BILINGUAL PUBLISHING GROUP

Forum for Linguistic Studies

https://journals.bilpubgroup.com/index.php/fls

ARTICLE

The Effect of Background Noise and Music on Speech Recognition Performance of Individuals with Normal Hearing and Hearing Loss

Eun Yeon Kim[1], Sang Eun Lee[2], Hye Yoon Seol[3*]

[1] *Department of Speech Language Pathology, Graduate School of Interdisciplinary Therapy, Myongji University, Seoul, 03674, Korea*

[2] *Department of Music Therapy, Graduate School of Interdisciplinary Therapy, Myongji University, Seoul, 03674, Korea*

[3] *Department of Communication Disorders, Ewha Womans University, Seoul, 03760, Korea*

ABSTRACT

This study explores speech recognition characteristics in background noise and music between normal hearing (NH) listeners, hearing aid (HA) users and cochlear implant (CI) users. Sixty individuals participated in the study: 20 with NH, 20 HA users, and 20 CI users. HA and CI users had a Categories of Auditory Performance score of 6 and open set sentence recognition of 85% or higher. They had been using the devices for at least one year. Babble noise (BN), piano solo (PS), piano + violin (PV), and piano + chorus (PC) were presented at +5- and +10 dB signal-to-noise ratio (SNR). The participants were asked to listen and repeat words and sentences from the Korean Standard Sentence List for Adults. At +5- and +10 dB SNRs, CI users performed worse than those with NH on word and sentence recognition in BN, PS, PV, and PC. HA users outperformed CI users in all conditions. Those with NH showed better sentence recognition than HA users across all conditions at +5 dB SNR and better word recognition in PV and BN at +5 dB SNR and in PC at +10 dB SNR. Correlational analysis revealed that the percentage of life with hearing loss before CI was not correlated with sentence and word recognition across all conditions in both SNRs. Statistically significant negative correlations were observed between the duration of deafness and sentence and word recognition in some conditions. Despite individuals with HL performing well on clinical tests, background music can still interfere with communication for those using hearing devices. To accurately evaluate individuals' communication abilities clinical tools that include background music need to be developed. Studies using different types of music could help develop and standardize such tools for assessing speech and language abilities in individuals with hearing loss.

Keywords: Hearing loss; Audiology; Rehabilitation

*CORRESPONDING AUTHOR:

Hye Yoon Seol, Department of Communication Disorders, Ewha Womans University, Seoul, 03760, Korea; E-mail: seol.helena@ewha.ac.kr

ARTICLE INFO

Received: 11 April 2024 | Revised: 2 May 2024 | Accepted: 15 May 2024 | Published Online: 26 June 2024

DOI: https://doi.org/10.30564/fls.v6i3.6583

CITATION

Kim E.Y., Lee S.E., Seol H.Y., 2024. The Effect of Background Noise and Music on Speech Recognition Performance of Individuals with Normal Hearing and Hearing Loss. Forum for Linguistic Studies. 6(3): 61–73. DOI: https://doi.org/10.30564/fls.v6i3.6583

1. Introduction

Communication can be explained through the speech chain (Denes & Pinson, 2016). When speech is produced, it gets transmitted to the auditory system of both the speaker and the listener in the form of sound waves. The auditory system consists of four parts: the outer ear, middle ear, inner ear, and auditory nerve (Møller, 2012). The outer ear, also known as the pinna and the ear canal, acts like a funnel, gathering sound and transmitting it to the ear drum in the middle ear. In the middle ear, there are also three small bones called the malleus, incus, and stapes, which transmit sound to the inner ear. Additionally, the middle ear contains a structure called the eustachian tube, which helps equalize the air pressure between the ambient pressure and the pressure inside the middle ear. In the inner ear, there is the cochlea, which houses the sensory organ of hearing. The cochlea is a snail-shaped structure, where the base of the cochlea processes high-frequency information, while the apex processes low-frequency information. The sound then gets transmitted to the auditory cortex of the brain through the auditory nerve. At this stage, the listener interprets the meaning of the heard speech using his or her linguistic knowledge. For effective communication, linguistic knowledge and appropriate neuromuscular activity are crucial, but acoustic signals must also be properly transmitted and interpreted by the auditory system; accurate perception of sound is vital for human communication and for individuals to imitate spoken language, auditory perception needs to be connected to motor skills (Prather, 2013).

Hearing loss (HL) is a major public health problem around the world (Diseases & Injuries, 2020; McDaid et al., 2021; Organization, 2017). Numerous studies have revealed that HL impacts various aspects of life negatively, ranging from communication to academic and job performance, and to social isolation (Cunningham & Tucci, 2017; Davis et al., 2016; Kramer, 2008; Wagner-Hartl et al., 2018; Wilson et al., 2017). Kramer et al. 2006 used the Amsterdam Checklist for Hearing and Work to investigate occupational performance between individuals with normal hearing (NH) and HL. A total of 210 participants (60 with NH and 150 with HL) were enrolled in the study and the results showed that HL was correlated with more effort required for listening, meaning that those with HL find listening to be a challenging task. The effort for listening was related to hearing tasks at work, such as sound detection. Additionally, when examining subjective noise levels at work, individuals with HL perceived higher levels of noise than NH listeners, indicating that those with HL are more sensitive to noise at work (Kramer, 2008).

In relation to speech and language development, particularly for children, receiving auditory input and feedback is crucial regardless of the type and degree of HL, as well as whether it is unilateral or bilateral. HL can lead to a lack of auditory stimulation, potentially causing delays in speech and language development (Anne et al., 2017; Ching et al., 2010; Halliday et al., 2017; Lieu et al., 2020; Stelmachowicz et al., 2004). Anne et al. 2017 conducted a systematic review of speech and language characteristics of unilateral HL in children. Among the 13 research studies the authors reviewed, seven studies showed poorer performance on speech and language tests, with these findings being particularly pronounced among children with severe to profound HL (Anne et al., 2017).

With these negative consequences, it is important to manage HL through the use of hearing devices, such as hearing aids (HAs) and cochlear implants (CIs). Both HAs and CIs are devices that aid individuals with HL in perceiving sounds and understanding speech; HAs amplify sounds (acoustic signals), while CIs, as surgically implanted devices, provide a sense of sound through electrical stimulation. Individuals with HL typically start their rehabilitation process through HA use. If HL becomes too severe that it can no longer be compensated by HAs, individuals consider CIs. Unlike HAs, CIs deliver electrical signals, so CI users' rehabilitation process involves matching these electrical signals to speech, music, and environmental sounds.

Music, commonly encountered in the form of background sounds in various places, plays a role not only in drawing attention but also in strengthening sustained attention. It has been noted in many research studies that music has an impact on depression (Siedliecki & Good, 2006), pain (Siedliecki & Good, 2006), work quality (Lesiuk, 2005), etc. From a linguistic perspective, researchers have reported similarities between language and music (Brandt et al., 2012; McMullen & Saffran, 2004; Temperley, 2022). Music and language are similar in a way that both of them are created based on one's database of sounds that could be chosen to formulate and can be adjusted or modified so that they can sound attractive to others. For example, when adults interact with infants and children, they tend to use infant-directed speech which has characteristics of slower rate, longer pause, and higher pitch (Fernald, 1992). Adults exaggerating sounds could lead to early learning of speech and language as it engages children's attention (Thiessen et al., 2005). Similar characteristics are observed for music—compared to songs targeting adults, songs for infants and children are usually simple and have repetitive pitch contours (Trainor & Trehub, 1998). Studies have shown that infants can develop their knowledge about the prosodic structures of their native language (Friederici, 2006; Ramus et al., 1999; Wermke et al., 2007). Using this knowledge about prosodic features, infants are known to differentiate between their native language and non-native language (Friederici, 2006). Wermket et al. 2007 examined melodies of infant cries using the Melody Complexity Index and reported that infants who show less than 45% complexity in their cries could experience a language delay (Wermke et al., 2007).

Although many studies have shown the positive effect of music on various aspects of life, music may not always be enjoyable to everyone—HA and CI users could have difficulty with music perception and appreciation. In order for HAs and CIs to enhance speech understanding and quality of life, HA and CI programming based on one's hearing characteristics and communication needs is required. Appropriately programmed HAs and CIs are known to improve speech understanding and quality of life (Cho et al., 2019; Ketterer et al., 2020; Laske et al., 2009; Mondelli & de Souza, 2012; Seol et al., 2021; Seol & Moon, 2022). Ketter et al. 2020 investigated CI benefit in speech perception, quality of life, tinnitus distress, and psychological comorbidities. Comparing their performance before implantation and 6- and 24 months after implantation, participants were able to understand speech better with CIs and their quality of life significantly improved as well (Ketterer et al., 2020). Mondelli et al. 2012 examined the quality of life before and after three months of HA use for the elderly. Thirty HA users completed the World Health Organization Quality of Life Questionnaire and the results revealed significant improvement in quality of life as all participants reported that their quality of life became good or very good after HA use. The participants were also satisfied with their personal relationships (i.e., friends, relatives, and colleagues) (Mondelli & de Souza, 2012). Although numerous studies have documented HA and CI benefits, optimizing the devices does not always lead to improvement in communication and quality of life; even with HAs and CIs individuals still struggle with speech understanding in noise, phone conversations, and music (Bruns et al., 2016; Jung et al., 2010; Looi et al., 2012; Nasresfahani et al., 2022; Philips et al., 2012; Riley et al., 2018). For example, the perception of music through a CI is influenced by multiple variables and the effects vary widely among individuals (Looi et al., 2012). While CI users may have temporal resolution skills equivalent to those with NH, their frequency-resolution skills are often affected, impacting music perception (Looi et al., 2012). CI sound processors have limited filter bands with fixed center frequencies, potentially hindering the accurate resolution of lower harmonics in complex sounds. Factors, such as electrode insertion depth and processing of complex acoustic signals, can also contribute to inaccuracies in pitch perception. Jung et al. 2010 investigated music perception ability in Korean CI users and reported that, irrespective of positive correlation between speech performance and pitch discrimination ability, CI users showed a wide range of performance when it came to pitch discrimination and melody and timbre identification (Jung et al., 2010).

Although there has been extensive research on the effects of music on human behavior and the perception and appreciation of music among CI users, research on speech recognition performance in situations where background noise and music are presented is limited, especially among individuals with various types of HL wearing hearing devices. Regardless of HL, when considering conversational environments in daily life, conversations occur in both quiet and noisy situations. Therefore, it is important to measure speech understanding abilities in various environments using noises encountered in the real world. This study investigates the effect of background noise and music on speech recognition in individuals with NH and HL with a hypothesis that compared to those with NH, noise and music may have a negative impact on speech recognition for HA and CI users.

2. Materials and methods

2.1 Participants

A total of 60 adults were enrolled in the study. Among the 60 adults, 20 were NH listeners, 20 were HA users, and 20 were CI users. The HL group was divided into CI and HA groups depending on the hearing devices they wore. The CI group consisted of individuals with sensorineural HL of 70 dB (equivalent to severe HL) or greater who have been wearing CIs for at least one year (mean = 4.7, SD = 2.7). The HA group comprised individuals with sensorineural HL of 26 dB (equivalent to mild HL) or greater who have been using HAs for at least one year (mean = 9.1, SD = 6.7). For CI and HA groups, individuals were eligible to participate in the study if they achieved a Categories of Auditory Performance (CAP) score of 6 and demonstrated a performance of 85% or above in Seoul National University Hospital (SNUH) Everyday Sentence Recognition Test, an open-set speech test commonly used in the clinical settings to examine the benefit of hearing devices. The CAP is an eight-point hierarchical scale that can evaluate an individual's auditory performance. The CAP categories range from 0 to 7, with 0 representing no awareness of environmental sounds and 7 representing the use of a telephone with a known speaker (Nikolopoulos et al., 1999). The CAP score of 6 indicates that after CI implantation, individuals can understand conversations without having to read lip movements at least. In addition, the Percentage of Life (PoL) with HL was calculated for both CI and HA groups. For CI users, PoL spans from the onset of HL to the CI surgery, while for HA users, the PoL covers the time from HL onset to the use of HAs. The average PoLs were 40.51% for the CI group and 19.78% for the HA group. Lastly, duration of deafness (DoD), the period from the point when no benefit could be obtained from HAs until CI surgery, was examined for the CI group. The average DoD was 5.45 years for the CI group. In terms of exclusion criteria, individuals with a history of neurological diseases or cleft palate, disorders of the articulatory organ, sensory disorders, cognitive disorders, behavioral disorders, and voice disorders were excluded from the study. All experimental procedures were approved by the Institutional Review Board (IRB) of Samsung Medical Center and an informed consent document was obtained for all participants.

2.2 Speech recognition test

The speech recognition testing was performed using the Korean Standard Sentence List for Adults (KS-SL-A). The KS-SL-A consists of a total of 80 sentences and 320 target words (10 sentences and 40 target words * 8 lists). The test sentences were presented under four conditions: babble noise (BN), piano solo (PS), piano + violin (PV), and piano + chorus (PC). The piano, violin, and chorus were from Nella Fantasia. The stimuli (test sentences) were presented at +5- and +10 dB signal-to-noise ratios (SNRs) through a speaker located 1m in front of the participant. + 5dB SNR means that the test sentences were presented 5 dB louder than the noise and music and +10 dB SNR means that the test sentences were 10 dB louder than the noise and music. In terms of scoring, percent-correct scores for sentences and words were obtained based on the correct responses from the participants.

2.3 Statistical analysis

Statistical analysis was performed using the SAS Package (ver. 9.1.3, SAS Institute Inc., Cary, NC, USA). Our results passed the normality test (Kolmogorov-Smirnov test). Repeated Measures ANOVA (RM ANOVA) was performed to examine differences in sentence and word recognition performance between NH, HA, CI groups in BN, PS, PV, and PC at +5- and +10 dB SNRs. Pearson's correlation was performed to investigate the relationship between PoL, DoD, and speech recognition in CI users.

3. Results

3.1 Demographic information

Participant characteristics are described in **Table 1**. The average ages of the NH, CI, and HA groups were 49.70 (SD = 14.4), 51.97 (SD = 14.3), and 51.08 (SD = 17.1) years, respectively. All participants in the HA and CI groups had post-lingual HL, meaning that HL occurred after these individuals acquired speech and language knowledge and skills. Based on individuals' hearing test results, the averages of hearing thresholds at four frequencies (500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz) were calculated. Regarding the degree of HL, for adults, the cut-off for NH is 25 dB. If the puretone average falls between 26 and 40 dB, it is considered mild HL; between 41 and 55 dB, moderate HL; between 56 and 70 dB, moderately severe HL, between 71 and 90, severe HL, and if it is 91 dB or greater, it is considered profound HL. The puretone averages were 15 dB in both ears for the NH group, 100 dB in the right ear and 99 dB in the left ear for the CI group, and 67 dB in the right ear and 64 dB in the left ear for the HA group.

Table 1. Demographic information.

Group	Number of participants	Age (years)	PoL (%)	DoD (years)
CI	20 (m = 2, f = 18)	49.70 (± 14.27)	40.51(± 17.72)	5.45(± 11.72)
HA	20 (m = 9, f = 11)	51.97 (± 16.35)	19.78(± 17.33)	NA
NH	20 (m = 3, f = 17)	51.08 (± 15.49)	NA	NA

Note: CI, Cochlear implant; HA, Hearing aid; NH, Normal hearing; PoL, Percentage of the patient's life with hearing loss before cochlear implant; DoD, Duration of deafness.

3.2 Speech recognition performance

Statistical analysis data regarding speech recognition performance in various listening conditions for both groups are shown in **Table 2**. At sentence level, for the +5 dB SNR condition, CI users showed significantly lower performance than HA users and NH listeners in BN (24.32 ± 20.78), PS (35.50 ± 31.37), PV (26.63 ± 29.40), and PC (33.50 ± 27.58) conditions ($p < 0.05$). The HA users' sentence recognition performance was significantly lower than the NH listeners, but their performance was significantly better when compared to that of the CI users in all test conditions ($p < 0.05$). The mean performance of the HA users was 54.00 ± 26.64, 76.50 ± 25.81, 60.50 ± 32.20, 64.50 ± 30.00 in BN, PS, PV, and PC conditions respectively. At +10 dB SNR, the CI group showed significantly lower performance than the HA groups except for PC (56.50 ± 25.80). They also showed significantly lower performance (40.00 ± 26.66 for BN, 65.75 ± 26.22 for PS, and 48.00 ± 32.54 for PV) than the NH group in all conditions ($p < 0.05$). Compared to the NH group, the HA group showed significantly lower performance in BN and PC conditions (63.50 ± 27.77 for BN and 73.50 ± 27.96 for PC). At word level, in the +5 dB SNR condition, CI users showed significantly lower performance than HA users and NH listeners in BN (44.21 ± 25.56), PS (35.50 ± 31.37), PV (39.88 ± 32.90), and PC (51.50 ± 32.13) conditions ($p < 0.05$). Comparing the HA and CI groups, HA users understood words significantly better than the CI users in BN (75.38 ± 30.15), PS (88.60 ± 17.52), PV (76.50 ± 26.98), and PC

(80.13 ± 29.22) conditions ($p < 0.05$). Comparing the HA and NH groups, the HA users showed significantly lower performance than the NH listeners in the BN and PV conditions. At +10 dB SNR, statistical differences were observed between the CI (61.18 ± 28.67 for BN, 77.12 ± 28.10 for PS, 65.25 ± 29.56 for PV, and 64.12 ± 26.13 for PC) and HA groups (82.25 ± 21.91 for BN, 93.37 ± 15.40 for PS, 90.13 ± 18.54 for PV, and 82.13 ± 25.58 for PC) and between the CI and NH groups (97.62 ± 2.86 for BN, 98.50 ± 3.07 for PS, 99.00 ± 1.70 for PV, and 99.50 ± 1.02 for PC) in all test conditions ($p < 0.05$). Statistical difference between the HA and NH groups was observed only in the PC condition ($p < 0.05$).

Table 2. Speech recognition performance for NH, HA, and CI groups.

Condition		+5 dB SNR			+10 dB SNR		
		CI	HA	NH	CI	HA	NH
PS	Sentence	35.50 (± 31.37) [a,b]	76.50 (± 25.81) [a,c]	98.00 (± 4.10) [b,c]	65.75 (± 26.22) [a,b]	86.50 (± 18.72) [a]	97.00 (± 7.32) [b]
	Word	57.88 (± 28.48) [a,b]	88.60 (± 17.52) [a]	99.38 (± 1.38) [b]	77.12 (± 28.10) [a,b]	93.38 (± 15.40) [a]	98.50 (± 3.07) [b]
PV	Sentence	26.63 (± 29.40) [a,b]	60.50 (± 32.20) [a,c]	92.38 (± 11.57) [b,c]	48.00 (± 32.54) [a,b]	78.50 (± 27.20) [a]	95.50 (± 6.86) [b]
	Word	39.88 (± 32.90) [a,b]	76.50 (± 26.98) [a,c]	98.63 (± 2.06) [b,c]	65.25 (± 29.56) [a,b]	90.13 (± 18.54) [a]	99.00 (± 1.70) [b]
PC	Sentence	33.50 (± 27.58) [a,b]	64.50 (± 30.00) [a,c]	93.00 (± 9.79) [b,c]	56.50 (± 25.80) [b]	73.50 (± 27.96) [c]	97.50 (± 5.50) [b,c]
	Word	51.50 (± 32.13) [a,b]	80.13 (± 29.22) [a]	98.38 (± 2.60) [b]	64.12 (± 26.13) [a,b]	82.13 (± 25.58) [a,c]	99.50 (± 1.02) [b,c]
BN	Sentence	24.32 (± 20.78) [a,b]	54.00 (± 26.64) [a,c]	84.50 (± 12.76) [b,c]	40.00 (± 26.66) [a,b]	63.50 (± 27.77) [a,c]	90.50 (± 8.87) [b,c]
	Word	44.21 (± 25.56) [a,b]	75.38 (± 30.15) [a,c]	96.25 (± 3.39) [b,c]	61.18 (± 28.67) [a,b]	82.25 (± 21.91) [a]	97.62 (± 2.86) [b]

Note: PS, piano solo; PV, piano and violin; PC, piano and chorus; BN, babble noise.

a, CI & HA: significant difference between speech recognition ($p < 0.05$); b, CI and NH group: significant difference between speech recognition ($p < 05$); c, HA and NH group: significant difference between speech recognition ($p < 0.05$).

3.3 Speech recognition performance according to the period of HL

For CI users, the relationships between PoL and speech recognition performance, between DoD and speech recognition performance, as well as duration of CI use and speech recognition performance were examined for all testing conditions at +5- and +10 dB SNR. Correlational analysis results are shown in **Table 3**. Correlational analysis revealed that for both words and sentences, no significant correlations were observed between PoL and speech recognition performance for BN, PS, PV, and PC conditions at +5- and +10 dB SNR. However, at +5 dB SNR, there was a statistically significant strong negative correlation between DoD and speech recognition performance in the BN (Rho = –0.4697, $p < 0.05$) and PC (Rho = –0.5665, $p < 0.01$) conditions for sentences. Statistically significant strong negative correlation was also found for words in the BN (Rho = –0.4754, $p < 0.05$) and PC (Rho = –0.5391, $p < 0.01$) conditions. At +10 dB SNR, statistically significant strong negative correlations at the sentence level were observed between DoD and speech recognition performance in both PS (Rho = –0.4875, $p < 0.05$) and PV (Rho = –0.5673, $p < 0.01$) conditions. A statistically significant strong negative correlations at the word level were also observed between DoD and speech recognition performance in both PS (Rho = –0.5056, $p < 0.05$) and PV (Rho = –0.5127, $p < 0.01$) conditions. Regarding the correlation between the duration of CI use and sentence and word recognition performance, no significant results were observed irrespective of SNR and testing conditions.

4. Discussion and conclusion

The current study explores how sentence and word recognition performance is impacted by several types of sounds including BN and music in people with NH, HA users, and CI users. The findings of the study showed that in terms of speech recognition performance, as expected, CI and HA users showed lower word and sentence recognition performance than those with NH regardless of the SNRs except in the PC condition at +10 dB SNR. Correlational analysis also revealed that longer DoD correlates with a decline in speech recognition performance in various listening conditions which was consistent with findings in previous studies to some extent (Bernhard et al., 2021; Moon et al., 2012). Bernhard et al. 2021 conducted a systematic review of the effect of DoD on hearing performance. In this systematic review, the DoD ranged from 0.1 to 77 years and the age at implantation ranged from three months to 14 years. The results showed negative correlations between DoD and monosyllabic word and sentence perception performance. In addition, the authors performed further analysis with subgroups: time of post-implantation testing and mean DoD. CI users who came to post-implantation follow-up sessions less than 12 months had a strong negative correlation between monosyllabic and sentence perception. When analyzing mean DoD data with a cut-off of 12 years, CI users with a DoD of 12 years exhibited poorer outcomes in monosyllabic word and sentence tests, meaning that the longer the DoD, the fewer opportunities for auditory input, leading to a decline in speech understanding ability (Bernhard et al., 2021). Comparing CI and HA users, also similar to pre-existing studies, the HA group showed better performance in all conditions for words and sentences except in one condition (Agelfors, 1996; Flynn et al., 1996; Kaandorp et al., 2015; Meilijson & Spitzer, 2015). In 1995, Agelfors examined speech perception performance in individuals with profound HL who were using HAs and CIs. The speech testing included a consonant test (/aCa/ syllables), a suprasegmental test, and a connected discourse tracking test. For the suprasegmental testing, prosodic contrasts were applied (number of syllables, vowel length, juncture, tone, and word emphasis) and the participants were required to choose between two options. The connected discourse testing involved a speaker reciting passages from a book (sentence by sentence) and the participants were asked to repeat the verbatim. The results showed that HA users showed better performance than CI users for suprasegmental and connected discourse tests. Kaandorp et al. 2015 performed speech testing in quiet and noise on 12 young adults with NH, 24 CI users, and 24 HA users. The speech testing involved consonant-vowel-consonant (CVC) monosyllables and sentences. The results revealed that there was a significant variation in the ability to recognize both CVCs and sentences and generally, CI users exhibited lower sentence recognition than CVCs, unlike HA users who did not show such a difference in performance. NH listeners performed significantly better than HA and CI users (Kaandorp et al., 2015). In our study, for sentence recognition, the HA group showed significantly better performance than the CI users in all conditions except for the PC condition at +10 dB SNR. For word recognition, statistical difference between the HA and NH groups was observed for all conditions at +5 dB SNR, but only in the PC condition at +10 dB SNR. Statistical analysis also revealed that CI users showed poorer performance than HA users and those with NH. Considering that only individuals who showed good performance on clinical tests (CAP score of 6 and 85% or higher on an open-set speech test) were able to participate in the study, the findings of the study illustrate that even background sounds may still hurt speech recognition ability in people with HL who use hearing devices and demonstrate good performance on clinical testing. The reduced sentence and word recognition performance observed in the CI group under the two SNRs, as presented in **Table 2**, illustrates that background sounds have a more negative impact on the CI group compared to the HA and NH groups. In contrast, the HA group, in the +5 dB SNR condition, demonstrated significant performance differences in sentence recognition scores compared to the NH group, while no performance differences were observed at the word level in some conditions, such as PS and PC. Even in the +10 dB SNR condition, significant differences with the NH group were only observed in some conditions, such as PC and babble noise. This infers that even if HA users do not hear all words in a sentence, they could exhibit performance comparable to individuals with NH if they hear keywords within a sentence. In addition, for all testing conditions, the HA group outperformed the CI group, even in the +10 dB SNR condition for PS and PV, where sentence recognition performance did not significantly differ from the NH group. However, in the PC condition, where speech sounds were embedded in the background music, the HA group's sentence and word recognition performance was significantly lower compared to the NH group. For HA users, the relative impact of music on speech perception may not be significantly negative, but for CI users, background music may act as a noise interfering with speech perception. In other words, for HA users, if they are communicating with others in an environment with only instrumental music (no chorus) at +10 dB SNR, they may not experience significant difficulty with speech recognition. Yet, for CI users to engage in communication, they may need to be in an environment that is free from background music or noise. These findings highlight the importance of creating an environment without background noise, especially in places where multi-talker conversations are present, to achieve successful communication with those with HL. This is part of communication strategies that can be used for individuals regardless of the presence of HL to achieve effective communication (Helvik et al., 2007; Stephens et al., 1999; Wilson et al., 1998). According to Tye-Murray et al. 1992, communication strategies include repair strategies, corrective strategies, and anticipatory strategies (Tye-Murray, 1992). Repair strategies are tactics that people can use when they misunderstand words. For example, they could ask the speaker to repeat, simplify, clarify, or rephrase what he or she said. They could also ask the speaker to provide key or specific information. Corrective strategies can be used to modify the speaker's behavior or the communication settings. The listener can ask the speaker to adjust his or her pace and volume of speech. People can also modify the environment, such as having good lighting, reducing any background noise, and talking in the same room. In good light, people can benefit from visual information, such as lip movements, facial expressions, and gestures. Reducing background noise and talking in the same room allow individuals to hear clean signals for communication rather than distorted signals. Lastly, anticipatory strategies involve reviewing potential vocabulary so that individuals can be ready for upcoming conversations. People can also benefit from taking turns in the conversations, paying attention to each other, grabbing the conversational partner's attention before speaking and so on. There are many communication strategies and they have been known to be beneficial for communication, especially for those with HL. In 1999, Stephens and colleagues investigated the most commonly used communication strategy that people with HL utilized among the five communication strategies through questionnaires (avoidance of conversation, interruption, pretending to have heard or understood, asking for repetition, and positioning self in order to hear) (Stephens et al., 1999). The results showed that people with HL used avoidance and request for repetition strategies most frequently, followed by pretending to have heard or understood, positioning self in order to hear, and interruption, in that order. The importance of communication strategy usage has become even more pronounced during the Covid-19 pandemic (Eby et al., 2020; Mansutti et al., 2023; Moon et al., 2022; Seol et al., 2023). During the pandemic, most countries enforced social distancing and mask measures to prevent infection. In this process, individuals with HL experienced greater challenges with communication as visual cues, such as facial expressions and lip movements, were lost and face masks filtered high frequency sounds that are important for speech understanding. Mansutti et al. 2023 examined communication issues that people with HL were experiencing during the pandemic and strategies that people could use to improve communication. Face coverings (i.e., face mask, and face shield etc.), physical and social distancing, and accessibility to information led to communication challenges. The authors mentioned that various strategies could improve communication challenges. For example, for those with HL, utilizing hearing devices (HAs and CIs) could be helpful. Along with ensuring face-to-face communication and avoiding shouting, individuals could also benefit from the use of, such as portable amplifiers (Mansutti et al., 2023). In sum, HL can lead to communication breakdown and delay in speech and language development, so it is vital to engage in the rehabilitation process through HAs and CIs. However, wearing HAs and CIs does not always lead to improved speech understanding. HA and CI users still struggle with understanding speech in noisy environments, and particularly CI users also report difficulties in enjoying and listening to music. This study is meaningful as it investigates speech recognition performance using noises encountered in the real-world, such as music, chorus, and babble. Additionally, to reflect real-world communication settings, sentence and word recognition performance was measured in environments with various listening conditions (+5- and +10 dB SNRs). In most cases, CI users showed lower word and sentence performance compared to HA users and those with NH. Despite showing high performance in speech tests commonly used in clinical settings, with scores of 85%, CI users still struggled to understand sentences and words in the presence of noise and music. Taken together, findings of the study implicate that the longer the duration of HL, the more speech recognition ability tends to decline. Since HL can lead to speech and language development delays in children, it is important to intervene at an appropriate time, but considering the fact that intervention does not always lead to improvement in speech recognition performance and music perception, it is necessary to assess speech recognition ability in various aspects (i.e., background noise and music) and encourage individuals to participate in rehabilitation.

In terms of limitations and future directions, subsequent studies utilizing a higher sample size and incorporating various participant and noise and music characteristics would be beneficial in assessing communication abilities across diverse environments and characteristics. Within music, considering a range of genres and types could be explored and investigating individuals' performance not only at the level of words and sentences but also at the level of phonemes may reveal differences. Currently, there are no tools available to evaluate speech performance using music as background noise. Findings from studies using various types of music could provide data that could aid in the development and standardization of tools for comprehensively investigating the speech and language abilities of individuals with HL in the future. Besides, the use of objective assessments (i.e., electroencephalography) along with subjective measures would provide information about biomarkers that can contribute to individuals' speech recognition performance.

Author Contributions

E.Y.K. and H.Y.S. conceptualized the study, E.Y.K. and S.E.L. conceived the experiments, E.Y.K., and H.Y.S. reviewed the concept. E.Y.K. and S.E.L. conducted the experiments, and E.Y.K.analyzed the results. E.Y.K. wrote the main paper and all authors reviewed the manuscript.

Conflict of Interest

Declaration of conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Funding

This research received no external funding

References

Agelfors, E., 1996. A comparison between patients using cochlear implants and hearing aids. Part I: Results on speech tests. Quarterly Progress and Status Report. 37(1), 63–76.

Anne, S., Lieu, J.E.C., Cohen, M.S., 2017. Speech and language consequences of unilateral hearing loss: a systematic review. Otolaryngol-Head and Neck Surgury. 157(4), 572–579.

DOI: https://doi.org/10.1177/0194599817726326

Bernhard, N., Gauger, U., Romo Ventura, E., et al., 2021. Duration of deafness impacts auditory performance after cochlear implantation: a meta-analysis. Laryngoscope Investigative Otolaryngol. 6(2), 291–301.

DOI: https://doi.org/10.1002/lio2.528

Brandt, A., Gebrian, M., Slevc, L.R., 2012. Music and early language acquisition. Frontier Psychol. 3, 327.

DOI: https://doi.org/10.3389/fpsyg.2012.00327

Bruns, L., Mürbe, D., Hahne, A., 2016. Understanding music with cochlear implants. Scientific Reports. 6(1), 32026.

DOI: https://doi.org/10.1038/srep32026

Ching, T.Y., Crowe, K., Martin, V., et al., 2010. Language development and everyday functioning of children with hearing loss assessed at 3 years of age. International Journal of Speech-Language Pathology. 12(2), 124–131.

DOI: https://doi.org/10.3109/17549500903577022

Cho, Y.S., Park, S.Y., Seol, H.Y., et al., 2019. Clinical performance evaluation of a personal sound amplification product vs a basic hearing aid and a premium hearing aid. JAMA Otolaryngol-Head and Neck Surgury. 145(6), 516-522.

DOI: https://doi.org/10.1001/jamaoto.2019.0667

Cunningham, L.L., Tucci, D.L., 2017. Hearing loss in adults. New England Journal of Medicine. 377(25), 2465–2473.

DOI: https://doi.org/10.1056/NEJMra1616601

Davis, A., McMahon, C.M., Pichora-Fuller, K.M., et al., 2016. Aging and hearing health: the life-course approach. The Gerontologist. 56(Suppl_2), S256–S267.

DOI: https://doi.org/10.1093/geront/gnw033

Denes, P.B., Pinson E.N., 2016. The Speech Chain: The Physics And Biology Of Spoken Language [Internet]. Available from: https://www.google.co.kr/books/edition/The_Speech_Chain/rYnjDAAAQBAJ?hl=en&gbpv=0 (cited 2024 Mar 8).

Diseases, G.B.D., Injuries, C., 2020. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the global burden of disease study 2019. The Lancet. 396(10258), 1204–1222.

DOI: https://doi.org/10.1016/S0140-6736(20)30925-9

Eby, T.L., Arteaga, A.A., Spankovich, C., 2020. Otologic and audiologic considerations for Covid-19. Otolaryngol-Head and Neck Surgury. 163(1), 110–111.

DOI: https://doi.org/10.1177/0194599820928989

Fernald A., 1992. Human maternal vocalizations to in-fants as biologically relevant signals. In: Barkow, J.H., Cosmides, L., Tooby, J. (Eds.). The adapted mind: Evolutionary psychology and the generation of culture. Oxford University Press, USA. pp 391-394.

Flynn, M., Dowell, R., Clark, G., 1996. Speech perception of hearing aid users versus cochlear implantees. The Journal of the Acoustical Society of America. 100(4), 261–265.

DOI: https://doi.org/https://doi.org/10.1121/1.417045

Friederici, A.D., 2006. The neural basis of language development and its impairment. Neuron. 52(6), 941–952.

DOI: https://doi.org/10.1016/j.neuron.2006.12.002

Halliday, L.F., Tuomainen, O., Rosen, S., 2017. Language development and impairment in children with mild to moderate sensorineural hearing loss. Journal of Speech, Language, and Hearing Research. 60(6), 1551–1567.

DOI: https://doi.org/10.1044/2016_JSLHR-L-16-0297

Helvik, A.-S., Jacobsen, G., Svebak, S., et al., 2007. Hearing impairment, sense of humour and communication strategies. Scandinavian Journal of Disability Research. 9(1), 1–13.

DOI: https://doi.org/10.1080/15017410600687073

Jung, K.H., Cho, Y.S., Cho, J.K., et al., 2010. Clinical assessment of music perception in Korean cochlear implant listeners. Acta Oto-laryngol. 130(6), 716–723.

DOI: https://doi.org/10.3109/00016480903380521

Kaandorp, M.W., Smits, C., Merkus, P., et al., 2015. Assessing speech recognition abilities with digits in noise in cochlear implant and hearing aid users. International Journal of Audiology. 54(1), 48–57.

DOI: https://doi.org/10.3109/14992027.2014.945623

Ketterer, M.C., Haussler, S.M., Hildenbrand, T., et al., 2020. Binaural hearing rehabilitation improves speech perception, quality of life, tinnitus distress, and psychological comorbidities. Otology and Neurotology. 41(5), e563–e574.

DOI: https://doi.org/10.1097/MAO.0000000000002590

Kramer, S.E., 2008. Hearing impairment, work, and vocational enablement. International Journal of Audiology. 47(Suppl 2), S124–S130.

DOI: https://doi.org/10.1080/14992020802310887

Laske, R.D., Veraguth, D., Dillier, N., et al., 2009. Subjective and objective results after bilateral cochlear implantation in adults. Otology and Neurotology. 30(3), 313–318.

DOI: https://doi.org/10.1097/MAO.0b013e31819bd7e6

Lesiuk, T., 2005. The effect of music listening on work performance. Psychology of Music. 33(2), 173–191.

DOI: https://doi.org/10.1177/0305735605050650

Lieu, J.E., Kenna, M., Anne, S., et al., 2020. Hearing loss in children: a review. JAMA. 324(21), 2195–2205.

DOI: https://doi.org/10.1001/jama.2020.17647

Looi, V., Gfeller, K., Driscoll, V., 2012. Music Appreciation and training for cochlear implant recipients: a review. Seminars in Hearing. 33(4), 307–334.

DOI: https://doi.org/10.1055/s-0032-1329222

Mansutti, I., Achil, I., Rosa Gastaldo, C., et al., 2023. Individuals with hearing impairment/deafness during the Covid-19 pandemic: a rapid review on communication challenges and strategies. Journal of Clinical Nursing. 32(15–16), 4454–4472.

DOI: https://doi.org/10.1111/jocn.16572

McDaid, D., Park, A.L., Chadha, S., 2021. Estimating the global costs of hearing loss. International Journal of Audiology. 60(3), 162–170.

DOI: https://doi.org/10.1080/14992027.2021.1883197

McMullen, E., Saffran, J.R., 2004. Music and language: a developmental comparison. Music Perception. 21(3), 289–311.

DOI: https://doi.org/10.1525/mp.2004.21.3.289

Meilijson, S., Spitzer, J.B., 2015. The language performance of hearing aid and cochlear implant adult users: a pragmatic approach. Journal of Interactional Research in Communication Disorders. 6(2), 237.

DOI: https://doi.org/10.1558/jircd.v6i2.27310

Møller, A.R., 2012. Hearing: anatomy, physiology, and disorders of the auditory system. Plural Publishing: San Diego.

Mondelli, M.F.C.G., de Souza, P.J.S., 2012. Quality of life in elderly adults before and after hearing aid fitting. Brazilian Journal of Otorhinolaryngology. 78(3), 49–56.

Moon, I.-J., Jo, M., Kim, G.-Y., et al., 2022. How does a face mask impact speech perception? Healthcare. 10(9), 1709.

DOI: https://doi.org/10.3390/healthcare10091709

Moon, I.J., Kim, E.Y., Jeong, J.O., et al., 2012. The influence of various factors on the performance of repetition tests in adults with cochlear implants. European Archives of Oto-Rhino-Laryngology. 269(3), 739–745.

DOI: https://doi.org/10.1007/s00405-011-1699-3

Nasresfahani, A., Dasdar, S., Kianfar, N., et al., 2022. Music appreciation of cochlear implant users versus Normal hearing individuals. Iranian Journal of Otorhinolaryngology. 34(122), 171.

DOI: https://doi.org/10.22038/IJORL.2022.62651.3152

Nikolopoulos, T.P., Archbold, S.M., O'Donoghue, G.M., 1999. The development of auditory perception in children following cochlear implantation. International Journal of Pediatric Otorhinolaryngology. 49 (Suppl. 1), S189–191.

DOI: https://doi.org/10.1016/s0165-5876(99)00158-5

Philips, B., Vinck, B., De Vel, E., Maes, L., D'haenens, W., Keppler, H., Dhooge, I., 2012. Characteristics and determinants of music appreciation in adult CI users. European Archives of Oto-Rhino-Laryngology. 269, 813–821.

DOI: 10.1007/s00405-011-1718-4

Prather, J. F., 2013. Auditory signal processing in communication: perception and performance of vocal sounds. Hearing Research. 305, 144–155.

DOI: https://doi.org/10.1016/j.heares.2013.06.007

Ramus, F., Nespor, M., Mehler, J., 1999. Correlates of linguistic rhythm in the speech signal. Cognition. 73(3), 265–292.

DOI: https://doi.org/10.1016/s0010-0277(99)00058-x

Riley, P.E., Ruhl, D.S., Camacho, M., et al., 2018. Music appreciation after cochlear implantation in adult patients: a systematic review. Otolaryngology–Head and Neck Surgery. 158(6), 1002–1010.

DOI: https://doi.org/10.1177/0194599818760559

Seol, H.Y., Jo, M., Yun, H., et al., 2023. Comparison of speech recognition performance with and without a face mask between a basic and a premium hearing aid in hearing-impaired listeners. American Journal of Otolaryngology. 44(5), 103929.

DOI: https://doi.org/10.1016/j.amjoto.2023.103929

Seol, H.Y., Kim, G.Y., Kang, S., Jo, M., et al., 2021. Clinical Comparison of a hearing aid, a personal sound amplification product, and a wearable augmented reality device. Clinical and Experimental Otorhinolaryngology. 14(3), 359–361.

DOI: https://doi.org/10.21053/ceo.2021.00297

Seol, H.Y., Moon, I.J., 2022. Hearables as a gateway to hearing health care. Clinical and Experimental Otorhinolaryngology. 15(2), 127–134.

DOI: https://doi.org/10.21053/ceo.2021.01662

Siedliecki, S. L., Good, M., 2006. Effect of music on power, pain, depression and disability. Journal of Advanced Nursing. 54(5), 553–562.

DOI: https://doi.org/10.1111/j.1365-2648.2006.03860.x

Stelmachowicz, P.G., Pittman, A.L., Hoover, B.M., et al., 2004. The importance of high-frequency audibility in the speech and language development of children with hearing loss. JAMA Otolaryngology-Head and Neck Surgery. 130(5), 556–562.

DOI; https://doi.org/10.1001/archotol.130.5.556

Stephens, S.D., Jaworski, A., Lewis, P., et al., 1999. An analysis of the communication tactics used by hearing-impaired adults. British Journal of Audiology. 33(1), 17–27.

DOI: https://doi.org/10.3109/03005364000000097

Temperley, D., 2022. Music and language. Annual Review of Linguistics. 8, 153–170.

DOI: https://doi.org/10.1146/annurev-linguistics-031220-121126

Thiessen, E.D., Hill, E.A., Saffran, J.R., 2005. Infant-directed speech facilitates word segmentation. Infancy. 7(1), 53–71.

DOI: https://doi.org/10.1207/s15327078in0701_5

Trainor, L., Trehub, S., 1998. Singing to infants: lullabies and playsongs. Advances in Infancy Research. 12, 43–78.

Tye-Murray, N., 1992. Preparing for communication interactions: the value of anticipatory strategies for adults with hearing impairment. Journal of Speech and Hearing Research. 35(2), 430–435.

DOI: https://doi.org/10.1080/21642850.2014.900450

Wagner-Hartl, V., Grossi, N.R., Kallus, K.W., 2018. Impact of age and hearing impairment on work performance during long working hours. International Journal of Environmental Research and Public Health. 15(1), 98.

DOI: https://doi.org/10.3390/ijerph15010098

Wermke, K., Leising, D., Stellzig-Eisenhauer, A., 2007. Relation of melody complexity in infants' cries to language outcome in the second year of life: a longitudinal study. Clinical Linguistics and Phonetics. 21(11–12), 961–973.

DOI: https://doi.org/10.1080/02699200701659243

Wilson, B.S., Tucci, D.L., Merson, M.H., et al., 2017. Global hearing health care: new findings and perspectives. The Lancet. 390(10111), 2503–2515.

DOI: https://doi.org/10.1016/S0140-6736(17)31073-5

Wilson, J., Hickson, L., Worrall, L., 1998. Use of communication strategies by adults with hearing impairment. Asia Pacific Journal of Speech, Language and Hearing. 3(1), 29–42.

DOI: https://doi.org/10.1179/136132898805577250

World Health Organization [Internet]. Global Costs of Unaddressed Hearing Loss and Cost-Effectiveness of Interventions. Available from: https://www.who.int/publications-detail-redirect/global-costs-of-unaddressed-hearing-loss-and-cost-effectiveness-of-interventions (cited 2024 Mar 8).