Title: Three-dimensional acoustic analysis of the nasal and paranasal cavities

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Abstract

The nasal and paranasal cavities are complex in shape, and thus it is difficult to examine their acoustic characteristics. In the present study, the shapes of the upper respiratory tract from the glottis to the nostrils for two male subjects (M1 and M2) and two female subjects (F1 and F2) were extracted during quiet breathing from head volumetric data obtained by X-ray cone-beam computed tomography. In all the data, the oral cavity was closed at its entrance near the velum. In the analysis, the transfer function was calculated by three-dimensional finite-difference time-domain simulation when the acoustic source point was placed just above the glottis and the observation point was placed 2 cm away from the nostrils. Then, to examine acoustic effects of the paranasal cavities, the transfer function was also calculated after each of the maxillary and sphenoidal sinuses was manually occluded. Note that the frontal and ethmoidal sinuses were not examined because the necks of the frontal sinuses were difficult to identify, and there were too many cells in the ethmoidal sinuses. As a result, all these cavities were found to generate spectral dips around a small peak at approximately 500 Hz, which was located between the first and second prominent peaks and commonly observed among the four subjects. The small peak at about 500 Hz disappeared when all the sinuses were occluded. Thus, the small peak could be generated by compound effects of these paranasal cavities. Occlusion of each sinus did not affect the frequency of the dips affiliated with the other sinuses. This fact indicated that there was no acoustic interaction among the paranasal cavities as observed for example in the bilateral piriform fossae. The effects of occlusion on the peaks varied among the subjects and cavities. Occlusion of the left maxillary sinus for F1 and sphenoidal sinus for M1 and M2 changed the second prominent peak to a pole-zero pair. A similar change was also found in the fifth prominent peak at 4000 Hz for M1 when the left maxillary sinus was occluded. Because the second prominent peak of the male subjects was lower in frequency than that of the female subjects (1100 Hz for M1, 1200 Hz for M2, 1450 Hz for F1, and 1550 Hz for F2), this peak seemed to reflect the overall size of the nasal cavity, and thus it could be the second nasal formant caused by the second longitudinal resonance of the nasal cavity. The change from a peak to a pole-zero pair, however, implied that the second prominent peaks for M1, M2 and F1 were generated not only by the nasal cavity but also by the paranasal cavities. In other words, the mechanism for generating the peak in the nasal and paranasal cavities could be different from that in the vocal tract from the glottis to the lips. [This research was supported by JSPS KAKENHI Grant numbers 15K00263, 25280066, and 25240026.]