Influence of amplification scheme and number of channels on aided speech-intelligibility performance

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Modern hearing aids offer a wide range of channels (i.e., filters) and amplification schemes. Our previous work revealed that increasing the number of channels, in conjunction with a fast-fast amplification scheme, resulted in (a) the spectral flattening of vowels (Amlani et al, 2011), and (b) reduced consonant- and vowel-identification accuracy in impaired listeners (Jivani et al, 2012). In the present study, we assess the performance of impaired listeners (HI) and their normal-hearing (NH) controls on the perception of everyday speech using the Connected Speech Test (Cox et al, 1987, 1988). The stimuli were processed through a simulated hearing aid with varying amplification schemes (linear, compression [fast-fast, slow-slow, fast-slow]) and number of channels (2, 8, 16). Findings revealed that while speech-intelligibility performance improved markedly with everyday speech compared to /CVC/ words for both groups, NH listeners identified the target words significantly better than HI listeners did. Speech-intelligibility performance was similar across number of channels for NH listeners, but decreased significantly with a fast-fast amplification scheme. For HI listeners, performance declined for channels greater than 2 and with the inclusion of the fast-fast amplification scheme. Implications of findings are discussed relative to clinical application and hearing aid design.
INTRODUCTION

Multichannel compression (MCC) hearing aids provide a practical method of mapping the wide-dynamic range of speech signals into the reduced dynamic range of listeners with impaired hearing. To date, however, there is no consensus on the appropriate number of channels that will provide the end-user with optimal speech-identification performance [1, 2]. Empirical evidence, for example, indicates that speech-identification performance improves with a single-channel scheme compared to a MCC scheme [3]. Conversely, other studies have shown no degradation in speech-identification performance in devices having 2 to 4 channels [4] and 4 to 16 channels [5] compared to a single-channel device.

One potential explanation for the decrease in speech-identification performance for sounds processed through a MCC hearing aid is the increased distortion in the amplitude envelope, which stems from a flattening in amplitude, or decrease, in spectral contrast between phonemes [6]. This reduction in, or flattening of, spectral contrast between phonemes is dependent on the number of channels and the amplification scheme used. Kuk [7], for instance, reported that increasing the number of channels in a hearing aid resulted in an increase in amplitude at the hearing aid’s output. In addition, hearing aids engineered with fast-compression times flatten spectral contrast by reducing the amplitude of high-level, low-frequency segments (i.e., vowels) and providing gain to low-level, high-frequency segments (i.e., consonants). Slower compression times, on the other hand, tend to preserve the spectral contrast between vowels and consonants processed through a hearing aid. Together, the effect of channels on amplitude and the rate at which compression occurs are known to affect the signal acoustics and therefore, the audibility in both normal and impaired listeners [4].

In a previous study, we quantified the spectral contrast of spoken vowels processed through a simulated hearing aid having 2-, 4-, 8-, and 16-channels of linear and compression amplification schemes [8]. Acoustical analyses revealed that increasing the number of channels and employing a fast-compression scheme reduced the spectral contrast of vowels. This reduction in spectral contrast is known to impact vowel-identification accuracy negatively in HI listeners [9, 10]. In a follow-up study, the influence of number of channels and amplification scheme on vowel- and consonant-identification accuracy of CVC syllables were examined in normal-hearing (NH) and impaired hearing (HI) listeners [11]. Results of the perception study validated the findings of the acoustic study by showing that the identification accuracy of vowels and consonants in HI listeners decreased with increasing number of channels and a fast-compression scheme.

To examine the ecological validity of the previous findings, the present study assessed the impact of amplification scheme and number of channels on understanding of everyday sentences. Specifically, the objective of the study was to examine the performance of HI listeners and their NH controls on the identification of target words from everyday sentences processed through a simulated hearing aid with different amplification schemes (linear, compression [fast-fast, fast-slow, slow-slow]) and varying number of channels (2, 8, 16).

METHODS

Participants

Two groups of 12 listeners each served as participants: listeners with NH sensitivity and listeners with mild-to-moderate, sloping sensorineural hearing loss (HI). The mean age of the NH group
was 24.6 years (SD = 1.8) and the mean age of HI group was 64.3 years (SD = 5.2). All listeners were monolingual speakers of American English, with no reported history of speech or language disorders. Participation was contingent on each listener passing the Mini-Mental State Examination [12], a cognitive screening tool. Listeners were paid volunteers.

**Hearing-Aid Processed Stimuli**

Participants heard passages of everyday speech adopted from the Connected Speech Test (CST) [13, 14]. The CST consists of 28 passage pairs (24 test and 4 practice pairs), with each passage pair containing 50 key words. Passage pairs are equivalent in difficulty for normal-hearing [13] and hearing-impaired listeners [14], in quiet and in noise. The CST is scored by determining the percentage of key words correctly identified, which are converted to rationalized arcsine units (rau) scores [15] prior to data analysis.

Each sentence of each CST passage was transferred digitally (16-bit resolution, sampling rate 44100 Hz) from a compact disk and stored on the hard-disk drive of a personal computer (PC). Each CST sentence was then processed offline by a simulated hearing aid developed in Matlab, using a filter-bank design. Each filter’s weightings were based on a critical-band approach to approximate the human auditory system. Because the typical commercially available hearing aid has a frequency bandwidth ranging between 200 and 6000 Hz, the bandwidth of the simulated device was programmed to the same frequency bandwidth. Within each filter, an envelope detector was included, followed by an amplitude compression stage. The amplitude compression stage allowed for the compression threshold, compression ratio, and attack/release time settings to be programmed independently. In the present study, each CST passage was processed through the simulated hearing aid having 2-, 8-, and 16-channels. Within each channel, we implemented one of four amplification schemes: linear, fast-fast compression (attack time [TA] = 1 msec; release time [TR] = 25 msec), fast-slow compression (TA = 1 msec; TR = 1500 msec), and slow-slow compression (TA = 100 msec; TR = 1500 msec). The compression threshold (36 dB SPL) and ratio (2.5:1) were held constant across all compression conditions. Each hearing-aid processed CST sentence was stored as a wav file (16-bit resolution, sampling rate 22050 Hz) on the hard-disk drive in a separate folder. Prior to data collection, we equalized the root-mean-square (rms) amplitude of each hearing-aid processed sentence to account for differences in output as a function of the number of channels [7].

**Procedure**

During testing, each participant was seated in a sound-treated room. Hearing-aid processed CST passages were presented to each participant by routing the hearing-aid processed stimuli from the PC to an audiometer (GSI-16) connected to Sennheiser HD 515 headphones. Each participant heard stimuli diotically, in quiet, at their most comfortable listening level and verbally repeated back what they heard. Prior to data collection, each participant was provided a practice passage from the original CST, in which identification of a minimum of 20 key words (out of a possible 25, or 80%) was required for participation in the experimental task. During the experimental task, each participant heard a minimum of 355 sentences ([3 passages, each having either 9 or 10 sentences each] x 3 amplification schemes x 4 channels). A three-way repeated-measures analysis of variance (ANOVA) determined the effects of amplification scheme, channel, and group. Post-hoc comparisons were analyzed using Bonferroni corrections.
RESULTS
Figure 1 illustrates speech intelligibility performance as a function of channel and amplitude scheme for the two groups of participants. Overall, results revealed statistically significant main effects for channel ($F_{2,21} = 22.53, p < .001$) and amplification scheme ($F_{3,20} = 67.00, p < .001$). Pairwise comparisons revealed that mean rau performance was significantly ($p < .05$) higher with the two-channel condition compared to the 8- and 16-channel conditions. No significant differences were found between the 8- and 16-channel conditions. Pairwise comparisons also revealed that mean rau performance was significantly ($p < .05$) higher in the slow-slow condition, followed by linear, fast-slow and fast-fast. Mean performance in each of the amplification schemes was found to be significantly different ($p < .05$) from one another.

![Figure 1: Speech-intelligibility performance measured in terms of mean rau score across number of channels, amplification schemes, and participant groups. (Key: FF = fast-fast; FS = fast-slow; LIN = linear; SS = slow-slow).](image-url)
A significant main effect ($F_{1,22} = 86.41, p < .001$) was also found for the variable group, with the NH group’s mean rau performance being significantly higher ($p < .05$) than that of the HI group. A significant two-way interaction was also found for group and channel [$F_{2,21} = 10.20, p < .001$]. Pairwise comparisons revealed that the mean rau performance for the HI group significantly ($p < .05$) decreased when greater than two-channels were utilized and in conditions where a fast-attack time (i.e., fast-fast, fast-slow) was employed. For the NH group, mean rau performance was not influenced statistically by the number channels, but decreased significantly ($p < .05$) only when the fast-fast amplification scheme was employed.

**DISCUSSION**

In the present study, we assessed the identification of target words from everyday sentences processed through a simulated hearing aid with different amplification schemes and varying number of channels in two groups of listeners. Speech-identification performance was similar across number of channels for NH listeners, but decreased significantly with amplification schemes having fast-attack times. For HI listeners, performance declined for channels greater than 2 and with the inclusion of the fast-fast amplification scheme. This decrease in speech-identification performance in both groups can be attributed to the lack of amplitude differences across the speech spectrum. Specifically, increasing the number of channels and employing a fast-fast amplification scheme reduced, or flattened, the amplitude spectrum in vowel formant frequencies [9, 16]. Modulations in the amplitude envelope also negatively affected the spectral contrast of consonant identification. For example, a salient perceptual cue for stop consonants is the relative amplitude between the transient noise burst and the formant slope of the adjacent vowel. Devices that utilize fast-acting compression tend to increase the high-frequency energy, especially the burst of the consonant, leading to perceptual confusion among various stop consonants [17, 18].

Overall, findings between the present and previous studies [8, 11] revealed that speech-identification performance improved markedly with everyday speech compared to /CVC/ words for both groups. Specifically, we found approximately a 3% and 8% improvement in the context of sentences versus CVC syllables for NH and HI listeners, respectively. This improvement in performance across stimuli was expected given the contextual cues in everyday sentences. Further, the present study examined ecological validity of previous findings by using speech materials consisting of everyday speech and hearing aid architecture that mimics similar technology in commercially available devices.

**CONCLUSION**

Given the findings of the present study, and those in the literature, devices configured with a large number of channels and a fast-attack time degrade audibility, and ultimately, speech intelligibility. To circumvent the decrease in speech-intelligibility performance, manufacturers are encouraged to provide audiologists and dispensers with options related to number of channels and differing amplification schemes. To maximize audibility, it would behoove audiologists to fit devices having a small number of channels and a slow attack and release time. If a large number of channels is warranted in a given device, audibility can be improved by employing a slow attack and release-time compression scheme.

Previous investigations have shown that audibility is improved in severe losses with devices engineered with a greater number of channels [19] and employing a fast-compression scheme.
For the fast-compression scheme, audibility is greatest at low-input levels, and decreases at high-input levels. Thus, the application of our findings to clinical practice is limited to listeners with mild-to-moderate hearing loss, speech-identification performance in quiet and at a single presentation level, and to devices that offer similar hearing aid architecture. Future studies should assess whether amplification scheme and channels at different sensation levels influence speech-identification performance in listeners with varying degrees of hearing loss.

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REFERENCES


