

A practical introduction to acoustic phonetics day 3: Vowels

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The acoustic theory of speech production (once again)

- The speech signal is generated by vocal tract filtering of a *source* sound
- Hence *source-filter* theory of sound production
- Sound sources in speech production:
 - ◆ Vocal fold vibration (voicing)
 - ◆ Turbulence noise produced at the glottis/in the larynx/pharynx (whisper)
 - ◆ Turbulence noise generated elsewhere (plosive releases, fricatives)

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Vocal tract filtering

- Some components of the voice source (or noise source) spectrum are enhanced because they correspond to *resonance frequencies* of (parts of) the vocal tract
- These resonance frequencies change when the shape of the vocal tract changes, leading to different sound qualities
- In vowels (and sonorant consonants) these resonances, which manifest themselves as broad peaks in the power spectrum, are commonly known as *formants*

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Resonances in the vocal tract

- With a neutral configuration (no constrictions at any point) the vocal tract can be approximated as a single tube with a single set of resonances
- The constricted vocal tract can be approximated using a model consisting of two tubes, each with its own set of resonances
- To understand how vocal tract resonances arise it is important to understand a few things about *standing waves*

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Resonant frequencies ($t = 1 - t = 4$)

+			
0	+		
-	0	+	
0	-	0	+
			-

Resonant frequencies ($t = 5 - t = 8$)

+	0	-	0
		-	0
0	+	0	-
	-	0	+
-	0	+	0
-	0	+	0
0	-	0	+
0	+	0	-

Resonant frequencies ($t = 9 - t = 12$)

+	0	-	0
+	0	-	0
0	+	0	-
0	-	0	+
-	0	+	0
-	0	+	0
0	-	0	+
0	+	0	-

Resonant frequencies ($t = 13$)

+	0	-	0
+	0	-	0

Non-resonant frequencies ($t = 1 - 4$)

+

-	+
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+	-	+
---	---	---

-	+	-	+
			-

Non-resonant frequencies ($t = 5 - 8$)

+	-	+	-
		-	+

-	+	-	+
	-	+	-

+	-	+	-
-	+	-	+

-	+	-	+
+	-	+	-

Non-resonant frequencies ($t = 9 - 12$)

+	-	+	-
-	+	-	+

-	+	-	+
+	-	+	-

+	-	+	-
-	+	-	+

-	+	-	+
+	-	+	-

Non-resonant frequencies ($t = 13$)

+	-	+	-
-	+	-	+

Resonances of tubes closed at one end and open at the other

- The lowest resonance of a tube that's closed at one end and open at the other has a wavelength of 4 times the length of the tube L
- Higher resonances λ_n occur at $\frac{4}{(2n-1)}L$, where n is the resonance number ($\frac{4}{3}, \frac{4}{5}, \frac{4}{7}, \frac{4}{9}$)
- As the frequency of a wave travelling in a medium depends on the propagation speed c , the frequency of the first resonance is $\frac{c}{\lambda_1} = \frac{c}{4L}$

Resonances of tubes closed at one end and open at the other

- More generally: $\frac{(2n-1)c}{4L}$, which yields higher resonances at odd integer multiples of the first resonance: $F_2 = 3F_1$, $F_3 = 5F_1$, etc.

Schwa – ə

- Given the speed of sound in air (atmospheric pressure; 20° C) of approximately 35,000 cm/s
- and a vocal tract of 17.5 cm
- we get $F_1 = \frac{35,000}{70} = 500\text{Hz}$ for the vowel [ə]
- ... an F_2 of 1,500 Hz, and an F_3 of 2,500 Hz

Two-tube models of vowel production

- Vowels that are characterised by a (modest) constriction somewhere in the vocal tract can be approximated using **two-tube models**
- The back tube or cavity represents the portion of the vocal tract behind the constriction
- The front cavity represents the portion of the vocal tract in front of the the constriction
- Each of these cavities produce their own set of resonances, in addition to the **Helmholtz resonance** that arises from the **coupling** of the two cavities

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