Relationships between turbulent flow configuration and sound source location of Japanese sibilant fricatives

Tsukasa Yoshinaga[1*], Kazunori Nozaki[2], and Akiyoshi Iida[3]

[1] Toyohashi University of Technology, yoshinaga@me.tut.ac.jp
[2] Osaka University Dental Hospital, knozaki@dent.osaka-u.ac.jp
[3] Toyohashi University of Technology, iida@me.tut.ac.jp

1. Introduction

The sibilant fricatives, one of the consonants, are known to be pronounced by controlling a turbulent flow in the front part of a vocal tract. The turbulent flow is generated by a constricted channel formed by a tongue tip and upper palate. The production mechanisms of sibilant fricatives have been investigated by several researchers using simplified vocal tract models [1, 2]. These simplified models were constructed by systematically varying the model geometries to represent the aeroacoustic characteristics of fricatives. However, relationships between turbulent flows formed by the constriction and locations of the aeroacoustic sound sources are still unclear. Therefore, in this study, we performed a numerical flow simulation on the vocal tracts of male Japanese subjects pronouncing sibilant fricatives [s] and [ʃ], and clarify the relationships between the flow configuration and source locations.

2. Method

The vocal tract geometries of sustained sibilant fricatives are extracted from magnetic resonance imaging (MRI). The subjects sustained [s] and [ʃ] for 32 s without vowel context in the MR machine (voxel spacing: 0.5 × 0.5 × 2mm, MAGNETOM Prisma fit 3T Siemens, Germany). The geometries of upper and lower incisors were separately collected by MRI and superimposed on the vocal tract geometries without incisors [3].

For the numerical simulation, the computational grids were constructed for each vocal tract. The minimum grid size is approximately 0.02 mm to resolve the turbulent vortices near the teeth walls. The three-dimensional compressible Navier-Stokes equations were solved by finite volume method software OpenFOAM 2.3.1 (OpenCFD. Ltd.). The details of the methods are presented in reference [4].

3. Results and discussion

The flow fields predicted by the simulation for [s] of subject A are shown in Fig. 1. The velocity magnitudes above 0.1 m/s were visualized by volume rendering. The flow accelerated by the constriction reached the maximum velocity in the middle of constriction and formed small vortices downstream from the constriction. The jet formed by the constriction was curved by the upper incisor and impinged on the lower lip surface for this subject.

The sound source calculated by Lighthill's analogy [5] is visualized in Fig. 2. The amplitudes of source fluctuation (RMS values of source term) above $\psi = 1.5 \times 10^{10}$ kg/m^2·s^2 are shown by red dots. The flow passing near the upper incisor firstly formed the source nearby the alveolar ridge, and the flow curved by the upper incisor formed the sources at the lower incisor edges and lower lip surface. Although the flow was first obstructed by the upper incisor, the maximum strength source appeared on the lip surface. This was because the lip surface was perpendicular to the flow direction. These results indicate that the sound waves propagating from these sources interacted with each other, and formed the acoustic characteristics of [s] in the vocal tract. The results for other subjects will be presented and discussed in the conference.

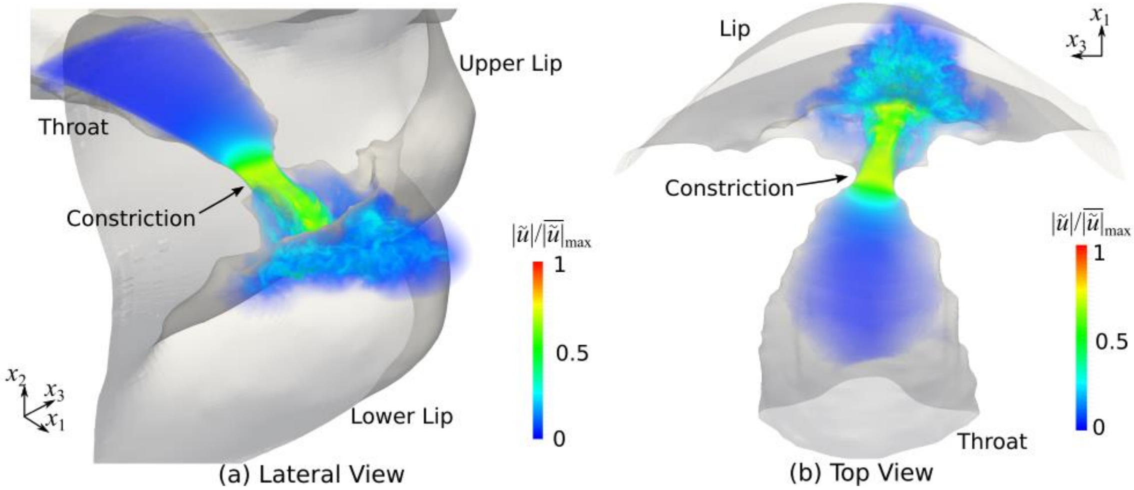

Fig. 1. Flow velocity fields in the vocal tract for [s] of subject A. (a) Lateral and (b) top view.

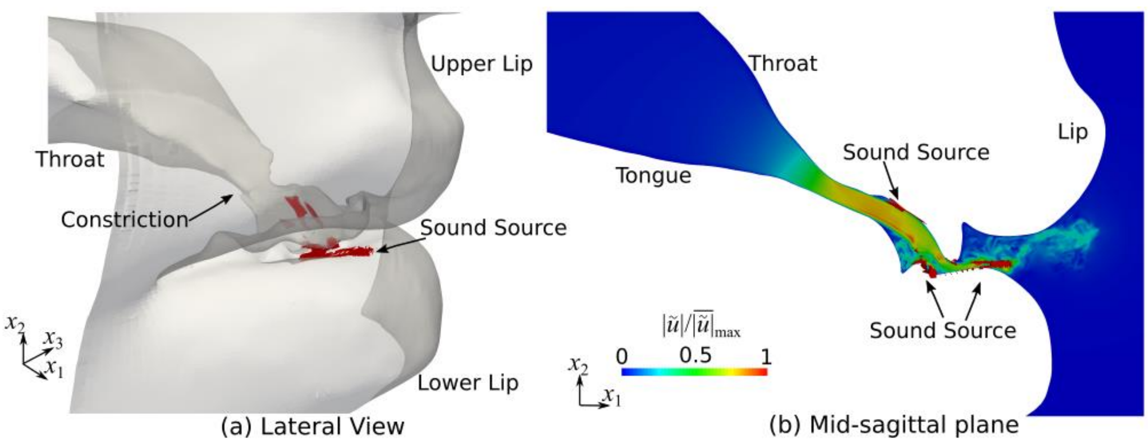

Fig. 2. Sound sources (red points) visualized in the (a) lateral view and (b) mid-sagittal plane of the vocal tract for [s] of subject A.

References

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