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Influence of Microphone Encrusting on the Efficiency of Cochlear Implants Preliminary Study with a Simulation of CIS and "n-of-m" Strategies

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Abstract

Ageing of hearing aids and prostheses is, nowadays, an important issue in our world dominated by the shortage of money affecting the replacement of medical devices.

In this work, we consider the consequences of the encrusting of the microphones in the case of cochlear implant and its links with the coding of acoustic signal.

This preliminary study explores the influence of two classical coding strategies and leads the way toward a comprehensive experiment including a sufficient number of control subjects and implantees.

Disyllabic words have been considered in this work (Fournier's lists) and they were delivered to three normal hearing subjects after being processed according to a simulation of two classical strategies seen with cochlear implants "CIS" and "n of m".

First results indicate that a small encrusting of the microphones does not affect badly recognition performances. Then, when listening conditions are not too adverse (positive SNR, weak encrusting) CIS strategy may lead to higher performances.

Following these results, it is worthwhile to go ahead toward the comprehensive study.

Key words:

Microphone encrusting, cochlear implants, CIS and "n of m" strategies, simulation of acoustical signal coding.

1) Introduction

Ageing and incrusting of equipment are two classical issues affecting medical devices. The functioning of the machines is affected [1,2] and it is necessary to study this effect in order to reduce its consequences.

In the case of deafness rehabilitation, a microphone starts the acquisition procedure. This microphone is subject to ageing and the deterioration of its membrane (mostly by the increasing of stiffness caused by dust and small particles encrusting) cannot be neglected [3,4]. The corrupted signal will be treated through successive steps in the machine.

This phenomenon has been considered with classical hearing aids and it is worthwhile to see it with cochlear implants (CIs). CI is used for the rehabilitation of deep cophosis, and this technology is, nowadays, widely used. More than 1,000 CI are fitted every year in France, and 15,000 to 20,000 CI are fitted throughout the world.

A study, on a sufficient scale, with the implantees and with control subjects cannot be undertaken without the approval of the ethic committee. Prior to this step, a pilot study is

necessary to see if the work can be continued and also to argue the matter when writing the manuscript to be submitted to the ethic committee.
In this pilot study, two classical coding strategies used in CI have been simulated [5, 6, 7]. The coded signal has been presented to normal hearing subjects, in the conversational acoustic range. The validity of this approach has been raised and specific studies [8,9] indicated that the main results obtained with this simulation can give a reasonable idea of what can be expected with the implantees. Also, coding strategies are concerned and the question of their behavior when they are fed by a deteriorated signal, needs to be discussed [10,11].
In this work, the influence of microphone alteration, in the case of cochlear implant coding, is considered through a pilot study.
The paper is organized as follow: the technique and the acoustic material are described (section 2), results and their discussion are presented (section 3) and finally a conclusion and some future prospects are indicated (section 4).

II) Material and methods

2.1 Signal processing in CI

CI is a prosthesis performing a transduction between the acoustic signal (input) and the electrical stimulation (output) which is finally delivered to the electrodes situated in the inner ear.
In this work, the simulation of coding will be represented with two parts, Fig. 1:

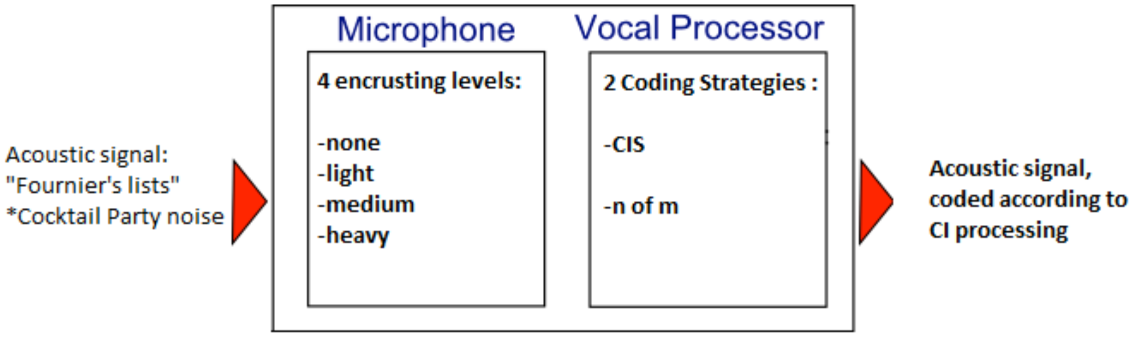


Fig. 1. Bloc diagram of the system : « Microphone + Cochlear Implant »

-the microphone, more or less deteriorated, mostly following an encrusting occurring over the time,
-the vocal processor in charge of coding the signal with two strategies, CIS (Continuous Interleaved Sampling) and "n of m" (n channels are taken on m possible). These strategies will be seen again in the simulation section.

2.2 Analysis of the microphones

a) Microphones

The company Knowles Electronics (Ataska, Illinois) is the leader in this field of transducers and their microphones are fitted on conventional hearing aids and cochlear implants. Microphones are usually omnidirectional.
In our work, the microphones transfer function were calculated using a classical Aurical device, which was the analyzer. In the Aurical, the input signal sweeps the frequency range from 200 Hz to 8,000 Hz; the intensity level was 60 dB. Different hearing aids provided the

material tested in this work (Trade marks were Otikon, Phonak, Siemens, Starkey); all of them were fitted with Knowles microphones. Measurements were performed on the hearing aids belonging to hearing impaired people who came to audiology laboratories for periodical checks. All the hearing impaired people agreed with the testing of their material. Usually, the frequency of these checks is 3 to 4 times a year.
For each hearing aid, two measures were performed: first after a deep cleaning of the output earphone, leading to the situation "clean earphone and dirty microphone", second after cleaning the microphone, leading to the situation "clean earphone and clean microphone".

b) Microphone sensitivity evaluation
The influence of microphone cleaning can be evaluated between these two situations; it was given in decibels (dB) for each frequency. The alteration of the microphone was mostly due to the encrusting of its membrane.

Four encrusting levels (categories) have been considered
-c1: no encrusting,
-c2: weak encrusting, corresponding to the encrusting of 50% of the microphones,
-c3: middle encrusting: corresponding to the 20% more encrusted microphones (percentile 80%),
-c4: Strong encrusting: corresponding to the 10% more encrusted microphones (percentile 90%).
In our experiment, the spectral analysis of the signal was modified, frequency by frequency at the input of the simulator, by subtracting the encrusting values corresponding to the four categories indicated above.

2.3 CI simulation
The simulator used in this work was constructed according to the vocoder principle. It is represented in Fig. 2.

Main signal processing steps were:
-the signal was captured by a microphone. Then, it entered a pre-emphasis filter (cutoff frequency was 1.2 kHz with a slope of 12 dB per octave),
-then, a FFT (Fast Fourier Transform) analyses the signal. Spectral beams were grouped into m=20 frequency bands logarithmically distributed according to the ear physiology. Analysis windows were 8 ms (milliseconds) and the sampling frequency was 16 kHz. Consequently, each window had 128 samples leading to 64 spectral beams equally spaced (125 Hz).
-at the end of this analysis, the n electrodes with the highest energy were selected for the CIS strategy. In this work 8 channels (n=8) were taken.
-in each frequency band, the energy was determined by the sum of the square of each spectral beam (Parseval's theorem),
-finally, a narrow band noise was taken for each channel. Its amplitude was proportional to the energy detected in each channel. The output signal was constructed by summing the n selected channel energies. For the first two-channel (which were very narrow) the stimulation is practically a sine wave.

2.4 Acoustic material

a) Fournier's lists (vocal signal)
Considering the difficulty of the test, we chose the lists suggested by Jean-Étienne Fournier. They contain disyllable words which are equivalent to the American "spondee lists".

Each list contains 20 words (for instance “le bouchon” = “the cork”). Forty lists are available. The recognition unit was the syllable.

b) Noise

A cocktail party noise is provided with the Fournier’s lists. It is composed by the mixing of 8 voices of French speaking persons: 4 males and 4 females.

This noise was added to provide a regular masking throughout the test.

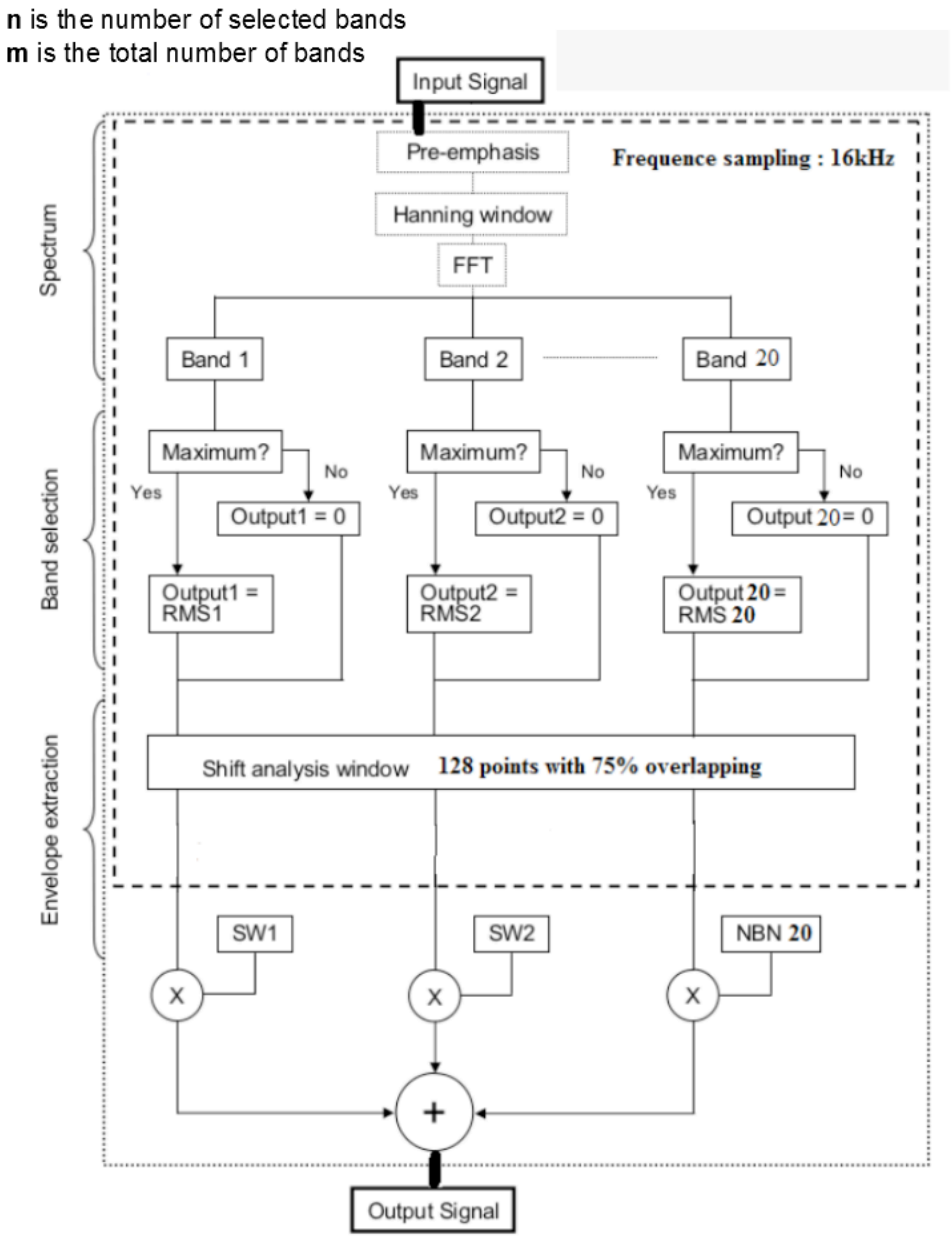


Fig. 2. Representation of cochlear implant coding

c) Acoustic signal

The acoustic signal delivered to the input microphone is a mixing of the noise and the Fournier’s words.

The signal was kept below 70 dB, 10 dB less than the maximum level admitted for professional exposition.
Six Signal to Noise Ratios (SNR) have been considered: -3 dB, 0 dB, 3 dB, 6 dB, 9 dB and 12 dB. The amplitudes of the tracks (signal and noise) can be adjusted in order to get the desired SNR.

d) Parameters
Eight situations have been considered:
-4 encrusting levels
-2 coding strategies
Each situation has been seen with the six SNRs.
Finally, 1920 files (2*4*6*40) have been constructed. The delivery of the lists was randomized.

2.5 Listeners
Three normal hearing subjects participated to this pilot study. Mean age was 42; the youngest was 25-year old and the oldest was 51-year old.
The auditory thresholds (hearing levels) of the subjects were tested prior to the listening session and the losses were below 20 dB for the frequencies ranging from 250 to 8000 Hz (with semi-octave steps).
According to the BIAP (French Bureau for Audio-Phonology International Office), the subjects were considered as normal hearing listeners.
Before the tests a short training session was performed to explain the rule to the listeners and to accustom them to the words.

III Results and discussion

3.1 Microphone study
Ninety-eight hearing aids were tested in this work, and their microphone transfer functions were calculated. The frequency range was 200 Hz to 6,300 Hz. The resolution was a third of octave. Out of this range, frequency measurements are not reliable; classical hearing aids are usually limited to this range.
1,568 frequency values were taken, and 1,206 were kept. The loudness of the input signal was 60 dB, and the output values below 60 dB (352 values) were rejected (lack of amplification) in this preliminary study. This step will be seen again in future. The microphones incrusting curves are presented on Fig. 3.

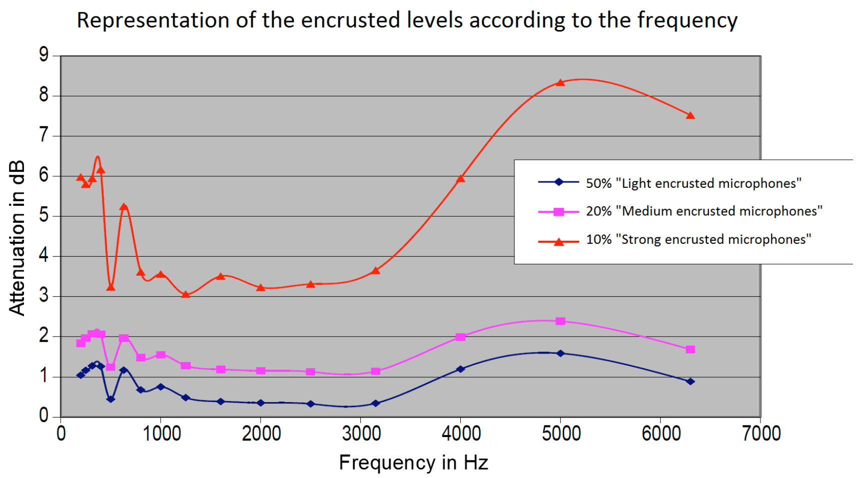
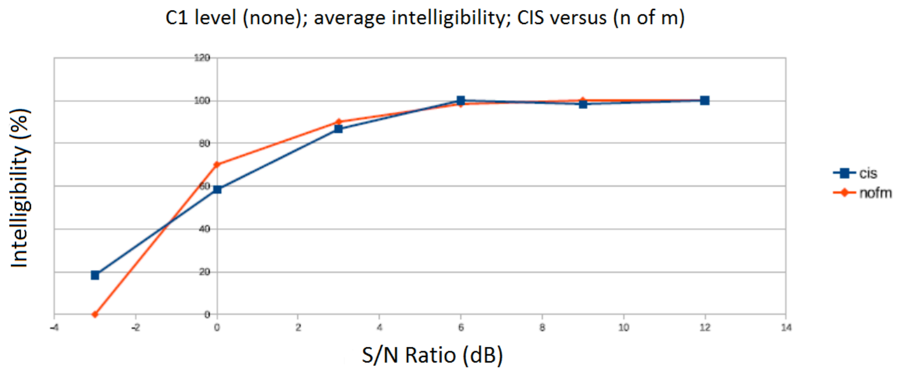
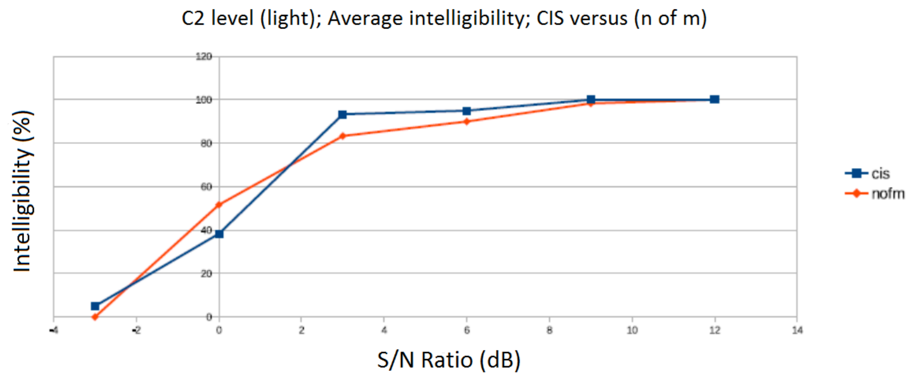


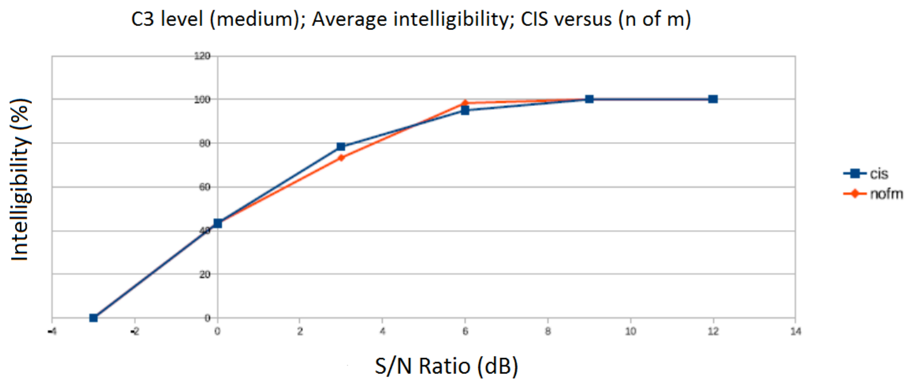
Fig. 3. Representation of the microphones « encrusting » according to the frequency, given in percentiles

3.2 Fournier's lists intelligibility

The recognition percentages, for each condition (encrusting + strategy), were evaluated for the six SNRs. Results are indicated on Fig. 4.







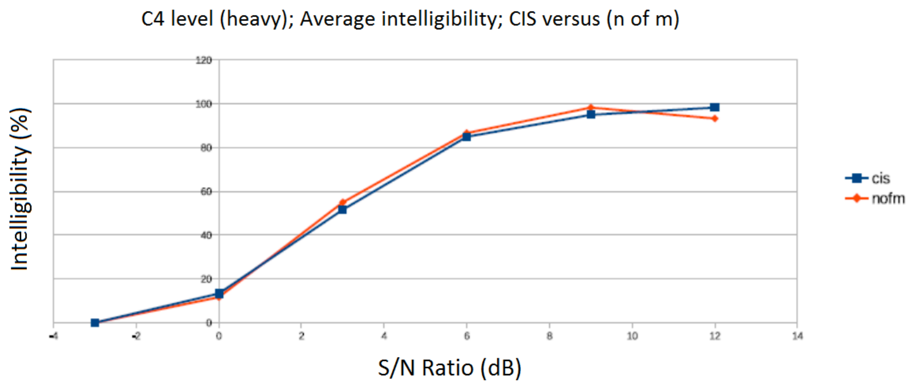


Fig. 4. Recognition percentages according to the microphone encrusting level (C1=none, C2=light, C3=medium, C4=heavy)

The curves are rather similar and, at this stage, it is rather difficult to separate the coding strategies CIS and “n of m”.

3.3 Encrusting influence

The influence of the encrusting, on syllable recognition, is represented on Fig. 5. These curves are a grand average (average on each listener and average among the listeners).
The more the encrusting, the less the performance, as expected.
Main differences were observed for the 0 dB SNR (signal and noise have the same intensity).
Also, when the encrusting is light, the performances are hardly altered.
At 0 dB SNR the performances differences can be 50%. Also, when the SNR is low (below 3 dB) or high (above 6 dB) differences are much smaller

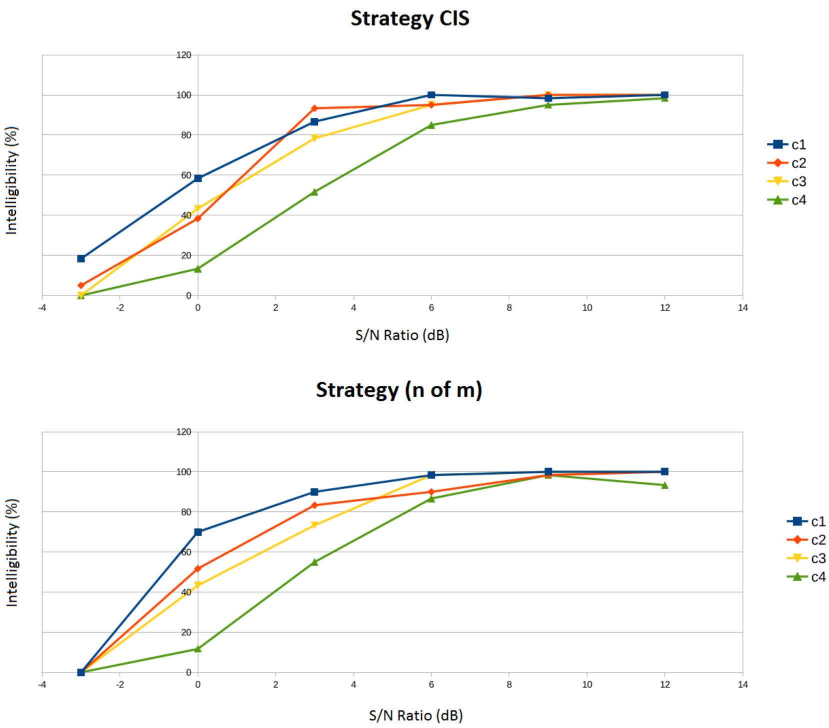


Fig. 5. Intelligibility according to the coding strategy and the microphone encrusting

3.4 Strategy influence

The differences in percentages, between the strategies, are indicated on Fig. 6.

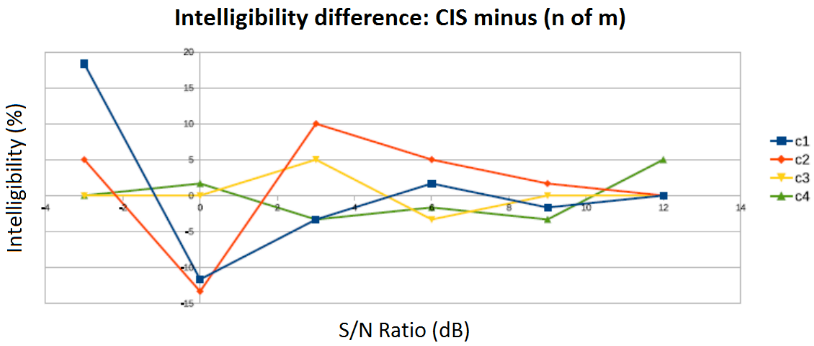


Fig. 6. Comparison of the strategies CIS and (n of m)

The differences indicated are CIS – "n of m" with the four encrusting levels.
Fig. 6 shows that the curve c2 is clearly positive in the 3 to 9 dB range. An explanation could be that CIS keeps its efficiency when the microphone is lightly encrusted and when the SNR is not adverse. Obviously, this suggestion should be seen with more subjects and with a sufficient number of implantees to be statistically validated.

3.5 General discussion

The results obtained in this work open the way to further investigations. They have been obtained in simulation with a limited number of subjects. A new study will be undertaken as soon as the ethics committee allows it.
Furthermore, the study on the microphones needs to be reconsidered; we need to understand why the signal was sometimes lowered by the hearing aid.
To sum up, the first findings seen in this work indicate that when the microphones are slightly encrusted (50% of the population) recognition performances were satisfactory.
About the coding strategy, CIS seemed to be better than "n of m", when the microphones are not badly deteriorated (slightly encrusted condition) and when the SNR is not to low. Following the curves presented in Fig. 5, results seem to be rather stable when the SNR is above 3 dB, with the CIS strategy.
Consequently, it is necessary to continue this investigation in order to validate (or to eliminate) these first trends.
Another advantage of this pilot study is to point out the necessary requirements of a work which will be made on a larger scale.
Also, this experiment pointed out the need of a good collaboration between MDs, audiologists, scientists and industrials.

IV Conclusion

This study was based on the deterioration over the time (mostly encrusting) of the microphones used in hearing aids. Then, the signal was processed in order to simulate the acoustic signal processing processed in CI.

The following results have been indicated:
-a small encrusting of the microphone does not alter too much the recognition performances,
-CIS strategy may be more robust than "n of m", when the listening conditions are good (SNR ranging from 3 to 9 dB),
-the microphone testing should be reconsidered.

Now, we must validate these hypotheses with patients fitted with a cochlear implant, and with a sufficient number of subjects allowing a statistical analysis.

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