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ACOUSTIC CHARACTERIZATION OF THE “PASAGGIO” IN THE LYRICAL VOICE

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The passage between two contiguous vocal registers is called "pasaggio". In lyrical singing, this change should go unnoticed by the listener. Therefore, it should be prepared through the 'voice coverage'. Within the framework of an interdisciplinary research project, the pasaggio was studied in a group of lyrical singers, through measurements with an acoustic camera, sound level meter and accelerometer. We worked with five lyrical singers with academic training and broad experience, each of them with a different vocal register: a soprano, a mezzo-soprano, a countertenor, a tenor and a baritone. Each of them performed a set of a cappella vocal exercises, while the aforementioned measurements were performed at their time; the set of exercises was selected by the singers to meet the objectives of this research. In particular, to study the pasaggio as an acoustic phenomenon, two exercises were particularly interesting: an ascending major scale and a 'Grand Vocalise' (a vocalise that covers an interval of an octave plus a fifth). Each exercise was repeated several times by each singer, while accelerometer records were taken on the glottis, sternum, and six points on the head (Mauran's point, nose, mastoid, occipital, eyebrow and 'third eye'). Through the records of the time evolution of sound pressure levels in third octave bands, the acoustic spectra and sonograms, the pasaggio can be clearly visualized. This enables the Song Masters to better explain to their students how to perform the voice coverage and pasaggio, the expected proprioceptions and the acoustic result to be obtained.

Keywords: voice, singers, pasaggio, voice coverage

1. Introduction

This paper refers to some possible acoustic characterizations of the passage in the lyrical voice. Beyond its more specific implications, it reports on some aspects of a broader work developed within the framework of the Interdisciplinary Project 2019-2020: 'Mapping of the Resonance of the Voice in the Lyrical Singing'.

With no antecedents in Uruguay, the research was carried out by a group that included professionals in the voice area, such as professional singers teaching vocal pedagogy, speech therapists as well as

acoustic engineers, all of them working (both as teachers and researchers) at the Universidad de la República.

2. What “pasaggio” is

In the singing voice, the change from one register¹ to another is called the passage² or "pasaggio." The passage supposes changing from one voice mechanism to another and, therefore, a break in the continuum of the emission of the sung voice, which must be avoided by the singers.

The vocal tract is not static, with a unique shape before the emission of a group of tones, of a melody, either by joint degrees or intervals, in an ascending or descending way.

The singer makes "adjustments" to direct the sound so that it is nourished by harmonics, in a flexible and gradual movement. Within these subtle variants there are occasionally areas where it is absolutely necessary to look for a modification because it is not physically possible continue singing in the same way: that means that the singer is faced to the register passage (pasaggio).

The passage is the transition zone between one record and the consecutive one. It is the place where the risk of breaking down of the voice is higher, since it changes from one emission mechanism to another. It is identified by corresponding to that frequency where the emission in full voice cannot continue its path in the extension, discomfort is felt and the note is emitted shouted, with poor harmonic quality, without the correct modifications of the vocal tract. This is accompanied by changes in tension in the facial muscles, in the neck and even in the shoulders.

The passage does not occur at the same pitch in all the voices of the same tessitura; moreover, each singer knows precisely in which musical note his passage occurs and surely it does not coincide with that of other singers of similar tessitura. Assuming that each voice comprises three registers, there are two passages in each voice. However, unless otherwise indicated, it is assumed that the term ‘passage’ refers above all to the second of the passages, the one that corresponds to the most important physiological change in lyrical singing: this passage is the result of a resonance adjustment and not of a laryngeal adjustment, as the first passage is.

Physiologically, if the passage is from lower to higher pitch, it corresponds to the change in the preponderance of action of the adductor muscles towards the preponderance of the tensor muscles, in coordination with the aerodynamic elements. On the other hand, if the passage is towards lower notes, it will be the reverse. The explanation of how singers achieve a passage in which the change in vocal mechanism is not perceived is given by the ability to control neuromuscular and aerodynamic mechanisms that are

¹ **Register** [1]: series of successive homogeneous tones, originated under the same mechanical principle. The registers may overlap in some tones. Different registers have different sonorities. These acoustic differences respond to the shaping that results from the passage of the air through the vocal tract and, fundamentally, to the differences in the source of the vocal signal. From the point of view of acoustic physics and phoniatrics, vocal registers are exclusively laryngeal events, consisting of a range of consecutive frequencies produced with identical phonatory characteristics, identifiable through perceptual, acoustic, physiological and aerodynamic parameters.

In the didactics of the singing voice, when speaking about ‘register’, it is understood that it is a series of consecutive sounds of homogeneous timbre produced by the same laryngeal mechanism, in equilibrium with particular couplings of the resonance cavities. These resonance adjustments, as Fussi [1] explains, have determined a varied and divergent terminology which has led to great confusion, at least in the technique of lyrical singing. The terminology issue is chaotic, due to historic musicological factors linked to the vocal development of lyrical singing, which calls "register" a proprioceptive sensation (e.g. "chest register", which would correctly be said "chest voice"). Also in lyrical singing the term 'register' is used to refer to 'second order registers' related to the behaviour of the resonance cavities, using the "aperto" and "coperto" modes that are characteristic of the voice emission. The secondary registers are not differentiated by the vibratory pattern of the folds but by the changes and forms that the vocal tract assumes. These changes are made to favour the vibrational patterns of the vocal folds.

² **Register passage ('pasaggio')** [1]: the passage is the transition zone between one record and the consecutive one. The passage occurs at a point where the emission in full voice cannot continue into the treble, without specific modifications to the vocal tract. There are multiple descriptions of which notes are involved for each type of voice, since the passage does not occur at the same pitch for all voices. The transitions associated with the passages would be caused by a change in the vibratory mechanism of the vocal folds or by resonance effects of the vocal tract.

acquired with learning, with practice, with perception and a good vocal technique. The study of the technique focuses precisely on the acquisition of this skill.

The singer's perception of performing a good passage is identified with relaxation, with abdominal diaphragmatic cost breathing, great support in high resonance areas and Mauran's point³, hard palate or palatine fossa, and the lack of sensations at the level of the larynx and neck. The vocal sound will be timbred ringing, rich in harmonics and with just the right vibrato.

As shown in figure 2 (left and center sonograms), the realization of an ascending major scale without preparing the passage through the cover, exhibits a limited spectrum of frequencies; it seems to be "roofed" around 5000 Hz and with a noticeable loss of harmonics and intensity from 2000 Hz. The sonogram on the right shows the repetition of the same scale, with a good passage prepared with coverage. An intense set of harmonics is observed that constitute almost a continuum in frequencies. In addition, the change at the resonance level that the passage implies is evident from approximately 2000 Hz, in which the harmonics have a fairly horizontal pattern although the scale continues ascending, as expected.

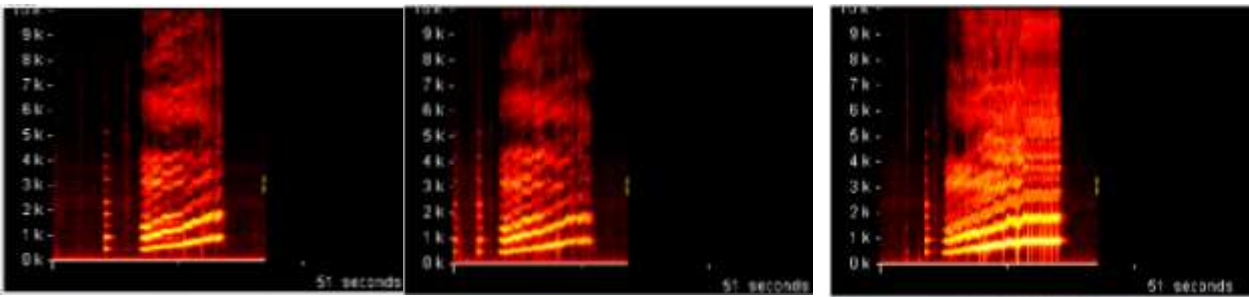


Figure 2: Sonogram. Ascending major scale. Left and center: stopovers without passage or coverage; right: with coverage to prepare the passage. The three performances are by the same singer (Soprano).

The passage must be anticipated to achieve a good homogeneity of timbre: it should begin some notes before the person's typical passage pitch and, once done, it must not be "undone" in the same musical or vocal phrase.

The modifications that every singer who works on his voice must consider to overcome the passage are made through the recollection darkening and coverage ("suono coperto" or "raccolto"⁴) of the sound and the control and descent of the larynx, so as not to continue rising in the falsetto register or with a shouted voice.

The coverage is the key so that the singer can emit the sounds of the second octave of the extension of his voice, which correspond in the spoken voice to the range of the shouted voice, without making a noticeable muscular effort and avoiding the possibility of breaking down of the voice. By making a correct coverage, the passage is facilitated and a homogeneous, expressive, flexible sound is achieved, with harmonics and without contractures or narrowing of the vocal tract. Physiologically, the voice is produced with raised epiglottis, with descent of the larynx and inclination of the thyroid over the cricoid, realization of a wide pharyngeal and vestibular laryngeal space, and elevation of the soft palate (figure

³ **Mauran point** [1]: also called maximum sound concentration point; The Mauran point is located behind the upper incisors. The voice has the maximum amplification in this point, before projecting itself to the outside. The characteristics that are achieved from the vocal sound with resonance are brilliance, richness in dynamics and roundness (it is related to the balance between the thickness and the tip of the voice).

⁴ **Coperto, raccolto or coverage sound** [1]: characteristic of the voice produced with raised epiglottis, maintenance of the lowered position of the larynx and inclination of the thyroid cartilage over the cricoid, realization of a wide laryngeal pharyngeal and vestibular space and elevation of the palate veil. This is the typical behaviour of the passage from the central sounds to the treble in lyrical singing. It is perceived as a vowel roundness, dark and soft in colour with 'a feeling of body'.

3). This is the typical behavior of the passage from central sounds to high-pitched sounds in lyrical singing. It is perceived as a vowel roundness, embodied in dark and soft color of certain consistency.

The study of the coverage allows to reach the treble and over-treble; educating the singer to carry out this strategy, he/she will be able to keep the larynx under control, regardless of the pitch of the sound that he/she must emit.

Coverage is not synonymous with 'closing', but with 'homogenizing' the tone emitted. The principle of "*aperto ma coperto*" on which the Italian technique is so utterly based, illustrates the balance that the sound should have towards the need to improve the resonant cavities in order to find the perfect point of equilibrium: a relatively more open emission concerning the bass and, increasing the vocal pitch, cover in an *aperto ma coperto*. The sensations that are noticed when performing the coverage are linked to the cranial bone structure, to trigeminal stimulations, and to sensible vibrations in the palate, from the upper incisors and back to the pharynx and veil.

Once, the coperto sound, together with the open timbre, were considered secondary registers since, alluding that the modifications of the vocal color were the exclusive task of the activity of the vocal cords that generated the so-called primary registers. Current studies have been able to prove a notable difference between coperto and open singing by referring to the activity of the thyroarytenoid and cricothyroid muscles. Figure 3 illustrates the vascular movement of the larynx, which is one of the main anatomical mechanisms that is relevant in the complex synergy of the passage process.

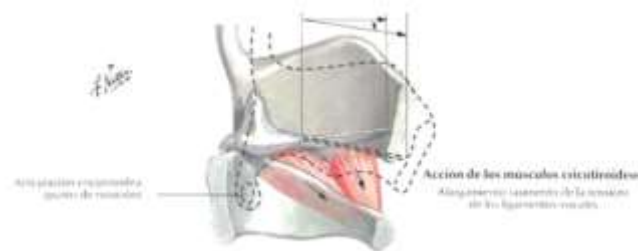


Figure 3. Cricothyroid joint (from Netter, 2007 [2])

Pola, an Italian singing teacher, who had Pavarotti as a student says *verbatim* [3]:

"All singers, both men and women, have those famous points, between the first and second octave, where they must cover the sung piece, so that the color of the note made in the center is the same as in the high pitched one. It has to be opened, covered, opened, covered [...] constantly, always depending on what is sung. Over the years you understand where it is best to open and where to cover".

In the spectrogram, coperto singing gives rise to a higher concentration of acoustic energy in the singer's formant⁵, which also shows a lower center of frequency and a reinforcement of the harmonic structure below 2000 Hz.

In summary, the *coperto sound* is characterized by an emission of greater resonance with perception of less effort, noting a more efficient and economical use of muscle work by virtue of the elegance and vocal quality.

⁵ The **formant of the singer** or **lyrical metaformant** is a peak of the frequency spectrum that is produced by amalgamating the group of F3, F4, and F5. Although in all voices the frequency bands around 3000 Hz are of special interest, since they are linked to the singer's formant, this recognized effect of the specific modifications of the vocal tract in the lyrical technique is more noticeable in terms of at lower frequencies and therefore more verifiable in male voices. In the sonogram the formant of the singer is clearly observed when the frequencies in the baritone and tenor voices come together and are reinforced, they are seen as in a compact block of intense color at frequencies close to 3000 Hz. more acute, the formant of the singer becomes poorer [1].

3. Some objective results from measurements

We present herein some excerpts of our measurements' results in the framework of our interdisciplinary research project.

3.1 Grand Vocalise

In the “Grand Vocalise” exercise, the five basic vowel patterns were reduced to a single comfortable vowel [a] in order to expand the vocal range to almost the entire register (see figure 4). This vowel [a] with components of [ɔ] shows few variations due to the changes imposed by the vocal tract in the passage zone or the extremes of the register, which in the other vowels moulds, would result in major tonal modifications. Successive “Grands Vocalises” were performed starting from ascending tonic by one semitone per exercise.

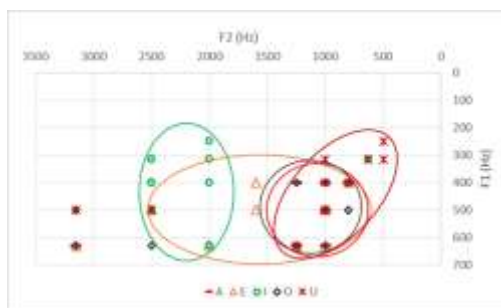


Figure 4. Vowel formants in the sung voices obtained through measurements (from [1]).

For the complex theme of the passage, the observation of a common pattern in all sonograms seems to be of interest. From the bottom of the frequency band around 1000 Hz the frequencies begin to rise slightly, coinciding with the arrival of the octave. As this process is established, the frequency bands begin to separate equidistantly to cluster in a stable pattern from the octave to the twelfth. The higher the pitch, the more pronounced the second pattern becomes, which would verify the existence of a threshold zone around a fixed pitch relative to each voice, where the graphic expressions of their respective acoustic characteristics are transmuted. This peculiarity from the lyrical technique is formulated within the concept of the passage, which would express the sum of the conditions to be modified to prepare and enable this new pattern.

The phenomenon of the singer's formant (the band of frequencies discernible between 3000 and 4000 Hz) is not only integrated into this new pattern (the sharper the voice is the more remarked it appears), but it seems to be one of the conditions for it to occur, since serves as a guideline to adequately modulate the acoustic signal.

In all the voices, the higher the relative altitude, a greater “organization” is observed in frequency bands. The sharp peak in this exercise is located at the crest of the wave, and its harmonics appear on the sonogram as a “ladder”, where each “rung” would correspond to a harmonic (Figure 5). The ‘Singer Formant’ does not manifest itself in the same tonal zone in all voices: it is higher in the tenor and lower in the baritone. This characteristic formant is related to the shape of the vocal tract and to the ability and training to flex and adapt the different mobile anatomical structures. The technical approach prepares on how to arrange and adjust the vocal tract according to their pitch class, especially in the registration passage. In Italian pedagogy, this complex process is referred to as the “aggiustamento” (adjustment) technique. While in male bass voices sensations are usually concentrated in the lower mask area, especially the maxillary sinuses, the tenor voice depends on a greater coupling of the resonances of the nose, frontal sinuses and sphenoid. This system could be described as having two tubes with the same pharyngeal base, which is being regulated by the activity of the soft palate as a valve, together with the back of the tongue. Naturally, it would not be a question of placing the voice in a single resonance path, since it

would result in a poor sound in formants, but of the fluid and skillful communication between both sub-systems according to the fundamental frequency emitted and, to a lesser extent, its vowel quality.

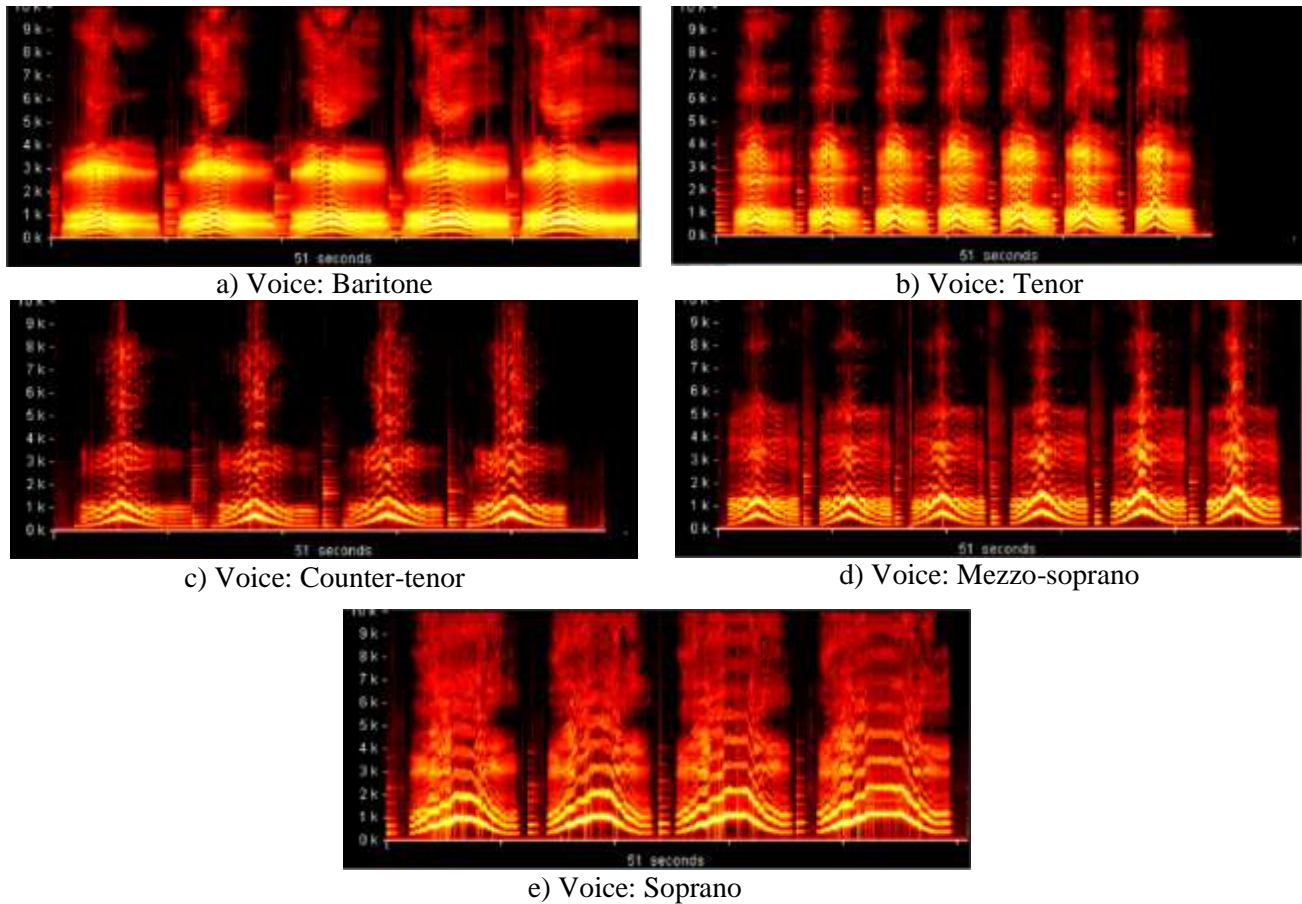


Figure 5. Sonogram. Grand Vocalise. (From [1])

To a large extent, the technical differences applied by the diversity of all kinds of singing methods emerge from the wide range of possible combinations and perceptions, as well as the ineluctable importance of the Mauran Point where both resonance systems are synthesized.

Figure 6 shows the results of measurements of sound pressure levels (principal axis of ordinate, dBA) and vibration amplitudes (secondary axis of ordinate, m/s^2) at different measurement points during the execution of Grands Vocalises by the soprano. As it can be seen, while the vibrations' amplitude reaches its maxima, the lower frequencies do just the opposite: minima at 500 Hz and 630 Hz appear before, and then, as time progresses and the sound reach higher pitches, the emission peak shifts to left (lower frequencies). Upon reaching the last Grand Vocalise, which corresponds to the last peak of the graph, the 1000 Hz and 2000 Hz curves behave in the same way as 500 Hz and 630 Hz, but decrease less. On the other hand, the one that increases its value in intensity level is 1250 Hz, which increases as time progresses. Its maximum occurs at the same point in which the minima of those that decrease occur. Since the preferential frequencies change, getting in tune with the frequencies of the formants; thus, the phenomenon of tuning occurs. The change between two different and successive emission systems is identified (the 'pasaggio') at the time where the vibration increases in some frequencies and decreases in others occur (see figure 6).

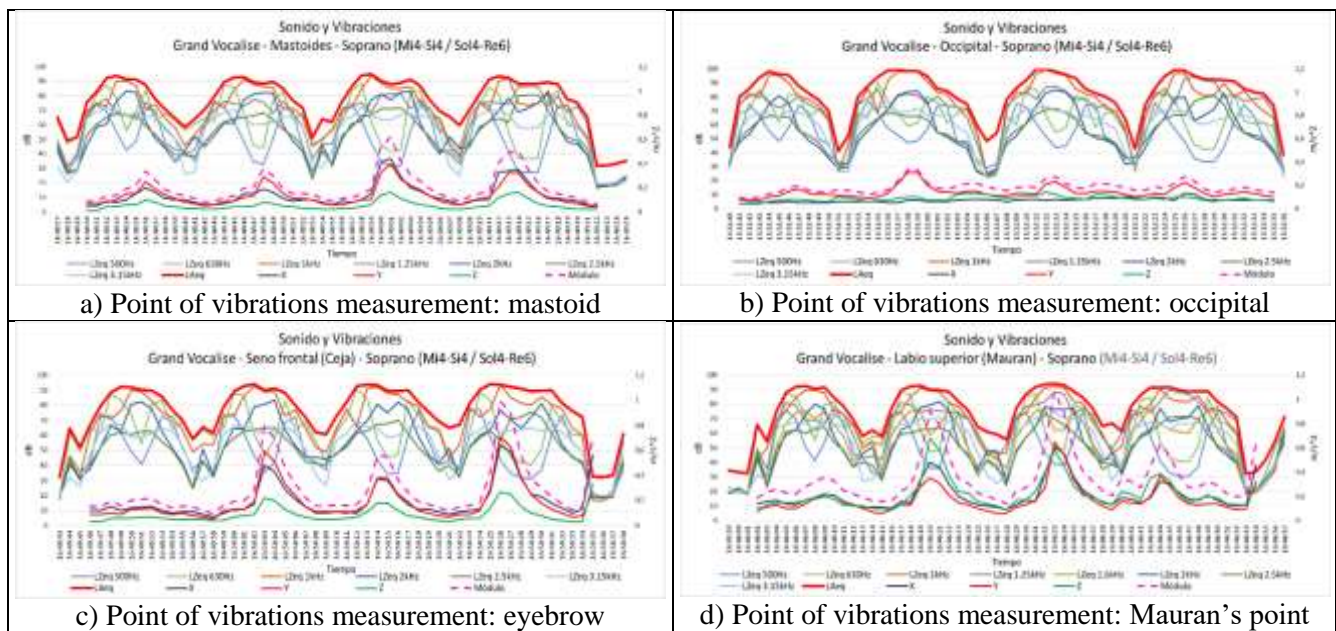


Figure 6. Sound pressure levels and vibration amplitude evolving during Grand Vocalise performances by soprano voice, in various measurement points on the head (From [1])

Whether the vibration maxima occur, the 500 Hz and 630 Hz curves decrease in value. Furthermore, at this point of vibration, as time progresses, the peak "shifts to the left" that is, towards lower frequencies. Some proprioception are strongly confirmed by measurements, as the large vibrations at Mauran's point and on the eyebrow and mastoids.

3.2 Ascending Major Scale

While different singers perform an ascending major scale, the pasaggio can be identified at different frequencies according to the voice and the amplitude of the scale; it is interesting to note that the phenomenon is the rather same, as the singers' technique is. Figure 7 attempts to show the pasaggio performed by two of the singers.

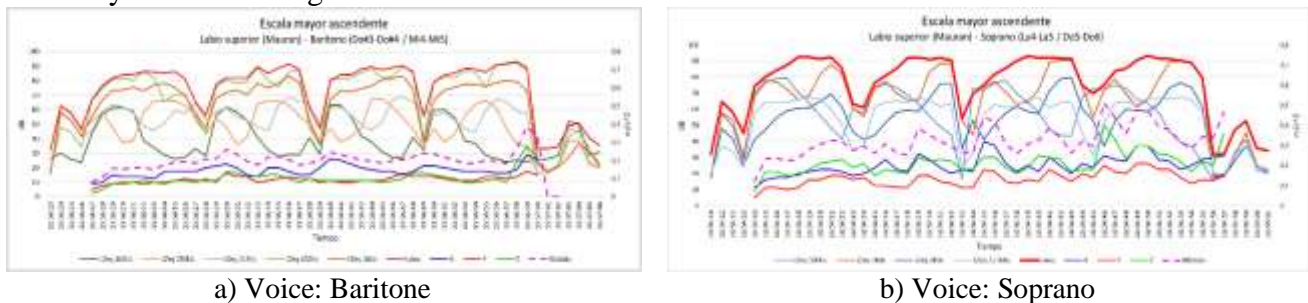


Figure 7. Sound pressure levels evolving at different frequencies during performances of a major ascending scale by baritone and soprano voices (From [1])

3.3 Examples that do not meet the pasaggio

At last, and for avoiding thinking this frequencies' management occurs at every performance, some graphics of exercises that don't meet the pasaggio have been included in figure 8.

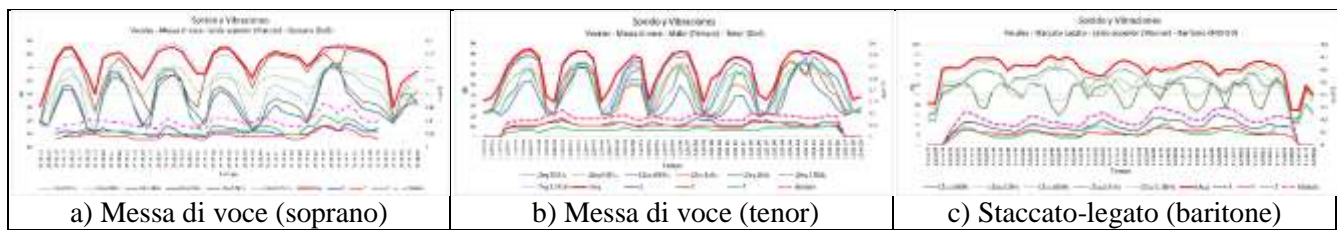


Figure 8. Sound pressure levels evolving at different frequencies during performances without pasaggio (From [1])

4. Conclusions

When speaking of the “pasaggio” in the singing voice, it usually refers more to an acoustic and objective reality than the many ways that in the history of lyrical singing have expanded on this specifically intricate and subjective subject would suggest at first glance suggest. In an integral and formative way, the intrinsic processes involved in the production of the operatic vocal sound would be closely linked to this reality. However, if we did not relate them to the information obtained by measuring, especially the sonograms, a synthetic image would have been missing in reference to the sum of a process that to be described by its partial aspects could easily be decomposed into even contradictory parts, not capable of explaining and much less encompassing what is commonly understood by the term “pasaggio”.

While in the graphs referring to the time evolving of sound levels, the “pasaggio” is identified in all cases through the crossing of certain frequencies that give faithful testimony to the modifications that the singer inflicts on the vocal tract, the sonograms express the result of these modifications through the identification of two differentiable patterns regarding the behavior of the organization of their frequency bands. Expressed in another way, the time evolving graphs have a closer relationship with the singer's physiology, while the sonograms would express the qualities of the vocal sound in a more general way. All of them help in a complementary way to understand the “pasaggio” in a more objective and holistic way.

Thus, our first results and hypotheses remain open to the scientific community, fully aware that the subject deserves further research.

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