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## RESEARCH ARTICLE

# EVALUATING THE LINGUISTIC ABILITIES OF IMPAIRED IN HEARING CHILDREN - MACRO LEVEL COMPETENCES VSPERSONALIZED DEVELOPMENT

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## ABSTRACT

A tremendous breakthrough in the fields of Medicine and Technology, the massive use of Digital Hearing Aids and Cochlear Implants, changes drastically the rehabilitation process and the educational experience of hard in hearing and deaf children. As a result, there is a steeply increasing interest, especially from the funding authorities and the scientific community, on how the application of extensive bionic, prosthetic and augmenting methodologies may reshape the filed of special education. This survey focuses on the linguistic development and the speech characteristics of children that use cochlear implants versus those using hearing aids. It also examines on how personal psychokinetic dexterities and social proficiencies enhance individual performance.

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## INTRODUCTION

A remarkable development in the fields of Medicine and Technology provides us with two important tools, the digital hearing aids and the cochlear implants, which change the education of deaf and hard of hearing children, increasing their opportunity to integrate in the mainstream educational system.
Hearing impairments are quite common in our era not only due to congenital causes and harsh to the senses environmental factors, but also due to the increased rate of diagnosis. Hearing loss is one of the commonest reasons to visit an Otolaryngology Department both in the clinic and in the acute setting. As it has been statistically anticipated [xxx], nearly 15% of American adults (37.5 million) aged 18 and over report some trouble hearing. One in eight people in the United States (13%, or 30 million) aged 12 years or older has developed hearing loss in both ears, according to standard hearing examinations. Around 2% of adults aged between 45 and 54 are diagnosed with disabling hearing loss. For the age zone 55 to 64 this variation rate raises to 8.5%. Even further, an up climb of 25% for those aged 65 to 74 and 50% for those who are 75 and older is reported with a disabling hearing loss. These figures depict an overwhelming impact on patients' quality of life; therefore, the necessity for early and accurate diagnosis and treatment is a key factor since technology is an enabler for astounding rehabilitation (Stavrakas *et al*., 2016). The extent of restoration for hearing can be emphasized by the number of devices that have been invented in order to assist hard of hearing individuals (Levitt, 2007; Mills, 2011). However, hearing loss or deafnessare far more critical when they occur in pre-school age. It is important to point out that for congenital hearing loss and deafness early diagnosis may prevent the development of dyslexia and pre-lingual disorders that resolutely disrupt speech communication and the proper development of the official language discourse in schooling (Holt *et al*., 2005). Although technological advances in hearing aids are formidable, the landmark for virtually complete restoration from deafness is the cochlear implant (Fig. 1). One of the first successful attempts to restore hearing in a deaf patient took place in 1957 by A. Djourno and Eyries (1957), who restored hearing in a deaf patient by electrically stimulating acoustic nerve fibers in the inner ear. Their observations lasted only a few weeks since the device they used stopped functioning in less than a month. Their observations where published in the French journal

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*PresseMédicale*. However, the first workable implant was placed at the Saint Antoine Hospital in Paris on September 22, 1976 and was performed by C. H. Chouard assisted by B. Meyer (Chouard *et al*., 1977). The patient recovered his hearing the next day and another five patients were also implanted. After a short period from the implantation, the recipients were able to recognize some words without lip-reading. Cochlear implants that have the contemporary, easily recognizable form of behind-the-ear audio processor were produced somewhere around 1991. The same year MXM-Neurelec (Chouard *et al*., 1995) presented their first fully digital multichannel implant that could be adapted to an ossified cochlea. Expanding their expertise, in 1994, Med-El (2015) presented the world's first electrode array capable of stimulating the entire length of the cochlea to allow a more natural hearing and in 1996 presented the world's first miniaturized multichannel implant at 4 mm. Along with the other pioneer in the field, Cochlear Inc., Med El was the first bilateral implantation for the purpose of binaural hearing. From that point on the capabilities of cochlear implants increased constantly leading to modern cochlear implants that coupled with their speech processors utilize wireless communication technologies to allow connectivity with various devices. Cochlear implants role is to override part of the natural auditory path described next (Kyriafinis and Chriskos, 2016).

A cochlear implant is a high fidelity electronic device that replaces the auditory system, mainly the sensory capillary cells in the organ of Corti in the cochlea (Kyriafinis, 2005). This device bypasses the natural hearing process transferring the converted auditory signal directly to the cochlea. A modern cochlear implant is surgically implanted in the recipient under the skin behind the ear and sometimes anchored on the temporal bone. Since the implant does not have a power source, in order to function properly it must be coupled with an external unit known as a speech processor. This device is commonly worn behind the ear, provides power to the cochlear implant and communicates with the implant via an RF transmitter. Both cochlear implants and their speech processors are mobile devices that interact with the user via a brain-computer interface, other devices, as well as, with the environment around them, altering their signal output depending on the environmental conditions. Cochlear implants are highly robust and precise implanted mobile devices that interact with a coupled speech processor and the recipient (Kyriafinis, 2005). Cochlear implants are composed of three basic parts. As seen in Fig. 1 at the top is the coil that is used as an RF link, and the coil magnet that paired with the coil magnet of the speech processor keep the coil in place through the skin. The middle part of the implant is known as the body contains the electronics that convert the input signals to electrical stimuli to stimulate the auditory nerve. The final part of the implant is composed of one or more "tails" one of which is implanted in the cochlea and is equipped with a number of electrodes to stimulate the auditory nerve.

During the communication with the speech processor cochlear implants, send and receive data to and from the speech processor. Data input contains a processed version of the audio signal captured by the speech processor. This signal is then converted to electrical impulses, which after the required processing are utilized to stimulate the auditory nerve, in order to allow the recipient to perceive sound. The process of converting the input to electrical signals is unique for each individual and varies greatly between different brands and is achieved through a digital signal processor with mapping parameters, that are set during the programming of the cochlear implant. The cochlear implant also transmits data either to the speech processor or other dedicated equipment used in the programming of the implant. Output data include diagnostics concerning the functionality of the different parts of the implant, power consumption and requirements, and the nerve response of the recipient. All of these data can be used to assess the needs of the recipient and the condition of the implant itself, and can be utilized by a monitoring clinician to provide for the needs of the recipient. One interesting characteristic of cochlear implants is that they are not fitted with a power source and must rely on the speech processor for power. The two devices are linked with an RF transmitter, that allows wireless power and data transfer between the two devices. All of the above are contained in the main body of the implant that is not actually implanted in the cochlea. The part that is implanted in the cochlea is an electrode array with the number of electrodes ranging from 12 to 22, depending on the model and brand.

## Post surgical rehabilitation: Instruments and Methods

Speech processors are wearable mobile devices that interact with the environment, the cochlear implant and also the user. The cochlear implant recipient can personalize the functions of the speech processor by using either the buttons on the speech processor itself or by using a remote controller that is supplied by the cochlear implant manufacturer. As devices, speech processors contain an analog to digital converter responsible for transforming the input sounds to digital signals, and a digital signal processor used as an intermediate step before the processing conduced in the cochlear implant. Speech processors communicate with various devices such as the cochlear implant and a remote controller, and are battery operated. Modern speech processors, apart from their traditional connectivity options, are 2.4 GHz enabled enabling communication with a wide range of devices as will be discussed later.

Consequently, post surgical treatment and rehabilitation focuses on three major issues:

### Calibration "on the ear" of the patient

Unlike hearing aids, cochlear implants do not make sound louder or clearer. Instead, they bypass damaged parts of the auditory system and directly stimulate the vestibulocochlear nerve. The ENT specialist periodically performs subtle operations and regulations by engineering methods to cope with any malfunctions, deregulated frequency band equalization, unguided inductions of the electrodes into the posterior semicircular canal or unsupervised electrode contacts within the vestibule (Stavrakas *et al*, 2016).

### Self-treatment

Although the full extent of medical care is received through sessions with the clinician, some degree of calibration can be performed via the parents of a cochlear implant user: microphone sensitivity, volume level, connections and selections of predefined programs available to the user adjusting the hearing conditions, like working within the noisy schooling environment or fine-tuning for discovering aural information when walking in the woods.

## "Ear training"

The term engulfs all the procedures aiming to develop such skills through practice and instruction, over a period of time, that turn one able to recognize by hearing, notes, tones, pitches, intervals, melodies, chords, rhythms, tempo, and other musical features. As ear training combines elements of music theory (scales, notes, chords) with an adequate understanding of instrumental music, singing and sound effects perceived in a daily basis, it provides the context for evaluating fundamental neuro-musicological factors involved in strenuous neurobiological efforts for accurate musical reproduction.

Predominantly, impaired in hearing patients have obvious problems with their phonological processing. As a result, patients receiving normal schooling are unable to timely process written words or properly develop oral communication. As a multitude of neurophysiological disorders may pile up, patients develop difficulties in learning to read or properly interpreting coherent letters. Furthermore, if impairments are not early diagnosed and cured, psychological implications evolve, and linguistic rehabilitation becomes a long term priority serviced in special education schools. On the contrary to medical training on the ear, ear training is partly committed with computer aided multimedia learning, either off line, with standalone tools, or guided with utilities and protocols delivered by a speech therapist. This research does not aim to diagnose dysmusia or musical dyslexia (Gordon, 2000). As patients are asked to sing tunes, by assessing melodic, rhythmic and dynamic recital, phonological and morphological biases of neurological processes are revealed. For instance, the accuracy of loudness in a singing voice, which relies on the control over subglottic pressures, or the ability to manage the laryngeal muscles that determine the phonation frequency (Sundberg, 1987), lead the factor analysis research on brain-computer interface (BCI) models (Politis *et al.*, 2014). Overall, by these arduous "stress tests" researchers may extrapolate their findings in synchrony and mostly in diachrony. Indeed, as written sources of our linguistic tradition exist dating back to many centuries, we are witnessing a slow, pertinent change in pronunciation patterns, which is responsible for the phonological and morphological weirdness of our written languages. Historical orthographic progression pertains the continuity of a language, but the same time it reprobates fundamental linguistic components, leading from grammatical anarchy to misinterpretations when it comes to conceptual semantics. It should be noted that more or less the languages spoken in the "Western" world lay on the foundations of the Indo-European languages. Their unattested, reconstructed ancestor, the Proto-Indo-European, is considered as spoken well before 3000 BC in a region somewhere to the south and east of the Black Sea (Harris, 1993). In contemporary terms, most of the languages we speak in our synchrony were molded phonetically during the 16th or 17th century, and this formation yielded the vastly spread languages:

- English (in fact Germanic - including Dutch, Saxon, Gothic, and the Scandinavian languages offsprings like Norman), mingled with Celtic and French
- Spanish, Portuguese, Catalan and French (in fact the Italic branch of the Indo-European family of languages, coming from Latin and the Romance Languages)
- Indic (including Sanskrit and its descendants)
- Slavic (including Russian, Polish, Czech, Slovak, Slovenian, Bulgarian, and Serbo-Croatian) and various smaller in expansion languages like Iranian, Greek, Armenian, Albanian (possibly descending from Illyrian), Baltic, Anatolian (an extinct group including Hittite and other languages),Tocharian (an extinct group from central Asia), etc.

Other languages spoken in Europe or mainly in Asia, like the Turkic, Finno-Ugric, Mongolian, Manchu, Azerbaijani, Kazakh, Kyrgyz, Uighur, Uzbek, and Tatar branches, have some bias by the dominant Indo-European pole, but they consist a clearly different linguistic group. Similar is the case for the Arabic and in general for the Semitic group of the Afro-Asiatic family.

More or less, all these languages as far as tonicity is concerned, are dynamic in their stress patterns. A special mention goes for Greek, since it was clearly a tonal language in antiquity (Spyridis and Efstratiou, 1989). Indeed, the Ancient Greek semantics with accents and “breath” spirits gave to its syntax and morphology phonological inflections that somehow resemble the prosodic elements of the contemporary Sino-Tibetan languages(Allen,1968; West, 1992). Nowadays Greek, like most Indo-European languages is rather dynamic in its intonation variations, and perhaps this may be the reason for the divergence from its historically written phonetic orthodoxy (Pöhlmann and West, 2001). Modern Greek exits in its written form since at least 9th century BC (Johnston, 2003) and thus may serveas a phonologic common denominator for the inflections of many historic languages. For instance, the Septuagint translation of the Bible that took place in 3rd century BC, operates as basis for European and Semitic correlations on how corresponding phonemes (and names) were pronounced since then in the synchrony and diachrony of our world. The same goes with the evolution of most European languages that use the Latin alphabet, a 6th century BC variant of the Greek Alphabet used originally in what is now Italy (Allen, 1978). As languages evolve grammatically and phonetically, the same occurred in Greek. For instance, the 10th century AD correlation with the Cyrillic alphabet (Dvornik, 1956), gives us a phonological convolution of how the "mother" alphabet, the medieval Greek, is phonologically connected with the "offspring", the Slavonic one. At that stage, for instance, is clearly detected in Greek *iotacism*, i.e. a set of inflections that makes 3 vowels and 4 diphthongs in Greek, namely [ι, υ, η - οι ηιυι ει ] to be pronounced as /i/ (Meister, 2012).

By way of illustration, when the Slavic people received the Cyrillic alphabet, somewhere in the 10th century, there was a letter for the dental unvoiced fricative /θ/. As a result, the name "Theodora" was more or less pronounced as is nowadays ascribed in English with speech sounds. For some reasons, this letter was gradually expelled some centuries afterwards (officially in 1917) and its sound correspondence was housed by the neighboring in spectral terms labial unvoiced fricative /f/, resulting to the word "Fedora". Interestingly, as new Slavic generations are well aware of the English language, they can easily again pronounce /θ/, remaining however puzzled on how to sort out this deviation from accepted phonological standards. The same sense of disbelief or alienation is experienced for the Western part of our civilization, originating from ambiguity in written communication forms. Users of languages that share the same alphabet are constantly confused, since there are many words that enjoy global penetration, and yet they are pronounced with considerable phonological diversity; as a result in most Western languages, apart English, /θ/ is replaced by the dental unvoiced stop /t/, as in the French "théâtre", or by the unvoiced alveolar fricative /s/ in Spanish "Zaragoza".

## Linguistic Profiling and Competences

An essential prerequisite for the successful mainstreaming of young students is the development of their speech, which will allow them to successfully follow the academic curriculum. Consequently, there is an increase of interest in the field of research concerning the comparison between the development and the characteristics of speech and language of deaf and hard of hearing children that use hearing aids and cochlear implants (Nikolopoulos *et al.*, 2004; Kyriafinis, 2005; Nikolopoulosand Papadimitriou, 2007). In order to evaluate the linguistic development of children with profound prelingualsensorineural hearing loss that used a cochlear implant from the beginning and compare it to those that underwent cochlear implantation after a period of hearing aids use, two standardized criteria were administered: The Detroit Test of Learning Aptitude - standardized Greek version of DTLA-P: 3 & DTLA-4 - (Tzouriadou *et al.*, 2008a) and the Psychometric Criterion of Language Acquisition Competence Test (L-a-T-o - see Tzouriadou *et al.*, 2008b). The above criteria are standardized in the general population of students and they are valid and reliable in terms of content and construct validity according to the international standards.

*Sampling:* 68 children that used unilateral cochlear implants were the sample of this study. They were between the age of 4 and 15, they were enrolled in mainstream classrooms, and used speech in order to communicate. All the children were under the supervision of the AHEPA Hospital team. 33 of them used cochlear implants from the beginning and 35 of them underwent cochlear implantation after a period of hearing aids use. Children that underwent cochlear implantation after a period of hearing aids use had a pure tone average in the four basic frequencies (Tsalighopoulos *et al.*, 2008)(500Hz, 1 kHz, 2 kHz, and 4 kHz) of 80 dBHL(Fig. 2).

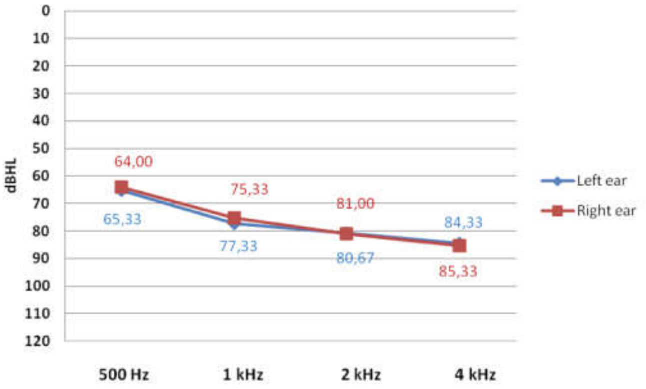

**Fig. 2. Pure tone average in the four basic frequencies of children that underwent cochlear implantation after a period of hearing aids use**

It is implied that the methodology used, although in Greek, has global projections. Indeed, the Greek language bears the burden of historic orthography and dictation, which turns spelling to a difficult activity to learn, memorize and master in general. However, the tests performed have been used in a number of counties using Indo-European languages and dialects, and has adequate proofing in depicting how well learners acquire linguistic competences.

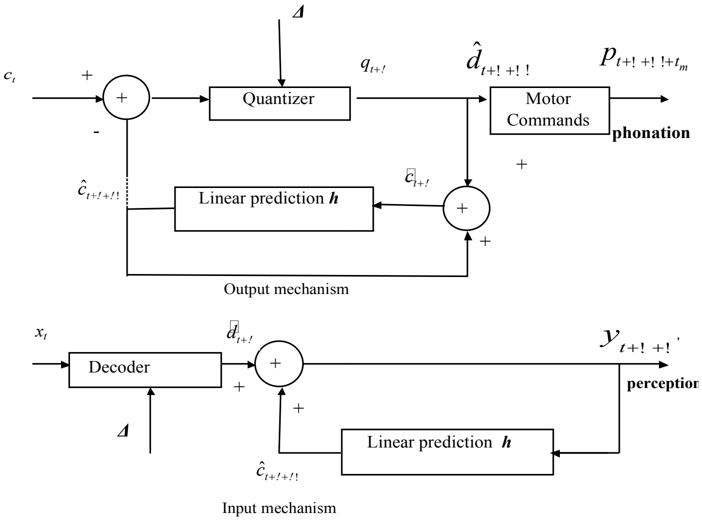

**Fig.3. Control diagrams for modeling aural and oral communication. Lower part: for auditory perception, the ear acts as an auditory decoder, mingled with neurophysiological linear prediction *h* of the incoming communication. Upper part: The phonation mechanism. Initial parameters are decoded and neurophysiological feedback determines the rhythmical, temporal and spectral characteristics of prosody and singing**

## Neurotological points of interest

Linguistic diversity affects speech therapy and therefore rehabilitation is dependent on the discourse of the language used. As a result, in each case specific tests are devised, usually as parallactic variants of successful assessments of the English speaking community, for monitoring progress towards schooling language acquisition. The testing methodologies that have acquired global acceptance claim to screen the modularity of the speech elements used (words, phraseology, vocabulary, narration, ... ) leading to a constuctivistic approach in terms of etymology, morphology and syntax as far as the situated learning of a schooling language is concerned (Lederberg, 2003). However, they have not yet dealt with the neurophysiological correlation of how people use sounds. In terms of physical modeling of vocalization, the lungs provide the air supply. The volume of the lungs is controlled by the surrounding rib-cage and the underlying diaphragm muscle. When the ribcage is expanded by the muscular system, and the diaphragm is contracted, the volume of the thorax increases, and inhalation takes place, inflating the lungs. Afterwards, the membranous tissue of the vocal cords takes action, along with the glottis in the throat, the oral cavity, the tongue, the jaws, the teeth and the nose, to name the most important myoskeletal factors that vibrate so to turn in the airstream to distinct articulated sounds. However, vocalization is far more complex than a mere sequence of physiological bodily functions. It has many neuroanatomical aspects (Svirsky *et al.*, 2000). Consequently, the linguistic profiling and competence of children that is assessed by their phonoprosodic linguistic vocalizations, their narrative skills, and their morphosyntactic aptitude (Volpato, 2010) is extended to speech audiometry and the phonatory pattern analysis of cochlear implant users with and without auditory feedback from the cochlear implant.

## Supra-segmental analysis of speech disorders

As a result, when an auditory signal $x$ arrives to human ears in time $t$, it is transformed at the vestibulocochlear nerve to a triggering signal $d$. $x$ and $d$ are not perfectly isochronous. In reality, hearing is constantly receiving auditory signals, but only when a change $\Delta$is detected in terms of pitch, loudness or rhythm, important cerebral processing occurs for the input sound. Cochlear implants simulate the nerve by instigating a calculated signal $\hat{d}$, usually invoked some $\tau$ms later. Generally speaking, signals x and d may differ depending on the physiological dysfunctioning and the electromechanical parameters that are involved within the aural channel of communication. Even further, real consciousness of the message (and not merely the signal) is achieved with some further delay in $\tau'$ms as a cerebral signal $c_{t+\tau+\tau'}$.

The linear prediction ***h*** factor implies that there is some kind of retrospective activity that aids speech perception. It may be invoking long or short memory phonetic patterns, that facilitate feature extraction, or it may be information received via the visual channel of communication: in any case, this side effect information exerts a feedback on interpreting the acoustic signal as meaningful linguistic information. When the cochlear implant is turned off, the input channel of communication is disrupted or it is severely limited and the patient can virtually rely only on the feedback he receives by the mnemonic patterns he can readily bring to surface by his cohesive memory or his visual input. For example, when the subject is hearing loud percussive sounds, he cannot sense much of the melodic content; in reality he receives very little information, which limits pitch identification. However, due to the loudness variability perceived for sounds of the lowest frequency range via the balance sensory input of the vestibulocochlear mechanism, he experiences some apprehension of the rhythm.

The conjugate of the hearing mechanism is the oral communication scheme seen on the upper part of Fig. 3. However, since we cannot clearly represent how a subject perceives auditory input, the mechanism that reveals the extend of phonatory understanding is the vocalization scheme seen in the upper part of Fig. 3. The function that drives the phonatory mechanism in this case is schematically described as follows

$$p_{t+\tau+\tau'+t_m} = f\,(\hat{d}_{t+\tau+\tau'}) \qquad (1)$$

This function takes into account a sensory feedback $\Delta$ and a linear prediction mechanism that has to do with the residual quantities both of short and long term memory repositories. When users of cochlear implants attempt to reproduce prosodic elements, the shape within their minds, rather as a neurobiological automaton, their intention in terms of vocalization.

A decoding mechanism, the "Quantizer" transforms this intention to specific phonemes, morphemes or words. When the cochlear implant is turned on, the subject receives aural input $\Delta$, which biases his vocalization. He has a more clear view of what he is producing, and therefore, he may perform necessary adjustments. For instance, he may sing louder or faster to sound as close as possible to the target melody he is reproducing (For more on how this mechanism works refer to Politis *et al*., 1996). When he is reading the words or phrases he has to articulate, then the "Linear prediction ***h***" factor is more or less short-circuited, and the "Quantizer" is the dominant driving force. When the cochlear input is turned off, the subject relies more on the feedback he gets from his short or predominantly the long term memory, i.e. factor ***h***. In some cases he may sing even better, without hesitations, since he relies more on what he has memorized, and does not bother to receive any real time feedback. In order to test if he is using more his long or short memory, the subjects are asked to reproduce melodies that are very well known, like the national anthem, and reside well within the long term memory, or some melodies that are not bound to be used on a daily basis. The latter are auditioned to the subjects, and they are asked to perform them based on what they have heard some minutes ago.

Therefore, a prediction mechanism is invoked, and the patient produces interesting vocalizations, demonstrating rigid adherence to long-term memory characteristics rather than complying wit the phonations actually tested. In all cases, the elasticity and vigorousness with which this complex neuro-muscular structure corresponds to the pitch array of musicality prescribes the idiosyncratic speed with which the performer conveys a specified impression as a distinctive time quality. Again, psychological dysfunctioning and vocal pathologies provoke transformations, either as transients or in other cases as dyslectic or dysmusal impairments. The induced variations, in any case, attempt to demonstrate with various examinations and assessments the degree of prosodic language acquisition.

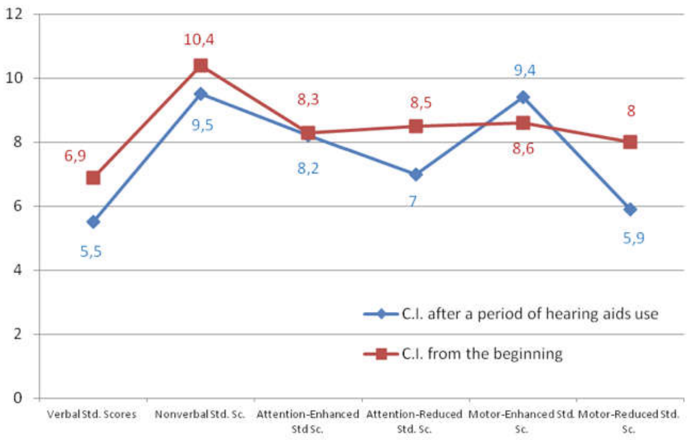

**Fig. 4. Comparison of Standard Scores of learning aptitude competence of children that used cochlear implants from the beginning and children that underwent cochlear implantation after a period of hearing aids use, according to the Detroit Test of Learning Aptitude (DTLA)**

## Phonetic processing and auditory transformations

The objective of this research is to monitor the dynamics of speech recognition and oral communication control, in terms of frequency, rhythm and intensity, aiming to evaluate in the higher-level structures the short and long memory residues. These factors determine how the aural channel of communication asserts positive or negative feedback over spoken language and singing. The following characteristics are monitored (Rabiner andJuang, 1993):

*Short time energy*. The intensity of speech signals varies considerably between periods of speech and periods of silence, different speech sounds, and over the extent of sentences and paragraphs as part of the prosodic information contained in the utterance. The parameter closely related to this is the short energy of the signal, i.e. the factor

$$\sum_{n=1}^{N} x(n)^2 \qquad (2)$$

*Voicing and the fundamental frequency*. A quantitative approach on how well the subject sings. The autocorrelation function used to smooth the curve is essentially a measure of the periodicity of the signal.

Indicatively, when speaking, the phonation frequency of an adult man is ranging between 100 Hz and 150 Hz; Women are easily within the 200 Hz - 300 Hz band, while children have an area of variation between 300 Hz and 450 Hz. However, when it comes to singing, male bass performers are sonorous from 65 Hz (note $C_2$) up to 330 Hz (note $E_4$), while baritones range from 110 Hz (note $A_2$) to 440 Hz (note $A_4$), and tenors can climb up to 523 Hz (note $C_5$). For women and children, contraltos, mezzo-sopranos and sopranos extend their pitches from 260 Hz (note $C_4$) up to 1320 Hz (note $E_6$).

*Spectrum analysis.* One of the essential tasks of speech analysis is the determination of the frequency distribution within the signal energy. The representation of phonetic elements in the frequency domain reveals the differences between speech sounds. Thus, as different vowels or fricatives have energy concentrations at their formant frequencies, the transformations in vocalization can be traced, resulting from the altered resonances at the vocal tract. Unvoiced consonants lack harmonic structure and therefore no fundamental frequency can be assigned to them. LPC analysis of order 16 up to 22, i.e. linear prediction based on combination of past values, is an optimization method that smooths the spectral representation of the speech signal. Usually, the first three formants are adequate not only to characterize a phoneme within the voice spectrum, but also reveal how the overall, "slow moving" trends of the spectrum are related with the motor commands of phonation.

*Rhythm progression:* Rhythm perception in music is a more complex phenomenon than the arrangement of highly contrastive stress patterns found on suprasegmentalintonation representations. In instrumental music rhythm evolves as a symmetrical and logical sequence of note values that periodically repeat within a melodic piece. In performance, rhythmic progressions involve as rather complex combinations of beats coming from a set of instruments. Since most subjects lack a profound musical education, they are not asked to reproduce the semantics of rhythm, but somehow to relate it with the way that human body functions e.g. according to the cardio-respiratory periodicity. Therefore, after hearing professional singing, as is the case of the national anthem, or well-performed instrumental melodic pieces, the mere phonetic reproduction with its overall variability of duration in the syllabic structure may not clearly reveal rhythmic content. For that reason, to monitor how well the subject has perceived rhythm, he is asked to reproduce with strong repeated patterns, in a fanfare style using ta-da's, syllables he pleases like that or claps, the rhythmic progression he has perceived of the monitored melodies.

## Results and Discussion: Linguistic Competence, Aural – Oral Communication and Music Perception

### Macro Level Competences in Groups

The comparison of the two groups according to the Detroit Test of Learning Aptitude (DTLA) showed that children that used cochlear implants from the beginning had better performance (Mean: 8,4 Standard Scores) compared to the children that underwent cochlear implantation after a period of hearing aids use (Mean: 7,6 Standard Scores) in all the fields of cognitive development (Fig. 4). Hard of hearing and deaf children that used cochlear implants from the beginning acquired a greater amount of typical grades of cognitive competence (50,5 Sum of Standard Scores) compared to the children that underwent cochlear implantation after a period of hearing aids use (45,7 Sum of Standard Scores), according to the Detroit Test of Learning Aptitude (DTLA), seen in Fig. 5.

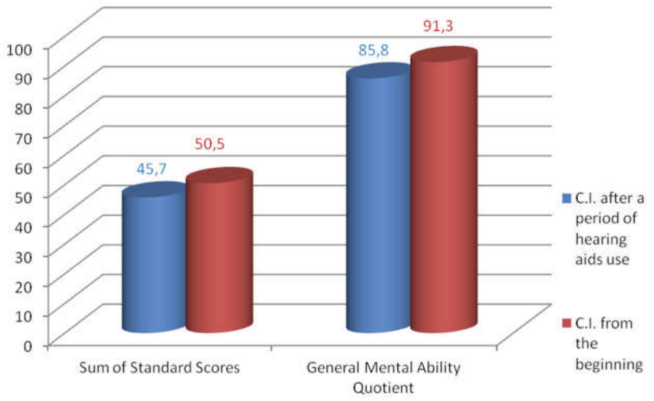

**Fig. 5. Comparison of Sum of Standard Scores and General Mental Ability Quotient development of children that used cochlear implants from the beginning and those that underwent cochlear implantation after a period of hearing aids use, according to the Detroit Test of Learning Aptitude (DTLA)**

These differences of 4,8 at Sum of Standard Scores reflected in the General Mental Ability Quotient of development since children that used cochlear implants from the beginning performed better (91,3 Quotient) compared to the children that underwent cochlear implantation after a period of hearing aids use (85,5 Quotient) with a difference of 5,8 units, according to the DTLA (Fig. 5). In order to analyze the differences in the cognitive competence of the two groups the Independent Sample T-test was administered. The analysis did not reveal statistically important differences between the means of the domains of cognitive competence of the two groups of children, which reveals that the two groups were equivalent in terms of cognitive potential according to the Detroit Test of Learning Aptitude (DTLA), depicted in Table 1.

### The analyzed characteristics concern:

1) The Verbal domain reflects the ability to complete, understand, and use speech. In addition, it reflects vocabulary and syntactic ability. This quotient can predict the writing ability since it relates to reading and writing. Children that receive low grading have poor vocabulary, do not use sophisticated speech, and have difficulty in recalling oral directions or in organizing in speech ideas in logical sequences.

2) The Nonverbal domain reflects the ability to realize spatial relationships and nonverbal symbolic thinking. In addition, it relates to the ability of recalling objects and letters and planning by means of memory. It allows children to realize logical and abstract relationships, and think without using words. Children that receive low grading have difficulty in recalling nonverbal information, in motoric responses, in organizing or solving visual problems, in handling visual abstract symbols like letters. In this field, there were statistically important differences between the means of the two groups.
3) The Attention-Enhanced domain reflects the ability of the children to succeed in actions that require instant recalling, use of the short term memory, and focused attention. Children that receive low grading experience difficulty in focusing.
4) The Attention-Reduced domain reflects the ability of the children to succeed in actions that require the use of long term memory, like in vocabulary activities, in understanding and reasoning, and in realizing abstract relationships. In addition, it relates to the ability to recall information and ideas, and use them in everyday situations.
5) The Motor-Enhanced domain reflects the complex motoric abilities, especially in the visual motoric coordination, and relates to writing and to the manipulation of objects. Children that receive low grading experience lack of coordination.
6) The Motor-Reduced domain relates to the ability of the children to act in a free motoric frame. Children that receive high grading are fluent in speech, naming, and recognizing of symbols. There were statistically important differences in the means of this domain ($p<0,05$) that did not relate to the linguistic development of the children.

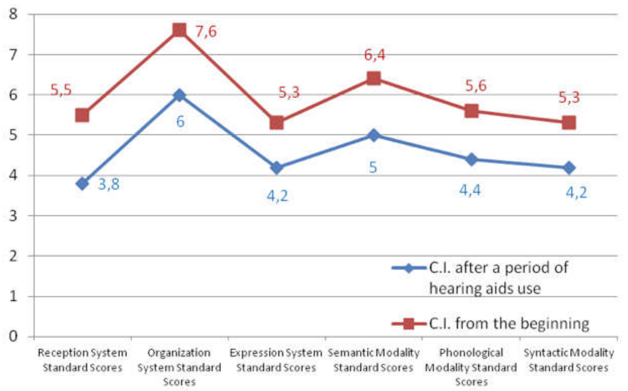

**Fig. 6. Comparison of Standard Scores of linguistic development of children that used cochlear implants from the beginning and children that underwent cochlear implantation after a period of hearing aids use according to the Language Acquisition Competence Test (L-a-T-o)**

The comparison of the linguistic development of the two groups according to the Language Acquisition Competence Test (L-a-T-o) revealed that children that used cochlear implants from the beginning had improved performance (Mean: 5,8 Standard Scores) compared to the children that underwent cochlear implantation after a period of hearing aids use (Mean: 4,4 Standard Scores) in all the systems (reception, organization, and expression) and language modalities (semantic, phonological, and syntactic) of linguistic development (Fig. 6).

Children that used cochlear implants from the beginning revealed improved performance compared to the childrenthat underwent cochlear implantation after a period of hearing aids use in all three linguistic systems:

1) In the reception system that evaluates the ability of the child to understand speech, semantically and syntactically as well.
2) In the organization system that examines the ability of the child to organize input, to relate pieces of information between them and with the knowledge constructed from before, and to use strategies.
3) In the expression system that evaluates the ability to produce eligible speech, to choose the appropriate concepts, and organize them syntactically.

Children that used cochlear implants from the beginning had better performance than children that underwent cochlear implantation after a period of hearing aids use in all three language modalities:

1) In the semantic modality that evaluate the knowledge of the concepts, the words, and their relationships.
2) In the phonological modality that examines the ability to decode and code the phonemes of language by using basic rules.
3) In the syntactic modality that evaluates the ability of the child to understand and produce syntactically and grammatically acceptable sentences.

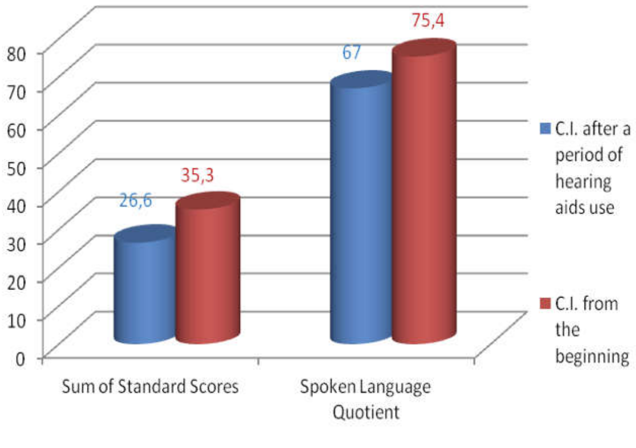

**Fig. 7. Comparison Comparison between the Sum of Standard Scores and the Spoken Language Quotient development of children that used a cochlear implant from the beginning and children that underwent cochlear implantation after a period of hearing aids use according to the Language Acquisition Competence Test (L-a-T-o)**

According to table 6, the hard of hearing and deaf children that used a cochlear implant from the beginning had an improved performance (35,3 Sum of Standard Scores) compared to the children that underwent cochlear implantation after a period of hearing aids use (26,6 Sum of Standard Scores) in all the fields of linguistic development, according to the Language Acquisition Competence Test (L-a-T-o). This difference of 8,7 at Sum of Standard Scores is reflected in the higher Spoken Language Quotient of linguistic competence of children thatused a cochlear implant from the beginning (75,4 Spoken Language Quotient) compared to the children that underwent cochlear implantation after a period of hearing aids use (67 Spoken Language Quotient) with a difference of 8,4 units, according to the Language Acquisition Competence Test (L-a-T-o) seen in Fig. 7. In order to examine the differences in the linguistic development of the two groups, the Independent Sample T-test was administered. According to Table 2, there were statistically important differences ($p<0{,}05$) between the means in all the fields of linguistic development of the two groups of children. The analysis revealed that the children that used a cochlear implant from the beginning had improved performance compared to the children that underwent cochlear implantation after a period of hearing aids use, according to the Language Acquisition Competence Test (L-a-T-o).

## Personalized Development Characteristics

In special education, complementary to general education is personalized care and instruction. Impaired students usually have suffered a severe damage of their interactional potential. Therefore, usually they are assigned a tutor that exercises a one-to-one encounter to confront their inability to properly receive synaesthetic stimuli. In the case of young schoolboys, subjects do not acquire all phonemes at once. Apart from their chronological evolution, they have a surplus of hindrance due to their implantation history. I.e., the later their impairments were cured, the more hysteresis they demonstrate in properly vocalizing phonemes. In the case of personalized development, researchers do not seek to monitor big datasets; they rather concentrate on specific cases that attract the exclusive engagement of clinicians, pedagogues, ENT specialists, psychologists, speech therapists, etc.In practice, for this part of the research, five (5) subjects were extensively tested with stringent phonological, prosodic and musical exercises from a group of interdisciplinary scientists. Till now in the relative literature, (Pavlidou *et al*., 2011) it was perceived that the absence of auditory feedback leads to poorer laryngeal function in terms of voice quality, frequency and intensity. Closed quotient reflects the glottal closure during phonation, which tends to be more hyperfunctional with the processor off. Lack of control of respiratory and phonatory functions leads to the reduction of Maximum Phonation Time (MPT). However, recent research has promulgated a neurotological model that involves, apart from direct sensing as equally important the rather irregular, variable and thus far unpredictable influence from short and mainly long term memory, the one that is directly linked with the schooling process (Politis *et al*., 2016). Human speech and singing are considered to be acoustic signals with a dynamically varying structure in the frequency and time domains. In general, voice sounds are in the broader sense all the sounds produced by a person's larynx and uttered through the mouth. They may be speech, singing voices, whispers, laughter, snorting or grunting sounds, etc. The speech production models envisage, however, to provide intelligibility not only on how vocalization is produced in a purely functional manner, but also to surpass limitations of present knowledge on how the human processes of cognition allow concepts, ideas, and messages existing in abstract form within the brain to be transformed into a complex set of motor commands used to drive the articulators in the vocal tract to produce indeed complex acoustic signals.

In acoustic terms, no matter how sounds are produced and what communication purposes they may serve, articulation is categorized to:

a. Voiced sounds that are produced in a person's larynx with a stream of air coming from the lungs and resonating the vocal cords. This stream continues to be modulated through its passage from the pharynx, mouth, and nasal cavity, resulting to an utterance in the form of speech or song.
b. Unvoiced sounds. Singing or utterance would be incomplete if unvoiced sounds where not produced. They do not come as a result of a vibration from the vocal cords, but as partial obstruction of the airflow during articulation.

Not all people however produce the same notes in a uniform manner. A particular quality may be observed that gives the timbre of our voicing. Since the voice channel of each individual varies in morphology, and each subject may uniquely control its internal characteristics, virtually each one of us is capable to produce music with a unique quality, apart from its pitch and intensity. Even further, any malfunction or disease that affects the human organ, not to mention ageing, has impact on our ability to produce prosody or melody. Since the voice organ consists of the breathing apparatus, the vocal cords and nasal-oral passages, it is obvious that the process of phonation is a rather complex and multi-parametric phenomenon. The human ability for oral-aural communication relies on the capacity to coherently set up sequences of sounds that encode acoustically logical propositions. When voicing produces musical or singing sounds, then the articulated sounds of speech communication are enriched with phonation tuned up to melodic, definite pitches, the notes of the melody. The lungs provide the air supply, the primordial energy source for phonation. In medical terms, the lungs consist of two spongy sacs situated within the rib cage, consisting of elastic bags with branching passages into which air is drawn, so that oxygen can pass into the blood and carbon dioxide be removed. The volume of the lungs is controlled by the surrounding rib-cage and the underlying diaphragm muscle. When the ribcage is expanded by the muscular system, and the diaphragm is contracted, the volume of the thorax increases, and inhalation takes place, inflating the lungs. The mechanism for vocalization is better understood from an acoustic point of view by considering a set of variable sound sources, coupled together to form the complex structures seen in Fig. 3. For programming purposes, a simulation of this multi-muscularly driven region that plays a key-role in the dynamic formation of the vocal tract activities is shown in Fig. 8 (Politis *et al*., 2007). The model used there is the source and filter model, which gives a rather sustainable approximation of the speech production process from an articulatory perspective. However, as we describe with more details the ways in which the anatomical structures of the voicing mechanism are developed, controlled, forcefully shaped, or dynamically changing position, we devise better models describing in motor command terms the vocal track muscular movement that serves as the motive force.

For this reason, a "stress test" process is used, involving reciting and singing, aiming to calculate how associated in memory patterns cast-off phonological transitions. The examinations performed intend to check the quality, performance, or reliability of language acquisition in phonological terms; they reveal the strengths, capabilities and more important, the shortcomings of speech communication as functions of cerebral activity (i.e. knowledge), motor commands and sufficient perception with the senses.

## Neurotology points of interest

The relation between cerebral activity and bodily movement is one of the most interesting topics of biomedicine. In the case of CIs, encephalic activity is measured using computerized systems that assess the voice parameters of profoundly deaf patients prior to and after cochlear implantation. However, reports of the phonatory patterns of cochlear implant recipients during phonation are lacking. The purpose of several studies (Hamzavi *et al*., 2000; Seifert *et al*., 2002; Campisi *et al*., 2005) is to analyze and compare the acoustic and aerodynamic measurements and the phonatory patterns of cochlear implant users with and without auditory feedback from the cochlear implant. Absence of auditory feedback leads to poorer laryngeal function in terms of voice quality, frequency and intensity.

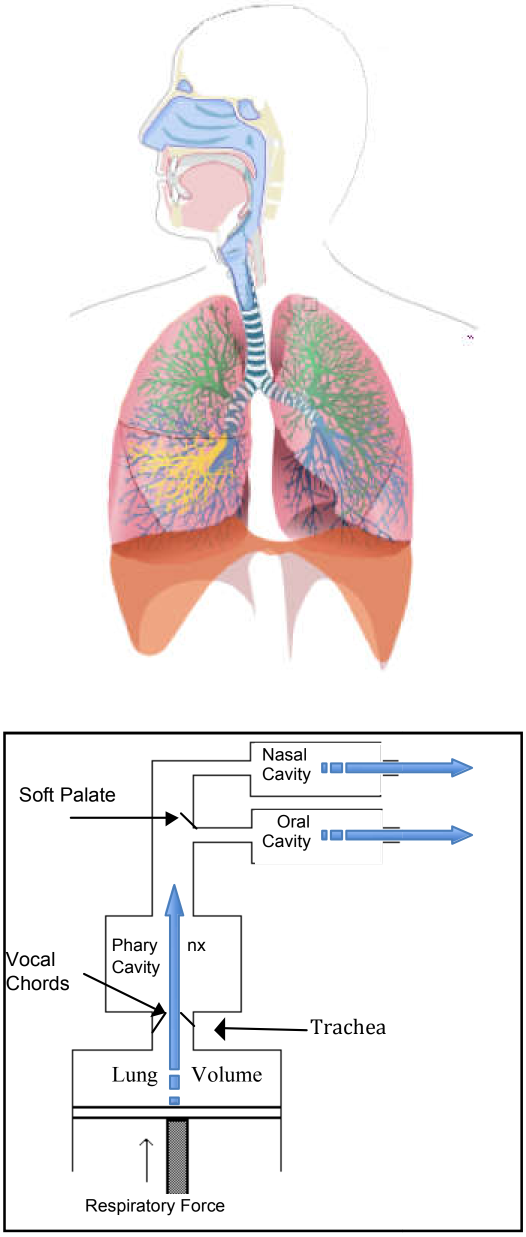

**Fig. 8. Physical modeling of the vocalization mechanism in coronal cross section. Left, the respiratory system and the upper vocal tract mechanism for phonation (from Wikimedia commons). Right, a computer programming simulation for synthetic vocalization. Sonification comes as output from both the nasal and oral cavities**

Closed quotient reflects the glottal closure during phonation, which tends to be more hyperfunctional with the processor off. Lack of control of respiratory and phonatory functions leads to the reduction of Maximum Phonation Time (MPT). The cochlear implant provides critical auditory feedback cues in terms of timing, intensity and frequency domains. Even further, ellectroglottographic analysis stipulates a holistic evaluation that allows physicians to ascertain meticulous therapeutic goals. Speech audiometry is a way to assess the level of rehabilitation in deaf patients who have underwent cochlear implantation, and can reflect the quality of their everyday life, taking into consideration the fact that aural (and oral) communication plays a vital role in it. The objective of our research is to evaluate the dynamics of speech recognition and oral communication control, in terms of frequency and intensity, aiming to high levels of comprehension for the spoken language of these patients. Besides that, in the contextual evaluation of speech rehabilitation, the entropy of a word is measured in conjunction with the circumjacent words of a common phrase. It exhibits with powerful clues for a word that frequents within a phrase, how “special” is its usage in a patient's text corpora. It is an indicator if a word is used in rich content surroundings (circumjacent with high entropy) or tends to appear in specific, levied in concrete circumjacent word sequences (low entropy).

From an electronic body of texts the following can be drawn:

a) Information on the frequencies of appearance for words or verbal sequences (collocations). The statistical analyses may focus on all the texts, or in relative subsets (subcorpora), if the domain is structured according to content semantics. For instance, when we talk about politics, we use a different domain compaired to the subcorpora for sports, science etc.
b) Concordance tables for the keyword in context.
c) Texts that represent certain linguistic varieties and dexterities.

Consequently, the use of the more frequented keywords for the Greek language (keyness), contributes to an increased text comprehensibility (Scott and Tribble, 2006). The first competence test, which gives a phonological categorization for the acquisition of linguistic ability, involves the proper vocalization of words with consonant complexes, or sequences of difficult to acquire consonants. This assessment analyzes the subject's prosodic and phonotactic maturity. Along with short phrases they monitor the subject’s ability to properly utter polysyllabic words with primary stress and accordingly shape pitch bendings that demonstrate interrogation. The speech therapy unit tests the subjects’ ability to properly pronounce difficult complexes of consonants like /sf/ in /pɔδɔsfɛrɪstɪs/ (football player) and /sfɪrɪhtrə/ (whistle) or perplexed everyday sequences – but not tongue twisters- /ɪ kɪtrɪnɪmbələɪnɛpənɔstɪvɪvlɪɔθɪkɪ/ (the yellow ball is on the bibliotheque) By the competence of the subject to meet the vocalization criteria, the real “schooling” age [stagiopoulos] and the how well he has acquiredphonetically the language are revealed.

For instance, although subject #4 has the proper age, she cannot utter fluently “difficult” consonant complexes nor read with pace phrases she has been however already trained to do so. Even further, when she sings the song /əh, kʊnɛləkɪ/ (Oh, little rabbit) which she seems to have mastered and stored in

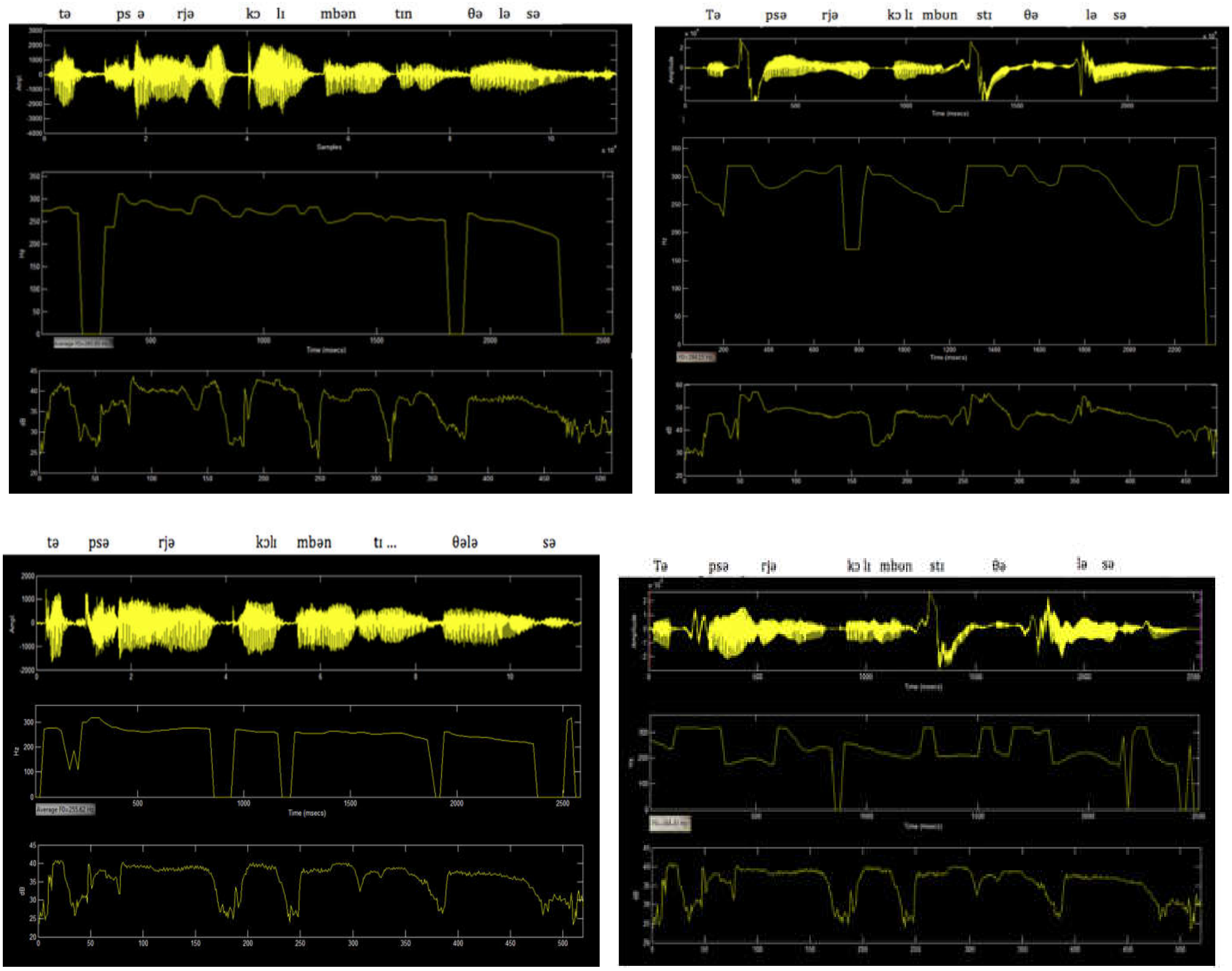

**Fig. 9.A comparison of how well subjects may reproduce affirmative (upper level pictures) and interrogative forms (lower level pictures) of a sentence with the C.I.s turned off. Subject #4 on the left cannot demonstrate any prosodic bendings that will turn the phrase to interrogative mode. Subject #3 on the contrary, in both the vocalizations demonstrates a richness in pitch variability that is far beyond the implied intonation curves by phonological functions (3b) and (3c)**

her long term memory, she sings fairly well, as far as basic musical qualities are involved, uttering the words fluently, but still she cannot avoid unintentional transitions of velar and palato-alveolar complexes to semivowels and glides.

The most prominent stress tests exploited and their results are analyzed as follows:

### Stress Test A: Phonoprosodic evaluation

Once the acquisition level of the subject is determined, its competence is tested in prosodic assimilation. In many languages, as is the case of Greek, the affirmative and interrogative form of a phrase have the same syntax and the intonation pattern of speech demonstrates the linguistic significance. When the patients are asked for instance to utter the phrase /the fish are swimming in the sea/ in affirmative and interrogative mode in Greek, they are asked to utter the following propositions in IPA and stress-signal semantics:

•  •  ~  ·  ·  •  ••  · ↷ (3a)
/təpsərjəkɔlɪmbʊnstɪθələsə/ (3b)
•  •  ~  ·  ·  •  ••  · ⤻ (4a)
/təpsərjəkɔlɪmbʊnstɪθələsə/ (4b)

However, it seems that pitch bendings have a more perplexed nature than what the rather simplistic intonation symbols depict. Indeed, in Fig. 8 the context and subject variable form of interrogation is revealed. Four utterances are compared with the subjects having their cochlear implants turned off. In Fig. 9, left side, subject #4 is unable to form the interrogative form of the phrase, producing a rather flat curve in its pitch representation. The vocalization in its affirmative and interrogative form is practically the same. Similar findings are demonstrated with the energy distribution of the phrase, which enhances the dysmusical findings: she cannot form the appropriate stress and intonation patterns. Also, using the long-term memory acquisitions, she uses a more vernacular form of the verb /kɔlɪmbʊn/, and instead of producing phonetically as it is written on the screen, she utters /kɔlɪmbən/. She also fails to pronounce properly the article /stɪ/, missing the unvoiced alveolar fricative /s/. On the other hand, subject #3 is able to produce excellently the interrogative form, as it seen when comparing the affirmative and interrogative vocalizations. Already, the affirmative form in Fig. 8b is characterized by a variety of pitch bendings, which reveal a more detailed structure than that of the (3a) stress signals. Even better, when the interrogative form is produced (Fig. 9c) she demonstrates excellent arrangements of stressed and unstressed syllables,

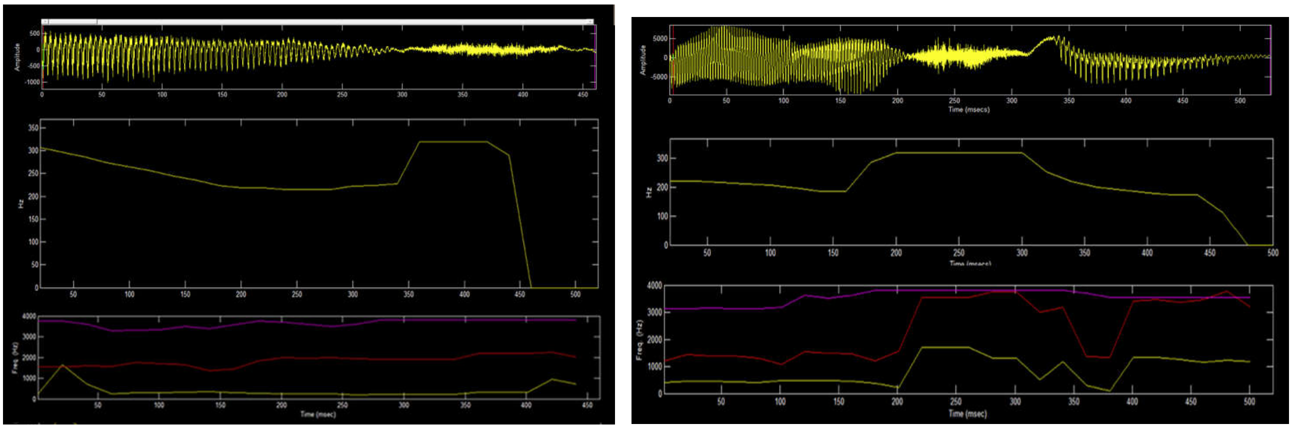

**Fig. 10. The fine-tuned diagrams for the time waveform, its F0 and the first three formants for the word /(θ)ɘlɘsɘ/ in affirmative and interrogative mode by the same subject #3 with the cochlear implant turned off. The phoneme/θ/ is not considered within the calculations to eliminate the effect of the labial and dental part of the mouth on the vocalization of /ə/**

surpassing many non-impaired in hearing subjects. This neat arrangement indeed surpasses any intonation stress marks, demonstrating skill and efficiency in producing highness or lowness for the pivotal last word. Already the patterns in Fig. 9 reveal steep variations that are beyond description in terms of intonation semantics. Even further, for the formation of the interrogation, it seems that the last word bears most of the burden for conceptualizing within the spectrum domain the rise and fall of the voice. It seems however, that F0 along with the energy distribution are not able to demonstrate how exactly this is achieved; therefore, the first three formants are also calculated along with the F0 bendings. Clearly, interrogation is a much more complex phenomenon than altering pitch patterns. It is more of a two dimensional pattern relocation in time - frequency representations of F0 mainly along with F1, F2, and F3, as it is seen in Fig. 10.

complete the test even with the CIs turned on. Especially for subject #4, there are clues that she may be suffering by multiple impairments since she demonstrates hysteresis in many sensory, motor, and cerebral perceptors (Fig. 3): she has failed to commit to her long term memory the phonatory mechanism for interrogation - while on the contrary she has memorized songs she can rhythmically and melodically somehow reproduce! Therefore, she cannot sense the stress and intonation curves needed even with the cochlear implant turned, presumably because in mental terms she has not a clear image of what interrogation means, she presumably has insufficient control on motor processes for articulation, and since she has not grasped basic grammatical knowledge, she will face evident problems in moving to the more complex morphosyntactic language. She clearly needs medical, psychological and special schooling treatment.

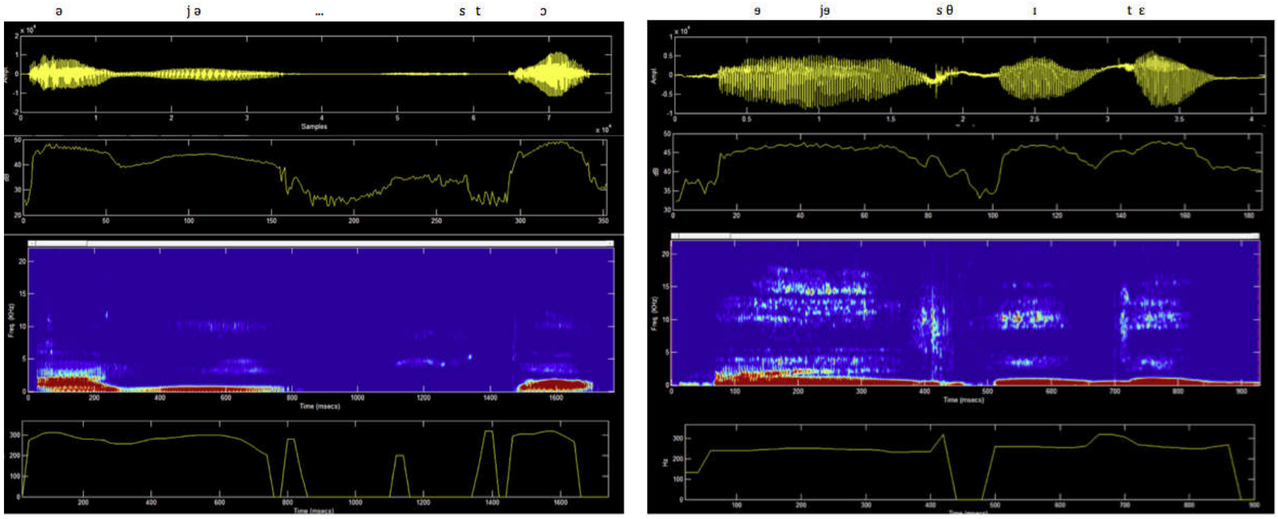

**Fig. 11.The waveform of /ɘjasθ'ɪtɔ/, in its time domain representation, spectral arrangement, short time energy distribution, and F0 curving contour. Left, as it is actually reproduced by subject #4 with the C.I. turned on, and right, how it is vocalized with the C.I. turned off**

Perhaps further linguistic research may produce subcategories for the stress patterns (4b) that will advance morphological inflections to a more detailed stage. Concludingly at this stage, for the 4 subjects tested on their ability to properly form interrogations, two were potent to do it sufficiently with CIs turned on and off, while the other two could not adequately

### Stress Test B: Articulatory - Acoustic Transformations

Moving a step further, using the equivalent of pretentious narration (Tzouriadou *et al*., 2008a and 2008b), subjects are asked to recite a Biblical text written 20 centuries ago (Mat. 6, 9-13), which is however daily used in schooling for centuries

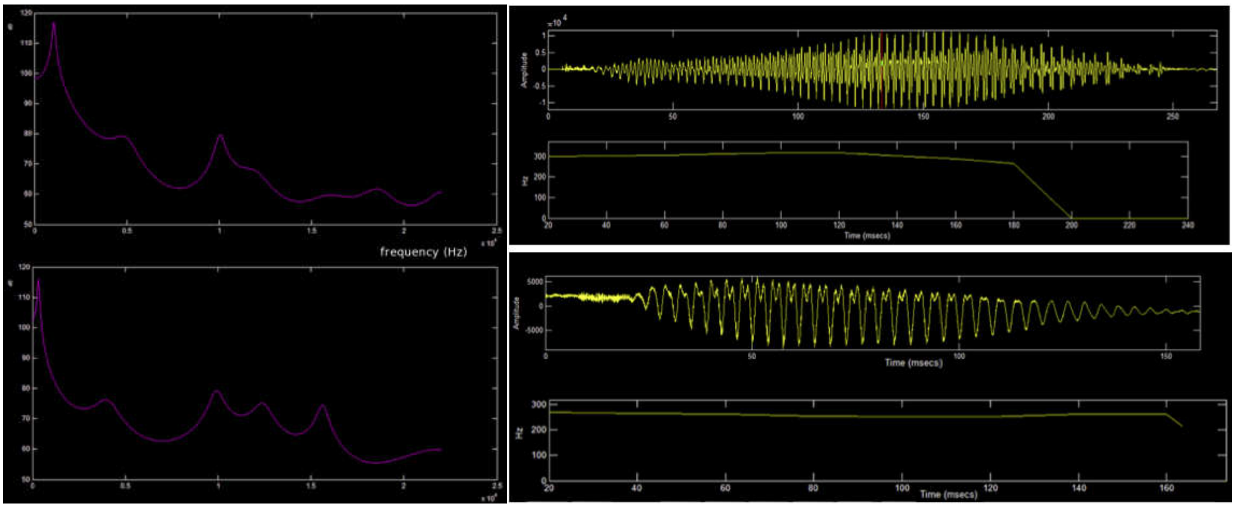

**Fig. 12. Formant shift for the suffix of the word /ɘjasθ'ɪtɔ/, from /ɔ/ to /ε/. The upper images depict the situation with the C.I. turned on, while the lower ones with the C.I. turned off. The images on the left display the LPC smoothed spectra for the ending vowels, while the ones on the left the time-frequency representation of F0 for the ending morpheme**

in its original form. Nearly all the words of it are also used in modern Greek, but with their suffices inflected in mood or tense. As a result, when the young subject #4 reads it with the implant turned on, she has enough visual and auditory feedback to properly vocalize the stem and suffix of the word /ɘjasθ'ɪtɔ/, but the word being rather complex for her linguistic stage is pronounced with hesitation as /ɘjas :tɔ/, as seen in Fig. 11, left. When the cochlear implant is turned off, she relies more on her memory, clearly the long term one, to recite the word, since most young children pertinently memorize the whole text during the first couple of years of their schooling. She vocalizes fluently, with very little hesitation, but turns the suffix to /tε/, as many young children do, since grammatically it is more consistent with the Modern Greek attestation (Fig. 11, right). In motor command terms, the soft palate is raised, the vocal tract filter has its shape varied using the tongue, lips and jaw, but without forming sufficient constriction or obstruction in the vocal tract to cause turbulence in the airflow through it. The tongue in the case of /ɔ/ is rather at the back of the oral cavity, while for /ε/ it shifts gradually to the middle. The jaw gets lowered from its neutral position and the lips being protruded and rounded become less constrictive and open up in producing clearly more energetic phonation.

It is evident that when she uses her long-term memory residues, she is able to produce a more fluent phonation. However, not having acoustic feedback, as depicted in Fig. 3, she is susceptible to grammatical errors. It is impressive, however, that in spectral terms the ending vowel /ε/ is very close to the /ɔ/ she produced with the C.I. turned on, as seen with the LPC smoothed imaging of Fig. 12, images on the left. Surprisingly, however, also subjects #3, who is impeccable at this level demonstrates this transition. Additionally, a comparison between the time length and the fundamental frequency of the final syllable is demonstrated on the right of Fig. 13. Some compression in terms of frequency and time lapse is recorded, with the utterance having the C.I. turned off being around 10% for both measurements. F0 is 304.41 Hz in the first place, drifting to 260.7 Hz in the second, while the length of the syllable drops from around 200ms to a mere 150ms. However, this kind of measurement, although used in the literature (Rabiner and Jung, 1993), cannot guarantee unblemished exertions as far as frequency transformations are involved. Indeed, as it will be demonstrated when singing attestations are measured, healthy subjects or professional singers both exhibit this kind of divergent performance, without giving obvious clues for which one is the correct and

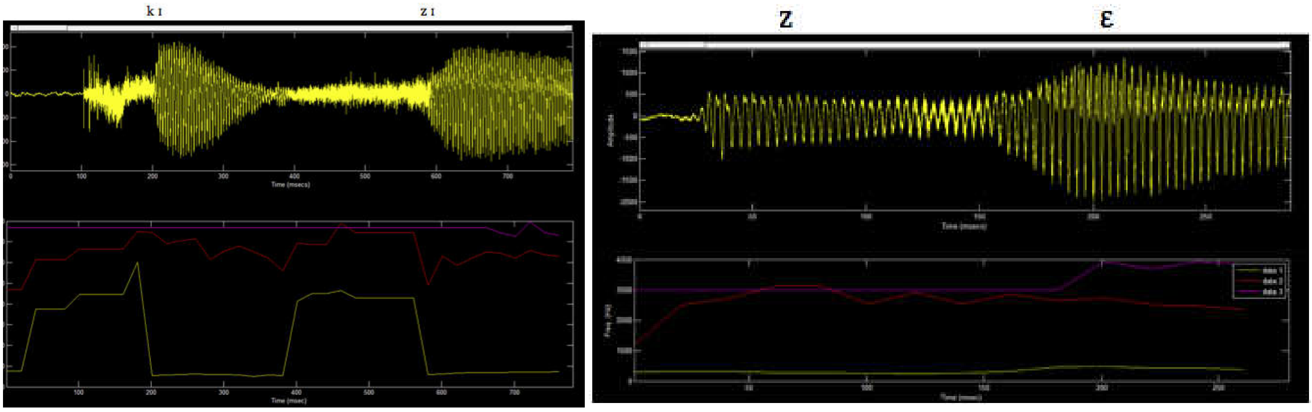

**Fig. 13. Phoneme transformation when there is no acoustic feedback. The /ks/ phoneme is turned gradually (left) or imminently (right) to /z/**

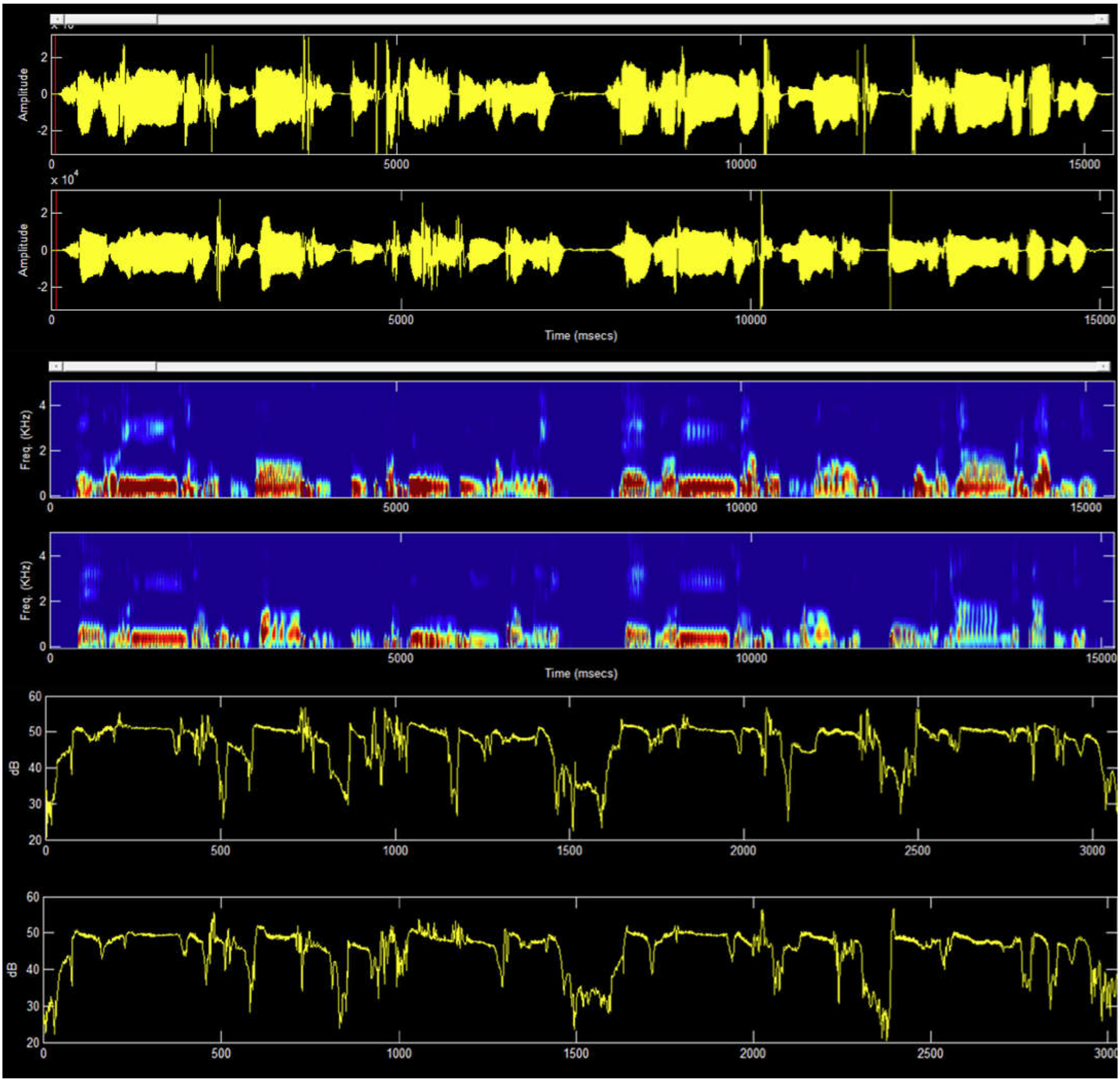

**Fig. 14. A segment of the national anthem sang with C.I. turned off (upper section) and turned off (lower section). The first two pictures are the time-series waveforms. The next two pictures contain the spectrograms and the last two the loudness contours**

which is the deviant. For instance, when well known singers perform the national anthem, they may differ in their musical execution in terms of time, frequency and phonetic ascriptions, and for this reason the exact measurement of pitch does not provide by it self particular findings or important conclusions. Had one applied stringent and detailed stress tests to them, as those applied to the subjects of this research, most of them would be characterized as divergent. Even further, it is very difficult to determine with the pitch curve alone which vocalization is the correct and which is the deviant. For this reason the rendition of the national anthem used is choral singing. As Greek speaking children have acquired the phoneme /θ/ little before the full integration of all phonemes at the age of five, a "stress test" on how they can correctly articulate this sound would be positive on most cases and therefore unable to unearth the difficulty in handling these sounds. A more decisive test has to do with how subjects handle /θ/ in clusters of three phonemes, one of them being a vowel and the other a consonant. A third pivotal phoneme may be the liquid alveolar approximant /l/, which is acquired after the 3rd year, or the equally difficult palato-alveolar liquid approximant /r/. The comparison is made for complexes like /lθε/, /ksɪ/, /psɪ/ that are common in Greek and seem to be producing phonetic transformations. For this test, subject #1 and #4 are mostly used, since they are the ones who have not acquired in depth all phonemes, and thus, they are the ones that reveal by their mistakes how phonemic and spectral deviations pair together. The transformation of the word *xeno* to *zeno* is very important in historical linguistics. In contemporary English, there are words transcribed since antiquity, like xenophobia, Xerxes or Xenophon that now are pronounced with /z/ instead of /ks/. It is not clear how this alteration took place, or when. This finding is crucial, since it signals an underlying mechanism causing in English a massive shift for words starting with x, virtually mixing letters x and z. Examples: Xenon, Zeno, Xerxes, Artaxerxes.

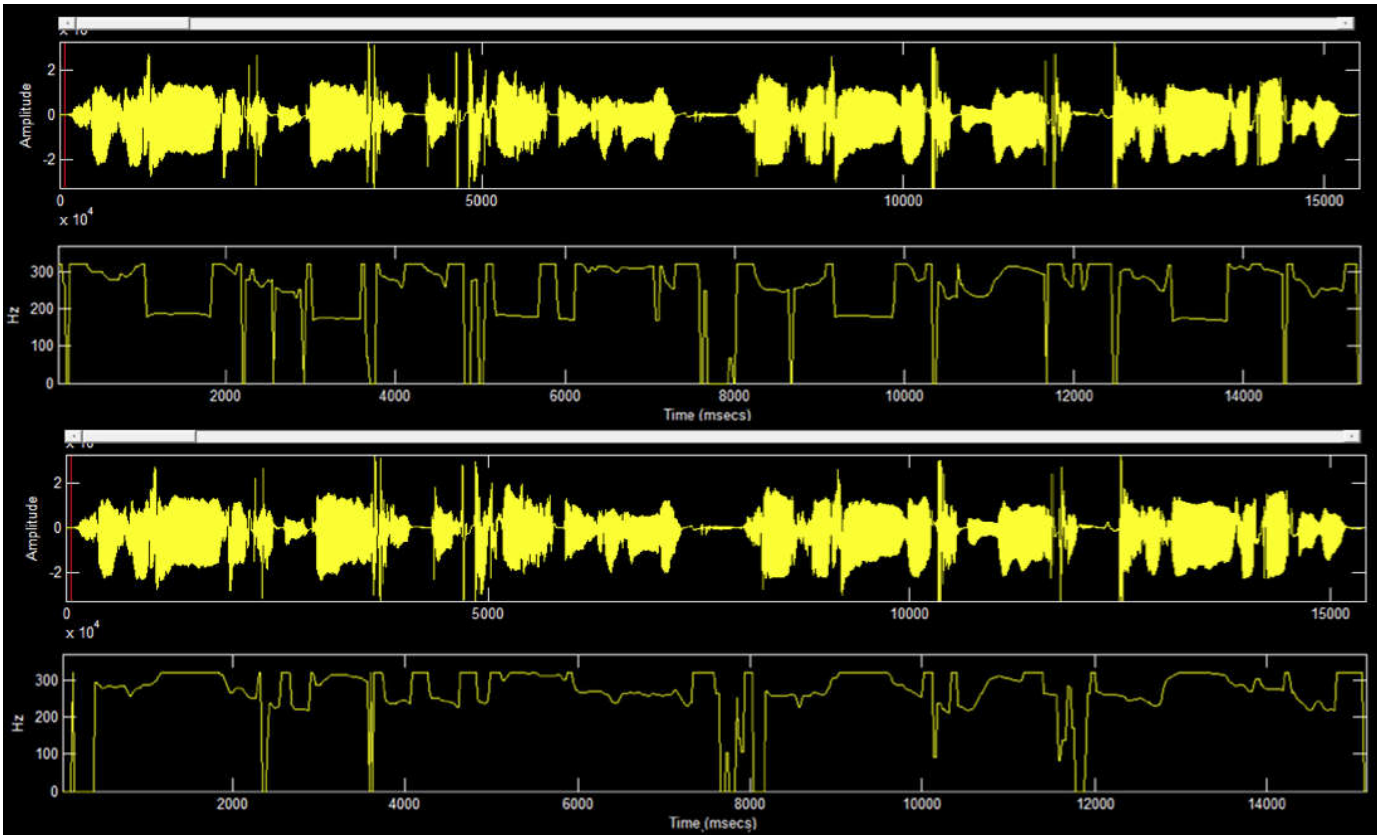

**Fig. 15. Singing segment with C.I.s turned on and off. Time series waveforms with their F0 contours**

More important, when subject #4 sings /əh, kʊnɛləkɪ/ (Oh, little rabbit) and tries to utter words /ksɪlɔ/ and /ksɛnɔ/ with the C.I. turned off, the morphemes depicted in Fig. 12 are heard. The subject gradually in the case of /ksɪlɔ/ decomposes letter x to a prolonged combination of /k/ and /z/, heard like /kɪzɪ/. The decomposition is evident with the formants that are clearly shaped on the former case, due to the On the latter occasion x is transformed to z, and therefore instead of /ksɛnɔ/ the word /zɛnɔ/ is uttered instead. It should be noted that with the C.I. turned on, this subject is successful in vocalizing phoneme /ks/ for the letter x.

### Stress Test C: Rhythm, Compression and Intensity

The third stress test examines the ability of the subjects to sing adequately a well known to them tune, the national anthem. They attempt to perform it with the C.I. turned on and turned off.

When the C.I. is turned off, they rely more on their long term memory, since they do not have a recent hearing of the prototypal tune. In some occasions they perform it more melodiously, since they receive no feedback, either positive or negative, from their environment. However, they cannot control adequately:

- the loudness of their phonation
- the time-length of their performance (uncontrollable time "compression")
- the richness of their expression in terms of spectral characteristics

When examining their performance, it is obvious that the lack of feedback makes the subject more hesitant, since it does not have a clear view of how loud his utterance is heard or how fast he speeds with his musical tempo performance (Fig. 14). Sometimes he performs more louder, while other times he is less emphatic. Usually, the lack of expression affects timing as well. Sometimes subjects perform faster, while more other times they prolong their rendition. It seems that this uncontrollable "compression" affects the tuning of the F0 as well (Fig. 15).

### Conclusion

C.I. users may reveal many unknown channels of human brain feedback with memory data and sensuous stimuli. Multimedia learning tests excite stronger cerebral activity and therefore exert more information on how learning intellect handles phonological, linguistic and musical structures. The research on this sector is promising to reveal more on how exactly cerebral control of speech is diverted between unconscious actions and highly skilled phonetic processes.

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