Noise Attenuation Effects on Speech Recognition of Cochlear Implant Users Inside Helicopters

Juliana Maria Araujo Caldeira; Maria Valéria Schmidt Goffi-Gomez; Rui Imamura; Ricardo Ferreira Bento

BACKGROUND: The speech recognition levels of cochlear implant (CI) users are still incompatible with ICAO hearing requirements for civil aviation pilots testing in the noisy background condition of the helicopter cockpit. In this study, we evaluated noise attenuation effects on speech recognition in the same background condition.

METHODS: The study involved the evaluation of 12 Portuguese-speaking CI users with post-lingual deafness and with a pure tone average up to 35 dB HL between 500 and 2000 Hz and up to 50 dB at 3000 Hz on at least one of the ears, and of three normal hearing pilots (controls). We performed speech recognition tests using sentences, numbers, and disyllables for all participants through the VHF radio. The assessment took place inside a helicopter with engine on, using three setups: 1) with headset without the active noise cancellation; 2) activating the noise cancellation system of the headset itself; and 3) connecting the speech processor directly to the helicopter radio system.

RESULTS: The headset active noise-cancellation improved only the recognition of sentences. The direct connection system compared to the headset without anti-noise attenuation significantly improved all the recognition tests. The median for numbers was 90%, but the best score for disyllables recognition was 56%.

DISCUSSION: The noise attenuation resources proposed in this study improved the CI users' speech recognition when exposed to the noisy helicopter cockpit. However, speech recognition of CI users still did not meet the standards of ICAO, which requires at least 80% for understanding disyllables in the speech in noise test.

KEYWORDS: cochlear implant, aviation medicine, hearing loss, noise attenuation, helicopter.

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Speech recognition is influenced by a combination of acoustic, linguistic, semantic, and circumstantial clues, but there is a decrease in the acoustic cues of the message for listening situations in noisy environments.[7,15] Advances in technology have allowed an improvement of signal processing strategies in cochlear implants (CI), which allows better performance in speech comprehension.[6,8] However, to recognize and understand the speech signal in the presence of noise has been the most frequent difficulty for users of these devices.[18]

In a previous study we found that the speech recognition levels of CI users were incompatible with hearing requirements established by the International Civil Aviation Organization (ICAO) for civil aviation pilots in the speech in noise tests.[3] Noise-canceling headsets can improve speech comprehension in noisy situations. The shells of the headsets are capable of blocking some high-frequency noise; however, active noise cancellation is necessary to reduce low-frequency noise.[21] The combination of active and passive attenuation provides a substantial attenuation of about 15 to 25 dB A at all audible frequencies.[20] The CI offers the appeal of external noise cancellation through a specific cable connection between the speech processor and external audio devices, such as mobile phones, portable CD players, and MP3 players.[5,17] In this way the anti-noise system of the headset and a direct connection of the CI to an audio device could improve the CI users' performance in a noisy situation such as the helicopter cockpit.

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The objectives of this study were as follows. 1) To assess whether there may be an improvement in speech intelligibility of CI users in the noisy helicopter cockpit through two resources of noise attenuation: 1.1) activating the system of noise suppression of the headset; and 1.2) activating a direct connection between the speech processor with the radio helicopter system. 2) To identify whether CI users, using the noise attenuation mechanisms proposed in this study, achieve speech recognition levels required by ICAO prerequisites for common avionics pilots in the noisy background condition of the helicopter cockpit.

METHODS

Subjects

Our sample comprised 12 Portuguese-speaking CI users (non-pilots) with postlingual deafness and at least 3 yr of implant experience. All had aided (sound field) pure tone averages up to 35 dB at 500, 1000, and 2000 Hz and up to 50 dB at 3000 Hz, as required for pilots. The distributions of the CI users with respect to the etiology of deafness and the device model are displayed in **Table I**. This study was approved by the Ethics Committee of the University of São Paulo School of Medicine (294.148/2013).

Procedure

The headset was positioned right over the external component of the implant. We had unilateral and bilateral users, and for the latter, the best ear was chosen for testing, disconnecting the contralateral device (monaurally) to standardize the sample. We also tested three normal-hearing pilots (controls) who used both ears (binaurally), their actual situation in flight. It was not our objective to statistically compare results between the control group (binaurally) and CI users (monaurally). Our intention was to compare the auditory performance of the same sample (CI users) in different situations and the responses of control pilots served for protocol validation and to set up reference values. In this way we assessed the sample in three groups inside the helicopter (AS350 B2 Airbus Helicopter – PP-JBB, serial No. 7155, TPX/SAE, 2011 – Helimarte Air Taxi Company), each with four CI users and one pilot, who were all tested at the same time. The helicopter remained on the ground with the engine on all the time, running at 380 rpm, and the sound level in the cockpit varied from 92.0 to 97.7 dB (A) (hand-held analyzer type 2250, Brüel & Kjær®, Nærum, Denmark). All subjects performed Brazilian Portuguese speech recognition tests presented through recorded lists of sentences, numbers, and disyllabic words (in increasing order of difficulty as recommended by the ICAO) and transmitted through radio communication (VHF compact radio, Icom®, IC-A14, Osaka, Japan) in each of the following three conditions: 1) first we evaluated their performance using the headset with anti-noise system off; 2) then, activating the anti-noise system of the headset itself; and finally, 3) dispensing with the headphones and connecting the speech processor directly to the radio system of the helicopter. For this latter situation, specific plug-in connectors to the helicopter radio system (output of David Clark headphones, Worcester, MA, USA) were adapted to fit the audio jack of the cochlear implant.

The listening tests were recorded by a male Portuguese speaker using a digital recorder (Samson®) associated with a versatile PC (Apple® Macbook Pro) inside a soundproof booth. Arrangements of 10 sentences (phonetically balanced) were recorded in the Portuguese language to be applied in an open setting, as depicted by Costa et al.[4] Recordings with 10 random numbers were dictated, as used in aeronautical communication, with the numbers pronounced separately when composed of two digits (e.g., 10 = one zero). We also used 25-dissyllables lists.[11] None of the lists used was repeated across conditions. The transmission of the recorded speech recognition tests was brought out through the mobile phone (Apple® iPhone 5C) and the mobile phone was connected to the VHF compact radio.

The headsets for all participants were calibrated prior to each test run, with the engine off, using a model made with an empty Styrofoam ball with two parallel gaps to mimic a head with ears and a third inferior opening to allow the insertion of the receiver of the sound level meter. This model was chosen to

Table I. Demographic Distribution of Sample.

SUBJECTS	ETIOLOGY	IC MODEL	SPEECH CODING STRATEGY	AGE AT IMPLANTATION	TIME OF DEPRIVATION (YEARS)	IMPLANT USE TIME (YEARS)
1	Autoimmune	Nucleus CI24RECA	ACE	32	2	7
2	Chronic otitis media	Nucleus 24K	ACE	49	14	10
3	Idiopathic	Nucleus CI24RECA	ACE	31	13	11
4	Idiopathic	Medel Combi 40+	FSP	50	2	3
5	Idiopathic	Medel Sonata	FS4	25	15	6
6	Idiopathic	Medel Combi 40+	FSP	47	3	3
7	Meningitis	Medel Sonata	FS4	74	1	4
8	Meningitis	Medel Sonata	FS4	14	10	17
9	Meningitis	Nucleus CI24RECA	ACE	47	3	7
10	Otosclerosis	Nucleus CI24RECA	ACE	61	4	3
11	Ototoxicity	Medel Sonata	FS4	55	25	5
12	Mumps	Nucleus CI24RECA	ACE	35	25	4

CI, cochlear implant; ACE, advanced combination encoder; FSP, fine structure processing; FS4, fine structure 4.

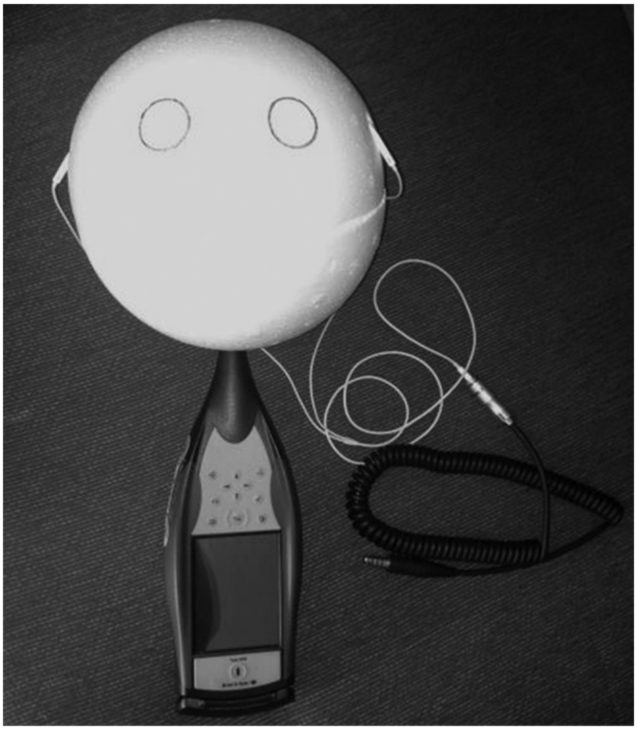

Fig. 1. Cable test for the direct connection system. The receiver of the sound level meter was inside the empty ball of Styrofoam with two holes that simulate a head with ears where plug-type headphones were positioned.

confirm the stability of the transmission among the six headsets using standard white noise, which resulted in a sound level difference lower than 2 dB (A).

To standardize the presentation level of the recorded lists for speech recognition tests for the three groups, the volume on the helicopter cockpit board was fixed to the position that allowed an output of LAeq = 70 dB (A) (± 4 dB) from the three transducers (helicopter headsets, mobile phone, and VHF radio). For this calibration, the volumes of the transducers were set at the highest volume setting with the sound level meter inside the Styrofoam ball, still with the engine off. Considering the passive attenuation of the headsets to be around 15 dB,[9] our calculated signal-to-noise ratio with anti-noise system off was approximately −15 dB: 97.7 dB noise measured outside the model (engine on) – 15 dB of passive attenuation – 70 dB presentation level. Transmission through the four cables with adapters for the direct connection between the CI and the helicopter radio system was also standardized. We used another Styrofoam ball with smaller lateral holes for attachment of plug-type headphones which had the same type of audio cable connector as cochlear implants (**Fig. 1**). The same white noise recording was reproduced, ranging from 68.1 dB A to 70.9 dB A between the four cables with adapters in the four audio outputs of the rear seats of the aircraft.

Because of the loud environment, verbal repetition of responses was impractical, so subjects were asked to write down their responses, as they understood them, on a provided tablet. When testing was finished, verbal responses were individually recorded in order to confirm what was written, thus eliminating the possibility of a handwriting misunderstanding. We scored the sentences completely correct.

Statistical Analysis

The nonparametric Friedman test was used to compare speech recognition under the three test conditions (headset with anti-noise system off, headset with anti-noise system on, and direct connection) for the CI user group. When the global test was significant, pairs of data were statistically analyzed using the post hoc Nemenyi test with the R (version 3.5.1) and R Studio (version 1.1.456) software. Level of significance was set at 0.05 for all the analyses.

RESULTS

Table II displays major impairment in understanding for sentences, numbers, and disyllables in the helicopter with the anti-noise system off, with progressive improvement as exposure to noise was reduced through the headset anti-noise system, and later through a direct connection to the radio system of the helicopter. When the anti-noise system of the headset was activated, we detected improvement of sentence recognition, although the difference was not significant ($P = 0.064$). However, the direct connection of the CI to the helicopter radio

Table II. Speech Recognition Tests of Cochlear Implant Users Under Different Test Conditions.

	CONDITION			GLOBAL TEST	PAIRWISE COMPARISONS (*)		
	ANTI- NOISE SYSTEM OFF (A)	ANTI-NOISE SYSTEM ON (B)	DIRECT CONNECTION (C)	FRIEDMAN	A × B	A × C	B × C
Sentences							
Median (IQR)	0% (10%)	15% (32.5%)	35% (33%)	<0.001	0.064	0.003	0.564
Min-max	0–30%	0–60%	0–70%				
Numbers							
Median (IQR)	40% (65%)	60% (35%)	90% (20%)	0.012	0.755	0.022	0.128
Min-max	0–90%	0–100%	60–100%				
Disyllables							
Median (IQR)	8% (25%)	16% (16%)	44% (29%)	0.015	0.629	0.016	0.158
Min-max	0–52%	0–48%	4–56%				

IQR, interquartile range; min, minimum; max, maximum; (*), pairwise comparisons using the Nemenyi test.

system significantly improved the sentence recognition tests compared to the anti-noise system off condition ($P = 0.003$) (Table II; **Fig. 2**).

The performance with the numbers did not improve significantly with the activation of the headset anti-noise system ($P = 0.755$). On the other hand, the direct connection brought a significant gain compared to no anti-noise system ($P = 0.022$) (Table II; **Fig. 3**). Similar results were observed in the disyllables recognition test, with no significant improvement with the activation of the anti-noise system of the headset ($P = 0.629$). However, the direct connection significantly improved the performance for disyllables ($P = 0.016$) (Table II; **Fig. 4**). Nevertheless, the best score of disyllables recognition in any condition was 56%.

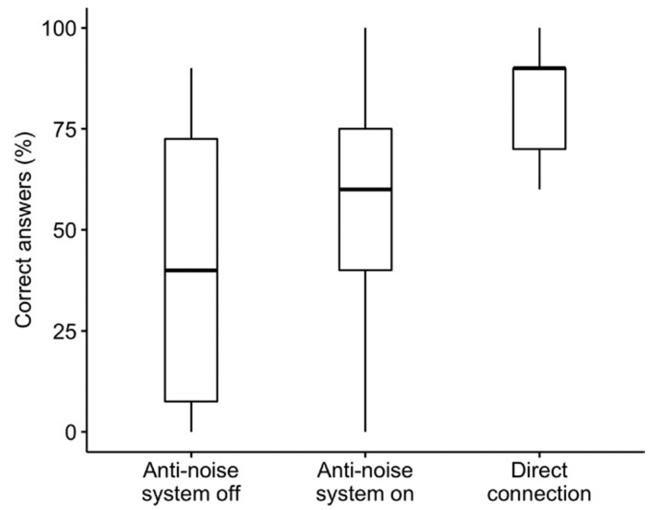

Fig. 3. Recognition of numbers with the anti-noise system off, with the anti-noise system on, and with the direct connection of the CI to the helicopter radio system condition.

DISCUSSION

In this study, we evaluated whether there was an improvement in the speech recognition of CI users in the helicopter cockpit environment using radio communication with noise attenuation mechanisms. According to ICAO, applicants who do not meet the requirements of pure tone thresholds must be submitted to a speech in noise test that reproduces the flight cockpit for which the flight license is being requested. Alternatively, a practical hearing test conducted in flight in the cockpit of an aircraft of the type for which the applicant's license and ratings are valid may be used.[14]

The hearing loss criteria for pilots are not uniform internationally. Our sample probably could fit one of the U.S. Federal Aviation Administration (FAA) standards,[24] for example. But considering that the auditory thresholds were reached through CI auditory rehabilitation, and even though the CI user may meet the audiometric threshold criteria required for pilots, speech recognition through a VHF radio and the in-flight noise conditions may not be adequate for safe communication in a real flight. Although our sample met, at least in one ear, the thresholds recommended by ICAO (up to 35 dB at 500, 1000, or 2000 Hz frequencies; and up to 50 dB at 3000 Hz), we observed in a previous study[3] that these CI subjects did not achieve the levels of speech recognition required for pilots in a noisy helicopter situation.

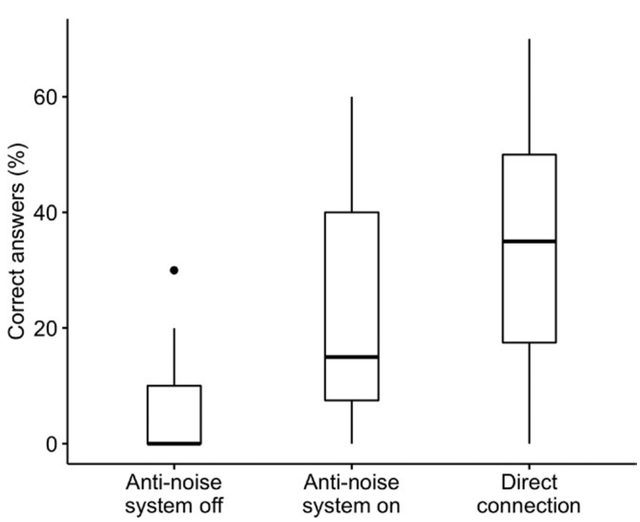

Fig. 2. Recognition of sentences with the anti-noise system off, with the anti-noise system on, and with the direct connection of the CI to the helicopter radio system condition. The black dot indicates an outlier.

Speech recognition is still a challenge to be overcome by CI users, especially when exposed to noise.[16,19,27] Our study was very demanding since we opted for tests in the noisy helicopter environment, presented at a signal-to-noise ratio of approximately −15 dB with the anti-noise system off.

Despite this unfavorable situation, it is noteworthy that speech recognition improved with the direct connection. The median recognition for sentences without the activation of the anti-noise system of the headset was zero, reaching 35% in the direct connection situation ($P < 0.05$). The median for the disyllables also improved from 8 to 44% ($P < 0.05$). Number understanding was the least compromised, improving from 40 to 90% ($P < 0.05$) in the most favorable situation in the noisy environment (direct connection). In this way, we expect better results with the direct connection to the helicopter radio system if CI users have a better baseline performance in noise with CI technological advancements.

The activation of the headset's anti-noise system did not lead to significant improvement for any test. We considered that this kind of noise attenuation was not enough to overcome the difficulty of CI users understanding radio communication in very noisy conditions. In fact, cochlear implant users may perform at 75% of speech recognition at +5 to +7 dB of signal-to-noise ratio.[8] Speech recognition in CI users did not meet the international standards of ICAO, which requires a set of at least 80% of speech recognition for disyllables in an aircraft noise intelligibility test,[14] even with the noise attenuation mechanisms presented in this study. However, the majority of CI users (8/12) reached 80% or more for number understanding in the direct connection situation. Our sample consisted of CI users from

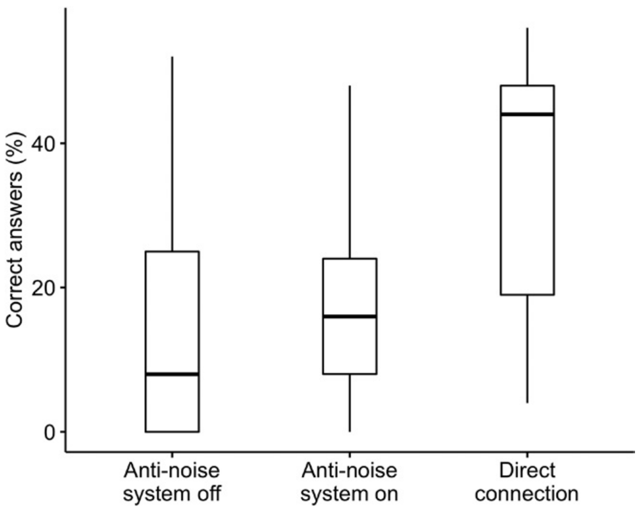

Fig. 4. Recognition of disyllables with the anti-noise system off, with the anti-noise system on, and with the direct connection of the CI to the helicopter radio system condition.

different cultural backgrounds. Undoubtedly, the experience of pilots with many hours of flight is of great importance in radio intelligibility. An intelligibility test based on aviation jargon used in radiotelephony communications resulted in excellent hearing discrimination (99–100%) even for the ears with a maximum discrimination of 65–70% in the audiometric speech test.[25] We speculate that pilot CI users, in the face of familiar aviation jargon, who are also more used to listening to radio communication, could have satisfactory understanding on the disyllable test or even in a practical hearing test conducted in a flight cockpit of an aircraft using the direct connection of the CI to the helicopter radio system.

Additionally, aviation has evolved its communication system through controller-pilot data link communication (CPDLC). It uses universal text messages, including a series of authorization, information, and requisition messages, which correspond to the phraseology used in radiotelephony. Thus, CPDLC, among other things, reduces the difficulty in understanding caused by VHF system interference and radio communication failures. It can be associated with auditory messages, even if redundant, in order to avoid misunderstandings and ensure flight safety. Pilots who used bimodal (audiovisual) displays had better performance than those who used only auditory communication.[12,23] CI users also have improved their performance when tested in situations with the use of auditory-visual information.[2] In this way, we expect that a pilot CI user could have better performance testing with CPDLC (audiovisual communication).

The CI, initially indicated for severe to profound bilateral sensorineural hearing loss,[2,26,28] may currently be an option for hearing rehabilitation for pilots with single-sided deafness (SSD).[10,13,22] In this situation the ICAO describes the possibility of using contralateral routing signal (CROS). However, it is described that CI improves the hearing abilities in people with SSD in a superior way to the alternative options, like CROS and osteo-anchored devices.[1] CI users with SSD also presented significant improvement of bilateral hearing in the location of the sound source when exposed to noise.[13] Hence, in order to improve speech recognition in noisy conditions, we predict that a pilot with SSD, rehabilitated with CI, could use the headset on the nonimplanted ear and the direct connection to the aircraft radio system on the other side with the CI.

However, more speech in noise tests are necessary on which to base criteria on the possibility of hearing rehabilitation through CI in civil aviation pilots. Better results are expected with the sample composed of pilot CI users under more communication friendly conditions, in quieter commercial aircraft cockpits, or using CPDLC, for example.

The main shortcomings of the study were that, in the case of bilateral implants, we opted to select the ear with the highest auditory discrimination in the silence to perform the tests with (even though bilateral cochlear implants provides a significant benefit in speech understanding in relation to a unilateral implant).[16] Although we have established that the direct connection was considered the most favorable condition for speech intelligibility, there was noise input through the microphone of the control pilots because the intercom system (internal communication) was connected. So there was no total noise cancellation, initially proposed in the direct connection condition, because there was some feedback noise from the microphone of the control pilots.

In conclusion, the noise attenuation resources proposed in this study improved the CI users' speech recognition when subjected to the noisy helicopter cockpit. Speech recognition of CI users did not meet the standards of ICAO, which requires at least 80% for disyllables understanding in the speech in noise test, even with the noise attenuation mechanisms presented in this study.

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