EVALUATION OF COCHLEAR IMPLANTED CHILDREN USING THE NEWLY DEVELOPED ARABIC LOW-VERBAL SENTENCE-IN-NOISE (LV-SIN) TEST

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ABSTRACT:

Background: *Hearing loss during the first 3 years of life can hinder speech and language acquisition. Speech performance deteriorates rapidly with increased levels of background noise in cochlear implant users compared with normal-hearing (NH) listeners, especially when the noise is dynamic e.g., competing speaker or modulated noise. Studying CI users' susceptibility to noise remains a major challenge for researchers and is an important step toward improving CI users' performance in the adverse noisy conditions.*

Aim of the work*: To evaluate speech perception in noise of a group of cochlear implanted (CI) children using different types of noise, at different signal to noise ratios (SNR) and explore the effect of age at surgery on speech understanding in noisy situations.*

Patient and Methods: *Forty subjects divided into 2 groups were included in the present study. Group I: Ten normal hearing children (NH) with mean age of 95.5 months. Group II: Thirty CI users with mean age of 100.2 months. They were tested using the newly developed low-verbal sentences in noise test* ***(LV-SIN)*** *using white, multi-talker babble and story noise. Language and speech evaluation were done. Scoring was done by measuring the SNR 50 which is the level at which the child repeated 50% of the number of words per list.*

Results: *Significant difference in LV-SIN test scores was obtained between NH children and CI users using the 3 types of noise. White noise showed the least challenging situation. Age at CI implantation was significantly correlated to the LV-SIN test scores.*

Conclusions: *Children with CI need much higher signal to noise ratios (SNRs) than their NH peers and age at CI surgery highly affects their speech perception in noise.*

Key Words: *Speech perception in noise, CI children, white noise, multi-talker babble noise, story noise, CI users, SNR.*

INTRODUCTION:

Sensorineural hearing loss (SNHL) is the most common congenital sensory deficit, with an incidence of one to three per 1000 live births; this incidence mounts up to 4-5% in neonates with risk factors for SNHL[1]. Hearing loss during the first 3 years of life can hinder speech and language acquisition with significant negative consequences on a child's educational, cognitive, psychosocial development and physiological function[2].

Perceiving language in noisy environment is a challenge for all children. The signal-to-noise ratio (SNR) is defined as the ratio between the speech dB level and the noise dB level. A negative SNR means that the noise is higher than the speech. Therefore, a SNR of +15 or +20 dB is recommended for classrooms by the American Speech-Language-Hearing Association [ASHA] (1995) and the British Association of Teachers of the Deaf [BATOD] (2001)

Children with hearing loss suffer as they require better signal-to-noise ratios (SNRs) than adults in order to achieve comparable speech recognition scores. Paradoxically, children spend much of their lives functioning in environments much noisier than adults[3]**.** Evidence from a range of studies indicated that reduced frequency selectivity, loudness recruitment and reduced ability to make use of temporal fine structure cues appear to contribute to difficulty in 'listening in the dips' of a background sound[4]**.**

Many CI recipients, fitted with the latest multichannel speech processors, perform very well in quiet listening situations. However, speech performance deteriorates rapidly with increased levels of background noise compared with normal-hearing (NH) listeners, especially when the noise is dynamic e.g., competing speaker or modulated noise[5]**.**

Various strategies have been proposed to improve segregation of signals from background noise in CI users and many noise reduction algorithms have been emerged over the years as Adaptive Dynamic Range Optimization (ADRO)[6] and more recent SNR-noise reduction (NR)[7]. Moreover, directional microphones and dual-microphone technologies can also improve speech understanding in noise for CI users[8].

CI recipients have variable outcomes, especially for speech perception in noise regardless of their performance in quiet, despite enormous improvements in the technology. Several factors contribute to variable CI outcomes such aetiology, age of onset, duration of hearing loss and the compliance to the rehabilitation programmes[9]**.** Other factors that influence speech intelligibility in noise include experience-related cognitive factors such as person's language background, expressive vocabulary knowledge, sensitivity to phonological structure and memory [10]**.**

Various tests have been developed to estimate the perception of speech in presence of noise, such as connected sentence test (CST), hearing in noise test (HINT), words in noise (WIN), quick speech-in-noise test (Quick SIN), Bamford-Kowal-Bench speech-in-noise test (BKBSIN), and listening in spatialized noise-sentences (LiSN-S). All these tests are different in terms of target age, measure, procedure, speech material, noise type and level. Because of the variety of tests available to estimate speech-in-noise abilities, audiologists often select tests based on their availability, ease to administer the test, time required in running the test, age of the patient, hearing status, type of hearing disorder and type of amplification device used[11]**.**

Studying CI users' susceptibility to noise remains a major challenge for researchers and is an important step toward improving CI users' performance in the adverse noisy conditions. Therefore, this study is conducted to explore how much CI user's speech in noise perception abilities differ from their normal hearing pears. The effect of age at CI surgery is studied. This is done using LV-SIN test using different types of noises presented at different signal-to-noise ratios (SNRs) to simulate as much as possible the natural noisy environment.

AIM OF THE WORK:

This work was designed to evaluate speech perception in noise in a group of CI children using different types of noise at different SNR and compare them to NH peers and to explore the effect of age at CI surgery on their performance.

MATERIAL AND METHODS:

Study Population: Forty subjects were included in this study. They were divided into 2 groups. **Group I** consisted of 10 NH children with mean age of 95.5 ± 13.56 months. They were 6 males (60%) and 4 females (40%). **Group II** consisted of 30 CI children with mean age of 100.2 ± 16.4 months with a language age not less than 2 years and 6 months. They were 17 males (56.67%) and 13 females (43.33%).

Methods: All subjects underwent full history taking, language age assessment using the standardized Arabic Language Test[12] and articulation assessment using the Arabic Articulation Test[13]. Aided sound field and speech-in-noise testing using the newly developed Arabic LV-SIN test were conducted in a double walled sound treated room I.A.C. model 1602. The test material is composed of 30 Arabic sentences classified into 3 phonetically balanced lists adapted from the Arabic PSI test[14] and digitally manipulated using Audacity software program. Material was delivered from the built-in CD player of the laptop connected to two channel audiometer model Grason-StadlerInc (GSI) model 61 via 2 loudspeakers; front for the speech material (at 0 degree azimuth in relation to the child) and back for noise (at 180 degrees azimuth). Noise was fixed at 65 dB (A) and the speech signal intensity varied according to the child's response to deliver different SNRs [15]. Scoring was done by measuring the SNR 50 which is the level at which the child repeated 50% of the number of words per list[16].

Ethical Considerations: Verbal consent was obtained from all parents before testing after explaining the aim of the study and procedure to be done.

RESULTS:

Demographic data:

This research was conducted on 30 children using CI (Study Group) with mean age of 100.2, SD= 16.4 and 10 NH children (Control Group) with mean age of 95.5, SD= 13.56. There was no significant difference in age between both groups. Language age in months of CI participants ranged from 30-84 with mean of 63.

Table 1: Mean, SD, median and range of age at diagnosis of HL, age at 1st HA fitting, duration of CI use and time in hearing in months (n=30)

	Mean	SD	Median (IQR)	Range
Age at diagnosis of HL	12.7	10.24	12 (6-18)	0- 42
Age at 1st HA fitting	19.33	10.69	18 (12-30)	6 - 48
Duration of CI use	57.07	19.57	56.5 (42- 72)	24- 90
Time in Hearing*	81.23	18.69	80 (64- 97)	48- 111

*Time in hearing stands for the duration of regular use of hearing aid plus duration of CI use in months.

Results of Low- Verbal Arabic Sentences in Noise Test (LV-SIN):

Comparison between study group and control group as regards LV-SIN test SNR 50% correct scores using (multi-talker babble, story and white noise)

Table (2) shows statistical significance difference between LV-SIN scores in study and control group using Student "t" test.

Table 2: Mean, SD and test of significance between the study and control group in LV-SIN test SNR 50% correct scores

SNR 50% Correct scores / Type of noise	Normal group n= 10		Study group n= 30		Test of significance		
	Mean	SD	Mean	SD	t- value	P- value	Sig.
Multi-talker babble	-14.3	1.42	8	3.69	-27.575	<0.001	S
Story	-13.6	1.43	10.47	3.76	-29.291	<0.001	S
White	-16.4	1.17	5.7	3.1	-32.668	<0.001	S

Comparison between LV-SIN test SNR 50% correct scores in CI children using the 3 types of noise

Table (3) show the difference between the 3 types of noise using one way ANOVA test revealed statistically significance difference between them.

Table 3: Mean, SD and one way ANOVA test of significance between the three types of noise (n=30).

SNR 50% correct / Type of noise	Study group (n= 30)		ANOVA test		
	Mean	SD	f value	p-Value	Sig.
Multi-talker babble	8	3.69	244.88	<0.001	S
Story	10.47	3.76			
White	5.7	3.1			

Comparison between LV-SIN test SNR 50% correct scores of the 2 subgroups of CI participants

According to **Zaltz et al., (2018)**[17] classification, CI children were divided into two subgroups as regards to the age at CI surgery: Subgroup 1: "early-implanted" (n = 15), subjects who were implanted under the age of 4 years (48 months) (Mean = 32.4 and SD= 7.09). Subgroup 2: "late-implanted" (n = 15), subjects who were implanted after the age of four years (Mean=53.8 and SD= 11.9).

Table 4: Comparison between LV-SIN SNR 50% correct scores of the 2 subgroups using the 3 types of noise revealed statistically significance difference.

Table 4: Comparison of LV-SIN test SNR 50% correct scores between the 2 subgroups of CI participants (n=30)

SNR 50% correct / Types of noise	Age at CI surgery				Student t-test		
	Subgroup 1 (Age < 45 ms) n=15		Subgroup 2 (Age> 48ms) g=15				
	Mean	SD	Mean	SD	t- value	p-value	Sig.
Multi-talker babble	6.13	3.38	9.87	3.04	-3.18	0.004	S
Story	8.6	3.31	12.33	3.29	-3.098	0.004	S
White	4.2	3.14	7.2	2.27	-2.994	0.006	S

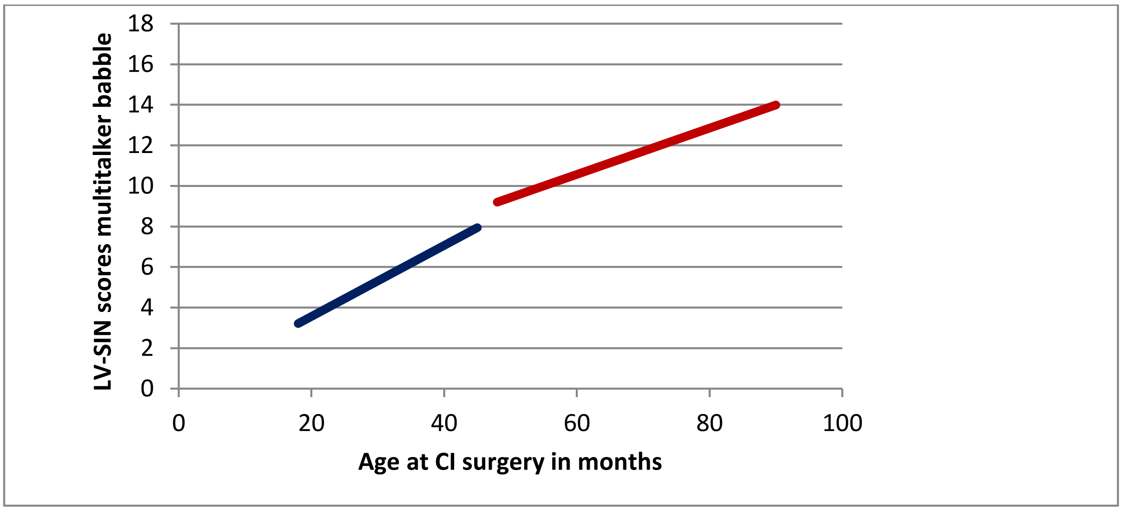

Diagram 1: Linear relation between LV-SIN test SNR 50% correct scores using multi-talker babble and 2 sub groups of study group as regards age at CI surgery in months (n=30)

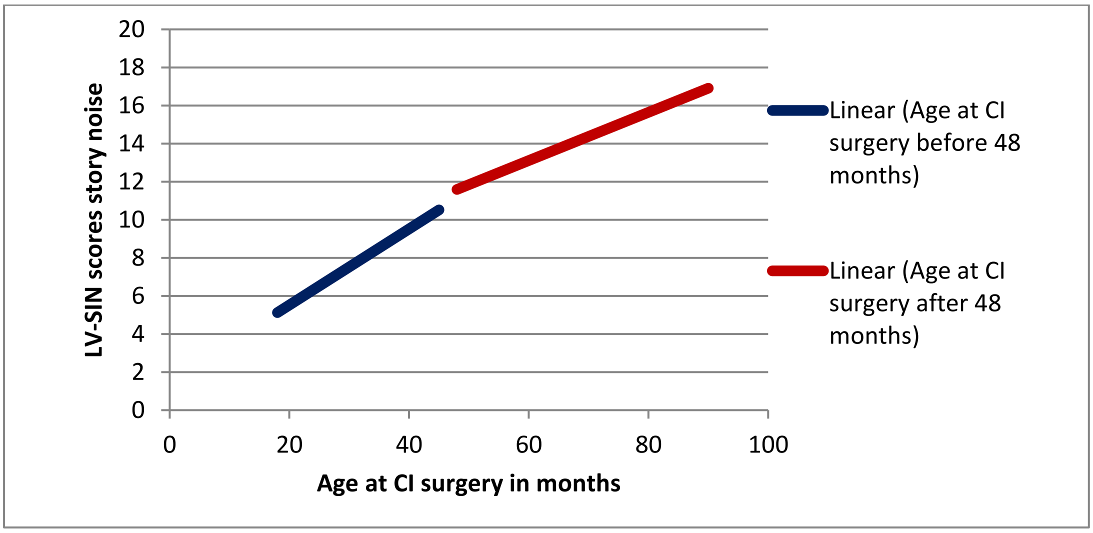

Diagram 2: Linear relation between LV-SIN test SNR 50% correct scores using story noise and 2 sub groups of study group as regards age at CI surgery in months (n=30)

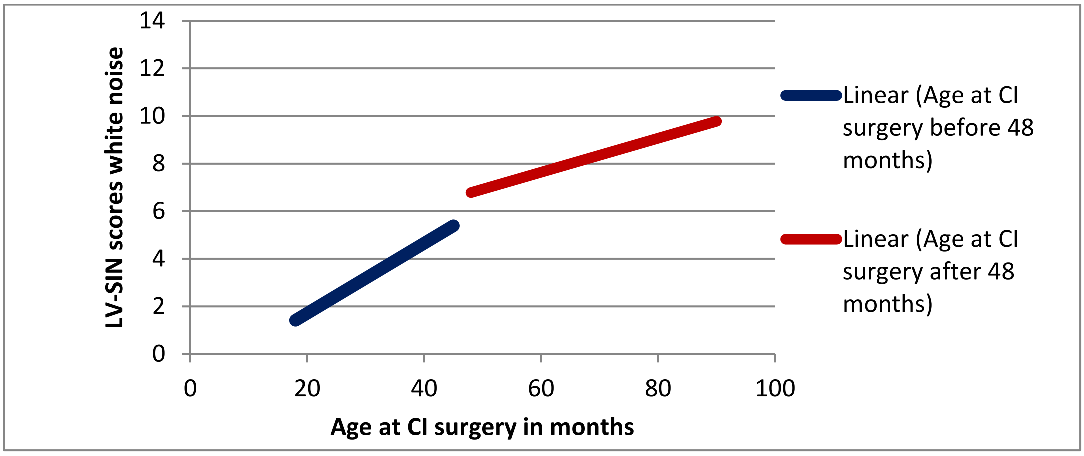

Diagram 3: Linear relation between LV-SIN test SNR 50% correct scores using white noise and 2 sub groups of study group as regards age at CI surgery (n=30)

DISCUSSION:

This study evaluated speech perception in noise ability in Cochlear Implant (CI) children as compared to normal hearing (NH) peers. As shown in table 2, there was a significant difference in the scores required for the CI children to achieve 50 percent correct than was required by the NH group. This indicates that the CI recipients in this study needed higher SNRs in order to achieve the same performance as their NH peers.

These results agreed with the data presented by **Eisenberg et al (2008)**[18] who conducted a study to evaluate sentence recognition in quiet and noise by 188 CI children and 97 NH controls. By applying HINT-C, scores of CI group were much poorer than NH group. It was explained by the fact that CI processors do not provide the fine-grained spectral details that would be required to recognize speech under the most challenging noise levels. Also, **Fu et al (2018)**[19] conducted a study on sixteen Mandarin-speaking Chinese CI children and twelve NH children with age range of 7–14 yrs. Speech perception (sentences) in the presence of steady noise (energetic masking) or competing speech (energetic + informational masking) was measured in both CI and NH listeners. Performance was significantly poorer for CI children than for NH children in all conditions.

Such findings were based on the general impairment in the peripheral, perceptual and cognitive processes compared to children with normal hearing added to the CI devices processes limitations. Another explanation is that the CI speech processor provides relatively weak frequency resolution[18] [20].

Three main mechanisms have been reported to explain the effect of hearing loss on speech-in-noise perception in CI users; First loss of audibility, especially at high frequencies where speech sounds are lower in intensity [21], second is distortion due to loss of spectral and temporal processing sensitivity and selectivity, which reduces speech perception in noise even when speech is entirely audible and third is less efficient binaural processing compared to typically hearing children[22].

Effect of noise on LV-SIN test scores between CI children:

A comparison was held between the CI children performance with LV-SIN using the 3 types of noise. Results showed statistically significant difference; white noise was less challenging than story and multi-talker babble noise (Table 3).

This data agree with results proved by several studies conducted to evaluate speech perception in different types of noise in CI children and compare them to normal hearers. **Friesen et al (2001)**[23] reported that the implant users perform much more poorly than the NH children in steady noise as well as in the competing-talker background noise "with more striking difference". Also, **Fu et al (2018)** [19] found that CI children achieved better scores in speech perception (sentences) in steady state noise (energetic masking) rather than competing speech (energetic + informational masking).

The acoustical properties of background sounds also affect speech perception differently and are often categorized as energetic versus informational masking [24]. The masking effect of energetic maskers, such as steady-state wideband noise, is primarily produced as a result of overlapping energy representations of the target speech and masker signals on the basilar membrane, thereby impairing speech intelligibility[25]. Informational maskers (e.g., one or more competing talkers) have energetic masking in addition to informational interference due to similarity to the target stimuli that causes difficulties at the phonetic and semantic levels of processing [26, 27].Thus informational masking performs much difficulty on speech perception than energetic masking.

In addition, CI users do not experience release from masking -unlike NH listeners- from fluctuating noise compared to steady state noise [19]. Steady-state noise is thought to produce more "energetic" masking at the auditory periphery, however, competing speech produces both energetic and "informational" masking as competing talkers (despite differences in timing or pitch) interfere with each other at more central levels of auditory processing[28].

Another explanation is the impairment of the Working Memory Capacity (WMC) that is required by children when listening to speech in noise [29]. Multi-talker babble noise reduces working memory performance in the auditory modality resulting in poorer SNRs[30]. Therefore with background noise, children with CI and/or HA will have to allocate more WMC to process the incoming signal leaving fewer resources to understand and encode information into long-term representations, which is the basis for learning[29].

Effect of age at CI surgery on LV-SIN test scores:

CI users were divided according to **Zaltz et al (2018)**[17] as regards age at CI surgery into 2 subgroups: Early implanted and late implanted. This classification was based on studies by **Kral and Tillein (2006)** [31] showing that the most sensitive period for auditory deprivation is up to 4 years of age. The performance of the 2 subgroups in the 3 noisy situations was compared and revealed statistically significant difference. Early implanted children achieved much better SNRs 50 scores than the late implanted group using the 3 types of noise (table 4 and diagrams 1, 2& 3).

This is in agreement with results obtained by **Ching et al (2018)**[32] who studied factors influencing speech perception in a group of 252 children with mean age of 5 years with hearing aids (HA) and CI. Using The Bamford–Kowal–Bench (BKB)–like sentence test material with multitalker background noise, age at implantation and language abilities were significant predictors and were highly correlated with better SNRs. Similar results were obtained by **Torkildsen et al (2019)**[33] who used Norwegian HINT for children (NHINT-C) on a group of 64 CI children.

Effect of early implantation on speech perception in noise is based on the sensitive period of auditory plasticity proved by **Knudsen (2004), Kral (2013) and Glennon et al. (2020)**[31, 34, and 35]. They conducted several studies which supported the hypothesis of a critical or sensitive period during which the auditory system is most responsive to stimulation. As the time course of the normal synaptogenesis in the human auditory cortex is well known; it continues from birth up to 4 years.

This was also confirmed by the electrophysiologcal studies conducted by **Sharma et al. (2002)** [(36)] **and Gordon al. (2005)** [(37)] in CI children who advised to perform cochlear implantation before the age of 4 years in the pre-lingually deaf children. However, since the most rapid increase in synaptogenesis takes place within the first 1–2 years of age, by extrapolation from the cat functional data, it may be suggested that the best benefit from cochlear implantation can be expected when done at 1–2 years of age.

In conclusion, low verbal sentences in noise test (LV-SIN) proved to be suitable, simple, easy test for toddlers, pre-school children and hearing impaired children with language age of 2 years and 6 months and above. Children with CI need much better SNR to match speech perception abilities of their normal hearing peers. Age at CI surgery significantly affected speech in noise perception abilities in CI children. Lastly, testing speech perception abilities in CI users using white noise underestimates the difficulties that they face in the real life situations.

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تقييم الأطفال مستخدمي القوقعة باستخدام اختبار الجمل المتوسطة لغويا المعد حديثا باللغة العربية

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هدف البحث: تقييم قدرة مجموعة من الأطفال مستخدمي القوقعة الصناعية علي إدراك الكلام في خلفيات مختلفة من الضوضاء ومقدمة بنسب إشارة إلي ضوضاء مختلفة ومقارانتهم بالأطفال ذو السمع الطبيعي في نفس العمر بالإضافة إلى دراسة مدى تأثير سن زراعة القوقعة على أداء الأطفال في الضوضاء المختلفة.

المرضى والطرق:40 من الأطفال يتراوح أعمارهم بين 6 إلى 10 سنوات تم تقسيمهم إلى مجموعتين: المجموعةالأولى: 10 أطفال يتمتعون بالسمع الطبيعي. المجموعة الثانية: 30 طفل من مستخدمي القوقعة الطبية. تم تقييم إدراك الكلام وفهمه في الضوضاء عن طريق استخدام الاختبار المعد حديثا للجمل العربية المتوسطة لغويا باستخدام أنواع مختلفة من الضوضاء (الضوضاء البيضاء, ضوضاء متعددة المتحدثين وضوضاء القصة). خضع الأطفال مستخدمو القوقعة لتقييم العمر اللغوي. تعتمد نتيجة اختبار تقييم وإدراك الكلام في الضوضاء المعد حديثا على حساب معدل الإشارة إلى الضوضاء الذي يحقق الطفل عنده 50% من عدد الكلمات في كل قائمة من الاختبار.

النتائج: هناك اختلاف احصائي كبير بين نتائج اختبار تقييم إدراك الكلام وفهمه في الضوضاء عن طريق استخدام الاختبار المعد حديثا للجمل العربية المتوسطة لغويا باستخدام أنواع مختلفة من الضوضاء في الأطفال مستخدمو القوقعة عن الأطفال ذو السمع الطبيعي. استخدام الضوضاء البيضاء يعد أقل الأنواع تحديا. سن زراعة القوقعة يؤثر بشكل كبير على فهم وإدراك الكلام في الضوضاء.

الخاتمه: الأطفال مستخدمو القوقعة الطبية يحتاجون مستوى أعلى من معدل الإشارة إلى الضوضاء مقارنة بالأطفال ذو السمع الطبيعي في نفس العمر. زراعة القوقعة في سن مبكر يؤثر بشكل كبير على أداء الأطفال وفهمهم للكلام في الضوضاء المختلفة.