Speech Identification with Single Channel Multichannel and Channel-free Hearing Aids

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Abstract

Results of investigations in multichannel and single hearing aids are equivocal; this is due to some acoustical modifications brought about by the multichannel hearing aids. ***The*** *present study is aimed to compare the performance of single channel multichannel and channel free hearing in quiet and two SNR conditions. 12 participants in the age range of 30-60 years participated in the present study. All the participants had sensory neural hearing loss with degree ranging from 41-70 dB. Speech identification scores were assessed in quiet and two SNR conditions (+10 dB and 0 dB SNR) for single, three, eight channel and channel free hearing aids. Results revealed that participants performed better with channel free hearing aid in quiet and in presence of noise conditions. The performance was better in 8 channel hearing over three and single channel only in noise conditions. Results suggest that the new technology overcomes the disadvantages of multichannel hearing aids. Performance of multichannel hearing aids showed better performance only in noise but no difference in performance between single and three channel hearing aids. So increasing the number of channels improves performance only in noise.*

Introduction

The last decade has seen numerous and significant improvements in the technology of hearing aids. With the advancement of digital technology, digital hearing aids have become increasingly common. Modern digital signal processing technology includes non-linear, adaptive, multiple channels/bands, speech enhancement, noise reduction, feedback management etc. The issue regarding the ideal number of channels has been a hot topic in rehabilitative amplification over a decade. Despite the ongoing debate, conventional wisdom indicates more number of channels in digital hearing aid is better and there has seen a surge in the number of channels in commercially available instruments over the last few years.

Compression is one such technology which helps to optimize the dynamic range of the individual with hearing impairment. Compression is nothing but a nonlinear amplifier which automatically adjusts its gain depending upon the incoming signal. Such a signal processing feature helps to improve the perception in hearing impaired individual by normalizing the loudness increasing the sound comfort and by reducing the inter-syllabic and inter-phoneme intensity difference (Dillon, 2001). Although compression technology helps the hearing impaired

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individual to perceive better, the benefit that compression provides partly depends on the way it is implemented in hearing aids. Broadly, based on the implementation of number of compression circuit in the hearing aids, it can be classified into either single channel or multichannel hearing aids.

In single channel compression the entire dynamic range is optimized across the full range of frequencies by a single compressor. In multichannel compression hearing aids this dynamic range is optimized at discrete frequencies by using multiple compressors. Currently, hearing aids with 1 to 20 channels are commercially available. Over the decades attempts have been made to investigate if increasing the channel helps the hearing impaired individual to perceive better. It may appear that the larger the number of channels the better the compensation for individual hearing impairment. However, increased numbers of channels may also have drawbacks, worthy of consideration.

Yund and Buckles (1993) measured speech discrimination for 8 channel compression and linear amplification. As the signal to noise ratio (SNR) decreased the speech identification became relatively better in multi-channel compared to linear amplification. Yund and Buckles (1995) reported that speech identification scores improve as the number of channel increases from 4 to 8 and did not vary significantly between 8 to16 channels. On the contrary, Bustamante and Braida (1987) reported that multi-channel amplification reduces the speech intelligibility in hearing impaired individuals. These findings are also supported by Drullman and Smoorenberg (1997). Hickson (1994) have reported that the performance with 4 channel hearing aid is similar to that of single channel hearing aid.

Studies have revealed equivocal results about the advantages and disadvantages of multichannel hearing aid. Relative to single channel compression, multi channel compression can increase intelligibility because it gives frequency specific amplification which in turn provides better audibility of speech. Unfortunately, multichannel compression also decreases some of the essential differences between different phonemes. Because compressor gives less amplification to intense signals than to weak signals, multichannel compressors tend to decrease the height of spectral peak and to raise the floor of spectral valleys. That is, they partially flatten spectral shapes. Spectral peaks and valleys give speech sounds much of their identity. Spectral flattening makes it harder for the hearing aids users to identify the place of articulation of consonants (De Gennaro, Braida & Durlach, 1986).

Considering these opposing effects of multichannel compression, it is not surprising that some experiments have shown multichannel compression to be better than single channel compression (Kiessling & Steffens, 1991; Moore & Glasberg, 1986, 1988) and some have failed to show any advantage for multi channel compression (Moore, Peters & Stone, 1998; Plomp, 1976; Walker, Byrne & Dillon, 1984). Multichannels decrease speech intelligibility for normal hearing people (Hohmann & Kollmeier, 1995; Yund & Buckles, 1995). If high compression ratio is used in multi channel compression hearing aid, intelligibility is also decreased for hearing impaired listeners (Bustamante & Braida, 1987; De Gennaro, Braida & Durlach, 1986).

Whether the positive effects of multichannel compression outweigh the negative effects depend on how much audibility is achieved in the reference condition. A net advantage for multichannel compression is thus least likely for sounds than in the single channel condition. They are comfortably loud and have been amplified by an appropriate gain frequency response shape. So, there is a dearth of studies comparing single channel and multichannel compression and most showing equivocal results. Hence further research is needed in the area to overcome the ambiguity that is seen in the literature. The emergence of new techniques such as channel free hearing aids necessitates it to be validated along with the existing techniques such as single channel and multichannel. Hence current study was undertaken to compare the speech identification score with the single channel, three channels, eight channels and channel free hearing aid in quite as well as in two noise conditions (+10 dB SNR and 0 dB SNR).

Method

Present study was designed to compare the hearing aid performance across the channel in quiet and different noise conditions.

Subjects

Twelve subjects (9 men and 3 women) in the age range of 35 to 60 years (mean age of 48.5) with confirmed diagnosis of sensorineural hearing loss participated in the study. They had audiometric 3 frequency average (500, 1000 and 2000 Hz) pure-tone thresholds in the range of 41 to70 dB HL with speech identification score of greater than 50%. Tympanometry results indicated no middle ear pathology. All of them were first time hearing aid users. All the participants were native Kannada speakers (Language spoken in Karnataka state of India).

Instrumentation

A Calibrated two channel diagnostic audiometer (OB922) was used for estimation of pure tone thresholds. Calibrated GSI-tympstar middle ear analyzer was used for Immittance measurements. A single channel (Terra), Three Channel (Cielo), Eight Channel (Syncro), Channel free (Symbio XT 110) hearing aids were used for the purpose of comparison of performance. Hearing aids were programmed with NOAH based Connexx 5.3 (Terra and Cielo), Genie 6 (Syncro) and (Symbio) Oasis plus 7 software. Hearing aids were connected with the computer using HiPro.

Stimuli were played in laptop 44.1 KHz sampling rate and 32 bit software using Cyberlink Power DVD Ultra software. Stimuli were routed through the OB922 two channel audiometer to the two sound calibrated Martin audio C115 speakers.

Stimuli

The speech stimuli used in the present study was taken from bi-syllabic word lists in Kannada developed by Yathiraj and Vijaylakshami (2005). This test contains four word lists, each with 25 bi-syllabic words, which are phonetically balanced and are equally difficult. All the four lists were selected for the present study. The words were spoken in conversational style by a female native speaker of Kannada. They were digitally recorded in an acoustical treated room, on a data acquisition system using 44.1 KHz sampling frequency and 32-bit analog to digital converter. All the word lists were mixed with speech babble (Anitha & Manjula, 2005) at +10 dB and 0 dB SNR. The speech babble is mixed with words with reference to RMS amplitude by program written in MATLAB 7.

Procedure

Puretone thresholds were obtained using modified Hughson and Westlate procedure (Carhart & Jerger, 1959) across octave frequencies from 250 to 8000 Hz for air conduction and 250 to 4000 Hz for bone conduction.

Tympanometric measurements were done using 226 Hz probe tone. This was done to rule out conductive hearing loss due to middle ear pathology. Appropriate probe tips were used to obtain hermetic seal and comfortable pressure for the subject. The parameters documented were types of tympanogram and acoustic reflex thresholds agreeing with ear canal volume, acoustic admittance and the tympanometric peak pressure. The results were also correlated with the ENT findings.

Hearing aids were programmed on the basis of audiometric thresholds with the default gain provided by software. Syncro and Cielo had noise management technology. While programming these noise management options were switched off in order to avoid any unwanted effect on result. All the hearing aids were switched to Omni directional microphone mode as there was no need of noise reduction during the testing.

Test was done in acoustically treated room with noise with in permissible limits as per ANSI (1991) specification. Subjects were seated at distance of one meter and at 45^{o} azimuths from the speakers. First the testing was done in unaided condition and later in aided condition. In the aided condition hearing aids were selected randomly for fitment and testing. Stimuli were played on a laptop at 44.1 KHz sampling rate with 32 bit operating system and were routed through the two channel audiometer (OB922). The intensity level was maintained at 40 dBHL throughout the testing and inter stimulus interval was kept constant at 5 seconds. Written responses were obtained from the subjects and in case of illiterate subjects the responses were scored by Kannada speaker.

Results

Speech Identification score in Quiet

The speech identification scores of 12 subjects (15 ears) in unaided and aided conditions are presented in Figure 1. A repeated measure of ANOVA was performed to assess the significant difference across conditions (unaided & 4 aided conditions). Results showed a significant difference across conditions ($F(4, 39.3) = 14.7$, $p<0.01$). Scheffe Post Analysis of variance reveled significant difference between unaided condition and aided conditions ($p<0.01$) but difference in means across different channel hearing aids data did not reach the significance. However from the figure it is observed that channel free hearing aid had higher scores compared to other different channel hearing aids.

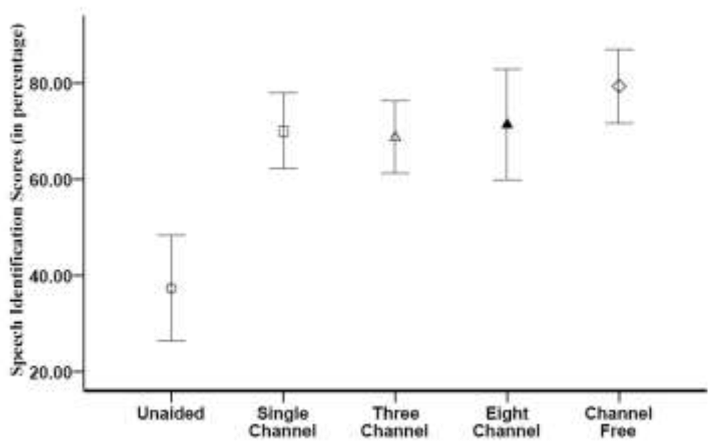

Figure1. Speech identification scores in quiet condition

B. Speech Identification Scores in Noise

Figure 2 shows the percentage of speech identification score in quiet, +10 dB SNR and 0 dB SNR conditions for various channel hearing aids (1 channel, 3 channel & 8 channel) and channel free hearing aid. It can be observed that participants performed better with channel free and 8 channel hearing aids than single and 3 channel hearing aids in all the conditions (quiet & +10 dB & 0 dB SNR). Furthermore, it is also clear from the figure 2 that channel free and 8 channel hearing aids show better performance in all the conditions. Participants performed better with channel free in quiet and 0 dB SNR conditions than 8 channel hearing aid.

Repeated measures ANOVA were performed to assess the significant difference across hearing aids in quiet and two different SNR conditions. Repeated measures ANOVA revealed significant main effect of quiet and two SNR conditions ($F(1.67, 112) = 143.05$, $p<0.01$) but no significant interaction was observed ($F(4.8, 96.6) = 0.283$, $p=0.98$). To see the significant difference across different channel hearing aids and channel free hearing aid, Post Hoc analysis of variance was performed and results revealed the mean difference across different channel hearing aid and channel free hearing aid did not reach significant difference (p>0.05).

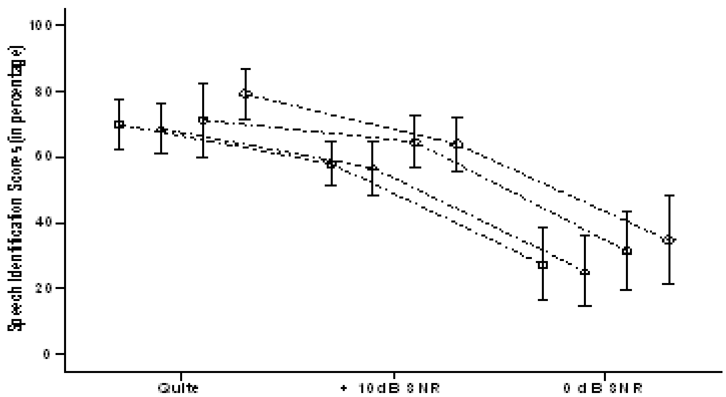

Figure 2: Speech identification scores in quiet and two noise conditions. Open square indicates Single channel, open triangle indicates three channel and open diamond for channel free hearing aid.

Discussion

A. Performance in quiet condition

Aided response with different hearing aids is better than in the unaided condition. Results of the present study revealed no significant difference across hearing aids used in this study. Although the mean scores did not reach the significance there is difference in mean scores across hearing aids. Furthermore, more variability in the scores was observed which would have led to no significant difference across hearing aids. One other reason is the age range studied in the present study which could have contributed for variability in the scores.

The performance with multichannel hearing aids was almost similar to that observed in single channel and 3 channel hearing aid. A number of investigators reported no significant improvement in speech identification by increasing the numbers of channels in multichannel hearing aid (Louise & Hickson, 1994). Souza, (2002) reported that multichannel hearing aids with fast compression time constants distort some speech cues, offsetting the benefits of improved audibility. In the present study, multichannel used syllabic compression, which has fast attack and release time constants which could have caused the distortion and lead to the much variability in performance. Anna O'Brien, (2002) has provided explanation for the poorer performance observed across studies in multichannel hearing aids. According to her, theoretically, when vowels, diphthongs and other phonemes are processed by a multichannel instrument, their key formant sounds may be managed and resolved by different channels, receiving more or less amplification and compression than was originally present and intended. This possible outcome distorts relationships among formants and potentially other key features of vowel, phoneme and word recognition (see Figure-3). As observed in figure 3, an annotation described by Dillon, (2001) shows that in stimulus /ii/ the spectral difference is lost and formant frequencies are distorted.

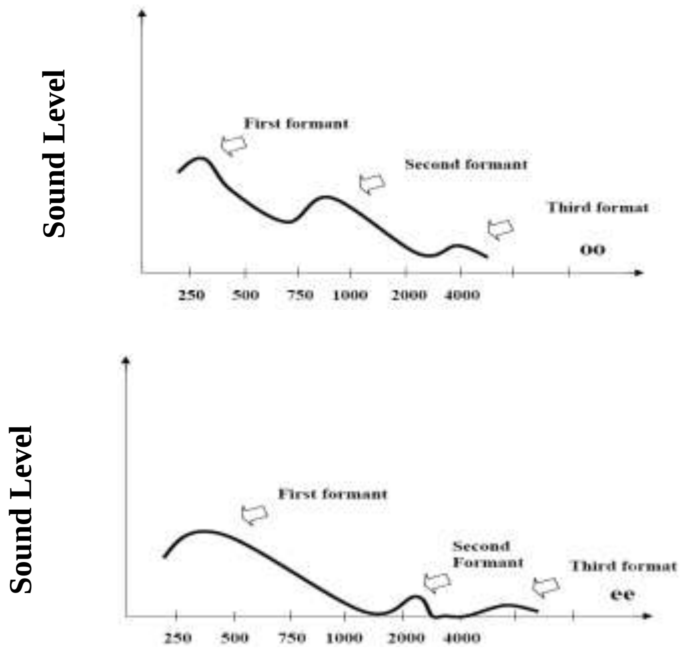

Fig: 3. Annotated diagram of vowel spectra

In addition, another consideration is that the number of channels, compression ratios and their time constants (attack and release times) all interact. Taken to an extreme, a large number of channels with high compression ratios can result in an amplified signal (Plomp, 1988), stripped of many of the identifiable speech elements. This effect is known as "spectral smearing." Because of the distorted formant information, spectral smearing is most deleterious to "place" of consonant articulation (e.g. difficulty discriminating between /b/, /d/ and /g/) and increases susceptibility to noise (Boothroyd et al, 1996)."

The mean scores of channel free hearing aid were 10% higher compared to other multichannel and single channel hearing aids. Similar to the present study, Dillon et al., (2003) showed that the performance of subjects in quiet, impulse noise, for male and female voice was better with channel free hearing aid compared with multichannel hearing aids. They also showed that internal noise and distortion seen in the channel free hearing aid is less than those observed with multichannel hearing aid and that low distortion and less internal noise would have contributed for the better performance in channel free hearing aid. CASI offers unique frequency shaping for optimal hearing-loss appropriate frequency response curves. Flexible input-dependent filter characteristics are applied to the whole signal, allowing frequency-dependent compression, without splitting the signal into channels and incurring the consequent spectral smearing potentially present in many-channel instruments.

B. Performance in Noisy condition

Results revealed that mean performance dropped significantly in noise for all hearing impaired subjects. No significant effect of channel was observed. The drop in performance across hearing aids may be due to the poorer performance of hearing impaired subjects in adverse conditions. From Fig. 2 it can be noted that channel free and 8 channel hearing aid performed better in two noise conditions. In addition, channel free aid provided better performance in 0 dB SNR condition compared to 8 channel hearing aid. No significant difference was observed in the present study. This may be due to large variability in data, because of the small number of subjects and age range studied in the present study (30-68 years).

A number of investigators reported that performance with 8 channel hearing aid is better than single to 6 channel hearing aids (Yund & Buckle, 1995). More number of channels will provide the possibility of better fit to the individual hearing impairment. The greater the number of channels and the narrower the channels, the greater the likelihood that important frequency components of the signal will fall into channels which do not include higher-intensity components of the noise of the signal itself. It is important that a signal component has a positive signal-to-noise ratio (S/N) within a channel because only then can the signal component determine the amplification in the channel to be amplified appropriately and become useful to the subject. Whenever the S/N is negative in the channel, the noise controls the amplification and the signal and noise components are amplified less than would have been appropriate for the signal component alone. In the multichannel compression haring aids with few broad channels, however, a signal component may be amplified too little (i.e., "masked electronically") due to the presence of a noise component which would not have masked it perceptually had the signal and noise components been amplified appropriately in two separate channel (Stone et. al.,1999).

Although number of studies has shown that multichannel hearing aid performance is better other group of researchers has shown that there is variability due to sensoryneural hearing loss (Yund, Simon, & Efron, 1987). It is because of the speech distortions that are caused by the type of compression and time constants applied in the multichannel hearing aids. That is when the input signal is broken into channels and applying compression and fast time constants the spectro-temporal characteristics become distorted and important speech transition information is lost which has been found to impair speech understanding (Boothroyd et al, 1996). In the present study also mean scores were higher but there was more variability (SD) indicating not all subjects improved with 8 channel hearing aid. Lippmann (1978) reported a deterioration of the scores when the signal was compressed with the noise and Barfod (1978) also obtained equivalent scores in his study.

Performance of channel free hearing aid was higher with less variability compared to the multichannel hearing aid. Similar results have been reported by Dillon, (2002). Because, the channel free hearing aid utilizes recently developed technology, Continuously Adaptive Speech Integrity (CASI). This strategy offers unique frequency shaping for optimal hearing loss appropriate frequency response curves. Flexible input-dependent filter characteristics are applied to the whole signal, allowing frequency-dependent compression, without splitting the signal into channels and incurring the consequent spectral smearing potentially present in many-channel instruments. CASI analyses incoming signals according to their intensity and dominant spectral elements and calculates the corresponding gain characteristic to be applied. Spectral characteristics of speech are maintained resulting in more "natural" sounding amplification. So the reduced spectral smearing and frequency dependent compression would have improved the performance of subjects with channel free hearing aid.

One important observation made in the study was that channel free hearing aid showed better performance over the eight channel hearing aid in 0 dB SNR and quiet condition. There was no difference in performance between eight channel and channel free hearing aid in 10 dB SNR. Bear and Moore (1993) and Ter Krause (1993) have shown no effect of spectral smearing on speech identification scores in normal hearing subjects in quiet but it has significant effect in adverse conditions. They further said that poor frequency resolution observed in cochlear hearing loss subjects affects identification scores in noise rather in quiet. From the above it is understood that in the adverse conditions (like 0 dB SNR) the amount of spectral information utilized for understanding speech is more compared to the conditions like 10 dB SNR and quiet conditions. In the multichannel hearing aids there is temporal distortion and spectral smearing. Small improvement observed for channel free hearing aid may be due to the reduced spectral smearing and temporal distortions which would have affected the speech identifications scores in multichannel hearing aids.

To conclude, performance of subjects with channel free hearing aid was better in quiet and noise conditions. Performance of multichannel hearing aids showed better performance only in noise but no difference in performance between single and three channel hearing aids. So increasing the number of channels improves performance only in noise.

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