Bifurcations in Excised Larynges Caused by Vocal Fold Elongation

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Abstract

The study presents experimental investigations of non-linear vibration effects, particularly bifurcation phenomena in the vibrations of human vocal folds. The vocal fold vibrations were excited by airflow and the microphone, the pressure transducers, an electroglottograph and the laser vibrometer registered the phonation and vibration of the vocal folds. Furthermore the vocal fold oscillations were observed optically by strobovideoscopy and videokymography. Bifurcations in the vocal fold vibrations were observed when smoothly changing the tension of the vocal folds.

1. Introduction

In a previous study by Švec *et al* [1] the authors have reanalyzed results of old experiments with an excised human larynx carried out by Jw. van den Berg *et al* [2,3]. In the "van den Berg experiment" the vibrating vocal folds were gradually symmetrically elongated and then shortened by applying an external force to the larynx while other parameters were held constant. The analysis revealed, that chest-falsetto jumps can be seen as manifestations of bifurcations in the vocal-fold vibratory mechanism, i.e., the jumps in frequency accompanying the change of the register can arise without any sudden change of the tension of the vocal folds. Since these results are highly important for understanding the mechanism of the control of the fundamental frequency of the vocal folds as well as the mechanism of change between the chest and falsetto register, the goal of the present study was to obtain more detailed information on these phenomena and to verify the previous results.

2. Experimental procedure

In the present study the van den Berg experiment was repeated several times in three excised human male larynges. Measurement framework originally developed by Vilkman *et al* [4] was used as a base for attachment of the excised larynges. Tested larynges were fixed horizontally to a plate through which the airflow, warmed up to 37°C and humidified, was delivered to the vocal folds. The air passed through a tube, the dimensions of which correspond to the volume of human subglottal space. Subglottal pressure in the tube was measured by pressure transducers. The supraglottal space was not modelled. Adduction of the vocal folds was adjusted as well as the airflow rate and kept constant. Longitudinal tension of the vocal folds, monitored by the force transducer, was smoothly increased or decreased by rotating the thyroid cartilage and the changes of the fundamental phonation frequency *F0* and of the vibration regimes were investigated [5,6].

3. Results

The chest-falsetto jumps (similar to those demonstrated previously by van den Berg) as well as the jumps to more complex vibratory regimes (diplophonic, biphonic, aperiodic) were observed. Each larynx appeared to exhibit slightly different vibratory regimes. The use of the high-speed videokymography enabled to follow how the quick changes of the fundamental frequency are produced in the vocal folds. Synchronous as well as asynchronous oscillations of the left and right vocal fold were observed during the bifurcations. Videostroboscopy revealed an "anterior-posterior mode" (lateral-medial oscillations of the glottis while its anterior part oscillates in an opposite phase to the posterior one) to be an important factor in a complex vocal-fold vibratory pattern of one of the larynges.

Results of a typical measurement of bifurcation phenomena are shown in Fig. 1. Spectrogram of the subglottal pressure is presented here together with time records of the relative changes ΔF of the vocal folds mean tension (the signal from the force transducer), subglottal pressure p_s, microphone signal p and velocity v of vibration of one vocal fold in vertical direction measured by the laser vibrometer. This measurement was performed at a constant flow rate Q=0.4*l*/s and the experiment duration was about 130s. During this measurement time there were registered two different stable regimes of phonation.

After a transition time of about 10s duration in the beginning of the measurement the phonation started. While decreasing the longitudinal tension of the vocal folds, the pitch gradually decreased from about $F0\approx350$Hz down to $F0\approx208$Hz. At the time instance of about $t\approx34$s this phonation regime (falsetto-like) changed abruptly into a chest-like regime. The pitch frequency jumped from about $F0\approx208$Hz approximately to $F0\approx80$Hz, simultaneously *rms* values of monitored sound, pressure and vibration signals suddenly increased. Afterwards the tension of the vocal folds was gradually increased which caused only very small and slow rise in pitch up to $F0\approx82$Hz. By the time $t\approx62$s the fundamental phonation frequency jumped up to $F0\approx216$Hz and the chest-like vibration regime was replaced again by the falsetto-like regime.

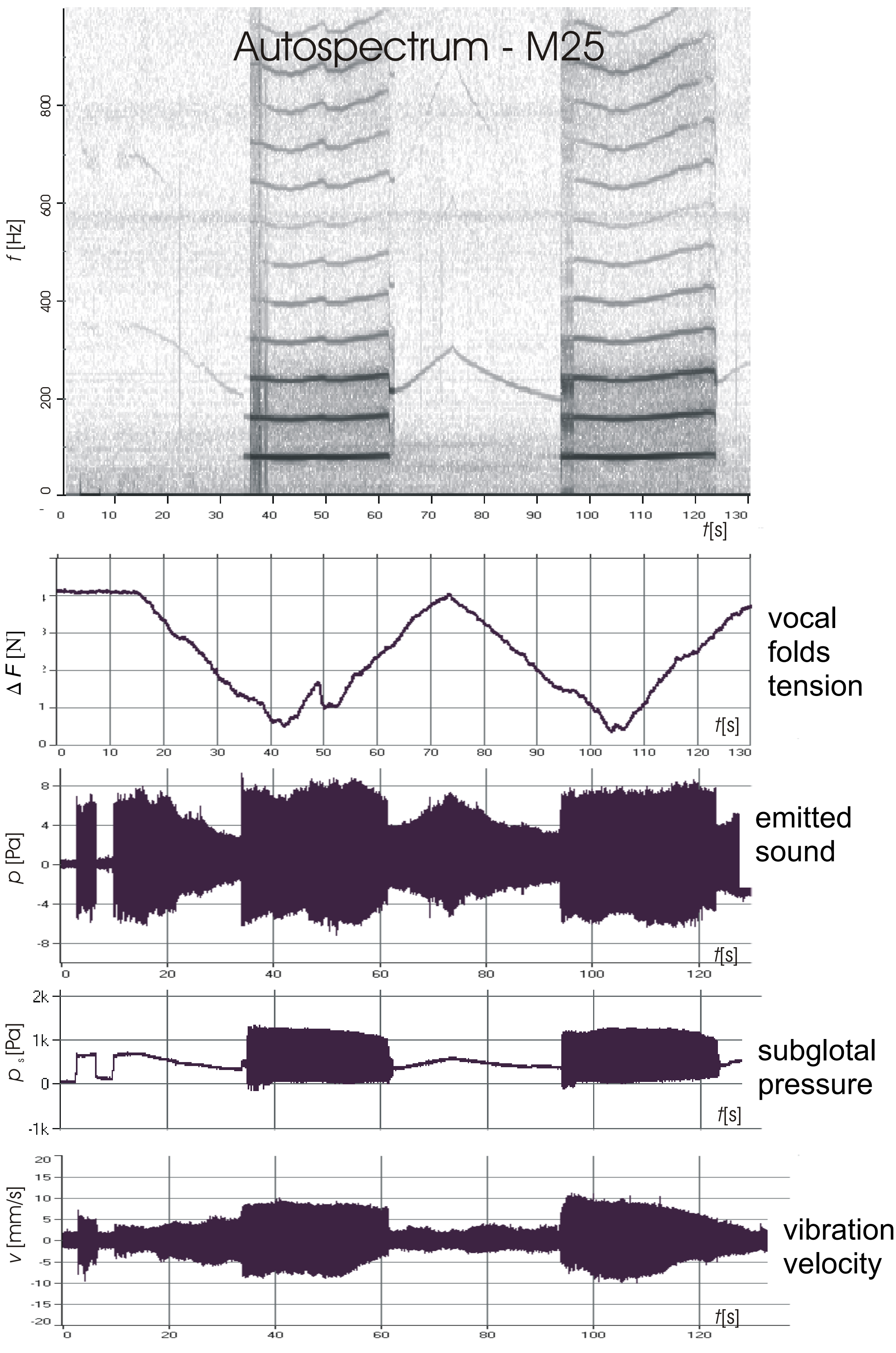

Fig. 1 Example of observed bifurcation phenomena during vocal folds oscillations while slowly changing the tension of the vocal folds and keeping the adduction and the airflow rate constant (measurement No 25, Q = 0.4 l/s). Notice that the abrupt changes of the frequency spectrum and subglottal and acoustic pressures happen at the moments of smooth changes ΔF of the vocal fold tension F.

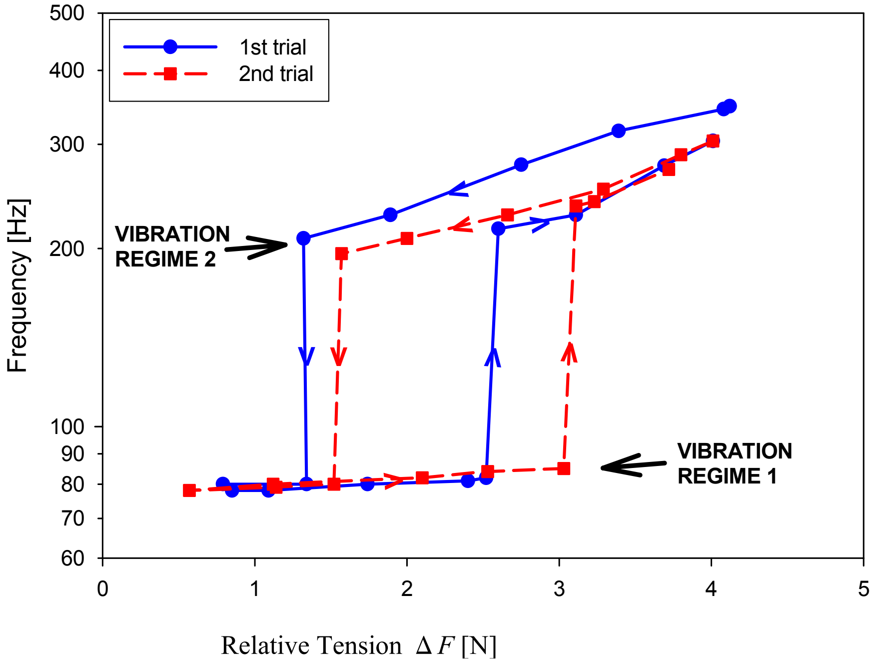

Fig 2. Hysteresis loops for the frequency *F0* in relation to the variation of the relative vocal folds tension Δ *F*. The data correspond to those of the measurement No 25 shown in Fig. 1. The stable vibration regimes 1 and 2 correspond to the chest-like and falsetto-like registers, respectively.

Increasing the tension further caused a smooth rise of the fundamental frequency up to *F0*≈304Hz by the time *t*≈74s. Afterwards the entire measurement cycle was repeated with a high reproducibility up to the end of the experiment (*t*≈130s). Sudden changes of fundamental frequency of vibration occurred while the longitudinal tension of the vocal folds changed gradually (see Fig.1), which means the frequency jumps and the register transitions should be understood as bifurcation phenomena. Corresponding hysteresis loops, evaluated for both trials from the time records of subglottal pressure and force transducer signals, are shown in Fig.2. From here the frequency jumps between the two vibration regimes and a rate of reproducibility of bifurcation phenomena are evident.

4. Conclusion

The results substantiate the correctness of the previous analysis carried on the old cinematographic recording of the experiment of Jw. Van den Berg *et al.* The results confirm and further specify the complex nonlinear-dynamic nature of the vocal-fold vibration and point out the possible relationship between regular (physiologic) and irregular (pathologic) vocal fold oscillations.

5. Reference

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