PHYSICAL MODELING AND NUMERICAL SIMULATION OF HUMAN PHONATION

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ABSTRACT

The human phonation is a complex interaction of fluid mechanics, solid mechanics and acoustics. As the lungs compress, air flows through the larynx passing the vocal folds which form a narrow constriction, the glottis. The air flow forces the vocal folds to vibrate resulting in a pulsating air stream, which is the main sound generating mechanism for phonation. Hence, our modeling approach is to resolve, within the larynx and adjacent regions, the physical details of the phonation process in space and time by means of partial differential equations (PDEs). Due to limitations in computer resources and current numerical methods, full coupling between all three fields for realistic 3D geometries is currently not feasible. Therefore, we concentrate on prescribed flow computations, evaluate the acoustic sources and perform acoustic computations of the generated sound. In this way the fluid-solid interaction problem, whose accuracy critically depends on reliable geometrical and material parameters of all layers of the vocal folds, is circumvented. We apply the open source program OpenFoam for solving the 3D incompressible Navier-Stokes equations, and CFS++ (in-house research code) to compute the acoustic sources as well as sound propagation. The main findings of our current simulations can be summarized as follows. The dominant acoustic sources of the fundamental frequency as well as its harmonics are located inside the glottis and the highest amplitudes are found in a thin layer right above the surface of the vocal folds. For the non-harmonic frequencies, the acoustic sources are concentrated in the vortical decay region. The simulated formant frequencies for the /i/ and /u/ vowels compared well with the formant frequencies measured on human subjects. Furthermore, the simulations suggested that the false vocal folds induce an amplification of higher harmonics in the radiated acoustic field.