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Evaluation of a personalized auditory-cognitive training on the improvement of speech understanding in noise in cochlear implanted patients

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Objective: The cochlear implant is a commonly used implantable device for the auditory rehabilitation of severe bilateral sensorineural hearing loss. The effectiveness of the implant, depends on many factors, including intensive auditory training, which is crucial. Intelligibility in a noisy environment is a current issue and poses a major difficulty for implanted patients. The aim of this study is to evaluate the improvement in auditory performance in noise among cochlear implant patients who underwent personalized auditory-cognitive training for speech understanding tasks in noise.
Design: This was a prospective study involving cochlear implanted patients divided into two groups. One group underwent auditory training in a noisy environment at home for 2 months (G1) while the other group served as a control (G0). A test of intelligibility performance in noise was conducted at inclusion and two months later.
Results: 52 patients were included in the study. The trained group, G1, showed a significant improvement with an increase of 4.8 dB in signal-to-noise ratio (SNR) between the two tests ($P < 0.01$). There was no significant improvement in the control group (G0) ($P = 0.756$).
Conclusions: This study demonstrated a significantly positive impact of personalized auditory training in a noisy environment for cochlear implant patients.

Keywords: Cochlear implant, Hearing in noise, Auditory-cognitive training

Introduction

Severe to profound bilateral sensorineural hearing loss has significant consequences. Indeed, it is responsible for cognitive decline, social isolation, and is a risk factor for depression, falls, and dementia (Loughrey *et al.*, 2018). The cochlear implant is a commonly used implantable device for the auditory rehabilitation of these hearing losses and has a positive impact on improving cognitive performance, social integration, and quality of life (Castiglione *et al.*, 2016; Mosnier *et al.*, 2018). The effectiveness of cochlear implantation, particularly in terms of speech understanding and quality of life, has been the subject of numerous studies aimed at identifying the factors that explain the variability of outcomes among patients (Busby *et al.*, 1991; Dawson and Clark, 1997). Factors related to the deprivation of auditory information are the most significant, and cognitive abilities determine the patient's brain plasticity capabilities, which enable them to adapt to this rehabilitation (Moberly, 2020).

Therefore, intensive speech therapy combined with daily cognitive work is crucial for most of cochlear implanted patients (Fu and Galvin, 2008; Kappel *et al.*, 2011). Speech therapy in the clinic forms the basis of auditory-cognitive training for implanted patients. However, access to professionals is increasingly limited. Therefore, home self-training appears promising as a complement to that performed in the clinic. Training programs on PCs or smartphone apps are provided by cochlear implant manufacturers, as well as by commercial providers or research initiatives. Several studies have already demonstrated the feasibility and effectiveness of computer based auditory training (CBAT) for patients fitted with conventional hearing aids or cochlear implants (Fu *et al.*, 2004; Henshaw and Ferguson, 2013; Humes *et al.*,

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2019). However, the level of evidence from studies on this subject remains low due to a lack of rigor in the protocols, and their applicability to implanted patients is limited (Henshaw and Ferguson, 2013; Stropahl *et al.*, 2020). While cochlear implant users achieve excellent performance in quiet, and improved noise reduction techniques in hearing aids are being used to process noisy speech signals, speech recognition in background noise remains a significant challenge for them (Zaltz *et al.*, 2020; Zhou *et al.*, 2020). The literature on the evaluation of auditory-cognitive training in noise for cochlear implant patients remains scarce. The aim of this study was to evaluate the effectiveness of personalized auditory-cognitive self-training for speech-in-noise tasks, conducted at home using computer software, on improving the auditory performance in noise of cochlear implant patients.

Materials and methods

Study design

This was an interventional, prospective, single-center, open-label and randomized study. Patients included in the study were selected from those followed in the Otology and Neurotology department of a French University Hospital Center. The selection of subjects was carried out during an audiology consultation, by telephone, or by email. These were adult patients who had at least one cochlear implant for more than a year and whose speech recognition performance in silence – assessed binaurally in silence using french Fournier's disyllabic word lists – was above 50% intelligibility at 45 dB HL (60 dB SPL). The patients were divided into two groups, one comprising patients undergoing auditory training in a noisy environment at home for two months (G1), and the other corresponding to the control group (G0). Written consent was obtained from participants after they were provided with clear and comprehensive oral and written information. Epidemiological data (age, sex, educational level, etiology of deafness), as well as implant-related data (duration of auditory deprivation, duration of implantation, brand of the implant, mono/bi-implantation), and audiological data with the use of the rehabilitation device (binaural pure-tone average, speech recognition threshold – assessed binaurally in silence using french Fournier's disyllabic word lists – at 45 dB HL and signal to noise ratio loss in speech audiometry in noise at 65 dB SPL) were collected. Speech audiometry in noise used the Vocal Rapide dans le Bruit test ('Vocale Rapide dans le Bruit', Hubsound software, Biotone) (Leclercq *et al.*, 2018).

Experimental procedure

Each participant included in the study underwent an evaluation of speech understanding in noise on the day of inclusion (T1) and then again two months later (T2). Group 1 received two months of home-based auditory-cognitive self-training using a computer program.

Audiometric evaluation of speech understanding in noisy environments

Patients' performance in noise was assessed to establish a Personalized Auditory Profile (PAP) for each patient. Initially, patients were questioned about their exposure and difficulties in seven daily sound environments (Home, Group, Train/Subway, Street/Car, Music, Restaurant, Television) using a visual analog scale for evaluating discomfort. Participants selected three out of the seven environments in which they most wanted to improve. Their speech understanding performance in each of the seven sound environments was tested. The auditory tests were conducted in a free-field setting with their hearing rehabilitation device in a soundproof stereo-audiometry booth. Three speakers delivered the auditory stimulus.

The software used to deliver the auditory stimuli was developed by Renard Audiology Care Laboratories. The speech stimuli presented consisted of sentences containing three key words, which served as the basis for scoring. These speech stimuli were based on recordings of real voices and could be parameterized to define the type of voice (female, male). The patient had to identify the three key words of the presented sentence, from among several propositions (three options per proposition).

Tests began with a sentence presented at +20 dB above the masking background noise. The level of difficulty increased with correct responses, by decreasing the intensity of the speech relative to the background noise (in 4 dB steps). The test stopped in the event of an error and resumed in the next sound environment. Participants were given a score out of 10 according to the difficulty of the signal-to-noise ratio (SNR) obtained: 1.6 points corresponded to a 4 dB change in SNR.

The test was repeated two months later using the same procedure, after auditory training for Group G1 and without intervention for Group G0. The average scores of each group at T1 and T2 were calculated for each of the seven sound environments, and for the three preferred sound environments.

Auditory training for speech understanding in noise

The training group (G1) benefited from home-based auditory training for speech understanding in noise, conducted using a digital platform, for three twenty-minute sessions per week over two months (24 sessions in total). Participants used their personal computers. Each session included seven successive exercises of tasks in silence and in noise, featuring a variety of stimuli from multiple speakers, inclusion of synthetic and analytic activities, use of corrective feedback for each response, and performance monitoring to keep patients on track with their program. Patients worked in the three sound environments chosen during the PAP. The difficulty of the speech understanding exercises in noise was calculated based on the initial PAP results for the first session (PAP score +4 dB), and adjusted each session based on the results from the previous session to work within a zone between 50 and 70% of maximum performance. Details regarding the procedure of a typical training session are provided in Appendix.

The monitoring of performance and daily participation of the included subjects was accessible to the study investigator.

Satisfaction survey

A questionnaire evaluating the effectiveness of the program, the improvement in discomfort in the noisy environments worked in their daily lives, the ease of use of the software, and the ease of adhering to the protocol's pace, was submitted to participants in Group 1 at the end of the protocol. A score from 0 to 10 was assigned to each item.

Statistical analysis

Statistical analyzes were carried out using R software version 3.6.1 (2019-07-05). A non-stratified block randomization of two groups was performed – 2/3 in the intervention group and 1/3 in the control group. Qualitative variables were described by their number and percentage. Quantitative variables were described by the mean and standard deviation (SD) in cases of symmetric distribution, and by the median and the first and third quartiles (Q1, Q3) otherwise. The independence between two qualitative variables was tested using a Chi-square test (Pearson, 1900). The independence between a qualitative and a quantitative variable was tested using a Student's t-test or a Wilcoxon (Wilcoxon, 1945) – Mann–Whitney test (Mann and Whitney, 1947), depending on whether the variables followed a normal distribution or not. Normal distribution was tested using a Shapiro–Wilk test (Shapiro and Wilk, 1965). A significance threshold of $P < 0.05$ was chosen.

Results

Study population

Sixty-two patients were included in the study. Five patients were lost to follow-up in Group G1 and five in Group G0 and were excluded from the final analysis (Figure 1).

Age, educational level, cochlear implant data (duration of implantation, duration of auditory deprivation, brand of implant, mono/bi-implantation) and auditory scores (detection, intelligibility in silence and in noise) were comparable between the two groups. The proportion of men was significantly higher in G0 group than in G1 group ($P = 0.010$). These data are included in Tables 1 and 2. The etiologies of deafness were variable and are included in Table 3. There were no significant differences between the groups regarding the etiology of deafness ($P = 0.251$). For patients in Group G1, 88% completed the training protocol on a computer (Mac or PC), 12% on a tablet.

Results of the personalized auditory profile at T1

The patients' choices for preferred sound environments were, in descending order: group conversations 97.4%; television 51.3%; restaurant 46.2%; musical environment 38.5%; traffic noise 35.9%; domestic noise 28.2%; train station noise 2.5%.

For each of the 7 sound environments, the average performance scores were not significantly different between groups. The overall average of performance scores obtained in the 7 environments was not significantly different between groups ($P = 0.170$). The

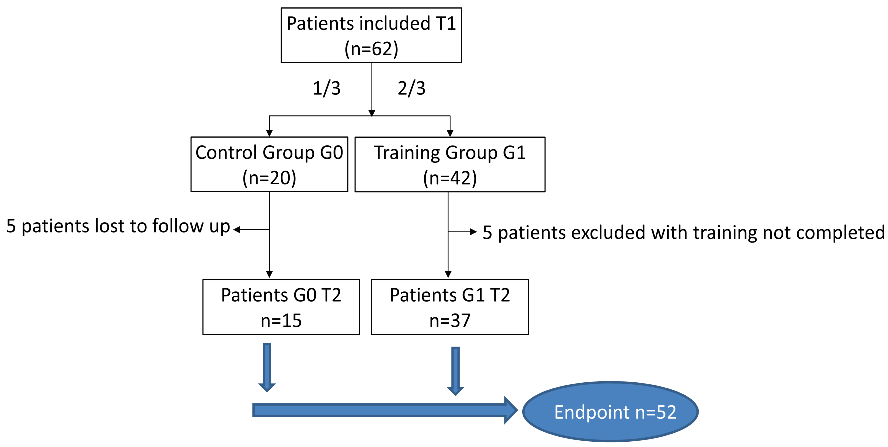

Figure 1. Flowchart.

Table 1. Characteristics of study population.

Study population data	Value of group G1 (*N* = 37)	Value of group G0 (*N* = 15)	P
Gender (%)			0.010
Female	26 (70.3)	6 (40)	
Male	11 (29.7)	9 (60)	
Âge moyen en année ± DS	57.6 ± 14.6	50 ± 18.5	0.603
Level of education in years (%)			0.863
>2	14 (37.8)	4 (26.7)	
0–2	8 (21.6)	5 (33.3)	
0	14 (37.8)	5 (33.3)	
Not specified	1 (2.7)	1 (6.6)	
Average Duration of Auditory Deprivation before Implantation in Years ± DS	1.6 ± 1.1	1.7 ± 1.5	1
Réhabilitation (%)			0.717
Implantation Unilatérale	6 (16,2)	3 (20)	
Implantation Bilatérale	20 (54.1)	8 (53.3)	
Réhabilitation Bimodale	11 (29.7)	4 (26.7)	
Average duration of cochlear implantation in years ± DS	4.8 ±4.4	7.8 ±7.6	0.075
Implantation Brand (%)			0.347
Cochlear	13 (35.1)	2 (13.3)	
Oticon	12 (32.4)	5 (33.3)	
Med-El	5 (13.5)	2 (13.3)	
Advanced bionics	7 (18.9)	6 (40)	

Table 2. Audiometric data of the study population (intelligibility score with dissyllabic lists at 45 dB HL in %, best ear tonal score in dB HL, score at the rapid speech audiometry in noise in loss of dB of SNR).

Study population data	Value of group G1 (N = 37)	Value of group G0 (N = 15)	P
Average tonal score ± DS (dB HL)	32.7 ± 8.1	33.8 ± 5.8	0.603
Average intelligibility score in silence ± DS	81.3 ± 16.3	84 ± 16.8	0.580
Average loss of intelligibility in noise ± DS	10.65 ± 5.0	11.1 ± 4.5	0.823

Table 3. Etiologies of deafness in the study population.

Etiology (%)	Value
Unknown	22 (35,484)
Genetic	13 (20,968)
otosclerosis	5 (8,065)
Meniere's disease	5 (8,065)
Meningitis	4 (6,452)
Acoustic trauma	3 (4,839)
Sudden deafness	3 (4,839)
labyrinthitis	2 (3,226)
Ototoxicity	1 (1,613)
chronic otitis	1 (1,613)
temporal bone fracture	1 (1,613)
neuropathy	1 (1,613)
acoustic neuroma	1 (1,613)

overall average of performance scores obtained in the top 3 preferred environments was significantly higher in group G0 than in group G1 (P = 0.044).

Results of the personalized auditory profile at T2

The overall average of performance scores was significantly higher in group G1 across the 7 sound environments (P = 0.014) and the top 3 preferred environments (P = 0.015).

Intra-group comparison

The gain (in dB) of signal-to-noise ratio achieved from T1 to T2 was significant for group G1 across the 7 sound environments (P < 0.001) and for the top 3 preferred sound environments (P < 0.001). In group G0, there was no statistically significant gain achieved between T1 and T2. These data are included in Table 4.

Inter-group comparison

The improvement in performance in noise was significantly higher in group G1 than in group G0 across the 7 sound environments (P < 0.001) and in the top 3 preferred sound environments (P < 0.001). These data are included in Table 5 and Figure 2.

Satisfaction survey

35 patients (95%) responded to the satisfaction survey at the end of the protocol. The patients rated the effectiveness of the program on average at 8.3/10 and the improvement in discomfort in noisy environments worked at 5.9/10. They rated the ease of use of the software at 9.4/10 and the ease of adhering to the protocol pace at 7.7/10. Ninety-one percent of the patients who responded to the survey found the session duration appropriate. Seventy-one percent found the duration of the protocol adequate and twenty-five percent found it too short.

Discussion

Comparability of groups

Speech understanding in noisy environments is a major challenge for cochlear implant patients. Our study demonstrated the feasibility and effectiveness of personalized, home-based auditory-cognitive training in noise, which led to an improvement in the speech understanding performance in noise for cochlear implant patients. Indeed, a significant gain of 4.8 dB in signal-to-noise ratio (SNR) was achieved compared to the initial test in the trained Group G1. No significant progress was observed in the control Group G0, and a significant difference in progress between the two groups in favor of the trained group was evident. However, the results of the patients in Group G0 across the seven environments tended to be better at T1, and this difference was

Table 4. Comparison at T1 between groups G0 and G1. Score out of 10 in each sound environment (Home, Group, Station/Subway, Street/Car, Music, Restaurant, Television), average score of each group across the 7 sound environments (SEVEN_ENV) and in the top 3 preferred environments (THREE_PREF).

	HOME_1		GROUP_1		SUBWAY_1		STREET_1		MUSIC_1		RESTAURANT_1		TELEVISION_1		SEVEN_ENV_1		THREE_PREF_1	
GROUP	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**1**	**0**	**1**
MEAN	4.087	3.732	2.867	2.214	5.147	4.432	3.367	2.884	2.807	3.672	2.821	3.049	4.467	3.754	3.834	3.174	3.672	2.821
Std.Dev	0.904	2.002	1.633	1.641	1.868	1.733	1.494	1.966	1.193	0.996	1.530	1.784	3.119	2.319	0.885	1.427	0.996	1.530
P	0.564		0.189		0.137		0.245		0.192		0.063		0.466		0.170		0.044	

Table 5. Comparison at T2 between G0 and G1. Score out of 10 in each sound environment (Home, Group, Station/Subway, Street/Car, Music, Restaurant, Television), across the 7 sound environments (SEVEN_ENV), and in the top 3 preferred environments (THREE_PREF).

	HOME_2		GROUP_2		SUBWAY_2		STREET_2		MUSIC_2		RESTAURANT_2		TELEVISION_2		SEVEN_ENV_2		THREE_PREF_2	
GROUP	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**
MEAN	3.740	5.881	2.620	3.795	4.853	5.743	4.247	5.084	2.673	3.995	4.127	5.019	5.447	6.054	3.958	5.082	3.733	4.857
Std.Dev	1.902	1.880	1.629	1.758	1.048	1.923	1.361	2.281	1.245	1.846	1.429	2.021	2.960	2.444	1.065	1.523	1.317	1.433
P	0.002		0.032		0.070		0.087		0.020		0.069		0.592		0.014		0.015	

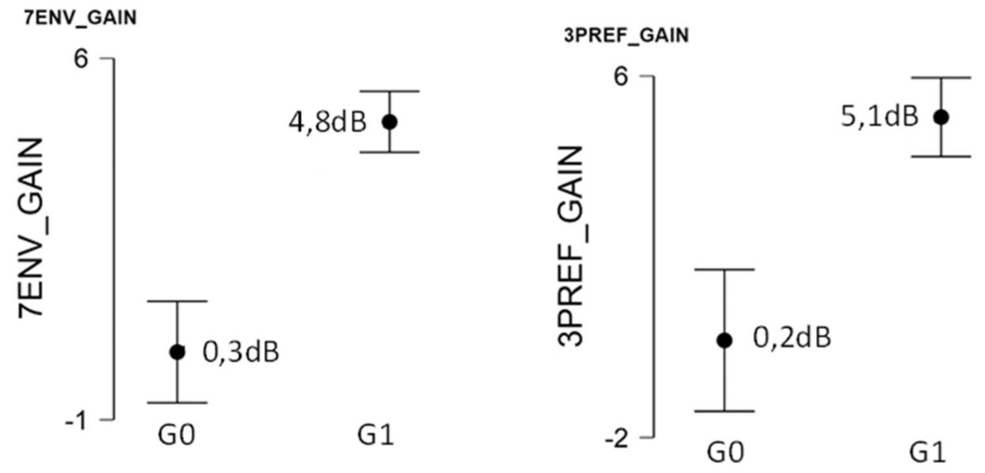

Figure 2. Box Plot. Gain in signal-to-noise ratio between T1 and T2 for the training group G1 and the control group G0 in the 7 sound environments (7ENV_GAIN) and in the top 3 preferred environments (3PREF_GAIN).

significant for their three preferred environments. In addition, the two groups were comparable on all biographical, audiometric and implantation characteristics except gender. Therefore, it is necessary to conduct this study with a larger number of patients to achieve initial comparability of the groups and on the T1 scores.

Validity of the auditory-cognitive training

Although data on auditory training in noise for cochlear implant patients in the literature are limited, the results of some studies are consistent with our findings of improved intelligibility in noise for cochlear implant patients through auditory-cognitive training. Indeed, some studies have demonstrated the effectiveness of auditory training for sound and phoneme discrimination in everyday sound environments (Green *et al.*, 2019; Reis *et al.*, 2021; Schumann *et al.*, 2014; Shafiro *et al.*, 2015). More broadly, a review of the literature has demonstrated the effectiveness of combined auditory and cognitive training on the cognitive functions of individuals with hearing loss (Lawrence *et al.*, 2018). However, the modalities of auditory-cognitive training vary significantly, especially in terms of frequency and duration, making it difficult to compare and reproduce results (Humes *et al.*, 2014; Tye-Murray *et al.*, 2017). Adherence appears to be a crucial factor for achieving improvements in speech intelligibility in this population (Chisolm *et al.*, 2013). In our study, the training was specifically conducted in three sound environments chosen by the patient to limit the duration of the sessions and target the specific needs of each patient. The duration of auditory and cognitive self-training was two months and each session lasted 15 to 20 min, which we considered appropriate to effectively improve speech comprehension in noise while maintaining participant adherence. The majority of the participants, whether employed or retired, completed the training. This suggests that the duration and frequency of the training sessions in our protocol were appropriate. Patients were satisfied with the format of the training and the ease of use of the software. A performance monitoring system was also implemented to encourage adherence and active participation of the patients. A performance follow-up had been set up to encourage the patients' assiduity and active involvement.

Regarding the content, some studies have described several criteria concerning the form and expected content of auditory-cognitive training such as ease of access, interactivity, and the work of perception, discrimination, and cognitive synthesis such as memory (Sweetow and Sabes, 2006; Watson *et al.*, 2008). The complexity should increase in an appropriate manner, and it must provide correction and performance monitoring to stimulate learning and aid in adherence. The training software developed by Renard audiology care Laboratories met these criteria (Tables 6, 7).

Similarly, a study detailed the criteria for developing and evaluating computer-based auditory training (CBAT) in hearing-impaired adults who are fitted with hearing aids or cochlear implants (Henshaw and Ferguson, 2013). CBAT should demonstrate its effectiveness on real-life intelligibility, cognition, and

Table 6. Comparison between T1 and T2 within the training group G1 and group G0. Average score in the 7 sound environments (7ENV) and in the top 3 preferred environments (3PREF).

	T1	T2	P
Groupe G1 moyenne score ± DS			
7ENV	3.174 ± 1.427	5.082 ± 1.523	**0.001**
3PREF	2.81 ± 4.857	4.857 ± 1.433	**0.001**
Groupe G0 moyenne score ± DS			
7ENV	3.834 ± 0.885	3.958 ± 1.065	0.756
3PREF	3.672 ± 0.996	3.733 ± 1.317	0.967

Table 7. Comparison of progress between T1 and T2 for the two groups G0 and G1: in the 7 sound environments (7ENV) and in the top 3 preferred environments (3PREF).

	Group 0	Group 1	P
Mean progress score ± DS			
7ENV	0.125 ± 0.711	1.906 ± 0.708	<0.001
3PREF	0.060 ± 1.132	2.037 ± 1.046	<0.001

communication training tasks. CBAT must use ecologically valid training, performance feedback should be added, and monitoring should be offered. The improvement perceived by the patient should be evaluated through questionnaires. CBAT must show adherence to the consistency of training over time. Our protocol validates all the criteria except for the assessment of patients on untrained tasks and on their cognitive performance. While hearing loss has a definite negative impact on cognitive functions, there is no consensus on the impact of cochlear implants on cognition. Results relating to cochlear implantation and cognition vary according to the cognitive domain assessed, and it would be interesting in future studies to add tools assessing memory and learning, global cognition and inhibition-concentration to assess cognitive benefit after implantation, and help explain the variability in speech recognition results in noise (Amini *et al.*, 2023).

Limits and perspectives of the study

This study has demonstrated the feasibility and benefits of auditory-cognitive training in a noisy environment at home but it is necessary to conduct this study with a larger number of patients.

The daily wearing time of the cochlear implant was not collected, and it is possible that patient participation in a study encouraged increased implant wearing in the G1 group. However, some authors seem to show that increasing the daily wearing time of the cochlear implant alone can improve intelligibility in noise (Holder and Gifford, 2021). It will therefore be interesting to collect this data in a future study to avoid confounding bias.

The improvement in signal-to-noise gain in the G1 trained group can be explained by a learning effect. However, the patients in this group showed an improvement in discomfort in the noisy environments they worked in on a daily basis. All patients had progressive post-lingual deafness. The applicability of the software should be tested in patients with pre-lingual deafness implanted in childhood. Currently, the vocabulary level of the software developed is not suitable for children. Some studies have used models adapted for children and suggest the effectiveness of self-training in patients with pre-lingual deafness (Alibert Benkhanouche *et al.*, 2018; Reis *et al.*, 2021).

It would also be interesting to study the effects of more prolonged rehabilitation and the benefits of supervision by a professional involved in the care of cochlear implant patients. Indeed, the results of the various exercises can be utilized by different care providers. Intensity and frequency discrimination exercises could be used by audiologists to fine-tune settings. Phonetic confusion exercises could be worked on with a speech therapist, targeting specific difficulties of the patient identified by the software. This self-training program should therefore be evaluated as a tool for monitoring the performance of cochlear implant patients, intended for professionals involved in patient care.

Conclusion

Speech intelligibility in noise for cochlear implant patients remains a significant challenge. The neuronal reorganization of auditory centers is a promising avenue for potential improvement through intensive auditory-cognitive training. This prospective study has demonstrated the feasibility and benefits of auditory-cognitive training in a noisy environment at home. The entire protocol was designed to personalize the rehabilitation as much as possible and to make it as educational as possible in order to achieve tangible results on the daily discomfort of patients. Further work is needed to overcome the limitations of a small-scale prospective study, particularly in terms of recruitment and duration.

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Notes on contributors

Guillaume Lloret is a medical doctor, involved in research into inner ear protection in surgery, cochlear implantation and the development of tools for diagnosing and rehabilitating deafness.

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Appendix: Outline of a training session

Each session is designed to last approximately 15 min. Since consistency drives effectiveness, the patient is asked to complete three sessions per week. All sessions follow the same structure, as repetition automates mental operations to the point of becoming unconscious, thereby freeing attentional resources for the exercises.

Exercise 1 is a recognition exercise involving 10 sentences in silence. These sentences are randomly selected from a database of 4,500 sentences generated using synthetic voices (two male voices and two female voices for each model).

The patient hears a sentence (which can be replayed) and must reconstruct what they heard by selecting the appropriate subject, verb, and object from three options. All the sentences in the proposed 'matrix' are syntactically and semantically correct while being lexically low-predictive. The probability of getting a correct answer by guessing is 1 in 27.

Once the answer is submitted, correct responses are displayed in green, and incorrect ones in red. If the patient makes a mistake, they are invited to replay the sentence to understand their error. Making mistakes is part of the learning process, provided this corrective feedback is available.

Due to its simplicity, this exercise serves as a kind of warm-up for the rest of the session. It also acts as a warning mechanism if a patient's performance drops significantly from one day to the next.

Exercise 2 is a 'Speech tracking' exercise. A sentence is displayed on the screen (from a database of 897 sentences), and the patient must determine whether what they hear is congruent with what they see. Background noise accompanies the audio. There are 11 types of background noise, but before training begins, the patient selects three based on their living conditions. These three noise environments will be used throughout the training sessions.

The exercise consists of six items: for the first three, an orange dot appears 250 milliseconds before the sentence audio to help the patient detect the signal. For the remaining three, this cue is removed. (The noise level depends on the patient's baseline SNR [Signal-to-Noise Ratio], as defined in Exercise 4).

Exercise 3 focuses on the perception of frequency variations. The patient hears three successive sounds and must identify the one that differs in frequency. (Five items are presented in silence, and five in noise.) Each of the 24 sessions targets a specific frequency range. For instance, in session 1, the patient works with narrow bands 1030–1160 Hz versus 1160–1290 Hz. Over the 24 sessions, the entire spectrum from 180 Hz to 8000 Hz is stimulated.

Exercise 4 involves understanding sentences in noise. The patient listens to three series of five sentences, each associated with one of the three background noises chosen earlier. The noise volume is adaptive: the first sentence is played with background noise slightly lower than the patient's final SNR success threshold from the previous session (+2 dB SNR compared to the previous session). If the patient succeeds, the noise level increases for the next sentence; if they fail, the noise level decreases. At the end of the five sentences, the interface records the new SNR value for that type of noise. The workflow is identical to Exercise 1.

Regarding background noises, they were recorded in situ using a 360° Zoom H3-VR microphone. A representative 10-second segment was selected for each noise. The 'sentence + background noise' combinations were mixed, time-locked, and normalized based on tests with 128 normal-hearing speech-language pathology students.

Exercise 5 focuses on the perception of intensity variations. The patient hears three narrow bands successively and must identify the one that is louder by 5 dB. The exercise is first conducted in silence (five items) and then in the presence of background noise (five items).

Exercise 6 addresses phonetic confusions. Each session targets one of the 24 minimal pairs in French (e.g. f-s, p-f, t-s, ch-s, l-n, p-b, t-d, k-g, f-v, s-z, ch-j, b-v, p-t, k-t, b-d, v-z, d-g, m-n, b-m, k-ch, d-z, j-z, g-j, d-n). The patient hears a sentence in which the minimal pair appears twice and must identify the sentence from four options. For the first two items, the exercise is conducted in silence. For the remaining items, the exercise includes the selected background noises, played at the reference level defined in Exercise 4.

Exercise 7 trains auditory attention and the four aspects of auditory-verbal memory (working memory, memory span, fusion task, and dual-task mechanism).

In the first question, the patient experiences a daily-life scenario and must pay attention to the auditory scene to answer a question (e.g. *You are walking down the street. Suddenly, you hear church bells. What time do they chime?*).

The second question tests working memory. The patient takes the role of a restaurant server, listens to a couple's order (starter, main course, cheese, dessert for each), and answers a question about one of the ordered dishes, choosing from four options.

The third question assesses memory span: a speaker provides their phone number (repeated once), and the patient must recall it.

The fourth question involves a syllabic fusion task: the patient hears a series of words and must retain the first syllable of each to reconstruct a target word, selecting it from four options.

The fifth and final question assesses the dual-task mechanism: the patient hears four sentences, determines whether each is true or false, and remembers the last word of each sentence. Afterward, they must recall all four words.

At the end of the session, the results are recorded in both tabular and graphical formats, showing the evolution of the SNR level for each selected background noise.