Communication in noise for aging adults: interactions of auditory, cognitive and social factors

M. K. Pichora-Fuller[1,2,3]

[1] Dept of Psychology, University of Toronto, 3359 Mississauga Rd N., Mississauga, Ontario, Canada L5L 1C6

[2] Toronto Rehabilitation Institute, 550 University Ave., Toronto, Ontario, Canada M5G 2A2

[3] Department of Behavioural Sciences and Learning, Linköping University, SE-581 83 Linköping, Sweden

INTRODUCTION

It is well known that many older adults report having disproportionate difficulties understanding speech in noise compared to younger adults (CHABA 1988). These reports are made even by those who have little difficulty understanding in quiet and who have audiograms considered to be normal for their age and gender (ISO 7029-2000) and within normal clinical limits up to 4 kHz. Over the last two decades, much has been learned about specific age-related differences in auditory and cognitive factors that may account for their difficulties in noise (Gordon-Salant et al. 2010).

The main thesis of the present paper is that, in addition to considering the now well-researched age-related differences in auditory and cognitive processing that play a role in communication in noise by aging adults, it is also important to consider socio-emotional factors that can influence listening and how older adults may differ from younger adults in coping with listening difficulties in noise. An appreciation of the connections between the trio of psychological domains shown in Figure 1 promises to offer new insights into the causes and consequences of the communication problems that older adults have in noise even if they have little audiometric loss.

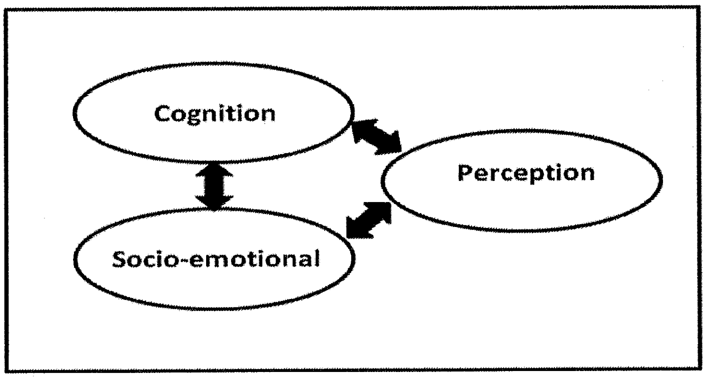

Figure 1: Trio of domains contributing to age-related differences in communication in noise

To explore these connections, preliminary evidence from four studies examining a variety of measures will be presented. The first study uses behavioral testing to examine the relationship between psychoacoustic measures and speech and music perception in older adults. The second set of studies involves the use of jittering as a simulation of auditory aging to determine if this type of temporal distortion can shift the performance of younger adults to mimic that of older adults. The third study examines age-related differences in self-reported listening difficulties. The fourth study explores the relationship between behavioral and self-reported measures of hearing with behavioral measures of memory and self-reported stigma and mood.

STUDY 1: AUDITORY AGING FACTORS AFFECTING SPEECH AND MUSIC

Over the last two decades, age-related differences in the auditory temporal processing of fine structure and envelope cues have been found (for a review see Pichora-Fuller & MacDonald 2008). To study the relationship between age-related differences across various measures of auditory temporal processing, we tested 48 older adults (mean age = 72 years, range 66 to 81) who had pure-tone thresholds within normal clincial limits ($\leq$ 25 dB HL from .25 to 3 kHz) using a battery of tests. The test battery was compromised of audiologic (including high-frequency audiometry and oto-acoustic emissions (OAEs)), psychoacoustic (including measures of frequency difference limens for .5 and 2 kHz tones and for voice fundamental frequency (F_0), gap detection thresholds for .5 and 2 kHz tone-pips and for within- and between-channel speech and non-speech markers, and amplitude modulation detection thresholds), and word tests (including monosyllabic words presented in babble and distorted by vocoding, time-compression and jittering).

The pattern of correlations suggests that there are three main factors: high-frequency pure-tone thresholds (HFPTA for .4, .6 and .8 kHz), envelope coding (gap detection and amplitude modulation thresholds), and periodicity coding (F_0). There were no strong correlations between pure-tone measures and temporal measures nor between temporal measures related to periodicity coding and those related to envelope coding. Age was significantly correlated with HFPTA, as well as with psychoacoustic measures related to envelope coding, including gap detection (especially between-channel gap detection with a broadband noise as the leading marker and a 500-Hz tone as the lagging marker) and amplitude modulation thresholds. Word recognition with competing multi-talker babble at -15 dB SNR was significantly correlated with the HFPTA and standard PTA (.5, 1 and 2 kHz) as well as with amplitude modulation threshold; however, a regression analysis showed that the HFPTA was the dominant factor related to speech in noise accuracy. Importantly, in a subsequent analysis that divided the participants into two groups, those with normal OAEs (N = 24) and those with abnormal OAEs (N = 15), it was shown that word recognition in noise was driven by amplitude modulation for the group with normal OAEs ($p = .02$) and by HFPTA for the group with abnormal OAEs ($p = .07$). Furthermore, in a sequel experiment examining the perception of music tonality, the factor which best predicted performance was F_0 (Russo et al., submitted).

These findings suggest that most (but not all) older adults with relatively good audiograms have sub-clinical auditory temporal processing deficits at various levels, including periodicity coding, onset-offset coding of gaps, and coding of envelope fluctuations over time. Each of these types of temporal processing seems to play a specific role depending on the type of signal, with F_0 contributing to the perception of music tonality while amplitude modulation and HFPTA contribute to word recognition in competing babble. In addition, the type of pathology influences the relative contributions of auditory abilities, with audibility being the dominant factor for those with abnormal OAEs, but with amplitude modulation being more important for those with normal OAEs, presumably because the former group have more outer hair cell damage than the latter group who may have more neural degeneration.

STUDY 2: USE OF TEMPORAL JITTER TO SIMULATE AUDITORY AGING

The prevalence of high-frequency hearing loss increases markedly with age, with the most typical causes being damage to the outer hair cells (OHC) and/or to reductions in the endocochlear potential (Mills et al. 2006); however, neural presbycusis can occur independent of the typical sorts of cochlear damage and without necessarily manifesting as elevated audiometric thresholds (e.g. Frisina et al. 2001; Walton 2010). At least for older adults with good audiograms, age-related differences in temporal processing seem likely to explain the particular difficulties they experience when listening in noise (Pichora-Fuller & Souza 2003). Such differences in temporal processing may be explained more by the neural changes in the aging auditory system than to changes in the OHCs (see also Kujawa & Liberman 2006). This view could explain why in Study 1 the word recognition scores in babble for older adults with good OAEs were driven by measures of temporal processing whereas they were driven more by HFPTA for those with abnormal OAEs.

In general, there is often a confound between age and the degree of audiometric threshold elevation. It is difficult to control both age and hearing loss experimentally because, even if the audiograms of younger adults are similar to the audiograms of older adults, there is no guarantee that they have the same underlying pathology. Conversely, if younger adults with good hearing are compared to older adults with good hearing, there is no guarantee that the older adults do not have neural damage that is not well indexed by the audiogram. One way to contend with this dilemma is to try to simulate the effects of the temporal aspects of auditory aging by distorting signals and presenting them to younger adults with normal hearing in an attempt to render their performance similar to that of older adults. In this way the consequences of signal properties to performance can be evaluated using a within-subjects design.

In general, older adults typically require a 3 dB SNR advantage compared to younger adults to achieve 50 % accuracy on word recognition in noise tests (e.g. Pichora-Fuller et al. 1995). When speech was temporal jittered to disrupt the periodicity of the signal, the threshold for 50 % accuracy on word recognition in noise by younger adults shifted by about 3 dB SNR to approximate the performance of older adults (Pichora-Fuller et al. 2007). Furthermore, as well as making younger adults recognize words in noise like older adults, their memory for recognized words was also reduced to match the word recall of older adults when temporal jittering was used to distort the speech, providing support for the claim that reduced memory for words heard in noise may be secondary to the auditory temporal processing problems of older listeners (Brown & Pichora-Fuller 2000). Jittering has also been successful in altering the performance of younger adults to become more like that of older adults on psychoacoustic and speech perception measures; for example, when within-channel gap detection is tested using periodic markers such as tones or vowels, when concurrent vowel identification is tested as a function of the vowel F_0 separation, or when the perception of musical tonality is tested. Taken together, these findings suggest that the subtle distortion of periodicity cues in jittered signals presented to younger listeners can affect their performance on psychoacoustic, speech and music tasks in ways that resemble age-related declines in performance. The results also suggest that for certain stimuli in certain tasks there is a connection between periodicity coding and other levels of temporal and cognitive processing.

STUDY 3: AGE-RELATED DIFFERENCES IN SELF-REPORTS OF DIFFICULTY

Experimental measures of auditory processing shed some light on why older adults may have difficulty when speech is masked or speeded, but the kinds of everyday listening situations that pose a challenge for older adults often involve additional nonauditory demands. Listener may need to focus, switch, or divide attention when there are multiple sound sources. They may need to not only hear, but also understand new information, remember a complex set of instructions, or synchronize the coordinated turn-taking in alternating roles as listener or talker as is required in a conversation.

The Speech, Spatial and Qualities of Hearing Scale (SSQ; Gatehouse & Noble 2004) is a questionnaire developed to measure a listener's self-reported ability to hear in a variety of everyday situations. The SSQ can be used to gain insights into the possible contributions of auditory and cognitive factors to the everyday listening difficulties of older adults. The SSQ was administered to 48 younger (mean age = 18.6 years, range 18 to 22) and 48 older adults (mean age = 70 years, range 64 to 80) (Banh et al., 2011). Significant differences ($p<0.05$) were found on 42 of the 46 questions. Table 1 lists the items for which the greatest age-related differences were observed. These items met the criterion that the younger adults scored at least 1.4 points (on a 10-point scale) higher than the older adults (1.4 = Mean + 1 SD of the between-group item difference scores). The situations that resulted in these pronounced age-related differences required the listener to use temporal processing to segregate voices, to judge the direction of moving sound sources, and to interpret reverberation, as well as using cognitive processing to focus and switch attention to a target voice during conversation. Clearly, both auditory temporal processing and cognitive processing contribute to age-related differences in everyday listening.

Table 1. Mean and standard deviation (SD) of the SSQ item scores for younger and older adults

		Younger adults		Older adults	
Speech hearing items		Mean	SD	Mean	SD
5	Talking with one person in continuous noise	9.1	1.1	7.5	2.1
7	Having conversation in echoic environment	8.7	1.3	7.1	2.0
8	Ignore interfering voice of same pitch	8.3	1.3	6.8	2.2
9	Ignore interfering voice of different pitch	9.1	0.9	7.2	2.1
12	Follow conversation switching in a group	8.7	1.3	7.1	1.8
Spatial hearing items					
13	Identify if vehicle is approaching or receding	9.2	0.9	7.7	1.6
Qualities of hearing items					
2	Sounds appearing jumbled	9.1	1.3	7.3	3.0

STUDY 3: STIGMA AND MOOD RELATED TO SELF-REPORTS OF DIFFICULTY

Beyond the age-related differences in auditory temporal processing and cognitive processing that seem to conspire to make listening in noise more difficult for older adults, it also seems likely that social and emotional factors may modulate their communication performance and the way in which they cope with these difficulties. Hearing problems may exacerbate psychosocial declines in older adults, but conversely, age-related psychosocial issues may aggravate hearing problems.

It is possible that social factors, in particular feelings of age-related stigmatization and low self-efficacy, may exacerbate poor perceptual and cognitive performance, with consequences to listening and communication (Kramer et al. 2002; Kempen et al. 1999). Social psychologists have made significant advances in the measurement of stigma (Kang & Chasteen 2009). Stunning findings from social psychology have shown that behaviors as widely ranging as walking speeds (Bargh et al. 1996) and hearing thresholds (Levy et al. 2006) can be affected by age-related stereotypes (Dijksterhuis & Bargh 2001) and that such effects impact not only non-members of a stereotype-group, but group members as well. "Stereotype threat" refers to the risk of confirming a negative stereotype of a group with which one identifies (Schmader et al. 2008; Steele & Aronson 1994; Steele et al. 2002). For example, the degree to which one holds stereotypic beliefs can negatively impact one's own memory performance (Beilock et al. 2007; Chasteen et al. 2005; Croizet et al. 2004; Hess et al. 2009; Schmader & Johns 2003). Another potentially important factor is self-efficacy, or the confidence listeners have in their abilities, which also may influence performance, with a relevant domain being speech perception and language comprehension abilities in daily conversational situations (Wingfield & Tun 2007). Self-efficacy has been shown to play an important role in the successful management of numerous health conditions; however, research directly focusing on self-efficacy related to listening abilities is limited (Smith et al. 2011).

To explore the relationships between auditory, cognitive and socio-emotional factors, to date 155 adults (55 years or older) have been tested on a battery of behavioral measures of hearing and cognition as well as self-report measures of their auditory and socio-emotional status. For the present paper, the analysis included two behavioral measures of hearing ability: audiometric thresholds (PTA for .5, 1, 2, and 3 kHz) and word recognition threshold [SNR threshold for 50 % correct word recognition on the Words-in-Noise Test (WIN); Wilson 2003; Wilson et al. 2007)]. There were also two behavioral measures of cognitive ability, a memory free recall test and a screening test for mild cognitive impairment [Montreal Cognitive Assessment (MoCA); Nasreddine et al. 2005]. In addition to the behavioral four measures, there were four self-report measures, two concerning listening, the SSQ and the Listening Self-efficacy Questionnaire (LSEQ; Smith et al. 2011), and two concerning socio-emotional status, The Fear of Aging Scale (FOA; adapted from Sarkisian et al. 2002) and the Profile of Mood States (POMS; McNair et al 1971).

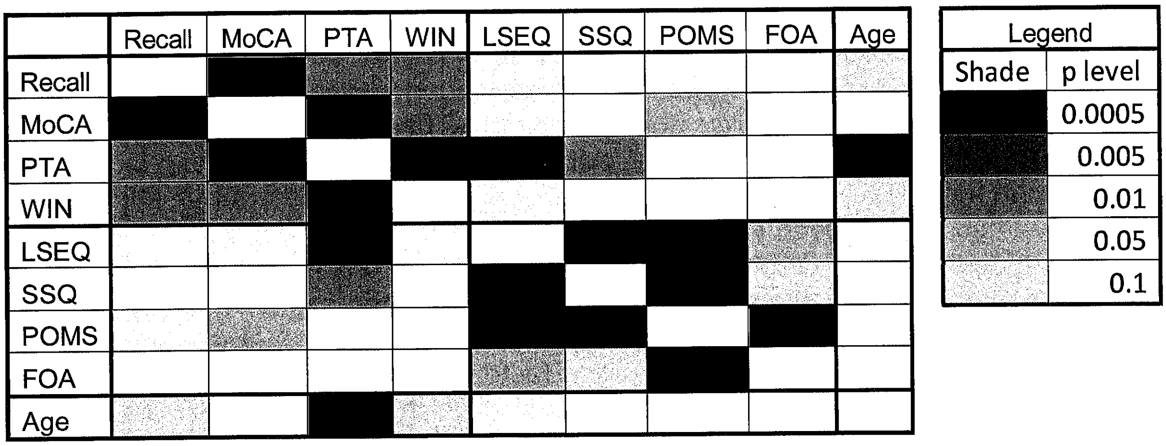

Figure 2: Correlations between behavioral measures of memory and hearing and self-reported measures of listening, stigma and mood

Figure 2 shows the correlations between the four behavioral and four self-report measures and age, with the darkness corresponding to the significance level that was reached. Not surprisingly, there were very strong correlations ($p<0.0005$) between the two behavioral tests of hearing ability, between the two behavioral tests of cognitive ability, between the two self-report measures of listening, and between the two self-report measures of socio-emotional status. There were also strong correlations ($p<0.005$) observed between the four behavioral measures. Likewise, there were strong correlations between the four self-report measures. Some significant correlations were observed between the behavioral and self-report measures (e.g., PTA and LSEQ or MoCA and POMS), but these tended to be less robust relationships ($p<0.01$). It is also interesting to note that age correlated significantly only with performance on the two behavioral hearing tests and the behavioral free recall memory test. Thus, there seem to be strong relationships between behavioral measures of hearing and cognition in older adults, as well as between self-report measures of listening and socio-emotional factors; however, the connections between behavior and self-report are relatively weak.

It is difficult to tell from this snapshot of results whether cognitive problems are the cause or the consequence of auditory problems or to tell if self-reported listening ability drives or is driven by socio-emotional factors. It is even more difficult to glean whether the auditory and cognitive behavioral performance of older adults affects their self-reported abilities or whether their self-appraisals influence their actual performance in the short or long term. Nevertheless, it is apparent that the listening difficulties of older adults involve not just auditory but also cognitive factors and that the behavioral changes measured in both auditory and cognitive abilities need to be considered in light of socio-emotional self-perceptions of their abilities.

SUMMARY

Over the last 20 years, research undertaken to understand why older listeners have disproportionate difficulties compared to younger listeners in noisy situations has advanced our knowledge concerning the nature of age-related differences in temporal processing. Most older adults demonstrate poorer auditory temporal processing than their younger counterparts for various temporal cues ranging from fine structure periodicity cues to cues provided by the ongoing fluctuations in the amplitude envelope of a signal. There seem to be three main types of auditory processing that are interrelated and these are typified by F_0 difference limens (periodicity coding), gap detection or amplitude modulation thresholds (envelope coding), and the HFPTA (audibility). The importance of these types of processing can depend on the type of task (speech or music) and whether or not the sub-type of presbycusis involves primarily OHC or neural damage. Nevertheless, evidence from experiments using jittering to simulate the temporal aspects of auditory aging suggest that there may be important inter-dependencies between periodicity coding and the processing of other temporal cues, such as the use of certain envelope cues when there is a gap in a periodic signal. The distortion of the signal caused by jittering also has cognitive consequences insofar as it places a demand on working memory with an observed reduction in working memory span. The role of cognitive factors, especially attention, is also evident when the largest self-reported age-related differences on the SSQ are considered. Finally, there are strong correlations between behavioral measures of hearing and cognition as well as strong correlations between self-reported listening abilities and socio-emotional status, although there are not such strong connections between the behavioral and self-report measures. Thus, the problems that older adults experience when listening in noise involve the trio of auditory, cognitive and socio-emotional factors.

Further research, including longitudinal and intervention research will be required to further understand how auditory, cognitive and socio-emotional aspects of aging interact during listening in everyday life. Now that the connections between auditory, cognitive and socio-emotional factors have been recognized, it remains to determine whether self-appraisal is the cause or the consequence of poorer behavioral performance by older adults and whether auditory declines precede or follow cognitive declines. A better understanding of the chain of effects in the interactions in the trio of psychological domains (perceptual, cognitive and socio-emotional) will enable better prevention and treatment of communication problems in older adults.

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