Modeling the Acoustics of Air Sacs

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Air sacs are "sac-like extensions of the larynx or other parts of the vocal tract" (Hewitt *et al.* 2000) There are many different types of air sacs in primates, but this poster focuses on air sacs that are connected to the vocal tract above the glottis. Such air sacs occur in many primates, including the great apes, but not in humans. Furthermore, fossil evidence (relating to the shape of the hyoid bone) indicates that *Homo heidelbergensis* (Martínez et al. 2008) did not have air sacs, whereas *Australopithecus africanus* (Alamseged *et al.* 2006) did. It is therefore tempting to seek a relation between air sacs and the evolution of speech.

There is considerable uncertainty about the role of air sacs. Bioacousticians generally assume an acoustic role and write about "resonance", "impedance matching", "radiation" (Gautier 1964, Hilloowala 1978, Schön Ybarra 1986). Other researchers propose functions not directly related to acoustics, such as rebreathing of air (Negus 1949) or prevention of hyperventilation (Hewitt *et al.* 2000) The situation is complicated by the lack of accurate acoustic models of air sacs. In the research presented here, a detailed model of supralaryngeal air sacs is constructed. Note that this research is intended as an exploration of the acoustic possibilities of air sacs, and that the intention is not at all to rule out potential other functions of air sacs.

A physical model of an air sac was constructed. The model takes into account air pressure, wall motion, radiation and the impedance of the tube connecting it with the vocal tract. A lumped element model models each of these influences as a single impedance. It therefore assumes wavelengths that are long compared to the air sac's dimensions. It was found that only the dimensions of the neck, the air sac volume and the mass of the walls have significant influence on the resonance frequencies. This corresponds well with the findings of Fletcher *et al.* (2004) in relation to ring dove vocalizations. Radiation should be taken into account when calculating the sound output. This model results in a peak and a zero in impedance. When an air sac is connected to an oral tract, it creates an extra low frequency resonance near the resonance frequency of the air sac, and it shifts the lower resonances of the oral tract up and closer to each other.

As a case study it was attempted to recreate the formant pattern of the vocalizations of a Brown howler monkey (*Alouatta guariba*). One of their vocalizations was found to have peaks around 300, 750 and 1410 Hz. A very approximate model with an 11cm oral tract and an air sac of 10cm diameter was found to have resonances at 215, 725 and 1215 Hz. The correspondence is close, as is the correspondence to the first three formants of a much longer (~35cm) straight tube. Deliberately, no attempt was made to fine tune the model, as this would result in an exercise in parameter tuning.

Air sacs appear to have a significant influence on vocalization. This might help a vocalizing primate to appear larger (Fitch & Hauser 2002). At the same time higher formants are shifted closer together, thus reducing the ability to articulate distinct speech sounds. This might be a reason why they were lost in human evolution.

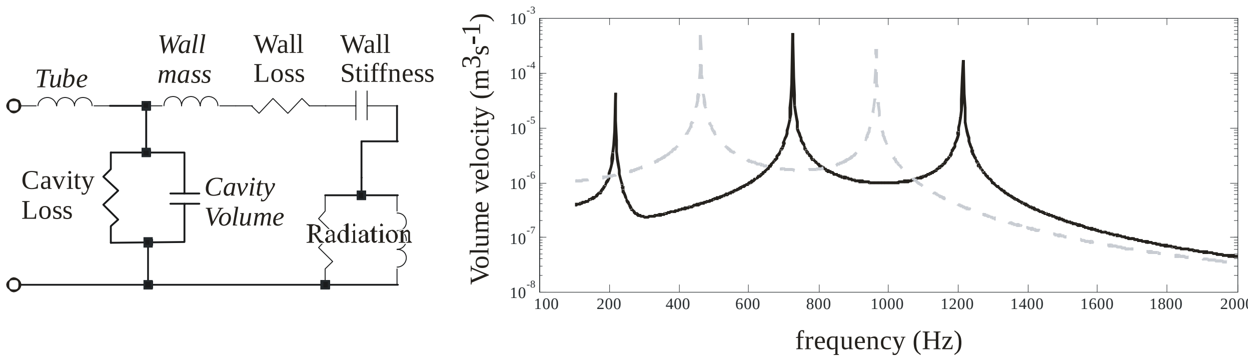

Fig. 1. (Left) Lumped element circuit analog of an air sac. Elements that have a significant influence on the resonance frequencies are shown in italic. (Right) Frequency response of a howler-monkey like vocal tract without (grey dashed line) and with (black solid line). Note that an extra low frequency formant appears and that higher formants are shifted up and closer together.

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