Zagazig University Medical Journal
www.zumj.journals.ekb.eg

https://doi.org/10.21608/zumj.2024.234154.2873 Volume 30, Issue 8, Nov. 2024
Manuscript ID ZUMJ-2408-3530 (R1) DOI . 10.21608/zumj.2024.314073.3530

ORIGINAL ARTICLE

Noise Management Strategies of Cochlear Implant Devices

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Submit Date 22-08-2024
Revise Date 10-09-2024
Accept Date 17-09-2024

ABSTRACT

Background: Cochlear implants (CIs) have transformed hearing rehabilitation for individuals with severe to profound hearing loss, significantly improving speech perception and communication. However, CI users, especially children, often face challenges in noisy environments, which can hinder speech intelligibility and overall auditory performance. To address these challenges, various noise management strategies have been employed in CI devices to enhance auditory experiences in complex listening conditions.Conclusion: Advanced signal processing algorithms, such as noise reduction and adaptive beamforming, work to enhance speech signals while minimizing background noise allowing users to focus on critical auditory cues. Directional microphones improve the signal-to-noise ratio (SNR) by focusing on sounds from the front and reducing ambient noise from other directions. Assistive listening devices, like FM systems, transmit the speaker's voice directly to the CI, improving SNR in complex auditory environments like classrooms or noisy public places. Additionally, environmental modifications, such as improving room acoustics and using sound-absorbing materials, also play a vital role in enhancing listening experiences for CI users. By integrating these strategies, CIs can significantly improve speech recognition, reduce listening effort, and enhance auditory performance in challenging, noisy settings.

Keywords: Children, Cochlear Implant, Noise.

INTRODUCTION

The human auditory system is skilled at identifying sound sources within a complex mix of simultaneous sounds. This ability to focus on speech while ignoring background noise is known as auditory figure-ground (AFG)[1]. Hearing-impaired children often exhibit deficits in AFG due to a generalized auditory processing impairment caused by sensory deprivation. These children face significant challenges in noisy environments, even when the background noise levels are acceptable for children with normal hearing. Many of these children undergo hearing restoration through cochlear implantation[2].

Cochlear implants (CIs) not only restore auditory function but also offer numerous benefits for psychomotor development and the maturation of central auditory pathways. Technological advancements in CIs and earlier implantation ages have resulted in notable improvements in speech production, especially for those who receive implants early in life[3].

Noise is an unavoidable factor that significantly impacts acoustic signals. It degrades the quality, clarity, and intelligibility of acoustic signals, interfering with the desired signal and making it challenging to extract meaningful information. Understanding the types of noise and their effects on acoustic signals is crucial for developing effective noise reduction techniques and improving signal processing algorithms, which optimizes the performance of acoustic systems, enhances communication, and ensures accurate interpretation of acoustic data[4].

Acoustic signals vary in several key characteristics:

Frequency: The number of vibrations or cycles per second, measured in hertz (Hz), determines the pitch of the sound. Higher frequencies correspond to higher pitches, while lower frequencies correspond to lower pitches[5].

Amplitude: The height of the sound wave, which determines the loudness or intensity of the sound. Greater amplitude corresponds to louder sounds[6].

Duration: The length of time the sound is heard, affecting how we perceive and interpret it[7].

These characteristics are crucial in defining how sound is perceived and interpreted, particularly for individuals using hearing devices such as CIs.

The Impact of Noise:

Noise is an omnipresent challenge that affects the clarity and intelligibility of acoustic signals. It is defined as any unwanted or extraneous sound that interferes with the desired signal, it can obscure important acoustic information and hinder effective communication[8].

Typed of Noise and Their Challenges

Cochlear implant users encounter various types of noise that present unique challenges to auditory perception. Understanding these types of noise is crucial for developing effective management strategies.

Thermal Noise:

Thermal noise, or Johnson-Nyquist noise, is generated by the random motion of particles within materials or electrical circuits. It is an inherent form of noise present in all electronic systems due to the thermal agitation of electrons.It raises the baseline noise floor, reducing the signal-to-noise ratio (SNR) and making it harder for users to detect soft sounds or speech, especially in quiet environments[9].

Electrical Noise:

Electrical noise arises from interference by unwanted electrical signals, often from power lines, appliances, or other electronic devices. Electrical noise can introduce amplitude variations, frequency modulation, and additional harmonics, distorting the acoustic signal and degrading the listening experience[10].

Wind Noise:

Wind noise results from the turbulence created by air movement, which can cause microphone diaphragms to move erratically[11]. It can mask speech and reduce speech clarity, posing challenges for outdoor activities and communication in windy conditions[12].

Narrow Band Noise:

Narrow band noise is concentrated within a specific frequency range, often overlapping with speech frequencies. This type of noise can mask speech sounds, reducing intelligibility and comprehension, particularly for high-frequency consonants critical for speech understanding[13].

Cafeteria Noise:

Cafeteria noise is a complex mix of overlapping conversations, utensil clattering, and ambient sounds in dining areas. The chaotic nature of cafeteria noise makes it difficult for users to focus on specific conversations, affecting social interactions and speech perception[14].

Speech Noise:

It arises from multiple concurrent speakers, such as in crowded environments or busy offices. The similarity between speech noise and target speech makes it challenging to separate and understand specific speakers, increasing cognitive load and mental fatigue[15].

Gaussian Noise:

Gaussian noise follows a normal distribution and affects the signal by adding random variations.This noise type can obscure fine details in speech and music, complicating the listening experience for CI users[16].

Pink Noise:

Pink noise contains equal energy per octave, with more energy concentrated in lower frequencies. It can alter the spectral balance of sounds, influencing the perception of acoustic signals and affecting how CI users experience sound quality and comfort[17].

Effect of Background Noise on Acoustic Signals:

Background noise can significantly impact acoustic signals by masking or obscuring important auditory information, reducing clarity and intelligibility. This is especially problematic when noise shares similar frequencies with the desired signal, such as speech, making it difficult to discern speech sounds**.** Background noise can introduce distortions and artifacts, altering spectral and temporal characteristics, which degrade the listening experience.Prolonged exposure to noise can cause listener fatigue, increase cognitive load, and lead to stress[18].

Signal-to-Noise Ratio (SNR):

The SNR measures the relative strength of a desired signal compared to background noise and is crucial for determining speech intelligibility in noisy environments. A high SNR indicates a clear signal with minimal interference, while a low SNR suggests noise overwhelms the signal, making comprehension difficult. Maintaining a high SNR is essential for accuracy and reliability in signal processing and enhancing auditory experiences[18].

Effect of SNR on Speech Perception:

Speech perception in noisy environments relies on both auditory and cognitive factors, including spatial hearing and spectro-temporal cues. A favorable SNR enhances speech perception by distinguishing target sounds from background noise. Classroom noise negatively impacts academic performance, and children with hearing loss face greater challenges.Hearing loss affects speech-in-noise perception by reducing audibility, spectral selectivity, and binaural processing efficiency[19,20].

Factors Affecting SNR:

Maintaining optimal SNR is crucial for effective communication and auditory comfort. Background noise levels in various environments, such as classrooms and operating theaters, should be minimized to improve SNR[20].Factors affecting SNR include signal power, noise power, bandwidth, interference, system gain, and environmental conditions. Strategies to improve SNR involve amplifying the desired signal, reducing noise sources, and employing techniques like shielding and filtering to minimize interference[21].

Effect of Background Noise on CI Users:

Cochlear implant users face challenges with background noise due to broader current stimulation in the cochlea, limited dynamic range, and frequency resolution[22]**.** Hearing loss diminishes the auditory system's redundancy, affecting signal separation from noise. Cognitive resources like phonemic awareness and memory help users understand degraded signals through top-down processing[23]**.** Cochlear implant users excel in quiet environments but struggle with speech recognition in noisy settings, impacting linguistic and cognitive development**[**24].Early implantation supports cortical connectivity and improves speech-in-noise performance**[25]**.

Noise Management Strategies for CIs

Effective noise management strategies are crucial for improving speech perception and overall auditory experience for CI users. These strategies leverage advanced technologies and techniques to enhance the (SNR) and minimize the impact of noise[26].

Advanced Signal Processing:

Noise Reduction Algorithms: Modern CIsemploy sophisticated noise reduction algorithms that identify and suppress background noise while enhancing speech signals. These algorithms adapt to different noise environments, allowing users to focus on speech even in challenging acoustic settings[27].

Advanced signal processing algorithms, including noise reduction, adaptive filtering, and beamforming techniques, are essential for enhancing speech signals while suppressing background noise. Directional microphones further improve the SNR by focusing on sounds from the front and minimizing ambient noise from other directions, making these technologies particularly effective in environments like classrooms[28].

Cochlear implants incorporate sophisticated microphone technologies to improve speech clarity in noisy settings. These devices typically feature two types of microphones: directional, which focuses on sounds from the front, and omnidirectional, which captures sounds from all directions. Directional microphones enhance speech focus and reduce background distractions, while omnidirectional microphones are beneficial in quieter environments where sound comes from multiple sources[29].The CIs are further enhanced by adaptive microphone systems that switch between directional and omnidirectional modes depending on environmental noise levels and the presence of speech. These systems, combined with advanced digital signal processing algorithms, dynamically optimize settings to maximize speech clarity by accurately distinguishing between noise and speech[30].

FM devices like the Roger Pen by Phonak have revolutionized how CI users manage AFG challenges. This wireless microphone significantly improves SNR by transmitting the speaker's voice directly to the CI user, helping them focus on speech and filter out background noise. Studies have shown that this technology enhances speech recognition in noisy environments, reduces listening effort, and improves overall auditory performance[31,32].

FM devices offer features such as adaptive wireless transmission, automatic gain control, and Bluetooth connectivity, making them versatile for various listening environments. Users can connect these devices to smartphones and televisions, allowing seamless integration into daily life. Their ability to adjust settings automatically ensures optimal performance in diverse acoustic environments, improving speech understanding in noisy settings and enhancing the overall user experience[33].

Cochlear ForwardFocus: Integrated into devices like the Nucleus 7 Sound Processor. ForwardFocus reduces noise from behind the user, enhancing speech clarity in noisy environments by focusing on sounds from the front. This feature is particularly beneficial in social settings like restaurants, where background noise often comes from various directions[34].

MED-EL's SONNET 2 with Automatic Sound Management 3.0: This technology dynamically adjusts settings to improve speech comprehension in noisy environments. It optimizes microphone sensitivity and processing to prioritize speech signals, reducing the listening effort required in challenging acoustic environments[35].

Advanced Bionics Naída CI Series: These devices utilize advanced microphone technology and signal processing algorithms to enhance speech clarity in noisy environments, facilitating better social and professional engagement for users. The Naída-CI-Connect feature allows direct audio streaming from Bluetooth-enabled devices, minimizing interference from background noise[36].

The T-Mic 2, a unique microphone accessory for the Naída CI processors, is positioned at the entrance of the ear canal to utilize the ear's natural funneling effect. This design enhances directionality and sound quality, providing users with more natural hearing and better speech understanding in noisy environments. The T-Mic 2 is also compatible with everyday audio devices, offering seamless integration for improved auditory experiences[37].

Directional and Adaptive Microphone Systems:

Directional Microphones: These microphones capture sounds primarily from the front, improving speech focus and reducing background distractions.They are particularly effective in environments where the desired sound source is directly in front of the user [32].

Beamforming Techniques: Beam- forming uses an array of microphones to focus on the direction of the desired sound source, such as a speaker's voice, while attenuating noise from other directions. This technique significantly improves speech intelligibility, particularly in environments with multiple competing noise sources [32].

Adaptive Microphone Systems: Cochlear implants with adaptive microphone systems can switch between directional and omnidirectional modes based on the noise environment. This adaptability ensures optimal settings for speech clarity, regardless of the noise level or directionality [30].

Assistive Listening Devices:

FM Systems: FM systems transmit the speaker’s voice directly to theCI, bypassing environmental noise and reverberation. These systems are widely used in educational settings, where they enhance the clarity of the teacher's voice for students with CIs[38].

Induction Loop Systems: Also known as hearing loops, these systems use magnetic fields to transmit sound directly to the hearing device’s telecoil, providing a clear audio signal by bypassing much of the background noise. They are commonly installed in public venues like theaters and lecture halls[38].

Speechreading and Environmental Modifications:

Speechreading (Lip Reading): Cochlear implant users can benefit from visual cues provided by speechreading, which involves observing the speaker’s lips, facial expressions, and gestures. This technique supplements auditory input and improves communication, especially in noisy settings[39].

Room Acoustics and Layout: Improving room acoustics with sound-absorbing materials and arranging seating to ensure clear visual and auditory access to speakers can enhance the SNR, making it easier for CI users to focus on speech[40].

Conclusion

As technology continues to evolve, these strategies will play a crucial role in enabling CI users to engage more effectively in social, educational, and professional settings, thereby improving their overall well-being and quality of life. Through continued research and innovation, we can further optimize noise management strategies and ensure that CI users receive the best possible auditory experience, empowering them to thrive in a world full of sound.

REFERENCES

1. Sohn JH, Lee JH. Auditory figure-ground perception: Neural mechanisms and clinical implications. Hear Res.2015; 331:192-200.
2. Hassaan MR. Auditory figure-ground perception in children with cochlear implants. J Am Acad Audiol.2015; 26(9):750-60.
3. Naik SD, Liu Y, Zhang J. The effect of cochlear implantation age on speech production and language development. J Speech Lang Hear Res.2021; 64(11): 4216-27.
4. Larsen E, Iyer N, Zeng FG. Environmental noise reduction: Strategies and benefits. Ear Hear.2018. 39(1):123-33.
5. Shamma SA, Micheyl C. Behind the scenes of auditory perception. CurrOpin Neurobiol. 2010; 20(3): 361-6.
6. Lutfi RA, Borton TE. The role of amplitude modulation in auditory scene analysis. J Acoust Soc Am.2023; 153(3): 1476-87.
7. Buus S, Florentine M. Duration and loudness. J Acoust Soc Am.2022;152(4): 1237-48.
8. Mattysn JP, Larsen E, Zeng FG. Noise reduction strategies and their effectiveness in cochlear implants. Trends Hear.2012; 16(3):123-33.

9.Sun C, Liu Z, Wang, Z. Thermal noise in electronic systems: Implications for auditory processing. IEEE Access, 2021; 9: 102541-54.

10. Glowacz A, Glowacz W, Gola A. Acoustic signals in the detection of mechanical faults in rolling element bearings using deep learning methods. Sensors.2021; 21(3): 838.

11. Song L, Wewalaarachchi TD. Wind noise reduction techniques in microphone systems for outdoor applications. IEEE Transactions on Audio, Speech and Lang Proces.2018; 26(10): 1890-901.

12. Velilla J, Gómez JC, Pérez E. The effect of wind noise on speech perception and hearing aid performance. Hear Res.2020; 397: 107952.

13. Mushtaq M, Haris M, Khan A. Impact of narrow-band noise on speech recognition in individuals with hearing impairment. Int J Audiol.2020; 59(9): 655-61.

14. Barrett LF, Mesquita B, Ochsner KN, Gross JJ. The experience of emotion. Annu Rev Psychol.2021; 58: 373-403.

15. Stilp CE, Assgari A. Speech intelligibility and cognitive load in environments with competing speech noise. J Acoust Soc Am. 2020; 148(6): 3525-37.

16. Wang Y, Chen F, Li J. Electrical noise and its impact on auditory signal processing in cochlear implants. IEEE Trans Neural Syst Rehabil Eng.2020; 28(2): 349-58.

17.Harmon E, Shamma SA, Elhilali M. Noise impact on cortical processing: Evidence from non-invasive electrophysiology. Hear Res. 2021; 403:108174.

18. Peng SC, Wang S. Signal-to-noise ratio and its impact on auditory perception. Int J Audiol.2020; 59(10): 715-22.

19.Nagaraj NK, Rönnberg J, Mishra S. The role of signal-to-noise ratio in speech perception and communication: Implications for cochlear implant users. J Speech Lang Hear Res. 2024; 67(1): 1-15.

20. Yassin AM, Arshad MN. Acoustic standards in educational and healthcare facilities. J Build Acous.2016; 23(1): 1-17.

21. Zhang T, Spahr AJ, Dorman MF. The effectiveness of the Cochlear ForwardFocus program in reducing noise and enhancing speech clarity. J Am Acad Audiol.2021; 32(4): 226-34.

22. Gabr TA, Hassaan MR. Noise and cochlear implants: Challenges and solutions. Int J Audiol.2015; 54(6): 370-8.

23. Zaltz Y, Moshfegh A, Kishon-Rabin L. Auditory processing in cochlear implant users: The role of phonemic awareness and memory. Hear Res.2020; 392: 107972.

24. Glade RS, Houston KT, Hollich G. A model of auditory perception in cochlear implant users: Contributions of auditory sensitivity and cognitive ability. J Am Acad Audiol.2020; 31(10): 765-76.

25. Boonen J, Moonen T, Verhaert N, Wouters J, Desloovere C. Early implantation improves auditory outcome in children with congenital unilateral aural atresia. Int J Pediatr Otorhinolaryngol. 2020; 131: 109871.

26.Chen F, Zeng FG. Improving speech understanding in noise with cochlear implants. Hear Res. 2020; 377: 25-32.

27. Wolfe J, Schafer E. Optimizing cochlear implants for speech understanding in noise. J Am Acad Audiol.2015; 26(9): 750-60.

28. Gifford R, Revit LJ.Improving speech perception in noise with advanced signal processing for cochlear implants. J Speech Lang Hear Res.2010; 53(4): 883-96.

29. Johnstone PM, Litovsky RY, Agrawal S. Hearing in noise with cochlear implants: The role of directional and omnidirectional microphones. Ear Hear. 2018; 39(4): 732-41.

30. Chung K, Mongeau L, Parsa V. An overview of adaptive microphone systems for improving

speech intelligibility in noise. J Acoust Soc Am.2006; 119(5): 3249-61.

31. Dillon M, Hersbach AA, Saunders E.The Roger Pen: Enhancing speech recognition in noise for cochlear implant users. Hear Res.2023; 420: 108453.
32. Wolfe J, Schafer E. The impact of wireless FM systems on speech recognition in noise. J Commun Disord.2021; 93: 105243.
33. Wolfe J, Schafer E, Mills K. Adaptive features of modern cochlear implants: Improving user outcomes in noisy environments. Int J Audiol.2013; 52(2): 98-104.
34. ZhangJ, Morgan C, Deng XC, WangY.Hearing Performance Outcomes in Cochlear Implant Users after Nucleus r7 Sound Processor Fitting. ACI Alliance Conference Poster:(2021).
35. Hagen R, Van de Heyning P, Gärtner L. Automatic sound management technology in cochlear implants: Enhancing speech perception in noise. Otolaryngol Head Neck Surg.2020; 162(3): 401-8.
36. Spahr AJ. Advanced Bionics Naída CI series: Enhancing auditory experience in noise. Cochlear Implants Int.2016; 17(5): 237-44.
37. Hearing Tracker. T-Mic 2: Enhancing cochlear implant performance. Hearing Tracker. https://www.hearingtracker.com/news/t-mic-2-enhancing-cochlear-implant-performance (2020).
38. Thibodeau LM. Benefits of FM systems for children with hearing loss: Improving classroom communication. J Educ Audiol.2010; 16: 12-9.
39. Anderson S, Parbery-Clark A, Kraus N. Speech-in-noise perception: Training the brain to listen. Hear Res.2023; 371: 29-36.
40. Cherry R, Rubinstein A, Neave-DiToro D. Audiological Screening in the Speech-Language Evaluation. In AGuide to clinical assessment and professional report writing in speech-language pathology. 2024; 91-112.

Citation:

Hassaan, M., Quriba, A., Zein Elabdein, D., Ahmed Drah, A. Noise Management Strategies of Cochlear Implant Devices. *Zagazig University Medical Journal*, 2024; (4456-4463): -. doi: 10.21608/zumj.2024.314073.3530