Bifurcation behavior in vocal folds and its impact on physiological conditions

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Abstract. The dynamics of voice production have recently spawned significant research interest due to the presence of phenomenological bifurcations and instabilities observed in abnormal patterns of phonation. Human voice is created by the onset of self-sustained limit-cycle oscillations (LCOs) in vocal folds. Several factors, like subglottal pressure, tension in the vocal folds and their pre-phonatory position influence the onset of LCOs and the vocal characteristics. Though the phonation mechanisms are quite well studied in the literature, the effect of some physiological parameters on vocal-fold dynamics have not been investigated in detail. The present study attempts to model bifurcations considering an asymmetric two-mass model of the vocal-folds that effectively captures the dynamics of vocal paralyses. This study will specifically focus on the dynamics observed with the variation in different physiological parameters (like asymmetry in vocal folds' tension, cubic nonlinearity in stiffness, etc.), in order to link the observed dynamics to clinical findings of vocal paralysis.

Introduction

The process of phonation, i.e, the production of voice in the larynx, occurs due to the onset of LCOs in vocal folds and its fine control by various laryngeal muscles. In this process, several pathologies of the vocal folds- lesions, polyps, paralysis, etc.- may lead to distortions in voice. Many models have been developed- ranging from low-fidelity discrete lumped-mass models to high-fidelity coupled fluid-elastic models to capture these abnormalities. The present study adopts a low-order discrete two-mass model [2], having a relatively low computational cost, which is sufficient to capture the essential nonlinear behavior of the vocal folds. Since phonation is a complex phenomenon governed by several variables [1]- subglottal pressure, tension asymmetry, stiffness of the vocal fold tissue, glottal flow velocity, etc., a significant change in the dynamical behavior can be observed with varying these parameters. Multiple bifurcation studies involving linear stiffnesses have been carried out in the past. However, since the vocal folds are intrinsically nonlinear, studying the effect of the same in a modelling context remains a gap to be bridged. An extensive bifurcation study of vocal dynamics with varying extents of non-linearity will help in gaining a better understanding of the underlying dynamical transitions behind the abnormal behavior of the vocal folds. Hence, the focus of the present study is to explore the effect of cubic nonlinearity in stiffness on the observed dynamics. This is done through an extensive bifurcation analysis, in regimes that show interesting dynamical transitions (coexisting attractors, quasi-periodicity, or chaos), using robust dynamical systems tools like Poincaré sections and phase portraits.

Results and Discussion

Multiple vocal paralysis cases were studied for a superior laryngeal paralysis [2] (for nondimensional subglottal pressures P_s= 0.010, 0.015), and inferior laryngeal paralysis [2] (for P_s= 0.010). The 1-D bifurcation diagrams with tension asymmetry (Q) as the control parameter were obtained for varying extents of cubic non-linearity (η). From the resulting bifurcations, it is seen that the increasing values of η leads to decreased distortions in voice. The dynamics for two different η values, for a paralysis simulation (P_s= 0.015) is presented in Fig. 1. The biphonation regime, characterized by the period-doubling regime, seen at $\eta = 0$ has become considerably smaller in the $\eta = 100$ case, and a larger portion of the Q- range is seen to yield period-1 LCOs which lead to a healthy voice. The present findings can help to draw suggestions for clinical applications.

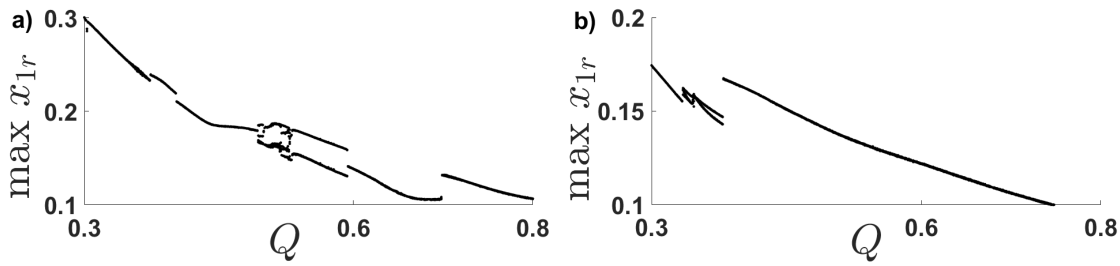

Figure 1: Bifurcation diagrams showing maxima of lower-right mass displacement (x_{1r}) for P_s=0.015 and for values of η : a) η=0 and b) η=100

References

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[2] Steinecke, I., Herzel, H. (1995). Bifurcations in an asymmetric vocal-fold model. Journal of the Acoustical Society of America, **97(3)**:1874-1884.