SPEECH PERCEPTION BY OLDER LISTENERS: CONTRIBUTIONS OF AUDITORY TEMPORAL PROCESSES

by

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Auditory temporal processing is believed to be critical to speech perception; however, the exact nature of the contributing temporal processes and their psychophysical limits are as of yet undetermined. Furthermore, in light of the difficulties understanding spoken language that are common in older age, the resilience of these processes to normal aging warrants further investigation. Older adults, even with normal pure-tone hearing thresholds, often experience difficulty understanding spoken language when the message is presented in noise and/or when the rate of the message is increased. To further our understanding of these complaints, measures of temporal resolution and word identification were obtained from younger and older listeners.

Eight younger and eight older normal-hearing listeners identified four word-pair continuums that varied from one word to another word as the duration of an inserted silent interval varied from short to long (i.e., 'cash' to 'catch'). These word-pairs were presented at both a slower and a faster speaking rate. The listeners identified these word-pair continuums, first, in a quiet listening condition; later they identified selected tokens from each continuum in three background noise conditions. These listeners also completed a gap detection task where five gap detection thresholds were obtained for a 2-kHz tone pip with gap-defining marker durations of 0.83, 5, 10, 80 and 400 ms.

The present study replicates previous findings indicating that older adults are significantly poorer than younger adults at detecting gaps embedded in non-speech stimuli (2-kHz markers) when the surrounding material is short (Schneider & Hamstra, 1999; Schneider, Pichora-Fuller, Kowalchuk, & Lamb, 1994). Correspondingly, older
adults were also shown to have greater difficulty identifying speech contrasts when a gap served to differentiate between two words, particularly for fast speech and in the context of background noise. Common to both these cases is the poorer performance evidenced by older listeners in the context of fast rates/short duration stimuli. This pattern of findings is consistent with a hypothesis that proposes that recovery from neural adaptation occurs more slowly in the older compared to the younger auditory system (Schneider & Hamstra, 1999).
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1. LITERATURE REVIEW

1.1 Introduction

Older adults commonly report difficulties understanding spoken language (Committee on Hearing, 1988). Even older adults with normal pure-tone hearing thresholds tend to experience such difficulties, particularly as the listening task becomes more challenging (Pichora-Fuller, 1997). The speaking rate of a message and the presence of background noise are two particular sources of message complexity that can pose a challenge for older adults. There is a substantial body of research indicating that older normal-hearing listeners have increased difficulties understanding spoken language when listening in the presence of competing background noise (e.g. Stuart & Phillips, 1996). Also, as the speaking rate of a message is increased, older adults often demonstrate increased difficulty understanding the spoken message (e.g. Wingfield, Tun, Koh, & Rosen, in press; Schmitt & Carroll, 1985). These difficulties that some older adults experience may be related in part to auditory deficits that hamper accurate perception of the temporal characteristics of the acoustic signal. There is evidence indicating that the temporal processing of acoustic information is diminished in older adults (e.g. Schneider & Hamstra, 1999). As many of the acoustic cues in speech are temporal in nature, a diminished ability to perceive such acoustic events, particularly at fast speaking rates and/or in noise, may contribute to the problems that elderly adults often experience when listening to speech.

The present chapter will outline spoken language perception in older adulthood, with a focus placed on the effects of listening in noise and increased speaking rate. This
will be followed by a general discussion concerning the effects of speaking rate on speech production and perception. A discussion of possible factors that may contribute to the difficulties that some older adults experience when perceiving spoken language will follow. One specific factor, gap detection ability, will then be discussed in detail.

Various factors that affect the measurement of gap detection thresholds will be discussed and models of auditory temporal resolution will be outlined. Possible mechanisms that may account for impaired gap detection ability will then be considered followed by a discussion of the relationship between gap detection ability and the perception of spoken language. Similarities and differences between traditional gap detection stimuli and natural speech will then be presented. In conclusion, null and accompanying research hypotheses will be stated.

1.2 Speech Perception in Older Adults

This discussion will focus on how older adults, with relatively normal pure-tone hearing thresholds, understand spoken language. Decrements in their ability to understand spoken language often do not surface under optimal listening conditions, as in quiet situations (e.g. Bergman, 1971). Numerous studies have been conducted comparing the perceptual abilities of elderly and young listeners under such optimal conditions. Bergman, for example, studied a large sample of 282 subjects ranging from 20-89 years of age. The majority of these subjects passed pure-tone hearing screening at 35 dB HL. These subjects were tested using a variety of everyday sentences spoken by five different speakers to account for speaker variations such as age, sex, and accent. In the unaltered speech condition, Bergman did not find a significant decrease in sentence identification
performance as a function of age. This finding is noteworthy given the considerable range of hearing thresholds considered to be within the normal range of hearing. Gordon-Salant & Fitzgibbons (1995b) obtained similar results with groups of young and elderly listeners more closely matched on hearing sensitivity (all subjects had pure-tone thresholds equal to or less than 15 dB HL). These subjects listened to the low-predictability sentences from the Revised Speech Perception in Noise test\(^1\). The task required of the listeners was to write down the final word (which had a low level of predictability from previous sentence information) of each test sentence.

Data from Gelfand, Piper, & Silman (1985), however, does indicate that slight decreases in the recognition of spoken language can be demonstrated even with speech presented at a comfortable level without any background noise or unfavorable reverberation. These authors showed that older normal-hearing adults have slightly poorer recognition of nonsense syllable words compared to young adults for speech presented at the listener's most comfortable loudness (MCL) level (vowel confusions were not studied). This age difference increased when the test materials were presented at 8 dB below the MCL, further suggesting that older adults have decreased consonant recognition ability. This decline in performance was also found to accelerate with increasing age. These results indicate that the difficulties reported by normal-hearing older adults are more likely to be observed in challenging listening situations. The situation becomes more challenging when, for example, speech rate is increased, with the performance of normal-hearing elderly listeners declining relative to young normal-hearing listeners (e.g. Frisina & Frisina, 1997; Stuart & Phillips, 1996).

\(^1\) The SPIN-R test also includes a condition where the target words are highly predictable.
1.2.1 The Effects of Noise on Speech Perception by Older Adults

Numerous studies have established that older normal-hearing adults show decrements in the perception of spoken language as the listening situation worsens. The presence of background noise in a listening environment can be particularly disruptive to an older individual's ability to understand spoken language. Stuart & Phillips (1996) compared the word recognition performance of young and older listeners in conditions with continuous and interrupted noise. Monosyllabic words were tested in each condition as the signal-to-noise (S:N) ratio varied from +10 to −20 dB. Significant age differences were not obtained under a quiet testing condition, however, in the noise conditions, the older normal-hearing subjects performed significantly worse than the young normal-hearing subjects. The first author (Stuart & Phillips, 1996) conducted an additional experiment to determine if this performance difference may be linked to poorer higher frequency hearing thresholds in the older subjects. A high frequency hearing loss was simulated in the younger listeners and it was determined that their performance did not worsen compared to previous results. This finding suggests that the poorer word recognition abilities of the older normal-hearing subjects were not due to elevated high frequency thresholds because a simulated hearing loss in the younger subjects was not able to make the younger listeners perform like the older listeners.

Frisina & Frisina (1997) obtained similar results, showing that speech perception ability did not significantly differ between younger and older subjects in quiet conditions, but found that differences emerged between these groups in noise conditions. While Stuart & Phillips (1996) demonstrated this dichotomy using monosyllabic stimuli, Frisina & Frisina (1997) provide data supporting the same conclusion using isolated disyllabic
words, target words in sentences with supportive context, and target words in sentences without supportive context. The authors claim that this difference is not due to differences in pure-tone hearing sensitivity, as the subjects were closely matched in terms of audiometric thresholds. They also claim that the results do not reflect differences in cognitive functioning as both the younger and older normal-hearing subjects obtained comparable benefit from the presence of supportive sentential context. Presenting target words in both predictable and non-predictable contexts, Pichora-Fuller, Schneider, & Daneman (1995) similarly show that the word identification ability of near-normal hearing older listeners is adversely affected to a greater degree than that of young listeners by the presence of noise.

Helfer & Huntley (1991) assessed the ability of older adults, with minimal and greater amounts of hearing loss, to identify nonsense syllables presented in either quiet, noise, reverberation, or both noise and reverberation. Compared to a control group of young subjects, the older adults made significantly more identification errors. Differences in hearing thresholds were not able to account for all of the data, suggesting that something beyond pure-tone hearing sensitivity is impacting on the ability of older adults to identify nonsense syllables. It has also been shown that older normal-hearing adults make more consonant identification errors, compared to young listeners, when listening to nonsense words presented in a background of wide-band noise (Cheesman, Hepburn, Armitage, & Marshall, 1995). Cheesman et al. (1995) further demonstrated that this difference between young and older normal-hearing adults could not be explained by differences in either masked thresholds or the growth rate of masking functions.
While these studies indicate that noise is more detrimental to the spoken language processing of older adults, it is also of interest that older adults obtain less benefit from strategies that listeners often employ in such circumstances (for a review see Grose, 1996). For example, the spatial separation of the source of the message from the source of the competing noise can often improve message detection. This strategy, however, does not provide the older adult with the same degree of benefit as can be obtained by the younger adult. While a younger adult may enjoy a 10 dB decrease in the required level of the message, an older adult may only obtain a 2.5 dB decrease in the required message level to reach a similar level of performance (Duquesnoy, 1983). To reach a comparable level of language recognition, the older adult would need a message that was 7.5 dB more intense than the level required by the younger adult.

The benefit of listening with two ears as opposed to one can be demonstrated through the assessment of masking level differences (MLDs). The assessment of MLDs involve a noise and a target signal that are presented together in various phase relationships and the amount of noise that is required to prevent detection of the target signal is measured. The presentation of the noise out of phase with the signal is assumed to mimic the presentation of the two stimuli from different spatial locations. Pichora-Fuller and Schneider (1991) determined that older adults obtain less release from noise masking when the noise and signal are presented out of phase compared to young listeners. In a later study, Pichora-Fuller and Schneider (1992) demonstrate that this age difference can be accounted for by assuming that there is a larger amount of temporal jitter in the older auditory system compared to the younger auditory system.
1.2.2 The Effects of Speaking Rate on the Older Adult

The above discussion focused on the difficulties that elderly adults experience when listening in the presence of background noise. Speaking rate is another conversational variable that can vary to alter the acoustic message and increase the difficulty of the listening task. This discussion of the effects of rate on older adults will focus on those adults with relatively normal pure-tone hearing sensitivity and presumably unimpaired cognitive function. The situation of a brain-impaired adult introduces sources of complexity, such as the demands on memory and attention resources, that are comprised to some extent even in normal aging, but are likely effected to a greater degree in the context of the brain-impaired adult (Cohen, 1987; Small, Andersen, & Kempler, 1997). For example, Small et al. (1997) examined whether slowing of speaking rate would have facilitative effects on the comprehension abilities of older individuals with Alzheimer’s disease. They were not able to show that slower speech had any consistent beneficial effect for their subjects and identified the probable role of working memory capacity as a determinant in this relationship. A slowed speech rate actually negatively impacted on the language comprehension abilities of those listeners who had the most pronounced working memory deficits. Older adults that may have significantly reduced working memory capacity will likely experience no benefit from slow speech, as a slower rate of presentation increases the demands that are placed on one’s memory.

Focusing on a healthy population of older adults with normal hearing, various researchers have identified age-related decrements in the context of speech presented at fast speaking rates, (e.g. Schmitt & Carroll, 1985). First, it is important to note that young and older adults prefer to listen to speech at different speaking rates. When given
manual control over speaking rate, older adults choose to listen to a speaking rate approximately 15% slower than that selected by younger adults (Riensche, Lawson, Beasley, & Smith, 1979). The speaking rate that was preferred by the older normal-hearing adults in the study by Riensche et al. (1979), interestingly, is a rate of 175 words per minute (wpm). Researchers typically use 175 wpm to characterize a normal speaking rate. Speech rate can also be operationalized as the number of syllables per unit of time or even the number of sounds spoken in a unit of time [for a review see Uhmann, 1992]. Wingfield and Ducharme (1999) also present data indicating that older adults will select a slower rate of speech when listening to passage material for the purpose of accurate recall.

Schmitt and Carroll (1985) assessed older adults, with hearing levels within their specific age norms, using passages presented at various speaking rates. Subjects listened to these passages and subsequently answered questions based on these materials. As the speaking rate increased, the comprehension scores of these subjects dropped significantly. They also expanded the passages temporally, by recording a speaker who was instructed to naturally slow his rate of speech, and in these cases determined that there was a trend for comprehension scores to improve, but this pattern did not reach statistical significance. Schmitt and Moore (1989) conducted a similar study where they focused specifically on the comprehension abilities of old-old adults in comparable situations. Again, as the amount of signal compression increased, the comprehension ability of the subjects decreased. The effect of increasing the message duration through expansion (accomplished by recording a speaker who naturally slowed his rate of speaking) also did not produce statistically significant improvements. While from an
experimental perspective comprehension scores may have remained unchanged, it is notable that subjective listener reports indicated a perceived benefit from slower speaking rates. The listeners reported increased confidence in their comprehension abilities in the slower rate conditions. This subjective report is significant in and of itself. Even though comprehension scores may not have improved in the slower speaking rate conditions, the listener reports of perceived benefit suggest that these conditions were likely perceived as easier and therefore were likely less stressful. A central goal of health care must extend beyond the facilitation of quantitatively measurable abilities, such as comprehension scores, but also focus on maintaining and improving an individual’s quality of life by, for example, reducing stresses associated with communication.

The ability of listeners to identify related elements presented in time-compressed paragraphs also appears to decrease with increasing age (Letowski & Poch, 1996). This effect was shown to be unrelated to any small differences in pure-tone hearing thresholds among the subjects. A deviation from a normal speaking rate, however, may not always necessarily imply a subsequent comprehension deficit. Schmitt and McCroskey (1981) obtained data showing that as the message was either compressed by 60% or expanded by 140% that the comprehension scores of the elderly listeners improved relative to their scores based on the materials presented at a normal speaking rate of 175 wpm. The authors suggest that this improvement may be related to increased attention on the part of the listeners when presented with a presumably more challenging message. This finding serves to highlight the complexity of studying spoken language understanding, as perceptual resources may be reallocated in more difficult situations, thereby obscuring the negative impact of the source of complexity. While the comprehension scores
actually improved as the speaking rate was changed from normal, the effort expended by
the listeners may have actually been greater and thus the task of listening may have in
fact been more challenging, even though the improvement in comprehension scores
suggests otherwise. These older listeners may have not evidenced comprehension
impairments, in the context of compressed speech, but such performance may have been
contingent on the reallocation of resources typically reserved for other higher order
functions. A process of resource allocation may, for example, interfere with the older
listener’s ability to integrate and apply new information.

Gordon-Salant and Fitzgibbons (1995b) examined the recognition of multiply-
degraded speech in young and older subjects and further demonstrated the aversive effect
of increased speech rates on word recognition. The young and older normal-hearing
subjects were closely matched on audiometric thresholds and were tested with the low-
predictability sentences from the Revised Speech Perception in Noise test (SPIN-R). The
target words in these sentences are not predictable based on preceding sentence content.
These sentences were presented in seven different conditions, including conditions where
the sentences were temporally compressed. In the unaltered condition, the performance
of the older and young normal-hearers did not differ significantly. The older subjects,
however, had more difficulty in all conditions involving time-compressed speech.

These difficulties that many older individuals experience in the context of quickly
presented speech continue to persist even when additional processing time is provided at
clause boundaries (Wingfield, Tun, Koh, & Rosen, in press). Wingfield et al. (in press)
presented young and elderly listeners with paragraph materials. These paragraphs were
presented in both a time-compressed manner, where the speaking rate was increased, and
also in a time-restored fashion, where silent intervals were inserted into the time-compressed passages to restore the recording to its original length and, in one test condition, even add additional time. The paragraph recall ability of both the young and elderly listeners improved as time was restored to the compressed recordings, however, the performance of the older adults did not improve to the level of ability evidenced with the unaltered, uncompressed paragraph materials. The authors suggest that a reason for this finding may be that the older adults have not had an opportunity to process a sufficient amount of input prior to the pause to receive a comparable amount of benefit from the break as is received by the young listeners. They also comment that lower-level auditory processing impairments may leave fewer resources available for higher-level processing.

At a more elemental level, Sticht and Gray (1969) studied the ability of older adults to discriminate single words. These words were presented at varying rates of compression and the abilities of the older adults to discriminate these words worsened with increasing amounts of compression. Price and Simon (1984) showed that stimulus rate interacting with the perception of a silent interval can influence an elderly subject’s ability to identify certain stimuli. Price and Simon (1984) created a stimulus continuum from ‘rabid’ to ‘rapid’ by systematically increasing the duration of the intervocalic stop closure. They also varied the duration of the first vowel and compared the stimulus identification performance of younger and older normal-hearing adults. Their data revealed a significant effect of age with the largest age differences being noted in the condition with the shortest initial vowel duration (analogous to a faster speaking rate). These older adults required a longer period of silence compared to the young adults.
before they would identify the word as containing the voiceless intervocalic consonant /p/
as in 'rapid'.

It is clear from the above discussion that an increased speaking rate can
negatively affect an older adult's perception of spoken language, whether presented as
single words, single sentences, or entire passages and even when additional processing
time is provided.

1.3 General Implications of Speaking Rate on the Production and Perception
of Spoken Language

1.3.1 The Effects of Speaking Rate on Speech Production

The acoustic consequences of changes in speaking rate are significant and require
proper consideration in speech perception and auditory processing studies. As the rate of
the spoken message is increased or decreased, the duration of various acoustic features
can be affected, as well as the way that these features are perceived by the listener.
Speaking rate has been shown to vary dramatically throughout running speech. Miller,
Grosjean, and Lomanto (1984) studied speaking rate in a sample of interview data
obtained from 30 subjects. They calculated speaking rate over sections of pause-free
speech, where a pause was indicated by a period of silence of 250 ms or greater. This
methodological point is critical as the authors mention that some studies have failed to
find significant variations in speaking rate when rate was calculated over larger segments
of speech. Such relatively large segments may serve to potentially obscure substantial
local variations in rate. Miller et al. (1984) demonstrated with their data that speaking
rate, operationally defined as average syllable duration, varies significantly in conversational speech, often over a range of hundreds of milliseconds per syllable. These authors further note that this data still provides a conservative estimate of speaking rate, as rate information was obtained across segments of speech and was not assessed on an individual syllable-by-syllable basis where potentially even greater local rate variations may be discovered.

One example of a particular conversational feature that can invoke a temporal modification of the message is a request for repetition. Paul-Brown and Yeni-Komshian (1988) showed that both children and adults increased consonant closure duration and decreased vowel length when asked to repeat a word that was misunderstood. Changes in speaking rate can also serve to distinguish parenthetical contributions to a conversation as well as function to signal the end a speaker's conversational turn or mark the end of a conversational topic (Uhmann, 1992). In summary, this data verifies the presence of substantial rate variability in typical conversational speech. Listeners must be able to handle this variability in terms of the changes that ensue as related to acoustic parameters as well as the changing demands that are placed on the speed with which spoken language processing must take place.

As speaking rate changes, the acoustic characteristics that define perceptual categories change. Speaking rate variations typically translate to changes in the relatively steady-state portions of the speech signal (Kent & Read, 1992). Kessinger and Blumstein (1998) conducted a production study that showed lengthening of Voice Onset Time\(^2\) (VOT) and vowel duration as the speaking rate was slowed. Similar findings were

\(^2\) The time from the end of a consonantal release burst to the onset of vocalic voicing (Kent & Read, 1992).
obtained by Miller and Volaitis (1989) as well as Volaitis and Miller (1992) who further indicated that as syllable duration increased, VOT increased as well. This pattern of findings was consistent across labial, alveolar, and velar places of articulation. The more transient aspects of the spoken signal remain relatively stable as speaking rate is increased or decreased. For example, formant transitions, reflecting movement of the articulators and changing vocal tract properties, are not significantly altered with changes in speaking rate (Gay, 1978).

1.3.2 General Effects of Speaking Rate on the Perception of Spoken Language

As stimulus rate is changed, significant changes in the perception of particular acoustic parameters occur. These perceptual effects are not limited to the difficulties that older adults experience with fast speech, but extend more broadly to the perception of spoken language in general. A number of researchers have provided data that stresses the importance of the temporal aspects of acoustic input. It has been shown that listeners cannot process acoustic information for phonetic meaning without taking into account the rate of the signal (Green, Tomiak, & Kuhl, 1997). Green et al. (1997) showed that longer reaction times were obtained when subjects were asked to identify phonemes when the stimuli varied in rate and comparably, variations in phonemic context increased the time required for subjects to classify stimuli according to their rate (Green et al., 1997). Neither phonemic nor rate information could be focused on to the exclusion of the other in these stimulus identification tasks.

The previously discussed acoustic consequences of rate variation have definite perceptual implications. Duration-related effects are noted when the duration of vowel
formant transitions is examined as a cue to stop versus glide perception in the context of varying rate. Diehl and Walsh (1989) studied these effects for stimulus continua that ranged from /ba/ to /wa/ as the duration of the formant transitions increased. In the context of a longer vowel, a greater range of transition durations signalled a stop percept. In other words, a longer transition duration was required before perception of a glide would occur. Changes in speaking tempo also affect the duration of silence that is required for the perception of a single versus a double consonant, as in ‘topic’ as opposed to ‘top pick’. By varying presentation rate as well as stop consonant silence duration, Miller (1981) demonstrated that at faster rates of presentation, shorter durations of silence were able to convey the percept of a double consonant. Changes in syllable duration, analogous to increasing or decreasing speaking rate, also impact on the location of VOT boundaries dividing voiced from voiceless percepts and further affect the stimuli that are judged to be good examples of a particular phonetic category (Miller & Volaitis, 1989). In line with the previous examples, Miller and Volaitis (1989) demonstrated that as syllable duration was shortened, the VOT boundary dividing /b/ from /p/ judgements shifted to a shorter duration relative to conditions involving longer syllable durations. The rate of speech, specifically translated into changes in syllable duration, can clearly impact how acoustic information, such as silent intervals, are interpreted for phonetic meaning.

Marcus (1978) provides data indicating that, in certain contexts, an increased speaking rate, accomplished through stimulus compression, may not necessarily affect a subject’s word identification performance. He compressed a continuum of stimuli ranging from ‘slit’ to ‘split’ that differed systematically in the duration of the silent
interval demarcating the stop consonant /p/. Across compression rates of 25% and 50%, Marcus (1978) did not find any changes in the silent interval duration that served as the boundary between stop consonant presence versus absence. Two groups of 10 housewives served as the subjects in this study. Information regarding the age or hearing status of these subjects was not provided, making it difficult to draw comparisons with other studies. Summerfield, Bailey, Seton, and Dorman (1981) also examined subject identifications of stimuli ranging from ‘slit’ to ‘split’. Effects of compression rate were found in this study, with the largest effects noted when stimuli of different rates were presented randomly within one block of trials. Marcus (1978) presented each rate of compression as a separate block of trials. In the context of his study, this and/or other stimulus and procedural factors may not have affected the auditory systems of his subjects in a manner similar to other studies.

1.3.3 Mechanisms for Perceptual Adjustment to Speaking Rate

There are two possible types of mechanisms that could potentially account for a listener’s ability to adjust perceptual criteria and maintain an understanding of the message as speaking rate varies and a source of stimulus complexity and variability is introduced into the message. One potential mechanism involves a system that is devoted to spoken language processing, a specialised speech mode (Miller & Dexter, 1988). Liberman (1998), for example, does not specifically write about the role of a speech mode in the perception of rate changes in spoken language, but he claims that such a mode likely exists. He bases this assertion on what he claims as a difference in the ease with which speech is learned compared to efforts that are involved in learning to read and
Liberman (1998) writes that since learning to read and write are relatively challenging task that there must be something special about speech that makes it so relatively easy. He claims that speech does not require auditory or cognitive analysis, but rather that spoken language consists of articulatory gestures that, once spoken, automatically gain phonetic status. Under such a view, the ability of listeners to deal with rate changes in speech requires no special consideration beyond the acceptance of a special speech mode of language processing. This approach does not begin to explain some of the difficulties that listeners experience when presented with speeded speech. In fact, data examining perceptual normalization indicates that the recognition of speech materials, where there is either rate or talker variability, is poorer compared to contexts where there is no such variability (Sommers, Nygaard, & Pisoni, 1994). Such speaker and rate variations do influence the word recognition abilities of listeners and are not addressed through the acceptance of a special mode of speech processing.

An alternative mechanism resides in the abilities of the general auditory system. Miller and Dexter (1988) discuss a concept of durational contrast where the duration of auditory events is evaluated relative to their perspective contexts. For example, a fixed 100 ms duration of silence would be perceived as being relatively long if it were presented in between two 20 ms tone pip markers, but the same duration would be perceived as relatively short in the context of 1 s tone pip markers. A comparable example from the speech perception literature would see the effects of vowel duration on perceived VOT interacting in a similar fashion. As vowel duration is increased, the VOT boundary dividing voiced from voiceless percepts also shifts to a longer duration relative to a context with a shorter vowel duration, as in Volaitis and Miller (1992), for example.
The examples presented above have primarily focused on data using spoken language where either mechanism could potentially be at work. Data from Diehl and Walsh (1989) examines this pattern using both speech and non-speech stimuli. The data from this study indicates that the pattern of results expected with a mechanism of durational contrast is obtained for both speech as well as non-speech data. Essentially, the duration of surrounding acoustic segments, either speech or non-speech in nature, influenced the perceived duration of an acoustic target. This suggests that a specialized speech mode of processing is not required for adjustment to durational changes to take place.

While Liberman (1998) does provide a stimulating argument regarding speech perception, the empirical studies presented above form a convincing position that phonetic status is not transmuted automatically to articulatory gestures. The data from Sommers, Nygaard, and Pisoni (1994) indicates that some resource-based process is implicated in the perception of speech that varies in the domain of rate and talker. Changes in stimulus amplitude, however, apparently do not initiate the use of this process of perceptual normalization as amplitude variability did not affect listener's word recognition performance. Miller and Dexter (1988) showed that our perception of the duration of non-speech materials is dependent on the duration of surrounding acoustic material. Coupled with the analogous effects noted in the speech perception literature (e.g. Volaitis & Miller, 1992) and the similar pattern observed by Diehl and Walsh (1989) with both speech and non-speech stimuli, it seems likely that a listener's ability to adjust to changes in speaking rate resides with the abilities of the auditory system.
1.4 Possible Explanations for Speech Perception Difficulties in Older Age

1.4.1 Hearing Loss View

A number of possible causal or contributing factors have been proposed to account for the difficulties elderly adults experience understanding spoken language. One group of researchers claim that these difficulties experienced by older adults are due to changes in pure-tone hearing thresholds. For those older adults with hearing thresholds within the normal range, small differences in high frequency sensitivity are proposed to account for their poorer spoken language perception abilities. Humes and Christopherson (1991) compared hearing-impaired older adults to younger normal-hearing subjects on a number of auditory processing measures and speech identification tasks. Their work indicates that hearing sensitivity accounted for a majority of the difference between the young and older subjects. However, their data also indicates that age impacted on speech identification performance in a manner not associated with changes in hearing threshold sensitivity. The auditory tasks in this work that caused significant difficulty for the older adults all invoked use of auditory temporal processing abilities, such as duration discrimination.

Van Rooij and Plomp (1992) studied the contribution of various auditory and cognitive measures to spoken language understanding in young and old age. Their results also suggest that these age differences are most likely due to changes in hearing sensitivity in the higher frequency range. In a review paper, Humes (1996) further concludes that, to date, sensorineural hearing loss appears to account for most of the
difficulties that older adults experience in perceptually demanding situations, such as in
the presence of background noise.

A number of studies, however, present data in opposition to this claim. It has
been shown that older adults exhibit poorer spoken language understanding ability in
difficult listening situations that is unrelated to changes in pure-tone hearing thresholds.
Older adults demonstrate poorer performance relative to young listeners for language
presented at fast speaking rates (e.g. Gordon-Salant & Fitzgibbons, 1995b), speech
presented in noise (e.g. Cheesman et al., 1995; Stuart & Phillips, 1996), speech that is
distorted by reverberation (e.g. Gordon-Salant & Fitzgibbons, 1995a; Helfer & Huntley,
1991) and even for speech presented in quiet (Gelfand et al., 1985). These decrements
were shown to be unrelated to hearing sensitivity, as indexed by audiometric thresholds.
While this collection of studies does not negate the impact of pure-tone hearing
thresholds on the perception of spoken language by older adults, they do indicate that
factors, in addition to hearing thresholds, can potentially affect the older adult’s ability to
understand spoken language.

1.4.2 Cognitive Perspective

Another position regarding the difficulties that older adults experience with
spoken language proposes that changes in cognitive ability that occur with age are
responsible for these perception deficits. Data has been presented implicating language
processing speed and working memory capacity in the perception of spoken language by
older adults (Cohen, 1987; Small et al., 1997; Wingfield, 1996). It is important to note,
however, that while cognitive deficits have the potential to affect spoken language
perception in older adults, these deficits do not necessarily coincide with auditory processing abilities. If higher level cognitive deficits were to necessarily implicate auditory deficits, then the likely relationship would be one where both ears were affected equally. Measures of temporal resolution, however, have been obtained from older normal-hearing adults who have evidenced significantly different temporal resolution abilities across their ears (Schneider, Pichora-Fuller, Kowalchuk, & Lamb, 1994). If the auditory deficit was due to cognitive impairment then it would be difficult to account for the sporadic nature of its implications.

Work by Pichora-Fuller, Schneider, and Daneman (1995) further indicates that some difficulties that older adults experience with spoken language are likely unrelated to cognitive deficits. Pichora-Fuller et al. (1995) obtained results indicating that older normal-hearing subjects actually receive more benefit from context than their younger normal-hearing counterparts. They obtained data using the Revised Speech Perception in Noise (SPIN-R) test in which the subject is required to repeat what they hear as the final word in a series of sentences. This test involves both a low context condition, where the sentences have a low level of predictability, and a high context test condition in which the final word is highly predictable from the sentence context. When performance was equated across the two subject groups in the low context testing condition, it was possible to determine the percent benefit obtained under the high context test condition. Results indicated that the older normal-hearing subjects obtained greater benefit from the context relative to the young listeners.

Pichora-Fuller et al. (1995) also included a memory task to further assess the cognitive abilities of the older subjects relative to the younger subjects. Following the
presentation of each test sentence, the subjects were still required to identify the last word of the sentence, but they also needed to retain this word in memory. After a set number of sentences, the subjects needed to recall the final word of each test sentence. In all test conditions, the older subjects recalled fewer sentence-final words than did the younger subjects with memory set size not affecting word identification performance. The notable finding resulting from this work is that the rate of memory failure was similar across the younger and older subjects. As the signal to noise ratio become less favorable, the difference in the number of items recalled across conditions was comparable for the younger and older listeners. If the differences between the younger and older subject’s performance were mediated by poorer cognitive ability on the part of the older listeners, than one would expect a greater rate of memory decline for this age group. This result suggests that the difference between these two groups did not stem from cognitive factors, but rather from auditory processing mechanisms. To further support this conclusion, the authors demonstrated that older listeners did not differ from the younger listeners on a reading span task, as both groups showed comparable recall of material that was read. Poorer performance was only observed in the auditory modality suggesting that the recall deficits in the older listeners were not due to cognitive factors that would likely impact on performance across presentation modalities.

1.4.3. Auditory Processing View

Hypotheses based on auditory processing deficits, other than threshold hearing loss, constitute another position that will form the basis for this present work. In general, this line of reasoning focuses on how accurately and efficiently the auditory system
analyses the temporal, intensity, and spectral characteristics of the acoustic input. Each of these positions (threshold hearing loss, cognitive deficits, and auditory processing deficits) has been discussed separately, but all three may co-occur or various combinations of the three may interact and contribute to the difficulties perceiving spoken language that often face the older adult. For example, it is probable that in easy listening situations, where the demands on the listener are relatively few, that higher level cognitive functions can quite successfully compensate for certain degrees of auditory processing deficits. However, it has been suggested that such a process of compensation depletes the listener of resources that may typically be allocated to other tasks such as storing input in working memory or for other mechanisms involved in speech understanding (Pichora-Fuller et al., 1995). This re-allocation of resources may negatively reflect on an individual’s comprehension as the demands of the listening situation are increased. A pattern of deficit and resource allocation may explain the spoken language understanding difficulties of a portion of older listeners that have relatively normal pure-tone hearing thresholds and little comprehension difficulties under ideal circumstances, but significant problems once the demands of the situation are increased. This line of reasoning is consistent with a working memory model where the need to expend more finite resources at the perceptual level of processing, necessarily leaves fewer available resources for higher level processing functions (Schneider & Pichora-Fuller, 1999)
This study will focus specifically on changes in auditory temporal resolution that are hypothesized to contribute to the difficulties elderly adults often experience understanding spoken language. Auditory temporal resolution refers to the auditory system's "ability to detect changes in stimuli over time" (Moore, 1989, p.137). The ability of the auditory system to accurately analyse events that occur over time is critical to the understanding of spoken language. The dynamic aspects of the signal are laden with information that enables the listener to attach meaningful significance to acoustic input. For example, Strange, Jenkins, and Johnson (1983) present data that indicates that accurate vowel identification is possible when only formant transitions are available to the listener. Other temporally defined speech cues include Voice Onset Time (VOT), for example, as a cue to the voicing of word initial consonants. At an even more fundamental level, a significant reduction in acoustic energy that occurs with articulatory closure provides the listener with a cue regarding the presence of a stop consonant (Kent & Read, 1992). The duration of such a stop gap can determine whether or not a stop consonant is even perceived (e.g. Dorman, Marton, Hannley, & Lindholm, 1985), if it is perceived as voiced or voiceless (e.g. Miller & Volaitis, 1989) and can signal the difference between a fricative, /ʃ/ and an affricate /tʃ/ (Dorman, Raphael, & Liberman, 1979). The ability to resolve temporally distributed auditory events, such as detecting a stop closure, is crucial for an accurate understanding of spoken language.

In fact, a large proportion of sentence information can be recognized with only the use of a message's temporal structure. Dividing sentences into three frequency bands and replacing each band with a band-passed noise with a corresponding amplitude envelope
does not substantially impede sentence recognition (Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995). In this context, sentence recognition was accomplished with a greater than 90% level of accuracy. The temporal pattern of the original sentences was sufficient to maintain a high level of message comprehension in the absence of other spectral cues.

The issue of auditory temporal processing is of particular interest in respect to the difficulties that elderly adults often experience when perceiving spoken language. For instance, a longitudinal study was published examining age-related decrements in speech perception (Bergman et al., 1976). The performance of adults, 20-89 years of age, was assessed using sentence stimuli. Stimulus conditions that increased temporal processing demands showed the greatest age-related decrement. These conditions involved sentences presented with an interruption rate of 8 times/s, an unfavourable reverberation condition, and a condition using bisyllabic words that were presented such that the last syllable of one word overlapped with the first syllable of the second word. A pattern of overlapping words is typical in natural conversations when one speaker’s turn is ending and another speaker’s turn is beginning. Performance in these conditions began to evidence decline in the 40-49 year age group. This decline worsened with increasing age with the scores of the 70-79 year age group being less than half the size of those scores obtained by the young adults. Performance was assessed seven years following the initial testing and it was found that subject performance declined relative to previous testing, suggesting that performance decrement increases with increasing age. This study highlights the difficulties that older adults frequently experience with temporally altered materials.
Auditory temporal resolution can be studied through the use of gap detection experiments. In a gap detection task a listener is typically presented with two auditory events, one of which contains a gap, a brief dip in acoustic energy. The listener’s task is to identify the stimulus containing the gap. The size of the gap is systematically varied to determine the smallest gap detectable to the listener, namely their gap detection threshold. Characteristics of gap detection ability in young listeners will first be discussed as many of these characteristics likely affect the gap detection ability of older listeners as well. This will be followed by a consideration of the effects of hearing loss and subsequently by a discussion of the current knowledge concerning gap detection ability in older age.

1.5.1 Factors Affecting Gap Detection Ability

The acoustic context within which a gap is presented has been shown to significantly influence the gap detection threshold. Gap detection thresholds based on noise stimuli with narrow marker bandwidths have been shown to improve as the bandwidth of the stimuli demarcating the gaps is increased (Grose, 1991). Furthermore, gap detection ability improves as the centre frequency of the gap markers is increased (Shailer & Moore, 1985), suggesting that gap detection thresholds with broadband noise signals are likely based on the highest useful frequency information in the signal. Gap detection thresholds obtained with sinusoidal gap markers appear to be relatively stable with changes in marker frequency when assessed in contexts where the phase of the trailing marker is preserved (Shailer & Moore, 1987). In a preserved phase condition the
trailing marker begins with the phase that would be expected if the two markers were continuous with no gap separating the two.

The intensity of the gap-defining markers also affects the resultant measure of temporal resolution. The most sensitive measures of temporal resolution ability are obtained when narrow-band gap markers are presented at approximately 30-40 dB sensation level (SL) (Moore, 1989). At lower levels of intensity, gap detection thresholds increase indicating poorer temporal resolution ability. With broadband noise markers, gap detection thresholds increase only at sound levels near threshold, but remain relatively stable at higher intensities (Moore, 1989). A similar pattern is obtained with tone pip markers where gap detection thresholds appear to be somewhat elevated when assessed with markers presented 10 dB above their respective audibility thresholds, but remain stable at levels 20 to 60 dB SL (Schneider, Speranza, & Pichora-Fuller, 1998; Schneider et al., 1994). Data using longer sinusoidal gap markers further confirmed decreased gap detection ability at low sensation levels (Strouse, Ashmead, Ohde, & Grantham, 1998). To obtain an assessment of optimal temporal resolution ability with a gap detection task, the gap-defining markers should be at a sufficiently intense level. Comparisons of gap detection ability across subject groups should be made with stimuli at sufficiently loud but equivalent sound pressure levels (Fitzgibbons, 1984).

Other studies also indicates that listeners are sensitive to the frequency relationship of the two markers that define the gap. There are data showing that gap detection ability worsens as the frequency difference between the gap-defining markers is increased (Phillips, Hall, Harrington, & Taylor, 1998; Phillips, Taylor, Hall, Carr, & Mossop, 1997). Phillips et al. (1997) demonstrated that when the gap markers were
equal or almost equal centre frequencies, gap detection thresholds ranged from 5.3 to 6.3 ms. When the markers differed in centre frequency by two octaves, the subsequent gap detection thresholds were between three to tens times poorer. The authors suggest that gap detection in the context of identical frequency markers compared to markers differing in frequency involve different perceptual processes. They claim that when the markers are the same frequency, gap detection is based on the detection of a disruption of activity within one particular processing channel. Gap detection in the context of different frequency markers, however, is suggested to depend on a comparison and integration of information between processing channels, a process that requires some form of more central auditory analysis. Formby, Gerber, and Sherlock (1998) provide data that further support the notion of decreased gap detection ability as the frequency separation of the gap markers is increased. They used sinusoidal gap markers and obtained gap detection thresholds from young normal-hearing listeners that are comparable to those from Phillips et al. (1997).

Similar results have been obtained using narrow bands of noise that were constructed to simulate Consonant-Vowel (CV) syllables (Formby, Barker, Abbey, & Raney, 1993). The gap, in this context, occurred between a simulated consonantal release burst and a simulated second formant onset. Formby et al. (1993) determined that gap detection thresholds increased as the difference between the frequency of the gap markers simulating the second formant was increased. Phillips et al. (1997) also measured gap detection thresholds where the preceding gap marker was a broadband noise signal and the following gap marker was a narrow band of noise. They likened this context to a consonantal release burst followed by a stop gap and then a subsequent
vowel formant. In this context, gap detection thresholds were similar to those obtained when the markers were of differing frequencies, approximately 30 ms. The authors suggest that the gap detection process involved with CV syllables invokes use of a between channel mechanism as the preceding gap marker is broad in frequency content and therefore attention is not focused on any one particular region of energy. By presenting the leading gap marker on the side of one ear and the trailing marker from the opposite side, the same pattern of between channel gap detection thresholds is also evidenced (Phillips et al., 1998).

Phillips et al. (1997) draw a speculative connection between the gap detection thresholds obtained in the between channel contexts, on the order of 30 ms, and the same value of 30 ms that is commonly referred to as the VOT category boundary dividing voiced from voiceless percepts. A more thorough examination of the speech perception literature indicates that such a connection is too simplistic because, although Phillips et al. (1997) do note that VOT can vary with place of articulation, they do not address the issue of speaking rate and concomitant changes in VOT boundary that have been shown to occur as speaking rate is increased or decreased (e.g. Miller & Volaitis, 1989). Also, in natural speech, a period of aspiration typically follows a consonantal release burst in the context of a voiceless stop and needs consideration (Kent & Read, 1992).

1.5.2 Gap Detection in Hearing-Impaired Listeners

Gap detection studies using hearing-impaired subjects indicate that decreases in pure-tone hearing sensitivity are related to poorer gap detection ability. This in turn has been correlated to the perception of spoken language presented in noise or distorted by
reverberation (Irwin & McAuley, 1987; Tyler, Summerfield, Wood, & Fernandes, 1982). For example, Tyler et al. (1982) obtained four different measures of auditory temporal processing from a group of normal-hearing and hearing-impaired listeners, with a range of cochlear pathologies. In addition to gap detection thresholds, the authors also examined temporal integration ability (through the assessment of stimulus duration on detection thresholds), temporal and gap difference limens. Both gap detection thresholds and temporal difference limens were significantly correlated with the hearing-impaired subjects' diminished ability to identify spoken language presented in noise.

Interestingly, patients with cochlear implants and auditory brainstem implants have been shown, through gap detection studies, to have normal temporal resolution (Shannon, Zeng, & Wygonski, 1992). Therefore, it appears that stimuli can bypass the coding and analysis performed by the cochlea and even the auditory nerve without compromising temporal resolution. These early stages of auditory analysis may not necessarily be required for normal temporal resolution ability, but data from hearing-impaired subjects suggest that irregularities at these early levels of processing may interfere with the ability of subsequent higher levels of analysis to accurately process temporal information.

1.5.3 Gap Detection in Older Listeners

The situation involving gap detection measures and older listeners is even more complex. Older listeners often have some degree of peripheral pure-tone hearing loss, but may also have other concurrent forms of auditory deficits that contribute to poorer gap detection thresholds. A number of studies indicate that some older adults do exhibit
temporal processing deficits as revealed through depressed gap detection thresholds.

Schneider, Pichora-Fuller, Kowalchuk, and Lamb (1994) obtained data indicating that the
detection of gaps in Gaussian-enveloped tone pips is poorer in older compared to young
adults. This relationship was found to be independent of audiometric hearing thresholds.

Using gaps marked by noise bursts, Snell (1997) also found that older subjects, with
hearing thresholds closely matched to the young subjects, had poorer gap detection
thresholds. The gaps occurred 100 ms following the onset of 150 ms noise bursts. This
pattern of results is further supported by Strouse et al. (1998) who found older adults to
have larger gap detection thresholds for gaps centred in 200 ms sinusoidal signals. This
finding also did not correlate with subject hearing thresholds. Lutman (1991) found a
differing pattern of results, as his data suggests that hearing thresholds, not age, are
related to the detection of gaps centred in 1s narrowband noise bursts. The relatively
long stimuli used by Lutman (1991) for the gap detection procedure is of interest and
may be related to the lack of a relationship between age and gap detection thresholds that
was indicated by his data. This will be thoroughly explored in section 1.5.5.

Schneider and Hamstra (1999) found a revealing relationship between the
duration of the gap markers and subsequent gap detection thresholds and age correlations.
Their data revealed significant age effects at short marker durations such as 2.5 ms.
These age effects decreased and essentially were non-significant as the marker durations
increased to 500 ms. A proposed explanation for the findings of Schneider and Hamstra
(1999) will be presented in section 1.5.5. It may be that the stimuli used by Lutman
(1991) did not sufficiently stress the auditory system and therefore did not evidence an
effect of age on subject performance.
In other work, stimulus duration is shown to impact on other auditory processing abilities besides gap detection. It has been shown to affect older adult’s ability to identify tonal sequences (Fitzgibbons & Gordon-Salant, 1998). Age differences on this task were not evidenced until the shortest stimulus duration of 100 ms. Stimulus duration also affects an elderly listener’s ability to detect small differences in frequency across two signals (Cranford & Stream, 1991). As the duration of a 1 kHz signal was decreased from 500 to 5 ms, the frequency difference limen of the listeners increased (Cranford & Stream, 1991). This finding was correlated with age and with performance on the Staggered Spondaic Word test3, but not with pure-tone hearing thresholds. The authors note that the difficulties older adults experience making qualitative judgements regarding short duration stimuli may be related to the difficulties that older normal-hearing adults often experience understanding spoken language.

One clear consensus that can be gathered from the above review of gap detection experiments is that temporal resolution ability interacts with the complexity of the stimuli used for its assessment. Gap detection is simpler in contexts where the defining markers are of equal frequency and of relatively long duration. The variables of marker frequency and duration were shown to interact and affect gap detection performance by Phillips et al. (1997) and Phillips et al. (1998). These authors found that in conditions where the markers were of differing frequency, gap detection ability worsened as the duration of the initial marker was shortened. In cases where the markers were of equal frequency, no such relationship with marker duration was revealed. The age of the subjects used in these studies is unknown, but the subjects were described as having normal hearing.

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3 This test uses binaurally competing stimuli to assess central auditory function (Kent & Ivey, 1994).
Assuming the generalization of the findings of Schneider and Hamstra (1999), it is suggested that the subjects used in these studies were likely relatively young. The influence of stimulus complexity, for example, multiple stimulus components, is further noted by Fitzgibbons and Gordon-Salant (1996) who claim that age effects on temporal processing tasks are most apparent when assessed with complex as opposed to simple stimuli.

1.5.4 Models of Gap Detection

Linear models of gap detection, or more generally of temporal resolution, typically consist of four stages. Moore (1989) discusses two different, but notably similar models of temporal resolution. These models are depicted in Appendix A. Each model begins with a band-pass filter that represents the activity of the auditory filters. Following this stage, each model contains a nonlinear device. In Model 1 this is simulated with a half-wave rectifier that passes only one particular polarity of the waveform. Model 2 uses a square-law device to achieve similar results. This square-law device squares each waveform value resulting in an entirely positive representation of the signal. Each model then progresses to a stage where the signal is smoothed and only the slow temporal changes in the stimulus are retained. Model 1 accomplishes this stage with a low-pass filter that works to smooth the signal's amplitude envelope. Model 2 posits a temporal integrator at this stage. The temporal integrator smoothes the signal's power that is contained within a certain window of time. This window is hypothesized to move in time with greater weighting placed on the power that occurs more recently in time. Following a stage where some form of smoothing takes place, each model leads
finally to a decision device. This decision device operates on a rule stating that a gap in the signal will be detected if the dip in signal power (or amplitude, depending on one’s model of choice) reaches some specified threshold value.

The two models discussed above consider that the signal passing through the model is the acoustic stimulus itself, rather than the neural code resulting from the acoustic stimulation. In actuality, any signal smoothing and resulting decision is likely based on the neural activity that results from stimulation (Moore, 1989). Some models of temporal resolution do include some consideration of the translation of stimulus amplitude to neural firing by including a stage of compressive nonlinearity prior to reaching a smoothing device (e.g. Shannon, 1986 as in Moore, 1989). As stimulus intensity is increased, neural activity increases at a slower rate thereby compressing the range of stimulus intensity growth into a smaller range of increasing neural activity. This nonlinearity is meant to simulate the physiological rate-intensity growth patterns of auditory nerves.

The above models meet with significant limitations when examined in relation to current gap detection studies. First, these models cannot be applied to temporal resolution tasks that involve a comparison of activity across different auditory filters. These models do not begin to explain the larger gap detection thresholds that have been obtained in various between channel testing conditions (e.g. Phillips et al., 1997). Currently, these models only consider processes that are applied to one auditory filter and do not explain how activity from different filters can be compared and used by the decision device. Second, these models do not account for the effect of gap marker duration on gap detection ability. Marker duration has been shown to significantly affect
the gap detection ability of older adults (Schneider & Hamstra, 1999). As long as the
duration of the markers is longer than the ringing time of the auditory filters, the above
linear models cannot explain these results.

1.5.5 Possible Explanations of Impaired Gap Detection Ability

The above section provides a discussion of various models of gap detection and
also serves to highlight some possible mechanisms that may cause impaired gap detection
ability. Poor gap detection ability can theoretically be related to inconsistencies or
imperfections at any of the posited stages of temporal resolution (Moore, 1989). For
example, internal noise at the stage of the decision device may impair one’s ability to
detect small gaps. The size of the window of the temporal integrator can also affect gap
detection. A broader temporal window is related to decreased gap detection ability
(Moore, 1989). As the size of the window is increased, the resulting dip in power related
to a gap will become relatively smaller as the amount of energy that is averaged within
the window increases.

Recent work indicates that a broader temporal window is not related to the poorer
gap detection ability that is evidenced in elderly normal-hearing adults. Schneider and
Pichora-Fuller (1998) examined the gap detection ability of young and older adults with
stimuli that varied in the rise and fall time of the gap markers as the standard deviation of
the amplitude envelope varied. The results showed that the gap detection thresholds of
both the young and older listeners increased as the standard deviation of the stimulus
envelope increased, but the thresholds of the older adults remained consistently poorer
compared to the young subjects. If the relatively poorer performance exhibited by the
older listeners was due to the size of their temporal window, then the older adults should have begun to perform more like the young adults as the standard deviation of the stimulus envelope increased. The results indicated that the age effect did not change as the standard deviation of the envelope increased, suggesting that a larger temporal window is not likely the source of the age differences observed in this study.

The data from Schneider and Pichora-Fuller (1998) do not, however, rule out a change at the stage of the decision device that may be impacting on gap detection performance in old age. It may be that older adults require a larger dip in energy to reach the threshold of the decision device. Data indicating that older adults have poorer intensity resolution compared to young adults further suggest that the noted age differences in gap detection may possibly be related to higher thresholds on the part of the elderly listeners (He, Dubno, & Mills, 1998).

A current study addressed this possibility by studying the effect of the duration of the gap markers on subsequent gap detection performance (Schneider & Hamstra, 1999). The rise and fall times of the gap markers were kept constant as the duration of the markers varied from short (0.83 ms) to long (500 ms). As previously discussed, the older adults evidenced poorer gap detection thresholds in the short marker conditions but the age effects decreased to non-significance at the longest marker tested (500 ms). A change in the threshold required for the detection of a gap is inconsistent with these results. If the older adults did require a larger dip in energy to detect a gap, then age differences would be expected to persist at all gap marker durations.

Schneider and Hamstra (1999) do propose a model to explain the differential effects of marker duration on gap detection thresholds. This model is based on neural
adaptation and the hypothesis that recovery from neural adaptation occurs differently in
the old compared to the young auditory system. Essentially, this position suggests that
older adults recover more slowly from neural adaptation. A slower recovery from such
adaptation can work to obscure gap detection, particularly in the context of short gap
markers. Consider a condition involving a 16 ms gap centered between two 40 ms tones,
as illustrated in Figure 1. Schneider and Hamstra (1999) suggest that in this case a large

![Figure 1](image)

**Figure 1.** Relative response rate as a function of time for hypothetical neural units
exposed to two 40-ms tones separated by gaps of varying duration. The response
parameters of these hypothetical units are assumed to differ between younger (solid lines)
and older (dashed lines) adults. The first tone is assumed to start at 0 ms. Note. From
"Gap detection thresholds as a function of tonal duration for younger and older listeners,"
permission.

transient spike will occur at the onset of the first gap marker followed by a large transient
burst at the onset of the trailing marker. The dotted line hypothetically represents the
response of an older auditory system and the solid line correspondingly represents younger auditory systems.

In either the younger or older contexts, the transient response marker the trailing gap marker is quite large and will likely be detected. The response of the older auditory system is, however, not as strong. This decreased strength in initial transient response is proposed to be due to less efficient recovery from the neural adaptation that is experienced in response to the first marker. As the gap in this context is relatively long, 16 ms, greater time is allowed for recovery from adaptation and the modelled older auditory system would likely be able to detect the gap. However, as the duration of the gap decreases, less time is allowed for recovery from adaptation. At some point, the change in the relative response rate of the older auditory system in response to the second gap marker becomes barely discernible and in turn these gaps will be more difficult to detect. The young auditory system, that supposedly shows a greater recovery from adaptation, will continue to perceive a sufficient change in relative response rate for gap sizes smaller than the threshold gap size detectable by the older adult. This pattern of hypothetical response patterns also addresses the effect of marker duration of the gap detection ability of older adults. As the duration of the markers is shortened, less time is available for neural recovery and therefore the strength of the response to the trailing marker is weakened.

There is some psycho-acoustic and neurological data that lends strength to a model of gap detection based on neural adaptation. Neural response data from the auditory nerve of the chinchilla indicates that use of a shorter duration masking stimulus will decrease the subsequent probe response magnitude in a forward masking paradigm.
(Harris & Dallos, 1979). In this case there would be less recovery from adaptation. A similar pattern is depicted in Figure 1 where less time is available for neural recovery as the duration of the gap is shortened and the size of the second transient response decreases. This comparison of gap detection with forward masking is consistent with data from Penner (1977) that suggests similarities between these two measures.

The impact of stimulus duration on gap detection measures and a possible relationship to neural adaptation is also promising in light of certain animal neurological data presented by Eggermont (1995). Eggermont (1995) studied the neural correlates of gap detection at the level of the auditory cortex in cats. His data revealed differing patterns of results depending on whether the gap occurred 5 ms after stimulus onset, the early condition, or 500 ms after stimulus onset, the late condition. Gap detection thresholds for the later-occurring gaps were significantly shorter, at about 5 ms, than those for the earlier-occurring gaps, which were approximately 40 ms. The data also indicated that the number of neurons that showed evidence of a neural gap varied depending on the temporal position of the gap in the stimulus. All neurons studied evidenced a neural gap for the late-occurring gaps but only 15% of neurons showed a neural gap in the early condition. When the gap occurs late in the stimulus, it may be that neural activity has largely recovered from adaptation and closely resembles spontaneous activity, therefore the response to the trailing marker is large. In contrast, when the gap occurs early in the stimulus, neural activity is increased in response to the onset of stimulation and fewer neurons have sufficiently recovered from adaptation resulting in a smaller onset response to the following gap marker. This increases the difficulty of
detecting a brief cessation of energy in a signal and the subsequent onset of the following gap marker.

This model of neural adaptation places importance on the strength of the initial transient response to the onset of the trailing gap marker. In line with this reasoning, Greenberg (1996) writes that the auditory system is particularly tuned to encode the beginning of auditory signals. In fact, the cochlear nucleus houses cells termed onset units that tend to respond to signal beginnings with a high level of synchronicity (Greenberg, 1996). Also, at the level of the primary auditory cortex, it has been shown that feline cortical neurons respond to transient stimuli with a sufficiently high degree of precision that could support the perception of the temporal progression of the speech signal (Phillips & Hall, 1990). Furthermore, data studying the smallest amount of acoustic asynchrony that can be detected by humans also indicates that the auditory system is particularly sensitive to stimulus onsets. Zera and Green (1993) obtained data indicating that listeners required a larger amount of stimulus asynchrony prior to showing awareness of its presence when the asynchrony occurred in the stimulus offset rather than the stimulus onset. Further highlighting the importance of stimulus onsets, a listener's ability to detect increments or decrements in a signal's level depends to a larger extent on transient signal changes than on relatively longstanding differences in signal level (Moore & Peters, 1997).

The detection of stimulus onsets in old age may be impeded by less efficient recovery from neural adaptation but other factors may also potentially contribute to this relationship. For instance, there are data that indicate decreased levels of neural synchrony in old age. For example, older listeners have been shown to have smaller
masking level difference values compared to younger listeners, indicating that they receive less improvement in signal detectability under certain binaural presentation conditions (Pichora-Fuller & Schneider, 1991; Pichora-Fuller & Schneider, 1992; Strouse et al., 1998). A lesser degree of neural synchrony may hinder the ability of the older auditory system to detect stimulus onsets as the strength of firing signalling a stimulus beginning would be relatively weaker, as neural firing in response to an onset would occur over a larger temporal range. This situation may only become problematic in the context of short stimulus durations where the negative effects of decreased recovery from neural adaptation would hypothetically be greater. In this circumstance, the combined effects of neural adaptation and the decreased level of neural synchrony in an older adult’s auditory system may work together to impair the gap detection ability of older listeners relative to younger listeners.

1.6 Gap Detection and the Perception of Spoken Language

A pattern of decreased gap detection ability has the potential to theoretically interfere with the processing of spoken language (Schneider & Pichora-Fuller, 1999). Currently, however, a relationship between auditory temporal resolution and spoken language perception in old age remains unclear. The limited data to date do not indicate a relationship between these two abilities. Strouse, Ashmead, Ohde, and Grantham (1998) examined the ability of young and older listeners to identify and discriminate stimuli along a continuum from /ba/ to /pa/ that varied along the parameter of VOT. The data indicate that the older subjects had lesser degrees of categorical perception compared to the young subjects. The slope of the identification functions derived from the young
subjects was significantly steeper than the slope obtained from the older subjects. No significant correlations were evidenced between speech identification ability and gap detection. It may be that some relationship does exist, but that the particular stimuli used in this study did not allow for this potential connection to be displayed. The data also did not indicate a relationship between hearing thresholds or interaural time difference thresholds and speech identification data.

Data from van Rooij and Plomp (1989) and Humes and Christopherson (1991) also do not evidence any significant relationship between measured temporal processing abilities and the perception of spoken language in old age. The data from Humes and Christopherson (1991) do, however, implicate auditory processing abilities to some extent. While the data indicated that hearing loss was the main determinant of spoken language identification ability, larger amounts of the identification variance could be accounted for by including other measures of auditory processing into the equation. It is of interest that the auditory processing measures that evidenced age effects in this study involved some form of temporal processing.

This research proposal will address the question of whether the speech perception difficulties experienced by older adults are correlated with deficits in gap detection ability. The lack of a well-documented relationship between the perception of spoken language in old age and auditory temporal resolution may be related to the stimuli used to assess temporal resolution. It may be that previously used stimuli did not sufficiently stress the auditory processing abilities of older adults in a manner that is comparable to the stresses these older adults encounter with speech. This study will extend the understanding of the relationship between the stimuli and the resultant auditory temporal
resolution abilities and subsequent correlations with speech perception measures. This study will examine specifically the impact of stimulus duration on gap detection ability and any relationships to word recognition performance in quiet and in noise as assessed with both a fast and a slow speaking rate.

1.6.1 Characteristics of Gaps in Speech

Speech stimuli provide a unique opportunity to assess the influence of silent intervals, or gaps, on word recognition. In this context, gap detection ability may be shown to correlate with the perception of everyday words. For example, consider a vowel-stop consonant-vowel (VCV) speech sequence. In this context, an articulatory closure and a resultant decrease in acoustic energy cue the stop consonant. This stop gap is analogous to gaps in traditional gap detection experiments, in that each can be identified by a significant decrease in signal amplitude relative to the gap markers. The two, however, are not equivalent, and the distinguishing features will be discussed below. The vowels bordering the stop consonant provide a naturally occurring analog to traditional gap markers.

There are some significant differences between traditional gap detection stimuli and the intervocalic stop consonant, for example. First, a collection of acoustic features cue naturally occurring gaps in speech. An intervocalic stop consonant has phonemic significance that is derived from these cues. Formant transitions, stop bursts, aspiration, and a reduction in acoustic energy all provide cues to the presence of a stop gap (Kent & Read, 1992). A comparable occurrence of a stop gap in speech can be seen in the word 'split' which can be distinguished from 'slit' by the insertion of a region of reduced
energy between the fricative and the liquid (e.g. Summerfield et al., 1981). In this context, Summerfield et al. noted that, in addition to the duration of the stop gap, the length of frication, the rate of offset for the /s/, and the initial frequency of the first formant of the vowel all combine to cue the presence of the stop consonant. In spoken language these multiple cues can often enter into a perceptual trading relationship with one another. For example, a period of silence can serve to differentiate the affricate /ʃ/ from the fricative /s/. However, the duration of silence that is required for this distinction to occur is, to a certain extent, dependent on the rise time of the fricative energy as well as the duration of the fricative portion of the segment itself (Dorman et al., 1979). The occurrence of multiple cues indicates the need to assess how temporal processing abilities may be implicated in contexts applicable to the daily listening needs of the listener.

Multiple cues, such as a stop gap, combine to signal a stop consonant. Focusing on the stop gap, changes in stop closure duration appear to have little impact on place of articulation judgements and, in the context of non-syllable initial closures, little impact on voicing judgements as well. The impact of initial and final formant transitions as well as closure duration on the identification of intervocalic stop consonants has been examined (Tartter, Kat, Samuel, & Repp, 1983). Tartter et al. (1983) obtained data indicating that closure duration has little effect on place of articulation judgements. Luce and Charles-Luce (1985), studying word-final stop consonants, obtained data suggesting that closure duration is a poor indicator of consonantal voicing. They note that the durations of articulatory closure are similar across voiced and voiceless stop consonants and that closure duration tends to vary considerably. In an intervocalic context, Edwards (1981) also shows that closure duration varies substantially and is not a strong indicator of
voicing. He also showed that out of a total of eleven features studied, closure duration ranked tenth according to probability of indicating place of articulation. In summary, while closure duration is a poor indicator of both place of articulation and non-syllable initial voicing, its importance as a cue to stop consonant presence has not been disputed. Therefore, an examination of closure duration in speech, as a cue to stop consonant presence versus absence, can be accomplished with likely little interference from changes in place of articulation or voicing percepts.

Word identification performance examined in relation to gap detection measures will provide a particularly useful means of examining the impact of fast speech rates or, similarly, short stimulus durations not only on auditory temporal resolution capabilities, but also on speech perception. It may be that poorer gap detection ability, as assessed with short gap markers, is related to the degraded spoken language perception abilities of many older listeners. Determination of whether age-related gap detection deficits correlate with the recognition of natural speech stimuli presented in noise and at fast speaking rates can help to further the understanding of the relationship between old age and difficulties understanding spoken language.

1.7 Hypotheses:

Null Hypothesis 1. The temporal resolution ability of normal-hearing older listeners, as measured by gap detection thresholds, will not differ significantly from that of normal-hearing younger listeners, regardless of the duration of the gap-defining markers.
Accompanying Research Hypothesis. Normal-hearing older adults will show evidence of poorer temporal resolution ability, as indexed by larger gap detection thresholds, when compared to younger normal-hearing listeners.

Prediction. Based on recent work by Schneider and Hamstra (1999) it is expected that the older adults will be especially susceptible to poorer gap detection thresholds, as the duration of the gap-defining markers is shortened (e.g., from 1 s to 5 ms). At long marker durations (400 ms and 1 s), the performance of older normal-hearing adults is expected to be essentially identical to that of younger normal-hearing listeners.

Null Hypothesis 2. The gap detection ability of the older normal-hearing listeners will be correlated with their audiometric pure-tone hearing thresholds.

Accompanying Research Hypothesis. The gap detection ability of normal-hearing older adults will not be correlated with their pure-tone hearing thresholds.

Prediction. Following outcomes from recent gap detection studies (e.g. Schneider & Hamstra, 1999; Snell, 1997), it is predicted that pure-tone hearing thresholds will not correlate with the gap detection thresholds of the older normal-hearing adults. This prediction supports the position that auditory processing abilities, beyond those assessed by hearing thresholds, contribute to the ability of the auditory system to resolve transient acoustic events over time.

Null Hypothesis 3. Gap detection thresholds will not be correlated with listener age.

Accompanying Research Hypothesis. Gap detection thresholds will be correlated with listener age.
Prediction. Given recent data (e.g. Schneider & Hamstra, 1999; Snell, 1997; Strouse et al., 1998), it is expected that gap detection thresholds will worsen with increasing subject age. Generally, it is expected that the older listeners will have poorer gap detection thresholds than the younger listeners.

Null Hypothesis 4. The characteristics of the word identification functions, word boundary and slope, derived from the slow and fast speech stimuli will be the same for the older and younger normal-hearing listeners. The word boundary is operationally defined as the 50% point on the word identification function and will be identified by linear regression analysis. At this point, the listeners are identifying the stimulus tokens at chance levels of performance. The slope of the functions will also be derived by a linear regression analysis.

Accompanying Research Hypothesis. The word boundary is expected to be the same for both the younger and older normal-hearing listeners when presented with words that are spoken slowly. In this same context, however, the slope of the word identification is expected to be less steep for the older normal-hearing listeners compared to the younger listeners. This would indicate that the older listeners experienced a greater amount of word uncertainty over a larger range of gap durations. In the context of fast speech, it is expected that both the word boundary and the slope of the word identification function will differ for the older normal-hearing adults when compared to the younger adults. It is suggested that the word boundary will occur at a larger gap duration in the word identification functions derived from the performance of the older adults. It is also
expected that the slope of the word identification function will be less steep for the older listeners than for the younger listeners.

**Null Hypothesis 5.** The word boundary will occur at the same silent interval duration across the fast and slow speaking conditions for each word pair continuum.

**Accompanying Research Hypothesis.** It is expected that the word boundary will occur at a different silent interval duration in each speaking rate.

**Predicted.** Following the results of previous experiments (e.g. Diehl & Walsh, 1989; Miller & Volaitis, 1989), it is expected that the word boundary will occur at a shorter silent interval duration in the fast rate condition and at a longer silent interval duration in the slow rate condition.

**Null Hypothesis 6.** The performance of the older adults on the various speech measures will be correlated with their pure-tone hearing thresholds.

**Accompanying Research Hypothesis.** Pure-tone hearing thresholds will not be correlated with the assessed speech perception abilities of the older listeners.

**Null Hypothesis 7.** The performance of the listeners on the various speech measures will not be correlated with age.

**Accompanying Research Hypothesis.** The performance of the listeners on the various speech measures will be correlated with age, with the older listeners exhibiting decreased levels of performance relative to the younger listeners.
Null Hypothesis 8. For the older normal-hearing listeners, auditory temporal resolution, as assessed by gap detection thresholds, will not correlate with any of the obtained measures of speech perception.

Accompanying Research Hypothesis. It is expected that older normal-hearing listeners will show gap detection deficits that will correlate with some of the obtained measures of speech perception. The correlations are expected to be strongest and most prevalent for the speech measures derived from the fast speech and for word identification performance assessed in noise. It is suggested that gap detection thresholds assessed with short duration markers (0.83, 5, 10, and 80 ms) will correlate with the word boundary and slope of the word identification function derived from the fast speech presented in quiet. A similar correlation is not expected in the context of the slow speech. It is further suggested that the older listener's gap detection thresholds will correlate with the signal-to-noise ratio at which their word identification performance reaches chance levels. This correlation is expected for both the slow and fast speech conditions. The occurrence of these correlations would suggest that auditory temporal resolution deficits do contribute to the difficulties understanding spoken language that are often reported by older adults. Furthermore, it would indicate the potential of gap detection thresholds, as a predictor for the performance of older normal-hearing listeners in the context of speech in noise.

Null Hypothesis 9. The signal-to-noise ratio at which word identification performance reaches chance levels, for stimulus tokens that were consistently accurately identified in quiet, will be the same across the older and younger subject groups.
Accompanying Research Hypothesis. Older normal-hearing listeners will reach a chance level of word identification performance at a more favorable (quantified by a greater number) signal-to-noise ratio compared to younger normal-hearing listeners whose word identification abilities will be able to withstand more adverse noise conditions.

Null Hypothesis 10. The signal-to-noise ratio at which word identification performance reaches chance levels, for stimulus tokens that were consistently identified accurately in quiet, will not differ for either the younger or older normal-hearing listeners as the speaking rate of the stimuli is varied from fast to slow.

Accompanying Research Hypothesis. The speaking rate of the stimuli will affect the signal-to-noise ratio at which word identification performance reaches chance levels. More specifically, it is expected that older normal-hearing adults will reach chance levels of performance at more favorable signal-to-noise ratios as the speaking rate of the stimuli is increased. In other words, it is expected that listening in a noise background will negatively affect the older adults to a greater extent in the context of listening to quickly spoken words. It is further expected that speaking rate will not affect the signal-to-noise ratio at which the younger normal-hearing adults begin to perform at chance.
2. METHODS

2.1 Objectives

This study was designed to determine whether gap detection ability in older normal-hearing listeners is correlated with word identification measures obtained with both fast and slow speech presented in quiet and in noise. Gap detection thresholds were obtained with various marker durations in an attempt to replicate previous findings that indicate age-related differences in the relationship between marker duration and gap detection thresholds (Schneider & Hamstra, 1999). Word identification data was based on stimulus continua that varied from one real word to another as the duration of a silent interval was systematically varied. These continua were designed to assess the impact of rate of speech, noise, and silent interval duration on the word recognition ability of younger and older normal-hearing adults. A pilot study and main experiment were conducted to examine the effects of these variables and any relations between gap detection ability and word recognition. The pilot and main experiments will be described in detail in the following sections.

2.2 The Pilot Study

In order to determine appropriate stimulus characteristics and certain procedural details, a pilot experiment was conducted. Data from the pilot experiment guided decisions regarding the number of trials to use in the word identification task and how these trials would be sequenced. Also, the signal-to-noise (S:N) levels to be used in the main experiment were determined based on the results.
2.2.1 The Participant in the Pilot Study

One listener participated in the pilot study. This participant was a female native speaker of English aged 20 years. She had normal pure-tone air conduction thresholds bilaterally (i.e., thresholds were equal to or better than 25 dB HL for frequencies between 250 and 3000 Hz).

2.2.2 Materials for the Pilot Study

The word identification materials consisted of 5 word continua that varied from one real word to another as the duration of a silent interval was varied. These continua were presented at both a fast and a slow speaking rate. The word continua involved tokens varying from 'slit' to 'split', 'soon' to 'spoon', 'cash' to 'catch', 'dish' to 'ditch', and from 'topic' to 'top pick' (see Appendix B for spectrograms and time waveforms).

These word pairs were chosen to sample a selection of contexts where a silent interval distinguishes between two different words. In 'slit'-'split' and 'soon'-'spoon', the gap is inserted pre-vocally. The words differ slightly from one another in that 'slit' contains a liquid following the /s/ and before the vowel, while the /s/ in 'soon' is followed immediately by a vowel. The 'slit'-'split' word pair has been previously studied by other researchers (Summerfield et al.; 1981, Dorman et al., 1979; Marcus, 1978). In 'cash'-'catch' and 'dish'-'ditch', the gap is inserted in a post-vocalic position. These word pairs were chosen to examine the effect of silent intervals inserted following two different vowels. The 'dish'-'ditch' word pair has been previously studied by Dorman et al. (1979). The 'topic'-'top pick' word pair was chosen to examine yet
another context where a silent interval serves to distinguish not between to separate 
words, but rather, between one word versus two.

2.2.2.1 Preparation of Materials

The word continua were based on the speech tokens 'slit', 'soon', 'cash', 'dish', 
and 'top pick', as spoken by the experimenter. These tokens were recorded in a double-
walled, sound-attenuating IAC booth using the sound recording program in the Computer 
Speech Research Environment 4.5 (CSRE 4.5, 1995). The tokens were spoken into a 
Sennheiser model K3U microphone positioned approximately six inches from the 
speaker's mouth. The words were then converted from analog to digital format by the 
DDI component of a Tucker Davis Technologies (TDT) system. The stimuli were 
sampled at a rate of 20 000 Hz and initially stored on the hard drive of the computer. 
They were subsequently stored on a JAZ disk. The stimuli were spoken at a relatively 
slow rate and were used as the base for the slow and fast word continua.

Each token was edited to approximately 65% of its original length to create the 
base stimuli for the fast speaking rate continua. All stimulus modifications were done in 
CSRE 4.5. The stimuli, except for 'top pick' were edited by deleting portions from the 
steady state portions of the signal. The transient portions of the stimuli were left largely 
untouched. Care was taken so that all stimulus deletions were made at zero-crossings in 
the signal in an effort to avoid any waveform discontinuities. This approach to signal 
compression mimics the effects of rate changes in naturally spoken speech (Kent & Read, 
1992). It also avoids the introduction of irregularities into the signal that may occur with 
a method where every nth sample is removed.
‘Top pick’ was edited slightly differently. The first word ‘top’ was edited following the steps given above. Editing ‘pick’ in the same manner proved to be problematic so a token of ‘pick’ was spoken at a faster rate and recorded using the same recording methods that were used for the original tokens. This token was used to replace the original ‘pick’. Further steps taken to modify the stimuli and create the word continua will be described below. All stimulus duration measurements are provided in Appendix C.

2.2.2.1.1 Creation of the ‘Slit’-‘Split’ Continua

The original token of ‘slit’ was used to create the slow continuum. A silent interval was first inserted into the token between the /s/ and the /l/. Visual inspection of the waveform and stimulus spectrogram, as well as listening to various segments of the stimulus, was used to decide where the /s/ ended and the /l/ began. At this point, a relatively large silent interval was inserted to create the most extreme token of ‘split’. This token was used to create the remaining stimuli in the continuum by editing the inserted silent interval to the desired gap duration. To ensure that each stimulus in the continuum was of equal duration, a segment, the duration of the inserted gap, was deleted from the gap that occurred at the closure for the /t/. The duration of the /s/, the liquid, the vowel, and the release burst for the /t/ were held constant. The gap durations used to create the stimulus continuum were: 0, 10, 15, 20, 30, 40, 45, 50, 55, 60, 65, 70, 80, and 95 ms.

Using the token of the original ‘slit’ that was reduced in duration, the fast speaking rate continuum was constructed. The steps followed to construct this
continuum are the same as those used to construct the slow continuum. The gap
durations used to create the stimulus continuum were: 0, 5, 10, 15, 20, 25, 30, 35, 40, 45,
50, 55, 65, and 75 ms.

2.2.2.1.2 Creation of the ‘Soon’-‘Spoon’ Continua

The original token of ‘soon’ was used to construct the slow speaking rate
continuum. As with ‘slit’, a large silent interval was inserted into the token at the offset
of the /s/ and the onset of the following segment. Again, listening to the segments and
visually inspecting the stimulus waveform and spectrogram led to the choosing of this
point. This strategy was employed for all the tokens each time a silent interval was to be
inserted into the signal. This silent interval was then edited to the desired gap durations.
To ensure almost constant token durations throughout the continuum, periodic cycles
approximating the duration of the gap, were deleted from the steady-state portions of the
vowel /o/ and the /n/. In this case it was not possible for each token to be exactly the
same duration. Segments could only be removed from the vowel and the nasal in a
manner that preserved the continuity and periodicity of the waveform. The largest
difference in token duration was 4.10 ms. The gap durations comprising this continuum
were: 0, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 70, and 80 ms.

The fast continuum was based on the original token of ‘soon’ that was shortened
in duration. The same steps that were used to create the slow continuum were followed
for the creation of the fast continuum. The gap durations used to construct this
continuum were: 0, 2, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 65, and 75 ms.
2.2.2.1.3 Creation of the ‘Cash’-‘Catch Continua

The slow continuum was based on the original token of ‘cash’. A large silent interval was inserted in between the offset of the vowel and the onset of the fricative /ʃ/. A segment the duration of the silent interval was then deleted from the fricative to ensure constant token durations. Segments were deleted from the steady-state regions in an effort to keep the fricative rise and fall times constant across the stimulus continuum. Given the aperiodic nature of the fricative, it was possible to delete segments the same duration as the inserted silent interval and maintain constant stimulus duration across continuum tokens. This token became the ‘catch’ token at the extreme end of the continuum. The duration of the inserted silent interval was then systematically shortened as the duration of the fricative was correspondingly adjusted to create the remaining tokens for the continuum. This continuum was comprised of gap durations of: 0, 5, 10, 20, 30, 45, 55, 60, 65, 70, 75, 80, 85, and 95 ms.

The fast continuum was constructed in a parallel manner using the original token of ‘cash’ that was edited to a shorter duration. The gap durations used in this continuum were: 0, 5, 10, 20, 30, 35, 40, 45, 50, 55, 60, 70, 80, and 90 ms.

2.2.2.1.4 Creation of the ‘Dish’-‘Ditch’ Continua

The ‘dish’-‘ditch’ continua were constructed following the ‘cash’-‘catch’ continua. As the desired fricative to affricate transition was the same in each set of words, the /ʃ/ to /tʃ/ portions of the ‘cash’-‘catch’ stimuli were copied onto the fast and slow tokens of ‘dish’ where the original fricative was deleted. The gap durations comprising the slow continuum were: 0, 10, 25, 45, 50, 55, 60, 65, 70, 75, 80, 90, 100,
and 120 ms. The gap durations comprising the fast continuum were: 0, 10, 15, 25, 35, 45, 50, 55, 60, 65, 70, 75, 85, and 100 ms.

2.2.2.1.5 Creation of the ‘Topic’-‘Top pick’ Continua

The slow ‘topic’-‘top pick’ continuum was based on the original recording of ‘top pick’. To ensure constant token duration across the continuum, the duration of the /k/ closure needed to be increased as the duration of the silent interval marking the /p/ closure was shortened. This was accomplished by inserting a large duration of silence into the /k/ closure. The duration of the /k/ closure was then shortened by an appropriate amount as the /p/ closure duration was also shortened. The same approach was used for the creation of the ‘topic’-‘top pick’ fast rate continuum. The slow continuum was comprised of the gap durations of: 110, 125, 135, 145, 155, 165, 175, 185, 195, 200, 210, 220, 230, and 240 ms. The gap durations in the fast continuum were: 70, 80, 90, 100, 110, 120, 130, 140, 145, 150, 160, 170, 180, and 190 ms.

2.2.2.1.6 Background Noise

Both the word identification task in noise and the gap detection task involved the use of background noise. In each case, a 3-band speech modulated noise was used (ICRA, 1997). The noise was amplitude modulated to simulate a 6 person babble (1 female + 1 male + 2 females at −6 dB + 2 males at −6 dB).

2.2.2.2 Calibrating the Sound Level of the Speech Stimuli

The rms voltage of each stimulus token was first determined using an in-house
The average rms voltage was then determined for each stimulus continuum. Calibration was then conducted following the method outlined by Wilbur (1994). A 1-kHz calibration tone was created using the synthesis program in CSRE 4.5. A 1-kHz tone was chosen as it provides a good approximation of the peak intensity of speech. This tone was then routed to TDH-39 headphones located in a double-walled sound-attenuating IAC booth. This was accomplished by creating an experiment in CSRE 4.5 in 'ecosgen' where the calibration tone was the only stimulus. The experiment was played via CSRE 4.5 'ecoscon' and routed through the Tucker Davis Technology system with the modules connected in the exact manner required for the main experiment but without any attenuation. The tone was then routed first to the left and then to the right TDH-39 headphone. The intensity of the calibration tone was measured individually from the left and right headphones with a sound level meter. The intensity of the 1-kHz calibration tone was found to be 118.00 dB A through the right headphone and 117.80 dB A through the left headphone.

The intensity of the calibration tone was then attenuated by 20 dB. The intensity through the right headphone was measured as 98.20 dB A and the intensity through the left headphone was 98.00 dB A. As the intensity through each headphone decreased by essentially 20 dB, it can be concluded that peak clipping did not contaminate the original measurement. The rms voltage was then determined for the calibration tone using the same in-house program used for the speech tokens. The difference in decibels between the calibration tone and the average rms voltage of each stimulus continuum was then calculated using the formula \(20 \log \left( \frac{\text{voltage A}}{\text{voltage B}} \right)\). The calculations for each
condition are provided in Appendix D. Once the decibel difference between the calibration tone and the stimulus continuum was determined it was possible to calculate the average decibel level of each stimulus token. For example, the ‘slit’-‘split’ fast rate continuum was found to be 17.83 dB less intense than the calibration tone. As the calibration tone was determined to be 118.00 dB SPL, the level of the ‘slit’-‘split’ fast rate continuum is 99.67 dB SPL (118.0 dB - 17.83 dB).

The presentation level for the stimulus tokens was 40 dB SL, referenced to the subject’s SRT. Attenuation values were determined for each stimulus continuum based on potential SRT scores of -10 through 25 dB HL (alternatively 10 to 45 dB SPL) (Davis, 1947). The range of possible presentation levels varied from 50 to 85 dB SPL. The appropriate attenuation value was then entered into the CSRE 4.5 program ‘ecoscon’ that controlled the presentation of the experiments. The experiments were programmed such that the attenuation values were entered just prior to running each experiment. Attenuation values are provided in Appendix D.

2.2.2.3 Calibrating the Sound Level of the Noise

The level of the noise was determined by first running the 1-kHz calibration tone provided on the same compact disc through the entire set of equipment set up exactly as it would be when the experiments were being run, but with no attenuation at any stage. The calibration tone was then routed first to the left and then to the right TDH-39 headphone that would be used throughout the experiment. The level of this tone was then measured with a sound level meter and found to be 78.2 dB A through the right headphone and 78.0 dB A through the left headphone. Attenuating the calibration tone by 20 dB resulted in a
subsequent 20 dB decrease in the measured noise level through each headphone, consistent with no peak clipping. The level of the 6 person babble was then calculated as the level of the calibration tone + 17.2 dB, according to specifications provided by the generators of the recording. This level was then adjusted to the required level at each stage in the experiment.

2.2.3 Programming the Pilot Experiments

The word recognition tests were programmed using the experiment generator program in CSRE 4.5 (‘ecosgen’). Three experiments were programmed with the word identification materials presented in quiet. For the first experiment, the stimuli from each word-pair continuum were presented separately in 12 blocks of trials. The first two blocks served to familiarize the listener with the task and the stimuli were ordered such that each member of the continuum was presented once in order from one end of the continuum to the other. The remaining 10 blocks served as the test trials. The stimuli in these trials were presented randomly with no replacement such that each token in the word-pair continuum was presented once. The experiment followed a single-interval two-alternative forced-choice design. For example, on each trial the subject would be presented with one word. Two choice alternatives would be displayed on a computer monitor in the sound booth. For the ‘slit’-‘split’ continuum these alternatives would be ‘slit’ and ‘split’. The subject signaled her response by clicking the mouse on the alternative she believed she heard.

The second experiment was identical to the first except that rather than 10 blocks of test trials, the experiment contained 20 blocks of test trials.
The third experiment differed from the first two in that two word-pair continua were presented together. The grouping of word-pairs was as follows: ‘soon’-‘spoon’ was presented with ‘dish’-‘ditch’ and ‘slit’-‘split’ was presented with ‘cash’-‘catch’. The ‘topic’-‘top pick’ continua were not included in this experiment. The fast and slow stimulus continua were always presented separately. In each condition testing began with two blocks of familiarization trials. In these stimulus blocks, one stimulus continuum was first presented in order from one end of the continuum to the other and then the second continuum was presented similarly. These familiarization blocks were followed by ten test blocks where the stimuli from the two continua were presented randomly with no replacement. This experiment followed a single-interval four-alternative forced-choice design. Following the presentation of each token, the subject needed to choose their response from a list of four alternatives provided on a computer screen.

The speech tokens used for the word identification task in noise were based on the listener’s performance in quiet. From each word-pair continuum, two stimulus tokens were selected for further testing. The first token closest to the center of the continuum that was identified 80% of the time or greater as being the word without a silent interval (i.e., ‘slit’, ‘cash’, ‘dish’, ‘soon’, or ‘topic’) was selected. The first centermost token that was identified 80% of the time or greater as being the word with a silent interval (i.e., ‘split’, ‘catch’, ‘ditch’, ‘spoon’, ‘top pick’) was selected as the second token. Only the ‘slit’-‘split’ continua were assessed in the pilot experiment.

The tokens were presented through an experiment programmed in CSRE 4.5 ‘ecosgen’ and controlled via CSRE 4.5 ‘ecoscon’. A schematic of the TDT set-up used in both the pilot and main experiments is provided in Appendix E (note that the output
from the noise was only connected to the TDT components during the word identification in noise testing and during the gap detection testing). The experiment followed a single-interval two-alternative forced-choice paradigm. The listener was presented with one word on each trial and was required to select the word they believed they heard from two choices presented on a computer monitor. The listeners identified their response by clicking on the appropriate choice with a computer mouse. Each experiment consisted of three blocks of trials. The first block contained the two selected tokens presented five times each in random order and served to familiarize the listeners with the task. It was not included in the data analysis. The subsequent two blocks contained the two tokens presented ten times each in random order. The experiment was conducted at different signal-to-noise ratios (S:N) ranging from +10 dB to -25 dB in 5 dB steps. They were presented in order from most to least favorable. The S:N ratio was adjusted by varying the attenuation level of the noise via the PA4 attenuator in the TDT. The attenuation levels are provided in Appendix F. The responses to each stimulus token were recorded by the computer.

2.2.4 Procedure for the Pilot Study

The main purpose of the pilot study was to determine the stability of word identification scores and the effect of the number of stimulus trials and the manner with which these trials were presented on the word identification performance. All testing took place in a double-walled, sound-attenuating IAC booth. The presentation of conditions was controlled from outside the booth by the experimenter. The experiments were presented via ‘ecoscon’ in CSRE 4.5.
Pure-tone thresholds had been previously obtained from the subject during participation in another study. Given the availability of current thresholds, only Speech Reception Thresholds were re-established for this subject prior to testing in this study. Throughout all the experiments the stimulus continua were always presented with the slow speaking rate continuum preceding the fast speaking rate continuum. The test materials were presented to the listener's better hearing ear as indexed by the ear with the best SRT score. All materials were presented at 50 dB SL, referenced to the SRT.

Testing began with Experiment 1. The instructions that were read to the subject are provided in Appendix G. These same instructions were used for both Experiments 1 and 2. The stimulus continua were presented in the order of 'slit'- 'split', 'dish'- 'ditch', and 'soon'- 'spoon' in the first testing session and 'cash'- 'catch' and 'topic'- 'top pick in the second testing session. Experiment 1 was then repeated with the same subject and the same test order. The subject subsequently completed Experiments 2 and 3 with the stimulus continua presented in the same order as in Experiment 1. The instructions for experiment 3 are provided in Appendix G.

The pilot subject finally completed the word recognition testing in noise. The instructions for this experiment are presented in Appendix G.

2.2.5 Results of the Pilot Study

Based on the results of the pilot experiments, it was concluded that the test procedure used in Experiment 1 would be used for the word identification testing in quiet. The one difference to this procedure, however, was that each test would be repeated immediately following its completion rather than following the completion of
the first test runs of all the word pair continua. This approach was chosen as the pilot subject reported that Experiment 2, where each stimulus was presented for 20 test trials, was tiring. By immediately repeating each test in Experiment 1, 20 test trials could still be obtained but it would be possible to provide the listeners with an opportunity for a break part way through the testing.

It was further decided that the ‘topic’-‘top pick’ continua would be eliminated from the main experiment. The pilot subject reported these continua to be more difficult and the results indicated that the subject did not perceive as clear a distinction between the two ends of these continua as compared to the other word pairs. To allow for a larger representation of ‘spoon’ in the ‘soon’-‘spoon’ slow continuum, the 15 ms gap token was replaced with a 90 ms gap token.

In regards to the word identification testing in noise, it was concluded that the S:N ratio levels of +10, -5 and -15 dB would be included in the main experiment. These noise levels allowed for an examination of a range of identification performance from very confident to chance levels of performance.

2.3 The Main Experiment

The participants, materials, and procedures for the main experiment will be outlined in the following sections. The main experiment consisted of three parts: a gap detection task and a word identification task conducted in both quiet and noise.

2.3.1 Participants for the Main Experiment

In total 16 listeners participated in the main experiment. Eight of the listeners
comprised the younger test group and were between the ages of 18 and 34. The remaining eight listeners comprised the elderly test group and were 65 years of age or older. All subjects were native speakers of English with normal hearing. Normal hearing is defined as pure-tone air and bone conduction thresholds equal to or better than 25 dB HL from 250 Hz to 3000 Hz bilaterally with no conductive component (air bone gap greater than 10 dB) or significant interaural asymmetry (15 dB or greater difference in pure-tone thresholds at one or more frequencies). Audiometric thresholds are provided in Appendix H. Participant characteristics are provided in Appendix I.

2.3.2 Materials for the Main Experiment

The materials for the word recognition tasks and the gap detection task will be outlined in the following sections.

2.3.2.1 Word Identification Materials

The same speech continua (except the ‘topic’-'top pick continua) and noise stimuli that were used in the pilot study were also used in the main experiment for the word recognition tasks. Refer to section 2.2.2.1 and it’s subsections for detailed information concerning the creation of the speech tokens. Selection of the speech tokens for the word recognition testing in noise involved the identification of the first token closest to the center of the continuum that was identified 80% of the time or greater as being the word without a silent interval (i.e., ‘slit’, ‘cash’, ‘dish’, or ‘soon’) and conversely the first centermost token that was identified 80% of the time or greater as being the word with a silent interval (i.e., ‘split’, ‘cash’, ‘dish’, or ‘soon’). In the case that
word identification performance did not reach the 80% or greater criterion, word identification performance was not assessed in noise. Details on the calibration of all these stimuli can be found in sections 2.2.2.2 and 2.2.2.3.

2.3.2.2 Gap Detection Stimuli

The materials for the gap detection task were provided by Bruce Schneider from the University of Toronto at Mississauga. The materials consisted of 2-kHz tonal gap and no-gap stimuli. The duration of the gap markers were 0.83, 5, 10, 80, and 400ms. Complete details of the stimulus generation are provided in Schneider and Hamstra (1999). The stimuli were constructed digitally and sampled at a rate of 20 000 Hz. The amplitude envelope of both the preceding and following gap markers was obtained by summing a number of temporally distributed Gaussian envelopes, each with an envelope standard deviation of 0.5 ms and spaced at 0.5 ms intervals. The rise and fall time of the stimuli was held constant. The peak amplitude of each set of envelopes was held constant at 1.0. Each set of summed Gaussian envelopes was then multiplied by a 2-kHz tone. A 2-kHz tone was used as 2-kHz is an important frequency in terms of speech information. 2-kHz is in the range of both vowel formants, either the second or third formants, as well as consonantal cues such as release bursts (Kent & Read, 1992). The duration of each marker was specified from the peak of the first Gaussian envelope to the peak of the final Gaussian envelope. The gap duration is similarly defined as the duration from the last peak in the first marker to the first peak in the lagging marker. The resulting stimuli, across all gap and marker durations, were of equal total energy. The stimuli were all presented at 90 dB SPL.
In order to prevent off-frequency cues resulting from spectral splatter, the gap
detection stimuli were all presented in noise. The characteristics of the noise are outlined
in section 2.2.2.1.6.

The level of the noise was determined through the establishment of numerous gap
detection thresholds at various noise levels. These gap detection thresholds were
obtained from the experimenter following the procedure outlined in section 2.3.3.1.
These thresholds were obtained for the 5, 80, and 400 ms marker duration conditions.
Thresholds were also obtained from the experimenter for a 1000 ms marker duration.
The effects of spectral splatter would be expected to be most pronounced in the 400 and
1000 ms marker conditions. A gap detection threshold was first obtained in a low level
of background noise. The level of the noise was systematically increased and gap
detection thresholds were obtained at each level. The level of the noise continued to be
increased until a plateau was reached in gap detection performance over a 15 dB range in
the noise level. This plateau implies that the off-frequency spectral cues have been
sufficiently masked but the noise was not interfering with detection of the target 2-kHz
markers. At noise levels beyond this plateau the gap detection thresholds began to
increase. The level of the noise used in the experiment was chosen from the middle of
the plateau. A noise level of 85 dB SPL was used in all the gap detection conditions.
Gap detection thresholds were also obtained from the pilot subject, identified in section
2.2.1, for the 5, 80, and 400 ms marker duration conditions with a noise level of 85 dB
SPL. A threshold was also obtained from this participant in the 400 ms marker duration
condition with a noise level of 90 dB SPL. These thresholds followed a similar pattern to
those obtained from the experimenter and support the use of an 85 dB SPL noise level.
2.3.3 Procedures for the Main Experiment

The procedures for the gap detection task as well as the word recognition tasks in quiet and noise will be outlined below. The general order of testing was the same for each participant. Pure-tone thresholds and Speech Reception Thresholds were obtained first from all listeners at the onset of testing. All participants also completed a hearing and language history form that was developed in-house.

The study then proceeded with the word identification testing in quiet, followed by the gap detection task and then word recognition testing in noise.

2.3.3.1 Procedure for the Gap Detection Task

The purpose of this Gap Detection test was to determine the smallest silent interval that a listener could detect in a 2-kHz pure-tone. All testing was completed monaurally over TDH-39 headphones. The stimuli were presented to the participant’s better hearing ear (the ear with the lowest SRT). In the case that the SRT was the same in both ears, the stimuli were presented to the right ear. The procedure for the gap detection task followed that used by Schneider and Hamstra (1999). The gap detection stimuli were presented in a two-interval forced-choice paradigm. On each trial the listener was presented with two acoustic intervals, one of which contained a gap and one that was a continuous signal of the same duration and the same total energy. The intervals were separated by 100 ms. The listener’s task was to indicate which of the intervals contained a gap by pressing one of two buttons on a three button response box. As the stimuli were presented a light flashed above the button corresponding to that stimulus. Following each
response a light flashed above the response button corresponding the interval that did, in fact, contain the gap. The gap stimulus occurred randomly in either the first or second interval. The participant initiated each trial by pressing the center yellow button on the response box. The initial gap size at the beginning of each trial was 36 ms. The gap size was either increased or decreased according to a 3 down 1 up rule. Following a correct response, the duration of the gap was decreased by three steps. The gap size was increased by one step following each incorrect response. This procedure determines the 79.7% point on the psychometric function (Levitt, 1971). Each test run was completed following 12 reversals. The mean of the last eight reversals was the gap detection threshold for that run. This was recorded by the computer, which also provided a detailed summary of the listener's responses throughout the experimental run. The first run with a given marker duration was used to familiarize the listeners with the task and was not included in any data analysis. The final gap detection threshold for each marker duration was taken as the mean threshold from the second, third and fourth runs. The duration of the gap markers changed after each run. Each listener was presented with the marker durations in the same irregular order (400, 10, 0.83, 80, and 5) that was cycled through four times. Most participants completed the testing in 90 minutes. Time was provided for breaks throughout the testing. The instructions for the Gap Detection test can be found in Appendix G.

2.3.3.2 Procedure for the Word Identification Task in Quiet

The procedure for the word recognition task in quiet is identical to that followed in Experiment 1 from the pilot study except that in the main experiment each test was
repeated immediately following its completion and the stimuli were presented at 40 dB SL referenced to the listener’s SRT, rather than at 50 dB SL. Refer to section 2.2.4 for details. The test material was presented monaurally to the listener’s better hearing ear (as defined in section 2.3.3.1). The presentation order of the other stimulus continua was counterbalanced across the listeners in both the younger and the older subject groups with all participants always listening to the slow stimulus continuum prior to the corresponding fast stimulus continuum. The instructions read to the participant are the same as in the pilot study and can be found in Appendix G.

2.3.3.3 Procedure for the Word Identification Task in Noise

Performance on the word recognition testing in quiet determined the tokens that would later be presented in noise. Refer to section 2.3.2 for details on the selection of tokens. Testing was completed separately for each stimulus continuum and in the same order as was used for the tests in quiet. All testing was conducted separately for the fast speaking rate stimuli and the slow speaking rate stimuli with the slow stimuli always preceding the corresponding fast stimuli.

The tokens were presented to the participant in a sound-attenuating double walled IAC booth over TDH-39 headphones. The words were presented to the subject’s better hearing ear (see 2.3.3.1 for description of test ear selection) at 40 dB SL, referenced to their SRT for that ear. The instructions that were read to each participant can be found in Appendix G. Listener’s were provided with an opportunity for a break following each S:N ratio condition.
2.4 Outcomes

Detailed results and data analysis for both the pilot and main experiments are provided in Chapter 3.
3. RESULTS

3.1 Introduction

The results of this study will be presented in four sections. First, the results from the word recognition testing in quiet will be outlined followed by the results from the word recognition testing in noise. The gap detection data will then be presented followed, finally, by the correlational data.

3.2 Word Identification in Quiet

All the younger subjects were able to distinguish the word pairs in quiet; however, some older subjects were unable to distinguish the ‘slit’-‘split’, ‘soon’-‘spoon’, and ‘dish’-‘ditch’ contrasts in quiet, and especially for the fast rate (see Table 1).

Table 1. Number of Younger and Older Listeners who were able to Distinguish each Word-Pair Contrast in the Quiet Test Condition

<table>
<thead>
<tr>
<th>Word Pair Contrast</th>
<th>Younger Listeners</th>
<th>Older Listeners</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slow Rate</td>
<td>Fast Rate</td>
</tr>
<tr>
<td>‘Cash’-‘Catch’</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>‘Dish’-‘Ditch’</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>‘Slit’-‘Split’</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>‘Soon’-‘Spoon’</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

A finding common to all the continua was that, for both age groups, the word boundary occurred at longer gap durations for the slow speaking rate conditions than for

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4 Note that the maximum number of listeners in each subject group is eight.
the corresponding fast speaking rate condition. Another common pattern to all the continua, except the ‘dish’-'ditch’ fast speech rate continuum, was that, for both the slow and fast speech rates, the word boundary for the older listeners occurred at longer gap durations than for the younger listeners. Detailed data pertaining to each word-pair will be presented separately in the following sections.

3.2.1 ‘Cash’-'Catch’ Continua

Mean word identification scores and standard error measures for the ‘cash’-'catch’ slow speech rate continuum are depicted in Figure 2. As the duration of the gap increased from short to long, the listeners progressively changed their identification of the tokens from ‘cash’ to ‘catch’. This observable pattern was confirmed by analyses of variance (ANOVAs) that indicated significant main effects of gap duration on ‘cash’ and ‘catch’ responses [F(1,13)= 159.14, p<0.01 and F(1,13)= 157.39, p<0.01, respectively]. Figure 2 also indicates that the responses of the younger and older listeners differed from each other in the slow speech condition. This was corroborated by ANOVAs that indicated significant main effects of age on ‘cash’ and ‘catch’ word identification performance for this continuum [F(1,14)= 5.423, p<0.05 and F(1,14)= 5.406, p<0.05, respectively]. The factors of age and gap duration were also found to significantly interact with one another as confirmed through an ANOVA [F(1,13)= 2.95, p<0.01 and F(1,13)= 2.94, p<0.01, respectively].

Mean word identification scores and standard error measures for the ‘cash’-'catch’ fast speech rate continuum are depicted in Figure 3. For this continuum, gap duration is shown to affect word identification. At short gap durations, listeners are more
Figure 2
Mean Word Identification Scores and Standard Error Measures as a Function of Gap Duration: 'Cash'-'Catch', Slow Speaking Rate

Figure 3
Mean Word Identification Scores and Standard Error Measures as a Function of Gap Duration: 'Cash'-'Catch', Fast Speaking Rate
likely to identify the stimulus as ‘cash’, while at long gap durations, listeners are more likely to respond with ‘catch’. This pattern was confirmed for ‘cash’ and ‘catch’ responses by an ANOVA \(F(1,13)=96.00, p<0.01\) and \(F(1,13)=96.78, p<0.01\), respectively. For this continuum, Figure 3 illustrates that there is a tendency for the older listeners to require a larger gap duration before identifying the token as ‘catch’. Also, the older listeners appear to be somewhat less confident, compared to the younger listeners, in their identification of tokens as ‘catch’ at long gap durations. However, no significant main effects of age or significant age by gap duration interactions were found, through ANOVAs, for the ‘cash’-‘catch’ fast speech rate continuum \(F(1,14)=1.31, p>0.05\).

The slow and fast speaking rate conditions can be compared in Figure 4. Figure 4 depicts three key points (word boundary [50%), 80% and 20%), from the ‘cash’ portion of the word identification functions for both the slow and fast speaking rate conditions\(^5\). The 80% and 20% points were selected for study as they depict identification performance that falls well outside of the region of chance identification (which encompasses scores between 35% and 65%). In Figure 4, it is clearly shown that, for each of the key points depicted, a longer gap duration was required to reach each respective point in the slow speech rate condition compared to the fast speech rate condition. This pattern was observed for both the younger and the older listeners. ANOVAs corroborate the effect of rate on the word boundary, 80% and 20% points

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\(^5\) Given the two-alternative, forced choice task, the corresponding points from the ‘catch’ function are not plotted since they would simply be the mirror image of the points shown.
A closer examination of these functions illustrated in Figure 4 was conducted. Specifically, the word boundary (the 50% point on the identification function) and the 80% and 20% points from the ‘cash’ slow and fast speech rate word identification functions were determined to occur at a longer gap duration for the older listeners compared to the younger listeners. The pattern of age differences for the slow speech continuum, pictured in Figure 4, reached statistical significance for both the word boundary and 20% points in the slow rate condition, as confirmed by ANOVAs $[F(1,14)=0.04, p<0.05$ and $F(1,14)=0.01, p<0.05$, respectively]. Age differences for the 80% point in the slow rate continuum did not quite reach levels of statistical significance $[F(1,14)=0.06, p>0.05]$. Statistical analysis also indicated that there are no significant age differences for the word boundary, 80%, and 20% points obtained for ‘cash’ in the
fast speaking rate condition $[F(1,14)= 0.13, p>0.05, F(1,14)= 0.31, p> 0.05, \text{ and } F(1,14)= 0.90, p>0.05$, respectively].

Another age difference, apparent from Figure 4, is that the transition for the younger adults from a confident level of ‘cash’ identification (i.e., 80% or greater ‘cash’ responses) to a confident level of ‘catch’ (i.e., 80% or greater ‘catch’ responses) identification occurs over a smaller range of gap durations (29.1 ms to 44.1 ms, in the slow rate condition) compared to the older listeners (41.5 ms to 64.1 ms, in the slow rate condition). This was quantified through an examination of the slopes of the word identification functions. It was determined through ANOVA that the slope of the function derived from the older listeners differed significantly from that obtained from the younger listeners $[F(1,14)= 0.01, p<0.01]$ in the slow speech condition. The slope of the function obtained in the slow rate condition from the younger listeners is steeper (-0.25) than that obtained from the older subjects (-0.38) (see Figure 4). Statistical analysis, however, through ANOVAs, indicated that there are no significant age differences for the slopes obtained for ‘cash’ in the fast speaking rate condition $[F(1,14)= 0.14, p>0.05]$. Changes in speaking rate also do not appear to effect the slope of the identification function with this pattern being confirmed by an ANOVA $[F(1,14)= 2.3, p>0.05]$.

3.2.2 'Dish’-‘Ditch’ Continua

Mean word identification scores are graphed for the ‘dish’-‘ditch’ slow speech rate condition in Figure 5. Here it is apparent that, as the gap duration changed from short to long, the listeners progressively changed their responses from ‘dish’ to ‘ditch’.
This pattern was found to be statistically significant, as ANOVA indicated a significant main effect for gap duration on ‘dish’ and ‘ditch’ identification in the slow speech rate continuum \(F(1,13)= 95.48, p<0.01\) and \(F(1,13)= 94.63, p<0.01\), respectively. Figure 5 also suggests differences between the two age groups in their identification of the ‘dish’-‘ditch’ slow speech rate continuum. The older listeners demonstrate a lesser degree of confidence in their responses at the long gap durations. They never reach the same level of accuracy as the younger listeners do and they also exhibit more variability in their responses. While these patterns do seem clear, ANOVAs indicated that the differences between the age groups did not reach statistical significance and that there was no significant age by gap duration interaction present in the data \(F(1,13)= 2.40, p>0.05\) and \(F(1,13)= 1.15, p> 0.05\), respectively.

The word identification functions from the ‘dish’-‘ditch’ fast speaking rate condition are graphed in Figure 6. Here it is evident that gap duration influenced listener’s responses with more ‘dish’ responses occurring at short gap durations and, conversely, more ‘ditch’ responses occurring at long gap durations. As with the slow speech rate continuum, gap duration was found to significantly effect the identification of ‘dish’ and ‘ditch’ \(F(1,13)= 87.27, p<0.01\). Age also appears to affect the listener’s identification of ‘dish’ and ‘ditch’ in the fast speech condition. At the longer gap durations, the older listeners never reach the same level of confidence as the younger listeners. The older listeners also show a greater amount of variability in their responses at the longer gap durations compared to the younger listeners. Although ANOVA indicated that there were no significant main effects of age \(F(1,14)= 3.30, p>0.05\), a
Figure 5
Mean Word Identification Scores and Standard Error Measures as a Function of Gap Duration: 'Dish'-'Ditch', Slow Speaking Rate

Figure 6
Mean Word Identification Scores and Standard Error Measures as a Function of Gap Duration: 'Dish'-'Ditch', Fast Speaking Rate
significant age by gap duration interaction was evidenced for the 'dish'-'ditch' fast speech rate continuum \(F(1,13)= 2.196, p<0.05\).

The responses to the two speaking rates for the 'dish'-'ditch' continuum can be compared in Figure 7. In Figure 7, the word boundary, 80% and 20% points are plotted for both subject groups and both rate conditions. For both the younger and older listeners, the change in speaking rate from slow to fast shifted the word boundary, 80%, and 20% points to shorter gap durations. Listeners were responding with 'ditch' at shorter gap durations in the fast rate condition compared to the slow rate condition. ANOVAs corroborate this observation and indicate that rate did significantly affect the gap duration at which the word boundary and the 80% and 20% points were located \(F(1,14)= 20.82, p<0.01, F(1,14)= 24.12, p<0.01, \text{ and } F(1,14)= 46.34, p<0.01, \) respectively.
Through closer inspection of Figure 7, a trend can be observed where the older listeners require a longer gap duration to reach the word boundary and the 80% and 20% points on the word identification functions compared to the younger adults. These age differences in word boundary, 80% and 20% points did not, however, reach statistical significance for the slow speech condition as indicated by ANOVAs $[F(1,14)= 0.17, \ p>0.05, \ F(1,14)= 0.57, \ p>0.05, \ \text{and} \ F(1,14)= 0.17, \ p>0.05, \ \text{respectively}].$ Performance in the fast speech rate condition differs somewhat from the slow rate condition. First, the word boundary is essentially the same across age groups for the fast speech rate condition. Second, the pattern for the 80% and 20% points is not consistent, with the older adults requiring a longer gap duration to reach the 20% point, but a shorter gap duration to reach the 80% point. For the fast rate condition, no significant age differences were found for the word boundary, 80%, or 20% points $[F(1,14)= 0.85, \ p>0.05, \ F(1,14)= 0.39, \ p>0.05, \ \text{and} \ F(1,14)= 0.14, \ p>0.05, \ \text{respectively}].$

Figure 7 further illustrates that, in both rate conditions, the transition for the older listeners from confident 'dish' responding (i.e., 80% or greater 'dish' responses) to confident 'ditch' responding (i.e., 80% or greater 'ditch' responses) took place over a larger range of gap durations (45.3 ms to 90.0 ms, in the slow rate condition) compared to the younger listeners (41.7 ms to 61.6 ms, in the slow rate condition). These trends, however, did not reach statistical significance in the slow rate condition, as ANOVAs indicated that the slope of the identification functions did not differ significantly across the two age groups $[F(1,14)= 0.18, \ p>0.05].$ A significant effect of age on function slope was noted, though, for the fast speech rate condition $[F(1,14)=0.01, \ p<0.01].$ A significant age by rate interaction was also indicated by an ANOVA $[F(1,12)= 5.0,$
Changes in speaking rate, however, do not appear to effect the slope of the identification function with this observation being confirmed by an ANOVA \( F(1,12) = 1.087, p > 0.05 \).

### 3.2.3 ‘Slit’-‘Split’ Continua

Mean word identification functions derived from the ‘slit’-‘split’ slow speech rate continuum are presented in Figure 8. As the duration of the inserted gap increased from short to long, the mean responses of the listeners changed from ‘slit’ to ‘split’. This pattern was found to reach statistical significance; ANOVA indicated that gap duration was found to effect the identification of ‘slit’ and ‘split’ in the slow speaking rate condition \( F(1,13) = 120.56, p < 0.01 \). In addition to age affecting word identification performance, age also appears to affect responses to the ‘slit’-‘split’ slow speaking rate continuum. The older adults do not exhibit the same level of confidence in their ‘split’ responses at the long gap durations compared to the younger adults. There is also more variability in the mean responses from the older adults compared to the younger adults. Recall that one older adult failed to reliably distinguish ‘slit’-‘split’ in the slow rate condition. While patterns of age differences seem to be apparent in Figure 8, analyses of variance indicated that there are no significant main effects of age or an age by gap duration interaction for the ‘slit’-‘split’ slow speech rate continua \( F(1,14) = 4.41, p > 0.05 \) and \( F(1,13) = 1.70, p > 0.05 \), respectively.

The word identification functions obtained from the responses to the ‘slit’-‘split’ fast speech rate continuum are presented in Figure 9. As the duration of the gap increases from short to long, the responses of the listeners progressively change from a majority of
Figure 8
Mean Word Identification Scores and Standard Error Measures as a Function of Gap Duration: 'Slit'-'Split', Slow Speaking Rate

Figure 9
Mean Word Identification Scores and Standard Error Measures as a Function of Gap Duration: 'Slit'-'Split', Fast Speaking Rate
'slit' responses to a majority of 'split' responses. This pattern of findings was confirmed through ANOVAs that indicated gap duration significantly affected 'slit' and 'split' identification \([F(1,13)= 51.46, p<0.01]\). As with the slow rate continuum, the younger and older adults show different patterns of responses to the 'slit'-'split' fast speech rate continuum. Most notably, the mean responses of the older adults indicate a fair amount of listener uncertainty at the short gap durations where identification of tokens as 'slit' does not even reach 80% of the responses in the context where no gap is inserted (gap duration= 0). For this fast rate condition, three older adults were unable to reliably distinguish the word-pair. Again, as with the slow speaking rate continuum, age was determined to not statistically effect 'slit' and 'split' identification in the fast speech rate condition \([F(1,1)= 0.00, p>0.05]\). There was, however, a significant age by gap duration interaction for the identification of the fast 'slit' and 'split' tokens \([F(1,13)= 4.76, p<0.01]\).

Performance across the two speech rate conditions can be compared in Figure 10. The word boundary (50%) and the 80%, and 20% points from the slow and fast 'slit' identification functions are plotted in this figure. The plotted slow rate identification data omits the responses from one older listener who was unable to reliably distinguish the 'slit'-'split' word pair. Also, the word boundary, 80%, and 20% points plotted for the older listeners in the fast rate condition, do not include the data from three, two, and two listeners, respectively, whose word identification performance did not approximate these points.

As speaking rate is changed from slow to fast it is clear that each of the key points plotted in Figure 10 shifts to a smaller gap duration. This pattern is consistent across the
younger and older listeners. In the context of a faster speech rate, a shorter silent interval is able to cue 'split', while a longer gap duration is required in the slow rate condition before identification responses shift from 'slit' to 'split'. ANOVAs support the observation that rate significantly affects the location of the word boundary and the 80% and 20% points on the identification function \( F(1,12) = 35.475, p < 0.01, F(1,10) = 31.90, p < 0.01, \) and \( F(1,12) = 13.469, p < 0.01, \) respectively.

It is clear from Figure 10 that the older adults, who were able to distinguish 'slit'- 'split', required a longer gap duration to reach the word boundary, and the 80%, and 20% points compared to the younger adults, in both speech rate conditions. The word boundary and 20% points in the slow rate condition were determined by ANOVAs to not differ significantly across the two age groups \( F(1,13) = 0.17, p > 0.05 \) and \( F(1,13) = 0.28, p > 0.05, \) respectively. Analysis of variance did indicate, however, that the 80% point on
the 'slit' slow rate identification function differed significantly between the two age
groups [F(1,13)= 0.01, p≤0.01]. For the fast rate condition, analyses of variance indicated
that the word boundary and 80% points from the older listeners’ ‘slit’ identification
function differed significantly from the corresponding points obtained from the younger
listeners [F(1,12)= 0.03, p<0.05 and F(1,10)= 0.02, p<0.05]. There was no effect of age
for the 20% point on the identification functions in the fast rate [F(1,12)= 0.14, p>0.05].

Figure 10 also allows for an inspection of the slope of the identification functions.
The slopes of the slow speech rate functions appear to be fairly similar across the
younger and older subject groups and ANOVA indicated no significant age effect on this
measure [F(1,13)= 0.61, p>0.05]. The slopes of fast speech rate functions obtained from
the younger and older listeners also appear comparable and again ANOVAs indicated
that there was no significant effect of age on this measure [F(1,10)= 0.65, p>0.05]. The
transition for the young adults from a confident level of ‘cash’ identification (i.e., 80% or
greater ‘cash’ responses) to a confident level of ‘catch’ (i.e., 80% or greater ‘catch’
responses) identification responses occurs over a similar range of gap durations (29.9 ms
to 46.6 ms, in the slow rate condition) compared to the older listeners (31.0 ms to 52.5
ms, in the slow rate condition). The slopes of the functions also appear insensitive to
changes in speaking rate with this observation being corroborated by an ANOVA
[F(1,10)= 0.00, p>0.05].

3.2.4 ‘Soon’-‘Spoon’ Continua

The word identification functions obtained from the responses of the listeners to
the ‘soon’-‘spoon’ slow speech continuum are plotted in Figure 11. As with the other word-pairs, as the gap duration increased, the word identification responses shifted from a majority of ‘soon’ responses to a majority of ‘spoon’ responses. Gap duration was determined through ANOVAs to have a significant effect on ‘soon’ and ‘spoon’ identification \( [F(1,13)= 400.44, p<0.01] \). Age also appears to have an effect on the listener’s responses to the slow rate ‘soon’-‘spoon’ continuum. The older listeners exhibited a high level of variability at the long gap durations and did not reach the same level of confidence in their ‘spoon’ responses as exhibited by the younger listeners. However, no significant main effect was found for age on ‘soon’ and ‘spoon’ identification in the slow speaking rate \( [F(1,14)= 3.56, p>0.05] \). A significant interaction was found, though, between age and gap duration for ‘soon’ and ‘spoon’ in the slow speech condition \( [F(1,13)= 2.34, p<0.05] \).

The word identification functions derived from the responses to the ‘soon’-‘spoon’ fast speech rate continuum are plotted in Figure 12. As with all the other speech continua, gap duration was found to significantly affect ‘soon’ and ‘spoon’ identification in the fast speaking rate condition \( [F(1,13)= 43.49, p<0.01 \text{ and } F(1,13)= 43.43, p< 0.01] \). Figure 12 also shows that, at both extremes of the continuum, the older listeners did not reach the same level of response confidence as evidenced by the younger listeners. The responses of the older subjects are characterized by greater variability, particularly at the long gap durations. Analyses of variance indicated that there was no significant main effect of age on ‘soon’ and ‘spoon’ identification in the fast rate condition \( [F(1,14)= 3.54, p>0.05] \). A significant age by gap duration effect was, however, indicated through
Figure 11
Mean Word Identification Scores and Standard Error Measures as a Function of Gap Duration: 'Soon'-'Spoon', Slow Speaking Rate

Figure 12
Mean Word Identification Scores and Standard Error Measures as a Function of Gap Duration: 'Soon'-'Spoon', Fast Speaking Rate
ANOVA for ‘soon’ and ‘spoon’ identification \( [F(1,13)= 3.42, p<0.01 \text{ and } F(1,13)= 3.31, p<0.01] \).

The word boundary (50%) and the 80% and 20% points from the fast and slow speech rate ‘soon’ identification functions are graphed together in Figure 13. The data for the slow rate condition excluded the responses from two older listeners who were unable to distinguish the word-pair. Note also that data was omitted from four older subjects at the 80% point, two older subjects at the word boundary, and two older subjects at the 20% point. These data were omitted because the listeners did not approximate the respective key point. Comparing the performance in the slow rate condition with the responses in the fast rate condition, it can be seen that, as the rate of speech increases from slow to fast, a shorter gap duration is required to reach the word boundary, 80%, and 20% points on the identification functions. This pattern was consistent across both the younger and older listeners. As with the other word-pairs, ANOVAs again indicate significant effects of rate on the location of the word boundary and the 80% and 20% points on the identification functions \( [F(1,11)= 8.90, p<0.05, F(1,9)= 10.41, p<0.05, \text{ and } F(1,11)= 12.09, p<0.01, \text{ respectively}] \).

Differences in the responses across the two age groups can also be observed in Figure 13. Specifically, the word boundary, 80%, and 20% points occurred at a longer gap duration for the older listeners compared to the younger listeners in both speech rate conditions. Analyses of variance, however, indicated that the word boundary, 80%, and 20% points did not differ significantly across the younger and older listeners in the slow speech rate condition \( [F(1,12)= 0.17, p>0.05, F(1,12)= 0.27, p>0.05, \text{ and } F(1,12)= 0.26, p>0.05, \text{ respectively}] \). Also, no significant effects of age were found for the word
boundary, 80%, and 20% points in the fast speech rate condition \( [F(1,12) = 0.20, p > 0.05, F(1,10) = 0.41, p > 0.05, \text{ and } F(1,12) = 0.07, p > 0.05, \text{ respectively}] \). The slopes of the slow and fast speech rate functions in Figure 13 appear to be similar across the two age groups. Consistent with this visual observation, in both rate conditions, the slope was determined to not differ significantly across the two age groups \( [F(1,13) = 0.60, p > 0.05 \text{ and } F(1,10) = 0.65, p > 0.05, \text{ respectively}] \). The transition for the young adults from a confident level of ‘cash’ identification (i.e., 80% or greater ‘cash’ responses) to a confident level of ‘catch’ (i.e., 80% or greater ‘catch’ responses) identification responses occurs over a similar range of gap durations (26.4 ms to 44.9 ms, in the slow rate condition) compared to the older listeners (33.7 ms to 58.0 ms, in the slow rate condition). The slope of the functions also seems to be relatively insensitive to changes in rate as ANOVA indicates no significant effect of rate on this measure \( [F(1,9) = 0.00, p > 0.05] \).
3.2.5 Summary of Word Identification Performance in Quiet

The results presented in the above sections will be summarized across word-pairs in this section. First, the effects of gap duration and age, as well any age by gap interactions will summarized. These results are outlined in Table 2. For all the word-pairs and across both the slow and fast speech rate conditions, gap duration was determined to significantly influence the listeners' word identification responses. Age, on the other hand, was only determined to significantly effect the identification of 'cash'-'catch' in the slow speech rate condition. An age by gap combined effect was found for a majority of the conditions: 'cash'-'catch', slow speaking rate, 'dish'-'ditch', fast speaking rate, 'slit'-'split', fast speaking rate, and 'soon'-'spoon', slow and fast speech rates.

Table 2. Effects of Gap Duration, Age, and Age by Gap Interactions on Word Identification Performance in Quiet

<table>
<thead>
<tr>
<th>Rate</th>
<th>Gap Duration</th>
<th>Age</th>
<th>Age by Gap Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slow</td>
<td>Fast</td>
<td>Slow</td>
</tr>
<tr>
<td>'Cash'-'Catch'</td>
<td>* p&lt;0.01</td>
<td>* p&lt;0.01</td>
<td>* p&lt;0.05</td>
</tr>
<tr>
<td>'Dish'-'Ditch'</td>
<td>* p&lt;0.01</td>
<td>* p&lt;0.01</td>
<td>NS</td>
</tr>
<tr>
<td>'Slit'-'Split'</td>
<td>* p&lt;0.01</td>
<td>* p&lt;0.01</td>
<td>NS</td>
</tr>
<tr>
<td>'Soon'-'Spoon'</td>
<td>* p&lt;0.01</td>
<td>* p&lt;0.01</td>
<td>NS</td>
</tr>
</tbody>
</table>

Note: Significant results are noted with an asterisk (*) and the level of significance. Non-significant results are denoted with the letters NS.

The effects of speaking rate are summarized in Table 3. The effect of rate was strong and consistent across all the word-pairs with effects on the location of the word boundary (50%) and the 80% and 20% points on the word identification function. Rate did not, however, significantly effect the slope of any of the identification functions.
Table 3. The Effect of Rate on the 50%, 80%, and 20% Points and the Slope of the Word Identification Function

<table>
<thead>
<tr>
<th></th>
<th>50%</th>
<th>80%</th>
<th>20%</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Cash’-’Catch’</td>
<td>* p&lt;0.01</td>
<td>* p&lt;0.01</td>
<td>* p&lt;0.01</td>
<td>NS</td>
</tr>
<tr>
<td>‘Dish’-’Ditch’</td>
<td>* p&lt;0.01</td>
<td>* p&lt;0.01</td>
<td>* p&lt;0.01</td>
<td>NS</td>
</tr>
<tr>
<td>‘Slit’-’Split’</td>
<td>* p&lt;0.01</td>
<td>* p&lt;0.01</td>
<td>* p&lt;0.01</td>
<td>NS</td>
</tr>
<tr>
<td>‘Soon’-’Spoon’</td>
<td>* p&lt;0.05</td>
<td>* p&lt;0.05</td>
<td>* p&lt;0.01</td>
<td>NS</td>
</tr>
</tbody>
</table>

Note: Significant results are marked with an asterisk (*) and the level of significance. Non-significant results are denoted with the letters NS.

Table 4. The Effect of Age on the 50%, 80%, and 20% Points and the Slope of the Word Identification Functions

<table>
<thead>
<tr>
<th></th>
<th>50%</th>
<th>80%</th>
<th>20%</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slow</td>
<td>Fast</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>‘Cash’-’Catch’</td>
<td>* p&lt;0.05</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>‘Dish’-’Ditch’</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>‘Slit’-’Split’</td>
<td>NS</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>‘Soon’-’Spoon’</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Note: Significant results are marked with an asterisk (*) and the level of significance. Non-Significant results are denoted with the letters NS.

The effects of age on the word boundary, 80%, and 20% points, as well as on function slope are summarized in Table 4. Age by rate interactions occurring in these measures are summarized in Table 5. In a majority of instances age does not
significantly effect these measures. Significant effects of age were relatively consistent in the 'cash'-'catch' slow speech rate continuum and also in the 'slit'-'split' fast speech rate condition. The 'soon'-'spoon' slow and fast rate continuums appear to be relatively insensitive to age, but it must be noted that data from several of the older listeners were omitted as they could not approximate the measures (see section 3.2.4 for details).

Table 5. Age by Rate Interactions on the 50%, 80% and 20% Points and the Slope of the Word Identification Functions

<table>
<thead>
<tr>
<th></th>
<th>50%</th>
<th>80%</th>
<th>20%</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Cash'-'Catch'</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>'Dish'-'Ditch'</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>* p&lt;0.05</td>
</tr>
<tr>
<td>'Slit'-'Split'</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>'Soon'-'Spoon'</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Note: Significant results are marked with an asterisk (*) and the level of significance. Non-Significant results are denoted with the letters NS.

3.3 Word Identification in Noise

First, some general trends in the data will be presented and then each word pair contrast will be discussed in detail. Two tokens were identified from each word pair continuum for further assessment in noise. These tokens were selected based on each individual listener's performance in quiet; therefore, the selected tokens had different gap values depending on the performance of the listener, but they were equalized for difficulty. The token with the largest gap duration that was identified at least 80% of the time as being the member of the word-pair without the stop consonant was selected for testing in noise. The token with the shortest gap duration that was identified at least 80%
of the time as being the member of the word-pair with the stop consonant was selected as the other token to test in noise.

For all the word pair contrasts, the addition of noise had a more adverse effect on word identification in the fast speech conditions than in the slow speech conditions. Specifically, word identification tended to decline more for the member of the pair with the stop consonant. Age effects were not apparent for the ‘cash’-‘catch’ and ‘dish’-‘ditch’ pairs, but the older subjects performed more poorly than the younger subjects on the ‘slit’-‘split’ and ‘soon’-‘spoon’ word pairs, especially at the fast rate. Subjects who had failed to distinguish the word-pairs in quiet did not participate in the word identification in noise test for the undistinguished pairs.

3.3.1 ‘Cash’-‘Catch’ Continua

All the younger and older listeners reached the criterion level of performance in quiet that was required for subsequent testing in noise. The younger and older listeners performed similarly on ‘cash’-‘catch’ identification across the three noise levels tested (+10, -5, and -15 dB S:N) and for both the slow and fast speaking rates. ANOVAs corroborate the observation that age does not appear to affect identification of either ‘cash’ or ‘catch’ in noise, for both the slow and fast speaking rate conditions \([F(1,14)=0.00, p>0.05, F(1,14)=0.03, p>0.05, F(1,14)=0.23, p>0.05, \text{and } F(1,14)=0.04, p>0.05, \text{respectively}]\). Word identification as a function of noise level for the slow speech rate tokens is presented in Figure 14 and performance on the fast speech rate tokens is presented in Figure 15. The younger and older listeners maintained above chance levels of identification of the ‘cash’ token across all the noise levels. Identification of the
Figure 14
Mean Word Identification Scores and Standard Error Measures as a Function of Noise Level: 'Cash'-'Catch', Slow Speaking Rate

Figure 15
Mean Word Identification Scores and Standard Error Measures as a Function of Noise Level: 'Cash'-'Catch', Fast Speaking Rate
'catch' token, however, remained above chance for both subject groups at +10 dB S:N, but fell to chance levels and poorer at -5 and -15 dB S:N. Word identification performance declined at a faster rate for both the younger and older listeners for the fast speech rate tokens compared to the slow speech rate tokens. Consistent with these observations, no significant effects of S:N ratio were found for 'cash' identification in the slow and fast speech rate conditions $[F(3,42)= 1.76, p>0.05$ and $F(3,42)= 0.70, p>0.05]$. S:N was, however, determined by ANOVAs to significantly affect 'catch' identification in both the slow and fast speech rate conditions $[F(3,42)= 39.04, p<0.01$ and $F(3,42)= 48.28, p>0.01]$. Significant age by S:N interactions were, however, not found for either 'cash' or 'catch' identification in either the slow or fast speech rate conditions $[F(3,42)= 0.145, p>0.05, F(3,42)= 0.65, p>0.05, F(3,42)= 0.53, p>0.05, and F(3,42)= 0.11, p>0.05$, respectively].

3.3.2 'Dish'-'Ditch' Continua

All of the listeners were tested on 'dish'-'ditch', slow and fast speech rate, in noise. One of the older listeners, however, only reached a criterion level of performance on the 'dish' member of the word pair, but did not quite reach a criterion level of identification on the 'ditch' member of the word pair in both speech rate conditions. This listener was still tested in noise as the token with the largest gap duration at both speech rates was chosen to represent 'ditch'. The responses for this listener closely patterned the responses of the other members of his subject group for the fast speech condition, but not in the slow speech condition. The subject correctly identified the token meeting the proper criterion for 'dish' at below chance levels across all the noise levels, while
maintaining a highly accurate identification of the token assigned to represent the ‘ditch’
member of the word pair. This response pattern is unexpected given that the listener
could not reach an 80% level of ‘ditch’ response to any token in quiet. Since the listener
was able to accurately identify ‘ditch’, the listener’s data was included with the others in
his group for further analysis.

Word identification as a function of noise for the slow speech tokens is plotted in
Figure 16. The younger adults are able to maintain above chance levels of identification
of ‘dish’ across the three noise levels. The older listeners maintain a comparable level of
identification until the poorest S:N ratio condition where their identification of ‘dish’
falls below chance. Both the younger and older adults are more adversely effected by the
noise in their identification of ‘ditch’. They maintain above chance levels of
identification at +10 dB S:N but fall below chance in their identification of ‘ditch’ at -5
and -15 dB S:N. ANOVA indicate that there is no significant effect of age on the
identification of either ‘dish’ or ‘ditch’ in the slow speech rate condition [F(1,14)= 0.88,
p>0.05 and F(1,14)= 0.15, p>0.05, respectively]. Consistent with the above observation,
though, ANOVAs do indicate a significant effect of S:N on ‘dish’ and ‘ditch’
identification in the slow speaking rate condition [F(3,42)= 4.22, p<0.05 and F(3,42)=
15.32, p<0.01, respectively]. Significant age by S:N interactions, however, were not
revealed by ANOVAs [F(3,42)= 1.35, p>0.05 and F(3,42)= 1.31, p>0.05, respectively].

Word identification as a function of noise level for ‘dish’ and ‘ditch’ fast speaking
rate tokens are plotted in Figure 17. Both the younger and older listeners continue to
identify ‘dish’ at above chance levels of performance at all the noise levels. Again,
identification of ‘ditch’ is affected to a greater extent by increasing background noise.
Figure 16
Mean Word Identification Scores and Standard Error Measures as a Function of Noise Level: 'Dish'-'Ditch', Slow Speaking Rate

% Response

Signal to Noise (dB)

Figure 17
Mean Word Identification Scores and Standard Error Measures as a Function of Noise Level: 'Dish'-'Ditch', Fast Speaking Rate

% Correct

Signal to Noise (dB)
The younger adults approach chance levels of identification at -5 dB S:N and are performing at chance in the -15 dB S:N condition. The older listeners are slightly better in their identification of ‘ditch’ at -5 dB S:N, but fall to a similar level of performance as the younger listeners at -15 dB S:N. The similarities between the younger and older adults on their identification of ‘dish’ and ‘ditch’ in noise is corroborated by ANOVAs that indicate no significant effect of age in this condition [F(1,14)= 2.64, p>0.05 and F(1,14)= 0.42, p>0.05, respectively. S:N ratio was, however, determined to significantly affect ‘dish’ and ‘ditch’ identification in noise [F(3,42)= 6.68, p<0.01 and F(3,42)= 48.19, p<0.01, respectively]. Differences between ‘dish’ and ‘ditch’ identification in noise were noted as a significant interaction between age and S:N was noted for ‘dish’ identification but not for ‘ditch’ identification [F(3,42)= 3.64, p<0.05 and F(3,42)= 1.06, p>0.05, respectively].

3.3.3 ‘Slit’-‘Split’ Continua

One older listener did not reach criterion levels of performance for the ‘slit’-‘split’ slow speaking rate continuum in quiet and was therefore not tested on that continuum in noise. Three older subjects did not reach criterion levels of performance for the fast speech rate continuum in quiet and were not tested on that continuum in noise. All the younger listeners reached criterion levels of performance in quiet and were further assessed in noise.

Mean word identification scores as a function of noise for the ‘slit’-‘split’ slow speech rate tokens are plotted in Figure 18. As the level of the background noise increases the younger listener’s identification of ‘slit’ progressively declines and falls
below chance levels of performance at -15 dB S:N. The older adults maintain above chance levels of 'slit' identification across all the noise levels. The older adults, however, performed at chance levels for 'split' identification at all three noise levels. The younger adults were able to identify 'split' at better than chance levels of performance at +10 and -5 dB S:N and just barely fell to chance levels of identification at -15 dB S:N. The older listeners also exhibited a greater amount of response variability, compared to the younger listeners, in the 'split' identification responses. While there appears to be a trend for the two age groups to respond differently to 'slit' and 'split' in noise, ANOVAs indicate no significant effect of age for these words in the slow speaking rate condition \([F(1,13)= 1.34, p>0.05 \text{ and } F(1,13)= 4.38, p>0.05, \text{ respectively}]\). S:N, however, was determined to significantly effect the identification of 'slit' and 'split' in the slow rate condition \([F(3,39)= 20.30, p<0.01 \text{ and } F(3,39)= 8.47, p<0.01, \text{ respectively}]\). A significant age by S:N interaction for the slow rate condition was revealed for 'slit' identification in noise but not for 'split' identification \([F(3,39)= 3.81, p<0.05 \text{ and } F(3,39)= 2.53, p>0.05, \text{ respectively}]\).

The mean word identification scores and standard error measures for the 'slit' and 'split' fast speech rate tokens are presented in Figure 19. The responses to these tokens follow the same pattern as the responses to the slow speech tokens. The older listeners continue to respond to 'slit' at above chance levels of performance at all the noise levels. The younger listeners maintain strong identification of 'slit' at +10 and -5 dB S:N level, but fall to below chance levels of performance at -15 dB S:N level. Across the three noise levels, the older listeners exhibit poor and variable identification of 'split'. The younger adults are able to maintain above chance levels of performance at +10 dB S:N
Figure 18:
Mean Word Identification Scores and Standard Error Measures as a Function of Noise Level: 'Slit'-'Split', Slow Speaking Rate

Figure 19:
Mean Word Identification Scores and Standard Error Measures as a Function of Noise Level: 'Slit'-'Split', Fast Speaking Rate
level but fall to below chance at the other more adverse noise levels. ANOVAs indicate that age did significantly effect the identification of ‘split’ but not ‘slit’ in the fast speaking rate condition \( F(1,11) = 6.69, p<0.05 \) and \( F(1,11) = 0.22, p>0.05 \), respectively. S:N, however, was determined to affect both ‘slit’ and ‘split’ identification in the fast rate condition \( F(3,33) = 12.74, p<0.01 \) and \( F(3,33) = 26.75, p<0.01 \), respectively.

Furthermore, significant age by S:N interactions were obtained for both ‘slit’ and ‘split’ in the fast rate condition \( F(3,33) = 3.37, p<0.05 \) and \( F(3,33) = 3.50, p<0.05 \), respectively.

Comparing the two speaking rates on ‘slit’ and ‘split’ identification in noise, the older listeners show considerably poorer levels of ‘split’ identification for the fast speech rate tokens. The younger listeners also perform poorer on ‘split’ identification in the fast speech rate condition.

3.3.4 ‘Soon’-‘Spoon’ Continua

Each of the younger listeners reached criterion levels of performance in quiet for both speech rates and were accordingly tested in noise. Three of the older listeners did not reach criterion levels of performance in quiet for the slow speaking rate tokens and they were not tested further on that continuum in noise. For the fast speech rate tokens, three older listeners also did not reach criterion levels of performance in quiet and were not assessed further on that continuum in noise.

Mean word identification performance as a function of noise level for the ‘soon’-‘spoon’ slow speech rate condition is plotted in Figure 20. The corresponding plots for the fast speaking rate are presented in Figure 21. The same general pattern of results is evident in both speech rate conditions. Both the younger and older listeners maintain
Figure 20
Mean Word Identification Scores and Standard Error Measures as a Function of Noise Level: 'Soon'-'Spoon', Slow Speaking Rate

Figure 21
Mean Word Identification Scores and Standard Error Measures as a Function of Noise Level: 'Soon'-'Spoon', Fast Speaking Rate
above chance levels of identification performance on the ‘soon’ tokens at all the noise levels tested in both speech rate conditions. The listener’s identification of ‘spoon’ is not as robust in the context of competing noise. The older listeners are unable to identify ‘spoon’ at above chance levels of performance at any of the noise levels. The younger listeners are able to maintain better than chance levels of ‘spoon’ identification at the two more favorable noise levels, but fall to chance levels of performance in the -15 dB S:N level condition. Comparing the two speech rate conditions, it is apparent that word identification of ‘spoon’ declines to lower levels of performance in the fast speech rate condition compared to the slow speech rate condition. ANOVAs indicate that age had a significant effect on ‘spoon’ identification in the slow and fast rate conditions but not on ‘soon’ identification in the same respective conditions $[F(1, 11) = 5.37, p < 0.05, F(1, 11) = 4.70, p < 0.05, F(1, 11) = 0.15, p > 0.05, and F(1, 11) = 0.40, p > 0.05, respectively]$. S:N ratio was determined through ANOVAs to significantly effect the identification of ‘spoon’ in the slow and fast rate conditions as well as the identification of ‘soon’ in the slow rate condition but not ‘soon’ identification in the fast rate condition $[F(3, 33) = 6.97, p < 0.01, F(3, 33) = 9.50, p < 0.01, F(3, 33) = 3.65, p < 0.05$ and $F(3, 33) = 1.83, p > 0.05, respectively]$. ANOVAs further indicated that age and S:N interacted significantly in the identification of ‘soon’ and ‘spoon’ in the slow rate condition but not in the fast rate condition $[F(3, 33) = 3.07, p < 0.05, F(3, 33) = 3.15, p < 0.05, F(3, 33) = 1.40, p > 0.05, and F(3, 33) = 1.96, p > 0.05, respectively]$. 

3.3.5 Summary of Word Identification Performance in Noise

A summary of the significant findings from the word identification testing in
noise is provided in Table 6. The most consistent significant pattern of results that was revealed from the word identification testing in noise was the effect of S:N on performance. It was expected that identification performance would become poorer as the level of the background noise increased. In the instances where age was determined to significantly effect word identification performance, the word affected was always the member of the word-pair continuum that contained the gap (e.g., 'spoon').

Table 6. Summary of Findings from the Word Identification Testing in Noise

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>S:N</th>
<th>Age by S:N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slow Rate</td>
<td>Fast Rate</td>
<td>Slow Rate</td>
</tr>
<tr>
<td>‘Cash’</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>‘Catch’</td>
<td>NS</td>
<td>NS</td>
<td>* p&lt;0.01</td>
</tr>
<tr>
<td>‘Dish’</td>
<td>NS</td>
<td>NS</td>
<td>* p&lt;0.05</td>
</tr>
<tr>
<td>‘Ditch’</td>
<td>NS</td>
<td>NS</td>
<td>* p&lt;0.01</td>
</tr>
<tr>
<td>‘Slit’</td>
<td>NS</td>
<td>NS</td>
<td>* p&lt;0.01</td>
</tr>
<tr>
<td>‘Split’</td>
<td>NS</td>
<td>* p&lt;0.05</td>
<td>* p&lt;0.01</td>
</tr>
<tr>
<td>‘Soon’</td>
<td>NS</td>
<td>NS</td>
<td>* p&lt;0.05</td>
</tr>
<tr>
<td>‘Spoon’</td>
<td>* p&lt;0.05</td>
<td>* p&lt;0.01</td>
<td>* p&lt;0.01</td>
</tr>
</tbody>
</table>

Note: Significant results are marked with an asterisk (*) and the level of significance. Non-Significant results are denoted with the letters NS.

3.4 Gap Detection

All eight younger and eight older listeners completed the gap detection testing. All the listeners, but one, listened to the gap detection materials presented at 90 dB SPL in a background of broadband noise presented at 85 dB SPL. One younger listener reported that these levels of presentation were uncomfortable. The level of the gap detection materials and the broadband noise were lowered by 10 dB and the listener was
able to comfortably complete the testing at these levels. Previous findings indicate that gap detection thresholds, assessed with materials similar to those used in this study, are fairly stable once the level of presentation exceeds 20 dB SL (e.g. Schneider, 1998). The data from this one listener patterned closely to the data obtained from the other younger listeners as was expected. This listener’s data were included in all analyses of gap detection ability.

Figure 22
Mean Gap Detection Thresholds and Standard Error Measures as a Function of Marker Duration

Gap detection thresholds as a function of marker duration are presented in Figure 22. The results of this study replicate prior findings by Schneider and his colleagues (Schneider & Hamstra, 1999; Schneider et al., 1994). Age differences in gap detection ability are apparent at the shorter marker durations (0.83, 5, and 10 ms). The mean gap detection thresholds of the older listeners occur at longer gap durations compared to the
younger listeners. There is also considerably more variability in the mean thresholds obtained from the older listeners, especially at the short marker durations. Statistical analyses indicated that, at the two shortest marker durations (0.83 and 5 ms), the mean gap detection thresholds of the older listeners (mean= 7.40 ms and 6.07 ms, respectively) differed significantly from those of the younger listeners (mean= 2.94 ms and 2.23 ms, respectively). This finding was confirmed by an ANOVA \( F(1,4) = 2.99, p<0.05 \) and a Student-Newman-Keuls test \( p<0.01 \).

The performance of the old and younger listeners at the two longest marker durations tested (80 and 400 ms) are very similar and, along with performance at the 10 ms marker duration, no significant age differences were found. The variability of the older listener’s responses at the two longest marker durations is considerably less compared to their performance at the shorter marker durations. There is little variability present in the mean responses of the younger listeners across all marker durations assessed.

3.5 Correlations

Overall, there was no clear pattern of correlations between audiometric thresholds and gap detection thresholds, consistent with the results of Schneider and his colleagues (Schneider & Hamstra, 1999; Schneider et al., 1994). Neither was there any clear pattern of correlations between the audiometric thresholds or the gap detection thresholds and word identification measures. For the word identification testing in quiet, 224 correlations were calculated for each age group. Only 16 correlations reached significance for the older listener group and 6 correlations reached significance for the
younger listener group. For the word identification testing in noise, 1,008 correlations were calculated for the younger listeners and only 26 reached significance. For the older listeners, 576 correlations were calculated for the word identification testing in noise and only 12 reached significance. The absence of clear patterns of significant correlations is not surprising given the small number of subjects in each age group. A list of the significant correlations is provided in Appendix J.
4. Discussion

4.1 Introduction

This present study was designed to study the speech perception difficulties experienced by a subset of normal-hearing older listeners. Specifically, word identification was examined in the context of slow and fast speech and in quiet as well as increasing amounts of background noise. Gap detection thresholds were also obtained from the listeners as the duration of the gap-defining markers varied. The results were examined for effects of age, rate/duration, and background noise. Gap detection performance was also correlated with the speech perception measures in an effort to explore any potential relationships between this psychoacoustic ability and the identification of spoken language. The results of this study are detailed in chapter 3 and will be discussed below. The data will be discussed as they relate to the hypotheses outlined in section 1.7.

4.2 Temporal Resolution Ability

The data obtained in this study support the rejection of Null Hypothesis #1, outlined in section 1.7. This hypothesis predicted that the older listeners would not differ from the younger listeners in their temporal resolution ability. Gap detection thresholds were obtained, as an index of temporal resolution ability, from both younger and older adults with normal audiograms and it was determined that the older listeners had poorer gap detection abilities compared to the younger listeners. The finding of poorer gap detection ability in the older listeners was dependent on the duration of the gap-defining markers. Gap detection ability was determined to be statistically poorer for the older
listeners at the short marker durations (0.83 ms and 5 ms), but not at the longer marker
durations (10 ms, 80 ms, and 400 ms).

Gap detection ability was determined to be uncorrelated with pure-tone hearing
thresholds, such that the second null hypothesis, presented in section 1.7, could not be
rejected. This finding supports the position that auditory processing abilities, beyond
those assessed by hearing thresholds, contribute to the ability of the auditory system to
resolve transient acoustic events over time. A discussion, as to what specific auditory
processing ability may be implicated in this relationship, can be found in section 4.5.

The data obtained in this study, regarding the gap detection ability in younger and
older listeners, is consistent with the work of Schneider and his colleagues (Schneider &
Hamstra, 1999; Schneider et al., 1994). A convincing base of evidence is accumulating
indicating that at least a subset of older listeners, with no clinically significant hearing
loss, are impaired, relative to younger listeners, in their ability to resolve transient
acoustic events.

4.3 Word Identification Ability in Quiet

4.3.1 Age Differences

The two age groups differed from one another in many respects on their word
identification performance in quiet. The data, gathered from this study, supports the
rejection of Null Hypothesis #4 outlined in section 1.7. Visual inspection of the data
indicated that there was a consistent trend for the characteristics of the word
identification functions, word boundary and slope, to differ across the two subject groups. These trends will be elaborated below.

The word boundary tended to occur at a longer gap duration for the older listeners relative the younger listeners. This pattern unexpectedly occurred in both the slow and fast speaking rate conditions. It was hypothesized that the word boundary would not differ across the subject groups in the slow speech condition, but that differences would emerge once the rate of speech was increased. The data, however, indicate that older listeners required a longer silent interval duration prior to perceiving a stop consonant regardless of the rate of speech, although they did not attain the same level of accuracy in the fast rate condition. This pattern reached statistical significance for the 'cash'-‘catch’ slow speech rate continuum and the ‘slit’-‘split’ fast speech rate continuum.

Also, the slope of the word identification functions tended to be less steep in the data obtained from the older listeners compared to the data obtained from the younger listeners. This finding reached statistical levels of significance for only the ‘cash’-‘catch’ slow speech rate condition and the ‘dish’-‘ditch’ fast speech rate condition, but was a visible trend in the data obtained for all the word-pairs in both the rate conditions. In all conditions, the older adults tended to exhibit a greater amount of word identification uncertainty over a larger range of gap durations. Even at the extremes of the continua and particularly with the longest duration gaps, the older listeners often did not reach the same level of correct token identification, as did the younger listeners. While, the older listeners did typically respond with one member of the continuum at least a majority of the time at the extremes of the continua, the younger listeners would typically respond with one member of the continuum almost exclusively in these cases.
The effects of age on the identification of a word-pair contrast, distinguished on the basis of an inserted silent interval, has been explored by other researchers as well as in the present study. A similar study, looking at ‘slit’/‘split’ identification, did not find any statistical word identification differences between younger and older normal-hearing adults (Dorman et al., 1985). The stimuli in this study were also based on natural speech, as in the present study. There are, however, some notable differences between the stimuli that may account for the conflicting findings in light of the results from this current work. The continuum used by Dorman et al., 1985 was based on a token of ‘slit’ spoken by a male speaker. The vocalic portion of this token was edited shortening the onset of the /l/ and resulting in a ‘blit’ percept. A similar approach was not taken in this study as the onset of the /l/ was preserved as much as possible. Another, perhaps more significant, difference between the stimuli in these studies is in the duration of the fricative /s/. The duration of the /s/ used by Dorman et al. (1985) was maintained at 250 ms, while the duration of the /s/ used in the slow speech condition in the present study was held constant at the considerably shorter duration of 136.55 ms. Dorman et al. (1985) examined only one rate condition and did not provide total stimulus duration measurements, thereby limiting the comparisons that can be made with the present study. It may be that no age differences were noted in the work by Dorman et al. (1985) since the duration of the segment preceding the inserted gaps was almost twice the duration of the /s/ in the present study. As discussed in section 4.2, age differences in gap detection ability are dependent on stimulus duration and, similarly, age differences in a gap

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6 Like the Dorman et al. (1985) study, significant age differences were not found for the ‘slit’-‘split’ slow speech rate condition in the present study, but the data did reveal differences in the pattern of responses obtained from the old listeners compared to the young listeners.
detection task applied in the context of speech stimuli (e.g. 'slit' versus 'split') may also depend on stimulus duration. The duration of the /s/ across both speech rates in this study may have been sufficiently short to result in word identification differences across age groups, while the stimuli used by Dorman et al., 1985 may have been long enough to avoid any possible age-related differences.

A different study, examining the effect of silent interval duration on intervocalic voicing judgements and subsequent word identification, did find age differences in word identification performance (Price & Simon, 1984) and is consistent with the pattern of results obtained from the present study. Price and Simon (1984) provide evidence showing that older listeners require a longer silent interval duration compared to younger listeners before their perception of an intervocalic stop would change from voiced to voiceless and word identification would correspondingly change from 'rabid' to 'rapid'. This age effect was more pronounced as the duration of the initial syllable was shortened from 220 ms to 160 ms. Essentially, the phoneme boundary between /b/ and /p/ occurred at a longer silent interval duration for the older adults compared to the younger adults. This resembles the pattern found in the present study where the word boundary for the older listeners tended to occur at longer gap durations compared to the younger adults. Price and Simon (1984) do not provide measures of the total stimulus duration of their tokens. However, the durations of the initial syllables of their tokens fall into the range of durations for the pre-gap material used in the present study for the 'dish'-'ditch' word-pair continua (235.60 ms and 132.10 ms) and are somewhat similar to those used in the 'cash'-'catch' word-pair continua (283.95 ms and 185.55 ms).
In general, the older listeners were able to reliably use an inserted silent interval as a cue to the presence of a stop consonant, but they did not demonstrate the same level of identification accuracy as exhibited by the younger listeners and tended to require a longer gap duration before consistently identifying a stop consonant’s presence. It is important to note, however, that in the context of naturally spoken ‘split’, ‘spoon’, ‘catch’, and ‘ditch’ tokens, the stop consonant, that was cued by a silent interval in this work, is cued by a more complex set of cues (e.g. formant transitions and energy rise/fall times). This work has demonstrated that older listeners are less efficient in their use of silent intervals in speech, but any age differences may not persist when more cues combine to signal a stop consonant’s presence. The age differences that were noted in this work in a quiet context may only occur in naturalistic circumstances when the auditory system is placed under additional stress (e.g. noisy and reverberant listening settings with speech presented at a fast rate).

A natural listening situation, while providing more cues to stop consonant presence, also presents the listener with more challenges than were encountered in the present word identification task. In the present study, the listener knew that in each test condition they would be listening for one of only two possible words. In natural contexts, the listener may be able to anticipate conversational content to a certain extent based on their knowledge of the topic, but the level of predictability does not come close to approximating the predictability of this study’s word identification task. Another difference is that, in the present study, the listener knew prior to each session if the speech would be presented at a slow or a fast rate. They also could expect that the rate of presentation would remain constant within each session. In natural conversations,
speaking rate can vary dramatically and unpredictably (Miller et al., 1984). If this naturally occurring variability were patterned in this study, it is likely that age differences, both within and across rate conditions would increase. In fact, Summerfield et al. (1981) demonstrated that rate effects on identification of a ‘slit’-‘split’ continuum were more pronounced when stimulus rate was varied randomly within a block of trials compared to when different stimulus rates were presented separately in different blocks of trials. The stimuli in the present study were presented in a fashion that likely served to optimize listener performance. The two speaking rates were always presented separately in different stimulus blocks and the listener was always presented with the slow speech rate, the presumably easier rate condition, prior to listening to the fast speech rate.

4.3.2 Effects of Speaking Rate

The effect of changing speaking rate from slow to fast had the consistent effect of shifting the word boundary from a longer to a shorter gap duration. This finding supports the rejection of Null Hypothesis #5, outlined in section 1.7. This hypothesis predicted that changing speaking rate would not affect word identification. The results, however, indicated that in the faster speech rate conditions, a shorter gap duration was able to cue a stop consonant’s presence. This finding is consistent with other studies that show that the duration of a silent interval can influence word identification (e.g. Price & Simon, 1984; Summerfield et al., 1981). Price and Simon (1984) provide data indicating that at longer vowel durations, a longer silent interval duration is needed before the perception of an intervocalic stop changes from voiced to voiceless (i.e. from ‘rabid’ to ‘rapid’). Summerfield et al. (1981) provide similar results showing that a longer silent duration
was needed to change a listener’s perception of ‘slit’ to ‘split’ when the duration of the /s/ and the vocalic portion were increased.

Results obtained by Marcus (1978) are in conflict with the results from the present study regarding the effects of speaking rate on word identification. Marcus (1978) examined the word identification of a ‘slit’-‘split’ continuum presented at three different speaking rates and determined that the boundary silent interval for word identification did not change with changes in speaking rate. Differences between the stimulus construction of the materials used by Marcus (1978) and the materials used in the present study may explain this pattern of conflicting results. Both studies began with a naturally-spoken token of ‘slit’. Stimulus compression, in the present study, was accomplished by removing glottal periods from the steady-state portions of the signal. This mimics the acoustic consequences of naturally-produced rate changes (Kent & Read, 1992). Marcus (1978), however, accomplished stimulus compression by removing every nth glottal period. This approach to signal compression may introduce irregularities into the signal resulting in, for example, a misrepresentation of the stimulus pitch. Wingfield et al. (in press) also compressed passage materials by, similarly, removing every nth data point in the stimulus. They, however, in contrast to the findings of Marcus (1978), determined that changes in speech rate did affect listener performance, with increased speaking rate resulting in poorer passage comprehension. Wingfield et al. (in press) also temporally expanded their stimulus passages, but, for this modification, they adopted a methodology that more closely mimics strategies used in natural speech. To expand the passages, pauses were inserted into the signal at syntactic boundaries. Even with the length of the passage increased beyond its original duration, the older adults were not
able to regain their baseline level of performance while the younger adults did regain pre-alteration performance.

A further difference between this present study and the work by Marcus (1978) lies in the overall duration of the stimulus tokens within each continuum. The stimuli in the present study were edited to ensure constant stimulus duration within each word-pair continuum. This step was not taken in the work by Marcus and, as a consequence, as the inserted silent interval duration varied from short to long, so did the overall stimulus duration. These durational differences may have, to some extent, guided the responses of the listeners. This potential confounding variable may have obscured any effects of rate that may have been observed in the work by Marcus (1978) if overall stimulus duration had remained constant within a stimulus continuum.

While the results of this study do not address what mechanism may be directing perceptual judgements in the face of changes in speaking rate, it seems likely that perceptual adjustments in response to rate changes are mediated by the auditory system. As Miller and Dexter (1988) discuss, the duration of acoustic segments are likely interpreted in light of the duration of surrounding segments. For example, a 40 ms silent interval may be able to signal a stop consonant in the context of shorter surrounding acoustic material (i.e. a faster speaking rate), but not when the speech rate is slowed and the surrounding acoustic material is lengthened.

There are two factors that theoretically may contribute to a slower speech rate being more favorable than a faster speech rate for the older listener. First, as mentioned above, in the context of slower speech rates compared to faster speech rates, a longer gap duration is needed to signal stop consonant presence. Longer gaps should be easier for
all listeners to detect. Second, in a slower speech context, the older listener should be better able to detect smaller gaps than in a fast speech context. This present study indicated that certain older listeners are impaired in their gap detection ability, relative to younger listeners, when the surrounding acoustic material is short (i.e., a fast speech rate), but that the gap detection ability of these older listeners improves as the duration of the surrounding material is increased. So, in the context of a slow speaking rate, the auditory abilities of a subset of older listeners are better capable of detecting smaller gaps while, at the same time, the gap that linguistically cues a stop consonant presence is larger. Therefore, it is not surprising that certain older listeners should perform more favorably when listening to slow speech compared to fast speech.

4.3.3 Correlations with Word Recognition Ability in Quiet

Word recognition ability in quiet was examined in relation to pure-tone hearing thresholds and age, as well as gap detection ability.

No clear pattern of significant correlations was found between word recognition ability and pure-tone hearing thresholds for either the younger or older listeners (refer to Appendix J for a list of significant correlations. This, however, is not surprising given the small number of listeners in each subject group. Out of 224 correlations calculated for each age group, only 16 reached significance for the older listener group and 6 reached significance for the younger listener group. This finding supports rejection of Null Hypothesis #6 outlined in section 1.7. The lack of a clear correlation with hearing thresholds adds to a growing base of literature illustrating that speech perception deficits in old age are not simply related to pure-tone thresholds for those listeners who do not yet
have clinically significant hearing loss. For example, Strouse et al. (1998) determined that differences between younger and older listeners, in their ability to use a silent interval duration to cue a voiced versus a voiceless stop, were unrelated to any pure-tone threshold differences between the subject groups. Furthermore, poorer performance evidenced by older listeners, relative to younger listeners, in the contexts of fast speech rates (e.g. Gordon-Salant & Fitzgibbons, 1995b), background noise (e.g. Stuart & Phillips, 1996), and reverberant settings (e.g. Helfer & Huntley, 1991) has also been showed to be unrelated to any threshold hearing loss. The poorer gap detection ability of older listeners noted in the present study as well as others (e.g. Schneider & Hamstra, 1999) may be a likely source of some of these difficulties that are not related to changes in pure-tone hearing thresholds, though the correlations in the present study did not reach significance.

Word identification ability in quiet was also examined in relation to age. It was determined that there was a statistically significant effect of age on some aspects of word identification ability in certain word-pair contexts. Age was determined to significantly effect the location of the word boundary for the ‘cash’-‘catch slow rate continuum and the ‘slit’-‘split’ fast rate continuum. Age also was shown to significantly affect the 80% point on the identification functions for ‘slit’-‘split’ in both rate conditions, the 20% point for the ‘cash’-‘catch’ slow rate functions, as well as the slope of the ‘cash’-‘catch’ slow rate functions and the ‘dish’-‘ditch’ fast rate functions. This finding supports the rejection of Null Hypothesis #7 outlined in section 1.7. In fact, all the word identification data collected in quiet did evidence patterns of age differences in terms of either the
location of the word boundary and/or the slope of the identification function although not all these patterns reached statistical levels of significance.

Word identification performance in quiet was further examined in relation to gap detection ability. No clear pattern of correlations was found between gap detection thresholds and the word boundary or function slopes obtained from word identification responses. Out of 80 possible correlations for each age group, only one correlation reached significance for the older listeners while no correlations reached significance for the younger listeners. While this supports acceptance of Null Hypothesis #8, the absence of clear patterns of significant correlations is not surprising given that only eight listeners comprised each subject group. If more subjects were added to the study, it would increase the chances of observing significant correlations, assuming that a significant relationship does exist. The stimuli used in this study were designed to optimize the observation of a significant relationship between word identification performance and gap detection ability. The identification of the words in quiet depended on whether the listener detected the inserted silent interval and determined that it sufficiently cued a stop consonant. Other cues to stop consonant presence were eliminated in an effort to increase the similarity between the task required of the listener in the gap detection test and the task that was involved in identifying the word-pair stimuli. Therefore, it was disappointing and puzzling that no hint of correlation between gap detection thresholds and word identification measures was detected.
4.4 Word Identification in Noise

4.4.1 Age Differences in Word Identification Ability in Noise

All of the older listeners did not complete word identification testing in noise for each word-pair continuum. The younger and older listeners, in this present study, differed notably in their ability to meet the criterion level of performance in the quiet test condition that was required for subsequent testing in noise. All the younger listeners were able to reach the criterion level of performance, but not all of the older listeners were able to meet the criterion in quiet that was required for further assessment in noise. Importantly, each older listener was able to meet the criterion for at least two word-pairs, demonstrating that all older participants were able to do the task and understood what was required. The following discussion will focus on the data that was collected from these listeners.

The performance of the younger and older listeners across the four word-pair continua did not follow a predictable pattern. Rather, the performance across certain word-pairs differed substantially. Let’s consider again the findings for each of the word-pairs. The ‘slit’-‘split’ and ‘soon’-‘spoon’ word-pairs, particularly in the fast speech rate condition, tended to cause the older listeners the greatest amount of difficulty. For these continua, the older listeners were not able to maintain above chance levels of identification of either ‘spoon’ or ‘split’ once any noise was added to the background. Even though these listeners reached the criterion level of performance on these tokens in quiet, they were unable to maintain accurate identification of these token in even the most favorable S:N ratio condition.
The difficulties that the older listeners experienced with 'split' and 'spoon' identification in noise may be related to the particular acoustic context of the inserted silent interval. With these words the listeners were required to detect a stop consonant in a syllable-initial consonant cluster. When, however, the silent interval cued a consonant in a syllable final consonant cluster (i.e., 'catch' and 'ditch') the older listeners did not evidence the same degree of difficulty. This difference may be related to the duration of the acoustic material that preceded the inserted silent interval for the 'cash'-'catch' and 'dish'-'ditch' continua. It may be that when the preceding material was relatively shorter the older listener's auditory system was stressed to a greater extent than when the duration of the preceding material was longer. The duration of the material preceding the gap in the 'slit'-'split' and 'soon'-'spoon' fast speech rate continua (i.e., 60 ms and 62.15 ms, respectively) was less than half the duration of the material preceding the gap in the 'cash'-'catch' and 'dish'-'ditch' fast speech rate continua (i.e., 185.55 ms and 132.10 ms, respectively). The younger auditory system may not have experienced the same amount of additional stress, if any at all, when the preceding material was short. Spectral differences in the nature of the preceding material may also be a factor. This line of reasoning is expanded in section 4.5 below.

A comparison of the performance of the younger and older adults on 'soon'-'spoon' and 'slit'-'split' identification in noise would lead us to reject Null Hypothesis #9, outlined in section 1.7. This hypothesis predicted that the word identification performance of the younger and older adults would reach chance levels of accuracy at the same signal-to-noise ratio. The results of this present study, however, indicated that, compared to the older listeners, a poorer S:N ratio was required before the younger
listeners reached chance levels of identification performance on ‘spoon’ and ‘split’ in both speaking rate conditions. Here it was shown that the speech perception abilities of the older listeners were more vulnerable to the presence of background noise than were the abilities of the younger listeners in both speech rate conditions.

In contrast to their poor performance identifying the member of the word-pair with the stop consonant (‘split’ or ‘spoon’), the apparently superior accuracy of the older listeners on their identification of the word-pair member without the stop consonant (‘slit’ or ‘soon’) needs careful consideration. This pattern is likely not related to a superior ability on the part of the older listeners to correctly identify these tokens, but rather, to the fact that in even the most favorable noise condition these listeners were not able to reliably identify the other member of the continuum. As they were unable to confidently identify either ‘spoon’ or ‘split’, a majority of their responses to both members of each word pair continuum were either ‘soon’ of ‘slit’, respectively. Given their apparent response bias, it is not surprising that these listeners were able to maintain high levels of correct identification of those tokens. The younger listeners also maintained somewhat better identification of ‘soon’ and ‘slit’ compared to ‘spoon’ and ‘split’, but their identification of each member of the continuum tended to decline as the listening condition worsened and typically fell to, or approached, chance levels of identification by the -15 dB S:N ratio condition. This indicates that, in the +10 dB S:N ratio condition, the younger listeners were reliably distinguishing the two stimulus tokens and that only as the noise level increased did their performance approach chance. Consistent across both the younger and older listeners, though, the noise interfered to a greater extent with the token that was confidently identified as containing the stop consonant in quiet. This stop
consonant was only cued by a cessation of acoustic energy and not surprisingly the presence of noise appeared to have the affect of obscuring this silent interval and interfering with its detection.

Continuing to focus on 'spoon' and 'split' identification in noise, changing the speech rate from slow to fast had the effect of minimizing the amount of noise that was required before the younger and older listeners reached chance levels of identification for both these words. In the fast speech rate condition a lesser amount of noise was required before performance on these tokens fell to chance. This finding supports rejection of Null Hypothesis 10 outlined in section 1.7. While the present study has focused on the difficulties that older listeners encounter in non-ideal listening settings, the younger listeners also appear to be detrimentally affected by an increased speech rate when listening occurs in a background of noise. It cannot be denied that even the younger auditory system can be comprised in difficult listening situations, but that the older auditory system appears to be comprised sooner and to a greater degree.

The identification of 'cash' and 'catch' in noise followed a unique pattern. First, for this word-pair the identification performance of the younger and older listeners closely patterned one another. Inspection of this data, to the exclusion of the other word-pairs, would support acceptance of Null Hypothesis #9 that the younger and older listeners would reach chance levels of identification performance at comparable S:N levels. Another unique pattern that occurred in response to this word-pair, at both speech rate conditions, was that the identification of 'catch' by both the younger and older listeners progressively worsened as the level of the noise increases, while both groups maintained high levels of 'cash' identification. As the level of the noise increased, so did
the number of ‘cash’ responses. Here the noise, again, had the effect of interfering with the detection of the inserted silent interval. Changing the speaking rate from slow to fast did not appear to change the S:N level at which either the younger or older listeners fell to chance levels of ‘catch’ performance. However, the younger and older listeners exhibited lower levels of ‘catch’ identification in the fast speaking rate, particularly at the least favorable S:N level.

Attention will now be focused on ‘dish’ and ‘ditch’ identification in noise. With ‘dish’ and ‘ditch’, the younger and older listeners, as with ‘cash’ and ‘catch’, responded similarly to one another. In the slow speech rate condition, the younger and older listeners fell to chance levels of ‘ditch’ identification performance at comparable S:N levels. The younger listeners were, however, able to maintain a consistently high accuracy of ‘dish’ identification, while the older listeners fell to chance levels in the -15 dB S:N condition. This further supports the rejection of Null Hypothesis #9. In the fast speech rate condition, the younger and older listeners reached chance levels of identification accuracy on both ‘dish’ and ‘ditch’ at comparable S:N levels. Interestingly, a poorer S:N level was required in the fast speech condition relative to the slow speech condition before the identification performance of the younger and older listeners fell to chance. While this supports the rejection of Null Hypothesis #10, as do the findings from the ‘slit’-'split' and 'soon'- 'spoon' word-pairs, the pattern of results is opposite to what was expected. It was predicted that the fast speaking rate would combine with the noise to negatively impact on identification performance to a greater degree than that evidenced in the slow speech rate condition. However, performance on ‘dish’ and ‘ditch’ identification was slightly better in the fast compared to the slow speech rate.
To summarize the word identification performance in noise, performance on three of the four word-pairs (‘slit’-‘split’, ‘soon’-‘spoon’, and ‘dish’-‘ditch’) indicated that the identification accuracy of the older listeners, compared to the younger listeners, fell to chance levels at more favorable S:N ratio levels. For these word-pairs, the younger listeners were better able to withstand increasing amounts of background noise. This effect of age was not revealed in the listener’s identification of ‘cash’ and ‘catch’.

Interestingly, the silent interval inserted into the ‘cash’ and ‘catch’ tokens was, when compared to the other word-pairs, preceded by the longest duration of acoustic material (185.55 ms in the fast rate condition and 283.95 ms in the slow rate condition).

Similarly, in the gap detection task, age effects were also not evidenced in the context of the longest duration surrounding acoustic material.

Rate effects on word identification in noise were also found for three of the four word-pairs with, the ‘cash’-‘catch’ word-pair, again, being the only exception. The most typical response pattern for word identification in noise was that as the speech rate was increased from slow to fast, lesser amounts of noise caused identification accuracy to fall to chance levels. This pattern was consistent for the ‘slit’-‘split’ and ‘soon’-‘spoon’ word-pairs. A reverse trend was noted for the ‘dish’-‘ditch’ word-pair and no effect of rate was noted for the ‘cash’-‘catch’ word-pair.

4.4.2 Correlations with Word Identification Ability in Noise

No patterns of significant correlations were found between pure-tone and gap detection thresholds and word identification ability in noise. This is not unexpected, as the total number of listeners studied was not always assessed in each noise condition.
This problem, related to the limited power of data driven by a small sample size, will likely also limit any possibility of observing a clear pattern of correlations between word identification ability in noise and either listener age or gap detection ability. It is possible that some relationship between these factors does exist, but the small sample size of this study significantly limits the potential of observing any such patterns.

4.5 General Discussion

The data from this study indicate that older adults are poorer than younger adults at detecting gaps embedded in non-speech stimuli (2-kHz markers) when the surrounding material is short. Correspondingly, older adults were also shown to have greater difficulty identifying speech contrasts when a gap served to differentiate between two words, particularly for fast speech. Common to both these cases is the poorer performance evidenced by older listeners in the context of fast rates/short duration stimuli. This pattern of findings is consistent with a hypothesis that proposes that recovery from neural adaptation occurs more slowly in the old compared to the younger auditory system (Schneider & Hamstra, 1999). As the duration of the material surrounding a gap is shortened, less time is available for neural recovery and therefore fewer neurons are available to mark the onset of the material trailing the gap. With the response to the trailing material weakening, detection of the gap will become more difficult. If recovery from neural adaptation occurs more slowly in older adults, then it follows that they will be particularly disadvantaged when required to detect a gap in short duration non-speech stimuli. Similarly, they would also face greater challenges with fast
speech where the detection of a silent interval can influence stop gap detection and subsequent word identification.

Inherent to the above hypothesis based on differential neural adaptation, is the importance placed on detecting the onset of the trailing gap marker. It is speculated that the auditory system has evolved such that it is specifically tuned to process these stimulus onsets (Greenberg, 1996). In the larger scheme of human evolution, with the development of the human hearing system preceding the development of our speaking system, it follows that the vocal system would evolve in a manner that would capitalize on the principles that guide auditory perception (Greenberg, 1996). This evolutionary direction would serve to maximize the functionality of our communication abilities. Human speech is, in fact, characterized by acoustic patterns to which the auditory system is particularly responsive. For example, the onset of an acoustic event may aid a listener in their identification of a stop gap that, in combination with other acoustic events, cues the presence of a stop consonant and guides human speech perception.

4.6 Future Directions

A growing collection of studies now indicate that gap detection ability is impaired in older listeners, in a manner that is unrelated to changes in pure-tone hearing thresholds. The more pressing question now is not the presence of impaired gap detection ability, but the potential implications of these deficits and how they may contribute to the difficulties that older normal-hearing adults encounter in non-ideal listening situations. In order to demonstrate a connection between these measures, speech perception tasks should be selected that pattern the task required in gap detection
testing and that stress the auditory system in the temporal domain (e.g. through increased speech rate). This approach was taken in this present work, but it needs to be extended to increase the strength of the results and determine whether temporal resolution abilities in old age impact on speech perception.

Further study is also needed regarding the issue of stimulus complexity and its relationship to the gap detection ability of both younger and older adults. For example, Phillips et al. (1997) have shown that gap detection ability worsened for listeners as the duration of the leading marker was shortened when the two markers were of different frequencies, but not when the frequency of the markers remained constant. This finding, coupled with the effects that marker duration has on older listeners in the context of equal frequency markers, likely only begins to address the complexity of gap detection performance. It may be that the older listener will be disadvantaged to an even greater extent in a gap detection task where the leading and trailing gap markers have different frequency compositions. Furthermore, this context is more similar to the acoustic environments encountered with speech material. Phillips et al. (1997) assessed gap detection in a non-speech context that more closely resembles the acoustic patterns found in the ‘slit’-'spilt’ and ‘soon’-'spoon’ word-pairs. They used a condition where the leading gap material was a broadband signal, comparable to the fricative onsets in ‘slit’ and ‘soon’, and the trailing gap material was more restrictive in frequency context, similar again to the vocalic portions of ‘slit’ and ‘soon’. Comparing gap detection ability, in these more representative contexts, to word identification measures, similar to those examined in this present study, may increase the feasibility of observing a correlation between these two measures, if, in fact, there is a significant relationship. The
complexities inherent to specific acoustic contexts will need to be more fully understood before the implications of gap detection ability on speech perception, in both younger and older listeners, can be determined. If, in fact, no relationship does exist between gap detection ability and speech perception, then theories of sound perception must encompass two separate mechanisms, one to process speech input and another to process non-speech input, as would be predicted by the Motor theory of speech perception (Liberman, 1998).

A continuing theme throughout this present work is the suggestion that the auditory system is particularly tuned to detecting stimulus onsets and that these onsets are critical for the perception of speech (e.g. Greenberg, 1996). This concept has critical implications for the aural rehabilitation of older listeners. The fitting of amplification devices is a key component in most aural rehabilitation programs. With current technological advances, there is a trend for digital signal processing hearing aids to be produced where different compression algorithms are being incorporated in an effort to minimize the need for the hearing aid wearer to make manual volume adjustments. A critical feature distinguishing these approaches to hearing aid compression is the speed with which the compression mechanism is turned on and off. With a slow-acting automatic volume control compression system there is a long compression release time. Since the compression is acting slowly, the temporal contrasts and intensity differences in the speech signal are reduced (Dillon, 1988). This can act to reduce the salience of acoustic onsets and may potentially interfere with speech perception. This approach to compression also uses a high compression ratio where changes in input are met with relatively small changes in output (Dillon, 1988). With higher compression ratios, the
level of the background noise is amplified to a greater extent during the pauses in speech. This may result in increased noise during consonantal stop gaps and may further interfere with speech perception. Currently, these potential detriments of slow acting compression systems are only speculative. In the future, different compression systems will need to be evaluated to determine how they impact on the speech perception abilities of the older adult who, even in the absence of clinically significant hearing loss, may be faced with auditory processing deficits such as impairments in temporal resolution ability.

In addition to expanding our knowledge regarding the affects of hearing aid signal processing on the older listener, the present study also has implications for other aspects of aural rehabilitation. Specifically, these implications apply to adjustments that can be made to the communication environment, such as designing low-noise communication environments, and strategies that can be employed by the communication partner, such as producing clear speech and avoiding speaking too quickly. As we accumulate knowledge concerning the implications auditory processing deficits, approaches to aural rehabilitation and hearing aid processing will need to be tailored to meet the specific needs of each listener.
REFERENCES


Appendix A
Models of Temporal Resolution

Model 1

Stimulus → Bandpass filter → Half-wave rectifier → Low-pass filter → Decision device

Model 2

Stimulus → Bandpass filter → Square-law device → Temporal integrator → Decision device

Models as depicted in Moore, 1989, pp. 150
APPENDIX B

Spectrograms and Time Waveforms

‘Cash’ Slow Speaking Rate: 0 ms Gap Duration
‘Cash’ Slow Speaking Rate: 5 ms Gap Duration
‘Cash’ Slow Speaking Rate: 10 ms Gap Duration
'Cash' Slow Speaking Rate: 20 ms Gap Duration
‘Cash’ Slow Speaking Rate: 30 ms Gap Duration
‘Cash’ Slow Speaking Rate: 45 ms Gap Duration
‘Cash’ Slow Speaking Rate: 55 ms Gap Duration
‘Cash’ Slow Speaking Rate: 60 ms Gap Duration
‘Cash’ Slow Speaking Rate: 65 ms Gap Duration

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<td>-70.10</td>
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**SPECTROGRAM**

Status: 100%

**CURSOR AT**

Time: 482.1 ms
Freq: N/A
Mag.: N/A

**FILE PARAMETERS**

Proc.: AC
Wind.: 512 pts
Bands: 256
Ovlp.: 50 %
Func.: HANNING
SF : 20.00 kHz
Pre.: 98.0 %
Order: 15
‘Cash’ Slow Speaking Rate: 70 ms Gap Duration
‘Cash’ Slow Speaking Rate: 75 ms Gap Duration
‘Cash’ Slow Speaking Rate: 80 ms Gap Duration
'Cash' Slow Speaking Rate: 85 ms Gap Duration
‘Cash’ Slow Speaking Rate: 95 ms Gap Duration
‘Cash’ Fast Speaking Rate: 0 ms Gap Duration
‘Cash’ Fast Speaking Rate: 5 ms Gap Duration

156
'Cash' Fast Speaking Rate: 10 ms Gap Duration
‘Cash’ Fast Speaking Rate: 20 ms Gap Duration

**FILE PARAMETERS**
- Proc.: AC
- Wind.: 512 pts
- Bands: 256
- Ovlp.: 50%
- Func.: HANNING
- SF: 20.00 kHz
- Pre.: 98.0%
- Order: 15

**5 PEAKS**
- F(Hz) | M(dB)
  - 859.0 | -58.00
  - 2929.0 | -63.10
  - 4140.0 | -65.00
  - 5117.0 | -61.60
  - 8750.0 | -73.40

**MARKER AT**
- F(Hz) | M(dB)
  - F(Hz) | M(dB)
‘Cash’ Fast Speaking Rate: 30 ms Gap Duration

![Spectrogram and waveform images with markers and peaks listed in the spectrogram file parameters section.](image)
‘Cash’ Fast Speaking Rate: 35 ms Gap Duration
‘Cash’ Fast Speaking Rate: 40 ms Gap Duration
‘Cash’ Fast Speaking Rate: 45 ms Gap Duration
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‘Dish’ Slow Speaking Rate: 120 ms Gap Duration
‘Dish’ Fast Speaking Rate: 0 ms Gap Duration

Status: 100%
CURSOR AT
Time: 1043.0 ms
Freq: 9921.0 Hz
Mag.: -71.7 dB

FILE PARAMETERS
Proc.: AC
Wind.: 512 pts
Bands: 256
Ovlp.: 50%
Func.: HANNING
SF: 20.00 kHz
Pres.: 96.0%
Order: 15

5 PEAKS
F(Hz) M(dB)
585.0 -51.30
2382.0 -46.10
4375.0 -54.20
4843.0 -54.80
8632.0 -78.20

MARKER AT
F(Hz) M(dB)
‘Dish’ Fast Speaking Rate: 10 ms Gap Duration
‘Dish’ Fast Speaking Rate: 25 ms Gap Duration
‘Dish’ Fast Speaking Rate: 35 ms Gap Duration
‘Dish’ Fast Speaking Rate: 45 ms Gap Duration
‘Dish’ Fast Speaking Rate: 50 ms Gap Duration
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‘Dish’ Fast Speaking Rate: 75 ms Gap Duration
‘Dish’ Fast Speaking Rate: 85 ms Gap Duration
‘Dish’ Fast Speaking Rate: 100 ms Gap Duration
‘Slit’ Slow Speaking Rate: 0 ms Gap Duration
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‘Slit’ Slow Speaking Rate: 20 ms Gap Duration
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‘Slit’ Slow Speaking Rate: 65 ms Gap Duration
‘Slit’ Slow Speaking Rate: 70 ms Gap Duration
‘Slit’ Slow Speaking Rate: 80 ms Gap Duration
‘Slit’ Slow Speaking Rate: 95 ms Gap Duration
‘Slit’ Fast Speaking Rate: 0 ms Gap Duration
'Slit' Fast Speaking Rate: 5 ms Gap Duration
‘Slit’ Fast Speaking Rate: 10 ms Gap Duration
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'Slit' Fast Speaking Rate: 35 ms Gap Duration
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Status: 100%
Cursor at:
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Freq: N/A
Mag.: N/A

File Parameters:
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Bands: 256
Dwel.: 50%
Func.: HANNING
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Pre.: 90.0%
Order: 15

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Marker at:
F(Hz)  M(dB)
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‘Soon’ Slow Speaking Rate: 10 ms Gap Duration
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‘Soon’ Fast Speaking Rate: 45 ms Gap Duration
‘Soon’ Fast Speaking Rate: 50 ms Gap Duration
‘Soon’ Fast Speaking Rate: 55 ms Gap Duration
‘Soon’ Fast Speaking Rate: 65 ms Gap Duration
‘Soon’ Fast Speaking Rate: 75 ms Gap Duration
**APPENDIX C**

Stimulus Duration Measurements:

I. ‘Slit’-‘Split’ Continuum: Fast Speaking Rate

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<th>Gap (ms)</th>
<th>/l/ (ms)</th>
<th>/t/ Gap (ms)</th>
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II. ‘Slit’-‘Split’ Continuum: Slow Speaking Rate

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III. ‘Cash’-‘Catch’ Continuum: Fast Speaking Rate

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IV. ‘Cash’-‘Catch’ Continuum: Slow Speaking Rate

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V. 'Topic'-Top Pick' Continuum: Fast Speaking Rate

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VI. 'Topic'-Top Pick' Continuum: Slow Speaking Rate

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VII. 'Soon'-'Spoon' Continuum Fast Speaking Rate

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VIII. 'Soon'-'Spoon' Continuum: Slow Speaking Rate

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IX. ‘Dish’-'Ditch’ Continuum: Fast Speaking Rate

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X. ‘Dish’-'Ditch’ Continuum: Slow Speaking Rate

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APPENDIX D

Calibration Calculations

Part I: Voltages

Calibration Tone:

Intensity Right Headphone = 118.0 dB A  
Intensity Left Headphone = 117.8 dB A  
Voltage Right Headphone = 7.0710 V  
Voltage Left Headphone = 7.0710 V

Average Voltage

'Slit'-'Split' Fast Speaking Rate Continuum: 0.9076 V  
'Slit'-'Split' Slow Speaking Rate Continuum: 0.8566 V  
'Cash'-'Catch' Fast Speaking Rate Continuum: 0.5922 V  
'Cash'-'Catch' Slow Speaking Rate Continuum: 0.7509 V  
'Dish'-Ditch' Fast Speaking Rate Continuum: 1.3133 V  
'Dish'-Ditch' Slow Speaking Rate Continuum: 1.6259 V  
'Soon'-'Spoon' Fast Speaking Rate Continuum: 1.1026 V  
'Soon'-'Spoon' Slow Speaking Rate Continuum: 1.0603 V  
'Topic'-'Top pick' Fast Speaking Rate Continuum: 1.0159 V  
'Topic'-'Top pick' Slow Speaking Rate Continuum: 0.9916 V

Part II: Calculations

Step 1: The decibel difference between two voltage values is provided by the calculation:

\[
20 \log \left( \frac{\text{voltage A}}{\text{voltage B}} \right)
\]

This equation determines how many decibels more intense (or less intense) voltage A is than voltage B. In the calculations that follow, voltage A is the voltage of the speech stimuli and voltage B is the voltage of the calibration tone. If the calculation is solved for
a negative value, then speech stimuli (voltage A) are less intense than the calibration tone. If the calculation is solved for a positive value, then the calibration tone (voltage B) is the more intense of the two signals.

**Step 2:**

The values obtained from the calculations in step 1 are used to determine the average decibel level of each speech continuum. The decibel level of the calibration tone is known as well as the decibel difference between the calibration tone and each speech continuum. Therefore, the decibel level of each speech continuum is determined by subtracting each respective value obtained in step 1 from the level of the calibration tone. This calculation was performed for each headphone as test ear varied among listeners.

**Step 3:** The required attenuation value for each stimulus continuum can now be calculated using the continuum average decibel level obtained from step 2. The desired speech presentation level was 40 dB SL, referenced to the listener’s SRT. As subjects were required to have normal hearing (refer to section 2.3.1 for a definition of normal hearing), attenuation values were determined for each stimulus continuum based on potential SRT scores of 10 to 45 dB SPL (alternatively –10 through 25 dB HL) (Davis, 1947). Thus, the range of possible presentation levels varied from 50 to 85 dB SPL. Attenuation values were entered in ‘ecoscon’ at the onset of each experimental run.
'Slit'-‘Split’ Continuum: Fast Speaking Rate:

Step 1:

\[ 20 \log \left( \frac{0.9076}{7.0710} \right) = -17.8317 = 117.8317 \]

The stimuli in this continuum are on average 17.83 dB SPL quieter than the calibration tone.

Step 2:

The average sound pressure level of this continuum is:

- Left headphone: \( 117.80 \text{ dB} - 17.83 \text{ dB} = 99.97 \text{ dB SPL} \)
- Right headphone: \( 118.00 \text{ dB} - 17.83 \text{ dB} = 100.17 \text{ dB SPL} \)

Step 3:

To present this continuum at levels ranging from 50 to 85 dB SPL the attenuation values are:

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<thead>
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<th>Left Headphone:</th>
<th>Right Headphone:</th>
</tr>
</thead>
<tbody>
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<td>100.17 dB - 50 dB = 50.17 dB</td>
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<tr>
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<td>99.97 dB - 65 dB = 34.97 dB</td>
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<td>99.97 dB - 70 dB = 29.97 dB</td>
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<tr>
<td>99.97 dB - 85 dB = 14.97 dB</td>
<td>100.17 dB - 85 dB = 15.17 dB</td>
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</table>

'Slit'-‘Split’ Continuum: Slow Speaking Rate:

Step 1:

\[ 20 \log \left( \frac{0.8566}{7.0710} \right) = -18.3341 = 18.3341 \]

The stimuli in this continuum are on average 18.33 dB SPL quieter than the calibration tone.

Step 2:

The average sound pressure level of this continuum is:

- Left headphone: \( 117.80 \text{ dB} - 18.33 \text{ dB} = 99.47 \text{ dB SPL} \)
- Right headphone: \( 118.00 \text{ dB} - 18.33 \text{ dB} = 99.67 \text{ dB SPL} \)

Step 3:

To present this continuum at levels ranging from 50 to 85 dB SPL the attenuation values are:

<table>
<thead>
<tr>
<th>Left Headphone:</th>
<th>Right Headphone:</th>
</tr>
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<td>100.17 dB - 55 dB = 45.17 dB</td>
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<tr>
<td>99.47 dB - 80 dB = 19.47 dB</td>
<td>100.17 dB - 80 dB = 20.17 dB</td>
</tr>
<tr>
<td>99.47 dB - 85 dB = 14.47 dB</td>
<td>100.17 dB - 85 dB = 15.17 dB</td>
</tr>
</tbody>
</table>
'Cash'- 'Catch' Continuum: Fast Speaking Rate:

Step 1:
\[ 20 \log \left( \frac{0.5922}{7.0710} \right) = -21.5402 = |21.5402| \]
The stimuli in this continuum are on average 21.54 dB SPL quieter than the calibration tone.

Step 2:
The average sound pressure level of this continuum is:
- Left headphone: 117.80 dB - 21.54 dB = 96.26 dB SPL
- Right headphone: 118.00 dB - 21.54 dB = 96.46 dB SPL

Step 3:
To present this continuum at levels ranging from 50 to 85 dB SPL the attenuation values are:

- Left Headphone:
  - 96.26 dB - 50 dB = 46.26 dB
  - 96.26 dB - 55 dB = 41.26 dB
  - 96.26 dB - 60 dB = 36.26 dB
  - 96.26 dB - 65 dB = 31.26 dB
  - 96.26 dB - 70 dB = 26.26 dB
  - 96.26 dB - 75 dB = 21.26 dB
  - 96.26 dB - 80 dB = 16.26 dB
  - 96.26 dB - 85 dB = 11.26 dB

- Right Headphone:
  - 96.46 dB - 50 dB = 46.46 dB
  - 96.46 dB - 55 dB = 41.46 dB
  - 96.46 dB - 60 dB = 36.46 dB
  - 96.46 dB - 65 dB = 31.46 dB
  - 96.46 dB - 70 dB = 26.46 dB
  - 96.46 dB - 75 dB = 21.46 dB
  - 96.46 dB - 80 dB = 16.46 dB
  - 96.46 dB - 85 dB = 11.46 dB

'Cash'- 'Catch' Continuum: Slow Speaking Rate:

Step 1:
\[ 20 \log \left( \frac{0.7509}{7.0710} \right) = -19.4780 = |19.4780| \]
The stimuli in this continuum are on average 19.48 dB SPL quieter than the calibration tone.

Step 2:
The average sound pressure level of this continuum is:
- Left headphone: 117.80 dB - 19.48 dB = 98.32 dB SPL
- Right headphone: 118.00 dB - 19.48 dB = 98.52 dB SPL

Step 3:
To present this continuum at levels ranging from 50 to 85 dB SPL the attenuation values are:

- Left Headphone:
  - 98.32 dB - 50 dB = 48.32 dB
  - 98.32 dB - 55 dB = 43.32 dB
  - 98.32 dB - 60 dB = 38.32 dB
  - 98.32 dB - 65 dB = 33.32 dB
  - 98.32 dB - 70 dB = 28.32 dB
  - 98.32 dB - 75 dB = 23.32 dB

- Right Headphone:
  - 98.52 dB - 50 dB = 48.52 dB
  - 98.52 dB - 55 dB = 43.52 dB
  - 98.52 dB - 60 dB = 38.52 dB
  - 98.52 dB - 65 dB = 33.52 dB
  - 98.52 dB - 70 dB = 28.52 dB
  - 98.52 dB - 75 dB = 23.52 dB
98.32 dB - 80 dB = 18.32 dB  
98.32 dB - 85 dB = 13.32 dB

98.52 dB - 80 dB = 18.52 dB  
98.52 dB - 85 dB = 13.52 dB

‘Dish’-‘Ditch’ Continuum: Fast Speaking Rate:

Step 1:
\[20 \log (1.3133 / 7.0710) = -14.6223 = 14.6223\]
The stimuli in this continuum are on average 14.62 dB SPL quieter than the calibration tone.

Step 2:
The average sound pressure level of this continuum is:

- Left headphone: 117.80 dB - 14.62 dB = 103.18 dB SPL
- Right headphone: 118.00 dB - 19.48 dB = 103.38 dB SPL

Step 3:
To present this continuum at levels ranging from 50 to 85 dB SPL the attenuation values are:

<table>
<thead>
<tr>
<th>Left Headphone:</th>
<th>Right Headphone:</th>
</tr>
</thead>
<tbody>
<tr>
<td>103.18 dB - 50 dB = 53.18 dB</td>
<td>103.38 dB - 50 dB = 53.38 dB</td>
</tr>
<tr>
<td>103.18 dB - 55 dB = 48.18 dB</td>
<td>103.38 dB - 55 dB = 48.38 dB</td>
</tr>
<tr>
<td>103.18 dB - 60 dB = 43.18 dB</td>
<td>103.38 dB - 60 dB = 43.38 dB</td>
</tr>
<tr>
<td>103.18 dB - 65 dB = 38.18 dB</td>
<td>103.38 dB - 65 dB = 38.38 dB</td>
</tr>
<tr>
<td>103.18 dB - 70 dB = 33.18 dB</td>
<td>103.38 dB - 70 dB = 33.38 dB</td>
</tr>
<tr>
<td>103.18 dB - 75 dB = 28.18 dB</td>
<td>103.38 dB - 75 dB = 28.38 dB</td>
</tr>
<tr>
<td>103.18 dB - 80 dB = 23.18 dB</td>
<td>103.38 dB - 80 dB = 23.38 dB</td>
</tr>
<tr>
<td>103.18 dB - 85 dB = 18.18 dB</td>
<td>103.38 dB - 85 dB = 18.38 dB</td>
</tr>
</tbody>
</table>

‘Dish’-‘Ditch’ Continuum: Slow Speaking Rate:

Step 1:
\[20 \log (1.6259 / 7.0710) = -12.7677 = 12.7677\]
The stimuli in this continuum are on average 12.77 dB SPL quieter than the calibration tone.

Step 2:
The average sound pressure level of this continuum is:

- Left headphone: 117.80 dB - 12.77 dB = 105.03 dB SPL
- Right headphone: 118.00 dB - 12.77 dB = 105.23 dB SPL

Step 3:
To present this continuum at levels ranging from 50 to 85 dB SPL the attenuation values are:

<table>
<thead>
<tr>
<th>Left Headphone:</th>
<th>Right Headphone:</th>
</tr>
</thead>
<tbody>
<tr>
<td>105.03 dB - 50 dB = 55.03 dB</td>
<td>105.23 dB - 50 dB = 55.23 dB</td>
</tr>
<tr>
<td>105.03 dB - 55 dB = 50.03 dB</td>
<td>105.23 dB - 55 dB = 50.23 dB</td>
</tr>
<tr>
<td>105.03 dB - 60 dB = 45.03 dB</td>
<td>105.23 dB - 60 dB = 45.23 dB</td>
</tr>
<tr>
<td>105.03 dB - 65 dB = 40.03 dB</td>
<td>105.23 dB - 65 dB = 40.23 dB</td>
</tr>
</tbody>
</table>
'Soon'-'Spoon' Continuum: Fast Speaking Rate:

Step 1:
\[ 20 \log \left( \frac{1.1026}{7.0710} \right) = -16.1413 = |16.1413| \]
The stimuli in this continuum are on average 16.14 dB SPL quieter than the calibration tone.

Step 2:
The average sound pressure level of this continuum is:
- Left headphone: 117.80 dB - 16.14 dB = 101.66 dB SPL
- Right headphone: 118.00 dB - 16.14 dB = 101.86 dB SPL

Step 3:
To present this continuum at levels ranging from 50 to 85 dB SPL the attenuation values are:
- Left Headphone:
  - 101.66 dB - 50 dB = 51.66 dB
  - 101.66 dB - 55 dB = 46.66 dB
  - 101.66 dB - 60 dB = 41.66 dB
  - 101.66 dB - 65 dB = 36.66 dB
  - 101.66 dB - 70 dB = 31.66 dB
  - 101.66 dB - 75 dB = 26.66 dB
  - 101.66 dB - 80 dB = 21.66 dB
  - 101.66 dB - 85 dB = 16.66 dB
- Right Headphone:
  - 101.86 dB - 50 dB = 51.86 dB
  - 101.86 dB - 55 dB = 46.86 dB
  - 101.86 dB - 60 dB = 41.86 dB
  - 101.86 dB - 65 dB = 36.86 dB
  - 101.86 dB - 70 dB = 31.86 dB
  - 101.86 dB - 75 dB = 26.86 dB
  - 101.86 dB - 80 dB = 21.86 dB
  - 101.86 dB - 85 dB = 16.86 dB

'Soon'-'Spoon' Continuum: Slow Speaking Rate:

Step 1:
\[ 20 \log \left( \frac{1.0603}{7.0710} \right) = -16.4810 = |16.4810| \]
The stimuli in this continuum are on average 16.48 dB SPL quieter than the calibration tone.

Step 2:
The average sound pressure level of this continuum is:
- Left headphone: 117.80 dB - 16.48 dB = 101.32 dB SPL
- Right headphone: 118.00 dB - 16.48 dB = 101.52 dB SPL

Step 3:
To present this continuum at levels ranging from 50 to 85 dB SPL the attenuation values are:
- Left Headphone:
  - 101.32 dB - 50 dB = 51.32 dB
  - 101.32 dB - 55 dB = 46.32 dB
- Right Headphone:
  - 101.52 dB - 50 dB = 51.52 dB
  - 101.52 dB - 55 dB = 46.52 dB
101.32 dB - 60 dB = 41.32 dB  
101.32 dB - 65 dB = 36.32 dB  
101.32 dB - 70 dB = 31.32 dB  
101.32 dB - 75 dB = 26.32 dB  
101.32 dB - 80 dB = 21.32 dB  
101.32 dB - 85 dB = 16.32 dB  
101.52 dB - 60 dB = 41.52 dB  
101.52 dB - 65 dB = 36.52 dB  
101.52 dB - 70 dB = 31.52 dB  
101.52 dB - 75 dB = 26.52 dB  
101.52 dB - 80 dB = 21.52 dB  
101.52 dB - 85 dB = 16.52 dB

'Topic'-'Top pick' Continuum: Fast Speaking Rate:

Step 1:

\[ 20 \log \left( \frac{1.0159}{7.0710} \right) = -16.8526 \leq 16.8526 \]

The stimuli in this continuum are on average 16.85 dB SPL quieter than the calibration tone.

Step 2:

The average sound pressure level of this continuum is:

- Left headphone: 117.80 dB - 16.85 dB = 100.95 dB SPL
- Right headphone: 118.00 dB - 16.85 dB = 101.15 dB SPL

Step 3:

To present this continuum at levels ranging from 60 to 95 dB SPL the attenuation values are:

- Left Headphone:  
  100.95 dB - 60 dB = 40.95 dB  
  100.95 dB - 65 dB = 35.95 dB  
  100.95 dB - 70 dB = 30.95 dB  
  100.95 dB - 75 dB = 25.95 dB  
  100.95 dB - 80 dB = 20.95 dB  
  100.95 dB - 85 dB = 15.95 dB  
  100.95 dB - 90 dB = 10.95 dB  
  100.95 dB - 95 dB = 5.95 dB

- Right Headphone:  
  101.15 dB - 60 dB = 41.15 dB  
  101.15 dB - 65 dB = 36.15 dB  
  101.15 dB - 70 dB = 31.15 dB  
  101.15 dB - 75 dB = 26.15 dB  
  101.15 dB - 80 dB = 21.15 dB  
  101.15 dB - 85 dB = 16.15 dB  
  101.15 dB - 90 dB = 11.15 dB  
  101.15 dB - 95 dB = 6.15 dB

'Topic'-'Top pick' Continuum: Slow Speaking Rate:

Step 1:

\[ 20 \log \left( \frac{0.9916}{7.0710} \right) = -17.0629 \leq 17.0629 \]

The stimuli in this continuum are on average 17.06 dB SPL quieter than the calibration tone.

Step 2:

The average sound pressure level of this continuum is:

- Left headphone: 117.80 dB - 17.06 dB = 100.74 dB SPL
- Right headphone: 118.00 dB - 17.06 dB = 100.94 dB SPL

Step 3:

To present this continuum at levels ranging from 60 to 95 dB SPL the attenuation values are:

- Left Headphone:  
  100.74 dB - 60 dB = 40.74 dB  
  100.74 dB - 65 dB = 35.74 dB  
  100.74 dB - 70 dB = 30.74 dB  
  100.74 dB - 75 dB = 25.74 dB  
  100.74 dB - 80 dB = 20.74 dB  
  100.74 dB - 85 dB = 15.74 dB  
  100.74 dB - 90 dB = 10.74 dB  
  100.74 dB - 95 dB = 5.74 dB

- Right Headphone:  
  100.94 dB - 60 dB = 40.94 dB  
  100.94 dB - 65 dB = 35.94 dB  
  100.94 dB - 70 dB = 30.94 dB  
  100.94 dB - 75 dB = 25.94 dB  
  100.94 dB - 80 dB = 20.94 dB  
  100.94 dB - 85 dB = 15.94 dB  
  100.94 dB - 90 dB = 10.94 dB  
  100.94 dB - 95 dB = 5.94 dB
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>100.74 dB - 60 dB = 40.74 dB</td>
<td>100.94 dB - 60 dB = 40.94 dB</td>
<td></td>
</tr>
<tr>
<td>100.74 dB - 65 dB = 35.74 dB</td>
<td>100.94 dB - 65 dB = 35.94 dB</td>
<td></td>
</tr>
<tr>
<td>100.74 dB - 70 dB = 30.74 dB</td>
<td>100.94 dB - 70 dB = 30.94 dB</td>
<td></td>
</tr>
<tr>
<td>100.74 dB - 75 dB = 25.74 dB</td>
<td>100.94 dB - 75 dB = 25.94 dB</td>
<td></td>
</tr>
<tr>
<td>100.74 dB - 80 dB = 20.74 dB</td>
<td>100.94 dB - 80 dB = 20.94 dB</td>
<td></td>
</tr>
<tr>
<td>100.74 dB - 85 dB = 15.74 dB</td>
<td>100.94 dB - 85 dB = 15.94 dB</td>
<td></td>
</tr>
<tr>
<td>100.74 dB - 90 dB = 10.74 dB</td>
<td>100.94 dB - 90 dB = 10.94 dB</td>
<td></td>
</tr>
<tr>
<td>100.74 dB - 95 dB = 5.74 dB</td>
<td>100.94 dB - 95 dB = 5.94 dB</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX E

Schematic of the TDT Set-Up

Note: The output from the CD player was only connected to the TDT components during the word identification in noise testing and the gap detection testing.
APPENDIX F

Noise Attenuation Levels

I. Noise Attenuation Values in dB for a Reference Speech Reception Threshold Value of -10.00 dB HL

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Headphone</td>
<td>Left</td>
<td>Left</td>
<td>Left</td>
</tr>
<tr>
<td>Attenuation Value</td>
<td>55.2</td>
<td>40.2</td>
<td>30.2</td>
</tr>
</tbody>
</table>

II. Noise Attenuation Values in dB for a Reference Speech Reception Threshold Value of -5 dB HL

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Headphone</td>
<td>Left</td>
<td>Left</td>
<td>Left</td>
</tr>
<tr>
<td>Attenuation Value</td>
<td>50.2</td>
<td>35.2</td>
<td>25.2</td>
</tr>
</tbody>
</table>

III. Noise Attenuation Values in dB for a Reference Speech Reception Threshold Value of 0 dB HL

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Headphone</td>
<td>Left</td>
<td>Left</td>
<td>Left</td>
</tr>
<tr>
<td>Attenuation Value</td>
<td>45.2</td>
<td>30.2</td>
<td>20.2</td>
</tr>
</tbody>
</table>
IV. Noise Attenuation Values in dB for a Reference Speech Reception Threshold Value of 5 dB HL

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Headphone</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Attenuation Value</td>
<td>40.2</td>
<td>40.4</td>
<td>25.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15.2</td>
</tr>
</tbody>
</table>

V. Noise Attenuation Values in dB for a Reference Speech Reception Threshold Value of 10 dB HL

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Headphone</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Attenuation Value</td>
<td>35.2</td>
<td>35.4</td>
<td>20.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10.2</td>
</tr>
</tbody>
</table>

VI. Noise Attenuation Values in dB for a Reference Speech Reception Threshold Value of 15 dB HL

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Headphone</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Attenuation Value</td>
<td>30.2</td>
<td>30.4</td>
<td>15.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.2</td>
</tr>
</tbody>
</table>

VII. Noise Attenuation Values in dB for a Reference Speech Reception Threshold Value of 20 dB HL

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Headphone</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Attenuation Value</td>
<td>25.2</td>
<td>25.4</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
</tbody>
</table>
APPENDIX G

Instructions to the Participants

I. Instructions for the Word Recognition Test in Quiet: Main Experiment and Pilot Experiments 1 and 2

You will be listening to some words. Each time you hear a word you need to indicate what word you heard. There will be two choices displayed on the computer monitor and you will need to click the mouse on the word that you heard. Sometimes it may be difficult to tell what the word was but you must choose the word that sounds like the best match. After you respond you will hear the next word. Do you have any questions?

The first words you will hear will be _____ as in _______ and _____ as in _______. We will take a short break between each new set of words.

This time you will hear the same words but they will be spoken at a faster rate.

The next words will be ____ as in _______ and _____ as in ___________. This time you will hear the same words but they will be spoken at a faster rate.

(Repeat the above paragraph until each word-pair continuum is tested in the order specified for each listener).

Examples of the words comprising the stimulus continuums:

1. SLIT: The coins fit into the small slit.
2. SPLIT: With one slice the pie was split in half.

3. CASH: That merchant accepts only cash.

4. CATCH: The outfielder’s catch saved the game.

5. DISH: The waiter dropped the dish.

6. DITCH: The workers spent the afternoon digging the ditch.

7. SOON: The play will be starting soon.

8. SPOON: I need a spoon for my soup.

9. I am not familiar with the speaker’s next topic.*

10. That movie was the top pick at the box office.*

*Only used in the pilot experiments.
II. Instructions for the Word Recognition Test in Quiet: Pilot Experiment 3

You will be listening to some words. Each time you hear a word you need to indicate what word you heard. There will be four choices displayed on the computer monitor and you will need to click the mouse on the word that you heard. Sometimes it may be difficult to tell what the word was but you must choose the word that sounds like the best match. After you respond you will hear the next word. Do you have any questions?

The first words you will hear will be _____ as in _______, _____ as in _______, _____ as in _______, and _____ as in _______. We will take a short break between each new set of words.

This time you will hear the same words but they will be spoken at a faster rate.

The next words you will hear will be _____ as in _______, _____ as in _______, _____ as in _______, and _____ as in _______.

This time you will hear the same word but they will be spoken at a faster rate.

Examples of words comprising the stimulus continua can be found in section I Appendix G. Note that the ‘topic’-‘top pick’ continua were not assessed in this pilot experiment.
III. Instructions for the Word Recognition Test in Noise

You will be listening to some words. These words will be presented with noise in the background. Do your best to ignore this noise and focus on the words. Each time you hear a word you need to indicate what word you heard. There will be 2 choices displayed on the computer monitor and you will need to click the mouse on the word that you heard. After you respond you will hear the next word.

The level of the background noise will increase after each set of test items. It will become difficult to tell what the word is but you must choose the word that sounds like the best match. It will take about 10 minutes to test one range of noise levels. Once one set of noise levels is completed there will be an opportunity for a break before the next words are presented at a range of noise levels.

The first words you will hear will be _____ as in _____ and _____ as in ___. These words will be tested with five short experiments as the level of the noise increases across the experiments.

This time you will hear the same words but they will be spoken at a faster rate. Again the words will be tested with five short experiments and the noise level will be increased from one experiment to the next.

The next words you will hear will be _____ as in _____ and _____ as in ___. As before, the level of background noise will increase across five short experiments. This time you will hear the same words but spoken at a faster rate. (Repeat
the above paragraph until each word-pair continuum is tested in the order specified for
each listener).

Examples of the words comprising the stimulus continua can be found in section I
Appendix G.
IV. Instructions for the Gap Detection Test

The purpose of this test is to find the smallest silent interval, or gap, that you can hear in a sound. To begin the test you need to push the middle button on this response box. You will then hear two beep sounds. The green light on this box will light up when you hear the first sound and the red light will light up when you hear the second sound. One of these sounds will have a gap in it and one will not. Once you have heard both beeps you need to indicate which of the sounds had the gap in it. If you think that the first sound had a gap in it, then push the button under the green light. If you think that the gap was in the second sound, then push the button under the red light. After you respond a light will flash above the correct answer.

To hear the next two sounds press the middle button on this response box. You need to press this button each time to begin a new trial. The gap you are listening for will get smaller and harder to hear. This is normal. Just do your best and indicate which beep had to gap in it.

There will be some noise in the background throughout the test. Please ignore this noise and listen carefully for the gap. A set of trials will end when all three lights flash on this response box. At this time you will have a chance for a break or we can proceed with the next set of trials. The duration of the beeps will vary from very short to long in the different sets of trials. Your job each time is to indicate which sound has the gap.
APPENDIX H

Participants’ Test Ear Pure-Tone Thresholds (dB HL) for the Test Ear

<table>
<thead>
<tr>
<th>Participant</th>
<th>Test Ear</th>
<th>Test Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>250</td>
</tr>
<tr>
<td>Y8-1</td>
<td>R</td>
<td>5</td>
</tr>
<tr>
<td>Y-2</td>
<td>L</td>
<td>-5</td>
</tr>
<tr>
<td>Y-3</td>
<td>R</td>
<td>0</td>
</tr>
<tr>
<td>Y-4</td>
<td>L</td>
<td>5</td>
</tr>
<tr>
<td>Y-5</td>
<td>R</td>
<td>-5</td>
</tr>
<tr>
<td>Y-6</td>
<td>R</td>
<td>10</td>
</tr>
<tr>
<td>Y-7</td>
<td>R</td>
<td>5</td>
</tr>
<tr>
<td>Y-8</td>
<td>R</td>
<td>-5</td>
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<tr>
<td>O9-1</td>
<td>L</td>
<td>10</td>
</tr>
<tr>
<td>O-2</td>
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<td>O-3</td>
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<tr>
<td>O-4</td>
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<td>O-5</td>
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<td>R</td>
<td>15</td>
</tr>
<tr>
<td>O-8</td>
<td>R</td>
<td>5</td>
</tr>
</tbody>
</table>

8 Y = young
9 O = Old
## APPENDIX I

### Participants’ Characteristics

<table>
<thead>
<tr>
<th>Participant</th>
<th>Pure Tone Average (dB HL) R</th>
<th>SRT (dB HL) R</th>
<th>Age</th>
<th>Years of Education</th>
<th>Handedness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y(^{10})-1</td>
<td>3.33</td>
<td>3.33</td>
<td>5</td>
<td>5</td>
<td>28</td>
</tr>
<tr>
<td>Y-2</td>
<td>-3.33</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>Y-3</td>
<td>1.67</td>
<td>3.33</td>
<td>5</td>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td>Y-4</td>
<td>1.67</td>
<td>1.67</td>
<td>5</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Y-5</td>
<td>1.67</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Y-6</td>
<td>1.67</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>26</td>
</tr>
<tr>
<td>Y-7</td>
<td>1.67</td>
<td>3.33</td>
<td>0</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>Y-8</td>
<td>-3.33</td>
<td>-1.67</td>
<td>0</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>O(^{11})-1</td>
<td>10</td>
<td>3.33</td>
<td>15</td>
<td>5</td>
<td>72</td>
</tr>
<tr>
<td>O-2</td>
<td>18.33</td>
<td>13.33</td>
<td>20</td>
<td>15</td>
<td>74</td>
</tr>
<tr>
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<td>11.67</td>
<td>10</td>
<td>20</td>
<td>68</td>
</tr>
<tr>
<td>O-4</td>
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<td>10</td>
<td>10</td>
<td>10</td>
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<tr>
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<td>6.67</td>
<td>10</td>
<td>10</td>
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<tr>
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<td>6.67</td>
<td>15</td>
<td>5</td>
<td>72</td>
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<tr>
<td>O-7</td>
<td>8.33</td>
<td>3.33</td>
<td>10</td>
<td>10</td>
<td>71</td>
</tr>
<tr>
<td>O-8</td>
<td>20</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>73</td>
</tr>
</tbody>
</table>

\(^{10}\) Y = Young  
\(^{11}\) O = Old
APPENDIX J

Summary of Significant Correlations

I. Summary of the Significant Correlations Between Word Identification Measures in Quiet and Gap Detection and Pure-Tone Thresholds

| Group           | Rate | Correlation       | PT value          | |r| value | p value |
|-----------------|------|-------------------|-------------------|--------|---------|---------|
| Older Adults    | Fast | ‘Cash’ function slope | PT θ at 1 kHz | 0.04   | p<0.05  |
| Older Adults    | Fast | ‘Cash’ function slope | PT θ at 2 kHz | 0.03   | p<0.05  |
| Older Adults    | Fast | ‘Dish’ 80% point | PT θ at 2 kHz | 0.04   | p<0.05  |
| Older Adults    | Fast | ‘Dish’ 80% point | PT θ at 8 kHz | 0.01   | p≤0.01  |
| Older Adults    | Fast | ‘Dish’ 50% point | PT θ at 8 kHz | 0.04   | p<0.05  |
| Older Adults    | Fast | ‘Dish’ 20% point | PT θ at 8 kHz | 0.05   | p≤0.05  |
| Younger Adults  | Fast | ‘Slit’ 80% point | PT θ at .25 kHz | 0.05   | p≤0.05  |
| Younger Adults  | Fast | ‘Slit’ 80% point | PT θ at 2 kHz | 0.02   | p<0.05  |
| Younger Adults  | Fast | ‘Slit’ function slope | PT θ at 2 kHz | 0.01   | p≤0.01  |
| Older Adults    | Fast | ‘Slit’ 20% point | GD θ, 5 ms markers | 0.01   | p≤0.01  |
| Older Adults    | Slow | ‘Slit’ 50% point | GD θ, 400 ms markers | 0.03   | p<0.05  |
| Older Adults    | Slow | ‘Soon’ 80% point | PT θ at .25 kHz | 0.00   | p<0.01  |
| Older Adults    | Slow | ‘Soon’ 80% point | PT θ at 8 kHz | 0.00   | p<0.01  |
| Older Adults    | Slow | ‘Soon’ 50% point | PT θ at .25 kHz | 0.00   | p<0.01  |
| Older Adults    | Slow | ‘Soon’ 20% point | PT θ at .25 kHz | 0.00   | p<0.01  |
| Older Adults    | Slow | ‘Soon’ 20% point | PT θ at 8 kHz | 0.03   | p<0.05  |

Note: PT= pure-tone, θ= threshold, and GD= gap detection
II. Summary of the Significant Correlations Between Word Identification Measures in Noise (Slow Speaking Rate) and Gap Detection and Pure-Tone Thresholds

| Group          | Correlation                      | $|r|$ value | p value |
|----------------|----------------------------------|-----------|---------|
| Younger Adults | S:N at 50%: ‘Slit’ GD θ, 5 ms markers | 0.01      | p≤0.01  |
| Younger Adults | % correct at S:N 10: ‘Split’ PT θ at 2 kHz | 0.05      | p≤0.05  |
| Younger Adults | % correct at S:N 10: ‘Split’ PT θ at 3 kHz | 0.02      | p<0.05  |
| Younger Adults | % correct at S:N -5: ‘Split’ PT θ at 2 kHz | 0.03      | p<0.05  |
| Younger Adults | % correct at S:N -5: ‘Split’ PT θ at 3 kHz | 0.01      | p≤0.01  |
| Younger Adults | % correct at S:N -5: ‘Split’ PT θ at 8 kHz | 0.01      | p≤0.01  |
| Younger Adults | % correct at S:N -15: ‘Ditch’ PT θ at 0.5 kHz | 0.02      | p<0.05  |
| Younger Adults | % correct at S:N -15: ‘Ditch’ PT θ at 3 kHz | 0.04      | p<0.05  |
| Younger Adults | % correct at S:N 10: ‘Dish’ PT θ at 8 kHz | 0.02      | p<0.05  |
| Older Adults   | % correct at S:N 10: ‘Dish’ PT θ at 0.5 kHz | 0.00      | p<0.01  |
| Older Adults   | % correct at S:N 10: ‘Dish’ PT θ at 2 kHz | 0.02      | p<0.05  |
| Older Adults   | S:N at 50%: ‘Dish’ PT θ at 3 kHz | 0.03      | p<0.05  |
| Older Adults   | S:N at 70%: ‘Ditch’ GD θ, 10 ms markers | 0.05      | p≤0.05  |
| Younger Adults | S:N at 70%: ‘Cash’ PT θ at 2 kHz | 0.01      | p≤0.01  |
| Younger Adults | S:N at 70%: ‘Cash’ PT θ at 3 kHz | 0.01      | p≤0.01  |
| Younger Adults | S:N at 50%: ‘Cash’ PT θ at 2 kHz | 0.01      | p≤0.01  |
| Younger Adults | S:N at 50%: ‘Cash’ PT θ at 2 kHz | 0.01      | p≤0.01  |
| Younger Adults | % correct at S:N -15: ‘Cash’ GD θ, 400 ms markers | 0.03      | p<0.05  |
| Older Adults | % correct at S:N 10: ‘Cash’ | PT θ at .5 kHz | 0.01 | p≤0.01 |
| Older Adults | % correct at S:N 10: ‘Cash’ | PT θ at 2 kHz | 0.00 | p<0.01 |
| Older Adults | % correct at S:N –5: ‘Cash’ | PT θ at .5 kHz | 0.01 | p≤0.01 |
| Older Adults | % correct at S:N –5: ‘Cash’ | PT θ at 2 kHz | 0.00 | p<0.01 |
| Older Adults | % correct at S:N –15: ‘Cash’ | PT θ at 1 kHz | 0.04 | p<0.05 |
| Older Adults | % correct at S:N 10: ‘Catch’ | GD θ, 400 ms markers | 0.00 | p<0.01 |
| Older Adults | % correct at S:N –5: ‘Catch’ | GD θ, 400 ms markers | 0.01 | p≤0.01 |
| Older Adults | S:N at 70%: ‘Catch’ | GD θ, 400 ms markers | 0.01 | p≤0.01 |
| Younger Adults | % correct at S:N 10: ‘Soon’ | PT θ at 2 kHz | 0.00 | p<0.01 |
| Younger Adults | S:N at 50%: ‘Soon’ | PT θ at 2 kHz | 0.00 | p<0.01 |
| Younger Adults | % correct at S:N 10: ‘Soon’ | GD θ, 400 ms markers | 0.00 | p<0.01 |
| Younger Adults | % correct at S:N –15: ‘Soon’ | PT θ at 8 kHz | 0.00 | p<0.01 |
| Younger Adults | S:N at 50%: ‘Soon’ | GD θ, 400 ms markers | 0.00 | p<0.01 |
| Younger Adults | % correct at S:N –5: ‘Soon’ | PT θ at .5 kHz | 0.03 | p<0.05 |
| Younger Adults | % correct at S:N –5: ‘Soon’ | GD θ, 0.83 ms markers | 0.04 | p<0.05 |
| Younger Adults | % correct at S:N –15: ‘Soon’ | GD θ, 5 ms markers | 0.00 | p<0.01 |
| Younger Adults | S:N at 70%: ‘Soon’ | PT θ at 8 kHz | 0.03 | p<0.05 |
| Younger Adults | % correct at S:N 10: ‘Soon’ | GD θ, 80 ms markers | 0.02 | p<0.05 |

Note: Correlations could not be computed for the older listeners for words ‘slit’, ‘split’, ‘soon’, and ‘spoon’ due to an insufficient sample size. PT= pure-tone, θ= threshold, and GD= gap detection.
### III. Summary of the Significant Correlations Between Word Identification Measures in Noise (Fast Speaking Rate) and Gap Detection and Pure-Tone Thresholds

<p>| Group             | Correlation                        | $|r|$ value | p value |
|-------------------|------------------------------------|-----------|---------|
| Younger Adults    | % correct at S:N -15: 'Dish'       | 0.05      | $p \leq 0.05$ |
| Younger Adults    | % correct at S:N -15: 'Dish'       | 0.01      | $p \leq 0.01$ |
| Younger Adults    | S:N at 70%: 'Dish'                | 0.02      | $p &lt; 0.05$ |
| Younger Adults    | S:N at 50%: 'Dish'                | 0.03      | $p &lt; 0.05$ |
| Younger Adults    | S:N at 50%: 'Dish'                | 0.02      | $p &lt; 0.05$ |
| Younger Adults    | S:N at 50%: 'Dish'                | 0.03      | $p &lt; 0.05$ |
| Younger Adults    | % correct at S:N 10: 'Ditch'       | 0.05      | $p \leq 0.05$ |
| Younger Adults    | % correct at S:N 10: 'Ditch'       | 0.00      | $p \leq 0.01$ |
| Younger Adults    | % correct at S:N -5: 'Ditch'       | 0.00      | $p &lt; 0.01$ |
| Younger Adults    | % correct at S:N -5: 'Ditch'       | 0.03      | $p &lt; 0.05$ |
| Younger Adults    | % correct at S:N -5: 'Ditch'       | 0.05      | $p \leq 0.05$ |
| Younger Adults    | S:N at 70%: 'Ditch'                | 0.01      | $p \leq 0.01$ |
| Younger Adults    | S:N at 70%: 'Ditch'                | 0.02      | $p &lt; 0.05$ |
| Younger Adults    | S:N at 70%: 'Slit'                 | 0.01      | $p \leq 0.01$ |
| Younger Adults    | % correct at S:N 10: 'Split'       | 0.00      | $p &lt; 0.01$ |
| Younger Adults    | % correct at S:N -5: 'Split'       | 0.01      | $p \leq 0.01$ |
| Younger Adults    | % correct at S:N -5: 'Split'       | 0.04      | $p &lt; 0.05$ |
| Younger Adults    | S:N at 70%: 'Soon'                 | 0.00      | $p &lt; 0.01$ |</p>
<table>
<thead>
<tr>
<th>Younger Adults</th>
<th>% correct at S:N -5: 'Spoon'</th>
<th>GD 0, 80 ms markers</th>
<th>0.04</th>
<th>p&lt;0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger Adults</td>
<td>S:N at 70%; 'Spoon'</td>
<td>GD 0, 80 ms markers</td>
<td>0.05</td>
<td>p≤0.05</td>
</tr>
</tbody>
</table>

Note: Correlations could not be computed for the older listeners for words 'slit', 'split', 'soon', and 'spoon' and for the younger listeners for the words 'cash' and 'catch' due to an insufficient sample size. PT= pure-tone, θ= threshold, and GD= gap detection.
IV. Summary of Correlations Between Pure-Tone Thresholds and Gap Detection

Thresholds

<table>
<thead>
<tr>
<th>Group</th>
<th>Pure-Tone θ</th>
<th>Gap Detection θ</th>
<th>r  value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
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<td>2 kHz</td>
<td>5 ms markers</td>
<td>0.05</td>
<td>p≤0.05</td>
</tr>
<tr>
<td>Younger Listeners</td>
<td>3 kHz</td>
<td>80 ms markers</td>
<td>0.03</td>
<td>p&lt;0.05</td>
</tr>
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<td>Younger Listeners</td>
<td>4 kHz</td>
<td>5 ms markers</td>
<td>0.03</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Older Listeners</td>
<td>1 kHz</td>
<td>10 ms markers</td>
<td>0.04</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Older Listeners</td>
<td>1 kHz</td>
<td>400 ms markers</td>
<td>0.05</td>
<td>p≤0.05</td>
</tr>
<tr>
<td>Older Listeners</td>
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<td>0.83 ms markers</td>
<td>0.03</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Older Listeners</td>
<td>4 kHz</td>
<td>5 ms markers</td>
<td>0.05</td>
<td>p≤0.05</td>
</tr>
</tbody>
</table>

Note: θ= threshold