Individual difference and acoustic effect of female laryngeal cavities

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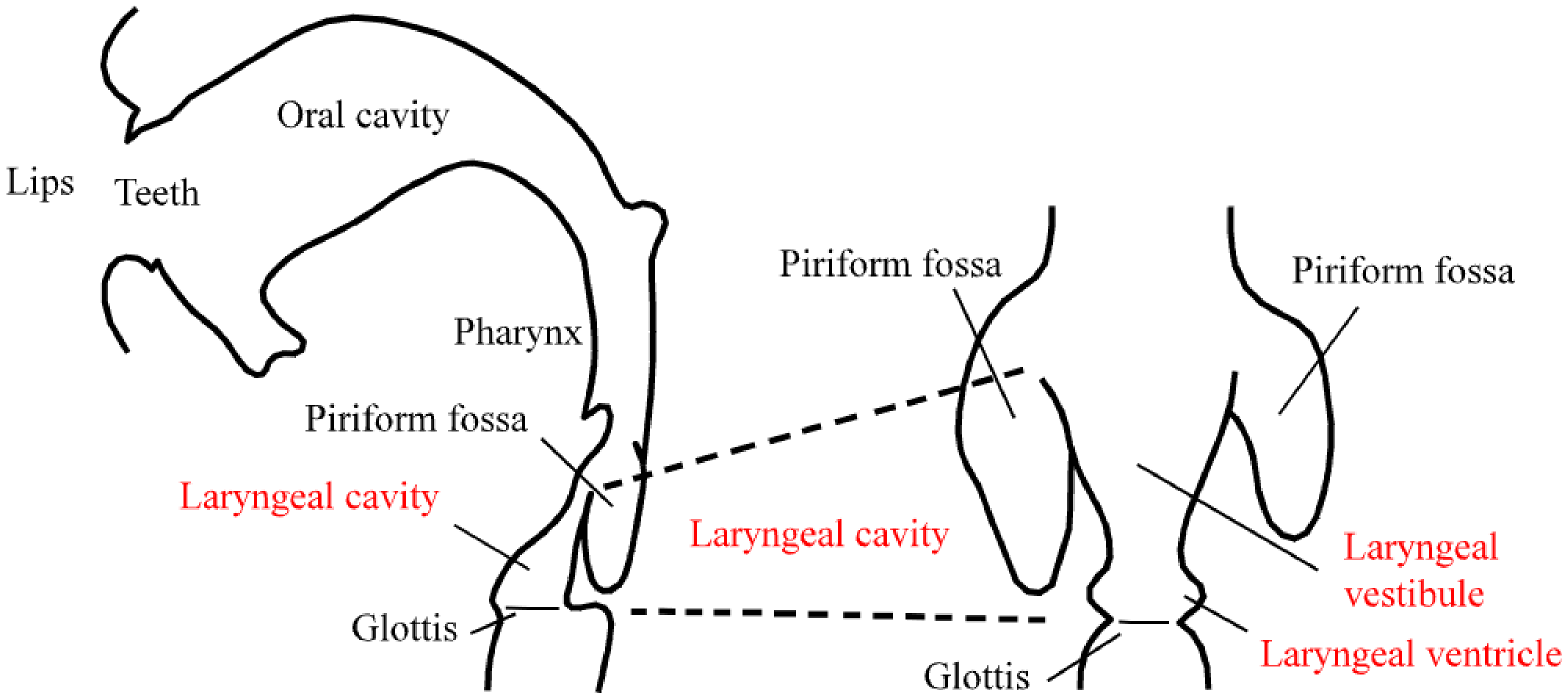
Background

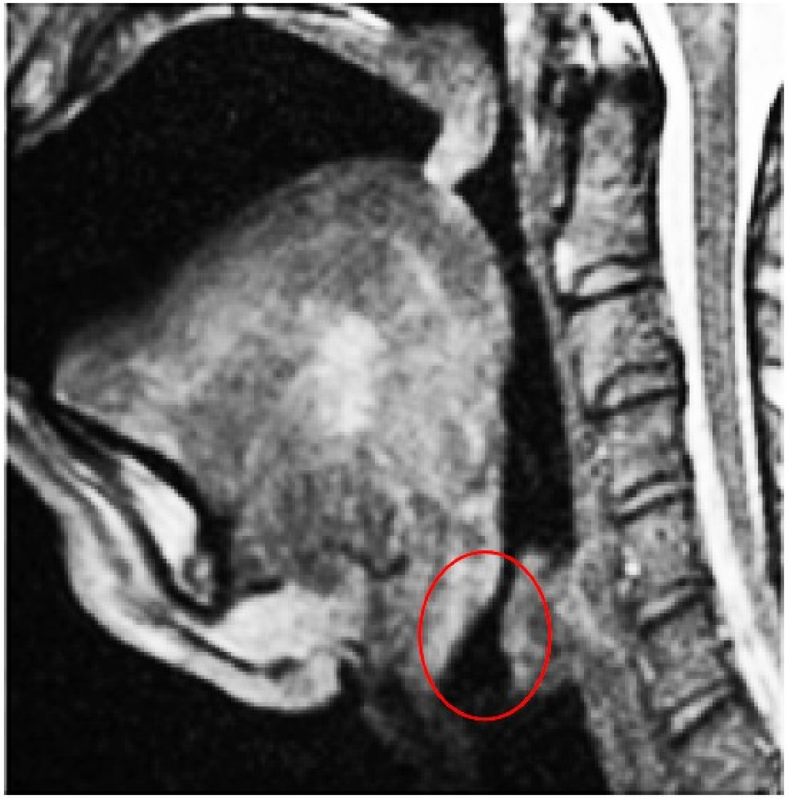
- **Laryngeal cavity as a source of individual vocal characteristics**
  - A lower part of the vocal tract above the glottis.
  - The cavity forms a Helmholtz resonator in male speakers.



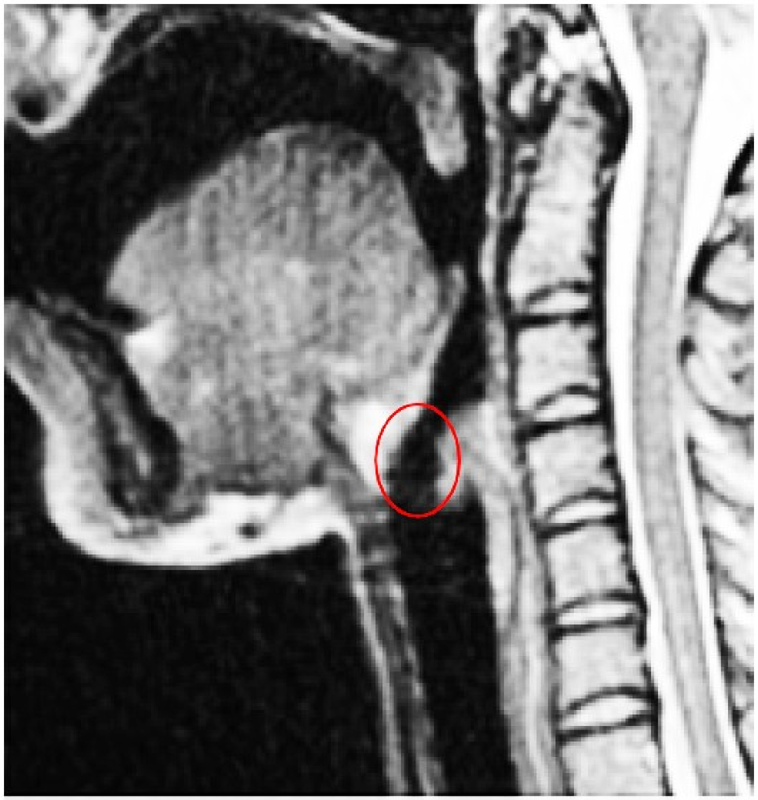
Background

➢ Laryngeal cavity

(a) Male laryngeal cavity



(b) Female laryngeal cavity



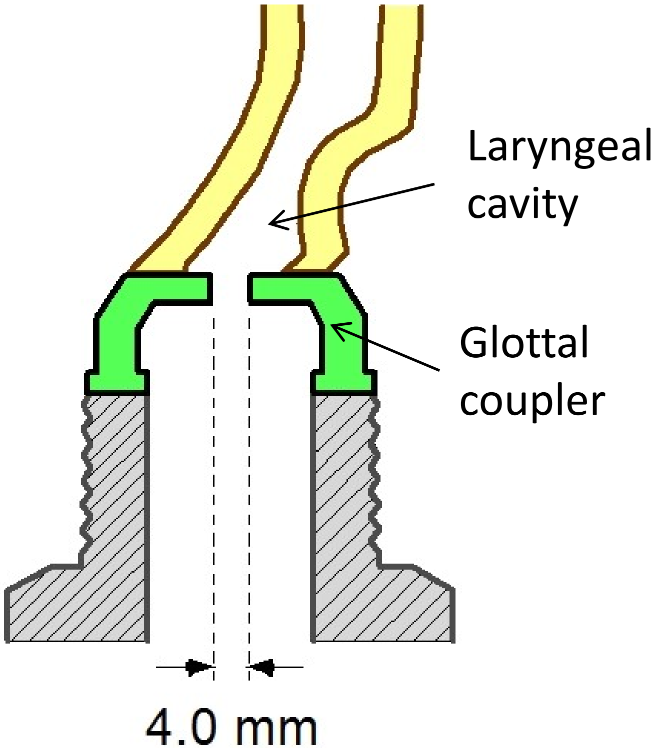
Previous studies

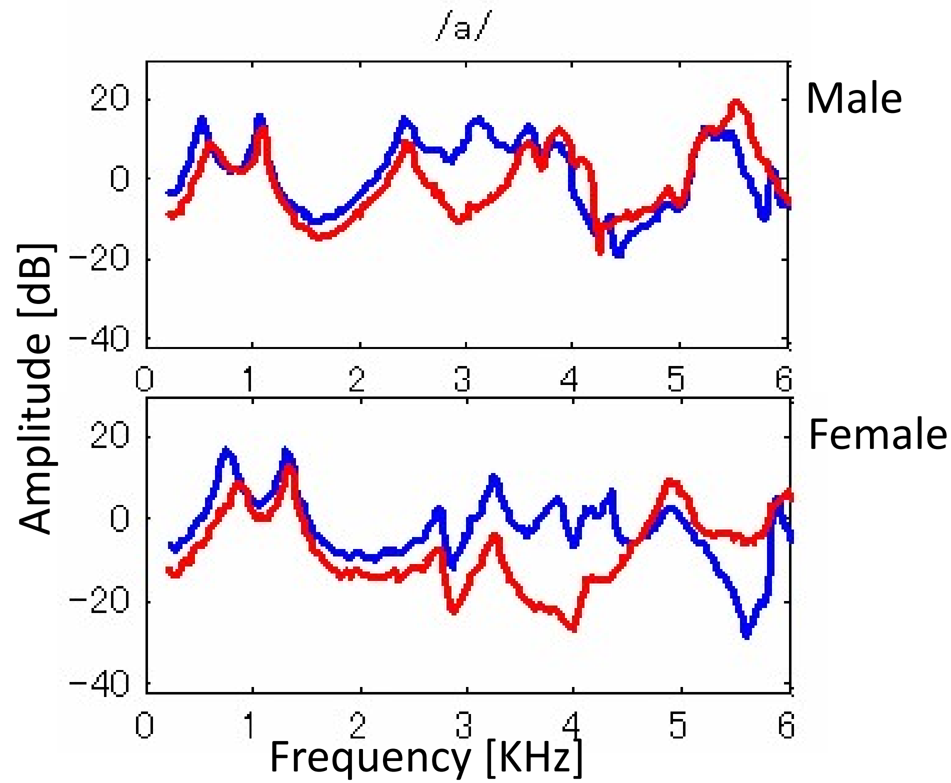
➢In search of causal mechanisms of vocal individuality

- Kitamura et al. (2005) : The hypopharyngeal cavities affect the frequency range of spectra above 2.5 kHz.
- Kitamura et al. (2006) : The laryngeal cavity generates closed tube resonance during the closed period of the glottis, which diminishes when the glottis opens.
- Takemoto et al. (2006) : The laryngeal cavity gives rise to the fourth formant of the vocal tract, with little effects to other formants.
- Honda et al. (2010): Conducted acoustic experiment using mechanical vocal-tract models. The female laryngeal cavity causes spectral changes in the wider spectral range.

Previous studies

Spectra: closed & open glottis
(Honda et al., 2010b)





The hole size of the glottal coupler simulating the open glottis (4.0-mm) may be too large for the female glottis.

Research purpose

- To examine **the role of the female laryngeal cavity** in generating individual acoustic characteristics of vowel sounds.

Materials

➢ Subjects

- CR, LH, SC (Female)
- WS (Male)

➢ Vowels examined

- Chinese vowels /a/ and /i/

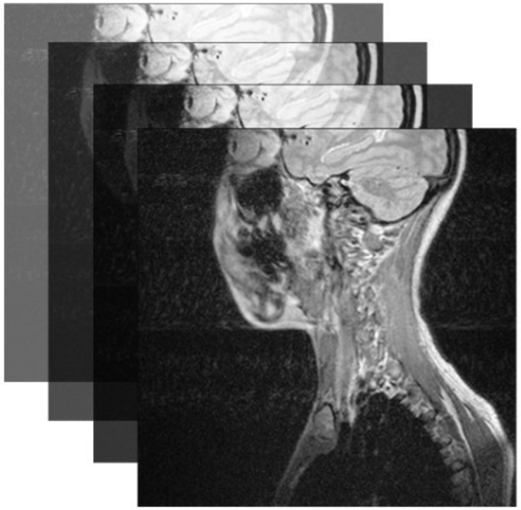
Research purpose

- To examine **the role of the female laryngeal cavity** in generating individual acoustic characteristics of vowel sounds.

Materials

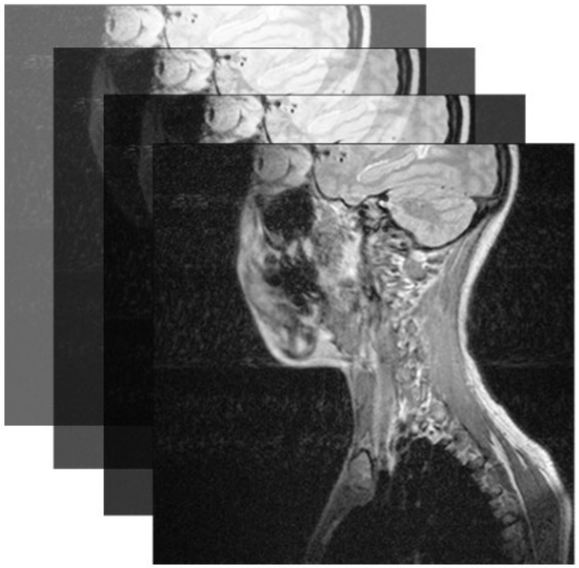
MRI data

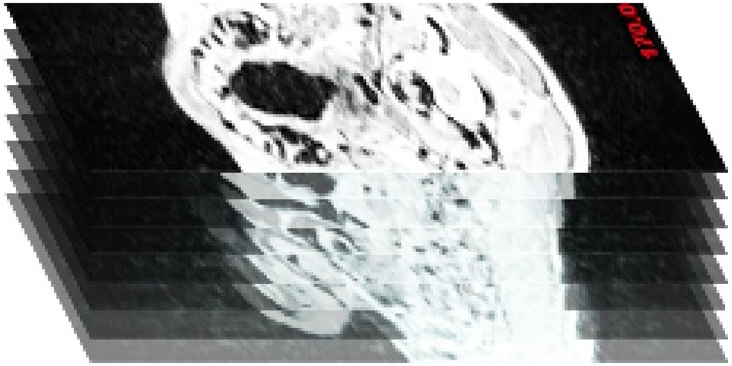
- Siemens Verio 3T MRI scanner
- Sagittal images
- Vowel data: 2-mm slice thickness
- Teeth data: 1-mm slice thickness



Method

Solid vocal-tract models



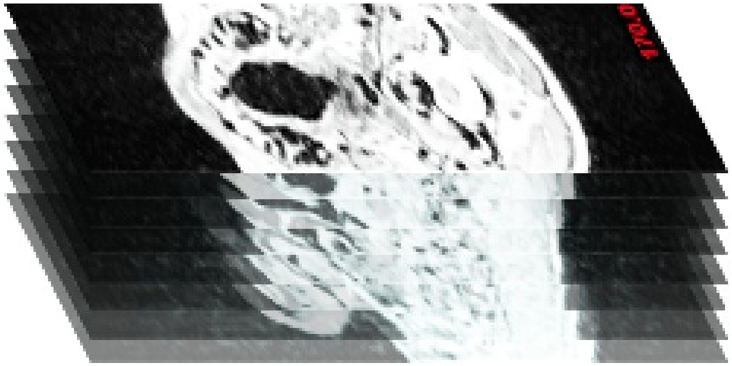


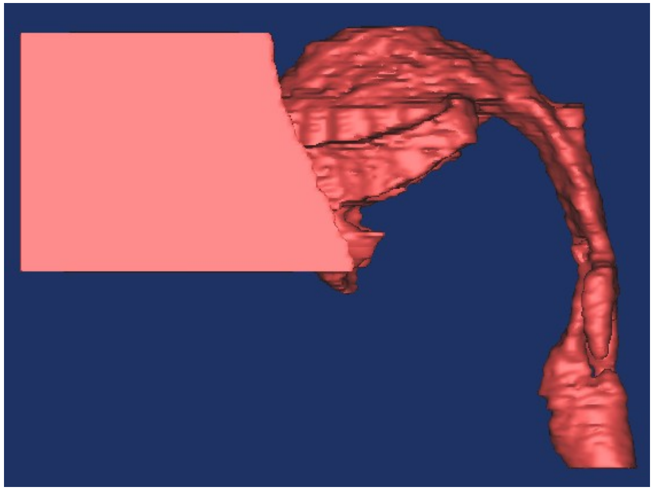
Sagittal images
2-mm slice thickness

Axial images
1-mm slice thickness

Method

Solid vocal-tract models





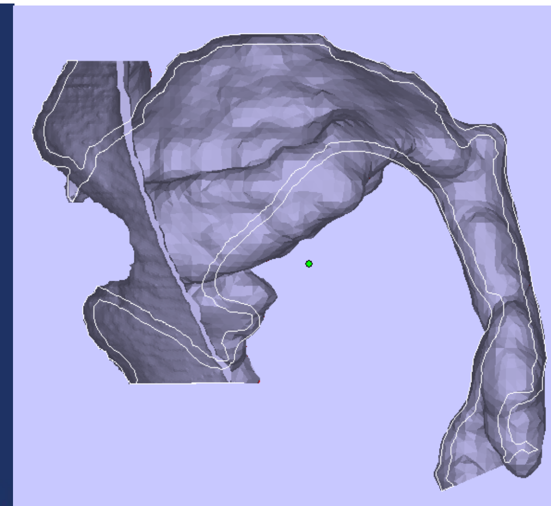
Axial images
1-mm slice thickness

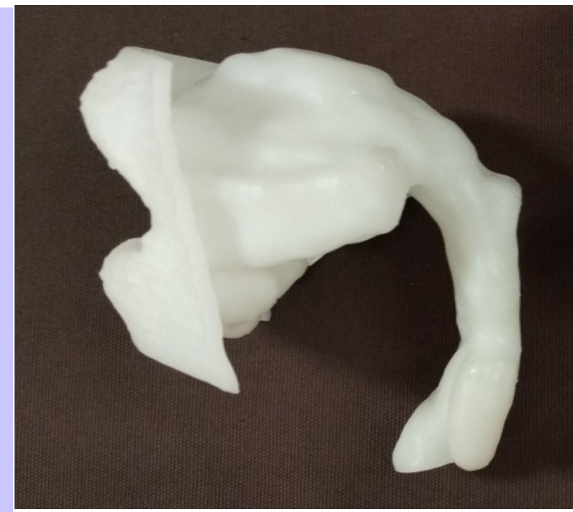
3D vocal-tract model
(Materialise MIMICS)

Method

Solid vocal-tract models

Two processes to build solid vocal-tract models





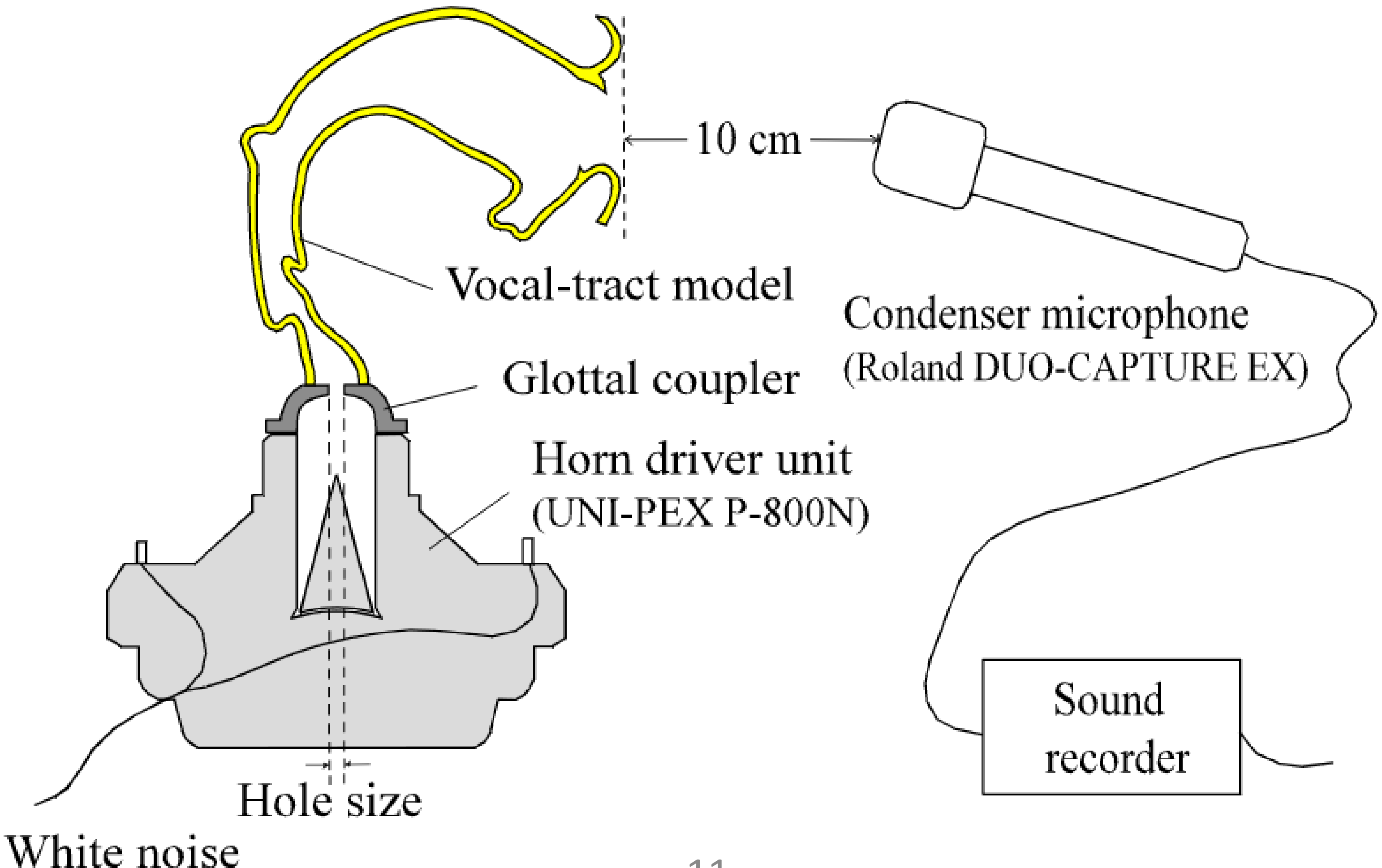
Trim to have an outward wall of 3-mm thickness
Cut the glottal and lip boundaries

Print the data by a 3D printer (Formlabs F1+)

Method

Acoustic experiment

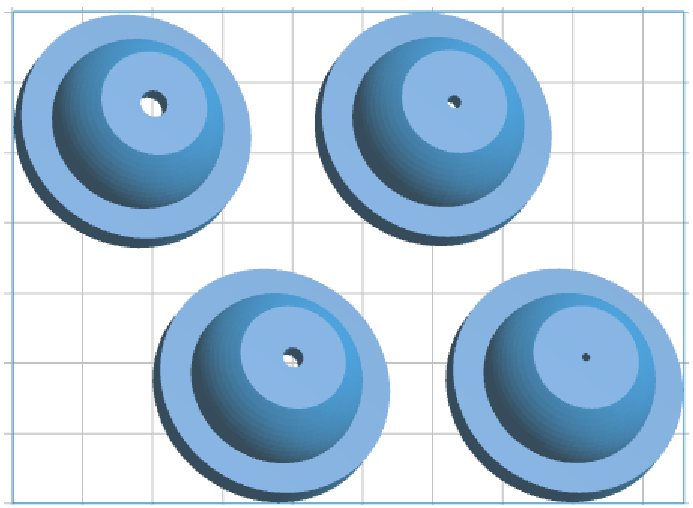
Experimental setup to record vocal-tract acoustic responses



Method

Acoustic experiment

- **On and off of laryngeal cavity resonance are controlled with different sizes of the hole of the glottal coupler**
  - 1.2-mm hole to simulate the closed glottis
  - 2.0-mm, 3.0-mm and 4.0-mm holes to simulate the open glottis

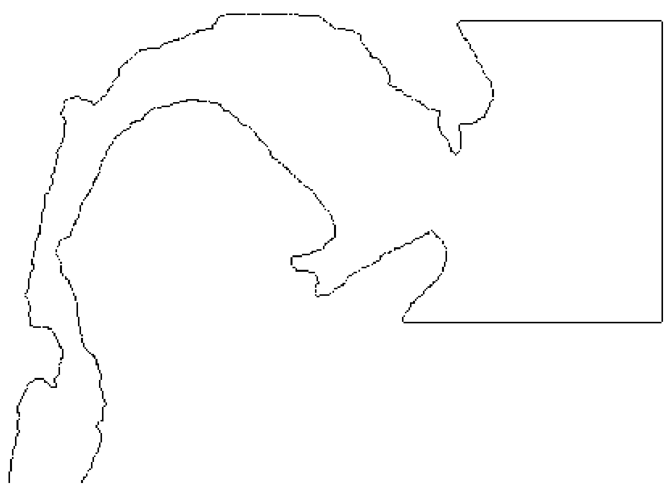


- **Spectral analysis**
  - Imai's cepstral method

Method

Simulation

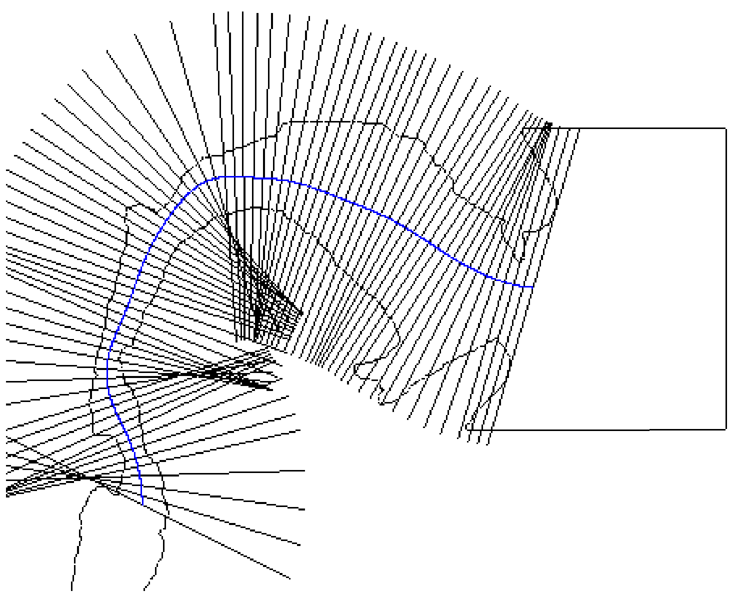
- ➢ **Examining calculated transfer functions of the vocal tract for comparison**
- ➢ **Area functions of the vocal tract**
  - Mid-sagittal vocal-tract images



Method

Simulation

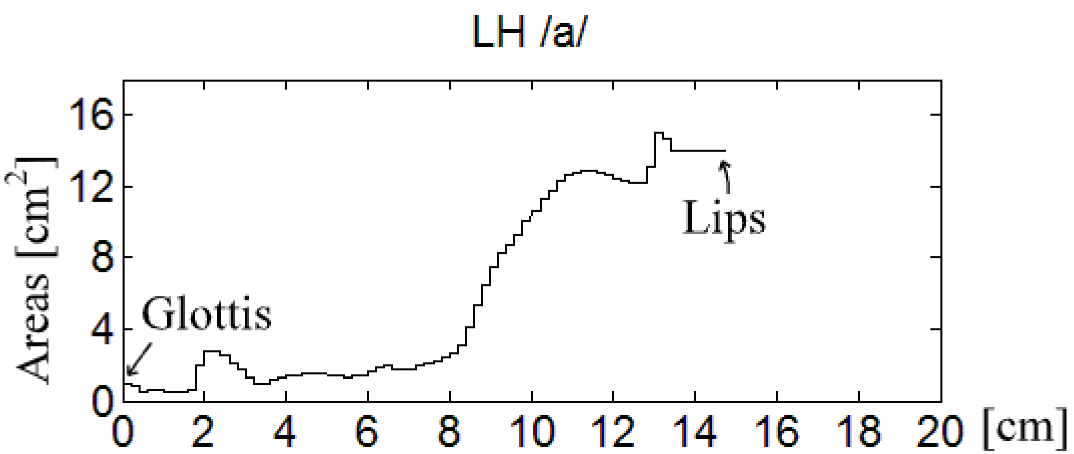
- **Examining calculated transfer functions of the vocal tract for comparison**
- **Area functions of the vocal tract**
  - Mid-sagittal vocal-tract images
  - Centroid points along vocal-tract midline and cross-sectional areas



Method

Simulation

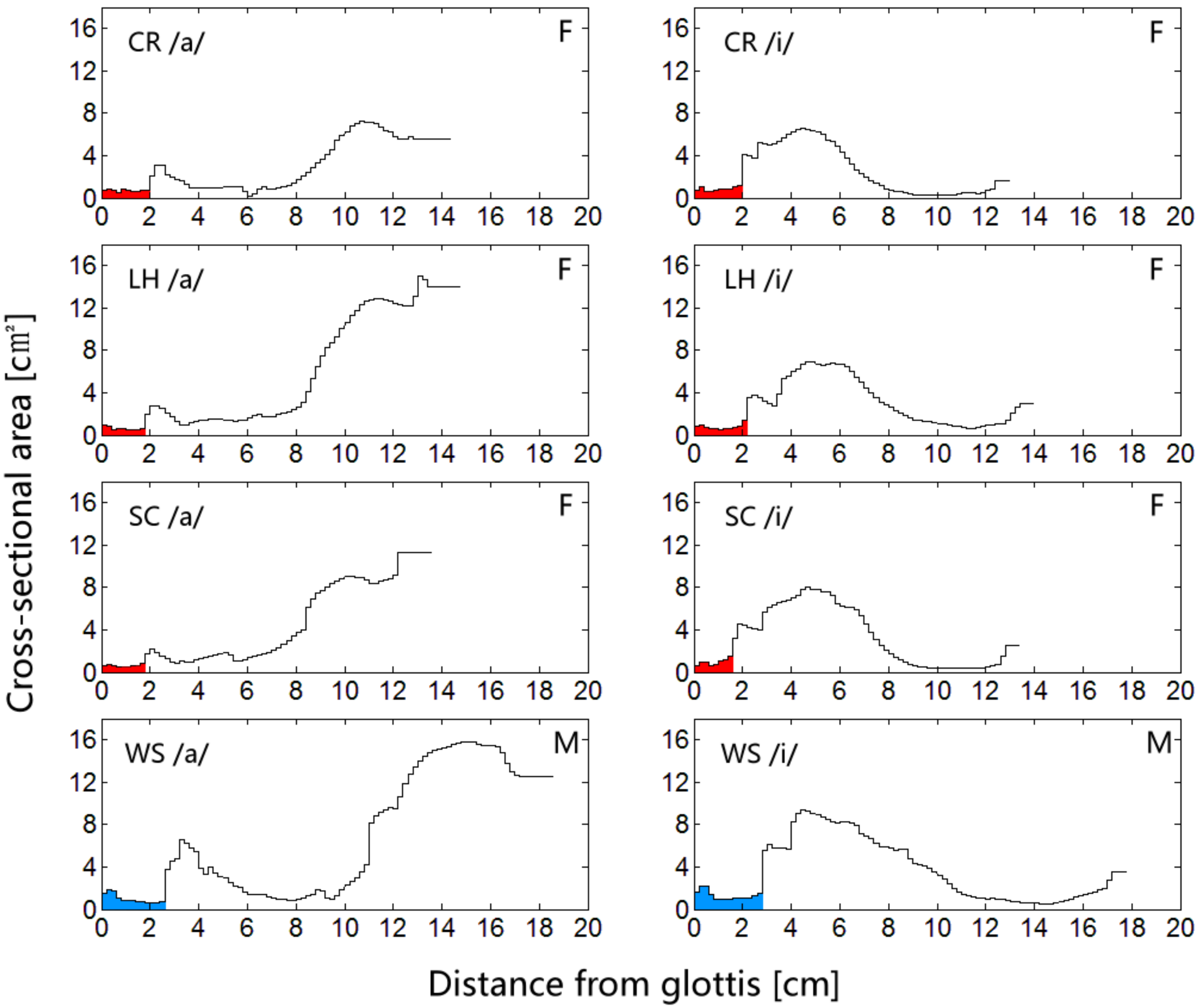
- **Examining calculated transfer functions of the vocal tract for comparison**
- **Area functions of the vocal tract**
    - Mid-sagittal vocal-tract images
    - Centroid points along vocal-tract midline and cross-sectional areas



- **Transfer functions**
    - Transmission line model

Result

Area functions of four subjects



Equal interval (0.2-mm) vocal tract area functions of vowels /a/ and /i/ for all the subjects. Red and blue regions indicate the laryngeal cavities.

F: Female
M: Male

Result

Evaluation of models' accuracy

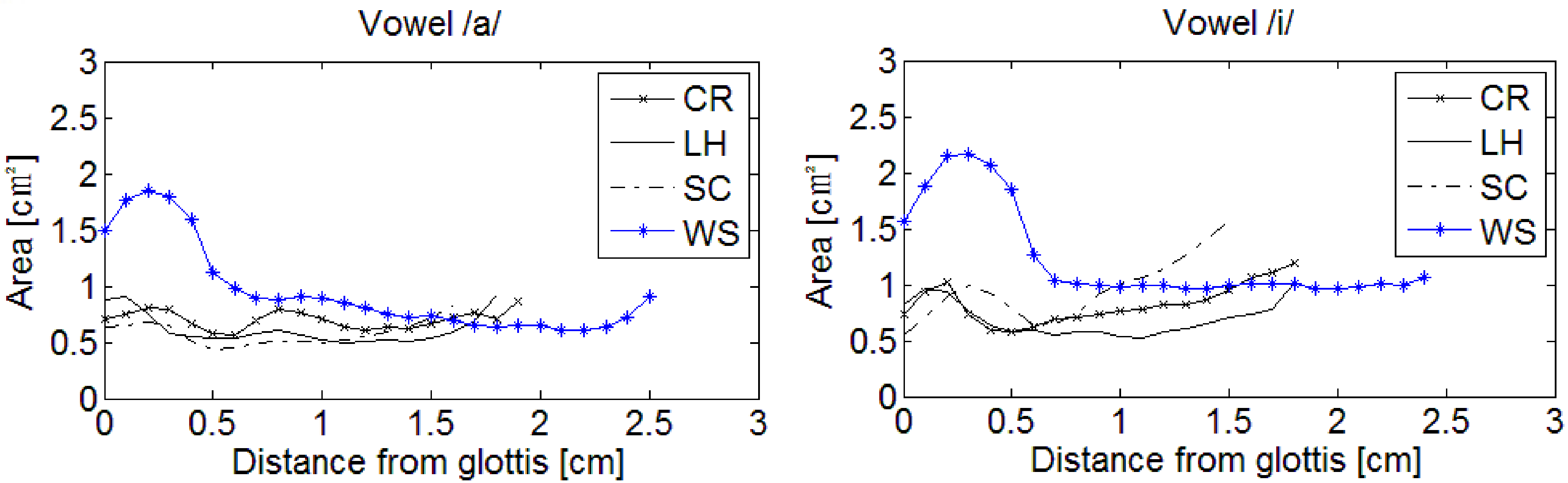
First to fourth formants (F1~F4) from the natural vowels and the transfer functions of the 3D vocal-tract models at vowels /a/ and /i/. "n" and "t" are natural and calculated formants, respectively. "e" is percent error between the two.

		CRa	LHa	SCa	WSa	CRi	LHi	SCi	WSi
Natural vowels	nF1	835	900	964	565	390	403	357	339
	nF2	1489	1441	1580	1102	3147	2634	2930	2104
	nF3	3518	3149	3264	2772	3687	3431	3997	2697
	nF4	4024	3855	3994	3391	4845	4410	5056	3416
Transfer functions	tF1	801	946	1036	611	346	441	321	311
	tF2	1441	1431	1656	1026	3171	2666	2926	2101
	tF3	3461	3026	3266	2606	3966	3416	4056	2691
	tF4	—	3716	3981	3686	4781	4186	4951	3136
Percent error	eF1	-4.1	5.1	7.5	8.1	-11.3	9.4	-10.1	-8.3
	eF2	-3.2	-0.7	4.8	-6.9	0.8	1.2	-0.1	-0.1
	eF3	-1.6	-3.9	0.1	-6.0	7.6	-0.4	1.5	-0.2
	eF4	—	-3.6	-0.3	8.7	-1.3	-5.1	-2.1	-8.2

Result

Morphological analysis

Equal interval (0.1-mm) laryngeal cavity area functions for vowels /a/ and /i/.



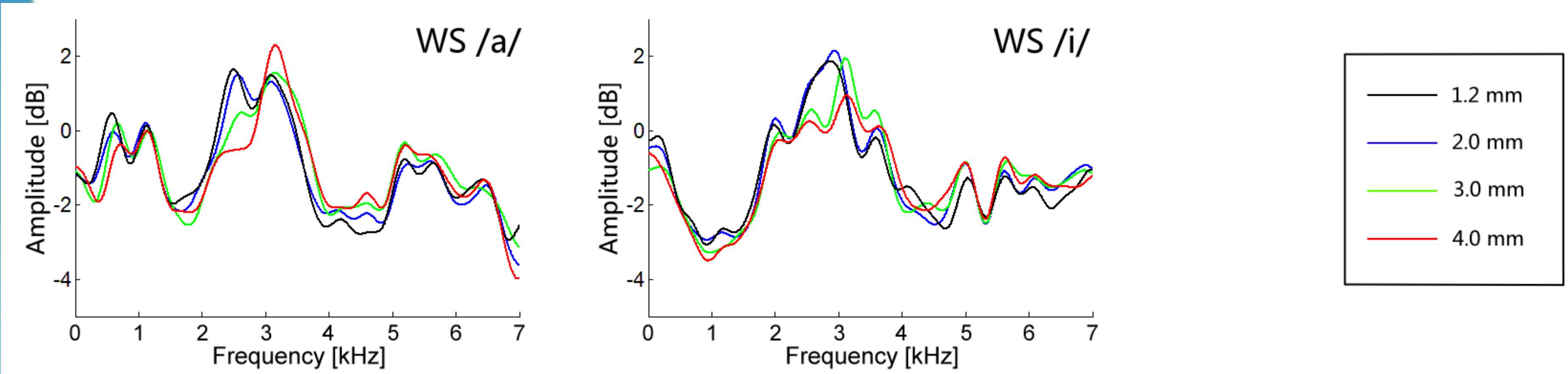
	CR(F)	LH(F)	SC(F)	WS(M)
$AVE_{ventricle}$	0.77	0.77	0.71	1.77
$STD_{ventricle}$	0.13	0.15	0.16	0.30
$AVE_{vestibule}$	0.75	0.61	0.78	0.88
$STD_{vestibule}$	0.16	0.12	0.32	0.16

Mean and standard deviation of the ventricle and vestibule areas (cm^2) for all the subjects.

F: Female
M: Male

Results of acoustic experiment

Vowel spectral with different glottal coupler hole size



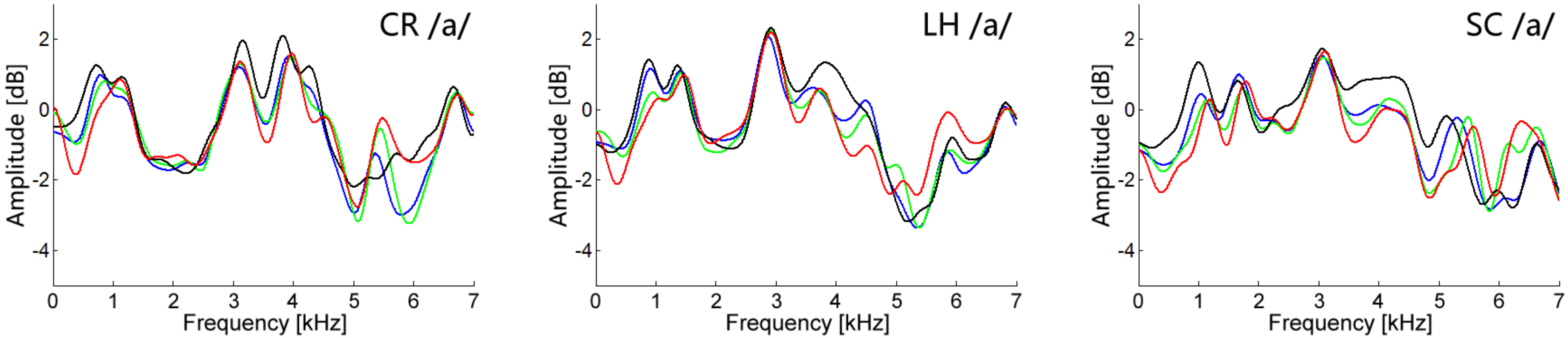
➢ **Male subject:**

- The primary differences are the spectral peaks at about 2.5-3 kHz.

Result

Results of acoustic experiment

Vowel spectral with different glottal coupler hole size



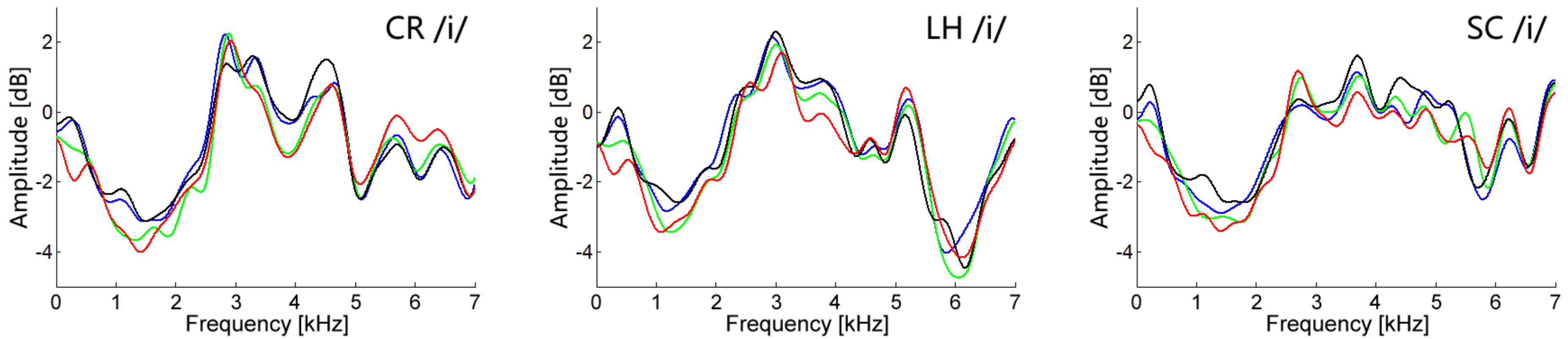
➢ **Female subjects' spectra in vowel /a/:**

	CR	LH	SC
Attenuation	3-4.5 kHz (2.0,3.0,4.0)	3-4.5 kHz (2.0,3.0,4.0)	3-5.5 kHz (2.0,3.0,4.0)
Amplification	5.5-6.5 kHz (4.0)	5.5-6.5 kHz (4.0)	5.5-6.5 kHz (3.0,4.0)

Result

Results of acoustic experiment

Vowel spectral with different glottal coupler hole size



- **Female subjects' spectra in vowel /i/:**

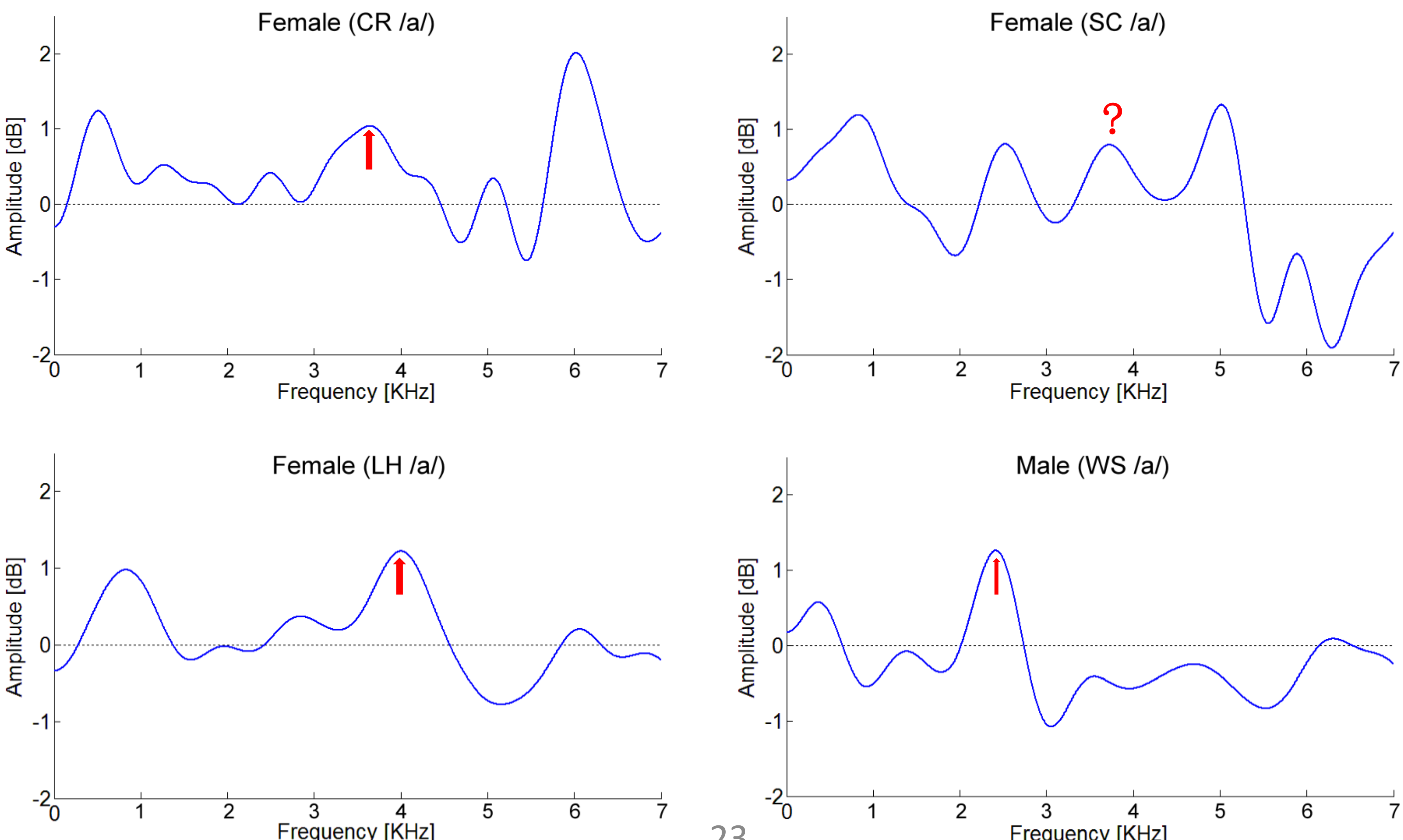
	CR	LH	SC
Attenuation	3-4.5 kHz (3.0,4.0)	3-4.5 kHz (3.0,4.0)	3-5.5 kHz (2.0,3.0,4.0)
Amplification	5.5-6.5 kHz (4.0)	—	—

Discussions and conclusion

- **Effect of the glottal aperture**
- **1.2-mm:**
  - Adequate for the closed glottis.
- **3.0-mm:**
  - Suitable to simulate the open glottis.
  - 2.0-mm glottal aperture was a little small to simulate the open glottis.
- **4.0-mm:**
  - Appears to cause the large effects on spectra in the wider frequency range.

Spectral subtraction

Spectral subtraction of 1.2-mm data minus 3.0-mm data



Discussions and conclusion

➢ Male subject:

- The frequency region of laryngeal cavity resonance was 2.5-3 kHz.
- It appears due to the large size of the subject's ventricle.

➢ Female subjects:

- The resonance frequency was in the region of 3-4.5 kHz, and the peak was broader.
- It may due to the uniform shape with the shorter length of the cavity.
- F1 region was deformed when glottal opening.

Future consideration

- The accurate geometry of females' small laryngeal cavities must be confirmed with the finer MRI experiment.

Thanks

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