

# Appearance and Disappearance of Laryngeal Cavity Resonance within a Glottal Cycle

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# Introduction

- The laryngeal cavity generates one of the formants.
- The formant is F4.

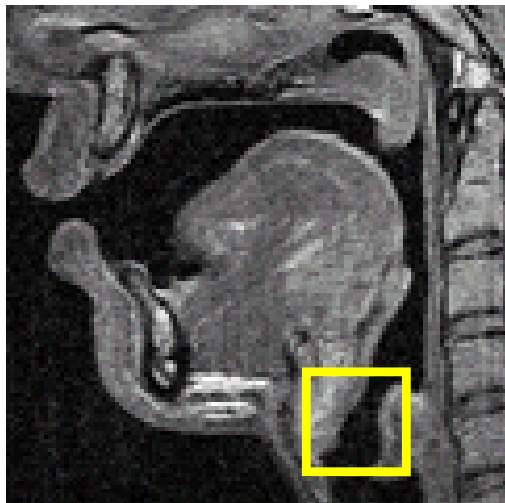


Fig. 1: Laryngeal cavity.

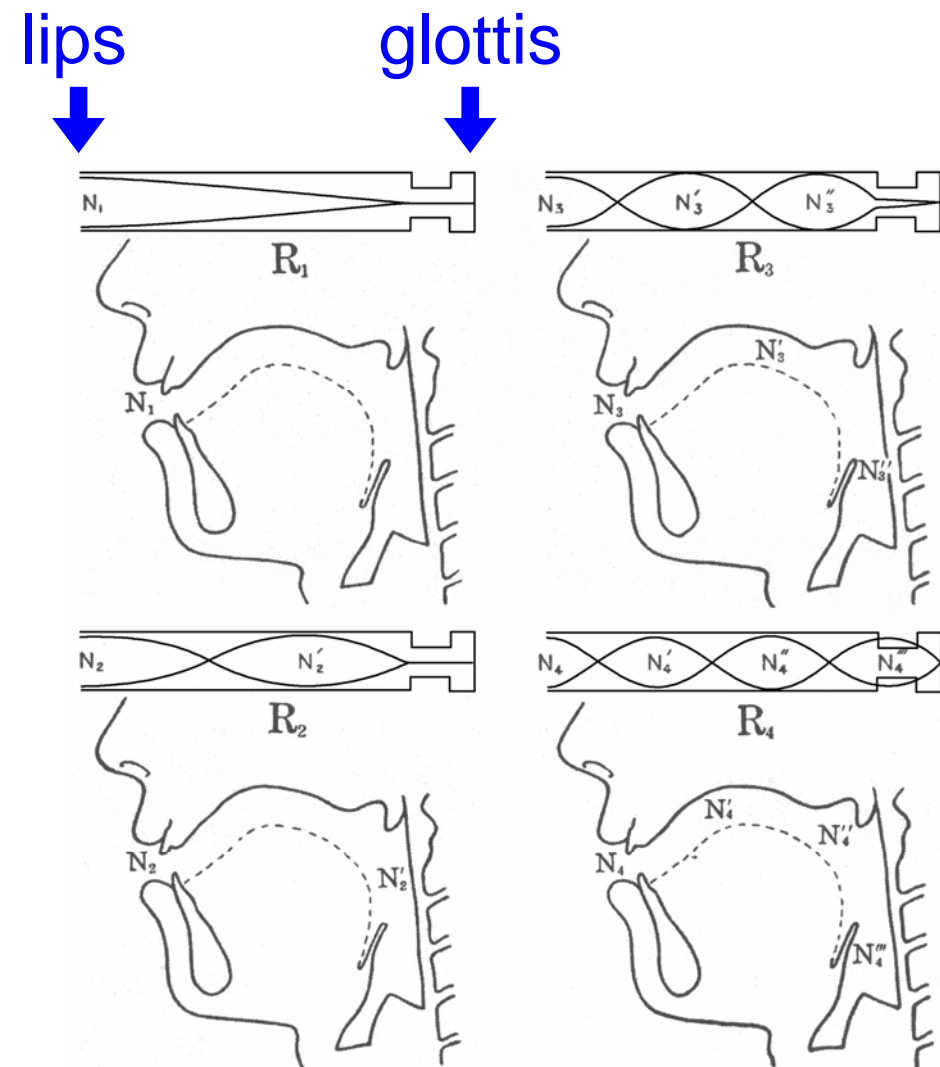


Fig. 2: The 1<sup>st</sup> to 4<sup>th</sup> resonance modes in the vocal tract (Takemoto *et al.*, 2006).

# Question

- The laryngeal cavity has been considered as a closed tube.
- But, the cavity is not a closed tube when the glottis opens.
- Is F4 affiliated with the laryngeal cavity stable during a glottal cycle?

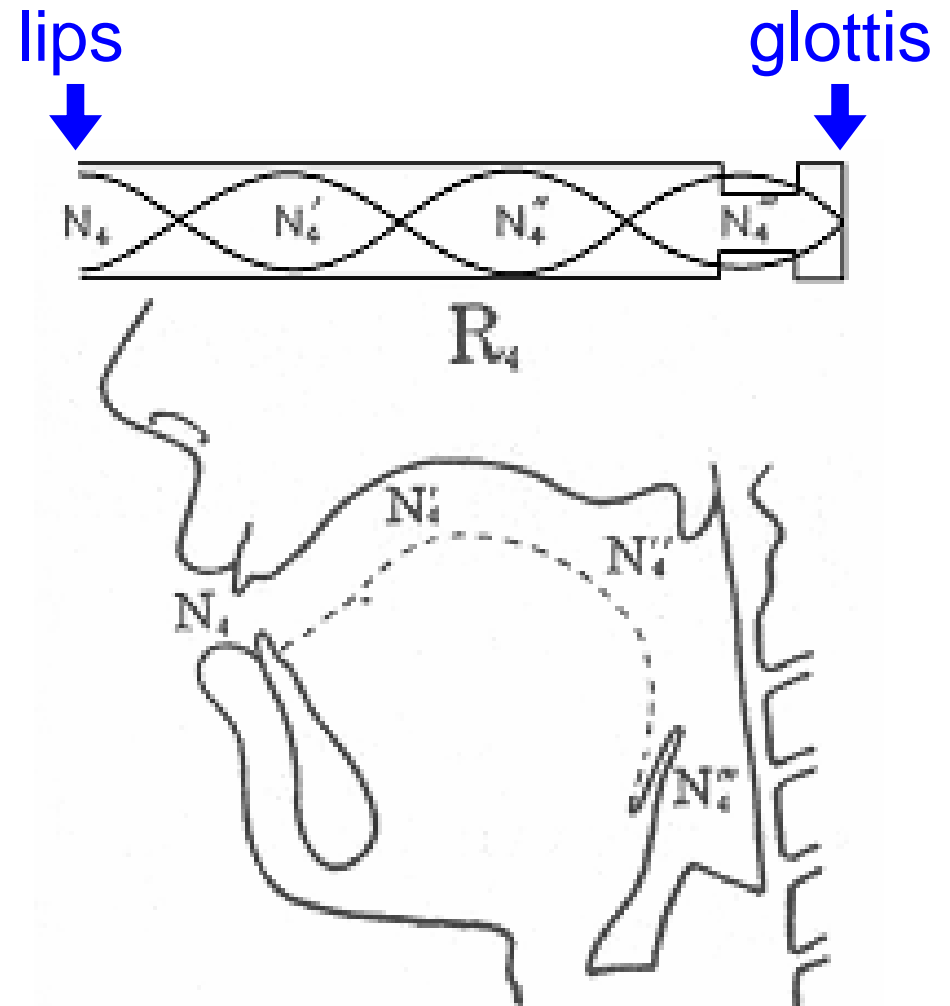


Fig. 3: The 4<sup>th</sup> resonance mode in the vocal tract.

# Previous studies

- When the glottis opens,
  - Bandwidths of the lower three formants are increased (Tarnoczy, 1962).
  - A higher damping of the first formant is observed (Fujimura and Lindqvist, 1971).
  - The frequencies and bandwidths of formants are increased, with the effect being greater at lower frequencies (Flanagan, 1972).

# Method

- Explore the effects of the open and closed glottis on the laryngeal cavity resonance during vocal fold vibration by
  1. Simulation using a transmission line model.
  2. Bandpass filter analysis of real speech.

# Simulation using transmission line model

- To estimate acoustic effects of glottal opening on the laryngeal cavity resonance.
- Vocal tract area functions (VTAFs)
  - Measured from 3D MR images of three Japanese male subjects A, B, and C.
  - The five Japanese vowels (/a/, /e/, /i/, /o/, and /u/).
- Calculate velocity-to-velocity transfer functions based on a frequency-domain transmission line model up to 5 kHz.

# Conditions

1. Closed-glottis condition:  $A_g=0.0 \text{ cm}^2$

glottal impedance  $Z_g = \infty$

2. Open-glottis condition:  $A_g=0.2 \text{ cm}^2$

$$Z_g = R_g + j\omega L_g$$

viscosity coefficient  $\mu$ , depth of the glottal slit  $d_g$ , length of the glottal slit  $l_g$ , air density  $\rho$ , subglottal pressure  $p_0$

$$= \left( \frac{12\mu d_g l_g^2}{A_g^3} + \frac{0.875}{A_g} \sqrt{2p_0\rho} \right) + j\omega \frac{\rho d_g}{A_g}$$

(Ishizaka and Flanagan, 1972; Flanagan, 1972)

3. Vocal tract proper

- Vocal tract excluding the laryngeal cavity.
- Closed-glottis condition.

# Parameters

- viscosity coefficient  $\mu$  :  $1.88 \times 10^{-5}$  kg/(sec·m)
- depth of the glottal slit  $d_g$  : 3 mm
- length of the glottal slit  $l_g$  : 18 mm
- subglottal pressure  $p_0$  : 10 cmH<sub>2</sub>O
- air density  $\rho$  : 1.12 kg/m<sup>3</sup>



# Results for subject A

blue line: closed-glottis condition  
red line: open-glottis condition  
black line: vocal tract proper

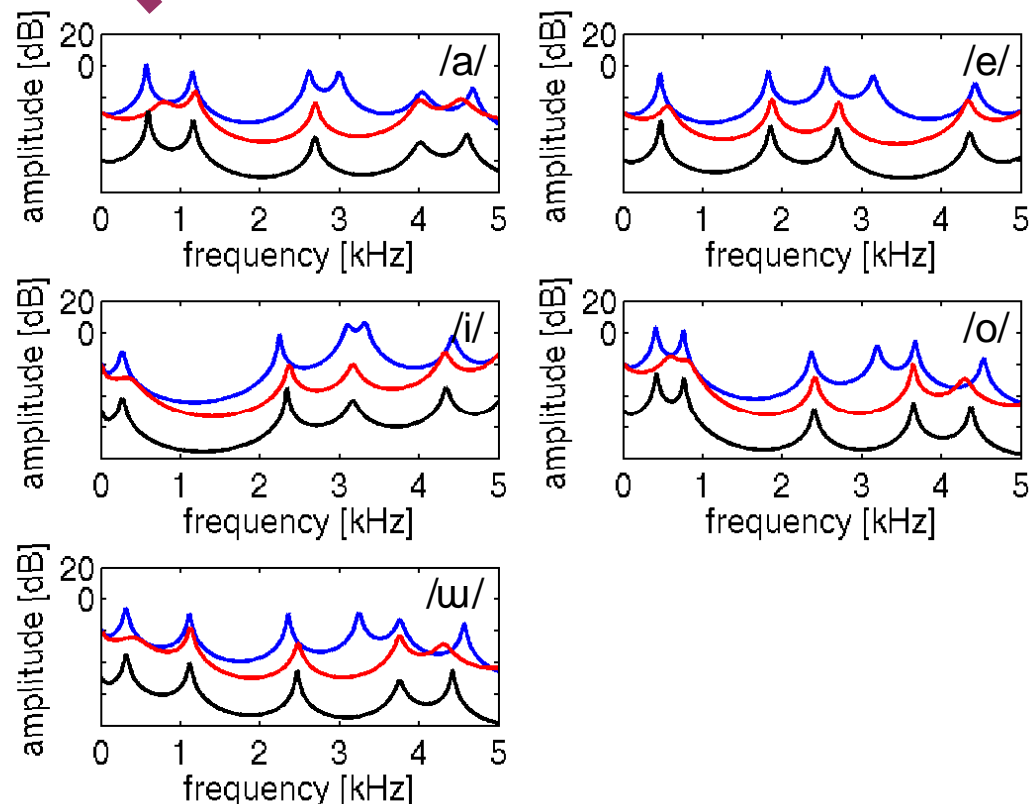
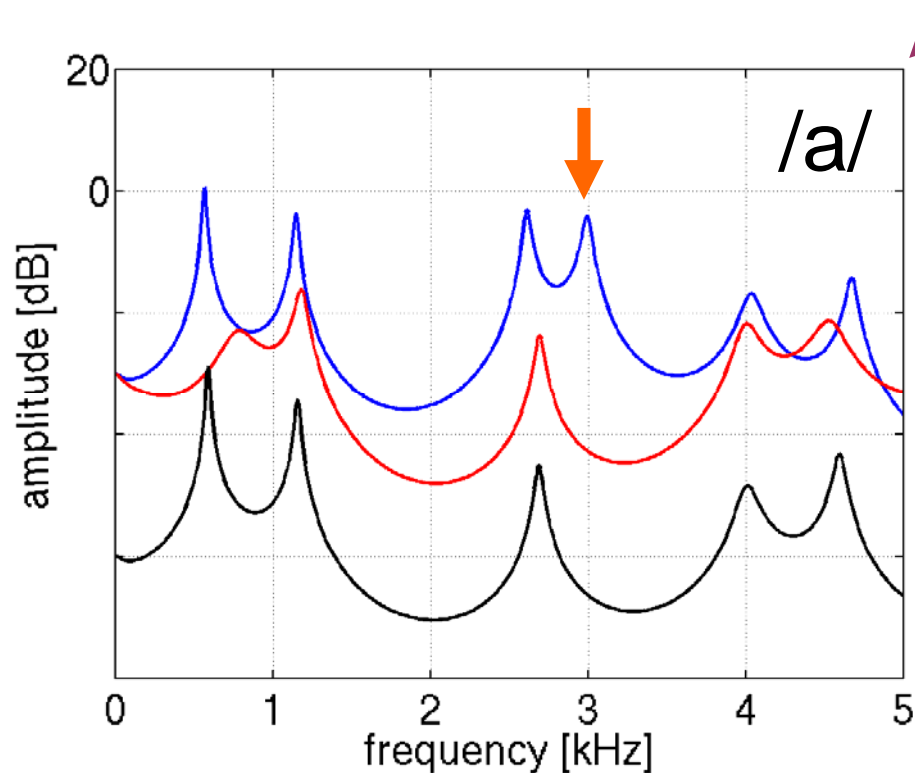


Fig. 4: Velocity-to-velocity transfer functions with the three conditions for the Japanese five vowels from subject A.

# Results for subjects B and C

blue line: closed-glottis condition  
red line: open-glottis condition  
black line: vocal tract proper

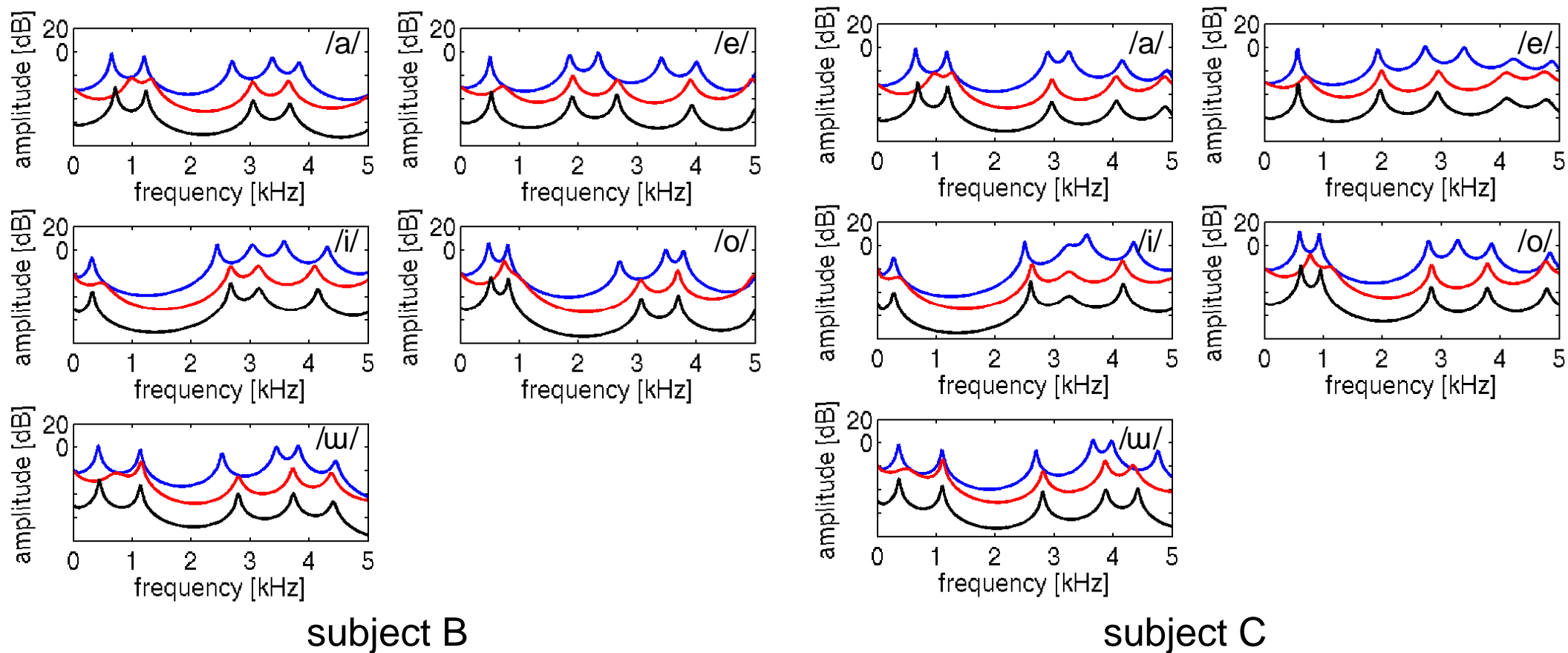
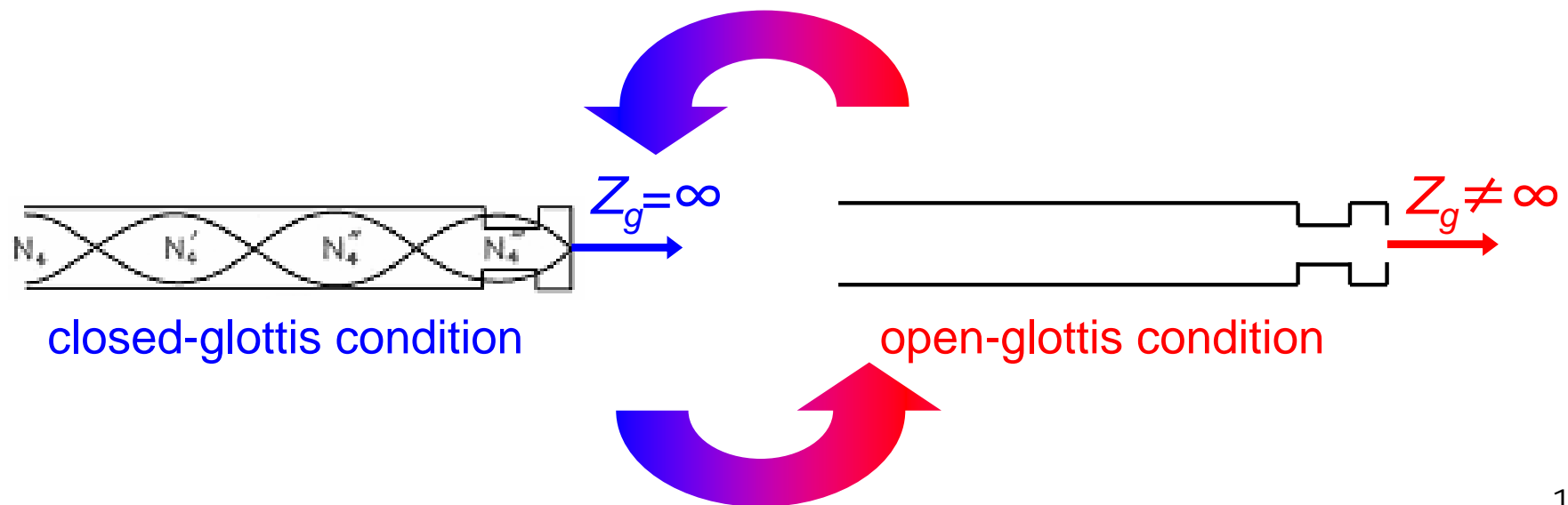


Fig. 5: Transfer functions with the three conditions for the Japanese five vowels from subjects B and C.

# Discussion

- One of the formants appears in the closed-glottis state and disappears in the open-glottis state.
  - This formant disappears on the transfer functions of the vocal tract proper.
- The formant is the laryngeal cavity resonance.



# Discussion

The transfer functions for the open-glottis condition.

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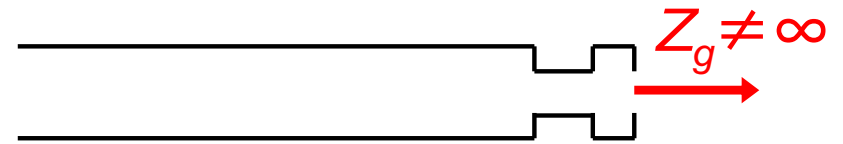
Those of the vocal tract proper.



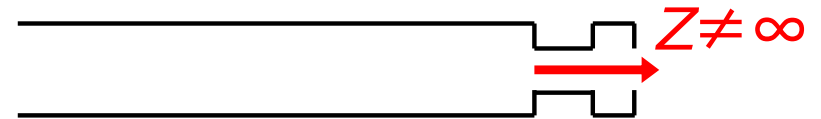
The vocal tract for the open-glottis condition.

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The vocal tract proper with a large loss at its closed end.



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# Transfer functions for the vowel /a/

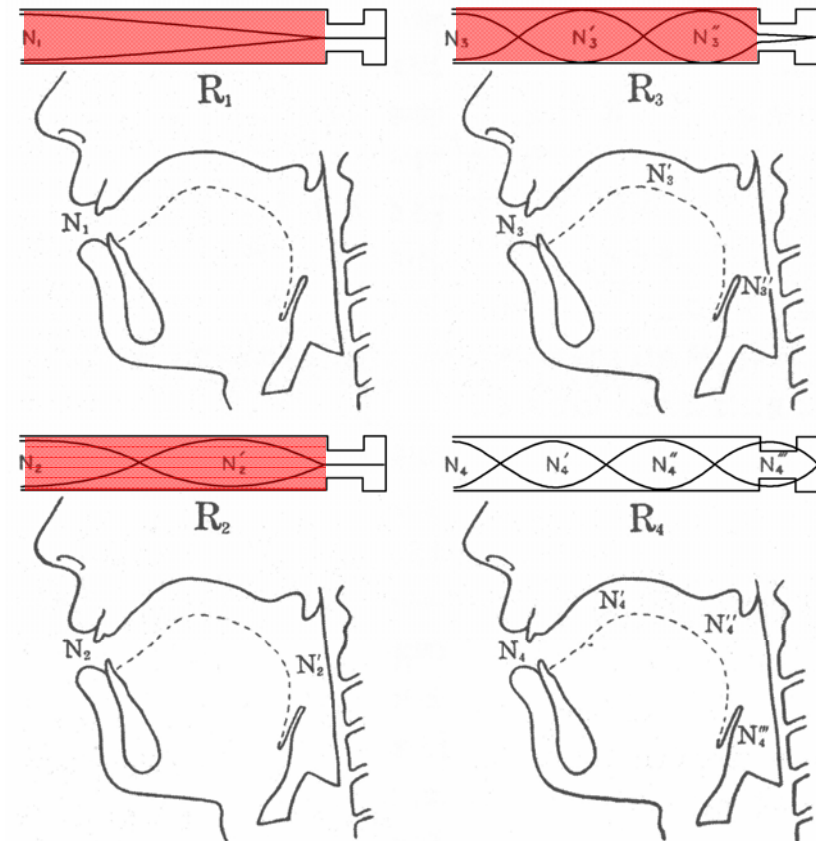
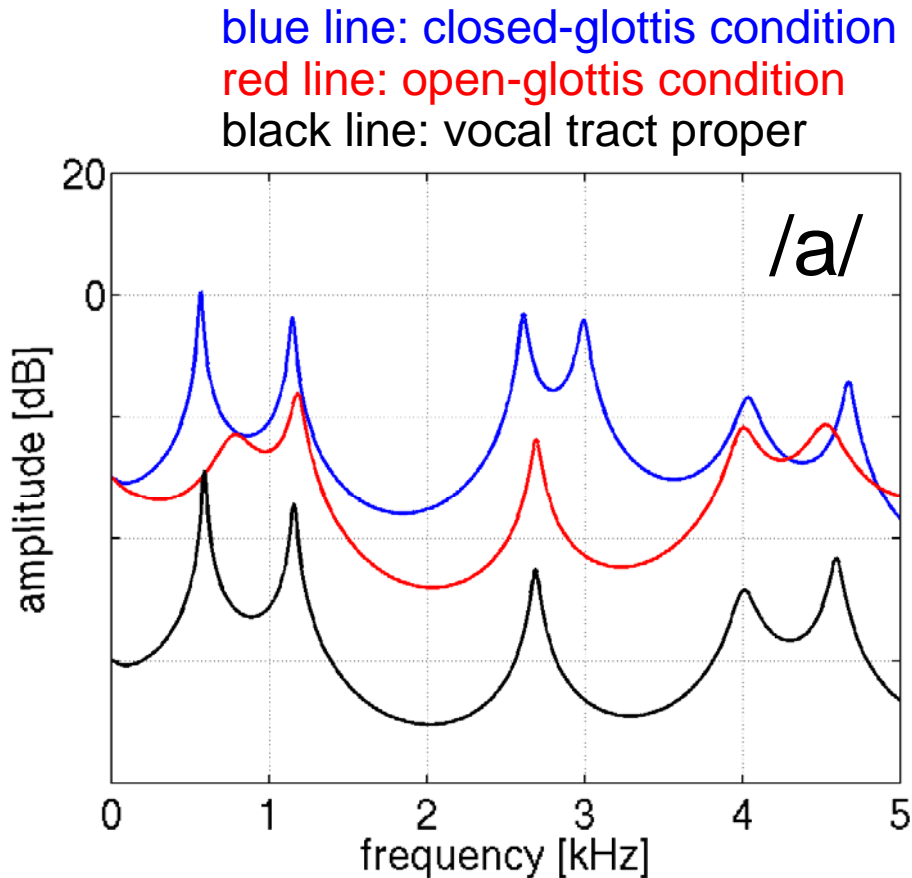


Fig. 6: Transfer functions with the three conditions for the vowel /a/ from subject A.

Fig. 1: The 1<sup>st</sup> to 4<sup>th</sup> resonance modes in the vocal tract.

# Bandpass filter analysis

- To extract the time-pattern of the laryngeal cavity resonance.
- Speech data
  - The sustained vowels /a/ and /i/ for the subjects.
- FIR bandpass filters (BPF)
  - designed by the window method
  - the passbands of the BPFs includes the subjects' F2, F3, F4 (the laryngeal cavity resonance), and F5.
  - the bandwidth of all the BPF is 0.4 kHz.

# Speech data

- The five vowels of the three subjects.
- Steady phonation.
- Recorded in an anechoic room at sampling rate of 48 kHz with 16-bit resolution.
- Electroglottograph (EGG) waveforms were recorded simultaneously to *estimate* open- and closed-glottis periods.
- The time lag between the speech and EGG waveform was compensated.

# Passband

Table 2. BPF passbands including the subjects' F2, F3, F4, and F5. The bandwidth of all bandpass filters is set to 0.4 kHz.

subject	vowel	F2	F3	F4	F5
KH	/a/	0.90-1.30 kHz	2.05-2.45 kHz	2.90-3.30 kHz	3.25-3.65 kHz
	/i/	1.90-2.30 kHz	2.75-3.15 kHz	3.05-3.45 kHz	3.40-3.80 kHz
TI	/a/	0.95-1.35 kHz	2.40-2.80 kHz	3.30-3.70 kHz	3.95-4.35 kHz
	/i/	2.00-2.40 kHz	2.70-3.10 kHz	3.40-3.80 kHz	3.55-3.95 kHz
YT	/a/	0.80-1.20 kHz	2.60-3.00 kHz	3.15-3.55 kHz	3.40-3.80 kHz
	/i/	2.00-2.40 kHz	2.80-3.20 kHz	3.20-3.60 kHz	3.80-4.20 kHz



# Results

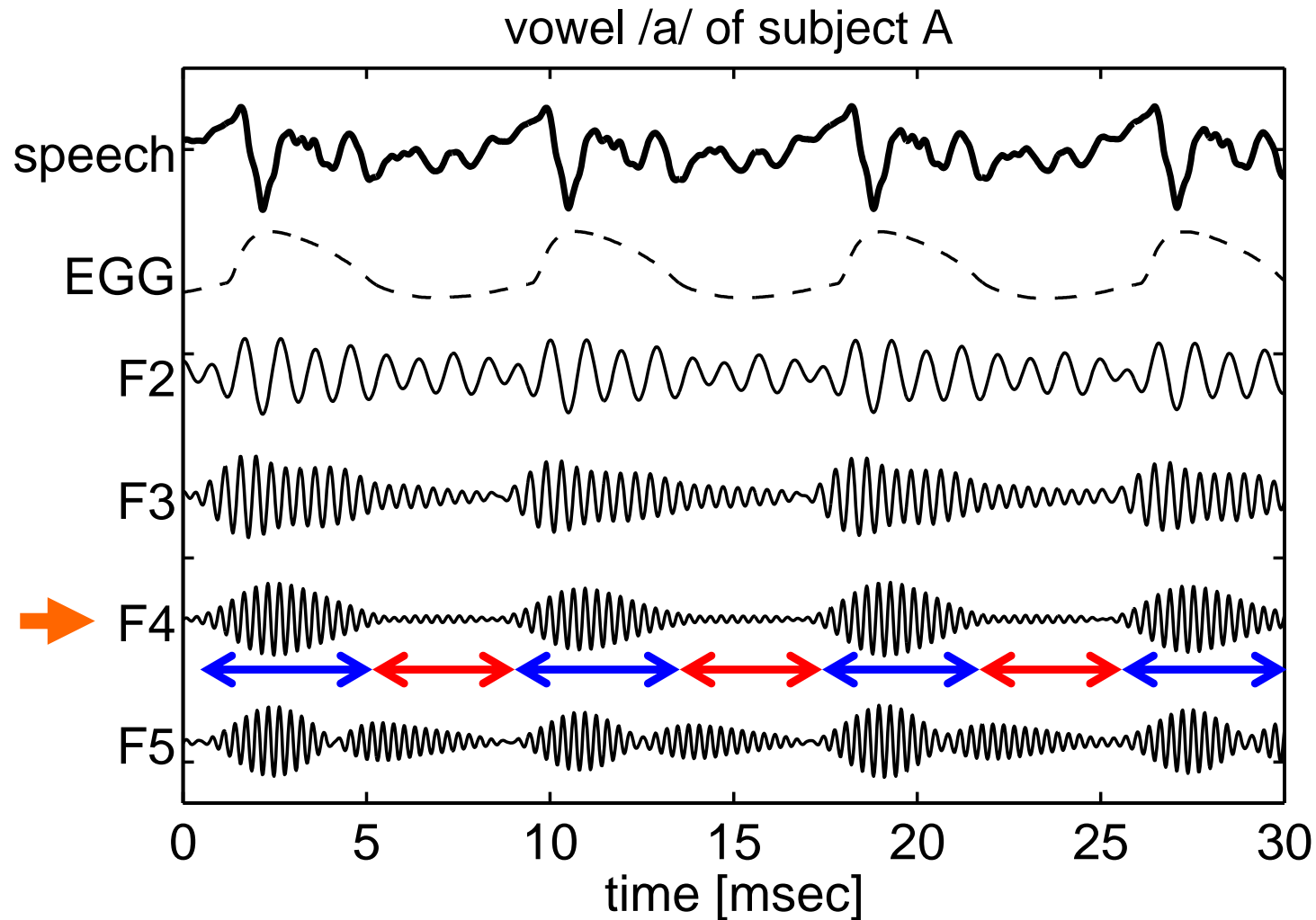


Fig. 7: Outputs of BPFs for with the passband includes F2, F3, F4, and F5 for sustained vowel /a/.

# Results

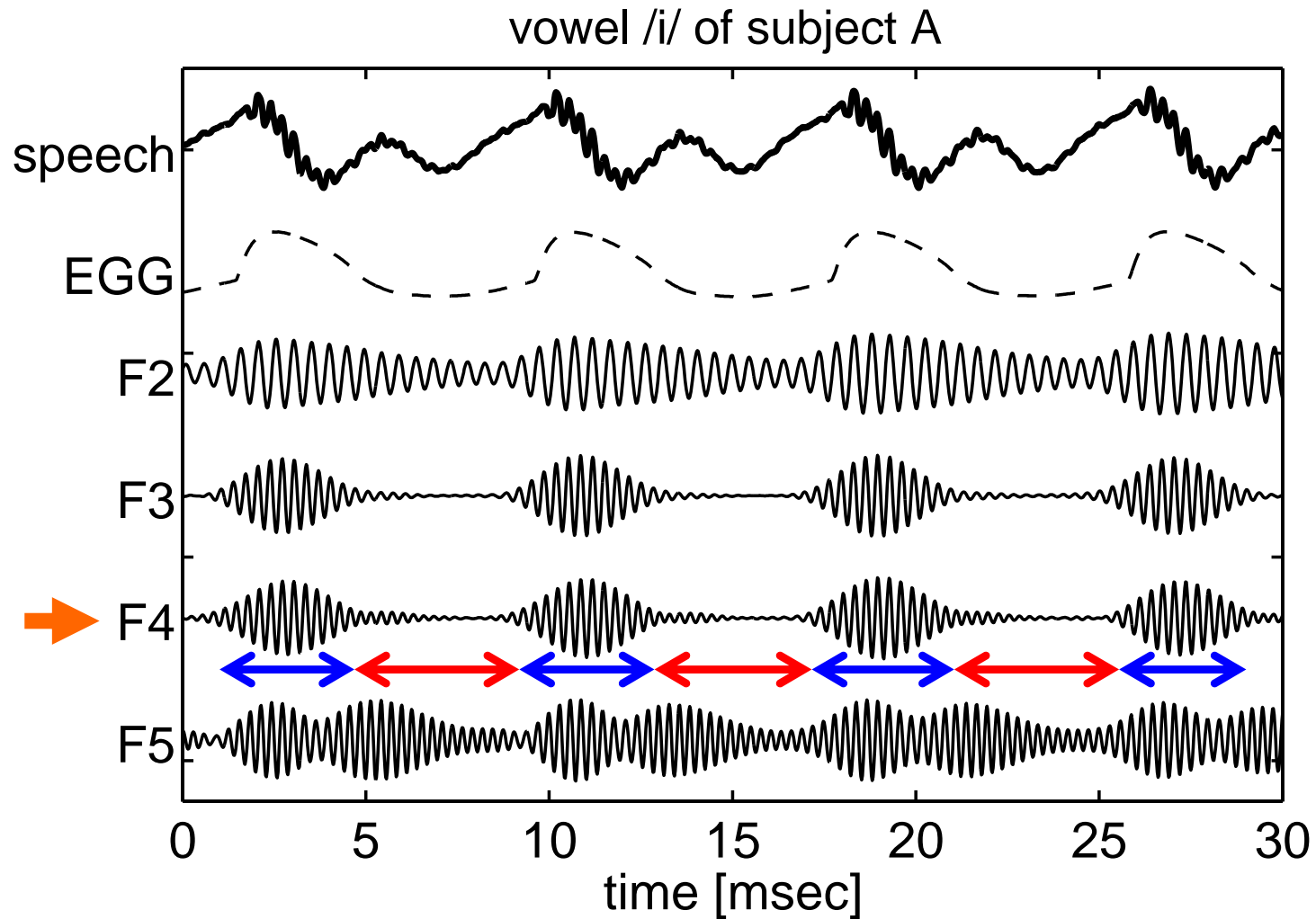


Fig. 8: Outputs of BPFs for with the passband includes F2, F3, F4, and F5 for sustained vowel /i/.

# Results

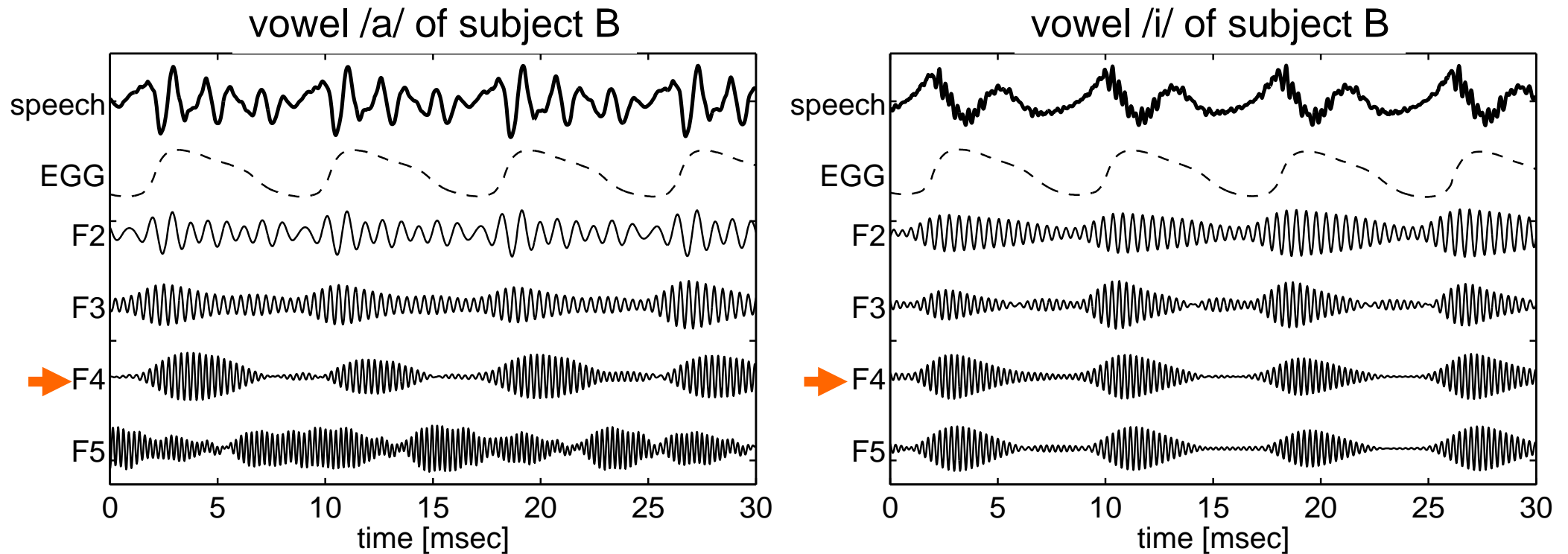


Fig. 11: Outputs of BPFs for with the passband includes F2, F3, F4, and F5 for sustained vowels /a/ and /i/.

# Results

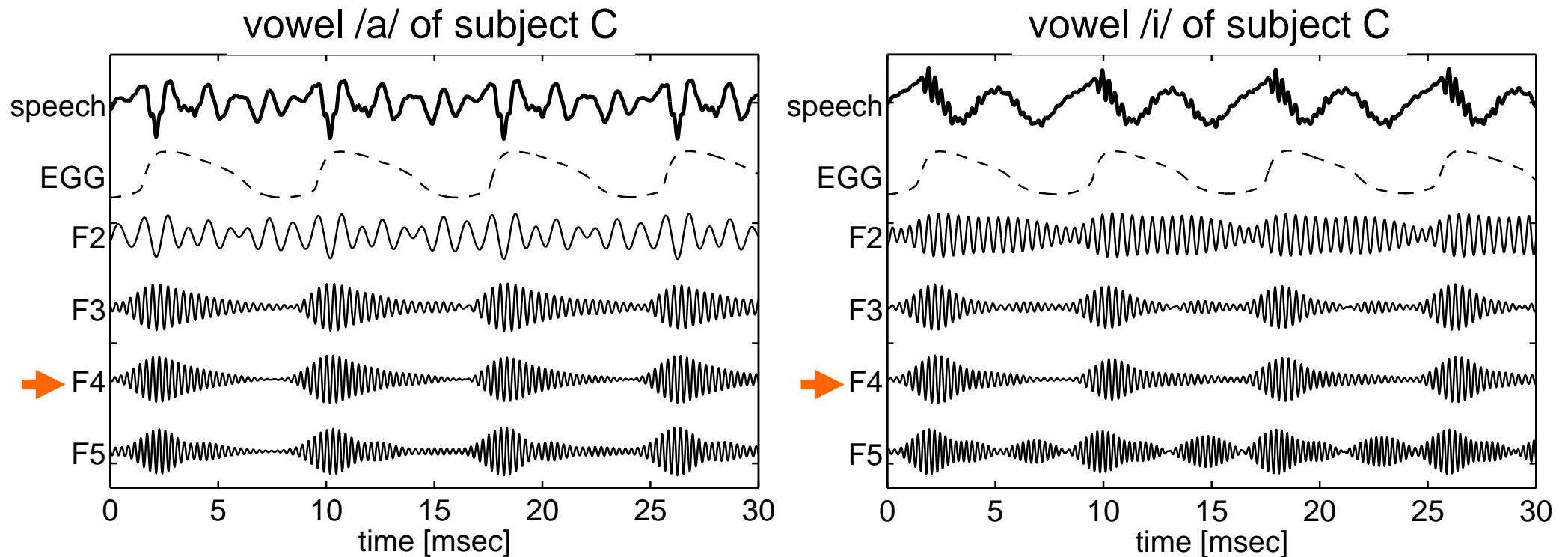


Fig. 12: Outputs of BPFs for with the passband includes F2, F3, F4, and F5 for sustained vowels /a/ and /i/.

# Conclusion

- One of the formants (the laryngeal cavity resonance)
  - appears during the closed-glottis periods
  - disappears during the open-glottis periods
- The laryngeal cavity
  - acts as a closed tube to generate the resonance when the glottis is closed.
  - damps the resonance off when the glottis opens.



# Pitch-synchronous short-term spectral analysis

- To explore the cyclicity of the laryngeal cavity resonance due to the glottal vibration for vowels.
- Method
  - Estimate power spectral densities (PSDs) during glottal open and closed periods by **Burg's method**.
  - PSDs were obtained from AR model parameters averaged over five successive periods.
  - AR model order  $p$  was chosen to minimize the minimum description length (Rissanen, 1983).

$$MDL[p] = N \ln(\hat{\rho}_p) + p \ln(N)$$

$N$  the number of data samples

$\hat{\rho}_p$  estimated white noise variance

# PSDs for subject A

blue line: closed-glottis period  
red line: open-glottis period

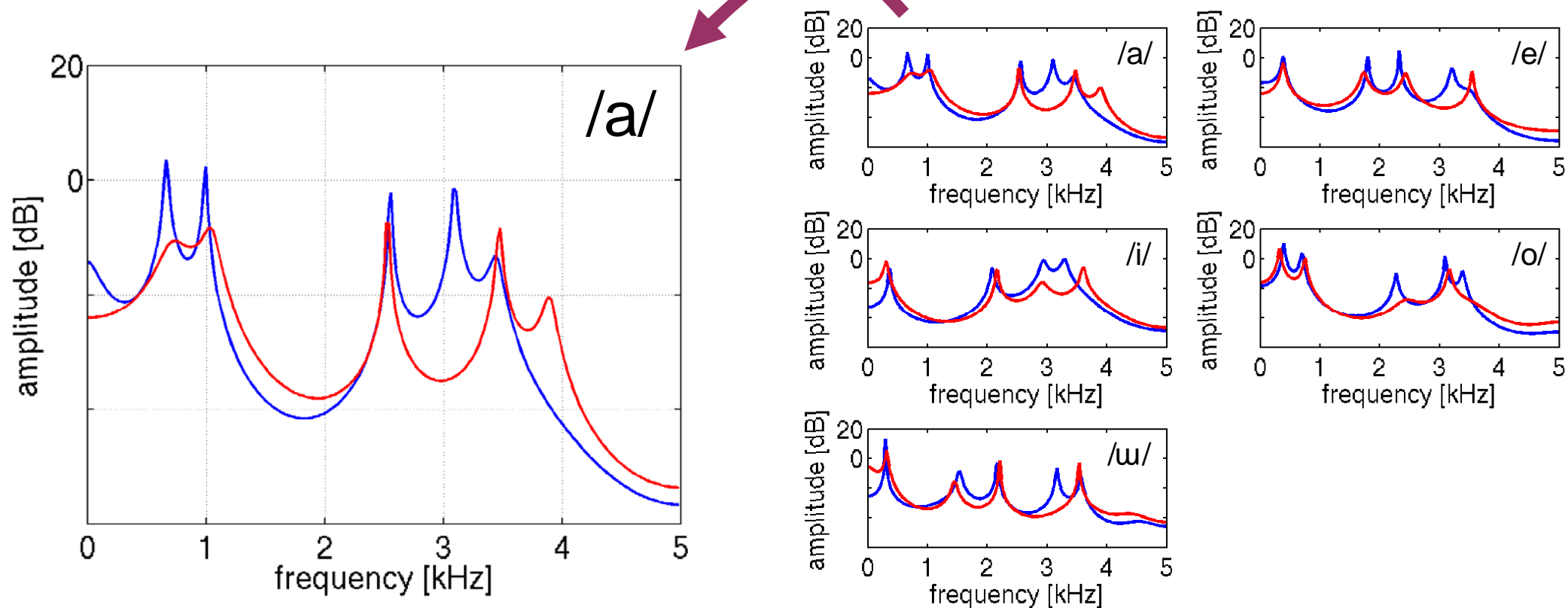


Fig. 6: Power spectral densities of closed- and open-glottis periods for the Japanese five vowels from subject A.



# PSDs for subjects B and C

blue line: closed-glottis period  
red line: open-glottis period

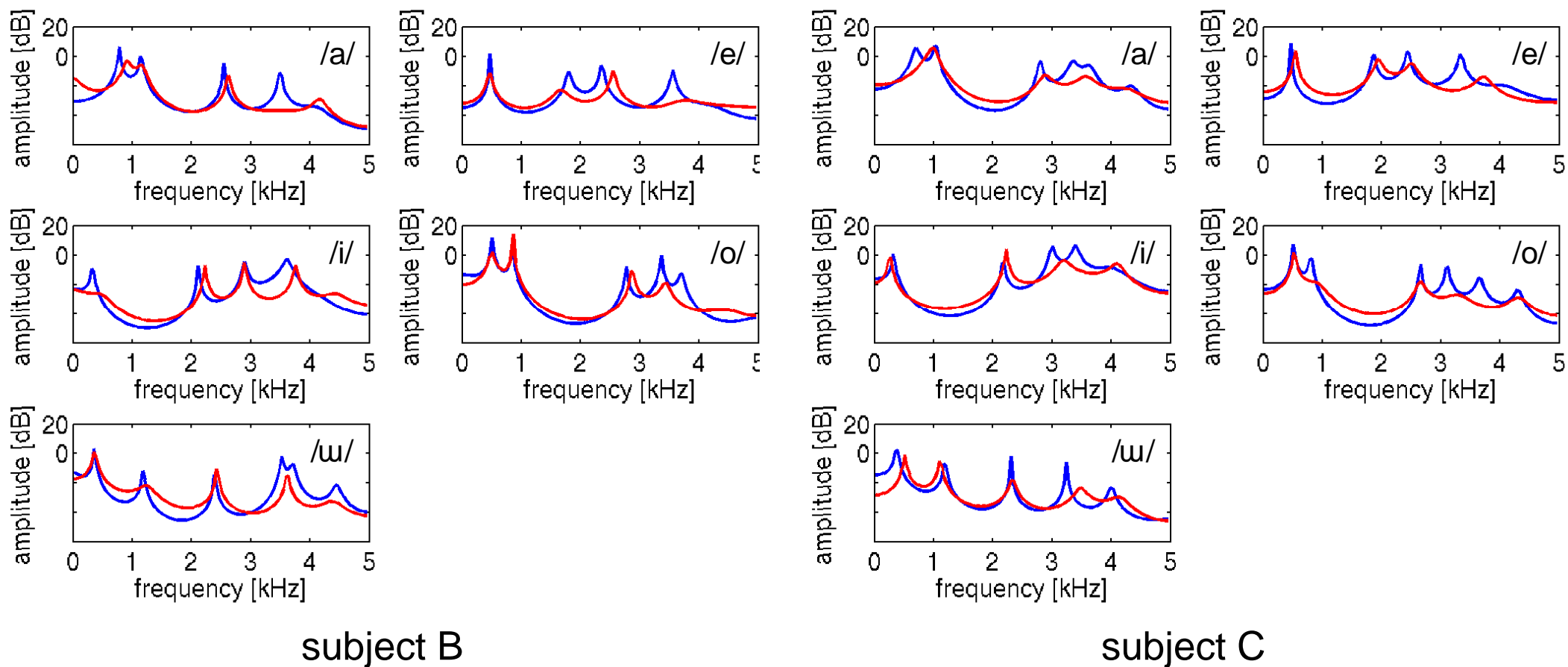


Fig. 10: PSDs of open- and closed-glottis periods for the Japanese five vowels from subjects B and C.

# AR model order

Table 1. Model order for short-term spectral analysis for open- and closed-glottis period of vowels optimized by minimizing the minimum description length.

subject	glottal condition	/a/	/e/	/i/	/o/	/u/
KH	closed	13	12	10	11	14
	open	11	10	11	11	13
TI	closed	11	10	13	12	13
	open	11	10	11	11	11
YT	closed	14	11	13	13	12
	open	11	10	10	10	10