Effect of Cochlear Implant Electrode Depth of Insertion on Speech Comprehension and sound Quality

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ABSTRACT

Introduction: Studies on cochlear implants (CI) have suggested that speech recognition is optimized when the frequency information is presented to the normal acoustic tonotopic cochlear location. Frequency-place maps that are shifted or distorted relative to the normal tonotopic map reduce speech recognition. However, if an electrode array is not fully inserted, the lowest frequency represented by the most apical electrode of that array may be 2000 Hz or higher. **Aim of work:** analysis of the influence of insertion depth and electrode length on the speech comprehension of cochlear implanted patients after 3 and 6 months of device use. **Methodology:** multicenter crossover study including 20 cochlear implanted patients, aided evaluation, speech tests and Nijmegen Cochlear Implant Questionnaire (NCIQ) were done. **Results:** Aided-Thresholds at 0.5, 1, 2 and 4 kHz were significantly higher at 4 as compared with 8 and 12 active electrodes. Aided-Thresholds at 0.5 kHz showed positive moderate linear correlation with CI duration at baseline assessment (12 Active Electrodes). The speech recognition threshold (SRT) was significantly higher at 4 active electrodes as compared with 8 and 12 active electrodes. Speech recognition in quiet was significantly higher at 12 active electrodes as compared with 8 and 4 active electrodes. Speech recognition in quiet was significantly higher among studied CI patients with hereditary causes of hearing loss. Testing in noise (+10 dB S/N) was significantly lower at 4 active electrodes as compared with 8 and 12 active electrodes. Testing in noise (-10 dB S/N) was significantly lower at 4 active electrodes as compared with 8 and 12 active electrodes. Nijmegen Cochlear Implant Questionnaire (NCIQ) total score was significantly higher at 4 Active Electrodes as compared with 8 and 12 Active Electrodes. **Conclusion:** We concluded that speech recognition generally increases as the insertion depth and number of electrodes activated increases. Our results support previous findings that cochlear implantation significantly improves quality of life and hearing capacity.

KEYWORDS: Cochlear Implant, Electrode Depth, Speech Comprehension, Sound Quality, Nijmegen Cochlear Implant Questionnaire (NCIQ).

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ABBREVIATIONS:

CI: cochlear implant, DM: diabetes mellitus, ENT: ear nose and throat, SRT: speech recognition threshold, PB: phonetically balanced, SPL: sound pressure level, SRQ: Sentence recognition in quiet, SRN: sound noise ratio, SRN: Sentence recognition in noise, WD: word discrimination, NCIQ: Nijmegen Cochlear Implant Questionnaire, QoL: quality of life.

1. INTRODUCTION

A cochlear implant (CI) is an auditory prosthesis that provides a sensation of hearing for listeners with severe to profound sensorineural hearing loss. State-of-the-art CI devices allow many users to achieve near-to-normal speech understanding in quiet acoustic conditions. However, background noises such as environmental sounds or competing talkers negatively affect CI users' speech understanding [1]. In 2004, Bass [2] stated that, while new electrode designs allow deeper insertion and wider coverage in the cochlea, there is still considerable variation in the insertion depth of the electrode array among cochlear implant users. His study measures speech recognition as a function of insertion depth, varying from a deep insertion of 10 electrodes at 28.8 mm to a shallow insertion of a single electrode at 7.2 mm and he found that speech recognition increased with deeper insertion. Other researchers found no positive or even negative correlation between insertion depth and speech understanding however, that many different devices, electrode types and surgical techniques have been investigated and compared in these studies, introducing a high level of variability and complexity [3].

Other studies on cochlear implants and simulations of cochlear implants have suggested that speech recognition is optimized when the frequency information is presented to the normal acoustic tonotopic cochlear location [4]. Frequency-place maps that are shifted or distorted relative to the normal tonotopic map reduce speech recognition. However, if an electrode array is not fully inserted, the lowest frequency represented by the most apical electrode of that array may be 2000 Hz or higher. Matching frequency information to the acoustic tonotopic place in this case will result in the loss of a range of frequencies that is critical for speech recognition. Electrode arrays for cochlear implants are usually inserted 22-30 mm into the cochlea. The depth of insertion should make a difference in performance on tests of speech understanding Although we suppose that speech understanding will be best in a situation in which the stimulation from a filter band is directed to the ‘‘correct’’ place in the cochlea, some patients with shallow insertions perform as well as patients with deep insertions [5].

Of course, in a clinical population the effect of electrode depth cannot be assessed independently of coexisting conditions. For example, by chance a patient who has a deep insertion may not have stimulatable neural elements near the electrodes, while a patient with a short insertion may have neural elements near each electrode [6]. If different pathologies contributed to the differences in electrode insertion depth, those pathologies might have also affected the residual nerve survival, and so speech recognition. In such a case poorer speech recognition with short electrode insertion may not be due to the short insertion per se, but rather due to the co varying pathology. Studies that simulated different insertion depths within subjects by selective activation of more apical electrodes found that deeper insertion generally resulted in improved speech recognition [7].

2. AIM OF WORK:

The current study was designed with an aim to analyze the influence of insertion depth and electrode length on the speech comprehension of cochlear implanted patients after 3 and 6 months of device use.

3. METHODS:

A total 20 cochlear implanted patients (13 females and 7 males; with a mean of 27.60 ±8.15 year old) were enrolled in the study between October 2019 to October 2020. The patients were recruited from three hospitals: Kasr El-Aini, Wadi El-Nile, and Beni-Suef university hospitals.

Inclusion criteria:

Patients with age older than 18 years using CI more than 12 months

Exclusion criteria:

Patients with age below 19 years or above 50 years, time of CI use less than 12 months and other impairments that could affect understanding and/or oral language, e.g., language disorders or speech disorders were excluded from the current study.

Following obtaining the written informed consent, all patients were subjected to full history taking including the demographic data, personal history, detailed history of hearing loss including: onset, course, duration and bilaterally, history of hearing aid usage including age of fitting, type of hearing aid, site of fitting, pattern of hearing aid use and response of hearing aid used, past history of: ototoxic drugs, hypertension, DM, ENT operations, cardiac attacks, physical trauma, acoustic trauma, ear discharge or infection, family history including positive consanguinity, similar conditions in the family and the presence of any familiar diseases. All subjects had careful otoscopic examination for any tympanic membrane abnormalities and pathological findings.

3.1. Aided Evaluation in the following steps:

Aided thresholds: Free-field audiometry with the cochlear implant: The patient was positioned at 0º azimuth, one meter away from the loudspeaker, inside the sound booth, using only their voice processor in the everyday-use setting. Once these conditions were set, the free-field audiometry was conducted with the cochlear implant, at the frequencies from 500 to 4.000 Hz, with warble-tone and survey of speech recognition threshold (SRT) using three-syllable words.

3.2. Speech test in quiet and noise: Participants were tested for open set word recognition using sentences of the Arabic version Monosyllabic (PB) word list for the implanted ear [8].

The word list consists of 25 monosyllabic phonetically balanced words; the patients' score percentage is the number of recognized words multiplied by four. Lists are constructed in multiple choice items for closed set response. Each set consists of four monosyllabic words. The syllabic structure is C V C. Words of a given item differ only in one phoneme either in initial or final position. All words were subjected to spectral analysis & tested on patients with high frequency hearing loss. The speech recognition test had been performed in a sound field in the best aided conditions, having the speech processor adjusted to the most comfortable listening level. The speech material had been presented at a loudness level of 70dB sound pressure level (SPL). The patient was positioned at 0º azimuth, one meter away from the loudspeaker.

- Sentence recognition in quiet (SRQ): It assesses the person's capacity to recognize sentences in quiet (condition ideal for conversation).
- Sentence recognition in noise (SRN): It verifies the capacity to recognize sentences in noise (condition unfavorable to conversation) in form of WD%. It had been assessed using monosyllabic words in noise at different signal to noise ratio (SNR): 0, +10 and -10.
- Prior to testing, each participant was read the following instructions: You will hear monosyllabic Arabic words (words with one syllable) at several different loudness levels. At the very soft loudness levels it may be difficult for you to hear the words. Please listen carefully and repeat the words you hear. If you are unsure of the word, you are encouraged to guess. If you have no guess, please be quiet and listen for the next word. Do you have any questions?

3.3. The Nijmegen Cochlear Implant Questionnaire (NCIQ)[9]: It is a specific instrument of high internal consistency used to assess QoL in adult CI users. It comprises 60 questions divided into three general domains and their respective subdomains: physical - basic sound perception, advanced sound perception, and speech production; psychological - self-esteem; and social - activity limitations and social interaction.

The NCIQ was formulated with 10 items in each subdomain. Each of the first 55 items has five possible response categories, namely, never (1), sometimes (2), often (3), mostly (4), and always (5). The final five items present response categories as follows: no (1), poorly (2), moderate (3), adequate (4), and good (5). Respondents are also offered a sixth response category to cover items that were not pertinent to them - not applicable (N/A). A minimum of seven of the 10 items must be filled in to complete a specific subdomain. The score for each subdomain response is recoded as follows: 1 = 0, 2 = 25, 3 = 50, 4 = 75, and 5 = 100. Computation of the subdomains is performed by adding the 10- item scores of each subdomain and dividing by the number of completed items.

3.4. STATISTICAL ANALYSIS OF DATA: Statistical analysis was done using statistical package for social sciences (SPSS) computer software (version 25), IBM software, USA. Continuous variables were presented as the mean ± standard deviation or median (interquartile range IQR). Categorical variables were presented by the count and percentage. Normality was checked by a Kolmogorov–Smirnov test. Paired samples Wilcoxon test (nonparametric alternative to paired t-test) was used to compare sets of data that come from the same participants (at baseline, three and six month's follow-up). Kruskal–Wallis one-way analysis of variance test was used to elucidate significance among group means, followed by pair-wise comparison. Differences were considered significant at p ≤0.05. P-values of pairwise analysis were expressed as small letters (a,b,c). Spearman's correlation analysis was done to evaluate linear relationship between studied variables and other parameters. Correlation graphs were drawn only for significant correlation which is considered significant at P ≤0.05.

4. RESULTS

The current study was conducted on a population of twenty cochlear implanted patients to analyze the influence of insertion depth and electrode length on the speech comprehension. Table (1) demonstrates the basic characteristics of the studied twenty CI patients. Studied patients were 13 females (65%) and 7 males (35%). Their ages ranged from 18 to 46 years with a mean of (27.60 ±8.15). The age at hearing loss onset was ranged from 1 to 44 years with a mean of (12.55 ±11.00). Hearing loss duration was ranged from 1 to 26 years with a mean duration of (11.35 ±6.95). Idiopathic hearing loss was found in eight cases (40%). eight cases (40%) had acquired hearing loss (4 cases Meningitis, 2 cases trauma, 1 case Mumps and 1 case Chronic Otitis media). While only 4 cases (20%) were due to hereditary causes. Age at CI was ranged from 4 to 45 years with a mean of (23.75 ±9.96). The duration of CI was ranged from 1 to 12 years with a mean of (3.85 ±3.0).

Figure (1); demonstrates the assessment of the aided-thresholds at 0.5, 1, 2 and 4 kHz according to different Number of Active Electrodes among studied CI patients. Aided-Thresholds at 0.5 kHz were significantly higher at 4 active electrodes as compared with 8 and 12 active electrodes (55.00 ±9.7 vs. 50.00 ±9.9 vs. 42.75 ±8.7) respectively with a statistically significant p-values <0.001. Aided-Thresholds at 1 kHz were significantly higher at 4 active electrodes as compared with 8 and 12 active electrodes (55.50 ±10.6 vs. 47.75 ±8.8 vs. 42.25 ±8.3) respectively with a statistically significant p-values <0.001. Aided-Thresholds at 2 kHz were significantly higher at 4 active electrodes as compared with 8 and 12 active electrodes (56.75 ±9.2vs. 49.00 ±8.8vs. 46.25 ±8.7) respectively with a statistically significant p-values <0.001. Aided-Thresholds at 4 kHz were significantly highest at 4 active electrodes as compared with 8 and 12 active electrodes (59.50 ±9.4 vs. 50.00 ±9.9 vs. 48.50 ±9.3) respectively with a statistically significant p-values <0.001; however non-statistically significant difference was detected between 12 Vs. 8 active electrodes (p-value= 0.055).

According to Spearman's rank correlation analysis; Aided-Thresholds at 0.5 kHz showed positive moderate linear correlation with CI Duration at baseline assessment (12 Active Electrodes); (r = 0.531, p = 0.016). Aided-Thresholds at 0.5 kHz showed negative moderate linear correlation with HA usage at 6 months assessment (4 Active Electrodes); (r = -0.505, p = 0.023).

Figure (2); demonstrates the assessment of speech discrimination score by the Arabic monosyllabic words according to different number of active electrodes among studied CI patients. The speech recognition threshold (SRT) was significantly higher at 4 active electrodes as compared with 8 and 12 active electrodes (48.00 ±8.8 vs. 45.00 ±7.9 vs. 44.00 ±6.8) respectively with a statistically significant p-values <0.001 between 4 as compared with 8 and 12 active electrodes; however non-statistically significant difference was detected between 12 Vs. 8 active electrodes (p-value= 0.104). Speech recognition in quiet was significantly higher at 12 active electrodes as compared with 8 and 4 active electrodes (80.60 ±15.6 vs. 74.00 ±16.9 vs. 68.60 ±17.6) respectively with a statistically significant p-values <0.001.

Regarding the speech recognition in noise, the initial SNR was set at 0 dB SNR; 0 SNR was significantly higher at 12 active electrodes as compared with 8 and 4 active electrodes (73.40 ±19.1 vs. 69.40 ±19.1 vs. 63.80 ±20.3) respectively with a statistically significant p-values <0.001. Testing in noise (+10 dB S/N) was significantly lower at 4 active electrodes as compared with 8 and 12 active electrodes (68.80 ±18.1 vs. 76.80 ±16.6 vs. 78.80 ±16.5) respectively with a statistically significant p-values <0.001; however non-statistically significant difference was detected between 12

Vs. 8 active electrodes (p-value= 0.171). Testing in noise (-10 dB S/N) was significantly lower at 4 active electrodes as compared with 8 and 12 active electrodes (55.90 ±22.7 vs. 62.00 ±22.9 vs. 65.00 ±21.1) respectively with a statistically significant p-values <0.001; however non-statistically significant difference was detected between 12 Vs. 8 active electrodes (p-value= 0.109).

Table (3) demonstrates the results of Nijmegen Cochlear Implant Questionnaire (NCIQ) subdomains and total score according to different Number of Active Electrodes among studied CI patients. Total Score was significantly higher at 4 Active Electrodes as compared with 8 and 12 Active Electrodes with statistically significant p-values (0.003, 0.001 and 0.001) for a 12 Vs. 8 Electrodes, 12 Vs. 4 Electrodes and 8 Vs. 4 Electrodes respectively. Advanced sound perception was lower at 4 Active Electrodes with statistically significant difference from 12 Active Electrodes (p-value= 0.028); however non-statistically significant differences were detected between 12 vs. 8 and 8 vs. 4 Active Electrodes (p-values= 0.095 and 0.055) respectively. Speech production was significantly higher at 4 active electrodes as compared with 8 and 12 active electrodes (45.00 ±5.9 vs. 41.37 ±8.5 vs. 39.87 ±7.8) respectively with a statistically significant p-values <0.001; however non-statistically significant difference was detected between 12 Vs. 8 active electrodes (p-value= 0.169). Self-esteem was significantly higher at 4 active electrodes as compared with 8 and 12 active electrodes (44.87 ±9.1 vs. 41.87 ±11.2 vs. 36.75 ±11.9) with a statistically significant p-values (0.011, 0.006 and 0.003) respectively. Activity limitations was significantly higher at 4 active electrodes as compared with 8 and 12 active electrodes (51.37 ±11.5 vs. 47.62 ±13.9 vs. 41.62 ±13.3) with a statistically significant p-values <0.001. There were non-statistically significant differences between number of active electrodes and each of basic sound perception and social interaction; (p-values >0.05).

According to Spearman's rank Correlation analysis, there were non-statistically significant correlation detected between scores obtained by the study participants in NCIQ and its subdomains with Aided-Thresholds at 0.5, 1, 2 and 4 kHz at the baseline assessment (number of active electrodes= 12), and also with speech Discrimination Score by Monosyllabic Words at the baseline assessment (number of active electrodes= 12), (p-values >0.05).

5. DISCUSSION

In the current study the speech recognition abilities of CI users programmed with the active cochlear electrodes' strategy tended to increase as the number of active electrodes was decreased from 12 to 4 active electrodes. The speech recognition threshold (SRT) was significantly higher at 4 active electrodes as compared with 8 and 12 active electrodes. This current investigation came in accordance with several previous findings in the same context; in a study designed to examine the relationship between number of cochlear implant channels and maximal speech intelligibility. The study demonstrated increasing speech understanding from 4 channels to 8, 12[10]. On the other hand, in another study aimed at evaluate how speech recognition performance is affected by the number of active electrodes that are turned off in multichannel cochlear implants. They reported that the speech recognition abilities of CI users tended to decrease as the number of electrodes was decreased from 20 to 8 [11]. The differences between studies may contributed to the different Methodological factors.

In the current study, Speech recognition in quiet was significantly higher at 12 active electrodes as compared with 8 and 4 active. Large performance improvements occurred when increasing from 4 to 8 active electrodes. Our findings were consistent with the previously reported early studies examining the speech recognition in quiet based upon experiments with normal listeners claimed that 4 independent perceptual channels were adequate to convey a good perception of speech. This has subsequently been revised upwards to about 12 channels for normal listeners [12]. Speech perception in quiet is reported in many previous studies, one of them [13] found a significant relationship between insertion depth and speech perception in quiet, and other studies [14], [15], [16-18]] reported no correlation.

In the current study all participants were tested using the Arabic monosyllabic words speech discrimination score in noise at 0° azimuth (S0N0) at a 10 dB signal-to-noise ratio (SNR) at different number of active electrodes, SNR-0 was significantly higher at 12 active electrodes as compared with 8 and 4 active electrodes. (+10 dB S/N) was significantly lower at 4 active electrodes as compared with 8 and 12; however non-statistically difference was detected between 12 Vs. 8 active electrodes, (-10 dB S/N) was significantly lower at 4 active electrodes as compared with 8 and 12; however non-statistically significant difference was detected between 12 Vs. 8 active electrodes. Those finding were in line with a similar which evaluated data from 92 cochlear implantations and found that longer electrode arrays, demonstrated much better hearing in quiet and noise than other electrode arrays [19]. We could explain this as it may be that active electrode number was correlated with speech perception in noise because this factor accurately reflected the number of intracochlear sites available for electrical stimulation and therefore the number of neural populations that could be activated by the implant. Another possible explanation for better hearing in the subjects with deeper arrays simply might be the larger electrode contact spacing with those electrodes leading to less crosstalk or channel interaction between neighboring contacts. There is evidence that less channel interaction leads to improved spectral resolution and better speech understanding in noise.

Studies looking at the benefits of cochlear implants generally focus on the acoustic benefits. Those that include a quality-of-life aspect usually do so from the perspective of the cochlear implant user [20]. In the current study we also investigate the effect of CIs on QOL for adult recipients. Nijmegen Cochlear Implant Questionnaire (NCIQ) is a specific instrument used by several researchers to evaluate a variety of aspects associated with the QoL of the adult CI user population which evidences the impact of the use of this electronic device on the daily life situations of its users, on the perception of speech sounds, and on the cost-benefit assessment of this type of intervention. NCIQ scores vary from 0 to 100, with higher scores indicating better HRQoL[21].

Our results support previous findings that cochlear implantation significantly improves QoL and hearing capacity [22]. In this study, the NCIQ total, Advanced sound perception, Speech production, Self-esteem and Activity limitations showed a statistically significant improvement over the six months follow-up duration. Whereas Basic sound perception and Social interaction did not change significantly. Among the physical domain of the NCIQ (basic sound perception, advanced sound perception, and speech production subdomains), the more statistically significant improvement was in speech production. These results agreed with a similar study reported the greatest overall difference in QOL ratings on follow-up was seen in the speech production [23].

In our results patients showed significant improvement in the activity domain quality of life. This result agrees with previous studies, post-implantation, the cochlear implant user has reported a lessened feeling of isolation and a decreased perception of burden on their family members [24]. The relatives of the cochlear implant user reported an improvement in the cochlear implant user's satisfaction with life with the increased ability to communicate [25] and an improved quality of life [26].

In this current study there were non-statistically significant correlation detected between NCIQ total score and its subdomains with speech discrimination score by Monosyllabic Words, this observation is consistent with what was stated in previous research in this area; few significant correlations were found for word or sentence recognition scores and health related quality of life [27]. Most subdomains/subscales of the QOL measures did not relate to speech recognition [28]. These findings agree with other studies suggesting a lack of, or only a weak, correlation between clinical speech recognition and measures of QOL. Most of the subdomains/subscales of these instruments must be tapping into other aspects of outcomes with CIs that are not being effectively measured using current speech recognition assessments.

The current study had some limitations, first, the sample size was small; and the demographic variables, audiological factors, language measures, and cognitive factors were not assessed in greater detail than what is typically available clinically. This study was only able to examine postoperative QOL because comparative preoperative QOL assessments were not available; evaluation of a change or improvement in QOL after implantation may serve as a better outcome measure. It is possible that the influence of specific auditory tests on QOL may differ before implantation and at different time points following implantation or may be influenced by individual expectations or preimplantation goals of our patients. Many of the demographic variables, audiologic factors, language measures, and cognitive factors were not assessed, such data would allow more in-depth analyses of potential predictors of QOL.

6. CONCLUSION:

We concluded that speech recognition generally increases as the insertion depth and number of electrodes activated increase. Our results support previous findings that cochlear implantation significantly improves QoL and hearing capacity.

7. Tables:

Table (1): Demographic characters of study group; (N= 20):

		DESCRIPTIVE STATISTICS
Age	Mean ±SD	27.60 ±8.15
	Minimum	18.00
	Maximum	46.00
Gender	Female	13 (65.0%)
	Male	7 (35.0%)
Cause of Hearing Loss	Idiopathic	8 (40.0%)
	Hereditary	4 (20.0%)
	Acquired Causes#	8 (40.0%)
Age at Onset	Mean ±SD	12.55 ±11.00

	Minimum	1.00
	Maximum	44.00
Age at implantation	Mean ±SD	23.75 ±9.96
	Minimum	4.00
	Maximum	45.00
Duration of CI use	Mean ±SD	3.85 ±3.0
	Minimum	1.00
	Maximum	12.00
Hearing Loss Duration	Mean ±SD	11.35 ±6.95
	Minimum	1.00
	Maximum	26.00
hearing aid usage	Mean ±SD	10.40 ±6.88
	Minimum	1.00
	Maximum	23.00

Table (2): Assessment of the Speech Discrimination Score by Monosyllabic Words according to different Number of Active Electrodes among studied CI patients; (N= 20):

		Number of Active Electrodes			
		12 Electrodes	**8 Electrodes**	**4 Electrodes**	***p-value***
SRT	**Mean ±SD**	44.00 ±6.8	45.00 ±7.9	48.00 ±8.8	0.104[a]
	Minimum	35.00	35.00	35.00	**<0.001*[b]**
	Maximum	55.00	60.00	65.00	**<0.001*[c]**
QUITE	**Mean ±SD**	80.60 ±15.6	74.00 ±16.9	68.60 ±17.6	**<0.001*[a]**
	Minimum	48.00	36.00	28.00	**<0.001*[b]**
	Maximum	96.00	88.00	84.00	**<0.001*[c]**
0 SNR	**Mean ±SD**	73.40 ±19.1	69.40 ±19.1	63.80 ±20.3	**<0.001*[a]**
	Minimum	32.00	28.00	24.00	**<0.001*[b]**
	Maximum	92.00	88.00	84.00	**<0.001*[c]**
+10 SNR	**Mean ±SD**	78.80 ±16.5	76.80 ±16.6	68.80 ±18.1	0.171[a]
	Minimum	44.00	40.00	24.00	**<0.001*[b]**
	Maximum	92.00	92.00	88.00	**<0.001*[c]**
-10 SNR	**Mean ±SD**	65.00 ±21.1	62.00 ±22.9	55.90 ±22.7	0.109[a]
	Minimum	24.00	20.00	16.00	**<0.001*[b]**
	Maximum	92.00	92.00	88.00	**<0.001*[c]**

[a] 12 Vs. 8 Electrodes
[b] 12 Vs. 4 Electrodes
[c] 8 Vs. 4 Electrodes
p-value ≤0.05 is considered statistically significant by **paired samples Wilcoxon test*
SRT: The speech recognition threshold, 0 SNR: in noise at 0˚ azimuth, +10 SNR and -10 SNR: at a 10 dB signal-to-noise ratio.

Table (3): Assessment of the NCIQ subdomains and total score according to different Number of Active Electrodes among studied CI patients; (N= 20):

		Number of Active Electrodes			
		12	**8**	**4**	***p-value***
Basic sound perception	**Mean ± SD**	46.62 ±13.3	46.62 ±10.9	46.87 ±10.8	0.999[a]
	Minimum	22.50	27.50	27.50	0.827[b]
	Maximum	75.00	70.00	70.00	0.541[c]
Advanced sound perception	**Mean ± SD**	46.62 ±13.3	51.62 ±8.2	53.25 ±6.4	0.095[a]
	Minimum	22.50	37.50	40.00	**0.028*[b]**
	Maximum	75.00	65.00	62.50	0.055[c]
Speech production	**Mean ± SD**	39.87 ±7.8	41.37 ±8.5	45.00 ±5.9	0.169[a]
	Minimum	25.00	27.50	35.00	**0.001*[b]**
	Maximum	57.50	55.00	55.00	**0.001*[c]**
Self-esteem	**Mean ± SD**	36.75 ±11.9	41.87 ±11.2	44.87 ±9.1	**0.011*[a]**
	Minimum	22.50	22.50	27.50	**0.006*[b]**
	Maximum	62.50	62.50	60.00	**0.003*[c]**
Activity limitations	**Mean ± SD**	41.62 ±13.3	47.62 ±13.9	51.37 ±11.5	**0.001*[a]**
	Minimum	15.00	22.50	30.00	**0.001*[b]**
	Maximum	77.50	77.50	75.00	**0.001*[c]**
Social interaction	**Mean ± SD**	50.50 ±14.4	54.25 ±15.1	53.75 ±13.4	0.120[a]
	Minimum	25.00	27.50	30.00	0.161[b]
	Maximum	80.00	77.50	75.00	0.428[c]
Total Score	**Mean ± SD**	43.66 ±8.8	47.22 ±8.7	49.18 ±6.2	**0.003*[a]**
	Minimum	26.67	34.58	40.42	**0.001*[b]**
	Maximum	62.92	64.58	62.50	**0.001*[c]**

[a] 12 Vs. 8 Electrodes
[b] 12 Vs. 4 Electrodes
[c] 8 Vs. 4 Electrodes
*p-value ≤0.05 is considered statistically significant by **paired samples Wilcoxon test***

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