VOCAL EFFORT IN SINGERS OF A NATIONAL LYRIC ORCHESTRA

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Abstract: **Scientific data in literature show that the singers of classical lyric orchestras are exposed to high risk of damage to the vocal apparatus due to the intense effort they have to face during the artistic performances.**

Vocal effort in a group of singers of a classical orchestra of a National lyric theatre is considered here. A specific protocol of measures has been defined with the aim of evaluating the quality of vocal emissions before and after the artistic performance during the rehearsal of a grand opera. Voice quality was parametrised in terms of average pitch value, quality ratio, vibrato frequency and extension.

A statistically significant difference was found between the quality ratio and the standard deviation of the fundamental frequency F0 and of the vibrato extension in the exercises executed before and after the vocal performance. These results confirm the hypothesis that such parameters are related to the laryngeal effort.

Keywords : **lyric singers, vocal effort, vocal quality**

I. INTRODUCTION

New protectionist laws impose to evaluate all different risk factors in the workplaces. All categories of workers are included and, among them, workers employed in recreational activities and shows should be considered. In this context, lyric national theatres are supplying to the assessment of the different risk factors to which their employees could be exposed.

Among such risk factors, noise and vocal effort are surely the most prominent. In addition, noise and vocal effort are often related to each other and both contribute to the injuries of the auditory and vocal apparatuses [1-3].

It is well know that professional singers are exposed to high vocal effort due to their performances. The stress to which the vocal apparatus is daily exposed can produce long-term effects ranging from the voice quality degradation to severe laryngeal pathologies. Previous scientific studies focused on the voice fatigue in singers and actors on the analogy of what was known about other workers categories exposed to vocal effort such as teachers [2,3]. The first studies lead on the teachers' vocal effort focused on the fundamental frequency (F0) analysis, on the phonation duration and on the emitted average sound pressure level at a certain distance during the working day [4].

Later, other parameters were specifically studied for singers to assess the vocal effort such as F0 variation, background noise, speech transmission index, signal to noise ratio, etc. [3-8]. These parameters were related to psychophysical evaluation subjectively reported by the subjects themselves [9,10].

The methodology of the vocal effort evaluation is based on the use of vocal dosimeters capable of registering the vocal emission during the whole working day [11,12].

The aim of this work was to individuate objective vocal parameters capable of an early detection of the voice quality degradation induced by the effort of the artistic performance. The main objective is to cast a non-invasive test to check the status of the vocal apparatus in workers exposed to vocal effort due to their working activity. Another main objective of the study is to understand the mechanism of the damage process with the aim of elaborating a prevention strategy.

II. METHODOS

Measurements were performed in the Teatro Regio in Turin during an experimental campaign finalized to the physical risks exposure evaluation in workplaces. Seven volunteer female lyric singers were enrolled into the present study: three Soprano, two Mezzo-Soprano, two Contralto. The singers were asked to execute some vocal exercises before and after the artistic performance during the rehearsal of a grand opera with the aim of comparing the voice quality before and after the vocal effort of a standard working day. Sound signals were recorded with a microphone and a sound analyzers Symphonie (01dB) in the rehearsal hall. Data were analyzed by means of the BioVoice software tool [13], that allows the extraction of vocal parameters also in singers. The emission quality was parametrized in terms of average fundamental frequency (F0) value, quality ratio, vibrato frequency and extension [13-16]. The following protocol was adapted from [10] :

Exercise n.1: Emit sustained \a\, \i\, \u\ vowels for 2 or 3 seconds with mild loudness and comfortable pitch (main tone of emission). Repeat 10 times without pauses, corresponding to a total time of about 30 s for each vowel.

Exercise n.2: Repeat exercise n.1 for the vowel \i\ with a very low sound intensity and moderately high pitch.

Exercise n.3: Emit vowel \i\ varying the main emission tone from low to high pitch at a low sound intensity

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Exercise n.4: Emit 10 times 5 short-duration \i\ at low sound intensity and moderately acute pitch.

Exercise n.5: Repeat the first strophes of the song "Happy Birthday" at low sound intensity and acute pitch and fill out a questionnaire in which the difficulty in producing low intensity sounds had to be reported with scores from 1 (low difficulty) to 10 (high difficulty).

Exercise n.6: Count aloud from one to three (repeated three times). Fill out a questionnaire (same scores as in exercise 5) reporting the difficulty in producing high level sounds and the laryngeal perceived discomfort. The subjects were also asked to specify if the discomfort was perceived into the larynx, outside the larynx, or in both districts.

In this paper, we present preliminary results relative to the analysis of the vowel \a\ emission as in Exercise 1. Specifically, the first and the tenth emissions before and after the vocal performance during a chorus proof were analyzed. More results will be presented elsewhere.

The BioVoice tool was applied to objectively quantify voice quality. According to [15] the analyzed parameters are: F0 (pitch), vibrato rate (Vrate), vibrato extension (Vext), and the first five formants. Vrate and Vext represent respectively the number of oscillations per second and the oscillation amplitude of the pitch's modulation in time. The standard deviation (Std) of all parameters was also measured.

Moreover, the Singing Power Ratio (SPR) [15] was defined and measured. SPR is related to the energy content of the vocal formants, whose amplitude and frequency correspond to the resonant peaks of the power spectral density (PSD). In particular, in the singing voice, the SPR is defined as the ratio between the area under the curve of the PSD relative to the cluster of the first two formants ($Area_{1,2}$) and that of cluster of the third, fourth and fifth formants ($Area_{3,4,5}$):

$$SPR = \frac{Area_{1,2}}{Area_{3,4,5}} \qquad (1)$$

The better the singer voice quality, the more closely the SPR should approach the unit value. In fact, in this case, the singer voice can be clearly distinguishable from the background orchestra.

A major difficulty in the SPR measure has been finding a reference "threshold frequency" that cuts the PSD integral into $Area_{1,2}$ and $Area_{3,4,5}$. Both a "static threshold" S0, set at 2500 Hz (i.e. midpoint between 2000 and 3000 Hz, approximately representing the second and the third formant respectively), and two "dynamic thresholds", $F_{ref}1$ and $F_{ref}2$, have been defined and tested. $F_{ref}1$ corresponds to the local minimum of the PSD in the range 2 - 3 kHz, while $F_{ref}2$ to the mean frequency value of the second and the third formant. Both dynamic thresholds gave approximately the same results, while S0 gave worse results. In this paper, $F_{ref}2$ has been applied and is named here $F_{ref}inf$. Finally, an upper threshold $F_{ref}sup$ has been introduced, corresponding to the first frequency minimum found after the 5th formant.

III. Results and discussion

Some figures, relative to a soprano singer, are reported here, as they are illustrative of a common behavior found in all cases. Fig. 1 shows the evolution in time of F0 that appears more unstable and irregular after the vocal performance as a consequence of the vocal effort.

In Fig. 2 the time evolution of vibrato is shown: the frequency modulation in time loses its sinusoidal behaviour after the vocal effort due to the performance. Along with the vibrato distortion, also the vocal intonation deteriorates and its time behaviour appears unstable.

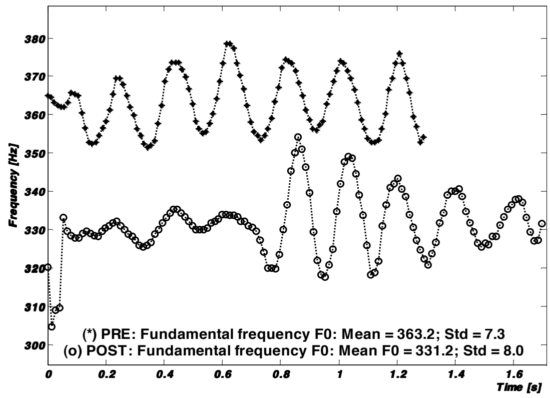

Figure 1- Pre-post performance F0 tracking

Moreover, the vocal effort causes a deterioraration in the SPR, which shows an increasing trend with the phonation fatigue. Fig. 3 shows the PSD before (grey) and after (black) the vocal performance, with SPR=3.9 and 15.3 respectively. In Fig. 3, dots correspond to the PSD maxima and stars to $F_{ref}inf$, $F_{ref}sup$ as obtained with BioVoice.

Finally, Figs. 4 and 5 show the signal spectrogram respectively before and after the vocal performance, pointing out a more regular behaviour of both harmonics and formants before the performance.

Though we analysed few cases, a statistical analysis was performed to find out possible significant differences between data before and after the vocal effort. Data were analyzed by means of a standard Student's t-test (significance criterion $p<0.05$) for paired samples to find statistically significant differences between voice quality parameters before and after the vocal performance. In particular, the first and the tenth vowel \a\ emissions before the performance were compared respectively to the first and the tenth emissions after the vocal effort. A mean emission was defined as the average between the first and the tenth emission. The mean emission characteristics before the vocal performance were compared to the characteristics of the mean emission after the vocal effort. As data distributions were found not normal, the non parametric Wilcoxon rank test was also applied. Results are shown in Table I.

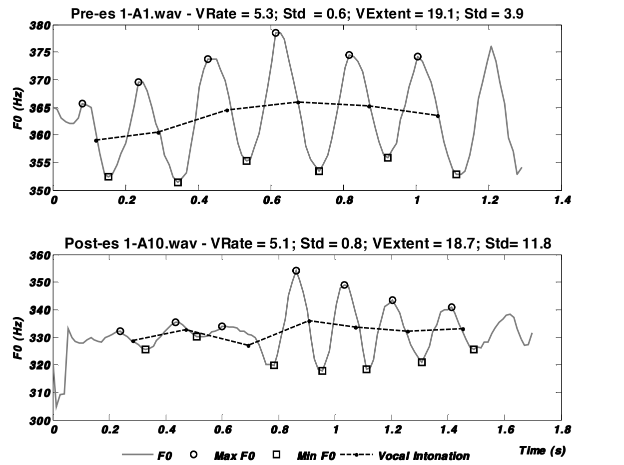

Figure 2: comparison between the vibrato before (first emission) and after (tenth emission) the vocal effort for a singer. Dots and squares correspond to estimated maximum and minimum F0 values, respectively.

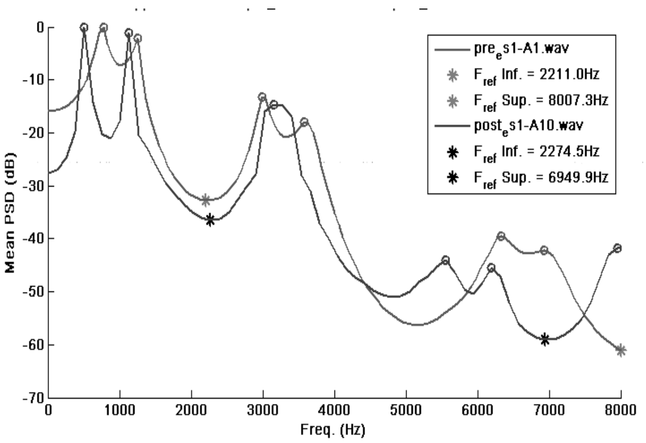

Figure 3: comparison between the PSD before (grey line) and after (black line) the vocal effort.

From the Table, the Std of F0,Vrate and Vext appears sensitive to the exposure to phonation fatigue, as all parameters show an increasing trend. Although the difference between F0 mean values before and after the vocal effort does not give statistical significance, F0 shows an increasing trend due to the exposure.
The parameter SPR seems to be one of the most sensitive to the exposure to the vocal effort. The differences between the SPR before and after the performance are in fact always statistically significant if the first, the tenth or the average of the two last emissions are considered. The statistical distribution of the SPR (mean value) before and after the performance is shown in Fig. 5.

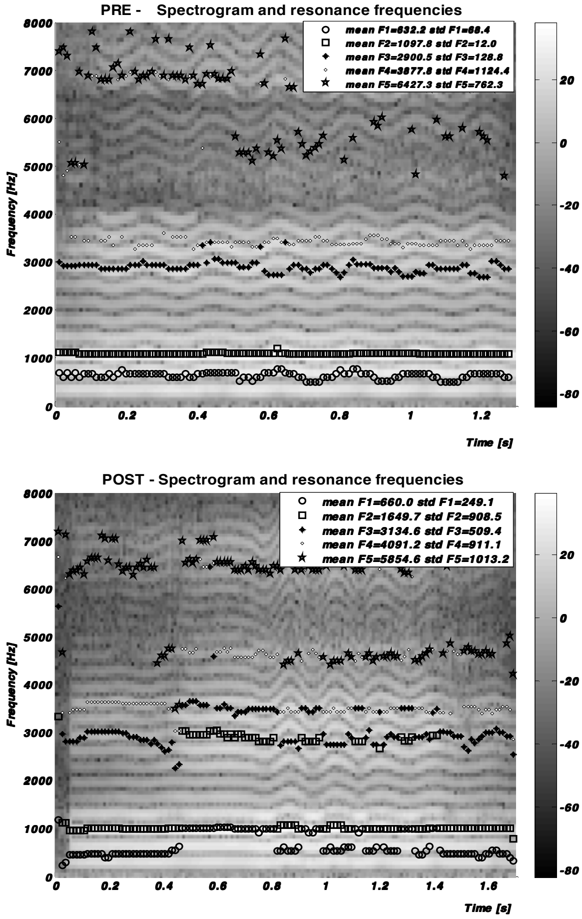

Figure 4: Spectrogram before (top) and after (bottom) the vocal performance.

As expected the parameter SPR, representing voice quality, deteriorates (increases) after a laryngeal sustained effort. Finally, notice that the parameters show a statistically significant difference not only between the exercises executed before and after the artistic proof but also between the first and the tenth vocal emission.

IV. CONCLUSION

Some of the voice parameters studied in this work before and after the artistic performance during the rehearsal of a grand opera seem to be sensitive to the vocal effort of a typical working day. In particular, statistically significant differences were found between the Std of F0, Vrate and Vext, before and after the artistic performance. Another sensitive parameter is SPR, specifically implemented in the BioVoice tool to define the quality of sung voice. Future work will be devoted to enlarge the data set for a better statistical analysis. Our results, if confirmed, could in fact be useful to define an effective protocol for monitoring long-term adverse effects of the vocal effort in exposed populations.

Table I: Student's t-test and Wilcoxon non-parametric rank test comparison between voice parameters measured before and after the vocal effort.

T-TEST	pre -post	pre -post	pre-post
	1st emission	10th emission	mean
F0	n.s.	n.s.	n.s.
Std F0	n.s.	0.037	0.055
SPR	n.s.	0.00044	0.00234
Vrate	n.s.	n.s.	n.s.
Std Vrate	0.01103	0.00669	0.00306
Vext	n.s.	n.s.	n.s.
Std Vext	0.02761	n.s.	n.s.
WILCOXON	pre -post	pre -post	pre-post
	1st emission	10th emission	mean
F0	n.s.	n.s.	n.s.
Std F0	n.s.	0.01563	0.01563
SPR	0.03125	0.01563	0.01563
Vrate	n.s.	n.s.	n.s.
Std Vrate	0.01563	0.03552	0.01991
Vext	n.s.	n.s.	n.s.
Std Vext	0.01563	0.07813	0.03125

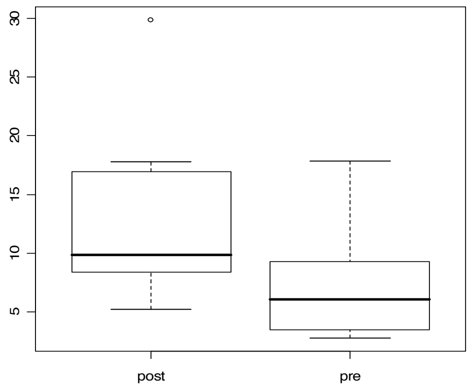

Figure 5: boxplot showing the mean SPR before (pre) and after (post) the vocal effort.

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