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Environmental sound awareness in experienced cochlear implant users and cochlear implant candidates

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Abstract

Objective: To determine if post-lingually deaf adult cochlear implant (CI) users have better environmental sound awareness (ESA) compared to adult patients eligible for CIs who have not yet undergone implantation.

Study Design: Cross-sectional cohort study.

Setting: Tertiary referral center

Patients: A group of 39 post-lingually deaf adult patients who are experienced CI users (ECI), and a group of 20 post-lingually deaf adult patients who are cochlear implant candidates (CIC) awaiting implantation.

Intervention: Cochlear implantation

Main outcome measure: Environmental sound awareness as measured by accuracy (percent correct) using the computerized, Familiar Environmental Sounds Test—Identification (FEST-I).

Results: There was no significant difference between ESA in our sample of ECI users versus CIC patients. The ECI users scored an average FEST-I accuracy of 59.9% (SD 14.3). In comparison, the CICs had an average FEST-I accuracy of 54.7% (SD 26.4). This difference was not statistically significant.

Conclusions: Our findings suggest that, despite the commonly held notion that improved ESA may be a benefit of cochlear implantation, our sample of ECI users did not demonstrate superior performance compared to CICs.

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Conflict of Interest:

Harris (Advanced Bionics consultant)

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INTRODUCTION

Speech perception and environmental sound awareness (ESA) are two domains that patients considering cochlear implantation (CI) expect to improve following device activation.^{1,2} Although ESA, especially for sounds with safety relevance, is an expected benefit of patients receiving CIs, most CI outcomes research has focused exclusively on speech perception, with comparatively little learned about ESA. The benefits of cochlear implants in the domain of ESA remain largely presumed and incompletely understood.^{3,4} Due to the lack of research regarding CI and ESA, it remains difficult for clinicians to appropriately counsel patients and their families regarding expectations in this area.

The notion of ESA benefit following CIs is often extrapolated based on the well-documented benefit of implantation on speech perception. However, fundamental acoustical differences between spoken language and environmental sounds suggest that this approach may be flawed.³⁻⁷ For example, environmental sounds differ from speech because they are often inharmonic, are produced by a wider variety of sources, occur over a broader frequency range, and are often associated with highly discrepant temporal patterns.³⁻⁷

Multiple studies have shown that CI users struggle with environmental sounds.^{3,4,8-10} Inverso and Limb⁸ demonstrated that experienced post-lingually deafened CI users scored 49% correct on the Nonlinguistic Sounds Test (NLST) containing 50 environmental sounds. Shafiro and coauthors⁴, using a different test composed of 60 different sounds, obtained 45% in 17 experienced post-lingual CI users. Harris and colleagues¹¹ demonstrated 61% correct identification accuracy with a smaller 25 sound test, described below, using a sample of 35 experienced CI users. Notably, normal hearing listeners tested with the same environmental sounds as used in each of the above studies demonstrate much higher accuracy of 90 – 100% on average. Thus, compared with normal hearing adults, previous studies consistently indicate deficits in environmental sound perception in experienced post-lingual adult CI users, who often demonstrate clear speech benefits. Interestingly, despite differences in acoustic properties between environmental sounds and speech and discrepant performance on measures of speech perception compared to ESA, several studies have shown a correlation between speech perception and ESA in patients with CIs.^{3,4,8,11}

A major limitation of most previous studies examining ESA in adults with CIs is that CI users' performance was compared either with that of normal hearing young or aged-matched older listeners.^{3,4,8,11} While the findings of these studies indicate poorer performance among CI users, it is unclear whether CI users nevertheless achieve greater ESA than individuals with hearing loss who qualify for CIs but have not been implanted.

We are aware of only a single study in which environmental sound perception was compared directly in CI users and CI candidates using hearing aids. Specifically, Looi and Arnephy³ examined identification of common environmental sounds in 10 experienced CI users and in four pre-implantation CI candidates, who were later implanted. This research relied on an independently developed environmental sound test with 45 sounds, each represented by two different tokens, which were identified with 92.9% accuracy by normal hearing controls. Using this test, Looi and Arnephy³ found 59.3% identification accuracy for experienced CI

users. The four CI candidates tested under the best aided conditions obtained 39.7% correct before implantation and 57.2% correct approximately 3–4 months after the implantation. This difference did not achieve statistical significance ($p < 0.07$).³

The trend toward improved ESA following implantation reported by Looi and Arnephy³ is encouraging but inconclusive, given that only four CI candidates were tested. A better understanding of ESA in CI users compared to CI candidates is needed to aid hearing health professionals in advising patients about the expected benefits of CIs and to provide a further benchmark for the assessment of a patient's postoperative adaptation to a CI. Additionally, understanding the magnitude and scope of ESA benefits is relevant to daily outcomes for CI users, because this ability plays a major role in a patient's safety (e.g., detection an alarm sound or the cry of one's baby) and is one of the reported motivating factors for CI.¹⁰

The purpose of the current study is to address this knowledge gap by examining the effect of CI use on ESA by comparing performance in this domain among adult post-lingual CI users to age-matched post-lingual CI candidates, who had not yet received implants.

MATERIALS AND METHODS

Participants

This study was approved by the Institutional Review Board (IRB) of The Ohio State University. Eligible participants were adults with bilateral severe-to-profound post-lingual sensorineural hearing loss, primary language of American English, and at least a high school level education. Experienced CI users were required to have at least 24 months of CI experience, with a traditional CI (i.e., excluding patients with partial electrode insertions or who received “hybrid” electric-acoustic devices), by which time they should have reached a plateau in speech recognition performance.¹² Participants were evaluated by clinical CI audiologists within 12-months prior to enrollment and were required to have better than 35 dB HL CI-aided thresholds across speech frequencies (0.25, .5, 1, and 2-kHz), ensuring sound detection with their CIs.

Potential participants were excluded from the study if they did not meet these inclusionary criteria. Known history of dementia, stroke, auditory neuropathy, brain tumor, or dyslexia were also grounds for exclusion. A screening test for cognitive impairment (the Mini-Mental State Examination), delivered in a non-auditory fashion, was used to rule out undiagnosed dementia, with all participants being required to score ≥ 26 out of 30. Finally, as the test procedures involved reading words on a computer screen, all participants were required to have 20/50 corrected near vision or better in at least one eye.

Socioeconomic status (SES) was quantified based on a metric consisting of occupational and educational levels.¹³ Two scales represented occupational and education levels, each ranging from 1–8, with 8 being highest. These two numerical scores were then multiplied, resulting in scores between 1 and 64. Table 1 summarizes demographic and audiological characteristics of the ECI users and the CICs. The two groups did not significantly differ in age, SES, and total duration of hearing loss (current age minus age at onset of hearing loss) as revealed by group comparisons with a t-test.

Thirty-nine experienced CI (ECI) users (mean age 67.7 years; range: 50 – 83 years) met these criteria and were enrolled. ECI participants had a mean of 7.3 years (range: 1.5 – 34 years) of CI use. Varying etiologies of sensorineural hearing losses and ages at implantation were included. All participants were found to be candidates for implantation using the clinical sentence recognition criteria in place at the time of implantation: typically sentence recognition scores of 60% or fewer words correct in the best-aided condition, in quiet or in noise. A group of 20 CI candidates (CIC) (mean age 69.1 years; range: 48 – 94 years), were also tested. These participants were post-lingually deaf candidates for CIs with similar characteristics to the ECI group but had not yet undergone implantation.

General Approach

All auditory signals were presented via a computer in an acoustically treated room, through a high-quality loudspeaker positioned 1-meter from the participant at zero degrees azimuth. Visual stimuli were displayed on a computer monitor. During testing, participants wore their CIs and hearing aids in their “everyday” settings. CIC participants wore their own hearing aids or loaner hearing aids when possible. Participants with bilateral CIs wore both during testing, and participants with contralateral hearing aids wore all devices in usual settings.

Familiar Environmental Sound Test – Identification (FEST-I)

The Familiar Environmental Sound Test – Identification (FEST-I) evaluates environmental sound identification skills.¹⁴ The FEST-I uses a closed-set, forced-choice paradigm that requires selection of one out of a total of 25 response alternatives. Figure 1 shows the graphical user interface for FEST-I that the participant sees on the computer monitor while taking the FEST-I. The sounds included on the FEST-I represent a broad sampling of familiar environmental sounds that can be encountered in everyday soundscapes. All stimuli materials have previously been found to be easily identifiable to normal hearing listeners.¹⁴

Statistical Analyses

Statistical analyses were performed using SPSS Statistics (Version 22). Demographic analyses and measures of central tendency were carried out to characterize the sample. An independent-samples *t*-test was performed to compare means of FEST-I scores between ECI users and CICs. Finally, an error analysis was performed using a confusion matrix in order to identify what environmental sounds were commonly confused between groups.

RESULTS

FEST-I Accuracy

Before performing our main analysis of interest, we sought to investigate whether FEST-I performance differed among our ECI participants who were bilateral CI users ($N = 12$), bimodal CI users (CI plus contralateral hearing aid, $N = 14$), and unilateral CI-only users ($N = 13$). There was a significant effect of group ($F(2,36) = 4.03$, $p = .026$), with post-hoc Tukey test demonstrating that this effect was due to significantly poorer performance by unilateral CI users (51.4% correct on FEST-I, $p = .037$). There was no significant difference between bimodal (64.6% correct) and bilateral (63.7% correct) CI users on FEST-I.

Next, individual performance was computed for every participant and compared between the two groups: ECIs and CICs. All ECIs and all but three CIC participants completed the FEST-I task. Three CIC participants could not undergo FEST-I testing due to their hearing loss severity and lack of hearing aid benefit. These three participants were assigned a score of 0% correct on the FEST-I. Our sample of 39 ECI users achieved a mean accuracy score of 59.9% correct (range: 16.0 – 88.0%, SD = 14.3), while the 20 CICs achieved a mean accuracy score of 54.7% correct (range: 0 – 80.0%, SD = 26.4) on the FEST-I. Note that this result was somewhat negatively skewed by the three participants who were assigned the FEST-I score of zero. An independent-samples *t*-test did not show a statistically significant difference between the two groups in regard to FEST-I accuracy ($t(59) = 1.07, p = .29$).

In order to address the concern that there were possibly fundamental differences in baseline pre-operative auditory processing performance between the ECI users and CICs, we reviewed the clinical records for these participants. We compared both the baseline pre-operative best-aided speech perception performance using AzBio sentences in quiet for both ECIs (i.e., when they themselves were being evaluated pre-operatively for CI candidacy) and CICs, as well as their better-ear unaided 4-frequency (0.5, 1, 2, and 4 kHz) pure-tone average (PTA). Unfortunately, pre-operative AzBio scores and PTAs were only available for 23% of the ECI sample. However, comparing best-aided pre-operative AzBio performance for these ECIs (mean accuracy = 31.7%, SD = 23.5) with the 20 CICs (mean accuracy = 33.1%, SD = 26.9), there was no significant difference in pre-operative best-aided speech perception ($t(28) = .14, p = .888$). There was also no significant difference in pre-operative unaided PTA between ECIs (mean PTA = 89.6 dB, SD = 19.9) and CICs (mean PTA = 85.7, SD = 16.9, $t(28) = .54, p = .591$). Interestingly, for the CICs, pre-operative AzBio performance correlated moderately with their scores on the FEST-I ($r = .53, p = .017$).

Error analysis

Confusion matrices computed for both the CIC and ECI groups are presented in Table 2 and Table 3, respectively. Nine of 25 sounds in FEST-I, or 36%, were identified with less than 50% accuracy by participants in both CIC and ECI groups. Seven of the nine poorly identified sounds overlapped between the two groups. These were ‘Alarm ringing’, ‘Footsteps’, ‘Trotting’, ‘Tires screeching’, ‘Seagulls’, ‘Splash’, and ‘Pickup receiver’. Four additional sounds were identified poorly by one, but not the other group. These were ‘Snoring’ and ‘Fog horn,’ identified with less than 50% correct by the CIC participants, and ‘Driving’ and ‘Dial tone,’ identified with less than 50% correct by the ECI participants. The percent accuracy for each individual sound within the two participant groups is shown in Table 4.

The ECI group was most likely to confuse the sound ‘Footsteps’ with ‘Waves crashing,’ ‘Pickup receiver’ with ‘Door closing,’ ‘Seagulls’ with ‘Police siren,’ and ‘Trotting’ with ‘Waves crashing’. The CIC group most often confused the sound ‘Splashing’ with ‘Waves crashing,’ ‘Trotting’ with ‘Waves crashing,’ ‘Crashing’ with ‘Waves crashing,’ and ‘Footsteps’ with ‘Waves crashing’. Both groups commonly mistook various sounds for ‘Waves crashing’ with ECI participants correctly identifying ‘Waves crashing’ 63% of the time and CIC participants doing so 54% of the time. These confusions are likely to have

arisen due to a combination of factors including signal processing performed by the implants, acoustic and semantic characteristics of the test sounds and patients' hearing abilities and perceptual skills. Overall, the overlap in poorly identified sounds between the two groups is consistent with findings of Looi and Arnephy³, who reported similar accuracy trends for CI candidates and CI users with a larger environmental sound test.

DISCUSSION

The present study compared environmental sound identification in experienced CI users with that of CI candidates under their best aided conditions. The key finding of this study is that ECI users did not outperform CICs in identification of isolated environmental sounds. Both groups performed considerably lower than 41 normal hearing and similarly aged older adults in Harris and coauthors¹¹, who achieved 90% average accuracy on the same test of environmental sound perception. The lack of significant difference in ESA between ECI and CIC groups runs contrary to our hypothesis and to longstanding clinical assumptions. Surprisingly, this finding was observed even though the CIC group included three participants with no residual hearing, whose FEST-I scores were zero.

The ESA performance of the current ECI users is very similar to that of the ten ECI users tested by Looi and Arnephy³, who obtained 59.3% correct on a more extensive test of environmental sound identification. The similarity in ECI users' results across the two studies is corroborative, especially given the differences in study periods, implant centers, group sizes and testing materials. On the other hand, the 54.6% correct average performance of the 20 present CIC participants was considerably higher than 39.7% correct performance of the four CIC patients tested by Looi and Arnephy³. The discrepancy in performance of CIC participants in Looi and Arnephy³ and the present study could have resulted from multiple factors, which may have been further influenced by the possibility of idiosyncratic performance associated with such small sample. Several factors that may have affected the performance of the CIC group in the present study and may have contributed to the lack of significant differences between the ECI and CIC groups are considered below.

First, the four CIC participants in Looi and Arnephy³ study may be different in their general auditory abilities from the present CIC group. It is conceivable that more conservative criteria for implantation were used at the time of that study, resulting in lower baseline scores for their four CIC patients. Similarly, in the cross-sectional design of the present study with two independent groups of ECIs and CICs, perhaps there existed some fundamental differences between the two groups' baseline pre-operative auditory processing performance. To address this concern, clinical records were reviewed for baseline pre-operative aided AzBio sentence scores and unaided PTAs for both the ECIs and CICs. Based on these comparisons, it does not appear to be the case that the current CICs demonstrated better pre-operative auditory performance than the ECI participants had prior to implantation. Nevertheless, this conclusion remains tentative and needs to be further corroborated with the same group of patients whose ESA skills are evaluated before and after implantation.

A second consideration is that isolated environmental sound testing, as assessed in this study using the FEST-I, may provide only a skewed representation of environmental sound awareness in these listeners, with limited ecological validity. In real-world listening environments, environmental sounds often have situational clues and occur in contexts that serve to narrow the set of potential sound sources the listener might consider. Related to this point, Altieri¹⁵ recently proposed the addition of multisensory cues to an environmental sound training program reported by Shafiro and colleagues.¹⁶ Drawing from experience reported in the literature on therapy for aphasic patients, Altieri¹⁵ proposed a “hierarchical cueing” approach as a more ecologically valid method of driving brain reorganization. Similarly, in the assessment of CIs’ effects on ESA, the addition of more context cues may potentially result in a different pattern of findings between ECIs and CICs.

Although no apparent benefit in ESA was seen with cochlear implantation in our sample, it is possible that CIs provide ESA benefit for subsets of patients who do not derive any benefit from any type of hearing assistive devices or hearing aids. All, except three, CIC participants in our sample used hearing aids for testing. However, there were three patients in the CIC group who had previously failed a hearing aid trial and, therefore, were completely unaided and unable to complete the FEST-I testing. These participants might conceivably have a greater improvement in their ESA scores after their sensory access to sound is restored following implantation. The present findings suggest that implantation may not necessarily lead to improved ESA for the majority of the CI candidates, who continue to benefit from hearing aids. Nevertheless, there is a possibility that ESA may improve more for patients with more severe hearing losses who do not receive any benefit from amplification.

The findings from this study challenge the assumption that CI leads to improved ESA along with the well-documented improvements in speech perception. As previously mentioned, there are substantial differences between spoken language and environmental sounds.^{3–7} Even though in several studies ESA has been found to correlate with speech perception abilities in patients with CIs,^{3,4,8,11} the magnitude of the improvement in speech perception appears to be much greater than that for ESA.

In addition to the considerations mentioned earlier in this discussion, the findings raise another question: Could CI patients benefit from some form of formal ESA training following implantation? Previous research suggests that they can. Several studies, using CI simulations, showed significant improvements in ESA following environmental sound training with feedback.^{9,17,18} A similar result was observed by Shafiro et al.¹⁶ with ECI users. Considering our unexpected result and the importance that ESA plays in safety, additional training to optimize the benefits of CIs is something that warrants further investigation.

This study has some significant limitations that should be considered. First, the sample sizes of both groups, particularly the CIC group, were relatively small. Second, due to cross-sectional study design, differences between CIC and ECI groups could have contributed to the similar ESA performance. Although pre-operative speech perception abilities were similar between the CIC and a subsample of ECI groups, the possibility that a fuller analysis may have revealed inherent differences in preoperative performance of the two groups could

not be ruled out. This expectation is supported by the knowledge that over the years cochlear implantations have been performed in patients with greater degrees of residual hearing. Thus, applying our findings to the larger population of CI candidates and CI users should be done cautiously.

CONCLUSION

Although many patients undergo cochlear implantation with the anticipation of improving their environmental sound awareness along with speech perception, very limited data have been available to evaluate the assumption that CI use leads to improved ESA. Unlike the well-documented benefits of CI use on speech perception, the effect of CI use on ESA is not well-understood, making it difficult for clinicians to provide adequate guidance to patients in this regard. The present study was designed to address this gap in our current knowledge about ESA. No significant difference in ESA was observed between experienced CI users and CI candidates under their best aided conditions. This result was surprising, considering the well-documented benefits of CIs for speech perception abilities. The findings of the present study may enable clinicians to provide more informed guidance regarding the realistic impact of CIs on ESA and enable the development of appropriate rehabilitation strategies for environmental sound perception. The current findings further suggest that additional research is needed to determine the factors that lead to improved environmental sound awareness in CI users. These may include the development of more ecologically relevant testing and training materials and determining acoustic and signal processing parameters and patient characters that influence ESA.

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REFERENCES

1. Tyler RS, Kelsay D. Advantages and disadvantages reported by some of the better cochlear-implant patients. *Am J Otol.* 1990; 11(4): 282–9. [PubMed: 2399950]
2. Zhao F, Stephens SD, Sim SW, Meredith R. The use of qualitative questionnaires in patients having and being considered for cochlear implants. *Clin Otolaryngol Allied Sci.* 1997; 22(3): 254–9. [PubMed: 9222632]
3. Looi V, Arnephy J. Environmental sound perception of cochlear implant users. *Cochlear Implants Int.* 2010; 11(4): 203–27. [PubMed: 19882594]
4. Shafiro V, Gygi B., Cheng M, Vachhani J, Mulvey M Perception of environmental sounds by experienced cochlear implant patients. *Ear and Hear.* 2011; 32: 511–523.
5. Shafiro V Identification of environmental sounds with varying spectral resolution. *Ear Hear.* 2008a; 29(3): 401–20. [PubMed: 18344871]
6. Lewis JW, Wightman FL, Brefczynski JA, Phinney RE, Binder JR, DeYoe EA, Human brain regions involved in recognizing environmental sounds. *Cereb Cortex.* 2004; 14(9): 1008–21. [PubMed: 15166097]
7. Houix O, Lemaitre G, Misdariis N, Susini P, Urdapilleta I. A lexical analysis of environmental sound categories. *J Exp Psychol Appl.* 2012; 18(1): 52–80. [PubMed: 22122114]

8. Inverso Y, Limb CJ. Cochlear implant-mediated perception of nonlinguistic sounds. *Ear Hear.* 2010; 31(4): 505–14. [PubMed: 20588119]
9. Loebach JL, Pisoni DB. Perceptual learning of spectrally degraded speech and environmental sounds. *J Acoust Soc Am.* 2008; 123(2): 1126–39. [PubMed: 18247913]
10. Reed CM, Delhorne LA. The reception of environmental sounds through wearable tactual aids. *Ear Hear.* 2003; 24(6): 528–38. [PubMed: 14663352]
11. Harris MS, Boyce L, Pisoni DB, Shafiro V, Moberly AC.. *Otol Neurotol.* 2017; 38(9): e308–e314. doi: 10.1097/MAO.0000000000001. [PubMed: 28731964]
12. Lenarz M, Sonmez H, Joseph G, Buchner A, Lenarz T. Long-term performance of cochlear implants in postlingually deafened adults. *Otol Head and Neck Surg.* 2012;147(1): 112–118.
13. Nitttrouer S, Burton LT. The role of early language experience in the development of speech perception and phonological processing abilities: evidence from 5-year-olds with histories of otitis media with effusion and low socioeconomic status. *J Commun Disord.* 2005; 38(1): 29–63. [PubMed: 15475013]
14. Shafiro V, Sheft S, Norris M, et al. Toward a nonspeech test of auditory cognition: semantic context effects in environmental sound identification in adults of varying age and hearing abilities. *PLOS ONE.* 2016;11(11): e0167030 <https://doi.org/10.1371/journal.pone.0167030> [PubMed: 27893791]
15. Altieri N Commentary: environmental sound training in cochlear implant users. *Front Neurosci.* 2017; 11: 36. [PubMed: 28203144]
16. Shafiro V, Sheft S, Gygi B, Ho KT. The influence of environmental sound training on the perception of spectrally degraded speech and environmental sounds. *Trends Amplif.* 2012; 16(2): 83–101. [PubMed: 22891070]
17. Shafiro V Development of a large-item environmental sound test and the effects of short-term training with spectrally-degraded stimuli. *Ear and Hear.* 2008b; 29: 775–790.
18. Shafiro V, Sheft S, Kuvadia S, Gygi B. Environmental sound training in cochlear implant users. *J of Speech Lang Hear Res.* 2015; 58(2): 509–19. [PubMed: 25633579]

Figure 1. Screenshot of FEST-I response screen. Shows what a study participant would be looking at as they hear the environmental sounds.

Table 1.

Participant demographics for experienced cochlear implant (ECI) and cochlear implant candidate (CIC) participants. *t* values and *p* values for independent-samples *t*-tests are shown.

	ECI (<i>N</i> = 39)		CIC (<i>N</i> = 20)		<i>t</i> value	<i>p</i> value
	Mean	(SD)	Mean	(SD)		
Demographics						
Age (years)	67.7	(9.6)	69.1	(12.4)	.47	.638
SES	26.3	(14.3)	25.8	(15.1)	.12	.909
Duration of deafness	40.0	(19.4)	33.4	(13.2)	1.37	.177
Duration CI use	7.2	(6.9)	---	---	---	---

Note: SD: Standard deviation; CI: Cochlear implant; SES: Socioeconomic status. SES is the product of educational and occupational metrics based on Nittrouer & Burton, 2005.

Table 2.

Familiar Environmental Sound Test - Identification (FEST-I) accuracy scores for experience cochlear implant (ECI) and cochlear implant candidate (CIC) groups. *t* values and *p* values for independent-samples *t*-tests are shown.

	<u>ECI (N = 39)</u>		<u>CIC (N = 20)</u>			
	Mean	(SD)	Mean	(SD)	<i>t</i> value	<i>p</i> value
FEST-I accuracy (% items correct)	59.9	(14.3)	54.7	(26.4)	.99	.329

Confusion matrix for cochlear implant candidates (CIC). The stimuli sounds presented to CIC participants are listed in the first column. Top row contains response sound names given to each sound heard. Cell values represent proportion correct for each stimulus-response combination.

Table 3.

	CIC Incent Response																			
	alarm ringing	barking	birds chirping	busy signal	crashing	dial tone	dialing	dog panting	door closing	doorbell	driving	fog horn	foot steps	honking	phone ringing	pickup receiver	police siren	rooster	seagulls	snoring
alarm ringing	0.11	-	-	-	-	0.05	0.05	-	-	0.11	0.05	-	-	-	0.16	-	-	-	-	0.16
barking	-	0.63	-	-	-	-	-	0.16	0.05	-	-	-	-	-	-	-	-	-	-	-
birds chirping	-	-	0.53	-	0.05	-	-	-	-	0.05	-	0.05	-	-	-	0.05	0.05	-	-	-
busy signal	0.05	-	-	0.79	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-
crashing	-	-	-	-	0.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
dial tone	-	-	-	0.11	-	0.63	-	-	-	-	-	0.11	-	-	0.05	-	-	-	-	-
dialing	-	-	0.05	0.05	-	0.05	0.63	-	-	-	-	-	-	-	-	0.05	-	-	-	-
dog panting	-	-	0.05	-	-	-	-	0.68	-	-	-	-	0.11	-	-	-	-	0.05	-	-
door closing	-	-	-	-	-	-	-	-	0.84	-	-	-	-	-	-	-	-	-	-	-
doorbell	0.05	-	-	-	-	-	-	-	-	0.79	-	-	-	-	-	-	-	-	-	-
driving	-	-	-	-	-	-	-	-	-	-	0.42	0.11	-	-	-	-	-	-	-	0.05
fog horn	-	-	-	-	-	-	-	-	-	-	-	0.84	-	-	-	-	-	-	-	-
footsteps	-	-	-	-	0.05	0.05	0.11	-	-	-	0.11	-	0.32	-	-	-	-	-	-	-
honking	-	-	-	-	-	-	-	-	-	-	-	0.05	-	0.84	-	-	-	-	-	-
phone ringing	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	0.68	-	0.05	-	-	-
pickup receiver	-	-	-	0.05	-	-	-	-	0.26	-	-	0.05	0.16	-	-	0.37	-	-	-	-
police siren	-	-	-	-	-	-	-	-	-	-	-	0.05	-	0.05	-	-	0.74	-	-	-
rooster	-	-	-	-	-	-	-	-	-	0.11	-	-	-	-	-	-	0.79	-	-	-
seagulls	-	-	0.16	-	0.05	-	-	-	0.05	-	0.05	-	-	-	-	-	0.05	-	0.26	-
snoring	-	0.05	-	-	0.05	-	-	-	0.11	-	-	-	0.05	-	-	0.05	-	0.05	-	0.47
splash	-	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-
tires screeching	0.11	-	-	-	0.16	-	-	-	-	-	-	-	-	-	-	-	-	-	0.11	-
troutling	-	-	-	-	-	-	-	-	-	-	0.05	-	0.21	-	-	0.05	-	-	0.11	-
waves crashing	-	-	-	-	0.05	-	-	-	-	-	0.11	-	0.05	-	-	-	-	-	-	-
yawning	-	-	-	-	-	-	-	-	0.05	-	-	0.05	-	0.05	-	-	-	-	0.11	-

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Table 4.

Confusion matrix for experienced cochlear implant (ECI) participants. The stimuli sounds presented to ECI participants are listed in the first column. Top row contains response sound names given to each sound heard. Cell values represent proportion correct for each stimulus-response combination.

	CIC Indent Response																			
	alarm ringing	barking	birds chirping	busy signal	crashing	dial tone	dialing	dog panting	door closing	doorbell	driving	fog horn	foot steps	honking	phone ringing	pickup receiver	police siren	rooster	seagulls	snoring
	alarm ringing	0.11	-	-	-	0.05	0.05	-	-	0.11	0.05	-	-	-	0.16	-	-	-	-	0.16
	barking	-	0.63	-	-	-	-	0.16	0.05	-	-	-	-	-	-	-	-	-	-	-
	birds chirping	-	-	-	0.05	-	-	-	-	0.05	-	0.05	-	-	-	0.05	0.05	-	-	-
	busy signal	0.05	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	crashing	-	-	-	0.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	dial tone	-	-	-	-	0.63	-	-	-	-	-	0.11	-	-	0.05	-	-	-	-	-
	dialing	-	-	-	-	0.05	0.63	-	-	-	-	-	-	-	-	0.05	-	-	-	-
	dog panting	-	-	0.05	-	-	-	0.68	-	-	-	-	0.11	-	-	-	-	0.05	-	-
	door closing	-	-	-	-	-	-	-	0.84	-	-	-	-	-	-	-	-	-	-	-
	doorbell	0.05	-	-	-	-	-	-	-	0.79	-	-	-	-	-	-	-	-	-	-
	driving	-	-	-	-	-	-	-	-	-	0.42	0.11	-	-	-	-	-	-	-	0.05
	fog horn	-	-	-	-	-	-	-	-	-	-	0.84	-	-	-	-	-	-	-	-
	footsteps	-	-	-	-	0.05	0.11	-	-	-	0.11	-	0.32	-	-	-	-	-	-	-
	honking	-	-	-	-	-	-	-	-	-	-	0.05	-	0.84	-	-	-	-	-	-
	phone ringing	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.68	-	0.05	-	-	-
	pickup receiver	-	-	-	0.05	-	-	-	0.26	-	-	0.05	0.16	-	-	0.37	-	-	-	-
	police siren	-	-	-	-	-	-	-	-	-	-	0.05	-	0.05	-	-	0.74	-	-	-
	rooster	-	-	-	-	-	-	-	-	0.11	-	-	-	-	-	-	0.79	-	-	-
	seagulls	-	-	-	0.05	-	-	-	0.05	-	0.05	-	-	-	-	-	0.05	-	0.26	-
	snoring	-	0.05	-	0.05	-	-	-	0.11	-	-	-	0.05	-	-	0.05	-	0.05	-	0.47
	splash	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-
	tires screeching	g 0.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.47	-	-
	troutling	-	-	-	-	-	-	-	-	-	0.05	-	0.21	-	-	-	-	-	0.11	-
	waves crashing	-	-	-	-	-	-	-	-	-	0.11	-	0.05	-	-	0.05	-	-	-	-
	yawning	-	-	-	-	-	-	-	0.05	-	-	0.05	-	0.05	-	-	-	-	-	0.11

Table 5.

Average percent accuracy on each individual sound by experienced cochlear implant (ECI) users and cochlear implant candidates (CICs). Table is organized from sound most commonly identified accurately to least commonly identified accurately within each respective group of patients.

ECI			CIC	
Sound	Average Percent Correct		Sound	Average Percent Correct
Doorbell	87%		Doorbell	84%
Honking	85%		Honking	84%
Barking	82%		Rooster	79%
police siren	82%		busy signal	79%
busy signal	79%		Driving	79%
Snoring	77%		police siren	74%
Rooster	74%		door closing	68%
door closing	74%		phone ringing	68%
fog horn	72%		Barking	63%
phone ringing	69%		Dialing	63%
Yawning	67%		dog panting	63%
birds chirping	64%		waves crashing	63%
Crashing	62%		Yawning	63%
dog panting	62%		Crashing	58%
waves crashing	54%		dial tone	58%
Dialing	54%		Birds chirping	53%
alarm ringing	46%		Snoring	47%
Driving	41%		Splash	47%
pickup receiver	38%		fog horn	42%
dial tone	36%		pickup receiver	37%
Splash	33%		Footsteps	32%
Seagulls	33%		seagulls	26%
tires screeching	31%		tires screeching	26%
Trotting	21%		Trotting	21%
Footsteps	13%		Alarm ringing	11%