INTRODUCTION

Adults with cochlear hearing loss have difficulty understanding speech both in quiet and in background noise. Plomp (1970) suggested that hearing loss was composed of two components, audibility and intelligibility, both of which affect understanding. The distortion component of hearing loss includes, but is not limited to, broadened auditory temporal processing deficits (Baer & Moore, 1993). One approach to understanding the effects that hearing loss has on speech is to simulate the effect on listeners with normal hearing by applying the speech signal in the spectral and temporal domains (Vilchitz, 1977). Based on models of broadening auditory filters, Baer and Moore (1993) developed spectral smearing algorithms, whereas Plomp–Ferre-S enthusiastically used temporal jitter to distort speech signals. Because it is impossible to create pure temporal distortion without also creating some associated spectral distortion, in an attempt to untangle the possible contributions of these two types of distortion, Picture-Go-Poorly was modified for the degree of temporal distortion that they compared the effects of spectral smearing (following Baer and Moore) to the effects of temporal jittering. Additional temporal distortion was created by jittering. They found that when speech components below 2 Hz were distorted, intelligibility on the Rescaled Speech Perception in Noise Task (Bilger et al., 1972) was reduced by jittering but not by smearing for young adult listeners with normal hearing.

P U R P O S E

To evaluate the effects of different combinations of spectral and temporal distortion on word recognition in quiet and in noise for young listeners and older listeners with hearing loss.

METHODS (Cont.)

Participants

- 16 listeners with normal hearing (mean age = 22.9 years, SD = 2.7)
- 72 listeners with sensorineural hearing loss (mean 70.1 years, SD = 5.7, see Figure 1)

Speech Materials

- Words in Quiet: Northwestern University Auditory Test No. 6 (NU-6; Tiffin & Cattell, 1966) spoken by a female speaker (Department of Veterans Affairs, 2004). NU-6 performance is measured in percent correct.

- Words in Noise: NU-6 words were modified to multibable babble, in which, the NU-6 words (female talker) are presented at 7 signal-to-noise ratios (S/N) from 24- to 0-dB in quiet and in noise for youngadult listeners with normal hearing.

Distortion Simulations

Digital algorithms were applied to the NU-6 and WIN materials using custom software. A jittering algorithm was used to mimic the loss of temporal synchrony in age-related hearing loss and a spectral smearing algorithm was used to mimic the effects broadened auditory filters in cochlear hearing loss. The algorithms applied independently were presented to the speech signal and the multibable babble (for further details see Plomp-Ferrier et al., 2007) and Bilger et al. (1972). The following four algorithms were applied to the speech materials:

- Jitter: A fast Fourier transform (FFT) was applied to separate the stimuli into two bands, one above and one below 1200 Hz, and then an inverse FFT (IFFT) was used to convert the band back into one time domain. Only the frequency band above 1200 Hz (1200 Hz). The amplitude values in the time waveform were replaced with values chosen at random delay values in the same signal, with the values of the random time delays being set according to the amplitude values at the corresponding time in a low-pass filtered with a 300-Hz filter and set at 0.5-s of time.

- Double Jitter: The jitter algorithm was applied twice.

- Smear: The time domain of the stimulus was divided into a series of time frames. A FFT was performed on each of these frames and then the frequency and power values were calculated. The amplitudes of the frequency bands were multiplied by a smearing matrix. The smeared power components were the recombined using an IFFT and the frames were recombined. A smearing factor of six, which is presumed to model a moderate-to-severe hearing loss. The jitter algorithm was applied twice. A fast Fourier transform (FFT) was applied to separate the stimuli into two bands, one above and one below 1200 Hz, and then an inverse FFT (IFFT) was used to convert the band back into one time domain. Only the frequency band above 1200 Hz (1200 Hz). The amplitude values in the time waveform were replaced with values chosen at random delay values in the same signal, with the values of the random time delays being set according to the amplitude values at the corresponding time in a low-pass filtered with a 300-Hz filter and set at 0.5-s of time.

- Jitter-Smear: Sequentially, the jitter and smear algorithms were applied.

RESULTS

Listeners with normal hearing (Experiment 1)

Table 1 lists the mean recognition performances for NU-6-words in quiet and the mean WIN data for listeners with normal hearing. The effects of the distortion conditions are displayed in Figure 2. The gray functions represent the mean performance for unaltered NU-6 (Wilson et al., 2003). The main findings from Experiment 1 are as follows:

- ANOVA with post-hoc comparisons showed performance on jitter-smear was significantly poorer than performance on jitter or smear conditions except for the jitter condition.
- ANOVA showed unaltered NU-6 performance (data from Wilson et al., 2003) was significantly better than performance on any of the distortion conditions.
- ANOVA showed unaltered NU-6 performances on jitter-smear were significantly poorer than performance on the other three conditions.
- ANOVA showed unaltered NU-6 threshold (50% point from Wilson et al., 2003) was significantly better than thresholds in all distortion conditions except for the smear condition. The threshold was measured using the modified method of limits.

Listeners with Hearing Loss (Experiment 2)

Table 2 shows the mean recognition performances for NU-6-words in quiet and the mean WIN data for the distortion conditions. The primary psychometric function for the WIN in the four conditions is displayed in Figure 3. The main findings are as follows:

- ANOVA showed participants performed best on unaltered NU-6 words, followed by jitter, smear, and jitter-smear.

- ANOVA showed both the NU-6 and WIN materials showed a significant main effect for condition (4 conditions) and level (80-and 104-dB SPL) and a significant condition by level interaction (p < .05).

- ANOVA with post-hoc comparisons showed performance on jitter-smear was significantly different from the other three conditions.

- Performance was a level effect of NUN-6 (data from Wilson et al., 2003) was significantly better than performance on any of the distortion conditions.

- ANOVA showed unaltered NU-6 threshold (50% point from Wilson et al., 2003) was significantly better than thresholds in all distortion conditions except for the smear condition. The threshold was measured using the modified method of limits.

Comparison between listener groups

Table 3 summarizes the results for the distortion conditions on the Deterred WIN conditions from Experiment 1 compared to three reference functions (unaltered WIN for listeners with normal hearing (mean age 55 years) and unaltered WIN for two groups of listeners with hearing loss (65 and 75 years). As seen in the figure, the listeners with normal hearing performed poorer on the distorted WIN conditions compared to the reference functions for listeners with normal hearing (Blair, 1993). The data in the table demonstrate that the effects of the distortion on word recognition performance are greater on the listeners with hearing loss than for the listeners with normal hearing, particularly with the quiet conditions.

CONCLUSIONS

1. Both listeners with normal hearing and listeners with hearing loss performed best on unaltered materials, followed by jitter, then smear, and poorest on jitter-smear.

2. Performance with speech word materials was not significantly poorer than performance with unaltered materials for listeners with normal hearing, which is not consistent with previous simulations, phoneme-matched materials (Plomp–Ferre-S, 2007).

3. Listeners with hearing loss performed significantly poorer on distorted materials than on unaltered materials, which means that the distortion on materials may aid in compensating for performance losses than for listeners with normal hearing, particularly in quiet.

4. None of the distortion simulations in quiet or in noise approached the performance of listeners with hearing loss on the unaltered materials, but were closer at the 80-dB S/N wins group with less hearing loss. This finding maybe because only the low-frequency portion of the materials was distorted and because the listeners with hearing loss have high-frequency hearing loss. A better approximation of simulating hearing in older listeners with clinically significant audiometric hearing loss may be to simulate distortions in the higher frequencies and to a greater extent than used currently.