally fast speech conditions. In the quiet condition, scores of speech understanding were better for both groups and had a similar pattern of findings compared with the noise conditions. Because of these findings, the authors concluded that digitally rate-altered speech may not fully represent the difficulties encountered in everyday listening situations.

In addition to time-compressed speech, some researchers have examined speech perception and understanding using slowed speech or time-expansion. Adams et al (2012) examined older adults' (with and without hearing loss) performance on speech tasks that were time-expanded and compressed. Quick Speech-in-Noise Test (QuickSIN; Etymotic Research, 2001) sentences were rate altered to be slow, average, and fast. Both older adult groups performed poorly under the fast speech rate condition; however, when the speech rate was slowed the normal hearing older adults showed improved speech perception in noise. The older adults with hearing loss were not able to take advantage of additional processing time and performed the same in the slowed speech condition as the average speech condition. The authors concluded that regardless of hearing status, rapid speech is detrimental to older adults and decreasing from a fast speaking rate slowing to a more normal rate of speech is beneficial especially when listening in noise.

Conversational speech rates vary across speakers. Average speaking rates have been documented to occur between 160 and 200 words per minute (wpm; Yorkston and Beukelman, 1981; Picheny et al, 1986) with everyday listening situations and conversations often exceeding 200 wpm (Wingfield et al, 1985). Because of the difficulties older adults experience with time-compressed speech, it is reasonable that listening in an environment with rapid speech may be particularly challenging for older adults. Research has indicated that older adults struggle with speech understanding when the speech signal is temporally degraded, but does temporal degradation affect the amount of background noise older adults are willing to accept?

Acceptance of background noise, or the acceptable noise level (ANL), was initially described by Nabelek et al (1991). The ANL quantifies an individual's willingness to accept background noise while listening to speech. The ANL is measured by introducing a primary stimulus continuous discourse at the individual's most comfortable listening (MCL) level and adding a competing background noise. The listener then is asked to set their background noise level (BNL) by adjusting the noise in an up and down manner until it is set at the highest level they are willing to accept while listening to the primary stimulus (i.e., discourse). The ANL is a calculated measure and is the difference between MCL and BNL (ANL = MCL-BNL).

Nabelek et al (2004) investigated speech perception in noise and the acceptance of background noise for listeners in aided and unaided conditions. Forty-one full-time hearing aid users and nine part-time hearing aid users (mean age of 71 yr) participated in this study. Findings of the study revealed that full-time hearing aid users accepted more background noise than part-time hearing aid users. The authors determined that this was due to lower BNLs for the full time hearing aid users. The MCL was found to decrease in the aided condition regardless of group. The BNL was found to decrease in the aided condition with a greater decrease for full-time hearing aid users. While both MCL and BNL decreased in the aided condition, BNL decreased more for the full-time hearing users. The authors stated that this caused the decrease in ANL for full-time hearing aid users. The authors found no significant difference in ANL between aided and unaided conditions. For R-SPIN scores, listening condition had a statistically significant effect. In the unaided condition, mean scores were 72.1% and in the aided condition mean scores were 83.1%. No correlation was found between the ANL and R-SPIN scores. The ANL and R-SPIN scores were found to be reliable and stable over a 3 mo period in aided and unaided conditions. However, ANL and R-SPIN scores were not related to one another. Hearing aid gain did not change listeners' ANLs (i.e., aided versus unaided ANLs are not different); however, hearing aid use (full-time user versus part-time user) impacts ANL. The authors suggested that ANL may be measured before hearing aid fitting. In addition, the authors concluded that ANL and speech understanding were independent of one another.

The influence of intelligibility of the primary speech signal on ANL was assessed by Gordon-Hickey and Moore (2008). Thirty young adult females with normal hearing participated. The stimulus conditions were intelligible and unintelligible (reversed speech and unknown language). The Arizona Travelogue (Frye Electronics, Inc.) was used for the intelligible stimulus condition with a reversed recording of the Arizona Travelogue and a recording of conversational Chinese serving as the unfamiliar or unintelligible stimulus condition. The MCL and BNL measurements were then conducted for each condition. The ANL was calculated by subtracting BNL from MCL. A repeated measures analysis of variance (ANOVA) was performed to analyze the differences among the MCL, BNL, and ANL. For MCL, no significant differences were found. For BNL and ANL, significant differences were found for primary discourse type and BNL, and significant differences were found for discourse type and ANL. Post hoc testing revealed significant differences for intelligible and unintelligible conditions (reversed and unfamiliar) for BNL as well as significant differences between intelligible and unintelligible conditions for ANL. For BNL, the intelligible condition and reversed condition were significantly different; however, the intelligible and unfamiliar conditions were not significantly different. The researchers suggested that listeners accepted more background noise when it was intelligible rather than unintelligible. For ANL, each condition was significantly different from one another with the lowest ANLs found for the intelligible condition. Overall, intelligibility of the primary discourse did not affect MCL, but affected BNL thus resulting in a change in ANL. The authors concluded that as speech intelligibility changes, ANL may change, further resulting in a potential change for a patient's predicted hearing aid success rate.

When Nabelek et al (1991) first described the ANL, they found that the ANL did not correlate with MCL, pure-tone average, or age. Nabelek et al (2006) further confirmed these findings when they evaluated the use of ANL as a predictor of hearing aid use with nonusers of hearing aids, part-time hearing aid users, and full-time hearing aid users. A statistically significant, but weak, correlation for age and aided ANL was found. The authors contributed this to the large sample size of the study and deemed the significant correlation for age and aided ANL as clinically insignificant. This finding has been questioned by Walravens et al (2014); however, there are substantial methodologic differences between the two studies. For this reason, the predictive value of ANL before hearing aid fitting should continue to be evaluated.

Studies have demonstrated that ANL is a predictor of hearing aid success and is related to hearing aid use (Nabelek et al, 2006). The ANL is quite variable with few known factors influencing a listener's ANL. Listeners with more self-control have lower ANLs, and listeners with less self-control have higher ANLs (Nichols and Gordon-Hickey, 2012). The ANL is also influenced by the intelligibility of the primary stimulus (Gordon-Hickey and Moore, 2008). The ANL improves with spatial separation of the primary and background stimuli (Freyaldenhoven et al, 2005; Ahlstrom et al, 2009). There are conflicting reports in the literature regarding several factors. Gordon-Hickey et al (2012) reported that ANL is influenced by the primary talker gender and the number of background talkers. However, Plyler et al (2011) reported that ANL did not differ because of the primary talker gender. While many researchers report that ANL is not related to speech perception in noise (Nabelek et al, 2004; 2006), some report that it is (Ahlstrom et al, 2009). There are also conflicting reports regarding the influence of hearing sensitivity on ANL (Nabelek et al, 1991; Walravens et al, 2014). ANL is not related to age (Nabelek et al, 1991; 2006; Crowley and Nabelek, 1996) and listener gender (Crowley and Nabelek, 1996; Rogers et al, 2003).

The purpose of the current study was to evaluate the influence of age and speech rate on acceptance of background noise. Previous research has demonstrated that compared with their younger adult counterparts, older adults perform more poorly on speech understanding and speech perception tasks when increases in speech rate occur. The specific goal of this study was to determine if the difficulty with speech understanding experienced by older adults when speech is rate-altered would translate to a difference in the amount of background noise this population is willing to accept. A slowed speech rate, normal speech rate, and a fast speech rate were used to evaluate background noise acceptance. The following questions were posed: Does listener age affect the ANL? Does speech rate affect the ANL? Do speech rate and listener age interact to influence the ANL?

METHODOLOGY

Participants

Forty-four adults were recruited from the University and surrounding community. Fourteen participants did not meet inclusionary criteria because ofpoor auditory thresholds, poor scores on the cognitive screening, or a combination of the two. Participants included in the study were grouped by age with fifteen younger adults ranging in age from 19 to 27 yr (mean = 21.93) and fifteen older adults ranging in age from 55 to 73 yr (mean = 61.8). Participant numbers were identified with power analysis software (G. Power version 3.1; Erdfelder et al, 1996). All participants had Type A tympanograms, bilaterally. All young adult participants were screened for normal auditory thresholds (i.e., 25 dB HL) and passed for the octave frequencies ranging from 500 to 8000 Hz, bilaterally. The older adult participants were also screened for normal auditory thresholds (i.e., 25 dB HL). All older adult participants passed the hearing screening except for four participants who had hearing loss that was within age normative data based on Cruickshanks et al (1998). Participants with significant hearing loss were referred for further audiological testing. All participants were native speakers of English and no participant had a significant history for receptive speech or language disorder. All participants passed the Montreal Cognitive Assessment (MoCA) with a score of 26 or better (Younger adults mean = 29; Older adults mean = 29; MoCA; Nasreddine et al, 2005). Case history information was obtained before inclusion in the study. All participants recruited for this study read and signed a Statement of Informed Consent approved by the University of South Alabama Internal Review Board.

Apparatus

Stimulus recordings, audiometric testing, and ANL testing were completed in an Industrial Acoustics Company double-walled sound-treated room meeting American National Standards Institute specifications for maximum allowable ambient noise levels for audiometric test rooms (ANSI, 2008). Stimulus recordings were completed using the Computerized Speech Laboratory (CSL) Model 4300B (Kay Elemetrics Corporation, Lincoln Park, NJ) and a head-mounted microphone. Audiometric screening and ANL testing were conducted with a computer-based audiometer (Madsen Astera Otometrics) calibrated in accordance with ANSI (2010) specifications for a Type 2 audiometer. The audiometric testing was completed using TDH-39P earphones mounted in supra-aural cushions. The ANL stimuli were delivered in a sound field routed through the audiometer to an Insignia loudspeaker. Participants were seated 1.5 m from the loudspeaker at 0° azimuth.

Stimuli Recordings

Primary and background stimuli recordings were created for the present study. Previous research indicated that when only one stimulus (primary or background) speech rate was altered, listeners easily distinguished between the primary and background stimuli as different sound sources (Gordon-Salant and Fitzgibbons, 2004). Because of this, both primary and background speech stimuli were recorded for each rate. In addition, recordings were created for the present study to achieve natural fast speech and natural slowed speech for the connected discourse. When attempting to digitally rate-alter the original connected discourse, distortion was created because of the length of the passage and desired compression and expansion percentages. Therefore, six volunteers (three female, three male) were recruited from the University and surrounding community to serve as talkers. All talkers were native speakers of American English and had no history of expressive speech and/or language disorder. Each talker recruited for the present study read two different passages, one for the primary stimulus and one for the background stimulus. For the primary stimulus recordings, each talker read the Arizona Travelogue script (ANL CD, Frye Electronics, Inc.). For the background stimulus recordings, each talker read a different passage from a novel about the history of each state quarter in the United States (Noles, 2008).

All vocal recordings were completed using the CSL and Adobe Audition (version 1.5) software. During the recording session, the talker was seated in front of a computer. The talker wore a head mounted microphone with the microphone placed 5 cm from the talker's mouth. The recordings included a 6-secsustained vowel, /a/, and six different one minute recordings of running discourse. The sustained vowel was recorded to complete objective vocal analysis through the CSL's Multi-Dimensional Voice Program-Advanced software. The running discourse was recorded for the creation of the primary and background stimuli and for the evaluation of each talker's vocal characteristics. For the running discourse recordings, the two passages (i.e., Arizona Travelogue and novel passage) were read with three separate instructions. Each participant was given the passage and asked to read it at a normal rate. The researcher then played an example file of fast speech (compressed) or slowed speech (expanded). The talker was then instructed to either slow or speed their speech rate similarly to the recording. A visual indicator of rate was provided via a metronome displayed on a computer monitor in view of the talker. The metronome was used to help maintain consistency of rate throughout the recording. At the completion of each successful recording, the researcher analyzed the speech rate in wpm to determine if the speech rate was slowed or speeded as needed. The researcher then provided feedback to the talker and requested additional recordings until the talker was able to approximate the goal for speeding or slowing the passage. The goal was to slow the speech by approximately 25% and speed the speech by approximately 50% from the individual's normal rate. For example, if the normal rate was 180 wpm for a given talker, the slowed speech rate of 135 wpm and speeded speech rate of 270 wpm served as goals for that talker. Once each recording was completed, the researcher then repeated the process with the talker for the remaining speech rate (i.e., slowed or speeded) and for the novel passage in all three conditions. All talkers were provided breaks as needed, and talkers were allowed multiple sessions to complete the requested recordings.

The sustained vowel recordings were trimmed to include only the center 4 sec. The trimmed and sustained vowel recordings were objectively analyzed via the CSL's Multi-Dimensional Voice Program-Advanced function. All talkers were within normal limits for jitter, shimmer, noise to harmonic ratio, and fundamental frequency for their gender. Root mean square (RMS) power for each of the discourse recordings was evaluated and adjusted with the use of Adobe Audition software so that all the recordings had the same RMS values.

Ten second excerpts of all primary stimulus recordings for the six talkers for each condition (normal, slow, and fast) were recorded to compact disc. Three Speech-Language Pathologists (SLP) served as raters for the recordings. The raters evaluated the discourse recordings for rate, articulation, voice quality, and pitch. The Appendix contains a copy of the rating scale used by the raters. Scores on the rating scale were totaled. Next, the speech rate for each condition and each talker was calculated and displayed in a tabular format. The relative percent increase or decrease in rate (e.g., 34% compression and 32% expansion) was then calculated for each talker and added to the table. Ratings, wpm, and compression/expansion percentages can be found in Table 1. The researcher then selected the primary stimulus recording based on the ratings from the SLPs, the normal speech rate falling within normal limits, and

Table 1. Primary Stimulus wpm, Time Expansion (TE), TC, and Gender for Each Talker at Slow, Normal, and Fast Speech Rates

Talker	Slow (wpm)	Normal (wpm)	Fast (wpm)	TE (%)	TC (%)	Gender	Total Score	Stimulus Type	Notes
1	143	193	288	26	49	F	224	Background	Primary investigator
2	124	178	226	30	27	F	235	Background	Could not achieve desired TC%
3	130	187	288	30	54	F	222	Primary	Neutral dialect; achieved desired TC and TE%
4	118	161	253	27	57	M	227	Background	Difficulty reading aloud with consistency
5	144	201	264	28	31	M	203		Dialect was not neutral Could not achieve desired TC%
6	119	170	244	30	44	M	196		Dialect was not neutral Could not achieve desired TC%
7*	136	169	234	19	39	M	226	Background	Could not achieve desired TC%

Note: *Recorded background stimuli only.

ability of the talker to maintain the targeted rate-alteration of 50% TC and 25% time expansion. Talker 3 served as the primary stimulus recording. This recording was ultimately selected because of the talker's ability to consistently maintain the targeted rate, neutrality of dialect, and overall quality of the vocal recordings. The talker with the lowest rating from the SLP's of the opposite gender of the primary talker was removed from the stimulus pool so that the same number of female and male talkers remained for creation of the background stimulus. On reviewing the ratings from the SLP's, two of the original male talker recordings were deemed unfit for use as background stimuli because of the lack of dialect neutrality and consistency of rate-altered recordings. Therefore, one additional male talker was recruited to serve as the final recording for the background stimuli. The remaining four talkers' recordings of the reading from a novel were then used to create the background stimulus. The two remaining female and two remaining male talker recordings from the novel reading were overlapped and concatenated to create a five-minute background stimulus of twelve-talker babble. This method was similar to Kalikow et al (1977). Twelve-talker babble was selected for use as the background stimuli to remain consistent with the commercially available ANL testing materials. For the slow and fast rate recordings, the same procedure was completed by overlapping and concatenating the recordings to create slow 12-talker babble and fast 12-talker babble recordings. The primary stimulus recording was then concatenated to create a five-minute recording of discourse. The relative RMS for the primary and background stimuli were then evaluated and adjusted so that the two recordings had the same relative RMS. The stimuli were then paired by speech rate (e.g., slow speech rate primary talker with slow speech rate twelve-talker babble background) and recorded to compact disc.

To assess ANL at multiple speech rates, three stimulus pairings (slow primary stimulus and slow twelve-talker babble paired, normal primary stimulus and normal twelve-talker babble paired, and fast primary stimulus and fast twelve-talker babble paired) were used for assessment of MCL and BNL. These stimulus pairings were at a slow speech rate, normal speech rate, and a fast speech rate.

Procedures

Pre-experimental and experimental procedures were completed during one session lasting approximately one hour. Participants completed a case history form that included age, gender, and native language, as well as medical history pertaining to middle ear disease, neurologic disorder, and speech language disorder. The cognitive screening (MoCA) and a pure-tone audiometric screening were then completed. Experimental procedures included measurement of MCL and BNL in three speech rate conditions (slow, normal, and fast). Participants were provided written and verbal instructions for MCL and BNL. For MCL, the participants were instructed to listen to the primary speech stimulus and adjust the level in an up-and-down procedure until it was set at their desired level. Participants used the "thumbs-up" hand signal to indicate an increase in loudness, and the "thumbs-down" hand signal to indicate a decrease in loudness. The level of the primary stimulus was first presented at 30 dB HL and the participants were instructed to adjust the signal to a level that was above their MCL and then adjust the signal to a level below their MCL. These adjustments were made using 5 dB step-sizes. For every thumbs-up or thumbs-down signal, the investigator adjusted the level by one step (i.e., 5 dB). Participants were then asked to adjust the level of the primary stimulus to their MCL. For this instruction, 2 dB step-sizes were used. Three trials were completed for each stimulus. Order of presentation for the three primary stimuli was randomized. Because BNL measures require presentation of the primary stimulus at the listener's MCL, all MCL measures were completed before measurement of BNL.

For measurement of BNL, the primary stimulus was presented at the listener's mean MCL and the background stimulus was introduced at 30 dB HL. Participants were instructed to adjust the level of the background stimulus to the level where they could no longer hear the primary stimulus clearly and then adjust the level of the background stimulus to a level where they could hear the primary stimulus clearly. These adjustments were completed with a 5 dB step size. Participants were then instructed to adjust the level of the background stimulus to the highest level of background noise they were able to "put up with" or tolerate without becoming tense or tired. For the final adjustment, the step size was reduced to 2 dB. Three trials were completed for each stimulus condition. The order of presentation of the stimuli was randomized. For MCL and BNL, the three trials were averaged for each condition. Mean MCL and BNL were used to calculate ANL (MCL − BNL = ANL) for each condition.

RESULTS

Reliability of MCL and BNL trials were evaluated using Pearson product-moment correlations. MCL correlation coefficients for each speech rate were statistically significant ($p < 0.001$), and r-values ranged from 0.863 to 0.933 indicating strong reliability for MCL measurements across trials within each speech rate condition. BNL correlation coefficients for each speech rate were significant ($p < 0.001$), and r-values ranged from 0.880 to 0.966 indicating strong reliability for BNL measurements across trials within each speech rate condition. MCL and BNL correlation coefficients for each speech rate are found in Table 2. Means were calculated for MCL

Table 2. Correlation Coefficients for MCL and BNL to Slow, Normal, and Fast Speech Rates

Rate	MCL1-MCL2	MCL1- MCL3	MCL2-MCL3	BNL1-BNL2	BNL1-BNL3	BNL2-BNL3
Slow	0.863	0.872	0.911	0.880	0.909	0.966
Normal	0.921	0.879	0.933	0.955	0.918	0.961
Fast	0.883	0.895	0.882	0.963	0.945	0.962

Note: All correlation coefficients are significant ($p < 0.05$).

and BNL. ANL was then calculated as MCL − BNL. Means and standard deviations for ANLs across speech rate and group are displayed in Figure 1.

A two-way mixed repeated measures ANOVA was conducted to evaluate the effect of age and speech rate on the acceptance of background noise. The within-subjects factor was speech rate (slow, normal, and fast), the between-subjects factor was group (younger and older adults), and the dependent variable was ANL. Mauchly's Test of Sphericity was not statistically significant ($p > 0.05$) for speech rate and therefore sphericity was assumed for the remainder of the statistical analyses. The main effect of speech rate [$F_{(2,56)} = 27.625, p < 0.001$] was statistically significant. The main effect of group [$F_{(1,28)} = 0.021, p > 0.05$] and the interaction effect between speech rate and group [$F_{(2,56)} = 0.370, p > 0.05$] were not statistically significant. To follow-up, the significant main effect for speech rate and pairwise comparisons with Fisher's least significance difference (LSD) correction factor were conducted. Each pairwise comparison was significantly different from one another. The ANL for the slow speech rate ($M = 3.03$, SD = 5.13) was significantly lower than for the normal speech rate ($M = 4.50$, SD = 4.74, $p < 0.05$) and for the fast speech rate ($M = 7.03$, SD = 4.55, $p < 0.001$). In addition, the ANL for the normal speech rate was also significantly lower than the fast speech rate ($p < 0.001$). Pairwise comparisons can be found in Table 3.

The between subjects factor of group was not significant; therefore, the data were collapsed across group and a repeated measures ANOVA was completed with speech rate as the factor. This follow-up repeated measures ANOVA revealed a significant main effect of speech rate [$F_{(2,58)} = 28.239, p < 0.001$] on ANL. The pairwise comparisons for speech rate revealed that all pairings were significantly different from one another with the same pattern as described in the omnibus ANOVA previously. Additional statistical analyses were completed with data collapsed across the group.

Analytical statistics were completed on MCL and BNL to determine their contribution to the significant change in ANL due to speech rate. A one-way repeated measures ANOVA was conducted to evaluate the effect of speech rate on MCL. The within-subjects factor was speech rate and the dependent variable was MCL. Mauchly's Test of Sphericity was not violated ($p > 0.05$), and sphericity was assumed for the remainder of the statistical analyses. The main effect of speech

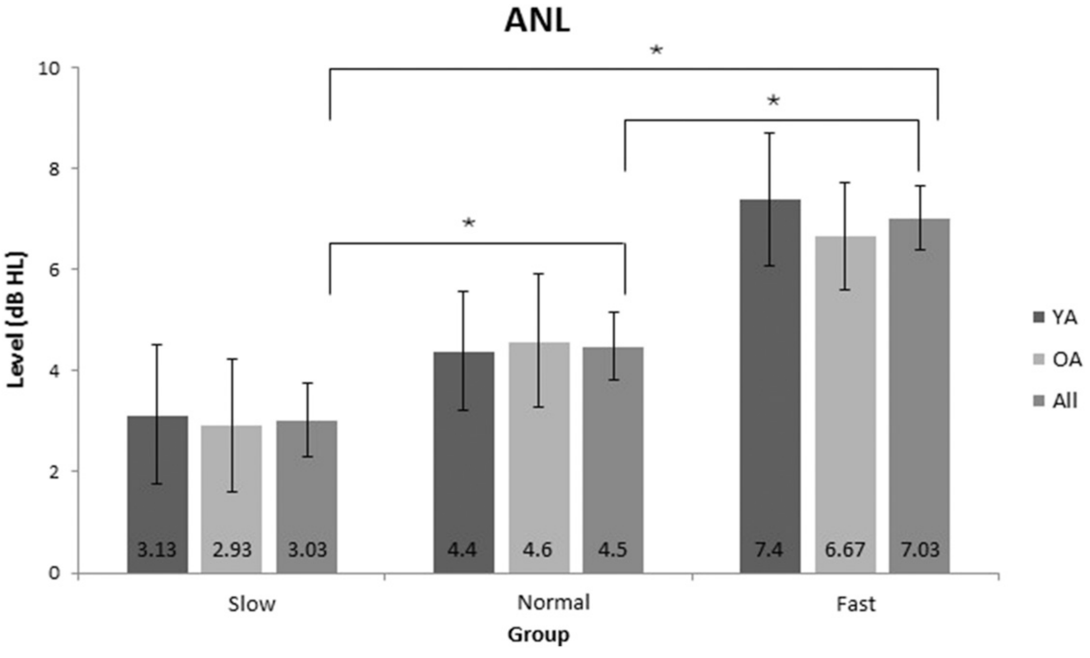

Figure 1. Means and standard deviations for ANL across speech rates and group. Horizontal bars with asterisks indicate significant differences between speech rates. Note: younger adults (YA); older adults (OA).

Table 3. Paired Comparisons of ANL with Slow, Normal, and Fast Speech Rates

Paired Comparison	*p*
Slow-normal	0.018
Slow-fast	0.000
Normal-fast	0.000

rate was statistically significant [$F_{(2,58)} = 7.931$, $p < 0.001$]. Pairwise comparisons using Fisher's LSD correction factor revealed that the MCL for the slow speech rate ($M = 46.83$, SD = 4.31) was significantly lower from the MCL of the normal speech rate ($M = 48.13$, SD = 4.97, $p < 0.05$). MCL for the slow speech rate was also significantly lower from the MCL of the fast speech rate ($M = 48.97$, SD = 4.49, $p < 0.001$). However, MCL for the normal speech rate was not significantly different from the fast speech rate ($p > 0.05$). Means and standard deviations for MCL across speech rates can be found in Figure 2.

A one-way repeated measures ANOVA was conducted to evaluate the effect of speech rate on BNL. The within-subjects factor was speech rate and the dependent variable was BNL. Mauchly's Test of Sphericity was not violated ($p > 0.05$), and sphericity was assumed for the remainder of the statistical analyses. The main effect of speech rate was statistically significant [$F_{(2,58)} = 4.906$, $p < 0.05$]. Pairwise comparisons using Fisher's LSD correction factor revealed BNL for the slow speech rate ($M = 43.77$, SD = 6.32) was not significantly different from the BNL for the natural normal speech rate ($M = 43.63$, SD = 6.26, $p > 0.05$); however, the BNL for the slow speech rate was significantly higher than the BNL for the fast speech rate ($M = 42.00$, SD = 6.98). The BNL for the normal speech rate was also significantly higher than the BNL for the fast speech rate ($p < 0.05$). Means and standard deviations for BNL across speech rates are displayed in Figure 3.

DISCUSSION

The purpose of the present study was to determine the effects of age and speech rate on the acceptance of background noise. Research suggests older adults struggle with temporally degraded speech. Older adults' speech understanding decreases as speech rate increases (Gordon-Salant and Fitzgibbons, 1993); conversely, older adults' speech understanding increases as speech rate decreases (Gordon-Salant et al, 2007; Adams et al, 2012). Naturally fast speech has been documented to be more detrimental to speech understanding than speech digitally time-compressed in a uniform manner (Gordon-Salant et al, 2014). The difficulty older adults experience with rapid speech may be due to memory constraints (Wingfield et al, 1994), limited contextual cues (Wingfield et al, 1985; Gordon-Salant and Fitzgibbons, 2001), or a general decline in cognitive processes (Wingfield, 1996). Because of the negative impact on speech understanding for older adults when speech is rate-altered, we were interested in how this population may adjust or change the amount of background noise they willingly accept in a variety of speech rates (slow, normal, and fast). The ANL was introduced in 1991 and has since been found to accurately predict hearing aid success. While the ANL requires that the patient listen to speech in noise, it is unrelated to the amount of

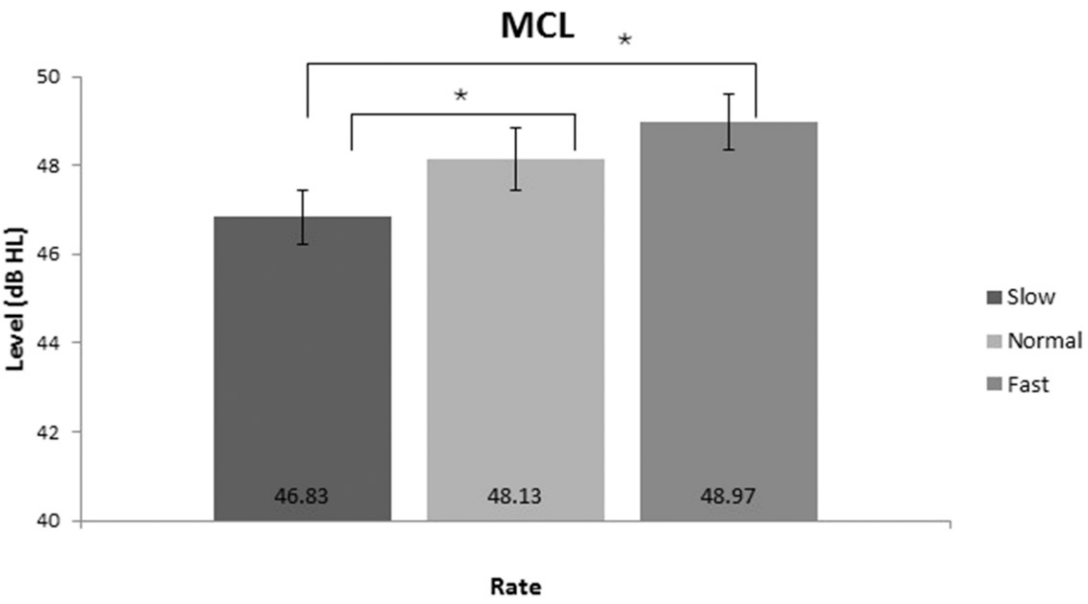

Figure 2. Means and standard deviations for MCL across speech rates (group data collapsed). Horizontal bars with asterisks indicate significant differences between speech rates. Note: younger adults (YA); older adults (OA).

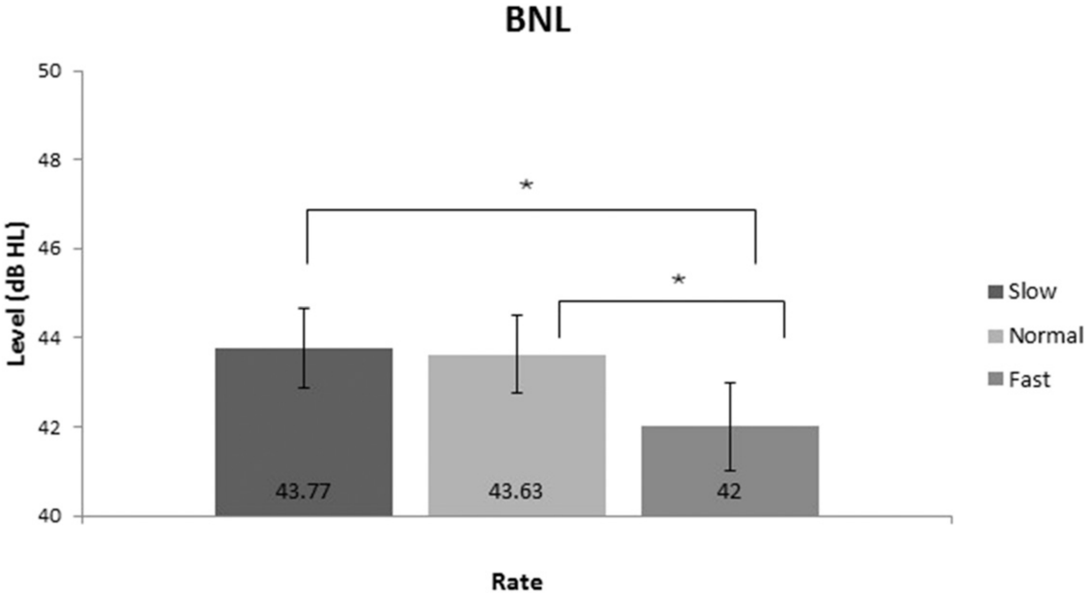

Figure 3. Means and standard deviations for BNL across speech rates (group data collapsed). Horizontal bars with asterisks indicate significant differences between speech rates. Note: younger adults (YA); older adults (OA).

speech in noise understood by the listener. Nabelek et al (2004) evaluated ANL and speech understanding in noise using the R-SPIN. The R-SPIN and ANL measures were found to be reliable over time, but not correlated with one another. Nabelek et al (2004) concluded that ANL and speech understanding in noise were independent measures. Nabelek et al (2006) further confirmed that R-SPIN scores and ANL were unrelated. Mueller et al (2006) evaluated ANL and speech understanding in noise using the Hearing in Noise Test. The ANL and the Hearing in Noise Test were found to be uncorrelated as well. However, more recent research indicates that ANL is affected by speech intelligibility of the primary stimulus and intelligibility may serve as a criterion used to determine the listener's ANL (Gordon-Hickey and Moore, 2008; Wu et al, 2014; Gordon-Hickey and Morlas, 2015).

Previous work investigating the impact of rate-alteration of the speech signal on speech understanding in noise tasks suggests that older adults are negatively impacted by increases in speech rate and may be positively affected by decreases in speech rate. Because changes in speech rate influence speech intelligibility, we hypothesized that speech rate would influence a listener's ANL, particularly for older adults. Specifically, when slowing speech we thought that the subtle improvement in intelligibility caused by slowing the speech may lead to a listener's ability to cope with more background noise (i.e., improved ANL). In addition, when speeding speech we thought that the decreased intelligibility would decrease a listener's ability to cope with background noise (i.e., poorer ANL). Therefore, we anticipated older adults would accept significantly more background noise in the slow speech rate condition and significantly less background noise in the fast speech rate condition than their younger adult counterparts. However, in the present study, there was no significant age effect. Younger adults and older adults both accepted more background noise as the speech rate decreased and became less accepting of background noise as the speech rate increased. This finding is consistent with previous research indicating that ANL is not affected by age. Perhaps this is due to the nature of ANL being a psychoacoustic decision that is intrinsic to each individual. Findings of the initial ANL study indicated that the ANL did not correlate with MCL, pure-tone average, or age (Nabelek et al, 1991). Later work by Nabelek et al (2006) confirmed that age does not influence ANL. The present study further supports these findings.

Findings of the present study demonstrate that ANL is influenced by speech rate of the primary stimulus. The ANL differed significantly across the three speech rates (slow, normal, and fast). Regardless of age, when listening to a slower rate of speech, listeners are more accepting of background noise. When in background noise, a slower speech rate may reduce the effort and attention required for listeners to attend to the talker. This appears to allow the listener to accept more background noise. A fast speech rate has the opposite effect. When listening to a fast speech rate, more effort is likely required to attentively listen to the talker. An even greater amount of effort and attention may be required when listening to a fast speech rate in the presence of background noise. This additional demand of effort and cognitive resources (attention) required of the listener negatively impacts the amount of background noise listeners are willing to accept. Increasing the speech rate may also lead to a decrease in sound quality for the primary stimulus. In addition, this could lead to frustration or annoyance for the listener and thus reduce the amount of background noise listeners are willing to accept. Interestingly, Adams et al (2010) found ANL to be resistant to the effects of reverberation (often used as a measure of temporal processing). In that study, acceptance of background noise was evaluated under five stimulus conditions with varying degrees of reverberation (reverberation time ranged from 0.4 to 2.0 sec). No significant effect of reverberation was found for ANL, and there was no significant interaction between age and reverberation. Thus, indicating reverberation does not impact the amount of background noise one is willing to accept. It is unclear why the rate of the primary stimulus impacts ANL and the reverberation of the primary stimulus does not affect ANL. Because rate-alteration and reverberation are both methods for altering temporal aspects of the signal, findings should be consistent. Future research should attempt to resolve this discrepancy.

To understand the changes in ANL due to speech rate, we evaluated differences in MCL and BNL across speech rates. As with ANL, no group differences were observed; however, consistent with ANL findings, speech rate significantly impacted MCL and BNL. Our findings indicate that when listening to a slower rate of speech, individuals can comfortably listen to connected discourse at lower loudness levels (i.e., lower MCL). Although this finding reached statistical significance, it may not be clinically significant because of the minor change (1 dB) in MCL, and thus should be interpreted with caution. On further investigation of speech rate and BNL, we found that the slow speech rate produced the highest BNL. With each subsequent increase in speech rate, BNL became poorer. The fast speech rate condition produced a BNL significantly lower than the other two conditions. This finding reached statistical significance; however, it may not be clinically significant because of the minor change (<2 dB) in BNL. Results of the present study indicate that individuals need a lower level of background noise when the speech rate is fast to comfortably manage the listening situation. As the speech rate decreases, individuals are better able to cope with the background noise and can accept higher levels of background noise. Gordon-Hickey and Moore (2008) found a similar pattern of findings when they studied the influence of intelligibility on ANL using intelligible and unintelligible speech stimuli. The results of that study revealed that the intelligibility of the primary discourse did not affect MCL, but affected BNL resulting in a change in ANL. The authors concluded that as speech intelligibility changes, ANL may change, further resulting in a potential change for a patient's hearing aid success rate. In the present study, the subtle change in MCL combined with the subtle changes in BNL, ultimately contributed to the overall significance across speech rates for ANL.

Audiologists often recommend the use of communication strategies for those that are hearing impaired and their communication partners. One such strategy is for a communication partner to slow their speaking rate. As suggested by Adams and Moore (2009), even slowing from a fast speaking rate to a more normal rate may be of benefit for hearing impaired patients. The present study provides support for this recommendation as listeners in the present study were willing to cope with more background noise in environments with slow and normal speech rates. Many listeners, especially older adults, struggle with understanding speech in the presence of noise. This may be exacerbated when another form of speech degradation, such as reverberation, is present in addition to noise. Similarly, speech rate changes in addition to background noise produce a difficult listening environment. To deal with listening situations where the speech signal is degraded in two different manners (e.g., noise and fast speech rate), listeners may move away from the noise source or have the noise source turned down. If there are no effective methods to reduce background noise, findings from the present study suggests that listeners may be more willing to listen if they ask the talker to slow their speaking rate.

Future work should expand on this study and test speech understanding at varying speech rates in addition to ANL. A speech understanding task may provide further clarification on how the listeners determined their ANL for each speech rate and the relationship of speech understanding in noise and ANL. In the present study, participants were younger and older adults with normal hearing. Four participants in the older adult group had some degree of hearing loss, but this was considered normal for their age based on the Cruickshanks et al (1998) data. Future work should control more for hearing sensitivity and add a hearing impaired group.

In summary, the findings of the current study suggest that ANL is influenced by the primary talker's speech rate. Specifically, when speech is altered to a rapid rate (e.g., 288 wpm), listeners, regardless of age, accept significantly less background noise than if the speech is of a normal rate (e.g., 186 wpm) or a slow rate (e.g., 130 wpm). The current study also supports previous works indicating that the ANL is not influenced by the age of the listener (Nabelek et al, 1991; 2006).

REFERENCES

Adams EM, Gordon-Hickey S, Moore RE, Morlas H. (2010) Effects of reverberation on acceptable noise level measurements in younger and older adults. *Int J Audiol* 49(11):832–838.

Adams EM, Gordon-Hickey S, Morlas H, Moore R. (2012) Effect of rate-alteration on speech perception in noise in older adults with normal hearing and hearing impairment. *Am J Audiol* 21(1): 22–32.

Adams EM, Moore RE. (2009) Effects of speech rate, background noise, and simulated hearing loss on speech rate judgment and speech intelligibility in young listeners. *J Am Acad Audiol* 20(1):28–39.

Adobe Audition. (2004) *Version 1.5*. San Jose, CA: Adobe Systems Incorporated [Computer software].

Ahlstrom JB, Horwitz AR, Dubno JR. (2009) Spatial benefit of bilateral hearing AIDS. *Ear Hear* 30(2):203–218.

American National Standards Institute. (2008) *Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms (ANSI S3.1-2003)*. New York, NY: American National Standards Institute.

American National Standards Institute. (2010) *American National Standards Specification for Audiometers ANSI S3. 6-2010. (Revision of ANSI S3. 6-1996, 2004)*. New York, NY: American National Standards Institute.

Bilger RC, Nuetzel JM, Rabinowitz WM, Rzeczkowski C. (1984) Standardization of a test of speech perception in noise. *J Speech Hear Res* 27(1):32–48.

Crowley HJ, Nabelek IV. (1996) Estimation of client-assessed hearing aid performance based upon unaided variables. *J Speech Hear Res* 39(1):19–27.

Cruickshanks KJ, Wiley TL, Tweed TS, Klein BE, Klein R, Mares-Perlman JA, Nondahl DM. (1998) Prevalence of hearing loss in older adults in Beaver Dam, Wisconsin: The epidemiology of hearing loss study. *Am J Epidemiol* 148(9):879–886.

Erdfelder E, Faul F, Buchner A. (1996) GPOWER: a general power analysis program. *Behav Res Methods Instrum Comput* 28(1):1–11.

Etymotic Research. (2001) *QuickSIN Speech-in-Noise Test (Version 1.3)*. Elk Grove Village, IL: Etymotic.

Freyaldenhoven MC, Nabelek AK, Burchfield SB, Thelin JW. (2005) Acceptable noise level as a measure of directional hearing aid benefit. *J Am Acad Audiol* 16:228–236.

Frye Electronics, Inc. *ANL Test*. Tigard, OR: Frye Electronics, Inc.

Gordon-Hickey S, Moore RE. (2008) Acceptance of noise with intelligible, reversed, and unfamiliar primary discourse. *Am J Audiol* 17(2):129–135.

Gordon-Hickey S, Moore RE, Estis JM. (2012) The impact of listening condition on background noise acceptance for young adults with normal hearing. *J Speech Lang Hear Res* 55(5):1356–1372.

Gordon-Hickey S, Morlas H. (2015) Speech recognition at the acceptable noise level. *J Am Acad Audiol* 26(5):443–450.

Gordon-Salant S, Fitzgibbons PJ. (1993) Temporal factors and speech recognition performance in young and elderly listeners. *J Speech Hear Res* 36(6):1276–1285.

Gordon-Salant S, Fitzgibbons PJ. (1999) Profile of auditory temporal processing in older listeners. *J Speech Lang Hear Res* 42 (2):300–311.

Gordon-Salant S, Fitzgibbons PJ. (2001) Sources of age-related recognition difficulty for time-compressed speech. *J Speech Lang Hear Res* 44(4):709–719.

Gordon-Salant S, Fitzgibbons PJ. (2004) Effects of stimulus and noise rate variability on speech perception by younger and older adults. *J Acoust Soc Am* 115(4):1808–1817.

Gordon-Salant S, Fitzgibbons PJ, Friedman SA. (2007) Recognition of time-compressed and natural speech with selective temporal enhancements by young and elderly listeners. *J Speech Lang Hear Res* 50(5):1181–1193.

Gordon-Salant S, Zion DJ, Espy-Wilson C. (2014) Recognition of time-compressed speech does not predict recognition of natural fast-rate speech by older listeners. *J Acoust Soc Am* 136(4): EL268–EL274.

Kalikow DN, Stevens KN, Elliott LL. (1977) Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. *J Acoust Soc Am* 61(5): 1337–1351.

Mueller HG, Weber J, Hornsby BW. (2006) The effects of digital noise reduction on the acceptance of background noise. *Trends Amplif* 10(2):83–93.

Musiek FE, Shinn JB, Jirsa R, Bamiou DE, Baran JA, Zaida E. (2005) GIN (Gaps-In-Noise) test performance in subjects with confirmed central auditory nervous system involvement. *Ear Hear* 26(6):608–618.

Nabelek AK, Freyaldenhoven MC, Tampas JW, Burchfiel SB, Muenchen RA. (2006) Acceptable noise level as a predictor of hearing aid use. *J Am Acad Audiol* 17(9):626–639.

Nabelek AK, Tampas JW, Burchfield SB. (2004) Comparison of speech perception in background noise with acceptance of background noise in aided and unaided conditions. *J Speech Lang Hear Res* 47(5):1001–1011.

Nabelek AK, Tucker FM, Letowski TR. (1991) Toleration of background noises: relationship with patterns of hearing aid use by elderly persons. *J Speech Hear Res* 34(3):679–685.

Nasreddine ZS, Phillips NA, Bédirian V, Charbonneau S, Whitehead V, Collin I, Cummings JL, Chertkow H. (2005) The montreal cognitive assessment, MoCA: a brief screening tool for mild cognitive impairment. *J Am Geriatr Soc* 53(4): 695–699.

Nichols AC, Gordon-Hickey S. (2012) The relationship of locus of control, self-control, and acceptable noise levels for young listeners with normal hearing. *Int J Audiol* 51(4):353–359.

Noles J. (2008) *A Pocketful of History: Four Hundred Years of America - One State Quarter at a Time*. Philadelphia: Da Capo Press.

Picheny MA, Durlach NI, Braida LD. (1986) Speaking clearly for the hard of hearing. II: acoustic characteristics of clear and conversational speech. *J Speech Hear Res* 29(4):434–446.

Plyler PN, Alworth LN, Rossini TP, Mapes KE. (2011) Effects of speech signal content and speaker gender on acceptance of noise in listeners with normal hearing. *Int J Audiol* 50(4): 243–248.

Rogers DS, Harkrider AW, Burchfield SB, Nabelek AK. (2003) The influence of listener's gender on the acceptance of background noise. *J Am Acad Audiol* 14(7):372–382, quiz 401.

Vaughan NE, Letowski T. (1997) Effects of age, speech rate, and type of test on temporal auditory processing. *J Speech Lang Hear Res* 40(5):1192–1200.

Walravens E, Keidser G, Hartley D, Hickson L. (2014) An Australian version of the acceptable noise level test and its predictive value for successful hearing aid use in an older population. *Int J Audiol* 53(Suppl 1):S52–S59.

Wingfield A. (1996) Cognitive factors in auditory performance: context, speed of processing, and constraints of memory. *J Am Acad Audiol* 7(3):175–182.

Wingfield A, Alexander AH, Cavigelli S. (1994) Does memory constrain utilization of top-down information in spoken word recognition? Evidence from normal aging. *Lang Speech* 37(Pt 3): 221–235.

Wingfield A, Poon LW, Lombardi L, Lowe D. (1985) Speed of processing in normal aging: effects of speech rate, linguistic structure, and processing time. *J Gerontol* 40(5):579–585.

Wingfield A, Tun PA, Koh CK, Rosen MJ. (1999) Regaining lost time: adult aging and the effect of time restoration on recall of time-compressed speech. *Psychol Aging* 14(3):380–389.

Wu YH, Stangl E, Pang C, Zhang X. (2014) The effect of audiovisual and binaural listening on the acceptable noise level (ANL): establishing an ANL conceptual model. *J Am Acad Audiol* 25(2):141–153.

Yorkston KM, Beukelman DR. (1981) Communication efficiency of dysarthric speakers as measured by sentence intelligibility and speaking rate. *J Speech Hear Disord* 46(3):296–301.

APPENDIX

Instructions and Rating Scale for Speech Samples

Each track on this CD contains a 10 sec sample of a female or male talker reading from a short story. There are 18 speech samples. Please place a check mark in the box appropriate for each track. *Thank you*.

Track #

Which gender do you believe the talker is? Female or Male

	Very True (5)	True (4)	Neutral (3)	False (2)	Very False (1)
The words spoken are intelligible and precisely articulated					
The talker demonstrates normal voice quality (no hoarseness, breathiness, etc)					
The talker is speaking at a rate that is not too fast or too slow					
The talker's speech does not differ significantly from Standard American English					
The talker's pitch is appropriate for his/her gender					
All aspects of speech and vocal quality are acceptable for use as auditory stimuli for a research task					
Total					