ORIGINAL ARTICLE

Randomized Controlled Trial

Word perception in noise at different channels in simulated cochlear implant listeners

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Abstract

AIM: To find out effect of different signal-to-noise ratios (SNRs) on word perception at different number of channels.

METHODS: Thirty participants with normal hearing in the age range of 18-25 years (mean age 23.6 years) were involved in the study. For word perception test, there were 28 key-words embedded in sentences comprises of four lists processed for different channels (4, 8 and 32 channel) using AngelSim program at -5, 0 and +5 SNRs. The recorded stimuli were routed through audiometer connected with computer with CD player and presented in free field condition with speakers kept at 0° azimuth in a sound treated room.

RESULTS: Repeated measure ANOVA showed significant main effect across different SNRs at 4 channel, 8 channel and at 32 channel. Further, Bonferroni multiple pairwise comparisons shows significant differences between all the possible combinations (4, 8 and 32 channel) at +5 dB SNR, 0 dB SNR and -5 dB SNR.

CONCLUSION: Present study highlights the importance of more number of channels and higher signal to noise ratio for better perception of words in noise in simulated cochlear implantees.

Key words: Cochlear implants; Perception; Signal-to-noise ratio; Speech; Noise

Core tip: Present study highlights the effect of different signal-to-noise ratios (SNRs) on word perception at different number of channels. Thirty young adults with normal hearing were involved in the study. Word perception test were carried out at different channels with multiple SNRs. Result showed significant main effect across different SNRs at 4, 8 and 32 channel. Further, Bonferroni multiple pairwise comparisons shows significant differences between all the possible combinations (4, 8 and 32 channel) at +5, 0 and -5 dB SNR. The present study highlights the significance of more number of channels and higher SNR for better word perception in noise in simulated cochlear implantees.

INTRODUCTION

Earlier studies in cochlear implant has revealed that performance in speech recognition enhanced with increase in number of channels[1-5]. Previous studies have shown that speech perception improves with increase in number of channels in quite listening condition up to 4 to 7 channels[6,7]. Fishman *et al*[2], in 1997 assessed speech recognition in subjects using Nucleus-22 speech processing strategy with increase in number of electrodes. Result showed that speech perception score was poor for all subjects with single electrode cochlear implant listeners and they also observed improvement in speech perception with increase in number of electrodes from 1 to 4 with all test materials. They also found no significant difference in speech perception when number of electrodes increases to 7, 10 and 20. In a similar way, Friesen *et al*[8] in 2001 assessed speech perception with vowel, consonant, word and sentence in listener with Nucleus-22 and Advanced Bionics Clarion cochlear implant and compared scores with normal hearing individual. In that study, speech perception was measured as a function of number of electrodes and signal to noise ratios (+15, +10, +5, 0 dB). Outcomes of the study showed that speech perception improves with increase in number of channels (up to 7 or 8) at all signal to noise ratios. It was also observed that with SPEAK speech processor there was no improvement in speech perception for vowel and consonant recognition with greater than seven electrodes at all noise levels. However, for individuals with normal hearing, performance continued to increase up to at least twenty electrodes. For difficult speech materials like word and sentences, marginal significant increase in speech perception with increase in number of electrodes, *i.e.*, 7 to 10 in Nucleus-22 listeners. In a similar line, Verschuur[4]

in 2009 compared patterns of consonants features recognition as a function of channel number in users of Nucleus 24 device with normal hearing subjects listening to acoustic model which mimics similar to that device. They reported that the large changes to channel number had no substantial changes in performance. Similarly, Friesen *et al*[5] in 2009 done speech perception test with CVC stimuli at 2, 4, 8, 12, and 16 spectral channels on 10 normal hearing subjects. They observed that performance with CVC stimuli enhanced with increase in number of spectral channels. Perreau *et al*[9], in 2010 also investigated speech perception test in spatially separated noise with different number of channels. They reported that the performance was affected for all subjects as the number of electrodes was reduced. A study done by Zeitler *et al*[10], in 2009 examined speech recognition outcome with reduction in the number of functional channel after post-implantation. The result showed that even though reduction in number of channels does not have a direct influence on performance of speech recognition, the reduction of five or more number of channels can suggest impending device failure. From the above literature it can be observed that most of these studies done in quite listening situation, whereas everyday listening situation contains background noise in our day-to-day life. So, there is a need to study the effect of different signal-to-noise ratio (SNR) on word perception at different number of channels of cochlear implant in simulated conditions. The aim of the study is to find out effect of different SNRs on word perception at different number of channels.

MATERIALS AND METHODS

Participants
Thirty participants with normal hearing in the age range of 18-25 years (mean age 23.6 years) were involved in the study. All the subjects were having hearing threshold within normal limits revealed by pure tone thresholds of $\leqslant$ 15 dBHL at 250 to 8000 Hz. Further, ipsilateral and contralateral reflexes were checked at 500, 1000, 2000 and 4000 Hz for all subjects and tympanometry with 226 Hz probe tone with middle ear analyzer was used to confirm normal middle ear functioning for all subjects. Those participants who were having any other otological, neuromuscular and neurological problem were excluded from the study.

Testing environment
All the behavioural tests were carried out in a sound treated room. The permissible noise level was as per the guidelines in ANSI S3.1 (1999). Laboratory room were well illuminated and air conditioned for the comfort of the researcher as well as subjects.

Instrumentation
For pure tone audiometry and word perception test, calibrated dual channel clinical audiometer (PIANO Inventis) was used for all participants. For tympanometry

Table 1 Mean and standard deviation of correct raw score (words) with different number of channels at various signal-to-noise ratios						
	-5 dB SNR		0 dB SNR		+5 dB SNR	
	Mean	SD	Mean	SD	Mean	SD
4 channels	4.00	3.25	5.26	3.27	8.63	5.14
8 channels	15.10	5.84	18.00	4.84	19.86	4.04
32 channels	23.90	5.17	25.63	3.71	26.93	1.70

SNR: Signal-to-noise ratio.

and reflexometry, calibrated GSI-Tympstar Immittance meter was used for all participants.

Procedure

Modified version of Hughson and Westlake procedure was used for pure-tone audiometry (Carhart and Jerger[11], 1959) across octave frequencies from 250 to 8000 Hz for air conduction and frequencies from 500, 1000, 2000 and 4000 Hz for bone conduction. To carry out tympanometry and reflexometry middle ear analyzer was used using a probe tone frequency of 226 and 500 Hz, 1000, 2000, and 4000 Hz stimuli were used for ipsilateral and contralateral reflex. For word perception test, there were 28 key-words embedded in sentences comprises of four lists processed for different channels (4, 8 and 32 channel) using AngelSim program at -5, 0 and +5 SNRs. The subjects were instructed to write the sentences. They were encouraged and motivated to predict the sentence. No repeat presentation and feedback were provided. All the subjects were asked to sit comfortably without excessive head movement. Testing was done from most adverse listening condition (4 channels, -5 dB SNR) to least adverse listening condition (32 channels, +5 dB SNR). Rest period was provided after completion of each channels condition. The recorded stimuli were routed through audiometer connected with computer with CD player and presented in free field condition with speakers kept at 0° azimuth in a sound treated room. During testing the listener was seated at 1 meter distance in front of loudspeaker (Grason-stadler audio monitors) in a sound treated room. The stimuli presented at three different SNRs (-5 dB, 0 dB and +5 dB) by varying the level of speech noise (generated by PIANO Inventis double channel audiometer), keeping signal constant at 40 dB SL at different number of simulated channels, *i.e.*, 4, 8 and 32 channels. The subjects were supposed to write the sentence heard from loudspeaker. Raw scores were calculated for keywords (number of correct keywords in each sentence).

Statistical analysis

The statistical analysis of the study was performed by a biomedical statistician. Data of the study was analyzed using SPSS 17.

RESULTS

Descriptive statistics, repeated measure ANOVA and

bonferroni multiple pairwise comparisons were done using SPSS 17 to analyze the data collected from all subjects. Descriptive statistics was done to find out mean and standard deviation of score at different channels with different SNRs. Repeated measure ANOVA was done to find out any significant main effect across different SNRs at 4, 8 and 32 channels. Further, Bonferroni multiple pairwise comparisons was done to find out any significant differences between all the possible combinations (4, 8 and 32 channel) at +5 dB SNR, 0 dB SNR and -5 dB SNR.

Descriptive statistics showed that mean score increased (better) with increase in number of channels for words (Table 1). Similarly, descriptive statistics also revealed that mean score increases (better) with increase in SNR, *i.e.*, -5, 0 to +5 dB for words (Table 1). Repeated measure ANOVA showed significant main effect across different SNRs at 4 channel [$F_{(2, 87)} = 125.05$; $P < 0.05$; $\chi^2 = 0.742$]; 8 channel [$F_{(2, 87)} = 198.09$; $P < 0.05$; $\chi^2 = 0.820$]; and at 32 channel [$F_{(2, 87)} = 167.85$; $P < 0.05$; $\chi^2 = 0.794$]. Further, Bonferroni multiple pairwise comparisons shows significant differences between all the possible combinations (4, 8 and 32 channel) at +5 dB SNR, 0 dB SNR and -5 dB SNR (Table 2 and Figure 1).

DISCUSSION

The aim of the present study was to find out effect of different number of channels on word perception at different SNRs. The result showed significant improvement in word perception with increase in number of channels. This study also revealed significant improvement in word perception with increase in signal to noise ratio at different number of channels. Present study also quantified the deteriorating effect on word perception with decrease in SNR at different channels. Finding of present study is in consonance with previous literature[1,3,5,8-10]. However, there are few studies not in agreement with present findings[2,4]. In general, performance increases with increase in number of channels (4 channels < 8 channels < 32 channels) and of favorable SNR (+5 dB SNR > 0 dB SNR > -5 dB SNR). However, minimum 8 channels are required to achieve at least more than 50% performance irrespective of adverse listening condition (-5 dB SNR). Probably at lesser numbers of channels, information is spectrally sparse and hence poorer performance which further deteriorates in adverse listening condition (-5 dB SNR). The outcome of present study also showed that deteriorating effect of noise persists even at 32 channels condition. Similarly, the outcome of present study revealed that effect of number of channels on word perception in noise and showed that most individuals with CI are unable to fully utilize the spectral information given by the more number of channels in noisy condition. Friesen *et al*[8], in 2001 measured speech perception with various number of electrodes at different signal to noise ratios of +15, +10, +5, 0 dB, and in quiet. The outcome of the study showed speech recognition score

Table 2 Bonferroni multiple pairwise comparisons at all the possible combinations for words (4, 8 and 32 channel) at +5 dB signal-to-noise ratio, 0 dB signal-to-noise ratio and -5 dB signal-to-noise ratio ([b]$P < 0.001$)

SNR	Channels	8 channels (mean difference)	32 channels (mean difference)
+5 dB SNR	4 channels	-11.23[b]	-18.3[b]
	8 channels		-7.06[b]
0 dB SNR	4 channels	-12.73[b]	-20.36[b]
	8 channels		-7.63[b]
-5 dB SNR	4 channels	-11.1[b]	-19.9[b]
	8 channels		-8.8[b]

SNR: Signal-to-noise ratio.

Figure 1 Error bar graph of mean score for words with 4, 8 and 32 channels at +5 dB, 0 dB and -5 dB signal-to-noise ratio.

improved with increase in number of electrodes (up to seven or eight). They also found that on administration of difficult speech material like words and sentences, performance was increased (marginally significant) with increase in number of electrodes, *i.e.*, 7 to 10 in nucleus-22 cochlear implant listeners. Liu *et al*[12], in 2004 assessed effects of number of electrodes on Mandarin tone perception in children using Nucleus CI 24 cochlear implant. They reported significant decrease in Mandarin tone perception score with decrease in number of electrodes in children using CI 24 implants. Similarly, Perreau *et al*[9], in 2010 also investigated speech-in-noise test at different numbers of electrodes in individuals with bilateral cochlear implant. The result revealed that 3 to 4 electrodes is sufficient to get maximal performance on speech-in-noise tests in individuals with bilateral cochlear implant. However, few individuals with cochlear implant shows gradual decrement in speech recognition in noise with decrease in number of functional electrodes. Zeitler *et al*[10], in 2009 showed that although deactivation does not have direct impact on speech perception score, the reduction of 5 or more electrodes can suggest impending device failure. The finding of the current study is in contrast with the study done by Fishman *et al*[2], in 1997 reported no differences in speech perception score on any test in the 7-, 10-, and 20-electrode conditions. They also showed no difference in speech perception score with 4 and 20 electrodes processor on sentence and consonant test. The outcome of present study is in contrast with the study done by Verschuur[4] in 2009 also showed that large changes in number of channels in the Advanced Combination Encoder signal processing strategy revealed no significant changes in speech perception score. However, the present study was done on simulated cochlear implantees, audiologist or clinical specialist needs to be cautious before implementing present finding on individuals with cochlear implant.

The outcome of the present study highlights the significance of more number of channels and higher SNR for better word perception in noise in simulated cochlear implantees. Present study also quantified the deteriorating effect on word perception with decrease in SNR at different channels. Current study also showed
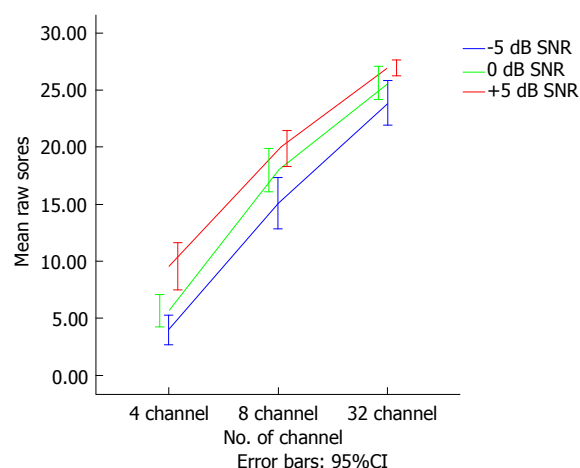
that minimum 8 channels are required to achieve at least more than 50% performance irrespective of adverse listening condition (-5 dB SNR).

COMMENTS

Background
Earlier studies in cochlear implant have revealed that performance in speech recognition enhanced with increase in number of channels. Previous studies have shown that speech perception improves with increase in number of channels in quite listening condition up to 4 to 7 channels.

Research frontiers
From the above literature it can be observed that most of these studies done in quite listening situation, whereas everyday listening situation contains background noise in the authors day-to-day life. So, there is a need to study the effect of different signal-to-noise ratio (SNR) on word perception at different number of channels of cochlear implant in simulated conditions. The aim of the study is to find out effect of different SNRs on word perception at different number of channels.

Innovation and breakthroughs
The authors compares word perception score at three different SNRs (-5 dB, 0 dB and +5 dB) by varying the level of speech noise (generated by PIANO Inventis double channel audiometer), keeping signal constant at 40 dB SL at different number of simulated channels, *i.e.*, 4, 8 and 32 channels. The result showed significant improvement in word perception with increase in number of channels. This study also revealed significant improvement in word perception with increase in signal to noise ratio at different number of channels.

Applications
The outcome of the present study highlights the significance of more number of channels and higher SNR for better word perception in noise in simulated cochlear implantees.

Terminology
Signal to noise ratio is signal-to-noise ratio (abbreviated SNR or S/N) is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels.

Peer-review
Well written paper with good language and grammar.

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