THE EFFECTFS OF HEARING AID FITTING ON TINNITUS

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ABSTRACT

Purpose : To develop a comparative method of different hearing aids fittings to attenuate tinnitus perception and to optimize hearing aid settings to manage tinnitus.

Protocol : Subjects (n = 18) gave their personal details before taking an audiometric test and a tinnitus test. This last assessment allowed to quantify the intensity of tinnitus perceived with a visual analogue scale (VAS), and to obtain the Minimum Masking Level (MML) and the Minimum Residual Inhibition Level (MRIL), using a method developed in 2016 by A Noreña. This method was used with and without hearing aids, in order to compare MML and MRIL obtained with various stimuli and hearing aid fittings.

Results : The psychophysical method developed by A Noreña is effective to compare MML and MRIL in various conditions. Without hearing aids, the lowest MMLs and MRILs are obtained for a narrow band noise centered on the frequency of tinnitus. With hearing aids, there are methods with an over-amplification at the tinnitus frequency and an over-amplification ½ octave below the tinnitus frequency which were most effective for tinnitus management. On average, tinnitus loudness perception decreased by the end of the study.

INTRODUCTION

Tinnitus is the phenomenom of hearing sound without any external sound sources (Jastreboff & Hazell, 1990). This hearing sensation can be felt in one or both ears, or in the head. Their occurrences can be very varied as can the inconvenience they cause. Tinnitus etiology is mainly idiopathic but there are several hypotheses about the mechnisms behind these phantom perceptions (Noreña & Farley , 2013 ; Noreña , 2011). There are also several therapeutic methods / treatments.

The fitting of hearing aids is a good treatment for tinnitus management, especially since 80% of tinnitus patients also have hearing loss (Beste & Stei-Lesniak, 2006). Many studies suggest a real benefit from hearing aids (HA) in tinnitus management (Hoare et al., 2014 ; Parazzini et al., 2011; Schaette et al., 2010; Moffat et al., 2009 ; Searchfield et al., 2010). However, none of them specifies how to fit them in these specific patients. The majority of hearing aid specialists fit them empirically, but would it not be worthwile to subjectively assess the effectiveness of HA methodology for tinnitus reduction?

Currently, there is no standardized method to evaluate this. It could be used to determine if one fitting method provides better results than another in reducing tinnitus.

This project is an exploratory study which builds on the reseach work carried out by A Noreña which validated a new psychophysical method allowing to assess the masking and residual inhibition of tinnitus. The purpose of this study is to use this innovative technique to compare the effects of HA fitting method on tinnitus. The main hypothesis is that a « more efficient » fitting method should bring lower MML and MRIL compared to other fittings.

METHODS

EQUIPMENT USED :

Assessments were carried out in a soundproofed room, according to standards set by article D4361-19 of the Public Health Code.

- *Audiometer and transducer :* MADSEN Astera^2 (GN Otometrics) allowing, with audiometric headphones HDA 300

(Sennheiser), high frequencies (HF) hearing tests up to 16 000 Hz.

- *Probe Microphone Measurement (PMM) :* AURICAL FreeFit (GN Otometrics).
  Probe microphones were calibrated for each subject.
- *Loudspeaker :* Inspire T10 (Creative). Given its non-linearity, we weighted the MATLAB program script which allows to generate sound stimuli in free field.
- *Software :*
  - Noah 4 : regroup our patients database, Signia (Connexx8) manufacturer software and audiological software (GN Otometrics)
  - MATLAB, to generate specific stimuli from A Noreña program
  - XLSTATS, for statistical analysis
- *Hearing aids (HA) :* in order to keep testing time down, we selected only one hearing aid model : *Signia Pure 7px* (20 tuning channels, up to 12 kHz bandwitdth), with M headphones (55/119). This is a Receiver In Canal (RIC) HA, with an algorithm dedicated to tinnitus treatment, « Tonal Tinnitus Therapy », which is useful to include in experiment.

STUDY PROTOCOL :

- *Origin of tinnitus :* at the beginning of the study, we gathered information on the subject hearing history (pathology or surgery) and on subject's tinnitus : left/right ear, age, fluctuating and pulsating, circumstances, other, their influencing factors and perceived intensity at the beginning and the end of the study, using a visual analogue scale (VAS).
- *Audiometry :* examining the ears with an otoscope to checked for blockages in the external auditory canals. We assessed air conduction thresholds with the HF headphones and with a pulsed pure tone (250 ms/ 250 ms) in order to help subjects to dissociate the stimulus from their tinnitus. Thresholds were measured by a step of 2 dB. When we reached the limits of the audiometer to establish a threshold (hearing or discomfort), we added an arbitrary value of 5 dB to the previous frequency threshold value.
  - *Hearing Threshold Level (HTL) :* perception thresholds obtained by descending method at 0.125 to 8 kHz (by ½ octave steps), then HF 10, 12.5 and 16 kHz and the tinnitus frequency.
  - *Uncomfortable Level (UCL) :* thresholds obtained by the ascending method at 0.5 to 8 kHz (by octave) and the TF. Instructions given : « *sound intensity will gradually increase, give me a sign when it becomes too strong, uncomfortable* ». Between each increment of 2 dB, there was a little downtime for every subject in order for them to say if their discomfort level was being reached.
- *Tinnitus testing :* air conduction with the HF headphones and with a continuous pure tone (facilitating tinnitus matching).
  - *Pitch matching :* to find the tinnitus frequency, at 1/12th octave, with a pairing method with an external sound (forced choice).
  - *Loudness matching :* variation of the pure tone intensity with 2 dB steps, until reaching a similar level to the tinnitus, at the TF and at 1kHz (this is a reference : at this frequency, HTL is usually normal and there is no loudness recruitment phenomenon).
  - *Minimum Masking Level (MML) and Minimum Residual Inhibition Level (MRIL), without HA :* these levels were obtained from a program developed in MATLAB by A Noreña. MML and MRIL were recorded for 3 different pulsed stimuli, generated in free field via the loudspeaker and from this program : pink noise (PN) and two narrow-band noises (one octave bandwidth) ; one centered on the TF (NB TF) and the other centered on the reference frequency 1 kHz (NB 1kHz). The intensity of these sounds varied by 3 dB steps. The set of these stimuli had a similar temporal sequence (Figure 1):

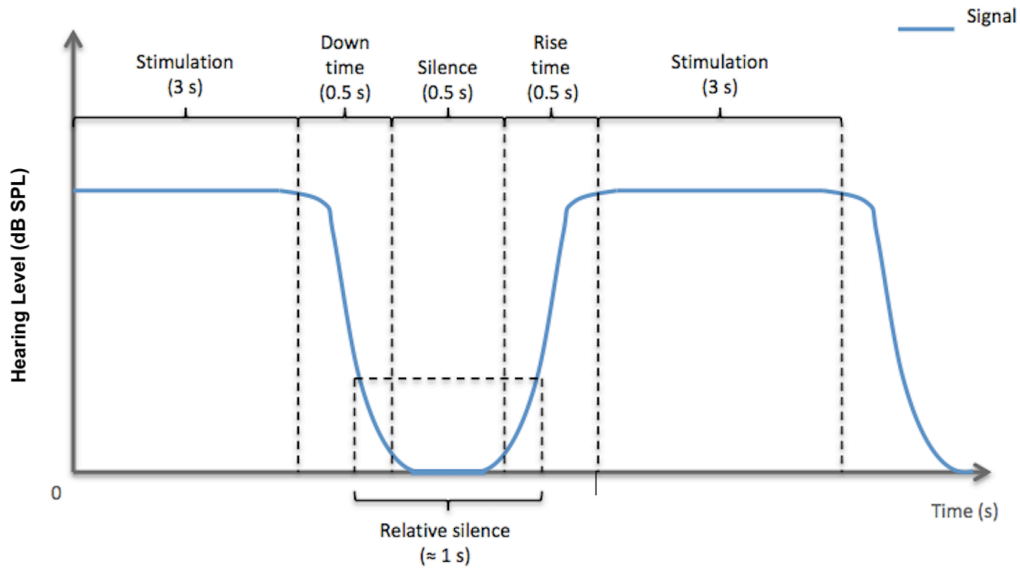


Figure 1 : Temporal sequence of the signal issued by MATLAB

The Minimum Masking Level (MML) corresponds to the lowest level of sound intensity required for a stimulus to mask / just cover the tinnitus, meaning that the subject no longer perceives tinnitus during signal issue. The Minimum Residual Inhibition Level (MRIL) corresponds to the lowest level of sound intensity required for a stimulus to « delete » perception of tinnitus (Feldmann, 1971) during the silent period of about one second of a pulsed signal. If this level is unattainable and reaches the maximum intensity tolerated by the subject before tinnitus completely disappears, the subject evaluated the level of tinnitus, using the VAS, at this maximum (intensity) level.

- *Hearing aids fitting :* ear moulds were chosen (open domes, tulips, closed domes, double domes) depending on the subject's hearing loss (especially low frequencies HTL), but in 78% of cases, open domes or tulips were chosen. The frequency compression was deactivated like other algorithms. HA were fitted with PMM : matching between output curves and targets prescribed by NAL-NL2 methodology, which was considered as the reference methodology. First, an ANSI speech noise was sent at 65 dB SPL, to fit the HA master gain, then the « International Speech Test Signal (ISTS) » at 50, 65 and 80 dB SPL to fit compression factors.

The order of different fittings was randomized, except for the reference setting (NAL-NL2), which was fitted first. Hearing aid fittings tested were :

- NAL-NL2 (reference)
- NAL-NL2 + bell over-amplification of 10 dB on TF
- NAL-NL2 + bell over-amplification of 10 dB below the TF (TF - ½ octave)
- NAL-NL2 + Signia algorithm (notch of 25 dB centered on TF, half-octave wide)

« Bell » term means that adjacent channels to the over-amplified channel are automatically amplified by a minimum value, imposed by the manufacturer, to limit hearing artifact. To achieve the characteristic fittings of each methodology relative to the reference (NAL-NL2), the master gain was modified without changing the compression factors.

- *Minimum Masking Level (MML) and Minimum Residual Inhibition Level (MRIL), with HA :* for the 4 hearing aid fittings, once the master gain desired had been reached, sound level intensity was gradually varied by 3 dB increments in order to obtain the minimum masking level (MML) then the minimum residual inhibition level (MRIL). For these measurements, the stimulus was the same pulsed noise PN (same characteristics) as that generated during the tinnitus testing with MATLAB.

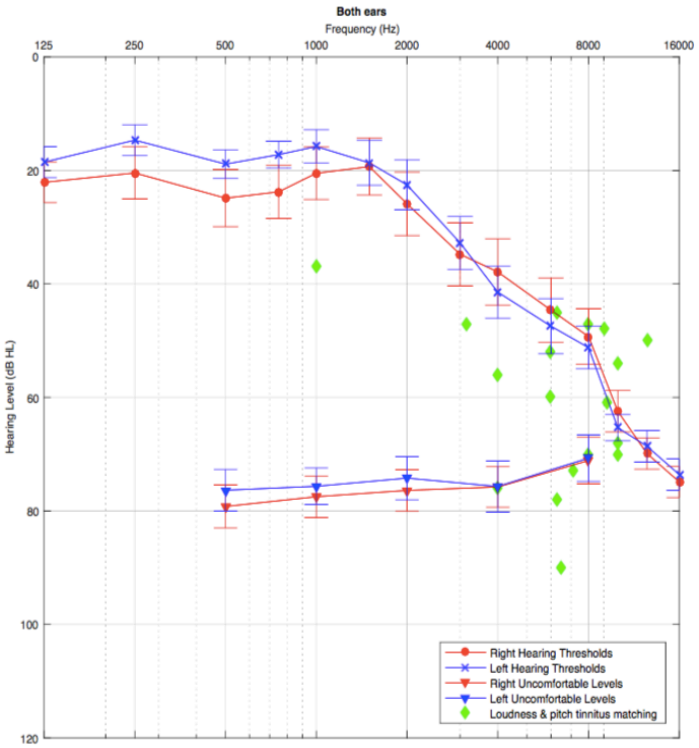
PARTICIPANTS

Recruitment of subjects was carried out on a voluntary basis : on site, by asking University of Aix-Marseille (AMU) and the National Center for Scientific Research (CNRS) staff and by soliciting follow-up patients at the Mediterranean Institute for Reseach and Treatment of Tinnitus (IMERTA), located at the Medical Ceter Clairval, Marseille.

- *Criteria for participation in the study :*
  - *Exclusion criteria :* subjects suffering from Meniere's disease.
  - *Inclusion criteria :* subjects with chronic tinnitus (for more than 6 months), unilateral or bilateral, with associated hearing loss, aged between 18 and 80, with or without hearing aids.
- *Participants :* a total of 20 subjects took part in the study, but 2 of them were removed from the results because the data collected were incomplete or invalid. So, the group consisted of 18 subjects, 13 men and 5 women, with an average age of 58.55 years (SD = 5.98 years).

	Lateralization					Fluctuation (stress, fatigue)		Description		Hyperacusis associated		Circumstances			
	RE	LE	Middle (center, head)	Bila-teral	Changing	Yes	No	Pulsing (« cicada »)	Constant (whistling, wind)	Yes	No	Sound trauma	Pres-sure trauma	Do not know	Others
Absolute Freq. (Relative Freq.) relative)	0 (0%)	4 (22%)	2 (11%)	9 (50%)	3 (17%)	15 (83%)	3 (17%)	2 (11%)	16 (89%)	8 (50%)	8 (50%)	6 (33%)	2 (11%)	5 (28%)	5 (28%)

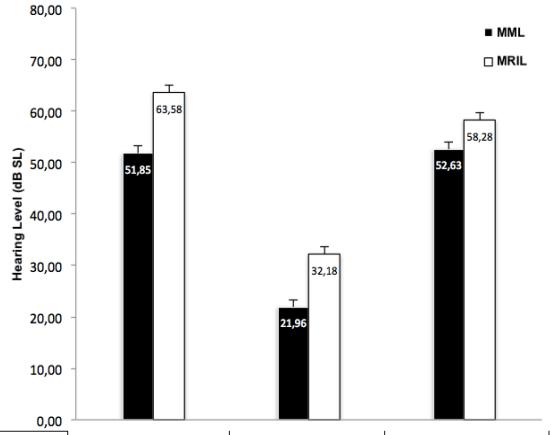
Figure 2 : Summary of tinnitus history for the 18 subjects. Five subjects had « Other » tinnitus circumstances : one subject associated it with a skiing accident (physical trauma), another during a period of great stress (burn-out), one associated it with a period of fatigue, another at a tennis match with a powerful racket (with neck blocked) and the tinnitus of 5th subject occured after a cholesteatome surgery (perhaps related to the sound trauma generated by surgical mill). The average age of onset of tinnitus was 12.73 years (SD = 9.88 years), but three subjects no longer remembered their date of onset.



Severity (IBA)	Absolute Frequency	Relative Frequency	Pure tone average (dB HL)
Normal	7	38,89%	13,75
Mild	8	44,44%	25,96
Moderate I	2	11,11%	42,88
Moderate II	1	5,56%	63,55
Severe I (and more)	0	0%	-

Figure 3 : Audiogram representing HTL and UCL average with tinnitus pitch and loudness matching, and table showing severity of hearing loss according to IBA, for the study population (n= 18). At the left, audiogram with HTL and UCL obtained for the right ears (red) and for the left ears (blue). Error bars represent standard errors. Tinnitus pitch matching the 18 subjects average is 7061 Hz (SD = 2873 Hz) and loudness is matching average is 60 dB HL (SD = 14 dB HL). Tinnitus loudness was also balanced to that of a pure tone 1kHz, where there is no hearing loss, so no loudness recruitment. At this frequency, the average loudness matching is 13.39 dB SL (SD = 9.35 dB SL) when it is 3.22 dB SL (SD = 2.71 dB SL) at the TF, significantly lower ($p < .001$) according to a parametric t test. At the right, the table shows the severity of hearing loss according to the International Bureau for Audiophonology (IBA). The hearing of 7 subjects is considered « Normal » because the calculation used to determine the Pure Tone Average (PTA) is based on 500, 1000, 2000, 4000 Hz, not considering the HF tonal losses. The PTA average of the 18 subjects is 25.18 dB HL (SD = 13.86 dB HL), considered as « mild » deafness by the IBA.

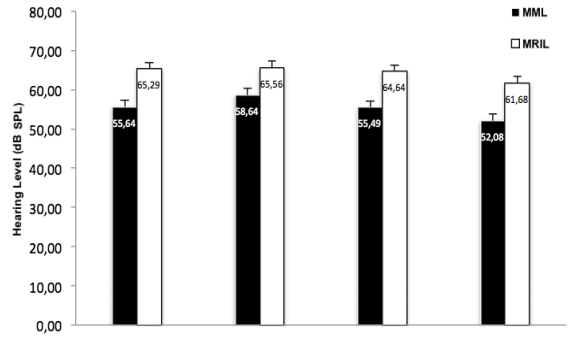
RESULTS



Stimulus type / RI type	PN (n = 13)	NB TF (n = 13)	NB 1 kHz (n = 12)
Persistent	1	0	0
Total	1	1	0
Partial	4	7	2
Absent	7	5	10
Reverse	0	0	0

Figure 4 : Minimum Masking Level (MML) and Minimum Residual Inhibition Level (MRIL) averages, with residual inhibition type obtained for each stimulus, without HA. The order of pulsed stimuli was not randomized. The experiment always started with pink noise (PN), then the narrow-band noise centered on the TF (NB TF), and ended with the narrow-band noise centered on 1 kHz (NB 1 kHz). To express MML and MRIL in dB SL (Sensation Level), the HTL of each central frequency was subtracted from the MML and MRIL values obtained in dB HL. For pink noise, the value of the 1 kHz HTL was used. For some subjects, it was impossible to supress their tinnitus and obtain a value of MML because they did not want to be exposed to a greater sound stimulation : their answers were not retained (PN (n = 5) ; NB TF (n = 4) ; NB 1 kHz (n = 5)). One subject had a persistent residual inhibition (RI) and was therefore unable to continue the study test. For a residual inhibition to be considered « partial », VAS results had to decrease by at least 2 points compared to the one measured at the beginning study. A reverse tinnitus was considered significant only when the VAS increased by at least 2 points. Error bars represent standard errors.

Repeated measures ANOVA analysis, without HA :
A repeated measures ANOVA including two intra-subject factors, measurement type (MML, MRIL) and stimulation type (PN, NB TF, NB 1kHz) was performed on the 9 subjects for whom measurements were obtained, for all conditions. The analyses revealed a significant effect for both factors and for their interaction : Measurement type : $F(1,8) = 40.5$, $p < .001$; Stimulation type : $F(2,16) = 32.7$, $p < .001$; Interaction between them : $F(2,16) = 3.8$, $p = .045$. When the interaction is analysed by post-hoc tests corrected for multiple comparisons (Bonferronni), all the stimulation types differ for MRIL ($p < .05$). But for the MML measurement, all the stimulation types also differ from each other, with the exception of the MML value obtained with the NB 1 kHz, which does not differ from that obtained with the PN.



Methodology type / RI type	NAL NL2 (n = 14)	Tonal Tinnitus Therapy (n = 14)	TF + 10 (n = 14)	(TF - 0.5 oct) + 10 (n = 15)
Persistent	0	0	0	0
Total	4	4	6	4
Partial	6	4	3	7
Absent	4	6	5	4
Reverse	0	0	0	0

Figure 5 : Minimum Masking Level (MML) and Minimum Residual Inhibition Level (MRIL) averages, with RI type obtained for each hearing aids fitting method. Two subjects could not be correctly fitted (hearing loss above 8 kHz, reaching PMM limits and absence of NAL-NL2 targets on HF). These subjects were removed from the results, in addition to subjects who had persistent RI. So, the sample consisted of 15 subjects. The order of different method was randomized, except for NAL-NL2, fitted first. For some subjects, the MML could not be measured below their discomfort values (NAL-NL2 (n = 1) ; « Tonal Tinnitus Therapy » (n = 1) ; TF + 10 (n = 1)). During MRIL measurement, VAS of one subject increased by one point for NAL-NL2 and for « Tonal Tinnitus Therapy », but RI was considered « absent » because there is not a minimum of 2 points increase compared to the beginning of the study. Error bars represent standard errors.

Repeated measures ANOVA analysis, with HA :
A repeated measures ANOVA including two intra-subject factors, measurement type (MML, MRIL) and stimulation type (PN, NB TF, NB 1kHz) was performed on the 13 subjects for whom measurements were obtained, for all conditions. The analyses revealed a significant effect for the main effects, but not for their interaction : Measurement type : $F(1,12) = 20.8$, $p = .001$; Hearing aid fitting method type : $F(3,36) = 6.5$, $p = .001$; Interaction between these 2 non-significant factors : $p = 0.242$.
However, when the interaction is analysed by post-hoc tests corrected for multiple comparisons (Bonferronni), for the MML values, the 3 method conditions differ from each other : « (TF – 0.5 oct) + 10 » vs « Tonal Tinnitus Therapy » : $p < 0.01$; « (TF – 0.5 oct) + 10 » vs « NAL-NL2 » : $p < 0.05$; « TF + 10 » vs « Tonal Tinnitus Therapy » : $p < 0.05$
For MRIL values, hearing aid fitting conditions do not differ from each other.

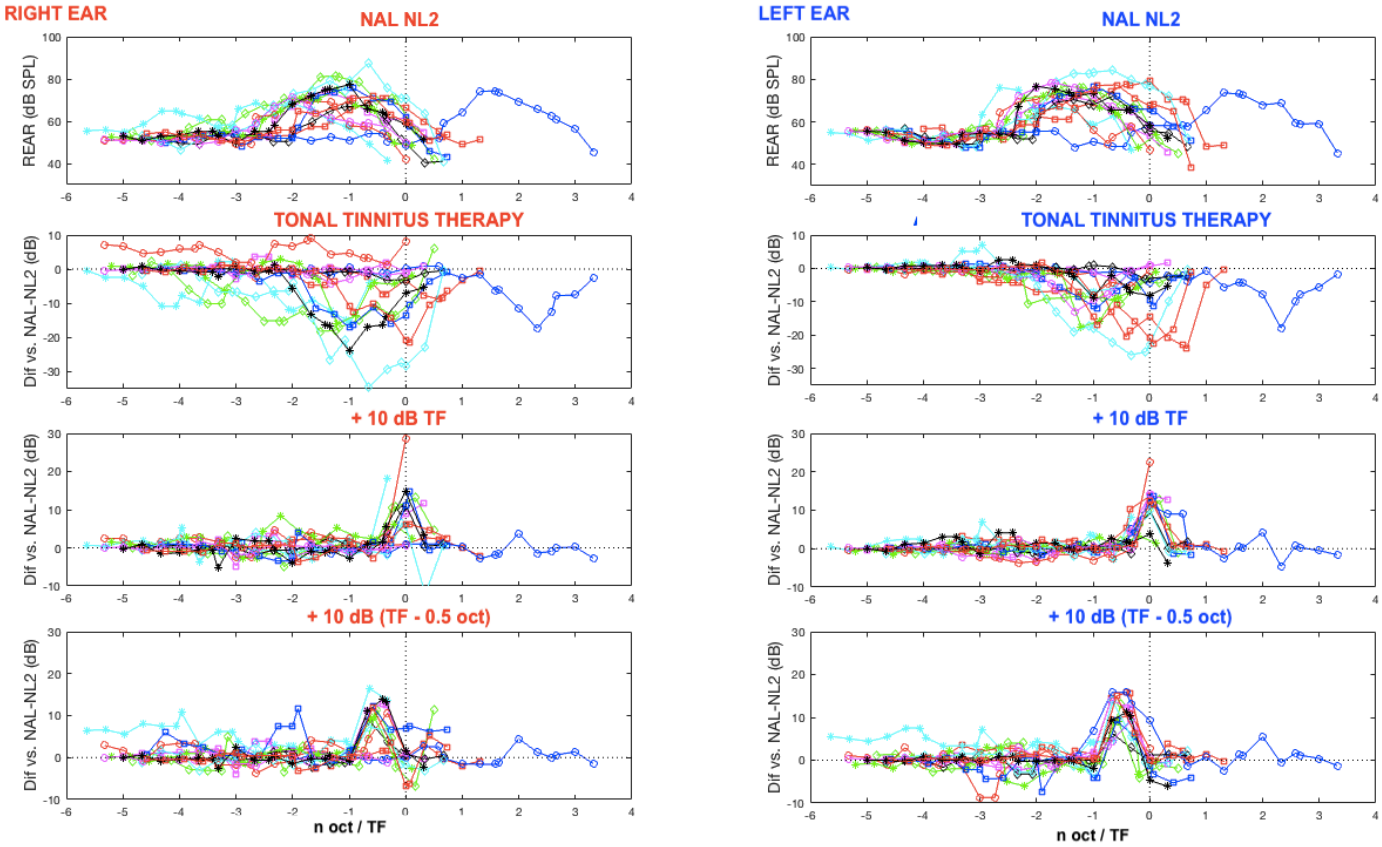


Figure 6 : Graphs of different Real Ear Aided Responses (REAR) obtained using PMM. This graph represents curves acquired with in vivo measurements for 15 subjects paired bilaterally : on the left, measurements collected for right ears (RE) and on the right, measurements collected for left ears (LE). « NAL-NL2 » graphs correspond to the REARs obtained with this method. Other graphs correspond to the gain difference between this reference method (NAL-NL2) and the other methods tested (respectively, NAL-NL2 + « Tonal Tinnitus Therapy », NAL-NL2 + 10 dB on TF and NAL-NL2 + 10 dB (TF - ½ octave).

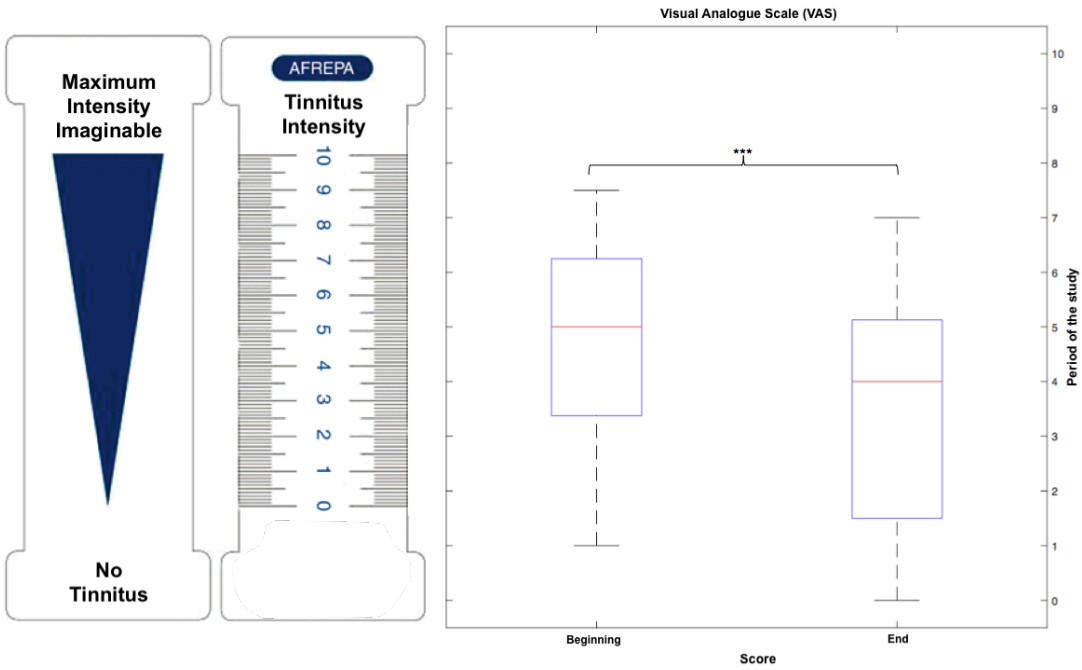


Figure 7 : Visual Analogue Scale (VAS) used to assess the perceived intensity of tinnitus. On the left, the VAS used is similar to that developed by the « Association Française des Équipes Pluridisciplinaires en Acouphénologie (AFREPA) », to assess the perceived intensity of tinnitus. On the right, comparison of VAS at the beginning and the end of the study, for 16 subjects (15 who were tested with HA + the subject who had persistent RI). At the end of study, another subject had a RI persistent. Another subject had a VAS score greater by one point (tinnitus perception stronger). At the beginning of the study, the mean VAS was 5.13 (SD = 1,77) and at the end of the study, the mean VAS was 3,53 (SD = 2,25), significantly lower ($p < .001$) from a parametric t test.

DISCUSSION

The main goal of this exploratory work was to compare different hearing aid fittings to evaluate their effect on masking and residual inhibition of tinnitus thanks to an innovative psychophysical technique.

As a first step, this study shows that this new method which was developed in the A Noreña unit, allows a quick and efficient comparison of different fitting methods.

Moreover, the results obtained in free field, without HA, demonstrated once more that the minimum level masking and the residual inhibition are maximized when the frequency of the noise issued is centered on the tinnitus (Cuvillier, 2016 ; Roberts et al., 2008 ; Terry et al., 1983).

By contrasting different fitting methods, the amplifications with an additional 10 dB gain at the tinnitus frequency and at ½ octave below the tinnitus frequency, are significantly better at obtaining a lower MML with a similar (but not significant) trend, for the MRIL. This absence of significant difference could be explained, in part, by the fact that several subjects reached an uncomfortable level of stimulation before perceiving partial or complete residual inhibition ; this problem did not arise for the minimum masking levels.

After analysing the in vivo measurements, we observed large differences in REARs for the « Tinnitus Tonal Therapy » method. As a result, we need to do more tests to determine the origin of this high variability. We could begin by determining if this « under-amplification » was correctly applied to each subject. We should also note that PMM have limits (probe position in a frequency node, reliability for high frequencies...).

At the end of study, most tinnitus subjects were really enthusiatic and grateful to have participated in this study, and felt that their tinnitus was less loud. The VAS average decreased from 5.13 (SD = 1.77) to 3.53 (SD = 2.25) at the end of study. In addition, the persistent residual inhibitions obtained in two individuals are very interesting. This prolonged effect has already been reported in another study (Cuvillier, 2016) although its origin remains unknown.

Only one hearing aid model was used in this exploratory work, but it would be interesting to expand the comparisons to HAs from several manufacturers and to include other hearing aid fittings methods. To go further, it would be useful to carry out a longitudinal study in whichs patients with hearing aids (and various settings) would be followed. The objective would be to establish whether the MML and MRIL measurements vary over time and predict possible benefits for reducing tinnitus to a greater or lesser degree depending on the fitting method over the long term.

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