Scientific Research Publishing

International Journal of Clinical Medicine, 2019, 10, 27-52
http://www.scirp.org/journal/ijcm
ISSN Online: 2158-2882
ISSN Print: 2158-284X

Augev Method and an Innovative Use of Vocal Spectroscopy in Evaluating and Monitoring the Rehabilitation Path of Subjects Showing Severe Communication Pathologies

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How to cite this paper: Campanella, A., Manca, F., Marin, C., Bosna, V., Salonna, I., Galatola, M. and Sabella, E.A. (2019) Augev Method and an Innovative Use of Vocal Spectroscopy in Evaluating and Monitoring the Rehabilitation Path of Subjects Showing Severe Communication Pathologies. *International Journal of Clinical Medicine*, **10**, 27-52.
https://doi.org/10.4236/ijcm.2019.102004

Received: January 13, 2019
Accepted: February 12, 2019
Published: February 15, 2019

Abstract

A strongly connotative element of developmental disorders (DS) is the total or partial impairment of verbal communication and, more generally, of social interaction. The method of Vocal-verb self-management (Augev) is a systemic organicistic method able to intervene in problems regarding verbal, spoken and written language development successfully. This study intends to demonstrate that it is possible to objectify these progresses through a spectrographic examination of vocal signals, which detects voice phonetic-acoustic parameters. This survey allows an objective evaluation of how effective an educational-rehabilitation intervention is. This study was performed on a population of 40 subjects (34 males and 6 females) diagnosed with developmental disorders (DS), specifically with a diagnosis of the autism spectrum disorders according to the DSM-5. The 40 subjects were treated in "la Comunicazione" centers, whose headquarters are near Bari, Brindisi and Rome. The results demonstrate a statistical significance in a correlation among the observed variables: supervisory status, attention, general dynamic coordination, understanding and execution of orders, performing simple unshielded rhythmic beats, word rhythm, oral praxies, phono-articulatory praxies, pronunciation of vowels, execution of graphemes, visual perception, acoustic perception, proprioceptive sensitivity, selective attention, short-term memory, segmental coordination, performance of simple rhythmic beatings, word rhythm, voice setting, intonation of sounds within a fifth, vowel pronunciation, consonant pronunciation, graphematic decoding, syllabic decoding, pronunciation of caudate syllables, coding of final syllable consonant, lexical

decoding, phoneme-grapheme conversion, homographic grapheme decoding, homogeneous grapheme decoding, graphic stroke.

Keywords

Re-Educational Method, Learning Difficulties, Developmental Disorders, Vocal Spectroscopy

1. Introduction

The method of Vocal-Verb Self-management (AUGEV) [1] is a systemic organic-educational and re-educational method aimed at overcoming interferences in verb-interplay communication [2] through the development of neuro-psycho-physiological learning bases [3]. The vocal verb adjective indicates a twofold purpose of this method that is aimed on one hand at promoting verbal structure learning, on the other at perceiving and using verbal language acoustic qualities [4]. This method is therefore a re-education path aimed at subjects with linguistic and communication difficulties of different degrees [5]: subjects with problems of phono-articulatory setting, subjects with pathologies of verbal-social-relational communication (autism disorders, aphasia, dyspraxia [6], attention deficit and hyperactivity disorder) and subjects with learning difficulties (dyslexia, dysgraphy, dysorthography, dyscalculism).

In subjects with serious problems of verbal communication, particularly in cases of language absence, the gap in regular and physiological development becomes increasingly pronounced with age progress, as it emerges:

1) a lack or partial use and training of pneumophonic coordination functions in expiratory phase [7];

2) an altered resonance of laryngeal sound in supraglottic cavities (pharyngeal, mesopharynx, nasopharynx) [8];

3) an altered sensation and perception of personal and others' vocal productions with following inactivation of phonatory feedbacks [9], which are essential to develop quality and quantitative voice self-control, to improve phonatory emissions and therefore to produce correctly the mnemonic process;

4) an inability to discriminate and "finalize" sounds coming from the surrounding environment.

These serious obstacles, therefore, in being aware of phonatory control mechanisms, in discriminating voices as well as one's voice above all, leave out the subject from speakers' reality [10], towards which he/she shows even greater inattention and lack of interest [11].

The main purpose of this method is to acquire spoken and written communication through developing physiological and neuro-psychological learning assumptions.

Based on neural interconnections among various cortical areas [3], AUGEV method uses simultaneous, integrated, interacting and interconnected multiple

stimulations of an esteroceptive (hearing-view), proprioceptive (muscle-taouch) and endoceptive (mucosa) nature, organized in 4 operating paths called: audio-visual-touch-speech, phono-kinesthesia and phono-linguistics, which find their highest enhancement in prosodic read-writing, electively aimed at pursuing an adequate learning process goal [12].

The method aims at helping a person to realize oneself as an harmonious unit which includes physical-motor and psycho-intellectual elements.

In particular, the method is recognized in three fundamental assumptions that characterize different rehabilitative actions:

1) The intrinsic connection between word and movement. In fact, it enhances the body as a medium of verbal learning based on the principle that structural elements of spoken language can be taught by linking vocal emissions to body movements [13] so that they can be more easily internalized to achieve smoother and more verbal expressive performances. Body mediation, which consists in functionally connecting verbal phonetic structures to body expressions and rhythms, is therefore the main didactic communication means through exercises in which a constant association is established among postures, gestures and voice. Motor acts have been organized with great precision, respecting some founding principles of mechanical physics and in particular static and dynamics [14] applied to human body [15].

2) The connection existing between spoken language and music [16], then verbal expression musicality and its corresponding expressiveness in music [17]. Since cortical areas assigned to functions of acoustic memory, and in particular those which preside over the processing of verbal solicitations, are sensitive to musical stimulations [18], AUGEV method includes exercises based on presentating sound solicitations as in a sung form, therefore exercises of listening and reproduction of melodic vocal sequences exemplifying the most recurrent rhythmical and tonal structures of spoken language [19]. Verbal messages are also presented and formulated in association with appropriate bodily movements, so that sound events and body gestures are analogically related to each other and mutually reinforcing.

3) The association of sounds and movements with simple graphic representations and immediately accessible. These are functionally important since they spatialize sounds [20] so that a subject can visualize their fundamental parameters: frequency (whose perceptual correlation is the height), duration (or emission time) and amplitude (whose perceptive correlation is intensity) [21].

Thanks to all these elements, a subject can gradually and physiologically [22] [23] acquire language basic structures [24] (words and their sentence combinations) and dynamics that regulate it (syntax and prosody) [25] in order to have access to its fruition and interpersonal communication use [26].

Peculiarities of systemic the organicistic method "*Verb-vocal self-management*"

A typical characteristic of this method, denoting its absolute innovation and effectiveness, is the punctual and precise perceptual enhancement carried out

among them by the main learning areas [27] (visual, acoustic, proprioceptive-tact-motor, verbal-motor...).

For example, this is perceptually and simultaneously strengthened by visual-graphic and phono-acoustic stimulations when the subject performs a tact-motor activity.

Similarly, this happens when stimulations specifically affect the other areas mentioned above: phono-acoustic activities are, in fact, coordinated with tactile-motor and visual-graphic information, whereas stimulations in visual area are combined with tactile-motor and acoustic-type activities.

This operative model allows—thanks to evocating sensory-perceptual information firmly anchored among them—the activation of acoustic, phonatory, visual, tactile and proprioceptive-motor feedbacks, which are fundamental for making any learning activity stable and coordinated [28], avoiding that an area develops in a prevalent or deficient way compared to the others.

Coordination and correspondence, which facilitate their use among stimulations, generate an important increase in duration and attention levels, elements that allow the subject to start the execution of activities (**Figure 1**).

This method applies to all age groups, pre-school children, adolescents and adults as well as to any cognitive-intellectual level.

AUGEV method consists of two stages: a preliminary and an operational one.

The first one concerns the evaluation of compromised areas in subjects with altered verb-vocal production through psychodiagnostics [29] [30], in order to organize a detailed rehabilitation program. The second one is conceived in such a way as to be customized according to a subject's needs and difficulties, respecting the perceptive-gnosic development considered from a general physiological perspective [31]. Operational stage consists of 3 phases, respectively called synchresis, analysis and synthesis [32].

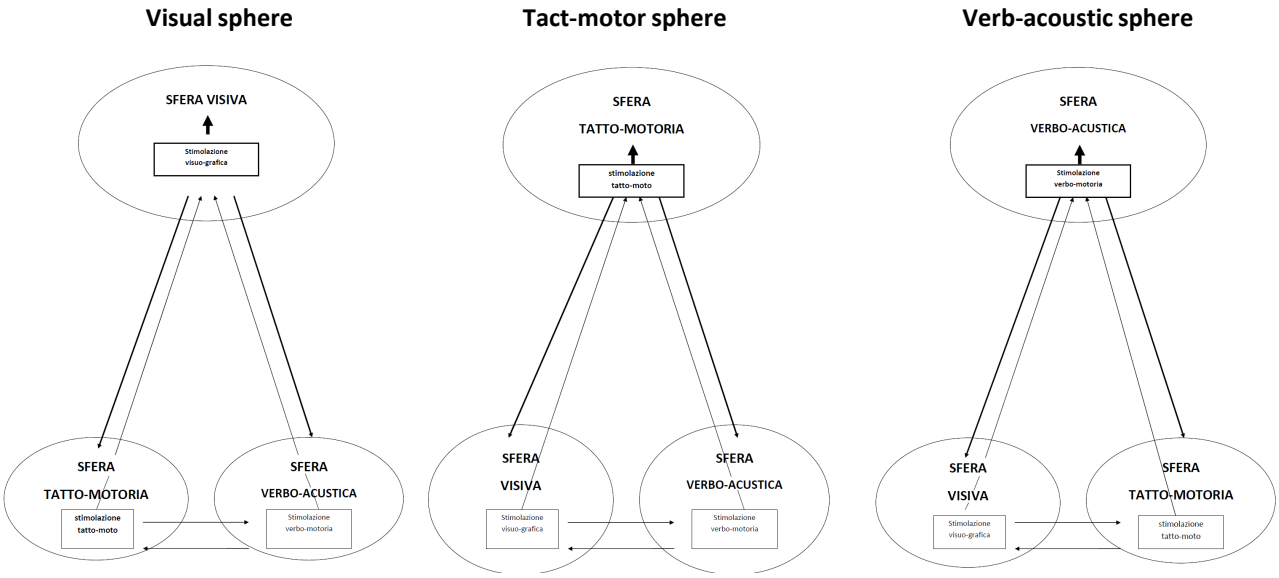


Figure 1. Coordinated cooperation of the learning spheres.

(Synchresis)

Synchresis stimulates the attention to simple and global sensory-perceptive information (auditory, visual, tactile and motor).

These stimulations leave weak and generic perceptive traces [33].

During this phase, a subject is guided by the operator who favors initiation of cognitive processes (attention, perception, memory, thought and language) [34] through coordinated and simultaneous multiple stimulations that exploit a mechanism of repetitiveness to activate a sense-perceptive feedback process that allows the subject to create and store correct and basic motor and verb-motor patterns.

(First Analysis)

After activating cognitive development which is globally realized by syncretic phase, a subject is analytically helped to achieve conscious and selective learning [35], a fundamental step to acquire knowledge, to use them at the right time and to conquer the others independently [36].

In this phase, it is possible to evaluate the activation of important perceptive areas: visual, acoustic and proprioceptive sensitivity [3].

The subject is no longer guided as in syncresis, but only helped by the operator who sets himself up as a model: a selective attention gradually activated by analysis activities makes it possible to start an imitative capacity.

2. Method

This research work is a systematic study on case histories that aims at analyzing the effects of applying AUGEV method, which was adopted at logopsicopedagogical centers "La Comunicazione" in the headquarters of Bitritto (Bari), Brindisi and Rome between 2002 and 2017. The study involved 40 subjects, 34 males and 6 females, whose age was between 2 and 21 years with a diagnosis being included into developmental disorders (DS), specifically with a diagnosis of the autism spectrum disorders according to the DSM-5 [29]. Personal data, in particular those on health, were treated in accordance with the responsibilities established by the regulations of the good clinical practice (legislative decree 211/2003). At the time of taking charge of those subjects at the center, we take a look at the clinical analysis performed by a specialist physician (neurologist, audiologist, phoniatrist, etc.) and then we proceed to functionally evaluating individual learning areas carried out by a multidisciplinary team, to start then the operational phase of applying AUGEV method. Based on the emerged results, an initial assessment of development degree of various learning areas is made and a targeted and personalized omnidirectional systemic rehabilitative educational intervention is developed. After a treatment period, patients are re-evaluated with the same diagnostic protocol performed at the beginning. The evaluation at the beginning and during subsequent checks is noted in medical records.

Clinical records of subjects with autism and autism specimens were analyzed in order to identify any progress, resulting from applying AUGEV method in

different learning areas: cognitive-behavioral, motor and linguistic.

In particular, data was inserted and processed using SPSS software (Statistical Package for Social Science) to calculate univariate descriptive statistics by frequency distribution and the bivariate ones by contingency tables. In order to evaluate the meaning of relationship in double entry tables, χ^2 test was adopted, taking into consideration only those tables for which p value was lower than 0.05.

It is essential to specify that in this study only data related to Syncresis phase and those related to the initial part of analytical phase were examined, called actually First Analysis to simplify. A following study will socialize the data concerning completion of educational-rehabilitation process implemented by Augev method.

However, the most significant analysis of data has concerned objective surveys carried out through vocal spectrographic examination.

Actually, physical-acoustic parameters of each subject's voice were found with a computerized sonograph: Fundamental Frequency (F_0), First and Second Forming (F_1 and F_2), Duration (T) and Phonatory Energy (E).

Monitoring was performed by comparing "captured" values during spectrographic recording with a standardized reference range which shows average values classified by age and sex.

It should be noted that frequencies (F_0, F_1, F_2) are measured in Hertz (Hz), Emission time in seconds (sec) and Phonatory energy in decibel (dB).

Method operating modes: Syncresis and First Analysis

Syncretic activities proposed in **motor area** involve the body as a whole and the subject, who is initially guided, experiences all space "dimensions" and individual movement succession over time.

In particular, 8 exercises of general dynamic coordination (summarized by graphical symbols) are provided during synchresis phase, which create tension states and large muscular district relaxation which facilitate the emission of vocal sounds associated with them [37].

The subject performs movements with the arms by moving them upwards, downwards or sideways, and makes coordinated leg movements (bends or lateral displacements) and listens to vocalic emissions spatialized by those motor acts (high, low, long, short sound, intense, weak). Sound stimulations are produced by an instrument and therefore "vocalized" by the operator. They are characterized by simple iterant sound combinations presented with the aim of improving acoustic sensitivity towards sounds in order to improve the ability to adapt to models [38].

By doing an activity that acts as a bridge between motor and linguistic areas, a recognition of rhythmic differences among words with different tonic accent [39] is also started by simple finger strokes on a support surface: very simple words are obviously proposed in synchresis, such as monosyllables (you, there, no, etc.) or bisyllables (mother, bread, ball, etc. or father, so, why, etc.)

In **linguistic area**, a subject is trained to listen to vowel sounds and is helped in their production.

These fundamental sounds during language practice are "hooked" even better at a perceptive level, thanks to their graphic trace (writing), which the subject begins to perform with the operator's help. The movements performed to execute each grapheme are sonorized by the operator who proactively highlights its specificities: its voice will therefore go upwards, downwards or it remains constant by being coordinated with the graphic section being created. Thus, the subject begins to familiarize with main melodic movements of linguistic expressions, that is, the interrogative, exclamatory, affirmative and suspensive ones [40].

A perceptual coordination that comes to be realized in each activity has an immediate implication in the cognitive-behavioral area [41]: a subject begins to feel capable of performing required tasks and then shows always greater interest towards them, gradually eliminating any behavioral intemperance that signaled an inadequacy perception [42].

Analytical phase activities proposed in **motor area** aim to achieve a segmental coordination, which is essential for a subject to experience dynamic potentials of body individual parts.

Exercises are performed in different postures and include movements aimed at indicating pre-established body points; as in syncresis, motor acts are combined with phonatory emissions that harmonize with body movements. The same sound concatenations are also spatialized by graphic scales that a subject has to perform with fingers.

In this phase, the acquisition of three fundamental sound parameters takes progressively place: the frequency perceived as sound height (acute and severe sounds), the emission time and the amplitude whose perceptive correlation is intensity (loud and weak sounds) [43], only generically presented in synchresis. In this way, high and low sounds can be discriminated, as well as long ones from short ones and strong ones from weak ones, which is a fundamental prerequisite for enjoying fundamental discourse elements such as intonation, duration, rhythm and accentuation in all its degrees.

Analytical phase includes a considerable number of exercises which, presented gradually and adapted to a subject's ability, aim at steadily acquiring spatial and temporal patterns, as well as obvious somatognosic ones which are essential pillars of learning in all of its form [44].

Sequences of rhythmic beats already presented in syncresis are proposed in a shielded mode so as to stimulate and simultaneously evaluate acoustic attention and the beginning of rhythmic-motor organization. The latter is further trained by presentating rhythmic patterns evoking words with different tonic accent, already proposed in synchresis where, however, they were related to simple bisyllabic words. Now rhythm becomes more complex extending to trisyllabic words (slippery, flat and truncated).

Thoroughly coordinated to the motor area, we go on with the **linguistic area** including activities that involve vowel sound improvement, so that subjects become aware of their distinctive traits by gradually learning to coordinate the organs used for phonation and articulation as well as for respiratory rhythm.

Absolutely in line with the method basic principle that provides always interconnected activities, stimulation of bed-writing leads [45] to a conscious acquisition of single phonic (phonemes) and graphic (graphemes) units as well as vowels and consonants, which are spatialized from appropriately emphasized easy graphic symbols. A subject learns to know even sound slightest differences, articulation [46] and graphics, starting with discriminating vibrant phonemes which have their own sound from the deaf ones which produce only noise [47]. These acquisitions allow a correct decoding and coding of phono-graphic units and, therefore, a chance to combine them correctly, proceeding slowly to initially reading and writing words at high use frequency and then more and more complex and correct from a graphic-spelling perspective [48].

Analysis marks a real turning point in the **cognitive-behavioral area,** because a subject who activates the above mentioned selective attention, obtained by coordinating all learnings, gradually manages to organize mental schemes that can start up a mnemonic process, which is obviously a short-term memory [30]. All this has important effects on behaviour, since the awareness of being able to manage a progressively greater number of learning has a significant influence on interests and self-esteem.

3. Results

3.1. Syncresis

Data highlighted in Table 1 clearly show that subjects' exposure to global stimulations during syncretic phase, sent coordinately and simultaneously to all the aforesaid cerebral areas, according to an inextricable method principle, provides important results in a short time. Starting from the second evaluation already, but even more from the third one, it should be noted that the majority of subjects report positive results in the considered areas related to syncresis. Regarding variables ascribable to cognitive-behavioral area, a supervisory status, which is absent and poor at the beginning, becomes present during following evaluations. It also improves attention capacity in all its aspects: attention level that is mostly low during the first evaluation phase becomes sufficient and good during following evaluations due to carrying out therapeutic interventions; the duration of patients' attention becomes short first, and then it gets prolonged after following stimulations. In line with solicitation simultaneity that characterizes AUGEV method, there are evident improvements in the motor area as well. In particular, an initial detected general dynamic incoordination is completely overcome. Patients who were not able to execute simple orders or who found them difficult to do at first evaluation, are afterwards able to reproduce simple or even complex orders. Subjects show also an improvement in executing simple

Table 1. Observed variables during syncresis.

Variables	*Modes*				*Asymptotic Significance*
Supervisory status	absent	poor	present		0.000
Attention: level	poor	sufficient	good		0.000
Attention: duration	short	prolonged			0.003
General dynamic coordination	absent	limited	present		0.000
Understanding and execution of orders	absent	partial	simple	complex	0.007
Performing simple unshielded rhythmic beats	absent	wrong	correct		0.000
Word rhythm: performing a flat bisyllable	absent	wrong	occasionally correct	correct	0.000
Word rhythm: truncated bisyllable	absent	wrong	occasionally correct	correct	0.000
Oral praxies	absent	lacking	present		0.000
Phono-articulatory praxies	absent	lacking	present		0.000
Pronunciation of vowels	absent	altered	slightly altered	correct	0.000
Execution of graphemes	absent	lacking	good		0.000

unshielded rhythmic beats. A similar positive trend in terms of achieved results following the treatments is recorded in executing measures that reproduce the rhythm of flat and truncated bisyllabic words compared to which, at second evaluation already, the share of those who cannot execute them decreases in favor of an increase of those who perform them wrong firstly, then intermittently correct and completely correct. Regarding the linguistic area, incoordination detected in first evaluations involves organization of verbal and written communication, considered unanimously one of the most complex activities of human mind. Thanks to the application of AUGEV method, almost all subjects are gradually able to recover from initial deficits related to oral and phono-articulatory praxis. Progress of vowel pronunciation is also evident: all subjects, who at the time of their taking in charge, were unable to emit vowels, recovered in following evaluations. Grapheme execution completes the picture of variables related to synchresis, towards which almost all subjects show inadequacies, afterwards recovered during following evaluations.

3.2. First Analysis

Regarding AUGEV method analytical phase, it is quite clear that in the evaluations following the first one subjects report positive percentages in three variables pertaining to three large perceptive areas: visual, acoustic and proprioceptive. Coordination and simultaneity of stimulations in the above-mentioned areas, which are extremely detailed in the analytical phase, have an important impact in the cognitive-behavioral area: attention becomes selective and begins

to address pertinent information, a progress that allows a mnemonic process activation, even if it is still a short-term memory. However, the latter becomes a stable acquisition only in second analysis. In the motor area, segmental coordination, which turns out to be absent or limited at the beginning, is acquired by a good number of subjects who become able to perform motor acts based on models that provide personal body awareness. A significant improvement of motor coordination, acoustic perception and short-term memory is obtained by evaluating simple shielded rhythmic beat executions. The start of rhythmic motor skills is also appreciated in executing rhythmic models related to trisyllabic words: in fact, in the fourth evaluation almost all subjects are able to execute word rhythms with three syllables (slippery, flat or truncated). Another important positive element in analytical path progress is data concerning the phonatory setting [49], which are significant of correct establishment of audio-phonator feedbacks. The analytic ability to manage small muscle areas is also evident in the meaning found in variables related to sound pitch within a fifth (remember that 5 are, generally, the shades within which natural speech moves) and in individual vowel sound refinement. In particular, for vowels a, è, i, ò, u [50] considerable improvements are made in evaluations following the first one, with an increasing incidence of subjects able to emit them in a guided manner first, then on a model basis. Some absolutely reliable difficulties remain in correctly producing the two closed vowels "é" and "ó", as they provide for perceptive discrimination and articulatory control not yet achieved by subjects who are acquiring language. The latter is strongly favored by an increasingly conscious use of bed-writing, which allows fixing sound-acoustic patterns by virtue of a coordinated use of graphics and tact-motors. The results in this area, highlighted in **Table 2**, are also positive: in pronouncing and reading individual alphabetic letters (graphical decoding), in the one concerning a variable combination between consonants and vowels (syllabic decoding), including the more complex consonant-vowel-consonant scheme (pronunciation of caudate syllables and coding of final consonants in syllables), finally in reading true words (lexical decoding) and in writing under phonemic dictation (phoneme-grapheme conversion). Perceptual training on analysis leads a subject to check also minimum differences between very similar phono-graphemes (for example, p-b, f-v, d-t, l-r, c-g): at the fourth evaluation almost all cases are able to decode them correctly. The ability to control graphic stroke improves significantly. Findings show that subjects are progressively acquiring a correct verbo-graphic production.

3.3. Spectrographic Examination: Definition and Results

From the qualitative analysis carried out on examined population, it emerges clearly a positive response of all subjects to stimulations contained in Augev method treatment protocol. However, it was considered proper in phono-linguistic field to confirm qualitative data with quantitative evaluations obtained thanks to voice spectrographic analysis. The spectrographic survey represents AUGEV method further strong point, which proceeds innovatively towards

Table 2. Observed variables during first analysis.

Variables	*Modes*				*Asymptotic Significance*
Visual perception	absent	limited	good	excellent	0.000
Acoustic perception	absent	limited	good	excellent	0.013
Proprioceptive sensitivity	absent	limited	good	excellent	0.01
Selective attention	absent	present			0.000
Short-term memory	absent	present			0.136
Segmental coordination	absent	limited	present		0.000
Performance of simple rhythmic beatings	absent	wrong	correct		0.002
Word rhythm: slippery three-syllable	absent	wrong	occasionally correct	correct	0.006
Word rhythm: flat three-syllable	absent	wrong	occasionally correct	correct	0.000
Word rhythm: truncated three-syllable	absent	wrong	occasionally correct	correct	0.012
Voice setting	undetectable	absent	lacking	present	0.000
Intonation of sounds within a fifth	absent	altered	present		0.000
Vowel pronunciation à	absent	guided	on model: lacking	on model:good	0.002
Vowel pronunciation è	absent	guided	on model: lacking	on model:good	0.012
Vowel pronunciation é	absent	guided	on model: lacking	on model:good	0.118
Vowel pronunciation i	absent	guided	on model: lacking	on model:good	0.039
Vowel pronunciation ò	absent	guided	on model: lacking	on model:good	0.04
Vowel pronunciation ó	absent	guided	on model: lacking	on model:good	0.376
Vowel pronunciation u	absent	guided	on model: lacking	on model:good	0.005
Consonant pronunciation	absent	altered	slightly altered	correct	0.000
Graphematic decoding	altered	partially correct	correct		0.04
Syllabic decoding	altered	partially correct	correct		0.041
Pronunciation of caudate syllables	absent	altered	correct		0.000
Coding of final syllable consonant	altered	partially correct	correct		0.000
Lexical decoding	altered	partially correct	correct		0.04
Phoneme-grapheme conversion	absent	partial	good		0.04
Homographic grapheme decoding	altered	partially correct	correct		0.001
Homogeneous grapheme decoding	altered	partially correct	correct		0.001
Graphic stroke	uncertain	excessively marked	definite		0.006

phono-linguistic evaluation of recording vocal signal data. It is made with a computerized sonograph through which a vocal sample is taken by means of a high sensitivity microphone that records a subject's voice as faithfully as possible. This survey aims at providing objective physical-acoustic and phonetic-acoustic values of voice and language [20]: fundamental frequency, formants, phonatory duration, intensity. In an extremely brief way we report definitions of these parameters:

- fundamental frequency (F_0), or first harmonic, is the lowest frequency among those of single waves that form a complex wave. F_0 measured in Hertz (Hz) is perceived as intonation (acute and severe sounds), the linguistic element that identifies utterance melodic trend;
- formants are frequencies resulting from groups of more intense harmonics, for instance multiple frequencies of F_0. They are also measured in Hz. The first (F_1) and the second formants (F_2) identify individual vowels and are directly implicated in voice resonance mechanism;
- phonatory duration refers to sound emission time, which is exclusively vocalic in our case;
- amplitude is an energy with which a sound wave propagates. Regarding human voice, it is measured in decibel (dB) and is perceived as a sound volume, that is, a quality that distinguishes sounds in weak and strong ones.

We can simply say that sounds generated by a vocal cord vibration (whose frequency is the fundamental one) go into resonance cavities (hypopharynx, oropharynx and rhinopharynx) and here they are amplified by resonance (measurable through the value of formants F_1 and F_2), resulting more intense and acquiring a timbre that characterizes each speaker's voice. Detection and evaluation of vowel signals carried out by a spectrographic examination are indicative of self-monitoring phono-acoustic ability (feed-back) acquired by a subject during an expressive-verbal act. During educational-rehabilitation process each subject performs more spectrographic evaluations, usually coinciding with significant changes that an operator recognizes on a skill/ability level acquired in perception, discrimination and speech sound production. Thanks to these periodic surveys and monitoring spectrographic traces over time, it is possible to target an intervention and verify progressive disappearance of initial anomalies. Referring to the population in our study, it is important to clarify that the majority of subjects could not make this instrumental evaluation from the start, given a total absence of spoken language and, therefore, an inability to emit articulate and finalized sounds. However, it is possible to appreciate in all subjects an acquired ability to emit vocal sounds from the following evaluation already, even if its production still takes place in a guided way in some cases.

These sounds, just sketchy and very inaccurate [51] in the beginning, become more and more defined during evaluation progress and acquire their own individual tone. A confirmation is unequivocally given by comparing the values of F_0, F_1, F_2 and E, measured for each of seven vowels with the reference physiological ones related to a subject's age and sex. In the table below, for each of the 40 cases, values of fundamental frequency (F_0), the first (F_1) and the second formant (F_2) and sound energy (E), recorded in first spectroscopy exam with those detected in the last one, were compared to highlight a sharp tendency to approximate the range that scholars have identified for each vowel as referable to average values falling within the norm.

For the sake of brevity, it was considered appropriate to present only the values measured for vowel "a" (**Table 3**), considered a typical vocal for its pho-

no-articulatory characteristics. In reference with fundamental frequency (F_0), it is possible to see how 29/40 subjects report values falling entirely within reference range in the last evaluation, while 7 of the remaining 11 show how they have started to fall within standard values.

Data related to first (F_1) and to second formant (F_2) are also positive, since respectively 65% and 67.5% of the cases show an improvement of last spectrographic examination compared to the first one with values that get close to the average values measured for vowel "a" (Tables 4-6). These are very interesting

Table 3. Basic frequency (F_0). Case distribution by fundamental vocal frequency (F_0) a.

Cases	Sex	Age	First spectrographic examination	Reference range	Average value reference	Execution 1° exam	Age	Last spectrographic	Reference range	Average value reference	Execution last exam
1	M	6	245	280 - 365	325	guided	12	234.57	170 - 245	210	on model
2	F	4	324	310 - 450	355	on model	14	245	195 - 270	235	on model
3	M	8	172.27	260 - 330	295	guided	10	256.4	195 - 275	235	on model
4	M	13	245	155 - 230	195	on model	18	149.52	100 - 155	125	on model
5	M	6	153.13	280 - 365	325	guided	8	280.12	260 - 330	295	on model
6	M	7	268.9	260 - 330	295	on model	9	272.12	220 - 300	260	on model
7	M	8	402	260 - 330	295	guided	22	115.23	100 - 155	125	on model
8	F	8	190.09	245 - 310	280	on model	10	166.72	225 - 320	265	on model
9	M	8	268.9	260 - 330	295	on model	11	254.54	185 - 260	225	on model
10	M	5	290.13	300 - 390	350	on model	13	191.69	155 - 230	195	on model
11	M	9	239.67	220 - 300	260	on model	10	266.43	195 - 275	235	on model
12	M	5	200.45	300 - 390	350	on model	8	263.53	260 - 330	295	on model
13	M	6	204.17	280 - 365	325	on model	8	197	260 - 330	295	on model
14	M	5	180.69	300 - 390	350	on model	6	167.46	280 - 365	325	on model
15	M	6	212.02	280 - 365	325	guided	12	218.7	170 - 245	210	on model
16	M	9	193.42	220 - 300	260	guided	12	177.37	170 - 245	210	on model
17	M	8	204.17	260 - 330	295	on model	11	218.84	185 - 260	225	on model
18	M	10	147	195 - 275	235	on model	12	221.33	170 - 245	225	on model
19	M	4	172.27	320 - 425	375	on model	15	160.34	130 - 195	155	on model
20	M	5	234.57	300 - 390	350	on model	9	163.45	220 - 300	260	on model
21	M	5	159.78	300 - 390	350	on model	12	134.5	170 - 245	210	on model
22	M	2	230.02	370 - 525	445	guided	4	286.39	320 - 425	375	guided
23	M	12	225	170 - 245	210	on model	13	139.81	155 - 230	195	on model
24	M	5	225	300 - 390	350	on model	12	193.42	170 - 245	210	on model
25	M	8	162.13	260 - 330	295	on model	10	247.96	195 - 275	235	on model
26	F	5	250.57	290 - 425	335	on model	7	261.94	245 - 350	290	on model
27	M	18	120.81	100 - 155	125	on model	19	137.05	100 - 155	125	on model
28	M	4	181.93	320 - 425	375	on model	6	250.22	280 - 365	325	on model

Continued

29	F	7	225.19	245 - 350	290	on model	9	165.52	235 - 335	275	on model
30	M	3	200.45	340 - 460	400	on model	9	265.8	220 - 300	260	on model
31	M	8	248.68	260 - 330	295	on model	9	264.29	220 - 300	260	on model
32	M	10	250.57	195 - 275	235	on model	18	207.43	100 - 155	125	on model
33	F	7	190.09	245 - 350	290	on model	15	236.18	185 - 260	220	on model
34	M	3	282.69	340 - 460	400	on model	10	275.63	195 - 275	235	on model
35	M	8	268.9	260 - 330	295	on model	10	249.91	195 - 275	235	on model
36	M	10	277.9	195 - 275	235	guided	11	245.63	185 - 260	225	on model
37	M	3	168.25	340 - 460	400	on model	4	185.24	320 - 425	375	on model
38	F	5	256.4	290 - 425	335	on model	10	268.9	225 - 320	265	on model
39	M	4	175.3	320 - 425	375	on model	5	150.53	300 - 390	350	on model
40	M	5	275.63	300 - 390	350	on model	10	235.7	195 - 275	235	on model

Table 4. Case distribution by first formant (F_1) vowel a.

Cases	Sex	Age 1°	First spectrographic examination	Reference range	Execution 1° exam	Age last one	Last spectrographic examination	Reference range	Execution last one
1	M	6	976.6	700	guided	12	696.4	700	guided
2	F	4	623.3	700	on model	14	938.8	700	on model
3	M	10	1003	700	guided	10	675.8	700	on model
4	M	13	1067	700	on model	18	775.5	700	on model
5	M	6	995.9	700	guided	8	1037	700	on model
6	M	7	1071	700	on model	9	840.7	700	on model
7	M	8	784	700	guided	22	639	700	on model
8	F	8	1105	700	on model	10	989.6	700	on model
9	M	8	1027	700	on model	11	911.1	700	on model
10	M	5	1463	700	on model	13	870.6	700	on model
11	M	9	982.9	700	on model	10	913.6	700	on model
12	M	5	882.7	700	on model	8	1019	700	on model
13	M	6	944	700	on model	8	802.2	700	on model
14	M	5	632.7	700	on model	6	741.5	700	on model
15	M	6	867.6	700	on model	12	845.9	700	on model
16	M	9	951	700	on model	12	723.2	700	on model
17	M	8	986.3	700	on model	11	860.7	700	on model
18	M	10	773.4	700	on model	12	917.2	700	on model
19	M	4	1030	700	on model	15	1372	700	on model
20	M	5	1297	700	on model	9	993.5	700	on model
21	M	5	1060	700	on model	12	1132	700	on model

Continued

22	M	2	824.1	700	guided	4	1157	700	guided
23	M	12	680.6	700	on model	13	715.8	700	on model
24	M	5	1039	700	on model	12	712.9	700	on model
25	M	8	820.2	700	on model	10	555.6	700	on model
26	F	5	1029	700	on model	7	963.2	700	on model
27	M	18	921.3	700	on model	19	849.1	700	on model
28	M	4	1045	700	on model	6	1036.74	700	on model
29	F	7	1447	700	on model	9	1276	700	on model
30	M	3	1230	700	on model	9	1080	700	on model
31	M	8	750.8	700	on model	9	1306	700	on model
32	M	10	1054	700	on model	18	1130	700	on model
33	F	7	894.5	700	on model	15	1010	700	on model
34	M	3	1093	700	on model	10	1001	700	on model
35	M	8	1055	700	on model	10	998.4	700	on model
36	M	10	352.1	700	guided	11	297.7	700	on model
37	M	3	649.3	700	on model	4	1136	700	on model
38	F	5	1364	700	on model	10	848.1	700	on model
39	M	4	913.7	700	on model	5	1214	700	on model
40	M	5	944.4	700	on model	10	1045	700	on model

Table 5. Case distribution as to second formant (F_2) vowel a.

Cases	Sex	Age	First spectrographic examination	Reference range	Execution 1° exam	Age	Last spectrographic examination	Reference range	Execution last one
1	M	6	1803	1250	guided	12	1424	1250	on model
2	F	4	1470	1250	on model	14	1670	1250	on model
3	M	8	1390	1250	guided	10	1367	1250	on model
4	M	13	1462	1250	on model	18	1433	1250	on model
5	M	6	1391	1250	guided	8	1707	1250	on model
6	M	7	1619	1250	on model	9	1163	1250	on model
7	M	8	1187	1250	guided	22	1682	1250	on model
8	F	8	1979	1250	on model	10	1919	1250	on model
9	M	8	1735	1250	on model	11	1266	1250	on model
10	M	5	2582	1250	on model	13	1319	1250	on model
11	M	9	1436	1250	on model	10	1219	1250	on model
12	M	5	1794	1250	on model	8	1735	1250	on model
13	M	6	1895	1250	on model	8	1253	1250	on model
14	M	5	1507	1250	on model	6	1549	1250	on model

Continued

15	M	6	2325	1250	on model	12	1566	1250	on model
16	M	9	1603	1250	guided	12	1908	1250	on model
17	M	8	1556	1250	on model	11	1828	1250	on model
18	M	10	1851	1250	on model	12	1981	1250	on model
19	M	4	2685	1250	on model	15	2919	1250	on model
20	M	5	2161	1250	on model	9	1387	1250	on model
21	M	5	1864	1250	on model	12	1556	1250	on model
22	M	2	1859	1250	guided	4	1949	1250	guided
23	M	12	1693	1250	on model	13	1456	1250	on model
24	M	5	1745	1250	on model	12	1357	1250	on model
25	M	8	1740	1250	on model	10	1586	1250	on model
26	F	5	1677	1250	on model	7	1864	1250	on model
27	M	18	1633	1250	on model	19	1600	1250	on model
28	M	4	2047	1250	on model	6	1795	1250	on model
29	F	7	1889	1250	on model	9	1664	1250	on model
30	M	3	2007	1250	on model	9	1799	1250	on model
31	M	8	1694	1250	on model	9	1953	1250	on model
32	M	10	1680	1250	on model	18	2949	1250	on model
33	F	7	1935	1250	on model	15	1756	1250	on model
34	M	3	1960	1250	on model	10	1393	1250	on model
35	M	8	1578	1250	on model	10	1493	1250	on model
36	M	10	1388	1250	guided	11	1295	1250	on model
37	M	3	1512	1250	on model	4	1823	1250	on model
38	F	5	1835	1250	on model	10	1832	1250	on model
39	M	4	1770	1250	on model	5	1924	1250	on model
40	M	5	1992	1250	on model	10	1491	1250	on model

Table 6. Case distribution by amplitude (E) Vowel a.

Cases	Sex	Age	First spectrographic examination	Reference range	Execution 1˚exam	Age	Last spectrographic examination	Reference range	Execution last one
1	M	6	53.79	50 - 65	guided	12	64.53	50 - 65	on model
2	F	4	60.28	50 - 65	on model	14	62.85	50 - 65	on model
3	M	8	61.79	50 - 65	guided	10	61.32	50 - 65	on model
4	M	13	62.84	50 - 65	on model	18	58.27	50 - 65	on model
5	M	6	56.84	50 - 65	guided	8	68	50 - 65	on model
6	M	7	59.8	50 - 65	on model	9	67.92	50 - 65	on model
7	M	8	50	50 - 65	guided	22	65.84	50 - 65	on model

Continued

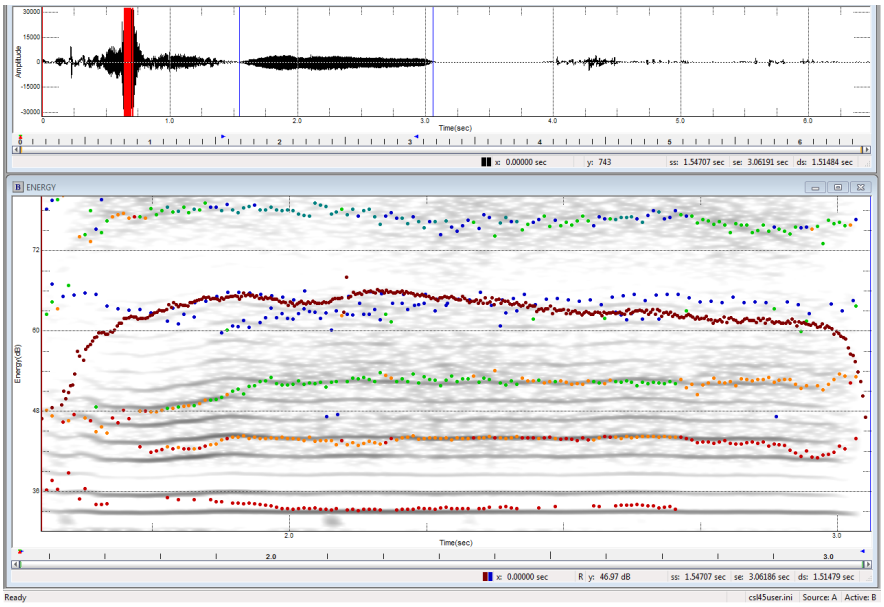
8	F	8	63.74	50 - 65	on model	10	65.81	50 - 65	on model
9	M	8	59.28	50 - 65	on model	11	59.12	50 - 65	on model
10	M	5	60.61	50 - 65	on model	13	65.69	50 - 65	on model
11	M	9	56.41	50 - 65	on model	10	61.36	50 - 65	on model
12	M	5	58.59	50 - 65	on model	8	59.66	50 - 65	on model
13	M	6	74.54	50 - 65	on model	8	59.33	50 - 65	on model
14	M	5	61.39	50 - 65	on model	6	56	50 - 65	on model
15	M	6	66.05	50 - 65	on model	12	62.16	50 - 65	on model
16	M	9	72.95	50 - 65	guided	12	65.47	50 - 65	on model
17	M	8	58.15	50 - 65	on model	11	57.34	50 - 65	on model
18	M	10	62.27	50 - 65	on model	12	57.85	50 - 65	on model
19	M	4	67.2	50 - 65	on model	15	64.67	50 - 65	on model
20	M	5	67.89	50 - 65	on model	9	62.37	50 - 65	on model
21	M	5	69.04	50 - 65	on model	12	63.26	50 - 65	on model
22	M	2	61.98	50 - 65	guided	4	69.3	50 - 65	guided
23	M	12	56.34	50 - 65	on model	13	61.4	50 - 65	on model
24	M	5	62.98	50 - 65	on model	12	61.5	50 - 65	on model
25	M	8	64.39	50 - 65	on model	10	57.81	50 - 65	on model
26	F	5	60.47	50 - 65	on model	7	58.35	50 - 65	on model
27	M	18	70.77	50 - 65	on model	19	62.7	50 - 65	on model
28	M	4	65.49	50 - 65	on model	6	55.06	50 - 65	on model
29	F	7	80.67	50 - 65	on model	9	63.14	50 - 65	on model
30	M	3	70.98	50 - 65	on model	9	64.81	50 - 65	on model
31	M	8	62.85	50 - 65	on model	9	63.09	50 - 65	on model
32	M	10	66.77	50 - 65	on model	18	58.48	50 - 65	on model
33	F	7	71.62	50 - 65	on model	15	64.51	50 - 65	on model
34	M	3	66.73	50 - 65	on model	10	66.41	50 - 65	on model
35	M	8	61.97	50 - 65	on model	10	66.46	50 - 65	on model
36	M	10	68.99	50 - 65	guided	11	53.41	50 - 65	on model
37	M	3	58.49	50 - 65	on model	4	63.82	50 - 65	on model
38	F	5	67.25	50 - 65	on model	10	54.5	50 - 65	on model
39	M	4	73.12	50 - 65	on model	5	64.57	50 - 65	on model
40	M	5	55.35	50 - 65	on model	10	60.64	50 - 65	on model

data, if we consider that 22/40 of the subjects do not have a starting spectrographic evaluation, because they were initially completely unable to emit vocal sounds as already mentioned, whereas 4 of the remaining 18 were able to emit vowel sounds in the initial examination by guided mode only, that is, by phoneme phono-articulatory setting. Referring to what briefly explained in synthetic

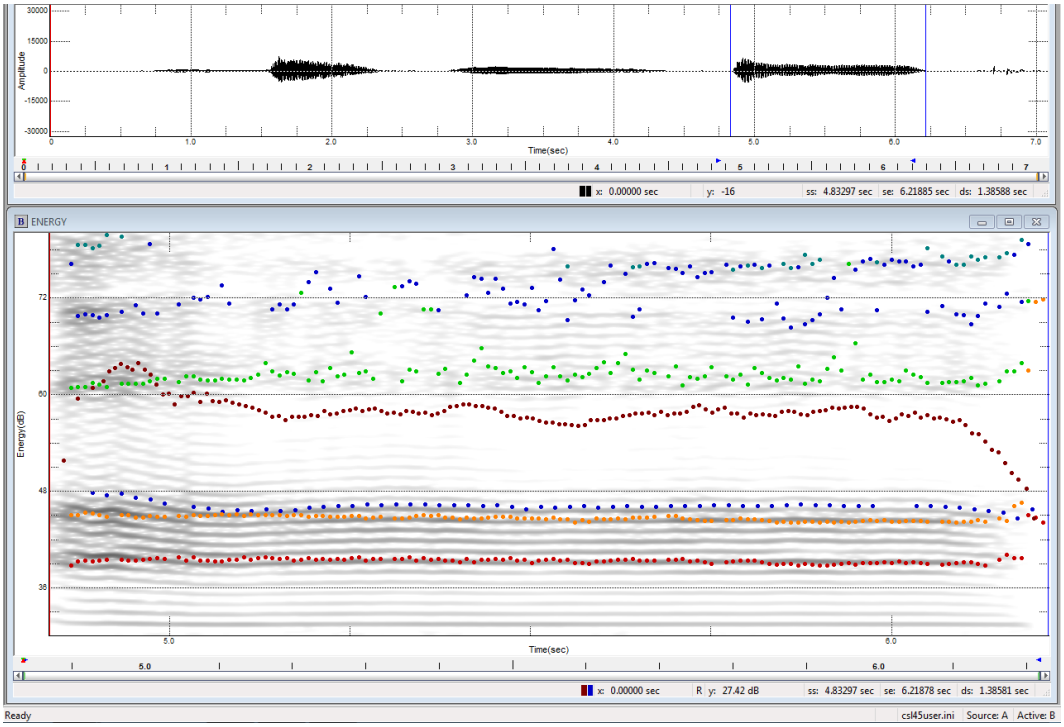
introductory notes about formants and remembering how the height of the first two F_1 and F_2 determines differences among vowels, we can well understand that values of the latter go to approximate reference value as a subject becomes more coordinated in articulating vowel sounds, a skill that acquires completely by completing the analytic phase (at the end of second analysis).

Regarding Energy, almost the totality of study population, that is 36/40 subjects, reports values within reference range, demonstrating a progressive acquisition of coordination and therefore self-control on vowel sound emission.

In order to prove more clearly what has been claimed so far regarding the positive evolution of educational-rehabilitation path implemented by AUGEV method, spectrographic exams of 6 subjects belonging to the population of this study are shown below. An employed method regards a presentation, for each of the 6 cases, of first and last performed examination and a selection of vowel "a" as "typical vowel". It is clear that initial examinations show marked anomalies in path time progressing (represented on the abscissa axis): an harmonic texture is generally not structured yet (**Figure 4(a)**, **Figure 5(a)**, **Figure 7(a)**) or irregular (**Figure 4(a)**, **Figure 5(a)**, **Figure 7(a)**), which is an index of a bad oropharyngeal resonance and, therefore, a missed or incorrect activation of phono-acoustic feedbacks when going back to causes. Obviously, also time trend of frequencies (F_0, F_1, F_2) and amplitude (E) is initially strongly irregular. Values measured by an instrument along with vocal segment to be analyzed are indicated by colored dots, where each color identifies a different parameter: blue color is combined with F_0, red and orange respectively with F_1 and F_2 and brown color with E. In no-pathological conditions, points of the same color are arranged next to each other in an ordered frequency alignment. In the examples shown, it is easy instead to see how the first tests show a markedly anomalous pattern with migrations (**Figures 2(a)-7(a)**), rarefactions (**Figure 5(a)**, **Figure 6(a)**) and/or frequent

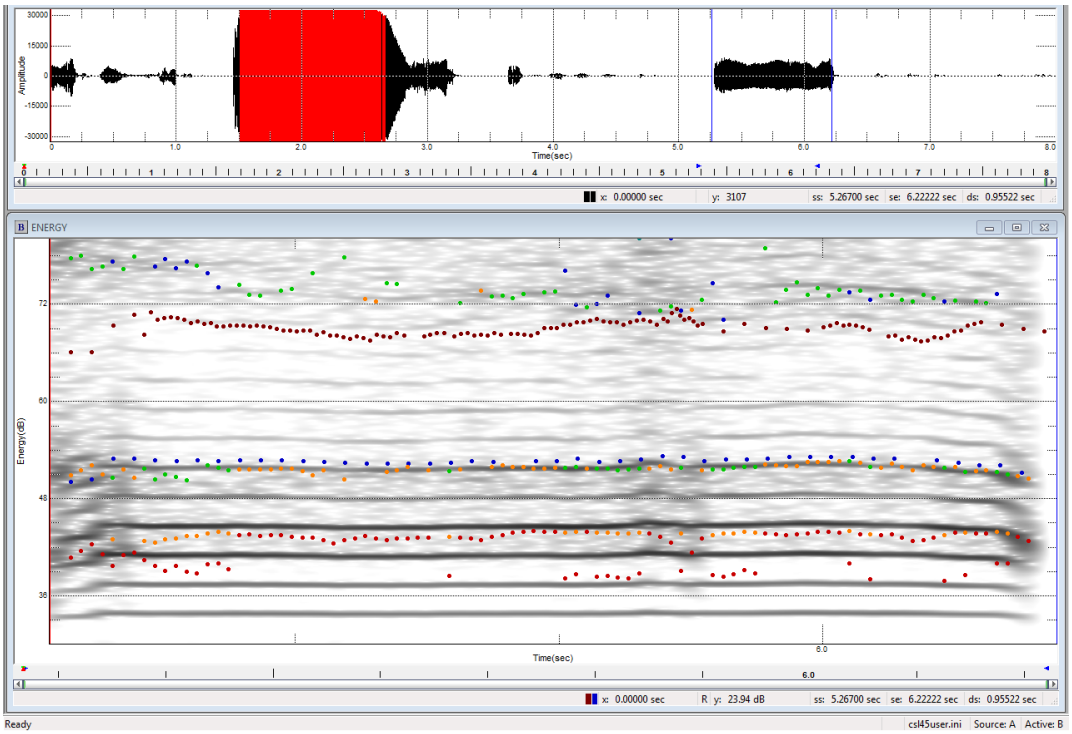


(a)

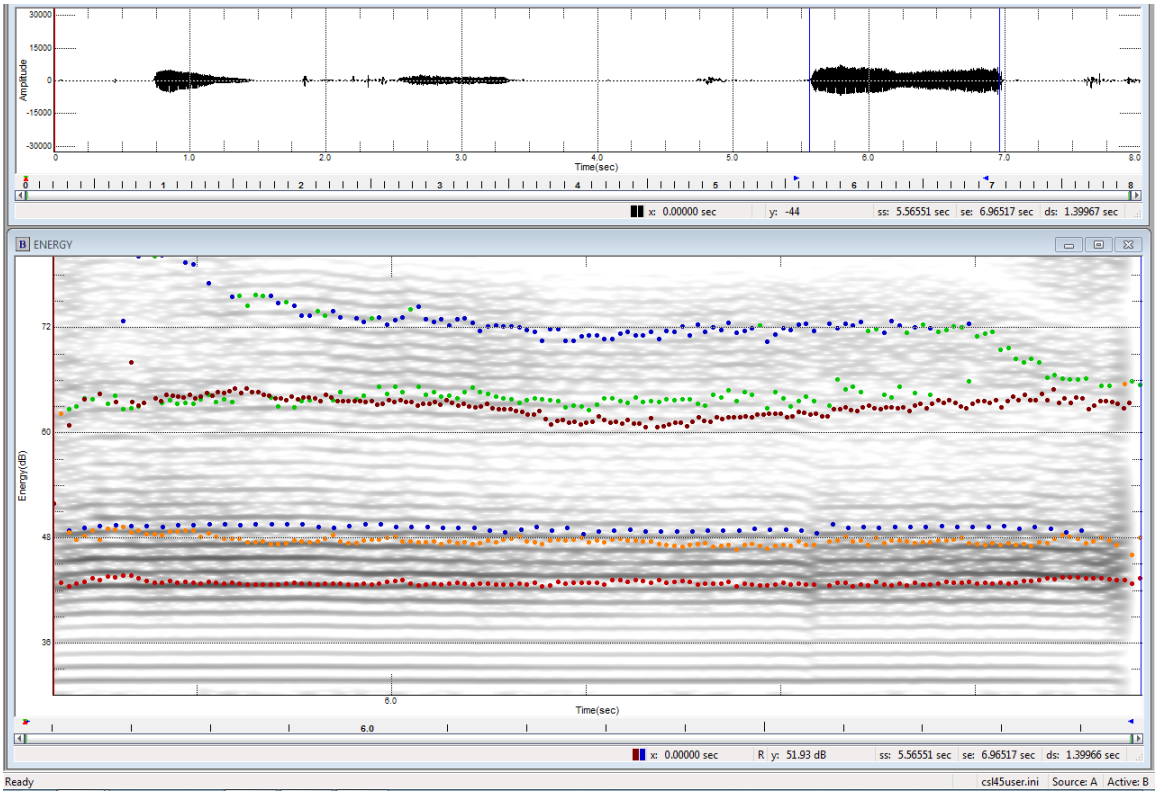


(b)

Figure 2. (a) Spectral examination of the vocal signal. ***Legend of all the figures beneath.*** Symbology of the phonetic-acoustic parameters detected in the spectrographic examination: ●●●●●●●●●●● = Fundamental Frequency (Fo), measured in Hz; ●●●●●●●●●●● = First Formant (F_1), measured in Hz; ●●●●●●●●●●● = Second Formantt (F_2), misurata in Hz; ●●●●●●●●●●● = Energy (E), misurata in dB; (b) Spectral examination of the vocal signal.

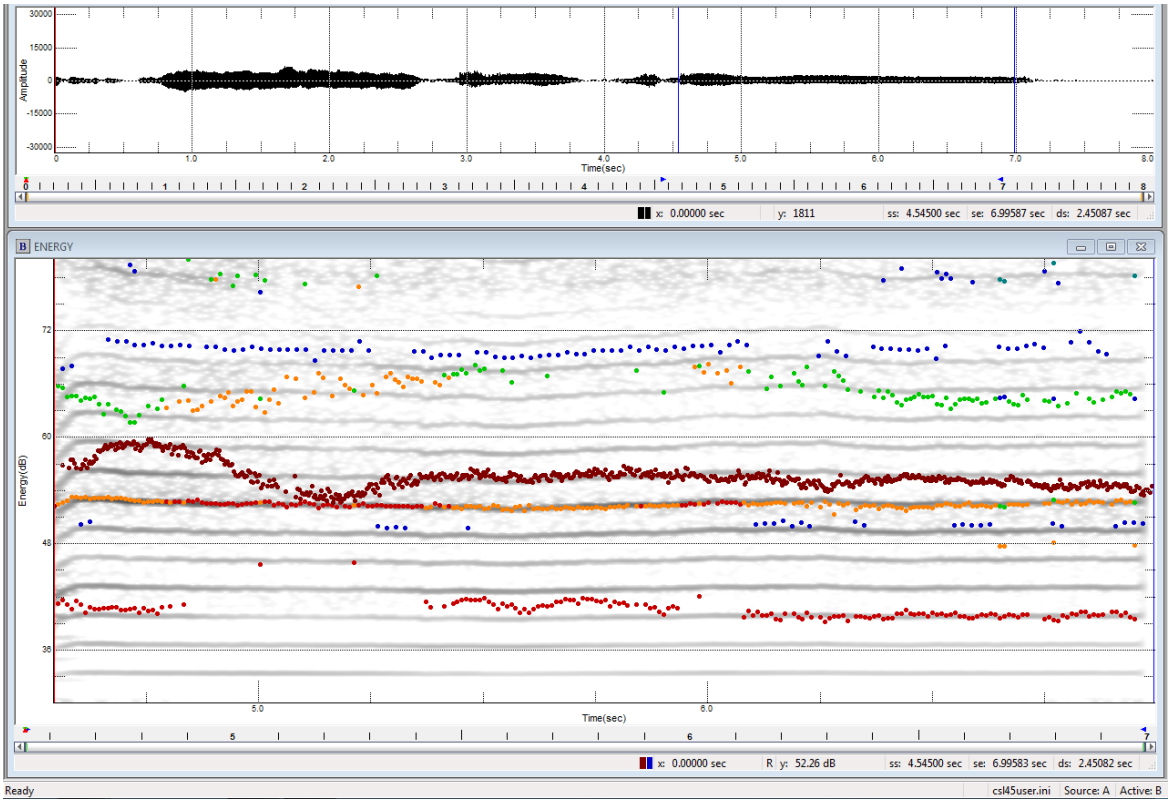


(a)

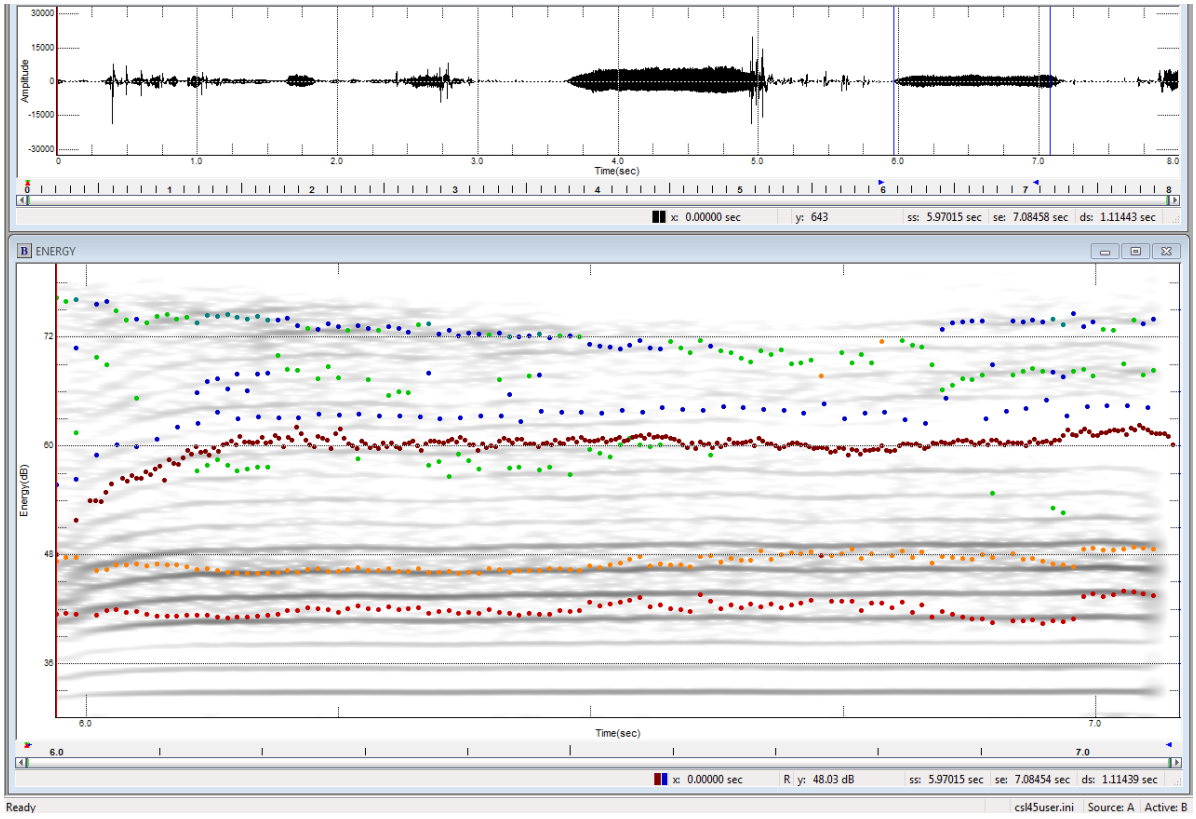


(b)

Figure 3. (a) Spectral examination of the vocal signal; (b) Spectral examination of the vocal signal.

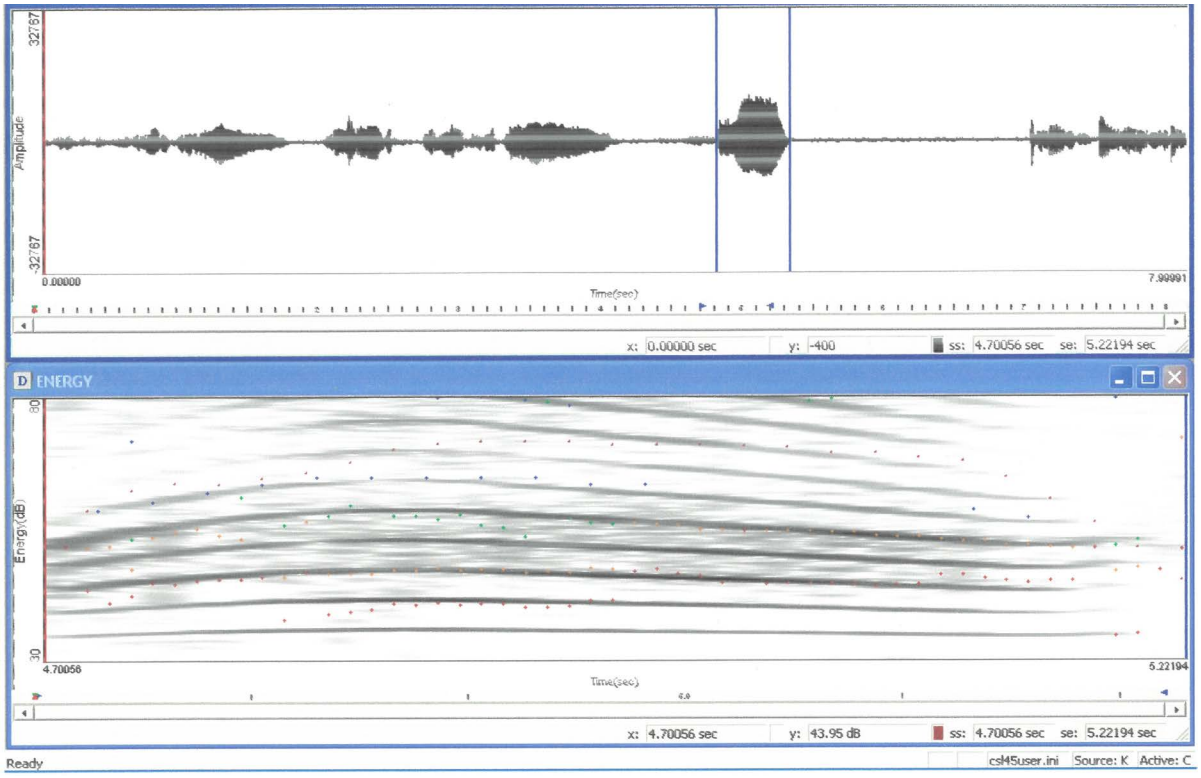


(a)

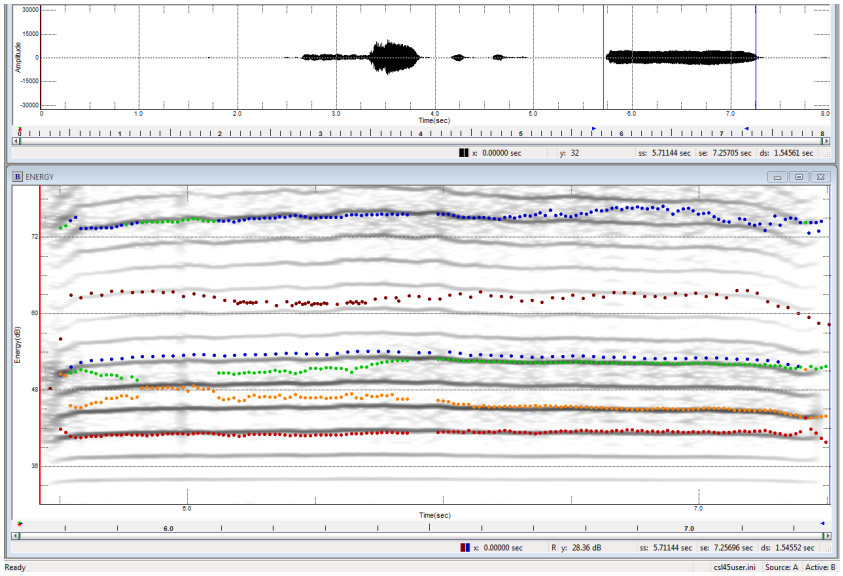


(b)

Figure 4. (a) Spectral examination of the vocal signal; (b) Spectral examination of the vocal signal.

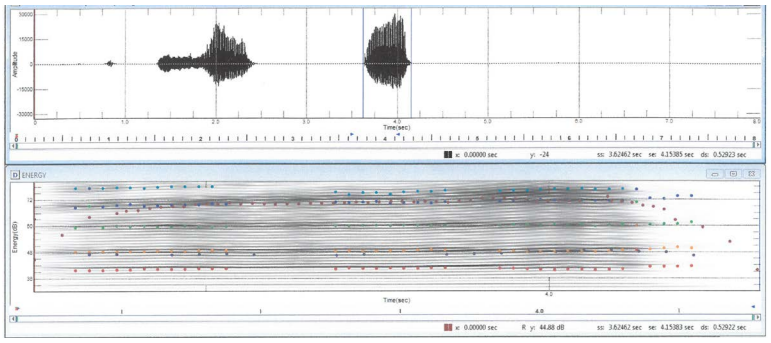


(a)

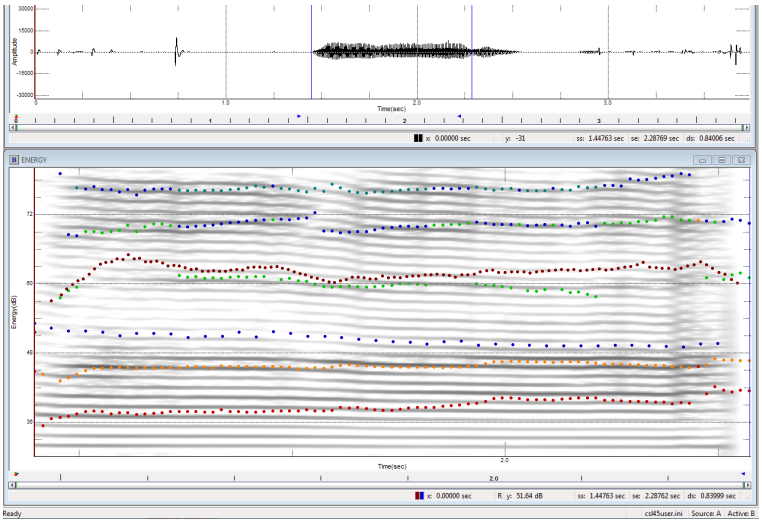


(b)

Figure 5. (a) Spectral examination of the vocal signal; (b) Spectral examination of the vocal signal.

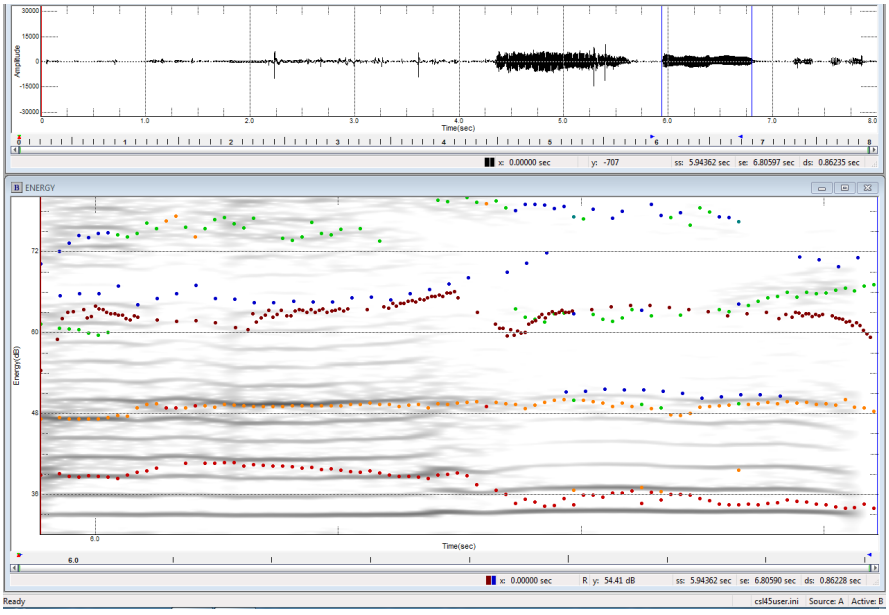


(a)

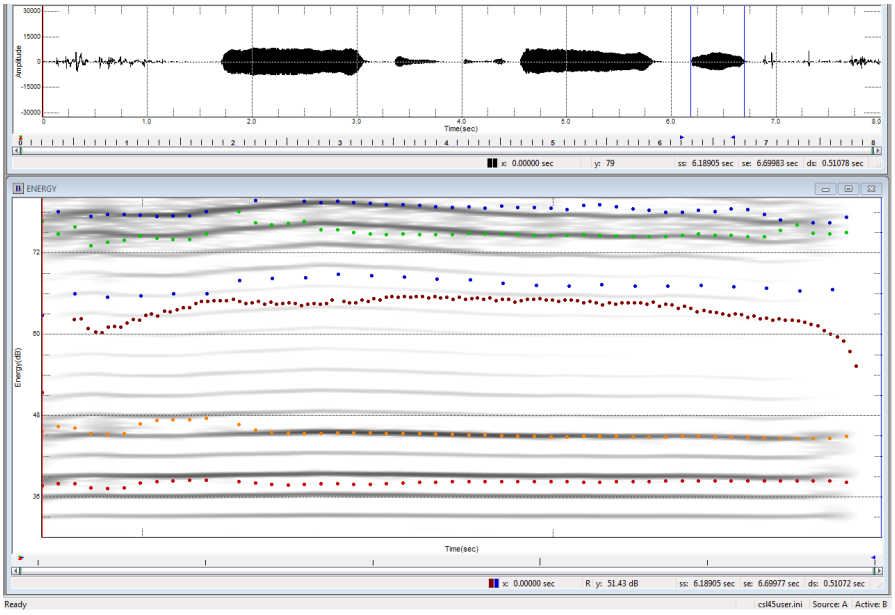


(b)

Figure 6. (a) Spectral examination of the vocal signal. (b) Spectral examination of the vocal signal.



(a)



(b)

Figure 7. (a) Spectral examination of the vocal signal; (b) Spectral examination of the vocal signal.

intrusions in an harmonic texture (**Figure 2(a)**, **Figures 4(a)-7(a)**). In a spectrographic framework, an aperiodic signal (noise) is often present (**Figures 2(a)-6(a)**), sometimes very strongly, which at high frequencies is to be mostly related to insufficient tension and cordial adduction, with a consequent fugatory air leak (blown voice) and at low frequencies it is mainly due to an irregular vibration of strings, due to their excessive adduction and rigidity. Phonatory attack is irregular (**Figures 2(a)-6(a)**) and often the presence of diplofony and/or bitonality is indicated on the diagram. However, this is indicative of a subject's

inability to control individual phono-articulatory productions, a difficulty also explained by the irregular intensity curve (E). This situation is clearly modified in each subject's last spectrographic examination: harmonic texture is now well defined (**Figure 2(b)**, **Figure 4(b)**, **Figure 5(b)**) and it is not "polluted" by an aperiodic signal (noise) (**Figure 2(b)**, **Figures 4(b)-6(b)**) and/or sub-harmonics (responsible for diplophony) (**Figure 4(b)**, **Figure 6(b)**). Individual frequencies (F_0, F_1 and F_2) are now aligned and phonatory intensity curve (E) has also been normalized (**Figures 4(b)-6(b)**). In the last exam, phonatory attack is partially or completely presented as a regularized examination (**Figures 4(b)-6(b)**) and is now generally soft.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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