QUANTITATIVE EFFECTS OF AUDITORY STIMULATION ACCORDING TO THE TOMATIS METHOD. A PRELIMINARY STUDY OF CORRELATION BETWEEN TOMATIS LISTENING TEST AND AUDITORY COGNITIVE EVOKED POTENTIALS

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Summary

Objectives

To determine the quantitative effects of an Tomatis auditory stimulation method using of clinical measures of hearing and cognitive P300 evoked potentials.

Method

Seventeen patients were included in this study. Nine patients received 100 non-consecutive hours of auditory stimulation, in the form of a personalized program. Eight control subjects did not receive any auditory stimulation. The patients were subjected to a listening test and cognitive auditory MMN (Mismatch Negativity) and P300 evoked potentials test before and after stimulation. The control group was subjected to two distant listening tests (without any interim auditory stimulation). The average time between the two tests was quite similar to that of the patient group. The clinical effects of this form of auditory stimulation were ascertained on the basis of a multiple-choice questionnaire.

Results

The listening test shows a significant improvement in the reduction in the difference between bone conduction and air conduction in the left ear. The amplitude of the MMN was reduced during the second session - which goes hand in hand with increased latency - and that the reaction times were shorter. We observe a significant decrease in N1/P2 amplitude at the P300 evoked potential. It was also found that a clear and moderate clinical improvement in patients.

Conclusion

The electrophysiological and hearing measures have been improved significantly in the subjects who received auditory stimulation. To eliminate possible sampling fluctuations or the effect of habituation to the test, they will need to be confirmed on a wider scale. Clinical improvements in patients who received auditory stimulation were observed. However, the correlation between these clinical improvements and the variations in the measuring tests were not examined. Progressive monitoring of the effects of this rehabilitation on the basis of a validated psychometric scale ought to be considered.

Keywords

Audio-psycho-phonology, Tomatis, listening rehabilitation, auditory integration

Introduction

"Musical training is a more potent instrument than any other, because rhythm and harmony find their way into the inward places of the soul. It enriches the soul, gives it grace and illuminates it. " Plato

Alfred Tomatis (1945), ear nose and throat specialist (ENT), dedicated most of his professional life to studying the process that links listening to language. During the 1950s, he presented 3 laws to the French Academy of Sciences.

1) The voice contains as overtones only those frequencies that the ear can hear.
2) When giving the ear the chance to hear frequencies that were previously not or not well perceived correctly again, they instantly and unconsciously reappear in the voice.
3) When repeated over a certain period of time, acoustic stimulation leads to a final change of hearing, and consequently the phonation.

So Audio-Phono-Psychology was born: "Listening is to hearing what sight is to seeing." Accordingly, hearing would be associated with a psychological dimension and not purely with physiological criteria pertaining to sound transmission (1). For Tomatis, *"The human ear is made, tailored, designed to hear and listen. The distortions that settle in, the blockages that are created, the deficiencies that appear are only there to stifle motivation, to prevent exchange, to disrupt dialogue, to disturb communication. Those who never experienced, enjoyed, true listening cannot appreciate what they are losing out on by holding on to their distortions. Listening is life."* (1,2)
Tomatis proposed two ideal listening curves which were based on listening tests of talented musicians, like Enrico Caruso. These bone and air conduction curves correspond to the audibility threshold curve, known as Wegel's "lemon-shaped curve" (figure 1A). The ideal listening Tomatis curves are the inverted Wegel's curves. They reflect maximum sensitivity in voice frequencies between 1000 and 3000 Hz. They follow an ascending curve, from the low to the medium frequencies, and slightly drop again in the high frequencies. The perception threshold is a reference for the method.

Tomatis developed a specific auditory test so-called listening Tomatis test (LTT). Classical audiogram is an examination that pertains to the field of ENT, and which is performed using an audiometer with a standardized calibration (figure 1B). In contrast, LTT is similar to an audiogram but uses the inversed Wegel curve with an adjustment of the minima to end up with linearized curves (figure 1C). LTT was developed with the help of an audiometer, calibrated in accordance with the standards that Tomatis entrusted to the company Inter-acoustics (table I). According to Tomatis, the LTT is more suitable to interpret a patient's audio-psycho-phonology profile and progress under auditory stimulation than an audiogram (3). The table I shows an osseous perception that was deliberately attenuated while the standard audiogram was performed because the audiometer is calibrated differently than the one used for LTT. On the assumption that bone conduction perception is an important factor, the listening test, devoid of attenuation, does indeed seem more relevant.

In the context of our research elaborated hereafter, it seemed logical to record the cognitive evoked potentials, an objective technique to collect non-invasively neurophysiological data during auditory process, and therfore to assess the effects on the brain of a method designed to enhance subjects 'attentional or sensorimotor skills. A number of studies on musical training (4–6), phonological training (7–9) or reading/writing training (10,11) have already been conducted in the past. They show changes in the components of these auditory potentials that vary with the circumstances.

Cognitive auditory evoked potentials (aCEP) are constituted of a succession of electrical brain waves that occur after 50 ms, associated with the progressive encoding of stimulations, which are highly dependent on attention. The main component is known as the P300 (or P3) wave because of its positive phase and its delay of about 300 ms after stimulation, irrespective of sensory modality. It is preceded by the N100 (or N1), P200 (or P2) and N200 (or N2) waves. To assess the attentional aspect, these waves are recorded on the basis of protocols that require the subject's active attention. P300 is obtained when an unexpected stimulus occurs (oddball paradigm). The amplitude of the P300 is all the greater as the stimulus is not expected. A subject could also be asked to passively listen to the auditory stimulations, which would give rise to a non-concordance wave (MMN for Mismatch Negativity) which occurs between 100 and 200 ms and shows that something new has been detected in the sound environment.

Tomatis's auditory stimulation method (TAS) is a personalized program, tailored to the subject's listening test. TAS generally includes music, filtered to a greater or lesser extent (Mozart, Gregorian chant), the mother's voice filtered at 6000 Hz and the patient's own voice; these sounds are processed in such a way that the high and low frequencies are continuously and irregularly altered, yet. The differences between sound are unpredictable and repeated and catch the subject's attention by surprise. The high frequencies are favored because they trigger the hair (sensory) cells of Corti's organ better than the low frequencies. This means that particular cortical reception and integration zones are stimulated in an unaccustomed way. Until his death in 2001, Tomatis continued to research, experiment and publish to explain that training the listening function aids social interaction, learning, language skills, discourse, voice, singing, posture, coordination, rhythm (1,12,13). Nevetheless, the reviews of the available literature are contradictory as to the significance of these Tomatis effects (14,15).

In this paper, we aim to determine the quantitative effects of Tomatis, auditory stimulation method using clinical and electrophysiological measures, as listening tests, auditory cognitive evoked potentials.

Our hypothesis is that Tomatis method of auditory stimulation has a marked positive quantitative impact on the objective measures of hearing. These variations are accompanied by psycho-cognitive-motor effects. This would have the consequences such as a) decreasing in the difference between right and left air conduction to bone conduction, b) decreasing in the difference between air conduction and the ideal right curve, c) improvement in the components of cognitive evoked potentials.

Patients and Methods

A) Study design and participants

The study ran from June 2016 until September 2017.

In a first phase, 17 subjects have been included in this study between June 2016 and September 2016 on a completely voluntary basis. Two groups were constituted. The subjects of patient group (n = 9, 5 males, 4 females) presented various problems whether of a physical, psychological or pedagogical nature (table 2). The mean age of our population is 31 years, consisting of 4 adults and 5 children or adolescents. The average time span between the two examinations analyzed (before and after the therapy) was 11.4 months. The control group was constituted by 8 subjects (4 males and 4 females) were on average 28.3 years of age (median: 33.5 years; from 7 to 39 years). All the subjects benefited from 2 LTT: at the beginning and at the end of the study. The patient group benefited of TASM for 5 weeks corresponding to 100 hours of therapy on average. For practical and logistical reasons in this feasibility study, aPEC were recorded in the patient group but not in the control one. Auditory cognitive evoked potentials were performed before and after the therapy.

B) Listening Tomatis Test

LTT was performed on a Interacoustics system (Atlantis Centre in Sint-Truiden, Belgium, model AD226, Tomatis calibration. The LTT was performed in patients before each new week of therapy so as to optimally tailor the musical program and sound modulation to the test trends. The "ideal curve" values of Tomatis suggested was used as reference. (table 1). In LTT, audibility threshold (in dB) was measured for BC and AC with the following frequencies: 125, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz. The values recorded were analyzed via automatic programming in Excel, for listening to the right and to the left side and the results synthetizing data were generated automatically.. The average threshold for all the frequencies was then calculated for BC and AC. Analyzed parameters were: 1) difference between averaged measured threshold for BC and the ideal curve, in absolute values; 2) difference between averaged measured threshold for AC and the ideal curve, in absolute values; 3) averaged BC threshold /averaged AC threshold ratio, in absolute values. In controls, LTT a second test was performed 6 months after the first test in patients the second LTT has been performed at the end of TAS.

C) Tomatis's auditory stimulation

After the first test TAS was performed in patients for 5 non-consecutive weeks. Each patient received 100 hours of sound stimulation, at a rate of 20 hours per week. Listening sessions were performed using the so-called "Tomatis Electronic Ear": More precisely, the patients were given 5 weeks of therapy: 2 consecutive weeks initially, followed by 3 non-consecutive weeks with a 6 to 8 weeks break in between. One week of therapy consisted of 5 consecutive days. One day of therapy was divided into 2 sessions of 2 hours' sound each, one in the morning and one in the afternoon. During the listening sessions, patients were encouraged to make themselves comfortable, to draw or play (jigsaws, cognitive games, games of skill or logic games). They were advised not to read. At the end of the therapy, they were asked to read aloud for 20/30 minutes per session (active phase).

D) Auditory cognitive evoked potentials:

Recordings were performed by means of a Neuro-Mep (Neurosoft) device for three derivations: one frontal and one central median (Fz and Cz), referenced in the linked mastoids, and one vertical oculogram above and under the eye. The bandwidth ranged between 0.1 and 35 Hz and the sampling frequency was 1000 Hz. The artefact rejection threshold was 100 µV. Acquisition times were 500 ms, made up of 50 ms of pre-stimulus for the MMN protocol and 1000 ms with 100 ms of pre-stimulus for the P300 protocol. Recording was stopped when at least 60 responses to deviant stimulations and 50 responses to targeted stimulations had been obtained. The duration of each ranged between 5 and 8 min.

Stimulation to both ears was ensured by means of headphones (TDH 39 headset) with alternating polarity. For the MMN protocol, a total of 600 stimulations at a frequency of 1000 Hz, a rate of 2 Hz and an intensity of 70 dB nHL were given. The standard stimulations consisted of tone bursts of 75 ms while the deviant stimulations lasted 25 ms. The ratio was 1 deviant to 8 standards in a random order. Subjects were advised to think of whatever they liked, without worrying about the sounds, and to keep as still as possible. Some ten standard stimulations were given prior to recording.

In the odd ball P300 protocol 250 tone bursts of 30 ms and 80 dB nHL were given at random intervals ranging between 0.9 and 1.1 s, divided between targeted and non-targeted stimulations. The targeted stimulations were random with a probability of 0.2 and a frequency of 2000 Hz. The non-targeted stimulations had a frequency of 1000 Hz. Subjects were asked to press a button as quickly as possible any time they heard a high-pitched sound and to try not to make any mistakes. Responses that came after 950 ms were rejected. Subjects were given a short training session before recording began.

For the MMN protocol, we measured the latency of waves N1 and P2 on the curves of response to the standard stimulations. The first were the most negative spike before 120 ms and the second the most positive spike between 100 and 170 ms. The N1-P2 amplitude was the difference spike to spike. The non-concordance wave (mismatch negativity) was measured on the differential curve: Its latency was the most negative spike between 120 and 230 ms and its amplitude the difference between the start of the wave and its peak. For the P300 protocol, the N1 and P2 waves were measured on the curves of response to the non-targeted stimulations, for the 80-120 ms and 120-210 ms windows. The N2 and P3 waves were measured on the curves of response to the targeted stimulations, for the 180-240 ms and 250-450 ms windows. The N1/P2 and N2/P3 amplitudes were the spike-to-spike differences of these waves.

Statistical analysis

Recording and the statistical analysis of the evoked potentials was performed by Dr Jacques Grapperon, neurologist. The statistical analysis was performed by the three-way variance analysis for repeated measures. The inter-subject variance came from 9 subjects while the intra-subject variance came from the derivation factor (frontal and central) and from the session factor (before and after the audio-psycho-phonology training sessions). In terms of response time, the percentage of correct responses and the number of errors, the same variance analysis was performed, but without taking the derivation factor into account. To check the significance of the variations in perception of the listening tests, the variances were checked against the variances obtained with the Fisher-Snedecor test. In the case of unequal variances, the bidirectional Mann-Whitney test was used. All the Excel files were compiled by an engineer, who also conducted the macro-based automated analysis.

Results.

As shown in the table 4, the main result is a reduction of mean left BC/AC value (significant, $p < 0.05$), on LTT , in patients after TAS (Table 4). A slight and not significant reduction can be observed also on the right BC/CA value. In controls, no significant variation in the different values between test 1 and test 2 was observed.

The results for auditory cognitive evoked potentials are presented in figure 2 and table 4. One can observe i) a an increase of of MMN latency after the TAS treatment ($F\ 1/24 = 3.51$; $p = 0.030$) , and ii) a decrease in amplitude of N1/P2 after the TAS treatment ($F\ 1/24 = 9.88$; $p = 0.004$). The amplitude of MMN reduced after the TAS treatment, but this effect is not statistically significant..

Discussion

A) Listening test

In 2009, Gerritsen conducted a review of the literature on the impact of auditory stimulation according to the method of Dr Tomatis (14). The analysis of the conclusions of the studies that were discussed in this review show a clear benefit from audio-phono-psychology in learning disorders, pervasive developmental disorders, the learning of foreign languages, pronunciation, vocal production, the length of labour and childbirth, the Apgar score, stammers, mental retardation, anxiety syndrome, depressive syndrome, behavioral disorders associated with a psychotic personality.

During 2011, the Cochrane Collaboration conducted a review of the literature on the technique of auditory stimulation, which it refers to as "auditory integration" (15). The authors' objective was to determine its effectiveness in people suffering from autism spectrum disorders (ASD). Six controlled, randomised auditory integration therapy trials were retained as against one Tomatis therapy trial. On the specific issue of ASD, even though numerous studies come to positive conclusions about the effects of the Tomatis method, only one seems to satisfy the trial inclusion criteria for a collaboration like Cochrane, authority on EBM (evidence-based medicine). What conclusions did they come to? Of the 7 studies counted to date, involving a total of 182 participants, only 2 (by the same author), on a cohort of 35 participants, report statistically significant improvements in the group after having received auditory integration therapy, for two evaluation criteria only.

The Collaboration specifies that the lack of conclusive proof about this technique should not be interpreted as proof that it is not effective. What's more, it encourages further research in the field of music therapy, as the current data from various scientific studies suggest that the benefits could be significant: social interaction, communication, social adaptation (autism spectrum disorders, schizophrenia), rhythm, coordination in the case of acquired brain injury, depressive syndrome, anxiety syndrome, blood pressure, respiratory rate (cancers) and sleep disorders. As a consequence, the French Health Authority stated in it last report on "managing autism": music therapy is advised, the Tomatis method not recommended (16). Even though the rules of the scientific game are clear and sure, we can see the complexity of furnishing conclusive data, which is inherent to the Tomatis method: a lack of human and financial resources, refusals from research laboratories, internal division, lengthy and face-to-face therapy, a non-standardised protocol, lack of potency of the samples, multiple judging criteria, qualitative studies, unpredictable psycho-cognitive-motor effects.

The trial presented in this article wishes to avoid these stumbling blocks and to stick to quantitative criteria to evaluate the effects of the method. The limited number of subjects included, the disparity in the variances of the groups compared and the diversity in the choice of sound programs make that this research is more akin to a feasibility test or a preclinical study. Of all the distortions that can be interpreted from a listening test, which auditory stimulation purports to modulate (hearing thresholds, air bone gaps, scotoma, spatialization, sound discrimination) (3), only the quantifiable distortions, common to the audiogram, were retained. The possibility of an approximation of the level of perception via air conduction in the right ear with the ideal curve was suggested on the basis of data that pre-date literature. Although not rigorously validated, they agree that right-sided hearing can be lateralized by progressively and predominantly increasing the air conduction-based auditory stimulation to the right and develop the analytical skills of the left hemisphere which is directly linked to it. The assumption of a decrease in the gap between osseous perception and air perception, to the left and to the right, when receiving auditory stimulation which is either mainly bone or air based, depending on the initial test, was also suggested on the basis of experimental data that pre-date the method (2,13).

The results obtained in our study (as referred as Tomatis Toulon Group) show a significant reduction in the gap between air conduction, AC, and bone conduction, BC, to the left ($p=0.012$). The decrease in the right AC/BC gap is not significant, just like the slight reduction in the gap between AC and the ideal curve ($p=0.5$). It is clear that there is a partially statistically significant improvement in the primary endpoint in terms of the analysis of the listening test.

In spite of a clear significant improvement, the quantitative results of the Toulon Group are considerably lower than the results obtained in the two other centers that use the method.

The Hermione Centre in Annecy was asked to analyse the trends in the listening tests of 10 of its patients before and after the therapy. This group is referred to as the “Tomatis Annecy” Group. The group consisted of 5 females and 5 males, with an average age of 16.3 years (median: 13 years; between the ages of 8 and 47). The average time span between the two analyzed examinations was 10.5 months until 2017. They received 100 hours of therapy on average.

The Atlantis Centre in Sin-Truiden (Belgium) was asked to analyze the trends in the listening tests of 10 of its patients before and after the therapy. This group is referred to as the “Tomatis Sint-Truiden” Group. The group consisted of 2 females and 8 males, with an average age of 8.7 years (median: 8.5 years; between the ages of 5 and 13). The average time span between the two analyzed examinations was 23 months until 2017. They received 250 hours of therapy on average.

The variation in age of the Toulon Group (average age 31 years, median: 15 years) was close to that of the Control Group (average: 28.3 years, median: 33.5 years). These ages were significantly different from the Tomatis Annecy Group (16.3 years, with a median of 13) and the TomatisSint-Truiden Group (8.7 years, with a median of 8.5).

The Toulon and Annecy Groups received 100 hours of therapy on average. The Sint-Truiden Group included patients with severe psychomotor impairment. They received 250 hours of therapy on average. The Control Group did not receive therapy.

The Tomatis Toulon Group was recruited on the basis of an invitation the therapist extended to the patient. At the time of recruitment, the average difference with the ideal was 3 decibels higher than in the Control Group. The Annecy and Sint-Truiden Groups were recruited the other way around, i.e. on the basis of a request the patient or the patient's parents had put to the therapist. At the time of recruitment, the average difference with the ideal was 10 to 11 decibels higher than in the Control Group. Might the young age of the subjects contribute to their greater sensitivity? Does a subject's initial average level of hearing play a role in the responsiveness or resistance to sound stimulation? Does a change in hearing level constitute a risk factor in mental health (17–19) ?

It is currently impossible to answer these questions. The essential point is however that (a) under difficult conditions (non-homogeneous population, hearing thresholds pooled for BC and AC in each side) we have been able to highlight an effect on quantified variables; b) in controls, the results of LTT are stable at several months intervals. It is now necessary to work on homogeneous populations better controlled and to differentiate the effects on the thresholds at low, medium and high frequencies.

B) Auditory cognitive evoked potentials:

The results of the P300 test shows a significant reduction in N1/P2 amplitude. It was also established that the amplitude of the Mismatch wave reduced during the second session, which goes hand in hand with increased latency and a shortening of the response times. On the whole, these results may also reflect a better performance with less active attention. In the absence of a relationship between the clinical and electrophysiological measures, no case can be made for the effect of audio-psycho-phonology training here. What's more, the studies that incorporate cognitive evoked potentials into cognitive training techniques mentioned in the introduction tend to record increased wave amplitudes. The effect we observed can therefore only be a non-specific habituation effect. Accordingly, it has been suggested that the increase in the amplitude of wave P2 was a non-specific learning marker (20).

The limitation of our study is due to the small number of subjects and their age heterogeneity. It is also due to the technique we used which is the most straightforward one and most compatible with common function studies in a clinical neurophysiology hospital laboratory. The reduced number of derivations does for instance not take the inter-hemispheric differences in the temporal regions that are sometimes mentioned into account. It contrasts with the more elaborate techniques that have been fine-tuned in research laboratories, but which remain linked to the equipment used. As a result, it has not been possible to test complex stimulations like musical suites or different syllables here.

C) Clinical improvement :

In first instance, this experiment was not designed to establish a formal link between a possible improvement in clinical and electrophysiological measures of hearing and the clinical evolution of patients who receive auditory stimulation. This approach is a complex qualitative one and must be preceded by the scientific validation of the devices that measure electrophysiological variations of the hearing and the significant potential effect of auditory stimulation on these variations. However, this would entail a second judging criterion to question and broaden the research perspectives ensuing from this work.

Some of the clinical improvements at least 4 of the patients mentioned at least once as a marked improvement after the final measures are listed here on account of their possible correlation with the significant changes observed in terms of the listening tests and the cognitive evoked potentials. This improvement concerns: concentration, self-esteem, daytime fatigue, mood, motivation/projection, independence, initiative-taking, speaking at home or in public, tonicity.

A number of confounding factors must be mentioned here because, in parallel with the auditory stimulation sessions, some patients also received osteopathic care, physiotherapy, speech therapy, psychotherapy. One of the subjects discontinued his Ritalin therapy. One of the subjects started a therapy for depression with SSRI. The recent conclusions by Inserm Bordeaux (January 2018) on the follow-up of the Paquid cohort merit reiterating here: 3777 participants over the age of 65, over 25 years. They confirm the direct link between the hearing profile of the patients included and the risk of invalidity, dementia and depression (17). Another recent publication of the Journal of European Psychiatric Association concluded that Tomatis training significantly improved subjects' cognitive functioning. They demonstrate its efficiency in relation to such parameters as reaction time, localization of sources of sound and over sensitivity to audio stimuli (19).

Conclusion

In spite of its limitations, the use of cognitive evoked potentials demonstrates its sensitivity in terms of analyzing the changes that are brought about by techniques that act on the attentional processing of sensory stimulations. A neurophysiological analysis of these techniques is needed to tailor the types of recordings to be used to facilitate an analysis of the neurological mechanisms.

The listening test shows a significant reduction in the gap between bone and air conduction to the left. This test has not been scientifically validated. Correlation between the cognitive evoked potentials changes and those of the listening test must be sought (13).

If the lack of conclusive proof about a technique must not be interpreted as proof that it is not effective, then the presence of a number of significant results on a small number of samples must, in the context of an essential improvement and the promotion of mental health care, be encouraged and pursued.

Other than a progressive follow-up of the effects of auditory stimulation, we can envisage an improvement in the choice of subjects that are likely to benefit from it (Watson, 1980).

Conflicts of interest:

J.V: financial interest in the Atlantis MBL company. Study collaborator for loan of equipment and development of auditory remediation programs

J.G: partly employed by health insurance which is a source of funding for the study. CHITS company.

T.R: partly employed by health insurance which is a source of funding for the study. CHITS company

JVD : no conflict of interest.

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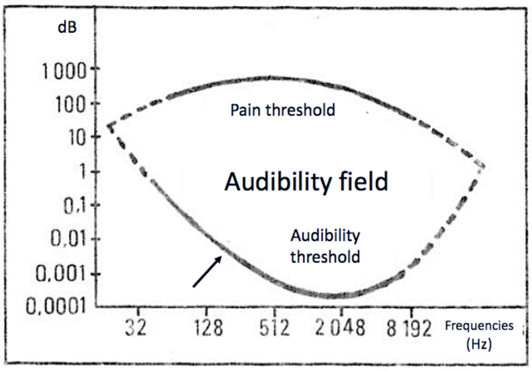
Figure 1:

A) Wegel’s graph. The minimum and maximum for pain and hearing threshold curves join at the edges and delineate the normal hearing range in the centre. In abscises, the sound frequencies, on the ordinate the acoustic pression in dB. For listening Tomatis test (LTT) the audibility field curve (arrow) is inverted.

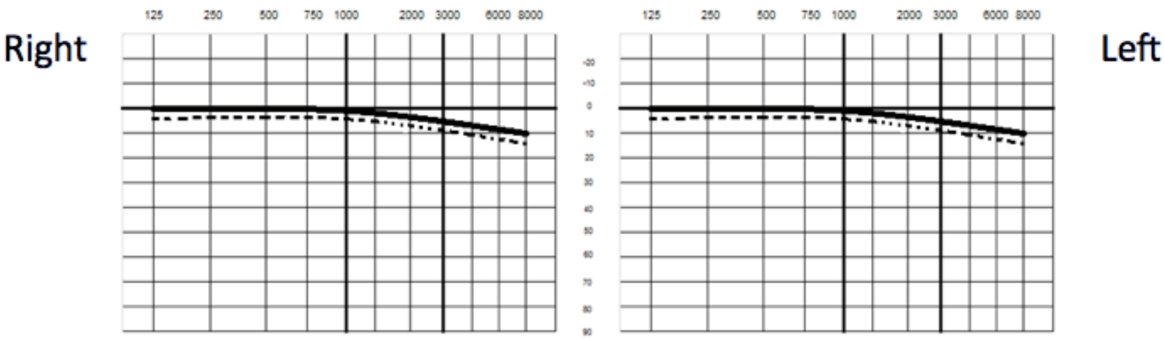
B) Graph of a classic audiogram’s reference curves, for a 20 year old patient. Air conduction is represented by the solid line, bone conduction by the dotted line Frequency is given in abscissa from 125 Hz to 8000 Hz. The extremities of the curves are linearized. Decibel are in ordinate. In dotted line, bone conduction, in full line, air conduction.

C) Graph of the ideal listening curves from the LTT . Air conduction is represented by the solid line, bone conduction by the dotted line. Frequency is given in abscissa from 125 Hz to 8000 Hz. Decibel (dB) are in ordinate . . In dotted line, bone conduction, in full line, air conduction.

A)



B)



C)

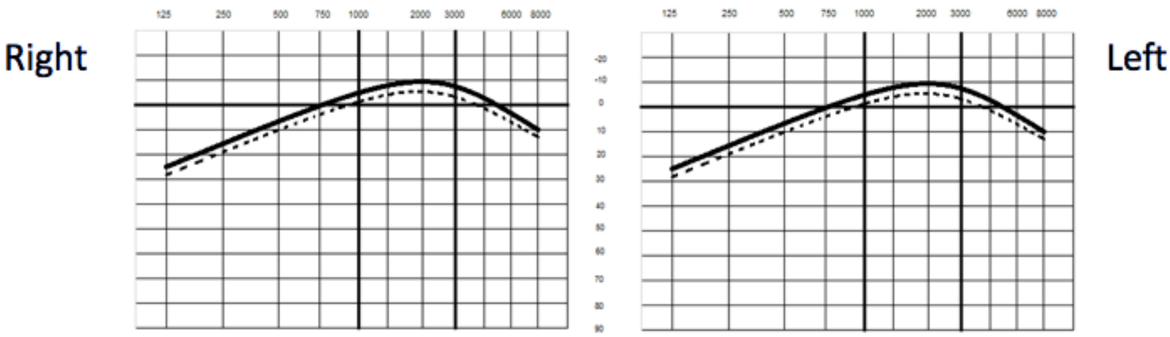


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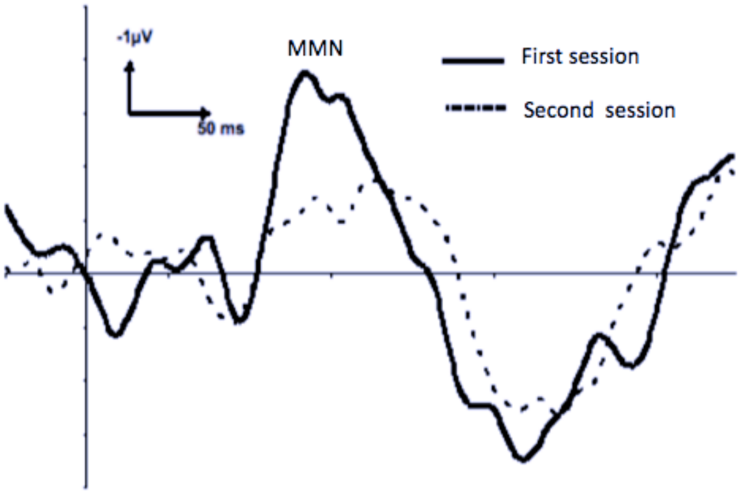
Figure 2

Auditory cognitive evoked potentials recorded, in the 9 patients of our study. The average traces are presented.

In A : mismatch negativity (MMN), on Cz (central)derivation

In B : P300 (oddball paradigm) on Fz (frontal) derivation: N1 : negativity at # 100 ms, N2 : negativity at # 200 ms, P2 : positivity at #200 ms, P3 (or P300): positivity at #300 ms.

A)



B)

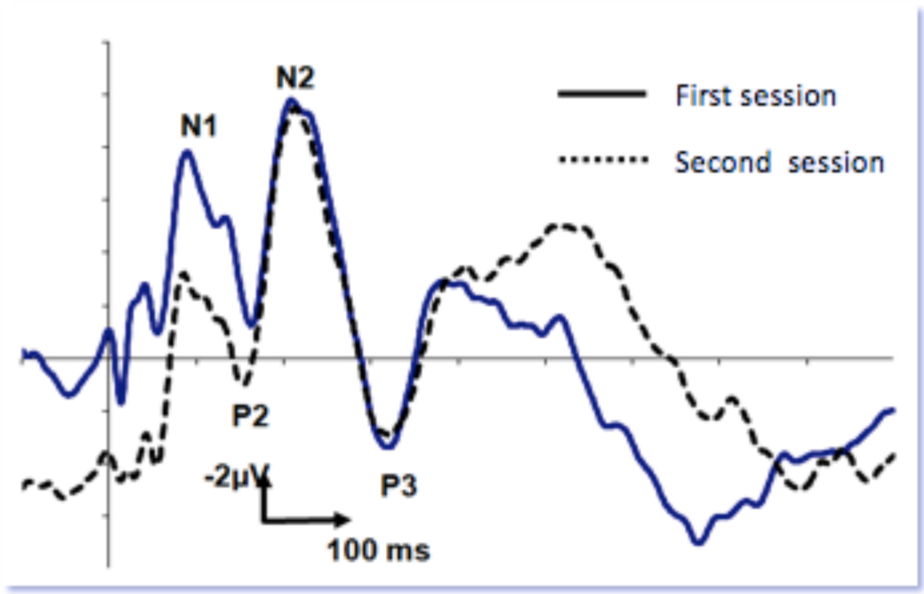


Table I: Values for the standard audiogram and for the listening Tomatis test (LTT, in grey) audibility thresholds for various frequencies. BC = bone conduction; AC = air conduction.

Frequencies (Hz)	125	250	500	750	1000	1500	2000	3000	4000	6000	8000
Standard audiogram: BO		-9,1	-1,1	-4,9	-5,8	-3,3	0,2	-0,3	-4,8		
Standard audiogram: AC	0	1,5	2,5	2,5	1	1.5	0,2	2,1	2,2	0,7	3
Ideal listening test curve (dB) of Tomatis (LTT): BO and AC threshold are considered as similar (+/-5dB)	20	10	0	-5	-10	-10	-10	-10	-5	0	10

Table 2.

Characteristics of the patient population studied.

Patient	age	sex	Symptoms
1	55	F	Burn out, sleep-wake cycle disorders
2	14	M	ADHD, school failure
3	10	M	Dreamy child, school failure
4	10	M	Dreamy child, school failure
5	14	F	School failure, inhibition without aggressiveness
6	70	F	Sleep-wake cycle disorder, concentration disorder, mild depressive disorder
7	32	F	Daytime hypersomnia in a context of lyme disease, attention disorders
8	16	M	School failure, inhibition
9	70	M	Barotrauma in 1971, deafness of transmission (1000 to 8000 hz)

Table 3:

Average values, (in dB), on right and left sides of audibility thresholds, in patients and controls of i) the difference between AC threshold measured values and the Tomatis ideal curve AC threshold values, ii) the difference between BC measured threshold values and the BC ideal threshold curve values ,iii) the difference between BC threshold /AC threshold ratios. See material and methods for details.
*: Significant effect (p<0,05, Mann Whitney test)

	Control group		Patient group	
	Test 1	Test 2 (11 months after test 1)	Test 1	Test 2 (after TAS, eg about 10 months)
AC left	9,4	9,9	11.3	11.3
AC right	9,1	8,8	14.7	14
BC left	7,7	7,7	8.4	8.6
BC right	7,1	6,8	9.3	9.2
BC/AC left	6,6	7,7	**8.8**	**6.3***
BC/AC right	6,4	6	9.8	8.4

Table 4: evoked potentials performed in the 9 patients of the study.

		First session	Second session
MMN (Mismatch Negativity test) averages (standard deviation) of the variables	N1 latency frontal	98 (12,6)	96 (13,6)
	N1 latency central	98 (12,2)	97 (15)
	P2 latency frontal	135 (10,2)	130 (17,3)
	P2 latency central	136 (11,2)	131 (16,2)
	N1/P2 amplitude frontal	5 (3,4)	4,2 (2,8)
	N1/P2 amplitude central	4,9 (3,3)	4,4 (2,9)
	MMN latency frontal *	**167 (26,2)**	**179 (29,5)**
	MMN latency central*	**164 (26)**	**178 (31,6)**
	MMN amplitude frontal	6.6 (4)	7.1 (4.5)
	MMN amplitude central	6.6 (3,4)	5.8 (3.2)
P300 test averages (standard deviation) between the electrophysiological variables	N1 latency frontal	88.7 (9.4)	95 (12.5)
	N1 latency central	87 (9.7)	90 (13)
	P2 latency frontal	160 (30.5)	156 (20.2)
	P2 latency central	167 (26.7)	157 (26.6)
	N1/P2 amplitude frontal**	**12 (5.5)**	**8 (8.3)**
	N1/P2 amplitude central**	**15 (6.2)**	**9 (9.2)**
	N2 latency frontal	216 (19.6)	212 (11.4)
	N2 latency central	209 (21)	211 (12,6)
	P3 latency frontal	334 (31.1)	329 (35.6)
	P3 latency central	334 (35.6)	325 (31.8)
	N2/P3 amplitude frontal	15 (8.9)	18 (8.4)
	N2/P3 amplitude central	14 (3.8)	19 (8.4)
P300 test averages (standard deviation) between the behavioral variables	Reaction time	479 (108)	428 (79)
	Number of errors	2,8 (2)	3,7 (3,3)
	% of correct responses	94 (17)	100 (0)

**significant effect: p < 0,005
*significant effect p < 0,05