AMSE JOURNALS-2016-Series: Advances B; Vol. 59; N° 1; pp 31-45
Submitted May 2016; Revised June 20, 2016, Accepted July 15, 2016

Effect of Microphone Cleaning on Syllable Recognition Performed by Cochlear Implant Users using the CIS and NofM Coding Strategies

P.A. Cucis[1], E. Veuillet[1,2], E. Truy[1,2,5], H. Thai Van[1,2,5], F. Seldran[1,3], S. Gallego[1,4]

[1]University Claude-Bernard Lyon1, 43 bd du 11 Novembre, 69622 Villeurbanne-Cedex, France
[2]Lyon Neurosciences Research Centre, (CRNL), INSERM U1028, 95 bd Pinel, 69675 Bron-Cedex, France
[3]Vibrant Medel France, 400 av Roumanille, Bât. C6, CS 70 052, 06072, Sophia Antipolis-Cedex, France
[4] Audition-Conseil Center, 34 av Lacassagne, 69003 Lyon, France
[5]CRIC, ORL Building, Edouard-Herriot Hospital, place d'Arsonval, 69437 Lyon-Cedex 03, France
(E-mail : cucis.pa@gmail.com)

Abstract

In contact with the external environment, the microphone is a fragile component of hearing rehabilitation devices, including cochlear implants (CIs). For CI users a regular maintenance of the microphone is performed during the periodical appointments with audiologists. In this work, the effect of cleaning the microphone has been studied.

Fifty-nine CI users were included in this study. Patients' speech recognition in noise has been tested using the Fournier's disyllabic lists mixed with a cocktail party noise. The tests were performed with a signal to noise ratio (SNR) ranging from -3 dB to +18 dB by 3 dB steps. Moreover, the coding strategy used by the subjects has been considered. Then, the microphones were cleaned, using two different procedures. First we had a classical brushing followed by an air jet ("brush and blow" procedure). In the second procedure, the microphone protection filter was replaced. The percentages of syllables recognition before and after cleaning were collected.

Then the syllable recognition percentages, versus the SNR, have been fitted by a sigmoid regression curve in order to give specific audiological values.

Results show that the continuous interleaved sampling (CIS) strategy was more resistant to the microphone loss of sensitivity than the number of maxima (NofM) strategy, mostly in the medium values of the SNR range. For high values of the SNR the NofM strategy led to the best results.

The improvement brought by the microphone maintenance was evaluated using the two cleaning procedures, "brush and blow" and "filter replacement". The improvement was around 5%, corresponding to one syllable in a Fournier's list.

This work brings new questions, such as the effect of N and M in the NofM strategy, the duration between two consecutive maintenances and the adaptation of the coding strategy to noisy environments.

Key words: Cochlear implants, Cleaning of the Microphone, CIS and NofM Strategies, Cochlear Implant Users, Microphone Sensitivity, Signal to Noise Ratio.

1 Introduction

Aging of CIs is important to study as it is a classical problem encountered with biomedical equipment. Moreover, it is related to devices dysfunctions. These dysfunctions are likely to affect the CI users' hearing performances [2, 3].

Today CIs are widely used in deafness rehabilitation and 30,000 per year are fitted in the world, among them 1,000 in France. This technology is very attractive and has been studied many times, on the medical aspect as well as on the scientific side. Sounds and speech are processed by the implant speech processor and then the global signal is delivered to the human ear. Several publications deal with this aspect [6, 11].

Nevertheless, some questions remain open and the choice of the coding strategy is still questioned [17]. The link between coding strategy and aging is worth to be studied. Thus, what is the relation between aging and the environment (including the noise level); this is a key issue [9]. In this work we have studied the relation between the strategy and the microphone loss of sensitivity when a microphone inlet occlusion is considered [13, 14].

Cleaning the microphone is a common process performed by audiologists in hearing care centers during periodical maintenances. About CI, the question of checking the microphone is raised when CI users come to the clinical setting center for a follow up.

In the present study, two different cleaning procedures are discussed. First, the microphone's inlet port can be brushed and dust can be removed by a dry air flow. Another possibility is the replacement of the microphone protective filter.

To be credible the results should come from a sufficiently large population allowing a statistical analysis of the results. Consequently an approval from an Ethics Committee was obtained.

The two main coding strategies used in CIs have been considered in this work; CIS and NofM (M channels are open and the N more energetic channels are kept and distributed along the cochlea). The CI users' recognition performances have been collected before and after cleaning the microphone. The test sessions were carried out in a noisy environment in order to assess the resistivity of the coding strategies. For the NofM strategy, only N channels are kept, in order to reduce the interaction between the electrodes. For the CIS strategy, the M channels are taken in order to keep a more complete spectrum and the signal should be less sensitive to the noise perturbation.

It can be reminded that the clinical team in charge of the implantation process takes the final decision which includes the choice of the implant's brand and consequently the strategy. This decision may have an impact on patient's performances. In order to have comparative results, a systematic study in simulation could test the two strategies at different degrees of microphone sensitivity loss for each subject.

This experiment in simulation has been conducted with normal hearing subjects listening to a CI simulator; results are described in a companion paper [5]. As the recognition percentages are collected on the same subject, efficient paired analyses can be done. But the extrapolation to the implanted population can be discussed even if several studies have established previously that this extrapolation is legitimate [7, 8, 10].

Results coming from the two studies have been compared; they bring further observations useful to understand the hearing mechanisms [4].

The recognition of syllables and speakers is a pending problem and this aspect deserve to be considered [1, 16], mostly with the tools offered by modeling and simulation.

In the present work, only CI recipients have been included. Recognition performances were compared before and after cleaning the microphone. The recognition percentages of the syllables were analyzed. The Fournier's lists were well adapted to the patients' recognition ability in the noise.

The paper is constructed as follow; after an introduction, the methods are described in the second section: the acoustic material, the participants and the mathematical methods used. Then the results (the recognition percentages) are presented and discussed in the third section. Percentages were collected before and after cleaning the microphone and they indicated the effect of the coding strategy and the impact of the cleaning procedure. Finally a conclusion points out the main findings coming from this study.

2 Material & Methods

2.1 Acoustic material

The acoustic material used in this work was the Fournier's lists (disyllabic words) mixed with a cocktail-party noise.

a) Fournier's lists

These lists are well adapted to the patients' recognition ability in this environment. They were uttered by a male voice and represented the vocal part of the signal. These lists are largely used in French audiology booths to assess speech perception in hearing impaired subjects.

They are similar to the spondees lists used in English.

Each list contains 10 disyllabic words (for instance "le bouchon" = the cork). Forty lists are available, and the recognition unit was the syllable. Thus the step was 5%.

b) Noise

A cocktail-party noise has been used. This noise was generated with a voice mix of 8 speakers, 4 males and 4 females.

c) Input signal

The acoustic material delivered to the CI recipients was constituted by the Fournier's lists mixed with the cocktail-party noise. A Madsen Orbiter 922 audiometer controlled the word and the noise levels to precisely adjust all the different SNRs.

The acoustic material was emitted in free field by a loud speaker, in an audiology booth and only one ear was stimulated. When a CI user was fitted with two implants, only the best ear was tested.

The level of the Fournier's list was 60 dB SPL and the noise levels ranged from 42 dB to 63 dB SPL with a 3 dB step. Consequently the output level was kept below 65 dB SPL (well under 80 dB SPL, the maximum sound level allowed for professional exposure). The level limitation was required by the Ethics Committee.

SNR levels were: -3 dB, 0 dB, 3 dB, 6 dB, 9 dB, 12 dB, 15 dB and 18 dB.

Furthermore, in this situation, the acoustic level delivered to the patient was limited by the implant.

d) Microphone conditions

The recognition scores of the CI users were collected before and after cleaning the microphone, leading to two different situations (“dirty and clean”). Our experiment took place at the beginning of the periodical clinical check and device setting occurring periodically at the CRIC (Cochlear Implant Setting Center) located in the ORL department of the Edouard-Herriot University hospital of Lyon. This check-up consists of an appointment with a speech therapist, a setting of the implant parameters and a clinical examination. Consequently, in our study the microphone cleaning occurred before the classical check-up. This device check follow-up is carried out at least once a year.

The following tasks were realized in our work:

-Verification of the patient’s medical file,

-Short training session to help the patient to understand the instructions,

-First test with the Fournier’s lists, before cleaning the microphone. The lists were presented to the patient with an increasing scale of difficulty (SNR decreased from 18 dB to -3 dB),

-Microphone cleaning,

-Second test with the Fourier’s lists with a clean microphone.

In most cases the recognition score was 0% when the SNR was -3 dB; starting with high SNRs avoids the discouragement of the patient.

The full session lasted about 30 minutes. Sixteen Fourier’s lists were used in this experiment (8 before + 8 after) and the lists were not repeated.

2.2 Participants

The work presented in this paper follows a pilot study [12] and it was approved by the French Ethics Committee “Sud Est 2” (August, 27, 2014), under the supervision of the HCL (Hospitals of Lyon).

All the participants signed an agreement form before entering the study. All results were recorded by a certified audiologist.

Fifty-nine implanted patients were included in this study. Their age ranged from 18 to 60 years (average 37 years old). Nineteen subjects were fitted with the CIS strategy (13 Medel® and 6 Advanced-Bionics®) and 40 had the NofM strategy (27 Cochlear® and 13 Neurelec®). The numbers of channels were: Medel® (M # 12), Advanced-Bionics® (M # 16), Neurelec® (N # 8; M # 20), Cochlear® (N # 8; M # 22). Medel®, Advanced-Bionics®, Neurelec® and Cochlear® are the four CI manufacturers in the world.

The population of the CI users had been parted into four subpopulations:

-SP1: Medel® and Advanced-Bionics® subjects (19 patients): “brush and blow” cleaning procedure and CIS coding strategy,

-SP2: Neurelec® subjects (13 patients); “brush and blow” cleaning and NofM strategy,

-SP3: Nucleus (Cochlear®) subjects (13 patients): “brush and blow” cleaning and NofM strategy,

-SP4: Nucleus subjects (14 subjects): replacement of the protective filter and NofM coding.

Two different investigations have been done in this work.

First, the effect of cleaning according to the coding strategy is studied. Two populations were compared, A (SP1) and B (SP2 + SP3). The cleaning procedure was “brush and blow”.

Secondly, we compared the cleaning procedures between the populations C (SP3) and D (SP4). Both populations had the same coding strategy (NofM) used in the Nucleus processor; cleaning procedures were “brush and blow” and “filter replacement”.

2.3 Statistical evaluation

a) Percentages comparison

In this study we compared the recognition scores for two independent populations. Non parametric tests have been used (Wilcoxon).

The significance threshold was 5%. Scores were compared according to the SNR.

The statistical tests compared the average recognition values for the following populations:

-populations A and B; the recognition percentages, before and after cleaning (“brush and blow”), were compared according to the two coding strategies CIS and NofM.

-populations C and D (Nucleus CI users). The two cleaning procedures “brush and blow” and “filter replacement” were compared.

b) Fitting with a sigmoid curve

The recognition percentages, versus the SNR, can be represented by a sigmoid regression curve (figure 1).

The following values, used in audiology, were considered:

-$x_{50\%}$: the SNR corresponding to 50% of the maximum recognition shows the word recognition ability,

-$\Delta_{75\text{-}25\%}$: related to the curve slope; it is the interval (in dB) needed to go from 25% to 75% of the maximum recognition score and it indicates the speed of acquisition of the syllables with the SNR. The smaller $\Delta_{75\text{-}25\%}$, the steeper the slope.

-y_{max}: maximal recognition score.

The sigmoid equation is:

$$y = \frac{a}{1 + e^{-b(x-c)}}$$

Parameters a, b and c were given by the XLSTAT software.

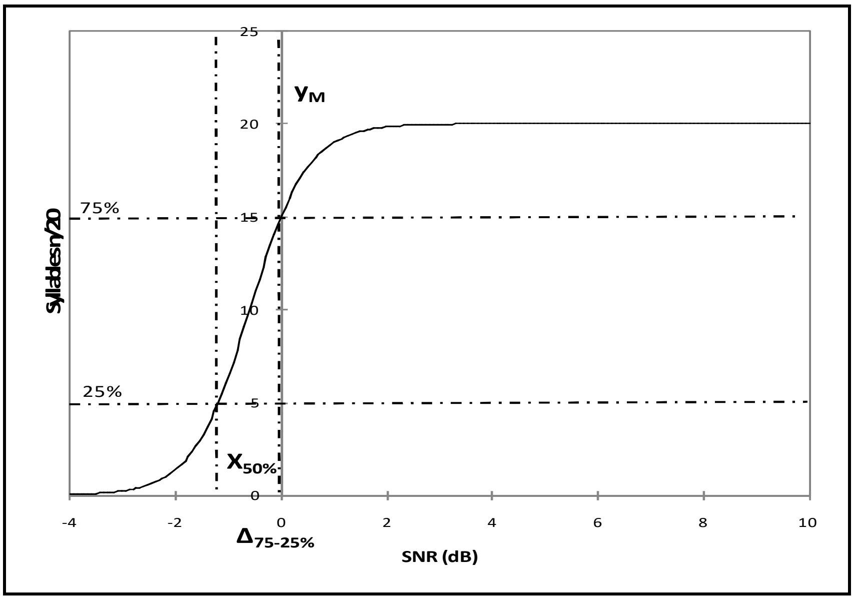


Figure 1: Fitting the recognition percentages, versus the SNR, by a sigmoid curve.

In the sigmoid curve equation, the following denotations are:

-y: recognition score (given in percentage),

-x: the SNR,

-a: y_{max},

-c: $x_{50\%}$,

-b: linked to the slope: $b = 2.2/\ \Delta_{75\text{-}25\%} \Rightarrow \Delta_{75\text{-}25\%} = 2.2/b$

In our case, the minimum percentage (obtained for SNR = -3dB) was 0%.

3 Results and discussion

3.1 Coding strategy

The effect of cleaning the microphone ("brush and blow" procedure) was evaluated by the recognition percentages; it is represented on figure 2 according to the two strategies. It indicates the influence of the cleaning.

Concerning the CIS strategy (19 subjects) the improvements were not significant.

With the NofM strategy (26 subjects) the scores after cleaning were also better, but only two differences were significant, for the SNRs 3 dB and 18 dB.

The average improvement was about 5% and corresponds to a syllable in the Fournier's lists. The population heterogeneity does not allow definitive conclusions and only gives clues.

For the CIS strategy, the best improvements were observed in the SNR range 0 to 9 dB (0, 3, 6, and 9 dB).

For the NofM strategy the improvements were mostly noticed for the high values of the SNR (12, 15 and 18 dB).

3.2 Cleaning procedure

Thanks to the Cochlear-France Company which offered the filters, we could compare the two cleaning procedures. Is the replacement of the protective filter of the microphone more efficient than the "brush and blow" procedure?

Results are indicated on figure 3.

As expected in the “brush and blow” case (13 subjects) the results given on figure 3a were equivalent to those presented on figure 2b (same coding, same cleaning). No significant difference was observed between the status before and after cleaning.

When the protective filter was replaced (14 subjects) the recognition percentages were more improved and two significant differences were noticed for the SNRs 0 and 12 dB (figure 3b). The filter replacement procedure led to an improvement of 5 to 12% (one or two syllables in the Fournier’s lists).

The comparison between “before” and “after” suggests two hypotheses:

-the microphones were not very dirty and the cleaning procedure did not change strongly the state of the microphone,

-the “brush and blow” procedure was not efficient and cleaning was ineffective.

The second reason does not seem to be sensible because all the treatments were performed by a qualified audiologist; he followed the classical procedure used in the hearing care centers, procedure which is widely accepted.

Figure 4 shows, on the same figure, the improvement observed using the two procedures. Changing the protective filter led to higher differences, mostly when the SNR was high (good listening conditions).

The population which participated to this experiment was heterogeneous and it did not help to conclude with the statistical analysis. A study with a larger population could be better but it leads to other difficulties.

Also, for the SNRs -3 dB and +3 dB, the “brush and blow” strategy led to a better improvement than the filter replacement. This aspect should be studied further.

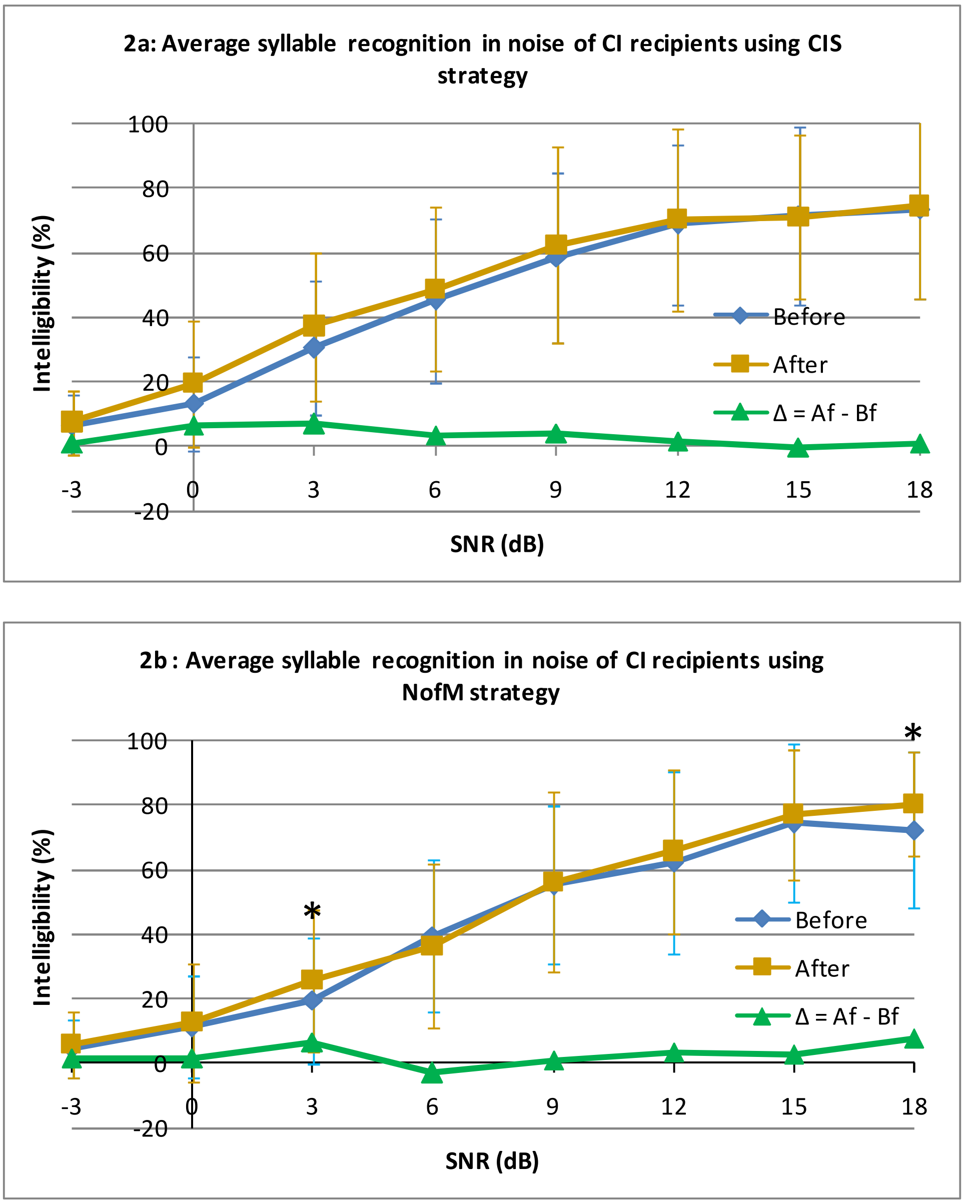


Figure 2: Recognition percentages with respect to the SNR, before and after cleaning; (2a) is for the CIS strategy and (2b) is for NofM. Δ indicates the cleaning effect.

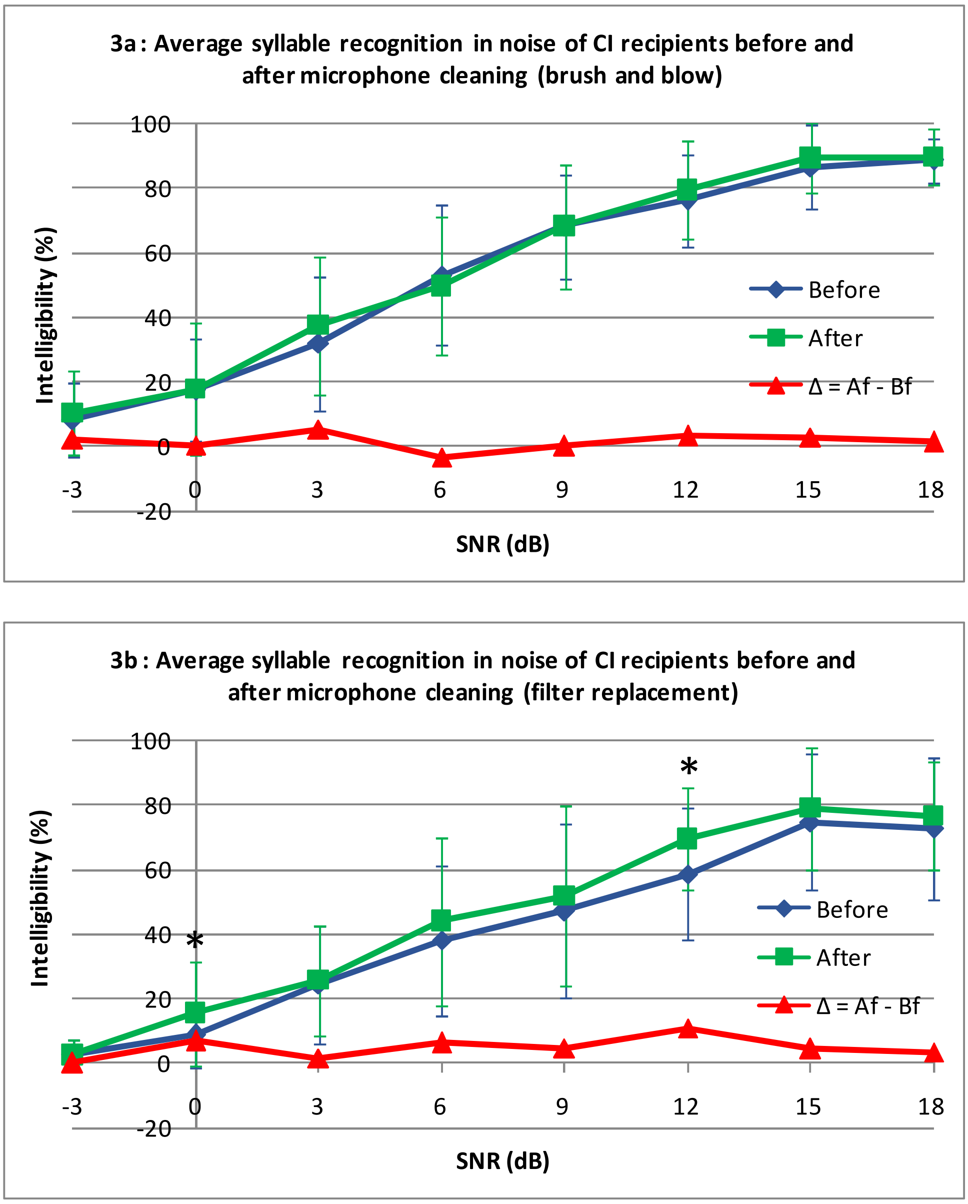


Figure 3: Recognition percentages before and after cleaning the microphone according to the cleaning procedure, "brush and blow" (3a) and filter replacement (3b). The cleaning effect Δ is also represented.

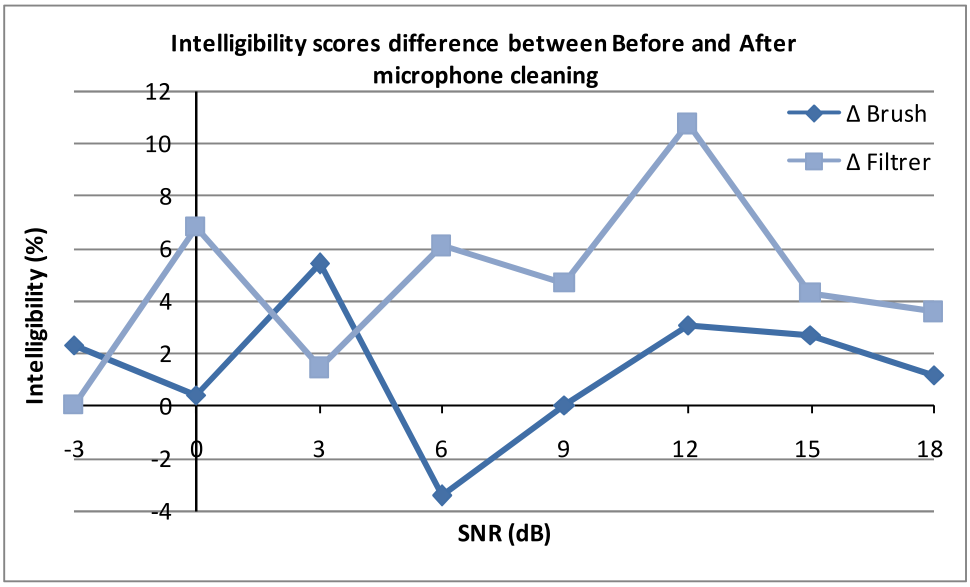


Figure 4: Comparison of the cleaning effect in the two procedures, "brush and blow" and filter replacement.

3.3 Audiological values

The audiological values are given by the sigmoid curves. The following values are indicated on table 1:

-$x_{50\%}$ (SNR for the 50% recognition score),

-$\Delta_{75\text{-}25\%}$ (slope),

-y_{max} (maximum recognition percentage given by the top asymptote).

a) CIS strategy and "brush and blow" (figure 2a and table 1a)

Cleaning the microphone improved the syllable recognition percentage: the curve "after" was above the curve "before"; consequently the SNR for 50% recognition was lower in the situation "after" than in the situation "before".

A steeper slope is associated to a shorter transition interval. The SNR range is clearly divided between two areas: poor recognition and good recognition. Is it linked to fibber recruitment?

The two values $x_{50\%}$ and $\Delta_{75\text{-}25\%}$ are calculated in the transition interval. Cleaning the microphone lowered $x_{50\%}$; but what is its impact on $\Delta_{75\text{-}25\%}$?

Then it is desirable that y_{max} reaches 100%. The average improvement brought by cleaning was 5% (one syllable in a list). The improvement did not reach the significant threshold in our study.

b) NofM strategy and "brush and blow"

The results are presented on figure 2b and table 1b. The main difference appeared on y_{max} (5%).

$x_{50\%}$ and $\Delta_{75\text{-}25\%}$ were rather similar before and after cleaning while y_{max} was improved.

c) Implants from Cochlear® and "brush and blow"

We are now with the Cochlear® CIs. Cleaning improved $x_{50\%}$ and y_{max}, but the differences were not significant (figure 3a and table 2a).

$\Delta_{75\text{-}25\%}$ was not modified.

d) Implants from Cochlear® and “filter replacement”

$x_{50\%}$ was not modified. The main difference appeared on y_{max} (figure 3b and table 2b). The improvement on y_{max} was one syllable per list. The transition slope was steeper.

	CIS (1a)			NofM (1b)		
	$x_{50\%}$	$\Delta_{75-25\%}$	y_{max}	$x_{50\%}$	$\Delta_{75-25\%}$	y_{max}
Bf	4,5	6,5	84,6	6,4	6,3	81,9
Af	3,9	7,5	89,8	6,2	6,1	86,2
Δ = Af - Bf	-0,6	1,0	5,2	-0,2	-0,2	4,3
p (Wilson)	0,63	0,29	0,41	0,66	0,85	0,35

Table 1: Modification of the audiological values introduced by the cleaning, according to the coding strategy; Bf is “before, Af is “after”.

	Cochlear® "Brush" (2a)			Cochlear® "Filter" (2b)		
	$x_{50\%}$	$\Delta_{75-25\%}$	m_{ax}	$x_{50\%}$	$\Delta_{75-25\%}$	m_{ax}
Bf	5,1	7,0	90,5	6,2	6,5	83,5
Af	4,8	6,8	92,0	6,1	7,3	89,5
Δ = Af - Bf	-0,3	-0,2	1,5	-0,1	0,8	6,0
p (Wilson)	0,67	0,94	0,73	0,96	0,62	0,19

Table 2: Modification of the audiological values on the Nucleus implant according to the cleaning procedure; Bf is “before, Af is “after”.

3.4 Comparison of the CIS and NofM strategies

In this subsection the percentages obtained using the two coding strategies were compared before and after cleaning (figure 5). The cleaning procedure was “brush and blow”.

The CIS strategy led to better performances mostly in the SNR range 0 to 12 dB (figure 5a).

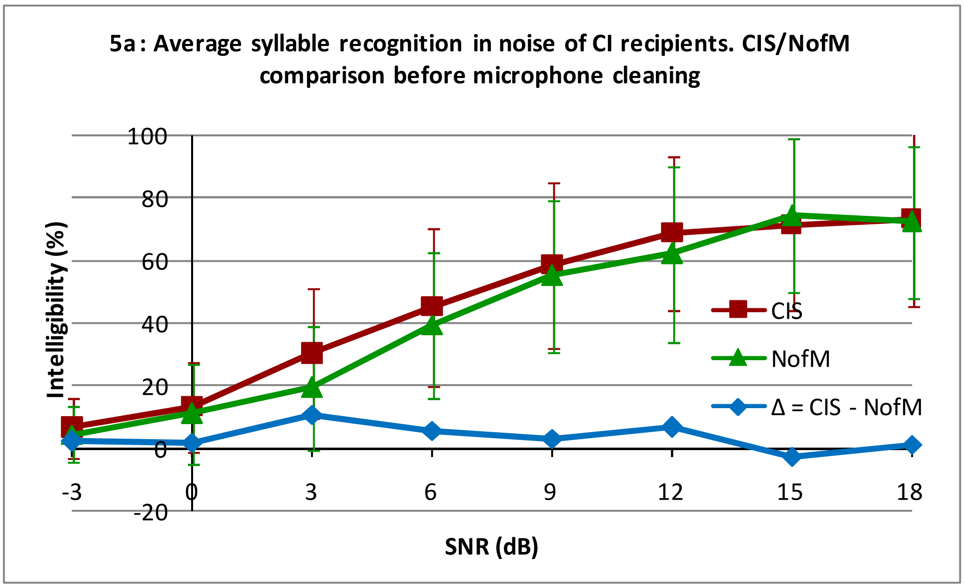
On figure 5b (after microphone cleaning) we observed that the results obtained with the NofM strategy were better than those obtained with the CIS for the high values of the SNR (15 to 18 dB).

The difference was about 10% (2 syllables in the Fournier’s lists).

These results are similar to those obtained in simulation [5].

They suggest that the CIS coding may lead to a better recognition when the SNR is in the (0-6dB) interval; NofM may be better in quiet or for low noise levels with a clean microphone.

A suggestion can be made: it may be useful to adjust the coding strategy according to the surrounding conditions. This point should be seen again in the future.



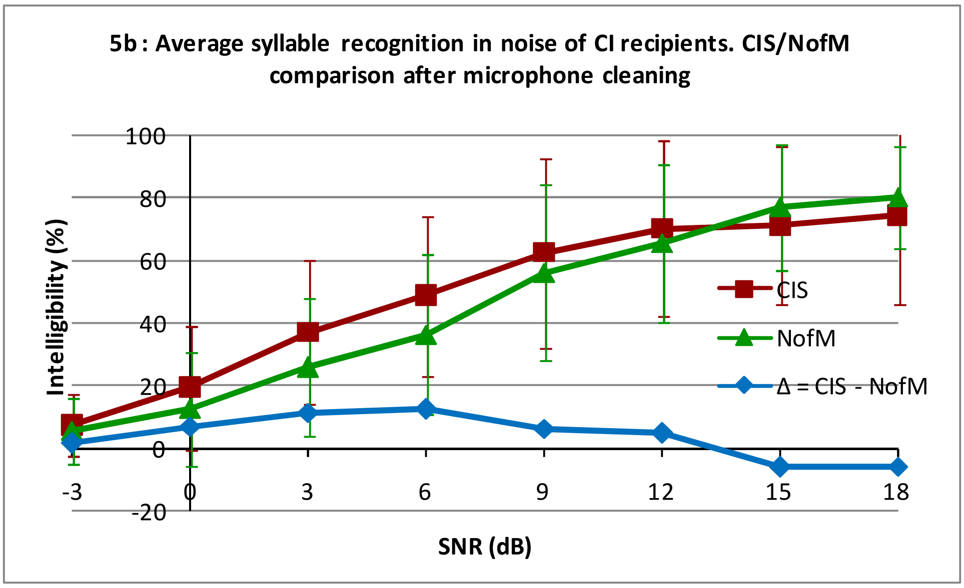


Figure 5: Recognition percentages before and after cleaning, with respect to the SNR; coding strategies are compared. Figure 5a (top) is before cleaning and figure 5b (bottom) is after cleaning.

For the two coding strategies the maximum percentages, given by y_{max}, were between 80 and 85% before cleaning. After cleaning they were between 85 and 90%. The improvement was one syllable per list.

The differences were not significantly different from zero.

Thus, as CIS and NofM are identical when N = M, a study on the effect of N is worthwhile to be explored [15].

4 Conclusion

In this study we evaluated the effect of cleaning the microphone of CIs. Fifty-nine subjects were included in this study; 19 used the CIS strategy and 40 used NofM.

Performances were the recognition of the syllables in the Fournier's dissyllabic words lists. The lists were mixed with a cocktail party noise. The acoustic material was then delivered to the CI users, before and after cleaning the implant processor microphone.

Two cleaning procedures have been studied: "brush and blow" and "filter replacement". The filter replacement procedure was only observed with the implants from Cochlear®.

Results showed that:

-Before cleaning, the recognition percentages observed with the patients fitted with CIS and NofM strategies were similar at high SNRs. For the middle values (SNR ranging from 5 to 12 dB) the results obtained with the CIS strategy were better than those obtained using NofM. The improvement was around 5% (one syllable per list).

-After cleaning the microphone, the CIS strategy led to higher recognition percentages in the SNR range 0 to 12 dB.

These results are similar to those observed in simulation with normal hearing subjects.

In the present work the differences were rarely significant. Studies with more homogeneous populations should be considered in the future.

About the cleaning procedure ("brush and blow" versus "filter replacement") the score improvements were better when the filter was replaced.

With the CIS strategy this improvement was mainly noticed for the SNRs 0, 3 and 6 dB. With the NofM strategy, the improvement brought by the cleaning was mainly noticed for 18 dB SNR.

The recognition percentages, versus the SNRs, have been fitted by a sigmoid regression curve allowing the determination of audiological characteristics, such as the SNR for 50% recognition, the recognition slope when the SNR was increased and the theoretical maximum value of the recognition (top asymptote). The 5% improvements induced by cleaning the microphone's inlet port, were confirmed.

Following this work future studies can be suggested, such as increasing the number of CI users and take more homogeneous populations, considering the influence of the number of global and activated channels (M & N), and investigating the efficiency of the strategies according the external conditions (SNR for instance).

Acknowledgements

The authors are grateful to the people and the institutions who helped them in this study: M. Fabien Millioz for the scientific support, the CRIC members of the ORL department from the Edouard-Herriot hospitals in Lyon who adapted the periodical check of the patients in order to include this study, the Hospitals of Lyon for the promotion of this work, and the Polytechnic school of the university of Lyon and the AMSE referrers for the improvements suggested to this paper.

References

1. B. Al-Diri, A. Sharieh, M. Qutiashat, “A speech recognition model based on tri-phones for the Arabic language”, AMSE Journals, Series Advances B, vol 50, no 2, pp. 49-63, 2007.

2. T. Balkany, A. Hodges, C. Buchman, W. Luxford, C. Pillsbury, P. Roland, J. Shallop, D. Backous, D .Frantz, J. Graham, B. Hirsh, M. Luntz, J. Niparko, J. Patrick, S. Payne, F. Telichi, E. Tobey, E. Truy, S. Staller “Cochlear implant soft failure consensus development conference statement”, Otol. Neurotol, vol 26, no 4, pp. 815-8, 2005.

3. R. Batmer, G. O’Donoghue, T. Lenartz “A multicenter study of device failure in European cochlear implant centers”, Ear Hear, vol 28, no 2 suppl, pp. 95S-99S, 2007.

4. P.A. Cucis, C. Berger-Vachon, E. Truy, H. Thai Van, F. Millioz, S. Gallego « Influence de la stratégie de codage de l’implant cochléaire sur la reconnaissance de syllabes en milieu bruité » Handicap 2016 Conference, IFRATH, Paris, June, 2016.

5. P.A. Cucis, E. Veuillet, E. Truy, H. Thai Van, F. Millioz, S. Gallego “Coding strategy robustness related to microphone integrity in cochlear implants using the recognition of syllables in a noisy environment” Companion paper submitted to the AMSE journals.

6. G. Clark “Cochlear implants: fundamental and applications” Springer Verlag, 2003

7. M. Dorman, P. Loizou, J. Fitzke, Z. Tu “The recognition of sentences in noise by normal-hearing listeners using simulation of cochlear-implant signal processors with 6-20 channels. J Acoust Soc Am, vol 104, no 6, pp. 3583-5, 1998.

8. M. Dorman, P. Loizou, A. Spahr, E. Maloff “A Comparison of the speech understanding provided by acoustic models of fixed-channel and channel-picking signal processors for cochlear implants. J Speech Lang Hear Res, vol 45, no 4, pp. 783-8, 2002.

9. T. Green, A. Faulkner, S. Rosen “Spectral and temporal cues to pitch in noise-excited vocoder simulation of continuous-interleaved sampling cochlear implants” J Acoust Soc Am, vol 112, pp. 2155-64, 2002.

10. S. Kerber, B.U. Seeber, B.U. “Sound localization in noise by normal-hearing listeners and cochlear implant users”. Ear Hear, vol 33, no 4, pp. 445-57, 2012.

11. Q. Nam Tran, H. Arabnia “Emerging trends in computational Biology, Bioinformatics and System Biology”, Moran Kauffmann publishers, Elsevier, 2015.

12. K.Perreaut, S.Gallego, C.Berger-Vachon, F.Millioz « Influence de l’encrassement du microphone sur les performances de l’implant cochléaire. Etude préliminaire en simulation des codages CIS et NofM », Conference Handicap 2014, Ifrath, Paris, June, pp. 169-173, 2014.

13. S. Razza, S. Burdo, S. Bonaretti “Acoustical signal check: microphone integrity evaluation through a common hearing aid analyzer”, 5th Objective Measures Symposium in Cochlear Implants and ABI; Varese, Italy, May 19-22, 2007.

14. S. Razza, S. Burdo "An underestimated issue: unsuspected decrease of sound processor microphone sensitivity, technical and clinical evaluation" Cochlear Implants Int, vol 12, no 2, pp. 114-23, 2011.

15. F. Seldran, S. Gallego, H. Thai-Van, C. Berger-Vachon "Influence of coding strategies in electric-acoustic hearing: a simulation dedicated to EAS cochlear implant in the presence of noise", Applied Acoustics, vol 76, pp. 300-30, 2014.

16. T.S. Sinha, G. Sanyal, "Modeling and simulation of neuro-genetic based speech and speaker recognition", AMSE Journals, Series Advances B, vol 51, no 1, pp. 48-64, 2008.

17. B. Wilson, C. Finley, J. Farmer, D. Lawson, B. Weber, R. Wolford, P. Kenan, M. White, M. Mezernich, R. Schindler "Comparative studies of speech Processing Strategies for Cochlear implants", Laryngoscope, vol 98, pp. 1069-77, 1988.