DOES SPEAKER AGE AFFECT SPEECH PERCEPTION IN NOISE IN OLDER ADULTS?

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Abstract

Purpose: To investigate the effects of speaker age, speaker gender, semantic context, signal-to-noise ratio (SNR) and a listener's hearing status on speech recognition and listening effort in older adults. We examined the hypothesis that older adults would recognize less speech and exert greater listening effort when listening to the speech of younger versus older adult speakers.

Method: Speech stimuli were recorded from 12 adult speakers classified as "younger" (three males and three females aged 18-31 years) and "older" (three males and three females aged 69-89) respectively. A computer-based subjective rating was conducted to confirm that the speakers were representative of younger and older speakers. Listeners included 20 older adults (aged 65 years and above), who were divided into two age-matched groups with and without hearing loss. All listening and speaking participants in the study were native speakers of New Zealand English. A dual-task paradigm was used to measure speech recognition and listening effort; the primary task involved recognition of target words in sentences containing either high or low contextual cues, while the secondary task required listeners to memorise the target words for later recall, following a set number of sentences. Listening tasks were performed with a variety of listening conditions (quiet, +5 dB SNR and 0dB SNR).

Results: There were no overall differences in speech recognition scores or word recall scores for the 20 older listeners, when listening to the speech of the younger versus older speakers. However, differential effects of speaker group were observed in the two semantic context conditions (high versus low context). Older male speakers were the easiest to understand when semantic context was low; however, for sentences with high semantic context, the older male group were the most difficult to understand. Word recall scores were also significantly higher in the most challenging listening condition (low semantic context, 0 dB SNR), when the speaker was an older male.

Conclusion: Differential effects of speaker group were observed in the two semantic context conditions (high versus low context) suggesting that different speech cues were used by listeners, as the level of context varied. The findings provide further evidence that, in challenging listening conditions, older listeners are able to use a wide range of cues, such as prosodic features and semantic context to compensate for a degraded signal. The availability of these cues depends on characteristics of the speaker, such as rate of speech and prosody, as well as characteristics of the listener and the listening environment.

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Introduction

A large proportion of the older population have a hearing loss great enough to affect speech recognition and impair communication (Gates & Mills, 2005; Gates, 2009), and this can have a significant negative impact on social interaction and quality of life in this population. Even when audiometric thresholds are matched for younger and older listeners, many older adults experience greater difficulties in speech understanding than their younger counterparts, because of declines in auditory processing and cognitive function (Martin & Jerger, 2005). Age-related differences are exaggerated in situations where listening conditions are less than ideal. Many studies have reported disproportionately poorer speech recognition in older adults when listening to speech in the presence of background noise (Gordon-Salant & Fitzgibbons, 2004; Wilson et al., 2010), or when target material becomes more complex (Wingfield & Tun, 2001).

Factors related to the speech signal itself, such as speech rate, the number of speakers within a stimulus set, semantic contextual support and foreign-accent, also exert a significant influence. Recent studies have also begun to examine the influence of speaker age on speech understanding and listener effort in older adults (McAuliffe, Wilding, Rickard, & O'Beirne, 2012; Spencer, 2011), with conflicting results. McAuliffe et al. (2012) found no significant effect of speaker age on speech recognition scores in a group of older listeners; however, participants reported significantly greater perceived listening effort when listening to the older speakers. A follow-up study by Spencer (2011), using a single older and younger speaker and a dual task paradigm to measure listener effort, found that both word recognition scores in the primary task and word recall scores in the secondary task were significantly lower when listening to the younger speaker. The difference was greater for low context sentences and for sentences with background noise. It was proposed that this finding was due in part to the faster speech rate of the younger speaker.

The present study extends prior work from this laboratory and aims to investigate the effect of speaker age on speech understanding in older listeners. In this investigation, multiple younger and older speakers, both male and female, are included. It is anticipated that this approach will reduce the possibility of individual intelligibility differences influencing the results, and better reflect the perceptual processes used to understand speech in natural listening conditions involving more variable stimuli (Mullenix & Pisoni, 1990; Sommers, Nygaard, & Pisoni, 1994).

Presbycusis

Age-related hearing loss, or presbycusis, is generally characterized by a symmetrical, sloping, high frequency sensorineural hearing loss, difficulty understanding speech in the presence of background noise and slowed central processing of acoustic information (Gates & Mills, 2005). While hearing aids enhance the audibility of speech, they do not compensate for the decreased frequency resolution and decreased temporal resolution of sensorineural hearing loss. Nor do they compensate for the age-related declines in working memory and processing speed, which also affect speech understanding in this population (Craik, 1994).

Although presbycusis affects a large proportion of the older population, it is not a universal condition, and many factors, both genetic and environmental, can affect its onset and severity. Environmental factors which have an adverse effect on hearing are known to include noise exposure, exposure to industrial chemicals, systemic disease and ototoxic drugs, such as aminoglycosides and chemotherapeutic agents (Gates & Mills, 2005; Liu & Yan, 2007; Van

Eyken, Van Camp & Van Laer, 2007). Willott, Chisolm, & Lister (2001) define presbycusis as "hearing impairment associated with various types of auditory system dysfunction, peripheral or central that accompany aging, and cannot be accounted for by extraordinary ototraumatic, genetic or pathological conditions". It is, however, difficult to isolate the effects of age from other life factors.

Classification of presbycusis types. Although the entire auditory system is affected by age-related change, structural changes to the outer and middle ear do not generally appear to have an adverse effect on audiometric function or speech comprehension (Liu & Yan, 2007). Cochlear degeneration, however, has a significant effect on both.

Schuknecht (1964) related audiometric patterns in presbycusis to pathophysiological changes in the auditory system. His findings, based on temporal bone examinations, led to the classic definition of six types of presbycusis. The first of these, sensory presbycusis, results from loss of outer hair cells, and is associated with a steeply sloping high frequency hearing loss (Schuknecht, 1999, as cited in Demeester et al., 2009). The second, strial presbycusis, is due to atrophy of the stria vascularis and is associated with a flat or slightly sloping audiogram configuration (Demeester et al., 2009). Neural presbycusis is due to degeneration in the population of neurons, and is associated with poorer than expected speech recognition. Other types of presbycusis are cochlear conductive, involving loss of elasticity in the basilar membrane, mixed presbycusis, involving pathologic changes in more than one auditory structure and indeterminate presbycusis, involving submicroscopic changes in the cochlea and accounting for up to 25% of cases (Gates & Mills, 2005).

It is important to recognize that, while presbycusis is generally associated with the characteristic loss of high frequency threshold sensitivity, age-related hearing loss is highly variable and may be characterized by distinct audiometric patterns. A large-scale study by Demeester et al. (2009) based on the audiograms of 1147 healthy males and females aged 55-65 years, found three distinct audiogram configurations, namely, “flat” (37%), “high-frequency gently sloping” (35%) and “high frequency steeply sloping” (27%). The “flat” configuration was significantly more common in older women, while the “high frequency steeply sloping” configuration was more common in males. This study also found a significant correlation between the occurrence of “high frequency, steeply sloping” audiograms and the amount of noise/solvent exposure (Demeester et al., 2009). In general, males experience a faster progression of hearing loss and a greater threshold shift, particularly in the high frequencies, than females (Gates, Cooper, Kannel, & Miller, 1990; Mills, Schmiedt, Schulte, & Dubno, 2006).

Prevalence of age-related hearing loss. A number of studies have reported the prevalence of hearing loss among the elderly population. However, because of differences both in methods of data collection and in criteria for defining hearing loss, these estimates vary greatly, making comparison difficult. A recent study based on census measures of self report found that the prevalence of hearing loss among older Americans was 16.8% among those aged 70-79 years and 45.4% in those aged 80 years and over (Dillon, Gu, Hoffman, & Ko, 2010), with a higher level in men than women. A New Zealand study, based on data from the 2001/2002 census, reported the prevalence of hearing impairment causing disability as 22.1% for those aged 65 years and over, and 28.5% for those aged 75 years and over (Greville, 2005). It is likely, however that studies based on self report underestimate the prevalence of hearing loss, either because older people are unaware of a hearing loss or because of the stigma associated with hearing loss (Cruickshanks et al., 1998).

Estimates of prevalence based on audiometric data also vary greatly according to the specific threshold criteria used to define hearing loss and whether the better or worse ear is used for the classification of hearing impairment. A large-scale population study, based on the Framingham cohort (Gates et al., 1990), found that 29% of those tested (aged 60-95 years) had a hearing impairment, with a generalized worsening of thresholds with increasing age. Hearing impairment was defined as a pure-tone average (PTA) at 0.5, 1.0 and 2.0 kHz of 26 dB HL or greater in the better ear. Another population-based study, the Epidemiology of Hearing Loss study (Cruickshanks et al., 1998), measured the prevalence of hearing loss in adults aged 48-92 years (average 65.8 years) in Beaver Dam, Wisconsin. The presence of a hearing loss was determined by PTA of thresholds at 0.5, 1, 2 and 4 kHz, greater than 25 dB in the worse ear. The prevalence of hearing loss in this later study was reported as 45.9%.

Speech Perception in Older Adults

The speech recognition difficulties experienced by many older listeners involve the interaction of both listener and signal characteristics. Deterioration in peripheral hearing, central auditory processing and cognitive abilities together account for a large proportion of the speech understanding difficulties experienced by older adults (Martin & Jerger, 2005). Characteristics of the auditory environment, such as background noise, as well as characteristics of the speech signal itself, such as rate of speech, number of speakers, semantic contextual support, and quality of the speech signal, also contribute to these difficulties.

Speech perception in older adults: Characteristics of the listener. Much of the research into age-related changes in speech perception originated from the Report of the Working Group on Speech Understanding and Aging, Committee on Hearing and Bioacoustics and Biomechanics, US National Research Council (CHABA, 1988). This report outlined three hypotheses regarding declines in spoken language comprehension in older adults, which related to changes in peripheral auditory function, central auditory processing and cognitive function (CHABA, 1988; Gates, 2009).

Peripheral auditory mechanisms. Age-related changes in peripheral mechanisms of the auditory system are reflected in the frequency specific threshold elevation shown in the audiograms of older individuals, most notably at high frequencies. Sensory cell degeneration typically affects outer hair cells and supporting cells at the extreme basal (high frequency) end of the cochlea first, leading to decreased hearing sensitivity in the high frequencies. This has a negative impact on the ability to understand speech in noisy or reverberant places (Gates, 2009; Liu & Yan, 2007). As the sensory loss progresses to the 2-4 k Hz range, many consonants become inaudible which makes speech perception in all situations more effortful.

Sensorineural hearing loss results not only in decreased audibility of speech sounds, but also in decreased frequency resolution, which depends primarily on the filtering that takes place in the cochlea (Moore, 1986, as cited in Peters & Moore, 1992). This filtering is highly dependent on the integrity of the outer hair cells, which are responsible for the active process in the cochlea and thereby, for the sharp frequency tuning along the basilar membrane (Patuzzi, 2002). Many studies have investigated the effect of sensorineural hearing loss on frequency selectivity (Peters & Moore, 1992; Dubno & Dirks, 1989; Dubno & Schaefer, 1992). Peters & Moore (1992) compared auditory filter shapes for young and elderly listeners who were matched for audiometric loss and concluded that filters tended to broaden with increasing hearing loss, rather than as a function of increasing age. Nevertheless, both age-related strial degeneration and loss of outer hair cells affect the cochlear active process and thus, the ability of older listeners with hearing loss to resolve frequency components of speech.

Humes (1996) argued that high-frequency sensorineural hearing loss was responsible for most of the variation in speech perception ability of older listeners, at least for speech in quiet or minimally demanding listening situations. This was supported by studies comparing older hearing-impaired listeners with audiometrically-matched younger listeners (Souza Turner,1994; Van Rooij & Plomp, 1992). However, older adults often demonstrate poorer speech perception than younger adults even when hearing thresholds are equated for the two groups (Sommers & Danielsen, 1999). Age-related deficits in central auditory processing, which may co-occur with peripheral hearing loss or be present when auditory thresholds are within normal limits, also play an important role in speech recognition (Humes, 1996).

Auditory processing. Age-related auditory processing deficits are salient in tasks requiring temporal resolution (the ability to maintain the ordering of rapidly arriving sounds), which is critically important for speech perception (Martin & Jerger, 2005; Pichora-Fuller, 2003; Pichora-Fuller & Souza, 2003; Wingfield, Tun, & McCoy, 2005). Speech cues in the temporal domain include supra-segmental or prosodic cues, which support syntactic and affective information, segmental cues which influence phonemic identification and sub-segmental periodicity or synchrony cues which influence voice differentiation (Pichora-Fuller & Souza, 2003; Schneider, Daneman, & Pichora-Fuller, 2002)

With regard to suprasegmental processing, research suggests that temporal processing at the prosodic level is relatively unaffected by aging (Schneider et al., 2002; Wingfield, Lindfield, & Goodglass, 2000). Prosody includes all suprasegmental acoustic correlates of speech, including the pauses that sometimes occur between important syntactic elements of a sentence and lengthening of final vowels in words preceding clause boundaries. Prosodic marking, therefore, plays an important role in the lexical and syntactic processing of speech (Schneider et al., 2002; Wingfield, Wayland, & Stine, 1992).

In an experimental study to determine the degree to which elderly listeners relied on appropriate prosody to overcome the effects of rapid speech rates, Wingfield et al. (1992), compared a group of 24 older listeners (61-82 years) and a group of 24 younger listeners (18-30 years) with regard to their reliance on prosodic cues. Both groups listened to and recalled sentences presented at various speech rates. Half the sentences were presented with a normal prosodic pattern which reinforced the lexically defined syntactic structure of the sentence, while the other half had a prosodic pattern that conflicted with that structure. Both younger and older groups showed better sentence recall at slower speech rates and when the prosodic patterns supported the syntactic structure of the sentence. When prosody was in conflict with the syntactic structure of the sentence, however, the older listeners were more likely than the younger group to produce responses with a syntactic structure that was consistent with the prosodic pattern. The researchers proposed that greater reliance on prosody in older listeners may be an adaptive mechanism to compensate for declines in peripheral auditory mechanisms and cognitive processes.

Wingfield et al. (2000) also studied the extent to which young and older adults can make use of prosodic information in word recognition. Participants attempted to identify words from their onset only, onset plus white noise that indicated the duration of the target word, and onset plus low-pass-filtered signal that indicated the number of syllables and syllabic stress of the target word. Although the older adults required longer stimulus durations for word recognition in all three conditions, they were able to benefit equally from the addition of prosodic information about the word.

While the preceding studies suggest that auditory processing at the suprasegmental level is relatively well-preserved in older listeners, research suggests that there are age-related differences at the segmental level which may have a negative effect on word identification. Gap detection thresholds have been found to be higher in older adults than in younger adults, and gap detection thresholds are generally not predictable from the pure tone audiogram. (Gordon-Salant & Fitzgibbons, 1993; Schneider & Hamstra, 1999). For short marker durations of less than 250 ms (characteristic of speech sounds), gap detection thresholds are significantly larger (Schneider & Hamstra, 1999) in older adults.

Gaps in speech provide segmental information that marks some types of phonemic contrast, such as the presence or absence of stop consonants in English. Schneider et al. (2002) found that older listeners had significantly greater difficulty than younger listeners identifying speech contrasts when a gap was the differentiating cue (e.g. cash/catch), especially in fast speech.

Age related changes in sub-segmental processes affect other speech cues in the temporal domain, including "fine-structure" variations in formant patterns, fundamental frequency and harmonic patterns (Pichora-Fuller & Souza, 2003; Schneider et al., 2002). Formant cues are important for differentiating individual voices. This is particularly important when there are competing speech signals, since they allow the listener to identify and attend to the target signal. Extraction of fine-structure cues relies on neural synchrony, the ability of auditory neurons to phase-lock to the frequency of the signal, providing an important cue for frequency coding, particularly at low frequencies. Age-related loss of neural temporal synchrony at different levels of the auditory system may affect the ability of older individuals to separate the target signal from competing speech noise, thus making many listening situations difficult, even in the absence of a clinical hearing loss (Frisina et al., 2001, as cited in Pichora-Fuller & Souza, 2003).

Pichora-Fuller, Schneider, McDonald, Pass, &Brown (2007), hypothesized that a loss of neural synchrony might contribute to age-related difficulties in understanding speech in noise. In a study of twelve young adult listeners, a loss of synchrony, or reduced phase-locking, was simulated by increasing the temporal jitter of the signal presented to the listeners in a range of signal-to-noise conditions. Jittering the low-frequency speech components resulted in similar word identification scores for the younger adults to those reported for older adults with good hearing, supporting the hypothesis that age-related decline in neural synchrony indeed contributed to the decline in speech comprehension in noise commonly experienced by older adults.

Cognitive factors. Cognitive changes associated with aging also affect speech understanding. While crystallized linguistic and world knowledge stored in long-term memory are generally thought to be well-preserved in old age, fluid or dynamic processing of information is known to decline with age (Pichora-Fuller & Singh, 2006; Salthouse, 1996). Some of the main dynamic processing components affected include speed of processing, attention to relevant information (and inhibition of distraction), and working memory.

Speed of processing. An age-related generalized reduction in processing speed is widely thought to be a factor in the difficulties experienced by older listeners in understanding rapid speech (Wingfield, 1996; Wingfield, Poon, Lombardi & Lowe, 1985). In an experiment comparing the performance of younger and older adults when speech was artificially speeded to speech rates more than twice the rate of normal conversation (up to 425 wpm), effects of speeding were found to be differentially greater for the older group (Wingfield et al., 1985). Age-related effects of time compression were reduced, however, when semantic and syntactic information was available to the listeners, compared to performance on random strings of words.

However, it is difficult to separate the effects of sensory impairment and cognitive slowing, since speeding speech also distorts the signal (Pichora-Fuller & Singh, 2006; Schneider, Daneman, & Murphy, 2005). Schneider et al. (2005) found that when listening conditions were matched for younger and older adults, by speeding speech in ways that minimized distortion, age-related effects were not apparent. This lent support to the view that sensory hearing loss results in a degraded representation of the speech signal, which affects higher order cognitive processes.

Attention to relevant information and inhibition of distraction. Inhibitory control, the ability to inhibit irrelevant information during cognitive processing, is also negatively affected by aging. (Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; Hasher & Zacks, 1988, cited in Pichora-Fuller & Singh, 2006). Studies suggest that selective attention involves both excitatory and inhibitory processes, by which relevant target information is highlighted, while unselected stimuli are actively suppressed (Tipper, 1985 cited in Kane et al., 1994). Hasher and Zacks (1988) proposed that inhibition of unselected stimuli was important in a number of cognitive tasks including memory and language comprehension, and that these inhibitory mechanisms were deficient in older adults. This proposal was supported by Hasher and Zacks' (1991) study, which compared two groups of 30 younger and 30 older adults in a distractor suppression experiment, which also allowed for increased suppression time. Reliable suppression effects were observed for the younger but not the older adults.

Working memory. Age-related declines in working memory capacity also contribute to speech comprehension difficulties in the elderly, particularly the manipulation of stored information and the coordination of simultaneous storage and processing operations. Working memory may be conceptualized as "a capacity-limited system that both stores recent information and provides a computational mental workspace in which the recently stored information can be manipulated and integrated with knowledge stored in long-term memory" (Pichora-Fuller & Singh, 2006).

In a study of 24 older adults with hearing loss, and 12 younger adults with normal hearing, Humes & Floyd (2005) used a Simon-memory paradigm with three stimulus modalities, auditory, visual and auditory-visual, to measure both working memory capacity and sequence learning in the two groups. In this study, the younger group outperformed the older group on all measures of working-memory capacity and sequence learning, though group differences were greater for the sequence learning tasks. Results were equivalent for both auditory and non-auditory modalities, suggesting that deficits in working memory were not attributable to modality-specific auditory processing decline, but represented a general cognitive decline.

Recent studies have shown that working memory is a crucial factor in speech understanding in noise for older listeners with hearing impairment (Ronnberg, Rudner, Lunner, & Zekveld, 2010; Rudner, Ronnberg, & Lunner, 2011). Ronnberg's (2003) model for Ease of Language Understanding (ELU) describes the interaction between explicit (effortful) and implicit (effortless) cognitive functions that operate in adverse listening conditions. According to the ELU model, if there is a mismatch between phonological information extracted from the speech signal and phonological information stored in long term memory, the system produces a "mismatch" signal and explicit working memory-related capacities are continually drawn upon to reconstruct the ongoing discourse. The individual's storage and processing capacity in working memory determines whether or not this induces a high cognitive load.

Speech Perception in Older Adults: Characteristics of the Auditory Environment. The preceding review has considered the influence of peripheral and central auditory functioning and cognitive factors on speech perception in the elderly. However, characteristics of the auditory environment, such as background noise and the signal-to-noise ratio, also affect speech processing in this population.

Background noise. Older listeners often have more difficulty than their younger counterparts listening in noisy situations, particularly when the competing signal is speech. (Pichora-Fuller, Schneider, & Daneman, 1994; Schneider, Li, & Daneman, 2007). When the background noise consists of multi-talker babble, the target speech signal may be masked by two types of masking. The first is energetic masking, which occurs when elements of the masking signal overlap with the target signal in time and frequency, producing interference at the auditory periphery, and making the target signal inaudible (Brungart, Chang, Simpson, & Wang, 2009; Schneider et al., 2007). The second is informational masking, which involves masking of the target signal by meaningful sound sources, such as competing speech. Informational masking prevents the listener segregating the audible target from the competing speech (Brungart et al., 2009; Durlach et al., 2003), and interferes with speech comprehension at more central levels (Hornsby, Ricketts, & Johnson, 2006; Schneider et al., 2007). It is likely that the relative contribution of energetic and informational masking depends on individual age-related changes to peripheral hearing and cognitive functioning, particularly the ability to allocate attention effectively (Helfer, 2009).

Differences in voice quality and fluctuations in intensity can provide a release from masking. However, research comparing younger and older listeners with normal hearing (but not identical audiograms) suggests that elderly listeners receive less benefit from fluctuations in interrupted noise, in speech recognition tasks (Dubno, Horwitz, & Ahlstrom, 2002). This reduction in release from masking may be a factor in the difficulties experienced by elderly listeners in everyday situations with a background of multiple talkers, since they are less able to take advantage of "windows" in the background noise when the SNR is relatively high (Gordon-Salant, 2005).

Signal-to-Noise Ratio. The signal-to-noise ratio (SNR) is also an important factor in the level of difficulty in competing speech situations, with a generally positive relationship between SNR and speech understanding. (Brungart, Simpson, Erikson, & Scott, 2001; Helfer, 2009). Brungart et al (2001) conducted a speech perception experiment, in order to examine the cues used by listeners to segregate competing speech signals when stimuli were presented diotically. Performance decreased systematically when the level of the target talker was reduced relative to the masking talkers.

Studies which have examined the effect of simple amplification on speech recognition in older hearing-impaired listeners (i.e. increasing the level of both target and speech masker), have found very little difference in performance between amplified and un-amplified conditions (Hornsby et al., 2006; Schneider et al., 2007). However, research suggests that older adults need a higher signal-to-noise ratio or a better quality signal than younger adults for effective speech understanding (Pichora-Fuller, 2008).

Speech Perception in Older Listeners: Characteristics of the Speech Signal. The preceding sections have examined the effects of age-related changes in the listener, and factors in the auditory environment on speech understanding in older adults. Factors related to the speech signal itself, such as the rate of speech, the number of speakers in the stimuli set, the amount of semantic contextual support in the speech signal, and foreign accent, also have a significant influence. Recent studies have also begun to examine the influence of speaker age on speech understanding and listener effort in older adults (McAuliffe et al., 2012; Spencer, 2011).

Rate of speech. Older listeners have more difficulty than younger listeners in processing rapid speech (Wingfield, Tun, Koh, & Rosen, 1999) and time-compressed speech (Gordon-Salant & Fitzgibbons, 1993; Wingfield et al., 1985), even when older and younger groups are matched for auditory acuity. Wingfield et al. (1999) reported that additional processing time inserted in time-compressed speech was most effective when it was inserted at sentence and clause boundaries, which represent natural processing points for connected discourse. This result is consistent with the findings of Gordon-Salant & Fitzgibbons (1997), who found that older adults did not benefit from silent intervals inserted between every word in sentences. Both studies support the age-related slowing of speech processing and the compensatory effect of preserved linguistic knowledge in older adults.

Number of speakers. Using multiple speakers within a speech stimuli set instead of a single speaker has also revealed age-related differences in speech processing (Sommers, Nygaard, & Pisoni, 1994; Sommers & Danielson, 1999), as has introducing unfamiliar talkers, (Nygaard & Pisoni, 1998; Yonan & Sommers, 2000). A listener's ability to change variable speech signals into a representation that matches examples stored in long-term memory is referred to as normalization (Johnson, 2005). Yonan and Sommers (2000) proposed that familiarity with a speaker's voice might offer support for perceptual normalization, and that older adults might benefit more from this than younger adults. A group of older and younger adults were first trained to identify six different voices and were then tested on word identification in sentences. The older adults performed consistently more poorly than the younger group in voice discrimination. However, they were able to benefit more than the younger listeners when sentences were produced by familiar speakers (speakers they had been trained to identify).

Semantic context. Older listeners have been shown to benefit more from semantic contextual support than younger listeners (Pichora-Fuller, 2008; Sommers & Danielson, 1999; Stewart & Wingfield, 2009). However, some studies have shown that this greater benefit is only apparent when the context precedes the target, whereas for younger listeners, contextual information presented both before and after the target is beneficial (Wingfield, Alexander, & Cavigelli, 1994). The conclusion drawn from this finding was that older adults have more difficulty in holding sentence-level information in working memory for retrospective analysis. Therefore, although older adults may rely more on meaningful context to support sensory deficits, top-down processing is limited by available memory and attentional resources.

Foreign-accented speech. Another aspect of the speech signal, which has been found in some studies to differentially affect speech understanding in older listeners, is the presence of a foreign accent. English spoken as a second or foreign language is generally characterized by changes in suprasegmental features such as stress and intonation, which affect the overall structure of the spoken message (Gordon-Salant, Yeni-Komshian, & Fitzgibbons, 2010b). Changes at the phonemic level, such as vowel duration and word-final voicing also have a significant effect on word recognition. Recent studies which have examined the effects of age and hearing loss on the ability to understand accented English in quiet and in noise have had conflicting results (Gordon-Salant et al., 2010a, 2010b; Ferguson, Jongman, Sereno, & Keum, 2010).

Gordon-Salant et al. (2010b) found that accented speech recognition scores for younger and older listeners were not significantly different in quiet. In noise, however, there was a significant effect of age, with the younger listener group scoring consistently better than older listeners, both with and without significant hearing loss. The researchers proposed that cognitive decline in the older listener groups made the complex task of processing the accented signal and simultaneously ignoring irrelevant background speech babble significantly more challenging. Age-related slowing increases the time required to process degraded speech signals, such as foreign-accented speech. With the added difficulty of listening to speech with distracting background babble, older listeners were disproportionately affected, because of reduced inhibitory mechanisms (Gordon-Salant et al., 2010b).

Ferguson et al., (2010) also investigated the effects of accent on the intelligibility of English words in quiet, in noise and in a telephone filter condition. As in the previous study, three groups of listeners were included (young listeners with normal hearing, older listeners with essentially normal hearing and older listeners with hearing loss). In contrast to the previous study, however, this study found that the negative effect of foreign accent was not significantly different for younger and older adults. All three listener groups in this study were similarly affected by accent, leading the researcher to conclude that talker-related distortions of the speech signal have a qualitatively different impact on speech perception than distortions that are applied to the signal after it is produced.

One major difference may explain the contrasting findings of these two studies. The stimuli in the second study were phonetically balanced words rather than low-context sentences, which may have been less cognitively demanding for the older groups.

Speaker age. Another signal characteristic that may influence speech perception in older listeners is the age of the speaker. Harnsberger, Brown, Shrivastav, & Rothman (2009) propose that speaker age is an important "indexical" non-linguistic aspect of the speech signal which is likely to be stored with linguistic aspects of the signal, such as phonemes, syllables and words, in long-term memory. Indexical variation, which arises from such differences as speaking rate and voice quality, plays an important role in speech processing (Goldinger, 1998; Johnson, 1997; Luce & McLennan, 2005). Like other indexical properties of speech, speaker age may influence the perception of linguistic information, particularly in degraded listening environments (Harnsberger et al., 2009).

Changes in vocal characteristics which occur naturally with aging are highly variable, but studies have, nevertheless, found a high level of accuracy in the perception of age from speech recordings (Harnsberger et al., 2009; Harnsberger, Shrivastav, Brown, Rothman, & Hollien,2008; Linville,1996; Ringel & Chodzko-Zajko, 1987; Ryan & Burk, 1974). Ryan & Burk (1974) reported that acoustic correlates of aging found to be strong predictors of perceived age, included five characteristics of phonation and articulation: voice tremor, laryngeal tension, air loss (breathiness), imprecise consonants and slow rate of articulation. More recently, Harnsberger et al. (2008) investigated the importance of two acoustic cues, speaking rate and fundamental frequency, in determining the perceived age of the speaker; speaking rate, but not fundamental frequency, was found to be a relevant cue to age perception in voice. In a follow-up study, Harnsberger et al. (2009) examined two additional acoustic cues, namely noise (corresponding to hoarseness) and tremor, and their relevance to perceived vocal age. Results of this later study indicated that voice quality (both tremor and noise) and speech rate together were salient cues to age perception in voice.

Age-related changes to the speech signal may affect speech perception in other older adults either negatively, because of changes in phonation and articulation, or positively, because of the slower speech rates associated with older speakers (Torre & Barlow, 2009). This is important since the communication partners of older speakers are likely to be other older adults, many of whom experience hearing loss.

The preceding review has examined the complex interaction of listener characteristics, characteristics of the auditory environment and characteristics of the speech signal, and their influence on speech perception in older listeners. These factors of the listening situation contribute not only to the ability of older listeners to comprehend speech, but also to the level of listening effort required, particularly in degraded listening conditions.

Listening Effort

Listening effort refers to the "attention and cognitive resources required to understand speech" (Anderson Gosselin & Gagné, 2010). In quiet environments with a clear speech signal, listening is easy and effortless, particularly for those with good hearing. However, as the "auditory scene" becomes more complex (e.g. greater number of speakers, more background noise), listening becomes more effortful and tiring (Schneider et al., 2007). This is particularly the case for older listeners and for those with hearing impairment. Even when auditory decline or a degraded signal are not sufficient to prevent correct speech recognition, the perceptual effort required for successful processing, can impact on processing resources required for "downstream operations of comprehension and memory of what has been heard" (McCoy et al., 2005). Older adults may be able to compensate for sensory decline to a certain extent by greater use of context and top-down processing. However, this is likely to reduce the resources available for other cognitive tasks.

Listening effort is an important aspect of communication and has been assessed in listening studies both through self-report and objectively using a dual-task paradigm. The dual-task model, in which participants perform a primary task such as word recognition, and a secondary task, is designed to test the limited processing capacity of the cognitive system (Baddeley, 1998; Pichora-Fuller et al., 1994; Sarampalis, Kalluri, Edwards & Hafter, 2009). One underlying assumption of such a model is that increased effort associated with the primary task, such as reducing the signal to noise ratio or reducing the predictability of the stimuli, results in reduced performance on the secondary task; this can be interpreted as greater listening effort, (Anderson Gosselin & Gagné, 2010; Anderson Gosselin & Gagné, 2011; Downs, 1982; Sarampalis et al., 2009).

Early studies, in which a dual task paradigm was used to quantify listening effort, found that speech recognition scores in the primary task remained high as the auditory situation became more difficult, while performance on the secondary task decreased (Broadbent, 1958; Rabbitt, 1966). These early studies provided support for the consideration of listening effort as well as intelligibility scores in the assessment of communicative ability.

More recently, researchers have used a dual task model to study the effectiveness of noise reduction algorithms in hearing aids (Sarampalis et al., 2009). Twenty-five young adults with normal hearing took part in two dual task experiments. The primary task involved reporting the final word of sentences presented from the SPIN-R lists (Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984). Secondary tasks involved either recall of these final words after each block of eight sentences, or in the second experiment, a visual reaction time task to measure speed of processing. Results from both experiments suggested that at low signal to noise ratios, speech reception thresholds were not improved by noise reduction algorithms in hearing aids, whereas recall of words and response time to the complex visual task showed improvement. The researchers explained these findings in terms of an “attentional effort hypothesis”, concluding that noise reduction in hearing aids might do some of the processing normally done by the listener, freeing resources for other simultaneous tasks.

In a 2011 study, Anderson Gosselin and Gagné used a dual task paradigm to objectively measure the listening effort of 25 younger (25-33 years) and 25 older adults (64-76 years) with normal hearing, when listening in background noise. The primary task involved a closed-set sentence recognition task, while a tactile pattern-recognition task was used for the secondary task. Participants were tested in two experimental conditions: the “equated level condition”, in which a fixed signal-to-noise ratio was maintained for all participants, and the “equated performance condition”, in which baseline word recognition performance was equated for the groups. A subjective rating task was also completed by all participants, in order to compare self-reported listening effort with the objective dual task measures.

In both experimental conditions, results suggested that older adults expended more listening effort than younger adults, as measured by the “dual task cost” of performing both tasks concurrently. There was no correlation between subjective measures of listening effort and the dual task measures. The researchers concluded that older adults were less likely than young adults to report a higher degree of perceived effort, despite significant objectively measured differences.

The extent to which age-related changes in the speech signal affect not only speech understanding, but also listener effort in older adults has been examined in two recent studies, using both subjective and objective measures of effort.

Previous Studies of Speaker Age and Speech Perception in Older Listeners

One recent study which examined the effects of speaker age on speech recognition and listener effort in older individuals with hearing loss used a subjective rating scale to measure listening effort. McAuliffe et al. (2012), in a study of 19 older adults with age-related hearing loss, found speech recognition in quiet to be unaffected by speaker age. Listening participants in this study were aged between 60 and 87 years, with pure tone average thresholds at 500, 1000, 2000, 4000 and 8000 Hz of 20 dB HL or worse in the better hearing ear. Speech stimuli were recorded from four older adults (two males and two females, M*age* = 80 years, SD = 5.8 years) and four younger adults (two males and two females, M*age* = 27 years, SD = 2.06 years). Listeners were required to listen to and repeat a series of high and low predictability phrases. They were also required to rate the amount of effort involved, using a computer-based sliding scale with a continuum from minimal to maximal effort. Effort ratings were measured according to the distance (in centimeters) from the left end of the scale to the point selected by the participant.

Participants in this study showed a similar level of difficulty understanding both the young and older speaker groups, with no significant effect of speaker age on speech recognition scores for either high or low predictability stimuli. However, listening effort was perceived to be greater when listening to speech from the older adults, highlighting the additional effort required for auditory processing when the speaker was an older adult. However, this study had two primary limitations. Firstly, the study included a subjective rating scale to measure listening effort. Secondly, the listening task was conducted in quiet only, which did not reflect the more challenging SNRs encountered in real life listening situations. For these reasons, a follow-up study by Spencer (2011) introduced different levels of background noise and also used a more objective paradigm, the dual task model to assess listening effort.

In Spencer's study, 18 older adults with hearing loss were required primarily to report target words in sentences reproduced from the Speech Perception in Noise (SPIN) test (Kalikow, Stevens and Elliott, 1977). These were recorded by one older and one younger male speaker. The secondary task required the listeners to memorise the target words for later recall after a specific number of sentences. Speech recognition was tested in three listening conditions: Quiet, or with a signal-to-noise ratio of either +5 dB (typical of everyday listening situations) or 0 dB (more challenging). Participants were given a score for the number of target words correctly recognized and recalled in each listening condition.

The percentage of words correctly identified was significantly lower in all three listening conditions and across high and low context sentences, when participants listened to the younger speaker. Inter-speaker differences were greater with the poorer signal-to-noise ratio and low context sentences. In the secondary task, word recall scores were also significantly lower when listening to the younger speaker. Results from Spencer's study, therefore, showed that the older listeners recognized less speech and expended more effort when listening to the younger speaker.

While Spencer's study addressed two limitations of the previous study by introducing different levels of background noise, and by using a dual task paradigm to measure listener effort, one important limitation of the study was the lack of variability in the speech stimuli; these were produced by a single older and single younger male speaker. While subjective ratings of the two speakers confirmed that they were perceived as being representative of older and younger speakers respectively, it is possible that they exhibited inherent intelligibility differences that might have influenced the findings.

Study Aims & Hypotheses

Study aims. The current study aims to overcome the lack of variability in the speech stimuli used by Spencer (2011), by including speech stimuli recorded by multiple younger and older speakers, both male and female. This will better reflect the variability encountered in real-life listening situations and limit possible effects of individual speaker characteristics on the performance of the listeners. Furthermore, the two previous studies by this laboratory have excluded older listeners with normal or near normal hearing. In this study, the differential effects of age and hearing loss on speech recognition will be examined, by including a group of gender and age-matched listeners with normal or near normal hearing, as determined by audiometric testing.

Therefore, the current study has two main aims: (1) to investigate the effects of speaker age, speaker gender, semantic context, SNR, and a listener's hearing status on word recognition scores in older adults; (2) to investigate the effects of speaker age, speaker gender, semantic context, SNR, and a listener's hearing status on word recall scores in older adults.

Study hypotheses. Based on the results of Spencer (2011), it is hypothesized that the percentage of target words perceived correctly by older adults will be equivalent for sentences presented in quiet (without background babble), by younger and older adult speakers. With background babble, however, it is hypothesized that the percentage of target words correctly identified will be significantly lower when sentences are presented by younger adult speakers compared to older speakers. It is expected that the effect of speaker age will be greater for sentences with low semantic context, compared to those with high context. It is further anticipated that the percentage of target words recalled in the secondary task will be significantly lower for sentences produced by the younger speakers, when presented with background babble.

Method

Participants

Speaker Group. The speaker group comprised six young adults (three males and three females, aged 22-31 years) and six older adults (three males and three females aged 68-89 years). All the speaking participants were native speakers of New Zealand English with no history of speech disorder or untreated hearing loss. The three younger female speakers and two of the younger male speakers were postgraduate audiology students at the University of Canterbury, while the third young male was a high-school teacher with a postgraduate qualification. The six older speakers lived independently in the local community and all had at least 10 years' formal education.

Listener Group. Twenty-one older adults were recruited for the listening study (10 males and 11 females), aged between 65 and 85 years (M_{age} = 72 years). All were native speakers of New Zealand English, who lived independently in the local community and had a minimum of 10 years' formal education. Participants with any surgically treatable ear-related condition, fluctuating or rapidly progressing hearing loss, and any cognitive, medical or language-based condition which might prevent completion of the study were excluded (Humes, 2005). All participants signed a consent form and received a $20 voucher on completion of the test battery.

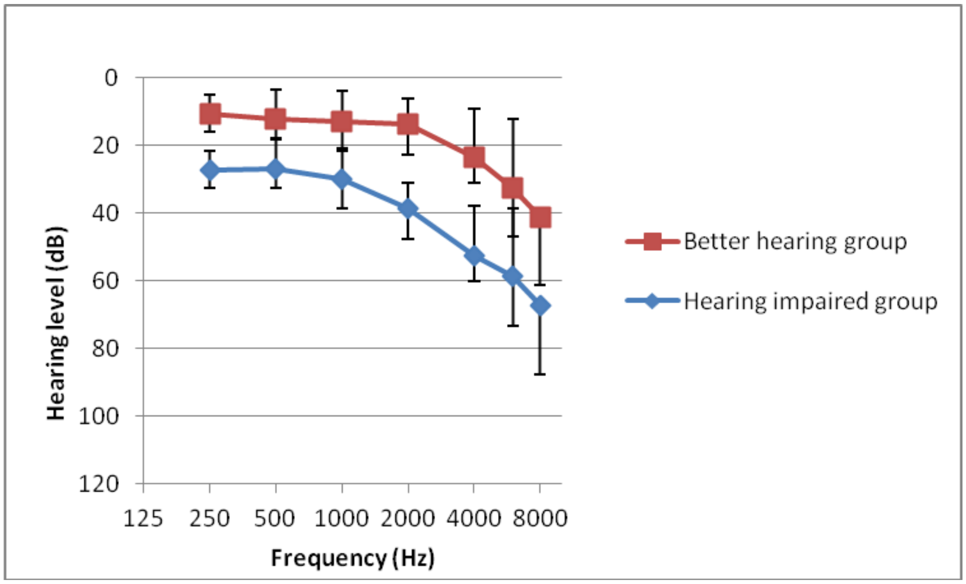
Audiological evaluation of participants, conducted according to the University of Canterbury Speech and Hearing Clinic Audiology Protocols and Guidelines (2012), included otoscopy, tympanometry and pure-tone air conduction and bone conduction audiometry. Tympanometry was conducted using a GSI 33 Tympstar (Grason-Stradler, Inc., Madison WI. USA). Pure tone audiometry was carried out in a sound-treated room in the Communication

Disorders Department at the University of Canterbury using a GSI 61 two-channel audiometer (Grason-Stadler, Inc. Madison, WI. USA), calibrated for use with Telephonics TDH-SDP supra-aural headphones and ER-3A insert earphones. All instruments used for audiological evaluation were calibrated to the manufacturer's specifications and were subject to daily checks.

Air conduction thresholds were measured at octave intervals between 250 Hz and 8000 Hz and bone conduction thresholds between 500 Hz and 4000 Hz where a hearing loss was present; masking was used as necessary. Exclusion criteria included audiograms which indicated that the hearing loss was predominantly conductive rather than sensorineural in origin (air bone gaps greater than 10 dB at three or more frequencies), or a significantly asymmetrical audiogram (interaural difference greater than 30 dB at any octave frequency), (Humes, 2005). One female participant was excluded on the basis of audiometric results.

Eleven participants with pure-tone average thresholds greater than 25 dB at octave frequencies from 500 Hz – 4 kHz in the worse ear were considered to have a hearing loss (Cruikshanks et al., 1998). This group included six males and five females, aged 65-85 years (M*age*= 72 years). The remaining nine participants had pure-tone average thresholds of 25 dB or better in the worse ear, although all but one of this group had increased thresholds above 4 kHz, typical of presbycusic hearing loss. The better hearing group comprised five females and four males, aged 65-82 years (M*age* = 71.55 years). One male participant had been prescribed hearing aids; however, he did not use these regularly and did not wear them for the listening study. Average pure-tone air conduction thresholds for the listener group are given in Figure 1.

Figure 1. Mean pure-tone air conduction thresholds (average of right and left ears) in decibel hearing level (dB HL) for the 20 listening participants.



The listening participants were also screened for mild cognitive impairment, using the Montreal Cognitive Assessment , (MoCa: Nasreddine et al., 2005). A validation study of the MoCA with 94 subjects (Nasreddine et al., 2005) found the sensitivity and specificity of the test for detecting mild cognitive impairment to be 90% and 87% respectively. The MoCA consists of a 30 point test which assesses a variety of cognitive skills, including short-term memory recall, visuospatial abilities, attention, concentration and working memory. Listeners took between ten to fifteen minutes to complete the test and required a minimum score of 26 points out of 30 for further participation in the listening study.

Speech Stimuli

The sentence lists of the Speech Perception in Noise (SPIN) test (Kalikow, Stevens & Elliott, 1977) were reproduced for use in this study. The reproduced SPIN materials consisted of eight lists of 48 short sentences, each containing six to eight syllables. Within each list, 24 sentences had contextual clues, which made the sentence-final word highly predictable from the preceding context, while the remaining twenty-four sentences had low predictability.

Recording and editing of speech stimuli. The lists were recorded in a sound-attenuated room in the Communication Disorders Department at the University of Canterbury, using an HSP 4 condensor head level microphone and MZA 900P preamplifier combination (Sennheiser, Germany), coupled to a TASCAM HD-P2 portable stereo recorder (TEAC, Japan). The microphone was placed at an angle of approximately 45 degrees to the speaker's mouth and at a distance of six centimeters, measured with a ruler. Recording levels were monitored to avoid peak clipping.

Participants were asked to read aloud the eight lists of sentences and were instructed to read in a relaxed conversational manner and to repeat any sentences containing errors or hesitations. Each sentence list was recorded as a separate file, and at the end of each list, participants were given the opportunity to rest. Participants took between 45 minutes and one and a half hours to complete the recording.

The audio signal was digitized directly to Compact Flash memory at a sampling rate of 48 kHz with 16 bit quantisation. Software, custom-written using LabVIEW 8.20 (National Instruments, TX, USA), was used to remove the non-speech elements from the recordings, and segment the audio into separate files for each sentence (O'Beirne, 2012). Edited recordings were then catalogued according to sentence list and number. An inverse filter process, implemented in LabVIEW 8.20, was used to ensure that all stimuli were at the same A-weighted dB sound level

(57 dB A) when presented through the InSync Buddy USB 7G soundcard and Sennheiser HD 280 supra-aural headphones, which were used in this study (O'Beirne, 2012).

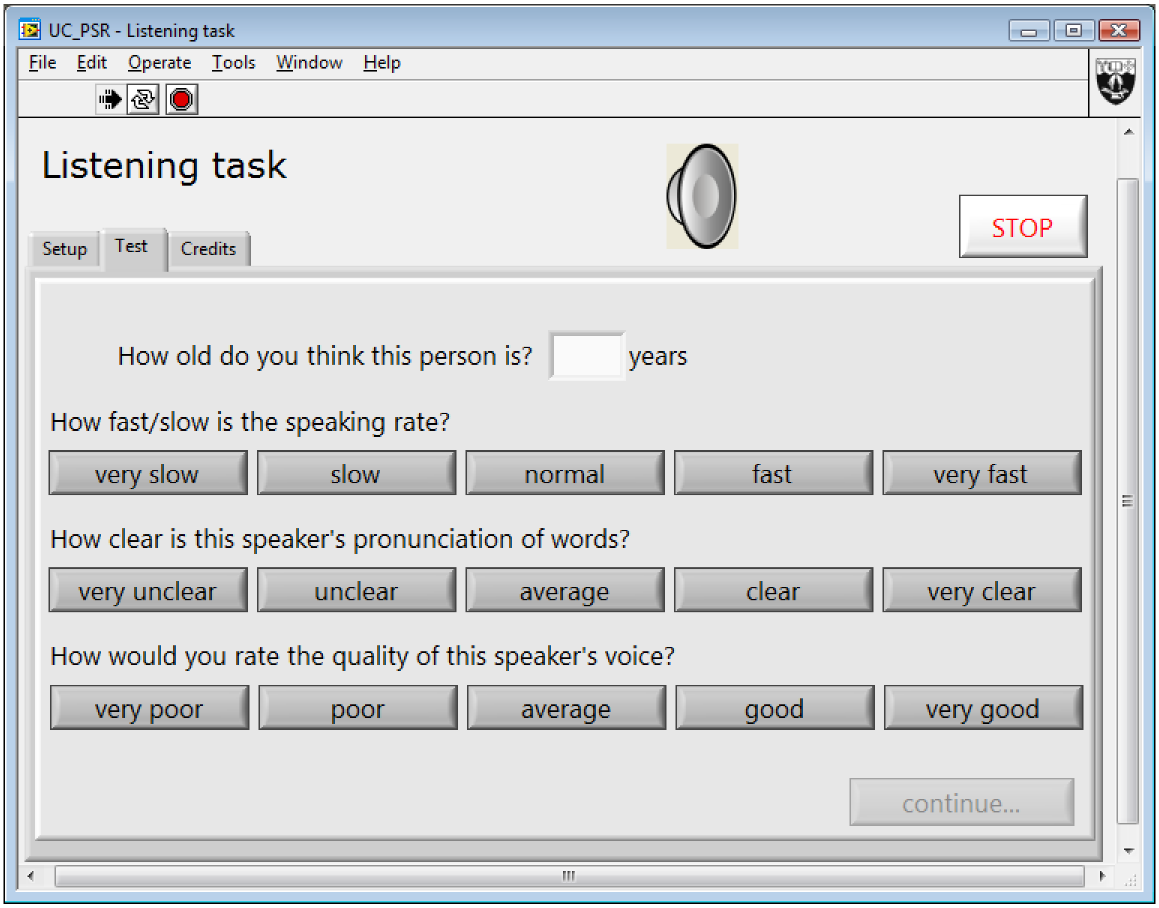
Six playlists were created for the listening experiment, comprising three sets of two SPIN lists, which each contained a block of eight sentences read by each of the twelve speakers. Sentences were selected which were free of errors or hesitations. Each block of eight sentences contained four high context and four low context sentences. A further playlist was created as a practice list. This comprised 48 sentences, with four sentences from each of the 12 speakers, again with an equal number of high and low context sentences from each speaker.

Confirmation speech stimuli represent 'younger' and 'older' voices. In order to confirm that the speech stimuli were representative of younger and older voices respectively, a perceptual rating task was conducted, using the University of Canterbury Perceptual Speech Ratings (UC-PSR) computer software, designed specifically for this study. All participants were seated at a laptop and fitted with Sennheiser HD 280 supra-aural headphones to complete the task. Eight undergraduate speech therapy students from the University of Canterbury (aged 20-32 years) and two older adults (aged 50-52 years), completed the rating task. All the raters were native speakers of New Zealand English, and had no reported hearing loss; they each received a $10 voucher.

In order to complete the task, raters heard each of the 12 speakers read four sentences each, two with high and two with low context. All sentences for the rating task were taken from the practice list used in the listening experiment and heard without background noise. The order of speakers was randomized to minimize ordering effects.

Before listening to the sentences, raters were given the opportunity to adjust the volume by means of a sliding scale on the computer screen. The volume then remained at this chosen level throughout the task. Raters were instructed both verbally and through on-screen information to listen to each speaker and then respond to four on-screen questions, regarding speaker age, rate of speech, clarity of speech and voice quality, as shown in the screenshot in Figure 2. These specific parameters were selected to confirm that speech production differences existed between the older and younger speaker groups, since research has identified these as relevant cues to speaker age (e.g. Ryan & Burk, 1974; Harnsberger et al., 2008; Harnsberger et al., 2009).

Figure 2. Perceptual rating screen, including response options for perceived age, rate, clarity and quality of speech (UC-PSR, O'Beirne, 2012).



After each rating session, information was automatically saved to the computer as a text file. The data for each participant was then transferred to a Microsoft Excel spreadsheet. The rating categories for each speaker characteristic were assigned a numerical rating from one to five, which corresponded to the left to right order of categories on the screen (e.g. very slow = 1, slow = 2, normal = 3, fast = 4, very fast = 5). Results of the speaker rating study are shown in Table 1. Mean chronological and mean perceived age is provided for each of the 12 speaker participants. For the perceived acoustic characteristics of the speakers, median scores have been converted back to linguistic labels (normal, slow etc.).

Table 1. Mean and standard deviation values (in parentheses) for chronological age and perceived age, and median values for acoustic characteristics of speakers' voices, obtained from the perceptual rating study.

	Actual Speaker Age in years	Perceived Speaker Age in years	Perceived Rate of Speech	Perceived Clarity of Speech	Perceived Quality
Old Female Group	82 (6.56)	66.73 (8.08)	normal	clear	average
Old Male Group	77.3 (8.08)	63.7 (9.35)	slow	clear	average
Young Female Group	25.6 (4.72)	27 (5.19)	normal	clear	good
Young Male Group	28.6 (3.21)	28.4 (7.77)	normal	average	good

Rater differentiation of the age groups was highly accurate, with group mean perceived ages for the older males and females being over 60 years and for the younger male and female groups under 30 years. Interestingly, the highest degree of accuracy was shown in assessing the age of the younger speakers. Group means for perceived age were within one to one and a half years of chronological age for the younger male and female groups, while for the older groups the difference between actual and perceived age was up to sixteen years. There was no crossover between groups for perceived age of any of the individual speakers.

Rate of speech was judged as very slow, slow, normal, fast or very fast. As shown in Table 1, the older male speakers were perceived to have a slow rate of speech, while the remaining three groups were all judged to speak at normal rates. Clarity of speech was rated as very unclear, unclear, average, clear or very clear. All the speaker groups except the young males were judged to have clear speech, while the young males were judged to have average clarity. Similarly, voice quality was rated as very poor, poor, average, good or very good. Raters were asked to consider such aspects of voice as tremor (unsteadiness), hoarseness and breathiness. Both younger groups were considered to have good voice quality, while the older groups were perceived to have average quality.

Listening Experiment

The listening experiment was conducted using the University of Canterbury Perceptual Speech Ratings (UC-PSR) customized computer software (O'Beirne, 2012), designed specifically for speech perception research. The UC-PSR software was run on a Toshiba laptop computer coupled to Sennheiser HD 280 supra-aural headphones via an InSync Buddy USB 7G soundcard. All participants were tested in a sound-attenuated room in the Communication

Disorders Department at the University of Canterbury. Following a similar dual task procedure to that used by Spencer (2011) and Sarampalis et al., (2009), the participants were instructed to report the final word of each sentence after the sentence was played, and to commit each final word to memory. Following a set of eight sentences, the listener was prompted to recall as many sentence-final words as possible.

Prior to commencement of the listening experiment, each participant was asked to listen to a recording of the first paragraph of the 'Rainbow Passage' through the headphones, and was given the opportunity to adjust the presentation volume to a comfortable level, using a sliding scale on the laptop computer screen. The presentation levels chosen by participants ranged from 58 – 71.5 dB A. After the initial adjustment, the volume remained at the same level throughout testing. One list of the SPIN stimuli was used as a practice list to familiarize participants with the task; this list did not include sentences from the experimental study. In the practice list, all sentences were played in quiet without background speech babble.

There was a pause after each sentence presentation and the listener was given frequent encouragement to guess if they were uncertain about the final word. As shown in Figure 3, the word was entered in a box on the laptop screen by the examiner and once submitted, the next sentence was presented to the participant. Following a set of eight sentences, the listener was prompted by the examiner to recall as many sentence-final words as possible. Recalled words which matched the reported words were marked as correct on the screen, as shown in Figure 4.

Figure 3. Examiner response screen for the word recognition task

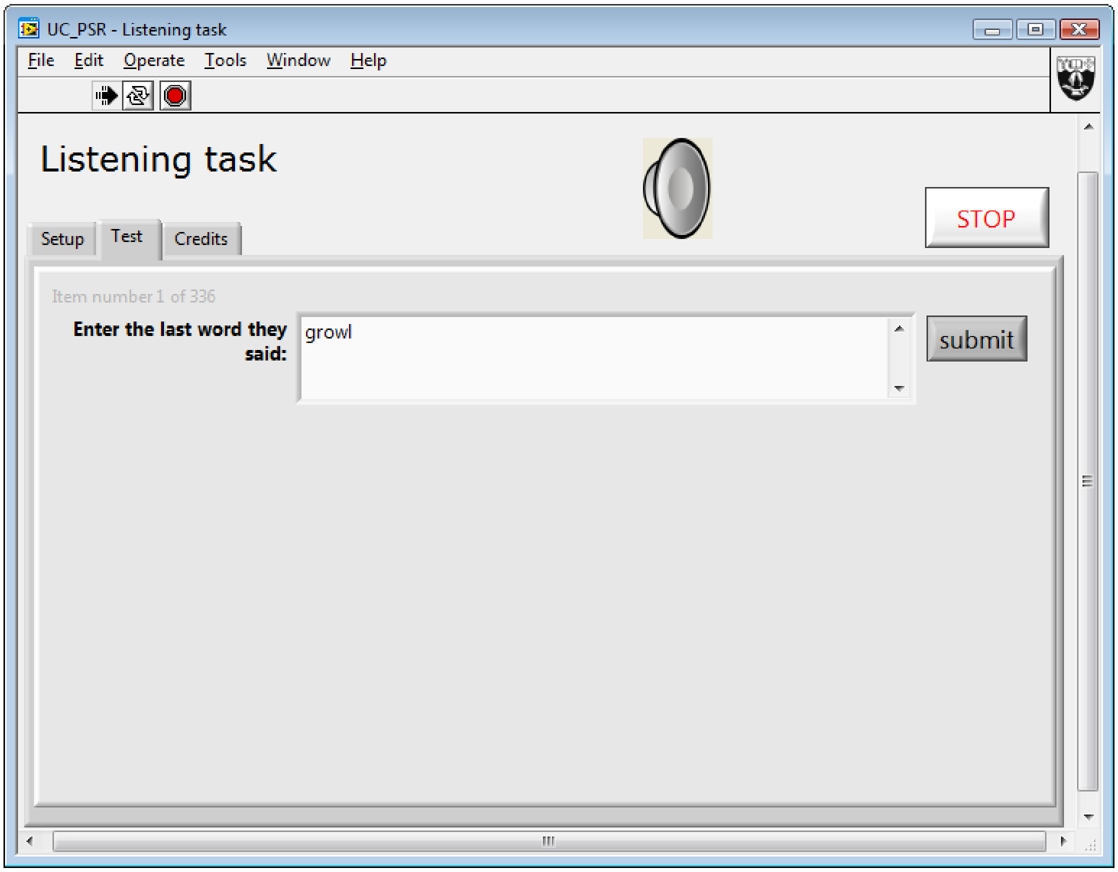
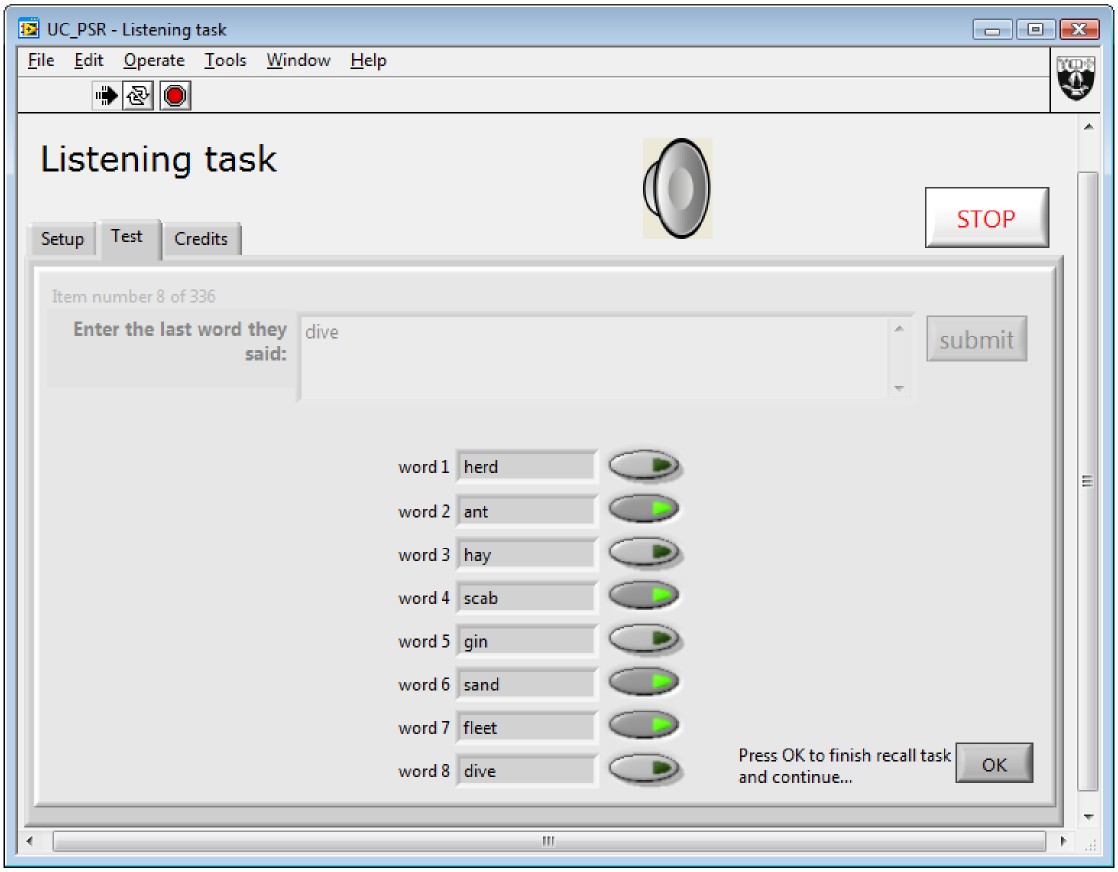


Figure 4. Examiner response screen for the word recall task.



The SPIN stimuli were heard either in quiet or in the presence of six-talker babble, which was developed for use in Spencer's study (2011). The babble continued for the length of the SPIN sentence and was mixed with the SPIN stimuli to achieve a signal-to-babble ratio of either +5 dB or 0dB. To minimize the effect of ordering, each sentence list, speaker and noise condition was heard an equal number of times across all serial positions.

The computer-based listening study took from one to one and a half hours to complete and the whole test battery, including the audiological and cognitive screening tests, took between two and two and a half hours. Participants were encouraged to take breaks during testing as necessary.

All information from each session was automatically saved to the computer as a text file. This included start and finish times for the session, presentation volume, final words reported and words recalled. The data for each participant was then transferred to a Microsoft Excel spreadsheet.

Statistical Analysis

A five-way Mixed Model Multivariate Analysis of Variance (MANOVA) was conducted on two dependent variables: the percentage of sentence-final words correctly identified (word identification score), and the percentage of words recalled in the secondary task (word recall score). The between-subjects factor was listener's hearing status (good vs. poor) and within-subjects factors were speaker age group (young vs. old), speaker gender, semantic context (high vs. low context) and SNR condition (0 dB, 5 dB, and quiet). The MANOVA was conducted to determine whether or not a linear combination of word identification and word recall scores was significantly affected by the five factors (i.e listener's hearing status, speaker age, speaker gender, semantic context and SNR condition). One advantage of using the MANOVA was the ability to test how the factors of interest were differentiated by a combination of the two dependent variables. A further advantage was to control the family-wise error rate, while increasing the sensitivity of the test in revealing a significant effect. Follow-up univariate ANOVAs and multiple pairwise comparison tests with Bonferroni correction were conducted if a significant effect was found. The statistical significance level was set at 0.05.

Results

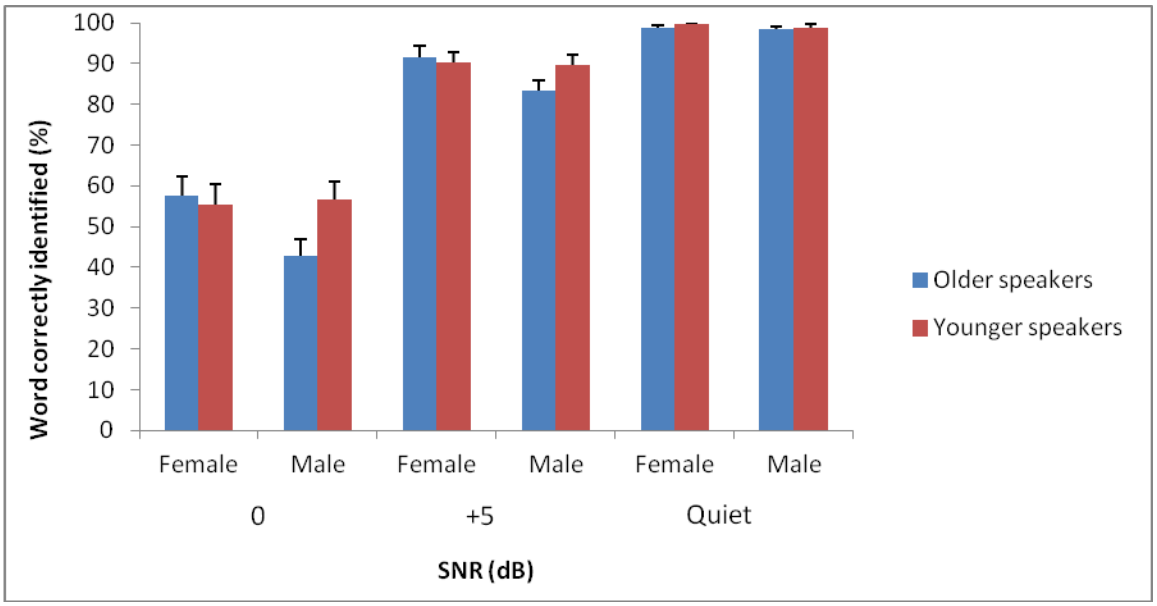
A summary of the MANOVA results is shown in Appendix B. The results revealed significant main effects of semantic context, $F(2, 17) = 162.090$, $p < 0.001$ and SNR condition $F(4, 15) = 287.261$, $p < 0.001$. Significant interaction effects were also found between Speaker Age X Semantic Context, $F(2, 17) = 6.545$, $p < 0.01$, Speaker Gender X Semantic Context $F(2, 17) = 14.863$, $p < 0.001$, and Semantic Context X SNR, $F(4, 15) = 39.051$, $p < 0.001$. A three- way interaction between Speaker Age X Speaker Gender X Semantic Context was also significant, $F(2, 17) = 6.735$, $p < 0.01$. The remaining interactions were non-significant. Follow-up univariate ANOVAs were conducted on the word identification and word recall scores to identify the source of any differences; summary tables of results are given in Appendix C and Appendix D respectively.

Word Identification Results

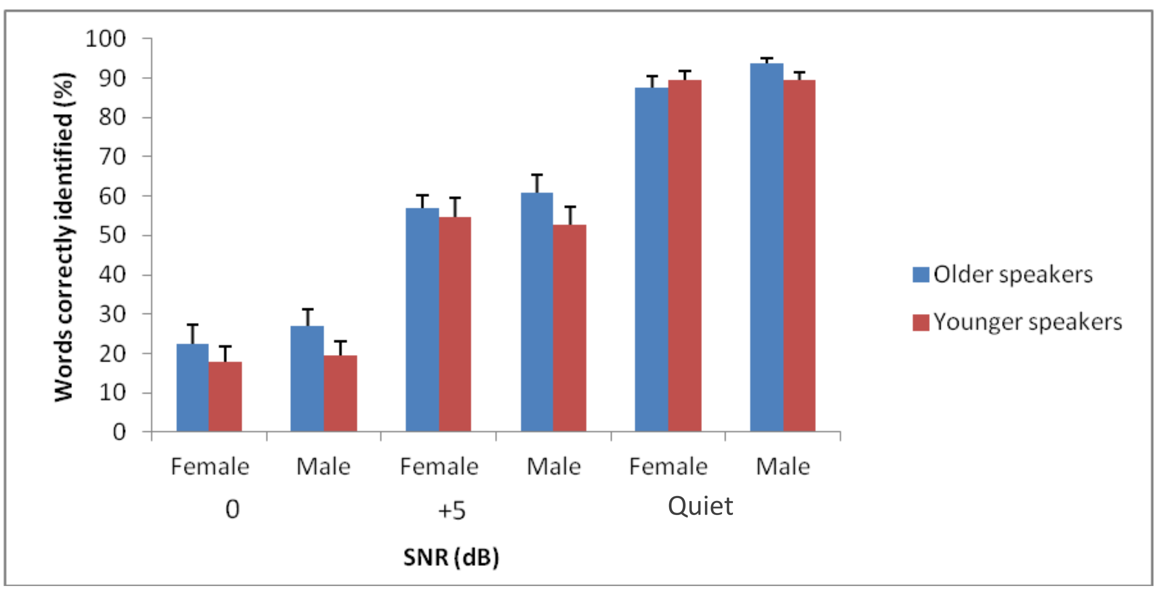
Full details of the follow-up univariate ANOVA relating to the word identification results are found in Appendix C. Overall performance data for the word identification task are displayed in Figure 5, which gives the mean percentage of sentence-final words correctly identified as a function of SNR condition. The two groups of listeners (better versus poorer hearing) are combined, and speakers are grouped by age (older versus younger) and gender, for high context and low context separately.

Figure 5. Mean word identification scores (with standard error in parentheses) as grouped by speaker age and gender and SNR condition in high context (top panel) and low context (bottom panel) respectively.

High Context



Low Context



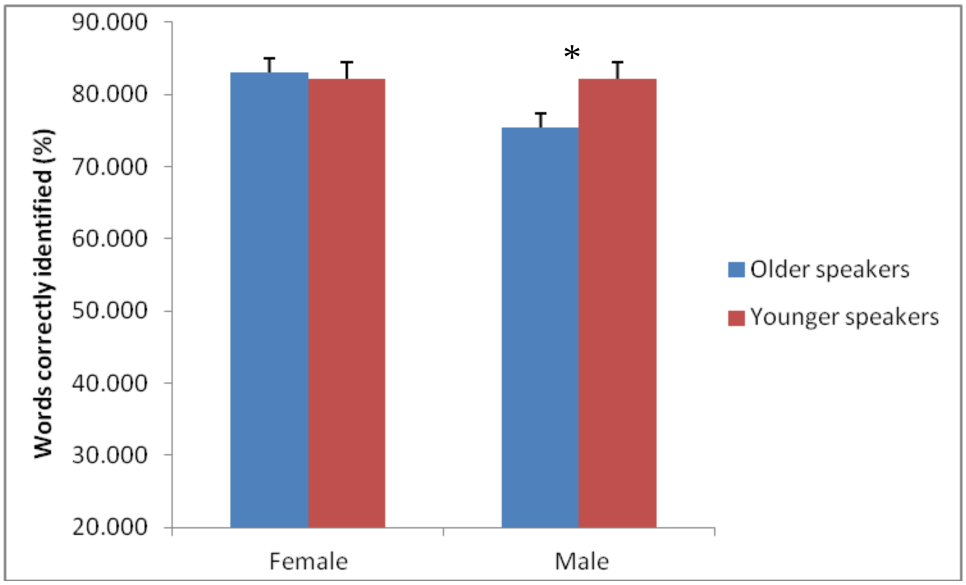
The follow-up univariate ANOVA conducted on the word identification results revealed significant main effects of Context, $F(1, 18) = 343.235$, $p < 0.001$, and SNR, $F(2, 36) = 496.409$, $p < 0.001$, which indicated that listeners exhibited significantly greater difficulty understanding sentence-final words in the low context condition and as the SNR decreased.

Two-way interaction effects of Speaker Age X Semantic Context, $F(1, 18) = 9.259$, $p < 0.01$, Speaker Gender X Semantic Context, $F(1, 18) = 14.400$, $p < 0.01$, and Semantic Context by SNR, $F(2, 36) = 30.669$, $p < 0.001$, were also significant, suggesting that the effect of context varied according to the SNR, with an increasing benefit of context as the SNR decreased. Word identification scores for low context sentences were generally higher when sentences were produced by an older rather than a younger speaker. The difference was greater as the SNR decreased and greater for the male speakers than for the female speakers.

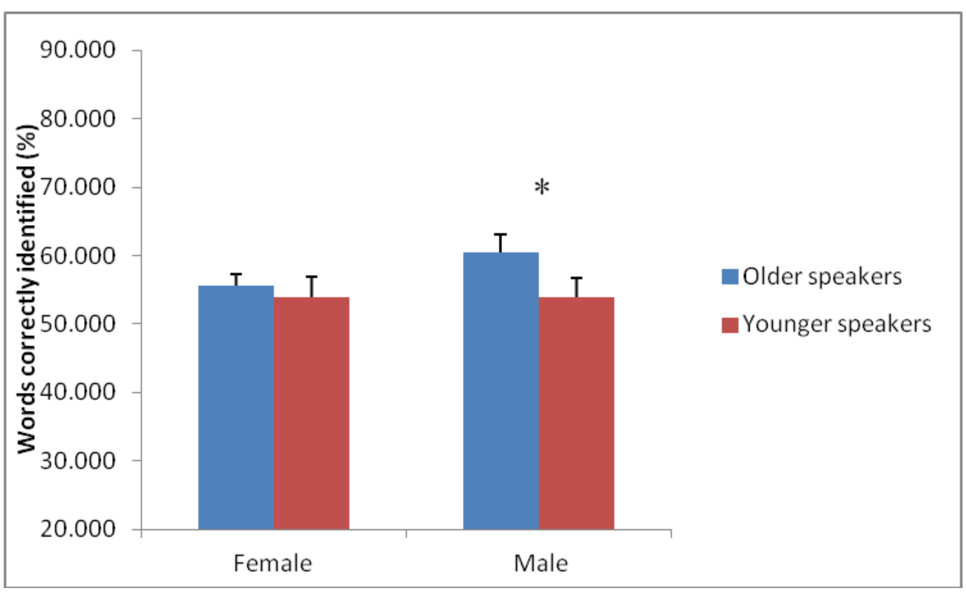
The analysis revealed two significant three-way interactions. The first of these involved Speaker Age X Speaker Gender X Semantic Context, $F(1, 18) = 10.006$, $p < 0.01$. This is illustrated in Figure 6, which shows the mean word identification scores of the 20 listening participants, grouped by speaker age and speaker gender for high context and low context separately. Pairwise comparison tests with Bonferroni correction revealed that word identification scores for the low context sentences were significantly higher for the older male speaker condition than for the younger male speaker condition. For sentences with high semantic context, the opposite was true; scores were significantly higher for the younger male speaker condition, ($p < 0.05$). There was no significant effect of age for the female speaker groups.

Figure 6. Mean word recognition scores (with standard error in parentheses) as grouped by speaker age and gender in high context (top panel) and low context (bottom panel) respectively. Significant comparisons between younger and older speakers in each subgroup were marked with an asterisk ("*").

High Context



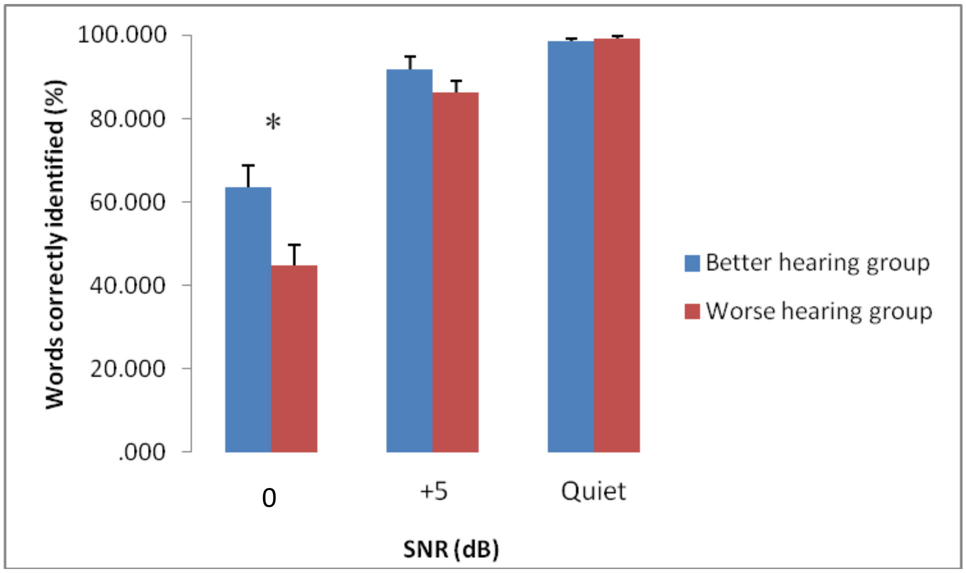
Low Context



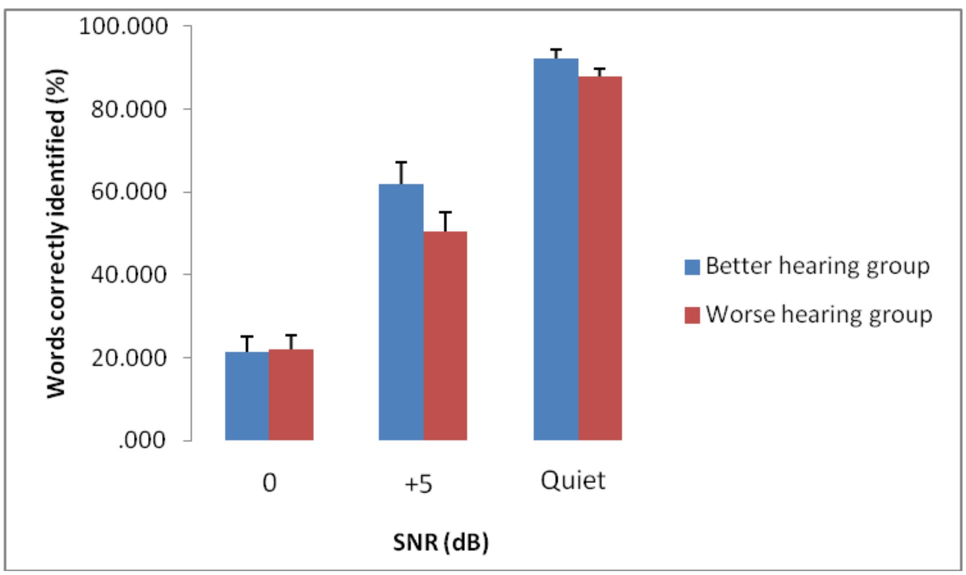
The second significant three-way interaction involved Listener's Hearing Status X Semantic Context X SNR, $F(1, 18) = 8.167$, $p < 0.001$.This is shown in Figure 7, which illustrates the interaction between listener's hearing status (good versus poor), and SNR (0 dB, +5 dB and quiet) for the high and low context sentences separately. Pairwise comparison with Bonferroni correction revealed a significant difference between the two listener hearing status groups for high context sentences presented in the most challenging 0 dB SNR condition; the better hearing group achieved a significantly higher mean word identification score than the poorer hearing group in the 0 dB high context condition, ($p < 0.05$). Mean word scores were also higher for the better hearing group in the moderate + 5 dB SNR condition, but this difference between the groups was not statistically significant. Other interactions were non-significant for the word identification scores.

Figure 7. Mean word recognition scores (with standard error in parentheses) as grouped by listener's hearing status type and SNR condition, in high context (top panel) and low context (bottom panel) separately. Significant comparisons between the better hearing group and poorer hearing group in each SNR condition are marked with an asterisk ("*").

High Context



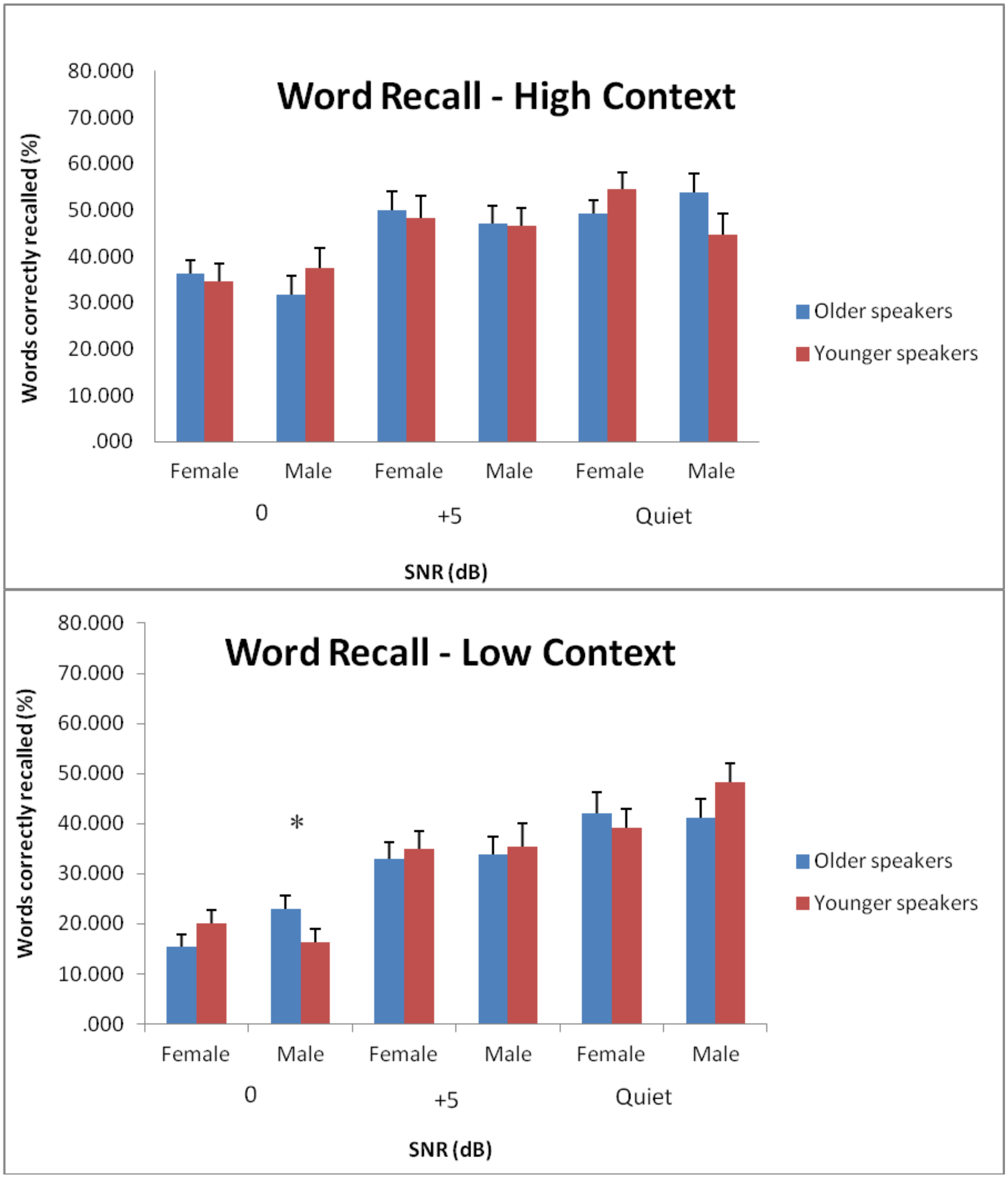
Low Context



Word Recall Results

A summary of the univariate ANOVA related to the word recall results is given in Appendix C. Figure 8 shows the mean word recall scores of the 20 listening participants, with better and poorer listeners combined. Speakers are grouped by age (older versus younger) and gender for each SNR condition (0 dB, +5 and quiet) and for high and low context separately. The same statistical analysis was conducted on the word recall results. The ANOVA again revealed significant main effects of Context, $F(1, 18) = 60.286$, $p < 0.001$, and SNR, $F(2, 36) = 47.140$, $p < 0.001$, indicating that listeners evidenced greater difficulty recalling sentence-final words in low semantic context conditions and as the SNR decreased.

Figure 8. Mean word recall scores (with standard error in parentheses) as grouped by speaker age and gender, and SNR condition in high context (top panel) and low context (bottom panel) respectively. Significant comparisons between younger and older speakers in each sub-group are marked with an asterisk ("*")



The two-way interactions of Speaker Gender X Semantic Context, $F(1, 18) = 8.529$, $p < 0.01$, and Semantic Context X SNR, $F(2, 36) = 4.132$, $p < 0.05$, were significant, as were Listener's Hearing Status X Speaker Age X Speaker Gender, $F(1, 18) = 5.603$, $p < 0.05$, and Listener's Hearing Status X Semantic Context X SNR, $F(2, 36) = 3.827$, $p < 0.05$.

Since the four-way interaction of Speaker Age X Speaker Gender X Semantic Context X SNR was found significant, $F(2, 36) = 6.610$, $p < 0.01$, follow-up pairwise comparison tests were conducted. In the low context 0 dB SNR condition, the mean word recall score for the older male speaker condition was significantly higher compared to the younger male speaker condition, ($p < 0.05$). There was no significant effect of age for the female speaker groups. The remaining interactions were non-significant.

Discussion

The aim of this study was to investigate the effect of speaker age and gender on speech recognition and listener effort in older adults. It was hypothesized that word identification scores for older listeners would be lower when stimuli were presented by younger rather than older speakers and that greater listener effort, measured objectively by performance on a secondary word recall task, would also be observed in the younger speaker condition. The 20 listener participants in the study were divided into two groups, one comprising participants with hearing loss, as defined by Cruikshanks (1998), and a second group with better hearing. The better and poorer hearing groups in this study were closely matched for age and gender, which allowed analysis of the influence of hearing loss on the results.

Firstly, results of the study indicated that there were no overall differences in speech recognition scores for the 20 older listeners, when listening to the speech of the younger versus older speakers. Also, speaker age did not have a disproportionate effect on older listeners with hearing loss, compared to those with better hearing. However, differential effects of speaker group were observed in the two context conditions (high versus low context), suggesting that different speech cues were used by listeners as the level of context varied. While speaker age did not have a greater effect on listeners with hearing loss, compared to those with better hearing, word recognition scores were generally higher for the better hearing group. The effect of hearing loss was greatest in the 0 dB high context condition, in which results indicated that the better hearing group obtained significantly greater benefit from the availability of semantic context. Secondly, with regard to word recall, there was no overall effect of speaker age and gender on word recall scores. In the most challenging low context 0dB SNR condition, however, scores were significantly higher when stimuli were produced by the older male compared to the younger male speakers.

Word Identification Results

There was no significant difference in word recognition scores when stimuli were produced by younger rather than older female speakers; this was true for both high context and low context sentences. However, in the low semantic context condition, speech recognition scores were significantly higher when the speaker was an older male as opposed to a younger male. In the high context condition, the opposite was true; scores were significantly lower when the speaker was an older male. This reversal of the speaker age effect, with varying levels of semantic context, suggests that listeners adapted to different cues in the speech signal in order to identify the sentence-final word. Studies suggest that older adults are able to use a wide range of cues or supports to compensate in challenging listening conditions, but the exact process by which older listeners adapt to the cues available in a particular speech signal is not clear (Pichora-Fuller, 2008).

One possible reason for the higher word recognition scores in the low context condition when stimuli were presented by an older male is that the rate of speech of the older male group was slower. Results of the perceptual rating study showed that the older male group was perceived as having a 'slow' speech rate, whereas the speech rate of the other three groups was perceived to be 'normal'. The slower speech rate of older males is supported by research showing that sentence, word and diphthong durations are significantly longer in older males compared to younger males (Harnsberger et al., 2008). Research suggests that speech rate is an important factor in speech recognition for older listeners (Gordon-Salant, 2005; Schneider et al., 2002; Wingfield & Tun, 2001), and that age-related deficits are greater for signals with low semantic context (Wingfield et al., 1985). The current findings are supported by the findings of Wingfield et al. (1985), which found that older listeners with normal hearing performed well in a speech recognition task when speech stimuli consisted of meaningful sentences, even when the sentences were presented at twice the rate of normal conversation (up to 425 wpm). However, when stimuli consisted of syntactic strings without semantic context, a significant age-related decline in performance was observed as speech rate increased. In the current study, while the younger male speaker group and the two female speaker groups were not judged in the perceptual rating task to have rapid speech rates, the relatively slower rate of the older male speaker group may still have afforded additional processing time which may have benefited the older listeners in the low context condition.

The previous finding supported the hypothesis that word identification scores for older listeners would be lower when listening to the younger speakers, at least for low context sentences. In contrast to this, however, for high context sentences, the opposite was found; listener participants demonstrated significantly greater difficulty understanding the older male speaker group, than the other speaker groups, indicating that less benefit was afforded by semantic context in the older male speaker condition. The difference was greatest in the most challenging 0 dB SNR condition.

It is possible that the slow speaking rate attributed to the older male speakers had an adverse effect on the prosodic contour of their speech. While acoustic analysis of the speech samples was not conducted, subjective perceptual analysis of the speech stimuli indeed indicated reduced pitch variation in sentences produced by the older males compared to the other speaker groups. Clearly, future studies would benefit from an objective acoustic analysis of stimuli. However, in support of this hypothesis is should be noted that monotone speech has been reported in previous studies of older speakers of NZ English. McAuliffe,Gibson, Kerr, Anderson & LaShell (revision submitted), in a study which examined the processing of dysarthric speech by younger and older listeners, compared speech samples from older individuals with Parkinson's Disease (PD), and an age-matched control group. Reduced variation in fundamental frequency is a characteristic of dysarthric speech; however, surprisingly, the control group of older male speakers exhibited the same reduction in pitch variation, resulting in flattened intonation.

Prosodic features, such as intonation, stress and duration, help to influence the processing of semantic information, by marking lexical and syntactic boundaries (Sommers, 2005). Natural prosody facilitates speech perception, and older listeners are able to use prosodic information to support spoken word recognition, especially under difficult listening conditions (Wingfield et al., 2000). In the high context sentences, the benefit of prosodic information to highlight the semantic context may have outweighed the benefits of the slower rate of speech.

It is also possible that spectral and temporal properties of speech produced by the older male group were more similar to those of the background babble than was the case for stimuli produced by the other speaker groups. Masking effects of the background noise depend on the acoustic similarity of the target and masker; the greater the similarity between the two, the more difficult it is for listeners to perceptually segregate the target signal from the background noise (Ben-David, Tse & Schneider, 2012). Older adults are slower and less efficient at segregating target speech from a speech masker (auditory stream segregation), with the result that information at the beginning of a spoken sentence may not be fully processed (Ben-David et al., 2012). In the current study, if auditory stream segregation was more challenging for stimuli produced by older male speakers, because of greater acoustic similarity to the speech masker, the semantic context preceding the sentence-final word may have been attenuated relative to the other speaker groups. Again, future studies would benefit from objective acoustic analysis of speech stimuli, to determine if this was indeed the case for the older male speakers in our study.

As discussed in the preceding sections, speaker age had different effects on the word recognition results, according to the level of semantic context available in the speech stimuli. These effects were not significantly different for the two listener groups (i.e. those with hearing loss and those with better hearing) However, findings of the current study highlighted the effects of age-related hearing loss in adverse SNR conditions, even when presentation volume was adjusted for optimum audibility in quiet. Word recognition scores were similarly high for both groups in the quiet condition, while listener group differences were observed in the more challenging +5 dB and 0 dB SNR conditions. The most significant difference between the two listener groups was observed in the high context 0 dB SNR condition, in which scores for the better hearing group were significantly higher than those of the poorer hearing group. In the most challenging low context 0 dB condition, floor effects appear to have influenced the results, with equally low scores observed for both groups.

Numerous studies support the preserved ability of older listeners to use semantic context to disambiguate a degraded signal (Aydelott, Leech & Crinion, 2010; Pichora-Fuller, 2008; Pichora-Fuller & Singh, 2006; Schneider et al., 2002). The benefit of semantic context for speech understanding in older adults relies on the interaction of perceptual bottom-up processes and cognitive top-down processes; top-down processes based on linguistic knowledge are more effective when the amount of acoustic (bottom-up) information is greater (Aydelott et al., 2010). When sensory impairment or background noise affects the quality of the signal, older adults may be able to compensate to a certain extent by greater use of context and top-down processing. However, in very challenging listening situations, increased processing demands associated with sensory impairment, can make it difficult for listeners to use their linguistic knowledge to decipher the speech signal (Kidd & Humes, 2012).

Word Recall Results

Analysis of the word recall results revealed no overall effect of speaker age and gender on word recall scores; however, a statistically significant difference emerged in the most challenging, low context, 0 dB SNR condition, indicating that in this condition, older listeners were able to recall more sentence-final words when the speaker was an older male. It is possible that the longer stimulus duration, associated with the perceived slower speech rate of the older male group, afforded greater processing time for the older listeners to encode target words in memory. Studies have shown that short term memory is limited in its capacity to hold and process information. The amount of processing resources available for a particular task depends on the attentional resources allocated to other tasks (Anderson Gosselin & Gagné, 2011; Pichora-Fuller & Singh, 2006; Schneider et al., 2002;). Under difficult listening conditions, as in the 0 dB low context condition, results of our study suggest that fewer attentional resources were allocated in the word identification task, when the listener was an older male.

Results of the word recall task also clearly indicate the effects of semantic context and SNR condition on the older listeners' ability to recall target words from memory. The mean percentage of target words recalled decreased as the SNR decreased and as the level of contextual support decreased; the effect of SNR was also greater for the low context than the high context condition. Findings of our study are consistent with previous dual-task investigations which reported that difficult listening conditions (e.g. reduction in SNR or low level of contextual support), placed greater demands on processing resources for the primary task (word identification), resulting in declines in secondary task performance, which may be interpreted as listening effort (Anderson Gosselin & Gagné, 2011; Sarampalis et al., 2009).

Clinical Implications

Results of the current study have two main clinical implications. First, while age-related changes to the speech signal did not have a significant overall effect on word recognition and word recall results in our study, differential effects of speaker age were observed under the most challenging listening conditions (low context and 0 dB SNR). Without the support of semantic context, older listeners, appeared to benefit from the slower speech rates of the older male speakers, whereas when semantic context was available, other speech cues, such as prosody appeared to offer more support.

Currently, aural rehabilitation is largely focused on the provision of hearing aids to make the speech signal audible, but these do not eliminate the problems experienced by older listeners in adverse listening conditions. Our results indicated that older listeners are able to flexibly use a variety of acoustic and linguistic cues to compensate for a degraded signal. Aural rehabilitation, focusing on the enhancement of these compensatory strategies should be considered for older individuals with and without hearing aids. Particular emphasis should be given to the use of supportive context in the rehabilitative training of older adults (Pichora-Fuller, 2009). Computer-based auditory training programmes such as Listening and Communication Enhancement (LACE: Sweetow, 2006), which incorporate training exercises with varying levels of background noise, should be considered.

Secondly, based on the results of the current study, aural rehabilitation training of older adults should involve frequent communication partners, who are generally older adults themselves. The focus of such training should be awareness of the speech cues which are likely to be beneficial in adverse listening conditions, such as cueing the listener into topic changes, slowing the rate of speech, or increasing the level of speech when there are competing talkers (Helfer, 2009).

Limitations and Directions for Future Research

Limitations of the current study need to be considered in evaluating the results. Firstly, the relatively small sample size of 20 may not generalize to the broader population. The listeners in our study were divided into two groups: a group with hearing loss (defined according to criteria used by Cruikshanks, 1998) and a group with better hearing, in order to analyse the differential effects of hearing loss on the perception of different-aged speakers. The small sample size in each sub-group is likely to have resulted in low statistical power.

Also, because of the additional time required to record and edit speech samples from 12 speakers in this study, there was not sufficient time, within the constraints of the author's clinical study programme, to include a group of younger listeners in the listening study. It would be valuable in future studies to enrol an additional young listener participant group in order to ascertain to what extent speaker-group effects in the word recognition and recall results were due to the age and hearing status of the listener.

Thirdly, the younger speaker group in this study comprised five postgraduate students from the Department of Communication Disorders at Canterbury and one postgraduate teacher. Students who are selected for postgraduate study in communication disorders and teaching are likely to be good communicators and, as such, this group may not have exhibited speech characteristics typical of all younger speakers. Subjective analysis of the speakers indicated that there were differences in the speech rate and voice quality of the younger and older groups, but objective analysis was not conducted to confirm these differences. Such an analysis would have enabled more accurate correlation of the acoustic characteristics of the speaker groups and the speech perception results. Future studies should include objective analysis of stimulus duration and acoustic features of speech in order to identify which specific features of the speaker groups made speech recognition more or less difficult.

Finally, the listening task in this study (identification of sentence-final words) may not allow generalization to the variety of real-life listening situations faced by older listeners. Speech stimuli consisted of short sentences which were read by the speaking participants in the study. While speakers were instructed to read in a relaxed, conversational manner, age-related speaker differences may have been limited by the constraints of the task. The addition of a discourse-based listening experiment in future studies might reveal greater differences in age-related speaker characteristics.

Conclusion

In summary, the ability of older listeners to understand speech, and the degree of listening effort required, were not directly related to speaker age. This finding supported the results of a previous study which found that speech recognition scores were not significantly different when stimuli were produced by younger rather than older adult speakers (McAuliffe et al., 2012). However, the addition of different levels of background noise in our study allowed speaker group differences to emerge in the more challenging SNR conditions. Our findings provide further evidence that older listeners rely on a wide range of speech cues, such as prosodic features and semantic context to compensate for a degraded signal. The availability of these cues depends on characteristics of the speaker, such as rate of speech and prosody, as well as characteristics of the listener and the listening environment.

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Appendices

Appendix A

Ethics Approval Letter from University of Canterbury Human Ethics Committee, Recruitment Letter for Participants, Information Sheet for Listener Participants, Information Sheet for Speaker Participants, Consent Form for Listener Participants, Consent Form for Speaker Participants, Debriefing Letter.

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2012/32

30 April 2012

Penny Harris
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Penny

The Human Ethics Committee advises that your research proposal "An objective measure of listening effort: effects of background noice and speaker age" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 18 April 2012.

Best wishes for your project.

Yours sincerely

Michael Grimshaw
Chair
University of Canterbury Human Ethics Committee

19 Creyke Road
Ilam
Christchurch 8041

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

26 June 2012

Dear ………………………….

You are invited to participate in a research project titled: “Effect of speaker age on speech recognition and listener effort in older adults”. For this project we require 20 adult listeners. Participants need to be aged over 65 years with normal hearing or a mild to moderate hearing loss. All participants should be native speakers of New Zealand English.

If you decide to volunteer for this study you will be required to complete the following tasks:

1. A full assessment of your hearing
2. Cognitive Test – Prior to completing the study tasks, we will administer a brief test of listening, memory and attention. You will be asked some questions such as “What day is it today?”
3. Listening task – you will be asked to listen to some short sentences from different speakers. Some of these sentences will be in quiet and some of them will be in noise. We will ask you to repeat the final word of each sentence and recall these after a short time.

In total, your involvement in this study will take approximately two hours. The tests will be carried out at the University Speech and Hearing Clinic (corner of Creyke Road and Engineering Road). You will receive a $20 voucher as compensation for your time. Participation is voluntary, and you are free to withdraw from the study at any stage.

Any information gathered will be kept strictly confidential, and you will in no way be identifiable through the results of the study. This study has received ethical approval from the Human Ethics Committee at the University of Canterbury.

Thank you for your consideration. If you would like more information or are interested in participating in this study, please contact Penny Harris on 332 4674 (email: pjh151@uclive.ac.nz) or Associate Professor Megan McAuliffe on 364 2987 ext. 7075 (email: megan.mcauliffe@canterbury.ac.nz).

Yours sincerely,

Penny Harris
Master of Audiology Student

Associate Professor Megan McAuliffe
Department of Communication Disorders & NZ Institute of Language, Brain & Behaviour

INFORMATION SHEET – LISTENER GROUP 20.03.2012

Project Name: How Speaker Age Affects Speech Recognition and Listener Effort in Older Adults

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

You are invited to take part in the research project titled: "How Speaker Age Affects Speech Recognition and Listener Effort in Older Adults". Please take the time to read this information sheet thoroughly and consider whether you would like to participate. Your participation is entirely voluntary. The following research team is conducting this study:

Principal Investigator:
Penny Harris, Master of Audiology Student

Associate Investigators:
Associate Professor Megan McAuliffe, Senior Lecturer, Department of Communication Disorders
Dr Greg O'Beirne, Senior Lecturer, Department of Communication Disorders
Prof. Jen Hay, Professor in Linguistics

We are interested in how older people understand speech in noise and the degree of effort required to understand younger and older speakers. An understanding of specific difficulties will be helpful for audiologists in the development of assessment and treatment plans.

Prior to completing the listening tasks, we will administer a brief test that screens for mild cognitive impairment. You will be asked some questions such as "What day is it today?" We will then assess your hearing. Your ears will be examined and earphones will be placed in your ears through which you will hear some beeps. You will be asked to press a button whenever a beep is heard. This will provide information about the degree and configuration of your hearing loss which is important for the study. Following this, the function of your middle ear will be assessed by placing an earphone in each ear separately and recording measurements. You may feel a slight change in pressure, but this test does not require you to respond. The hearing assessment will be administered by a Master of Audiology student in the soundproof testing booth at the Department of Communication Disorders. It is expected that this will take approximately 45 minutes. Should the results of your hearing assessment show an unexpected hearing loss, this will be discussed with you.

Once the hearing test has been completed, you will be asked to undertake the listening task. Earphones or headphones will be fitted onto your head. You will hear sentences spoken by different speakers. Some of these sentences will be in quiet and some will be in noise. We will simply ask you to repeat what you think you heard.

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In total your involvement in the study will take approximately two hours. The tests may be completed in one session or over two sessions if you prefer.

CONFIDENTIALITY

- Your privacy and confidentiality will be maintained at all times.
- All information will be kept in a locked filing cabinet at the Department of Communication Disorders, University of Canterbury. Only the researchers or research assistants involved in this project will have access to the information.
- The results of this project will be published; however, no material which could personally identify you will be used in any reports of this study.
- Feedback on individual assessment results will be provided at the time of testing.
- If you wish, you will be advised of the results of the study.

COMPENSATION

- You will receive a $20 voucher for your participation in this study.

RISKS OF PARTICIPATION

There are no physical risks involved in participating in this project. If you become tired during testing, you will be given as many breaks as you feel necessary. If you feel uncomfortable or unable to continue at any time, you can withdraw from the study.

WITHDRAWING FROM THE STUDY

It is important to note that this study is voluntary and you are free to withdraw form it at any time. If you choose to withdraw, any data collected prior to withdrawal will not be used for research purposes without your consent.

ETHICS

This study has received ethical approval from the Human Ethics Committee at the University of Canterbury. Please do not hesitate to contact Associate Professor Megan McAuliffe if you have any concerns about your participation in this project (see contact details below). If you would like to speak to someone not involved in the study, please contact the Secretary of the Human Ethics Committee, University of Canterbury.

FOR MORE INFORMATION

If you have further questions regarding the research, please feel free to contact Penny Harris on 332 4674 or email pjh151@uclive.ac.nz. Alternatively, you can contact Associate Professor Megan McAuliffe on 364 2987 ext. 7075 or email megan.mcauliffe@canterbury.ac.nz.

INFORMATION SHEET – SPEAKER GROUP
26.03.2012

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Project Name: How Speaker Age Affects Speech Recognition In Older Adults.

You are invited to take part in the research project titled: "How Speaker Age Affects Speech Recognition and Listener Effort in Older Adults".
Please take the time to read this information thoroughly and decide if you would like to take part. Your participation is entirely voluntary. The following research team is conducting this study:

Principal Investigator:
Penny Harris, Master of Audiology Student

Associate Investigators:
Associate Professor Megan McAuliffe, Senior Lecturer, Department of Communication Disorders
Dr Greg O'Beirne, Senior Lecturer, Department of Communication Disorders
Prof. Jen Hay, Professor in Linguistics

We are interested in how older people understand speech in noise and the degree of effort required to understand younger and older speakers. An understanding of specific difficulties will be helpful for audiologists in the development of assessment and treatment plans.

You will be required to attend one voice recording session, which will last approximately 90 minutes.

You will be seated in a sound-attenuated booth in the Communication Disorders Research Laboratory at the University of Canterbury. A headset microphone will be placed over your head and you will be asked to read sentences aloud from printed text. In total you will be asked to read 8 lists of 48 short sentences, each containing 6-8 syllables. You will be asked to repeat any sentences containing errors or hesitations. At the end of each sentence list you will be given the opportunity to rest.

CONFIDENTIALITY

- Your privacy and confidentiality will be maintained at all times.
- All information will be kept in a locked filing cabinet at the Department of Communication Disorders, University of Canterbury. Only the researchers or research assistants involved in this project will have access to the information.
- The results of this project will be published; however, no material which could personally identify you will be used in any reports of this study.
- If you wish, you will be advised of the results of the study.

WITHDRAWING FROM THE STUDY

You may end the task at any time and are free to discontinue participation in this study.

COMPENSATION

- You will receive a $20 voucher for your participation in this study.

ETHICS
This study has received ethical approval from the Human Ethics Committee at the University of Canterbury. Please do not hesitate to contact Associate Professor Megan McAuliffe if you have any concerns about your participation in this project (see contact details below). If you would like to speak to someone not involved in the study, please contact the Secretary of the Human Ethics Committee, University of Canterbury.

Thank you for choosing to take part in this study. Your participation is greatly appreciated.

FOR MORE INFORMATION
If you have further questions reg*ar*ding the research, please feel free to contact Penny Harris on 332 4674 or email penny.harris@pg.canterbury.ac.nz. Alternatively, you can contact Associate Professor Megan McAuliffe on 364 2987 ext. 7075 or email megan.mcauliffe@canterbury.ac.nz.

CONSENT FORM – LISTENER PARTICIPANTS

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

<u>Project Name:</u> How Speaker Age Affects Speech Recognition and Listener Effort in Older Adults

<u>Principal Investigator:</u> Penny Harris, Master of Audiology Student

<u>Associate Investigators:</u>
Associate Professor Megan McAuliffe, Senior Lecturer, Department of Communication Disorders
Dr. Greg O'Beirne, Senior Lecturer, Department of Communication Disorders
Prof. Jen Hay, Professor in Linguistics

- I have read and understood the information sheet for volunteers taking part in the study designed to assess speech recognition and listener effort when listening to speakers of different ages.
- I have had the opportunity to discuss this study with the researcher/s. I am satisfied with the answers I have been given.
- I understand that my participation in this study is confidential and that no material that could identify me will be used in any reports of this study.
- I have had time to consider whether to take part.
- I understand that taking part is voluntary and that I may withdraw from the study at any time. I am also aware that this will in no way affect my future interactions with the Department of Communication Disorders.

I am happy to be contacted for future studies **YES/NO**

I consent to the results of these assessments being made available for future studies if required **YES/NO**

I give permission to the research team to access my previous audiological clinical records

I wish to receive a copy of the results **YES/NO**

<u>I hereby consent to take part in this study:</u>

NAME (please print) ____

Signature: _____________________________________ Date: _____________________________

Project explained by: ________________________________

Project role: ____

Signature: ____

CONSENT FORM-SPEAKER PARTICIPANTS

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Project Name: An objective measure of listening effort: Effects of background noise and speaker age

Principal Investigator: Penny Harris, Master of Audiology Student

Associate Investigators: Associate Professor Megan McAuliffe, Senior Lecturer, Department of Communication Disorders
Dr. Greg O'Beirne, Senior Lecturer, Department of Communication Disorders Prof. Jen Hay, Professor in Linguistics

- I have read and understood the information sheet for volunteers taking part in the study designed to assess speech recognition and listener effort when listening to speakers of different ages.
- I have had the opportunity to discuss this study with the researcher/s. I am satisfied with the answers I have been given.
- I understand that my participation in this study is confidential and that no material that could identify me will be used in any reports of this study.
- I have had time to consider whether to take part.
- I understand that taking part is voluntary and that I may withdraw from the study at any time. I am also aware that this will in no way affect my future interactions with the Department of Communication Disorders.

I am happy to be contacted for future studies **YES/NO**

I wish to receive a copy of the results **YES/NO**

I consent for the speech samples to be used in the current study **YES/NO**

I consent for the speech samples to be used in future studies by this group of researchers **YES/NO**

I consent for the speech samples to be played in a classroom or at a conference without any information that would identify the speaker **YES/NO**

I hereby consent to take part in this study:

Name (please print) ____

Signature: ____________________________________ Date: ____________________________

Project explained by: _______________________________

Project role: ______________________________________

Signature: _________________________________

Date: 21.03.2012

DEBRIEFING LETTER

Project Name: How Speaker Age Affects Speech Recognition and Listener Effort in Older Adults.

Principal Investigator:

Penny Harris, Master of Audiology Student

Associate Investigators:

Associate Professor Megan McAuliffe, Senior Lecturer,
Department of Communication Disorders

Dr Greg O'Beirne, Senior Lecturer, Department of Communication Disorders

Professor Jen Hay, Professor in Linguistics

Thank you for participating in this study. The purpose of this research is to determine the effects of speaker age and background noise on speech perception and listener effort in older adults. Listening effort is an important aspect of speech understanding.

The pre-study information sheet given to you partly describes your role in the *listening task*. It was only revealed to you immediately before this task that in addition to repeating the target words, you also had to ***memorise the target words for later recall***. The later part of this task was not disclosed initially, as this may have had a negative impact on your willingness to participate or given you an opportunity to practise memorising speech phrases which may have biased your results.

It has been shown in young adults with normal hearing that listening effort can be measured objectively by performance on a second, competing task such as memorising words. It is proposed that when more effort is required to understand speech, because the sigal is degraded, fewer cognitive resources are available to perform other competing tasks. An understanding of how much effort older listeners with hearing loss have to use to recognise speech will be helpful for audiologists in the future development of assessment and treatment plans.

We will be running this study over the next few months. We would ask you to maintain confidentiality about the procedures of this experiment, since any pre-knowledge of the procedures will bias the data we obtain for subsequent participants (and therefore exclude such data from our final analysis). If you are uncomfortable about not being informed about the memory component prior to the listening task, you are free to withdraw from this study.

If you have any comments, concerns or questions regarding the research, please feel free to contact Penny Harris on 332 4674 or email: pjh151@uclive.ac.nz. Alternatively, you can contact Associate Professor Megan McAuliffe on 364 2987 ext. 7075 or email: megan.mcauliffe@canterbury.ac.nz. If you would prefer to speak with someone not involved in the study, please contact the Secretary of the Human Ethics Committee, Private Bag 4800, Christchurch 8140.

Appendix B

Summary table for the five-way (2 Speaker Age Groups X 2 Speaker Genders X 2 Semantic Contexts X 3 SNR Conditions X 2 Listener's Hearing Status Groups) Mixed Model MANOVA.

Effect	Pallai's Trace	F	Hypothesis df	Error df	p	η_p^2
Hearing Status (H)	0.229	2.52	2	17	0.110	0.229
Speaker Age (A)	0.033	0.288	2	17	0.753	0.033
Speaker Gender (G)	0.108	1.031	2	17	0.378	0.108
Semantic Context (C)	0.950	162.090	2	17	< 0.001*	0.950
SNR (S)	0.987	287.261	4	15	< 0.001*	0.987
H*A	0.030	0.261	2	17	0.773	0.030
H*G	0.083	0.766	2	17	0.480	0.083
H*C	0.083	0.768	2	17	0.479	0.083
H*S	0.227	1.101	4	15	0.392	0.227
A*G	0.068	0.618	2	17	0.551	0.068
A*C	0.435	6.545	2	17	0.008*	0.435
A*S	0.013	0.050	4	15	0.995	0.013
G*C	0.636	14.863	2	17	< 0.001*	0.636
G*S	0.148	0.652	4	15	0.635	0.148
C*S	0.912	39.051	4	15	< 0.001*	0.912
H*A*G	0.246	2.773	2	17	0.091	0.246
H*A*C	0.016	0.134	2	17	0.875	0.016
H*A*S	0.115	0.485	4	15	0.746	0.115
H*G*C	0.016	0.140	2	17	0.870	0.016
H*G*S	0.287	1.509	4	15	0.249	0.287
H*C*S	0.379	2.290	4	15	0.108	0.379
A*G*C	0.442	6.735	2	17	0.007*	0.442
A*G*S	0.237	1.162	4	15	0.367	0.237
A*C*S	0.192	0.892	4	15	0.493	0.192
G*C*S	0.096	0.398	4	15	0.807	0.096
H*A*G*C	0.101	0.959	2	17	0.403	0.101
H*A*G*S	0.177	0.806	4	15	0.541	0.177
H*A*C*S	0.122	0.523	4	15	0.720	0.122
H*G*C*S	0.116	0.491	4	15	0.742	0.116
A*G*C*S	0.376	2.260	4	15	0.111	0.376
H*A*G*C*S	0.028	0.110	4	15	0.977	0.028

* Significant at 0.05 level

Appendix C

Summary table for the five-way (2 Hearing Status Groups X 2 Speaker Age Groups X 2 Speaker Genders X 2 Semantic Contexts X 3 SNR Conditions) Mixed Model ANOVA conducted on the word identification scores.

Effect	F	Hypothesis df	Error df	p	η_p^2
Hearing Status (H)	2.825	1	18	.110	.136
Speaker Age (A)	.216	1	18	.648	.012
Speaker Gender (G)	1.621	1	18	.219	.083
Context (C)	343.235	1	18	< 0.001*	0.950
SNR (S)	496.409	2	36	< 0.001*	0.965
H*A	.532	1	18	.475	.029
H*G	1.621	1	18	.219	.083
H*C	1.145	1	18	.299	.060
H*S	2.512	2	36	.095	.122
A*G	.513	1	18	.483	.028
A*C	9.259	1	18	0.007*	0.340
A*S	.085	2	36	.919	.005
G*C	14.400	1	18	0.001*	0.444
G*S	.859	2	36	.432	.046
C*S	30.669	2	36	< 0.001*	0.630
H*A*G	.000	1	18	.994	.000
H*A*C	.280	1	18	.603	.015
H*A*S	.433	2	36	.652	.024
H*G*C	.016	1	18	.900	.001
H*G*S	3.040	2	36	.060	.144
H*C*S	8.167	2	36	< 0.001*	0.312
A*G*C	10.006	1	18	0.005*	0.357
A*G*S	1.397	2	36	.260	.072
A*C*S	1.666	2	36	.203	.085
G*C*S	.617	2	36	.545	.033
H*A*G*C	.659	1	36	.427	.035
H*A*G*S	.483	2	36	.621	.026
H*A*C*S	.766	2	36	.472	.041
H*G*C*S	.208	2	36	.813	.011
A*G*C*S	.683	2	36	.512	.037
H*A*G*C*S	.086	2	36	.917	.005

* Significant at 0.05 level

Appendix D

Summary table for the five-way (2 Hearing Status Groups X 2 Speaker Age Groups X 2 Speaker Genders X 2 Semantic Contexts X 3 SNR Conditions) Mixed Model ANOVA conducted on the word recall scores.

Effect	F	Hypothesis df	Error df	p	η_p^2
Hearing Status (H)	4.602	1	18	0.046	0.204
Speaker Age (A)	.061	1	18	.808	.003
Speaker Gender (G)	.102	1	18	.753	.006
Context (C)	60.286	1	18	< 0.001*	0.770
SNR (S)	47.140	2	36	< 0.001*	0.724
H*A	.290	1	18	.597	.016
H*G	.148	1	18	.705	.008
H*C	1.154	1	18	.297	.060
H*S	2.512	2	36	.095	.122
A*G	.521	1	18	.480	.028
A*C	.128	1	18	.724	.007
A*S	.021	2	36	.979	.001
G*C	8.529	1	18	0.009*	0.321
G*S	.147	2	36	.864	.008
C*S	4.132	2	36	0.024*	0.187
H*A*G	5.603	1	18	0.029*	0.237
H*A*C	.100	1	18	.756	.006
H*A*S	.224	2	36	.801	.012
H*G*C	.296	1	18	.593	.016
H*G*S	.286	2	36	.753	.016
H*C*S	3.827	2	36	0.031*	0.175
A*G*C	.008	1	18	.931	.000
A*G*S	.064	2	36	.939	.004
A*C*S	.564	2	36	.574	.030
G*C*S	.273	2	36	.763	.015
H*A*G*C	.322	1	18	.578	.018
H*A*G*S	1.150	2	36	.328	.060
H*A*C*S	.526	2	36	.595	.028
H*G*C*S	1.147	2	36	.329	.060
A*G*C*S	6.610	2	36	0.004*	0.269
H*A*G*C*S	.085	2	36	.918	.005

* Significant at 0.05 level