Project: Agent-Based Simulation of Anatomical Biases using VTL
Content: Definition of the Canonical Vowels of the Training Set

Number	Text Label	IPA	Cardinal Number	avg. F1	avg. F2	avg. F3	avg. F4	Notes
1	i	[i]	1	249	2387	2961	3335	
2	I	[ɪ]	-	437	1867	2635	3571	
3	y	[y]	9	243	2039	2406	3056	
4	Y	[ʏ]	-	349	1895	2585	3154	
5	e	[e]	2	417	2100	2688	3497	
6	E	[ɛ]	3	576	1808	2602	3527	
7	oe	[ø]	10	442	1805	2366	3097	
8	OE	[œ]	11	503	1703	2366	3166	
9	ae	[æ]	-	691	1752	2582	3625	
10	u	[u]	8	300	497	2784	3099	
11	U	[ʊ]	-	458	909	2575	3495	
12	o	[o]	7	394	546	2581	3033	
13	O	[ɔ]	6	466	655	2590	3177	
14	a	[ɑ]	5	645	816	2738	3328	
15	i-	[ɨ]	17	360	1241	3062	3899	
16	schwa	[ə]	-	545	1184	2482	3107	
17	er	[ɚ]	-	453	1222	1409	2633	double bunched R
18	r	[ɹ]	-	514	1025	1370	2935	tongue tip up R

Method:
The list of vowels was recorded three times by Scott Moisik. Each vowel was produced for approximately 2 seconds. The vowel spectra were obtained from 1 second windows positioned during the most stable portion of each vowel. Vowel formants were calculated using PRAAT over comparable ~1 second windows; averages of these were then obtained. Some manual measurement of F3 and especially F4 was necessary. The vowels were then recreated in VTL through manual adjustment of the free parameters in the context of the 'default' VTL anatomy (see Rick Janssen). The recreated vowels thus represent reasonable approximations based (primarily) on acoustic criteria. Images of the 2D VTL state are provided for reference and the VTL parameters are listed for each vowel. (Note: All formant values given in Hz.)
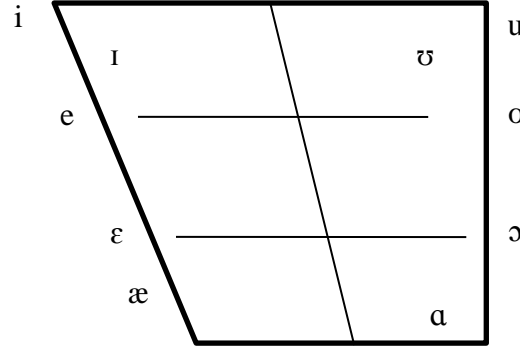
Vowel Sets
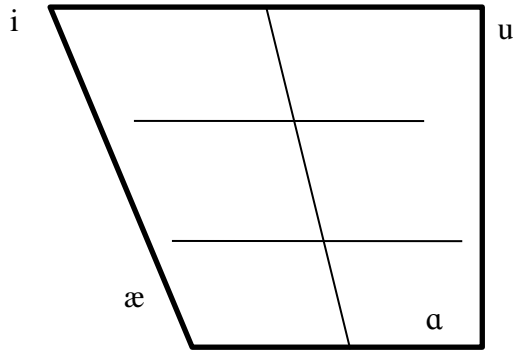
Set 1: Corner Vowel Set
[i] = 1
[æ] = 9
[u] = 10
[ɑ] = 14

Set 2: Expanded 10-Vowel Set
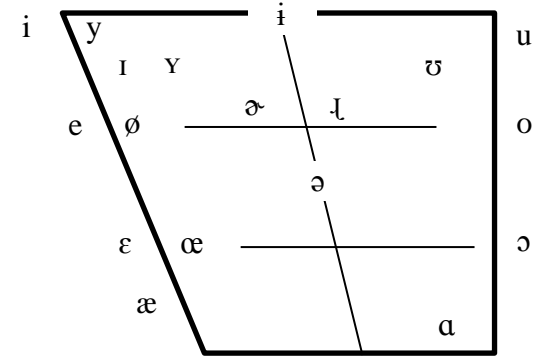[i] = 1
[ɪ] = 2
[e] = 5
[ɛ] = 6
[æ] = 9
[u] = 10
[ʊ] = 11
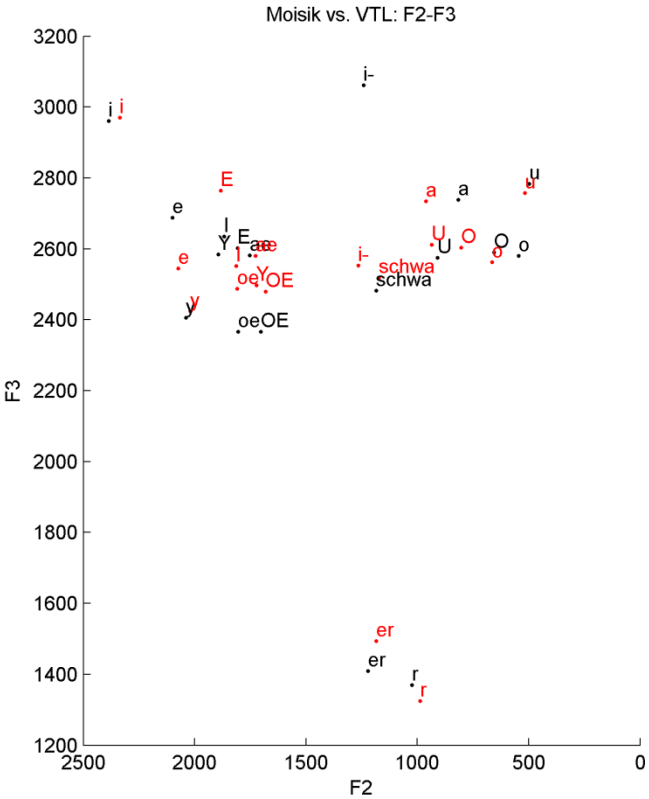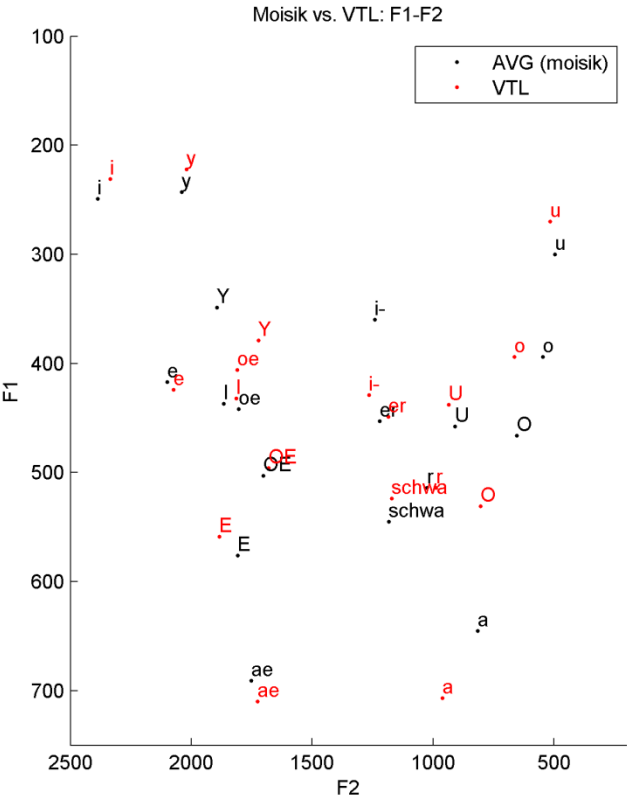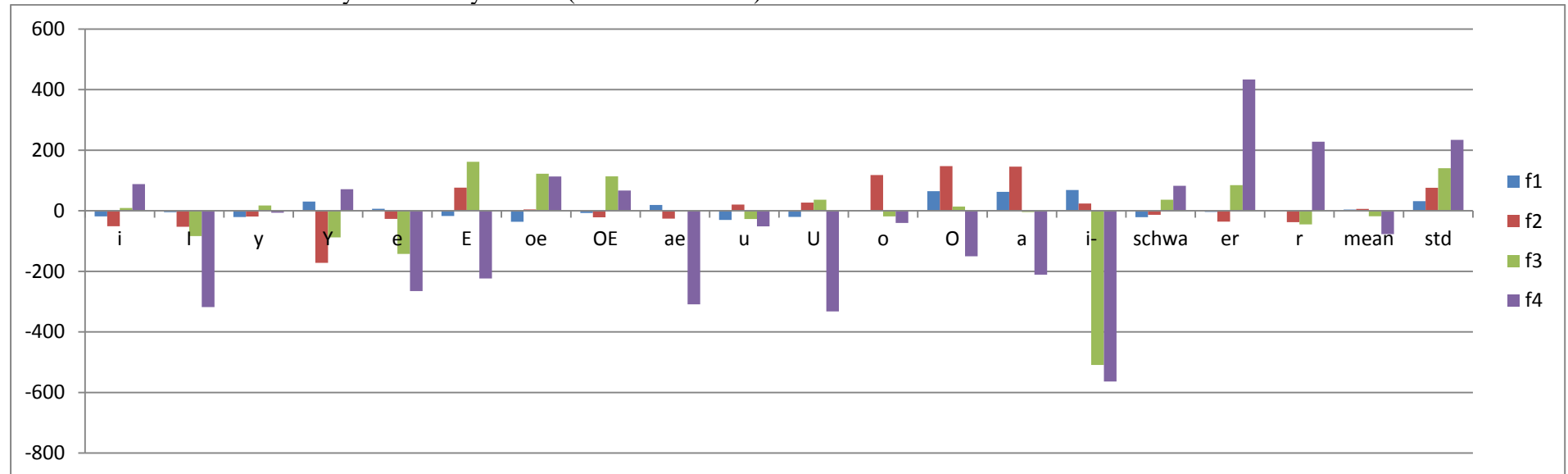[o] = 12
[ɔ] = 13
[ɑ] = 14

Set 3: Full 19-Vowel Set
(see above for vowel
numbers)

Moisik Averages vs. VTL: Formant Comparisons (Hz)
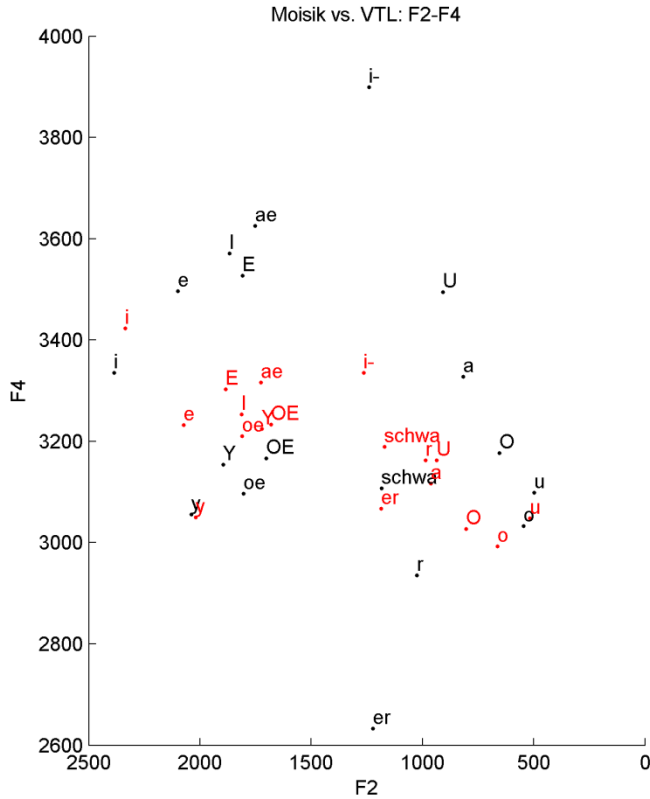
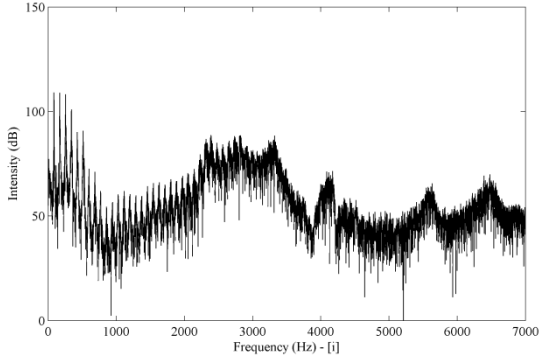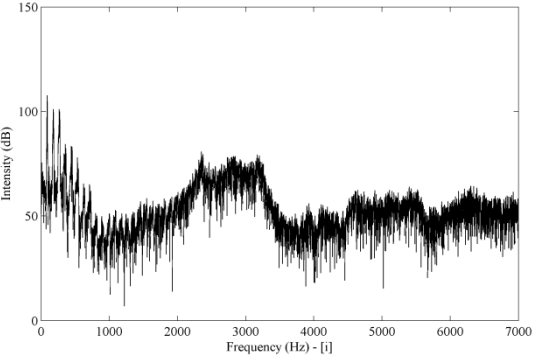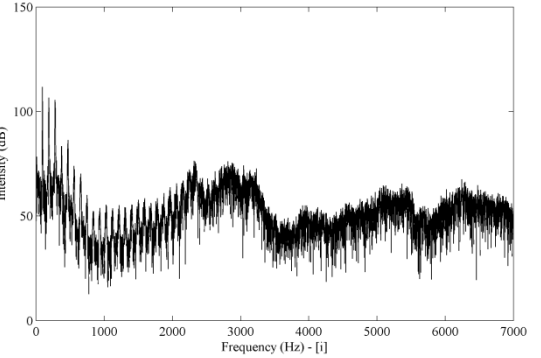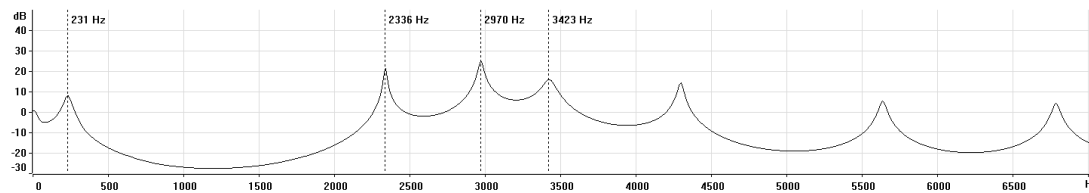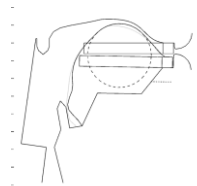Moisik vs. VTL: Errors in Hz by Formant by Vowel (+ mean and STD)

Note: Values are obtained by taking a given VTL formant and subtracting the (Moisik) AVG

Vowel 1: i, [i]

|	Example 1	Example 2	Example 3
F1	251	249	248
F2	2422	2382	2357
F3	2924	2991	2967
F4	3352	3450	3203

	AVG	VTL
F1	249	231
F2	2387	2336
F3	2961	2970
F4	3335	3423

VTL Params:
1,-4.67909,0,-0.97958,-0.548442,0.281444,0.5,-0.1,0,2.20395,-0.711257,4.42325,-1.1652,3.76754,0.272148,-0.897216,-1.19852,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 2: I, [ɪ]

	Example 1	Example 2	Example 3
F1	448	447	415
F2	1904	1821	1875
F3	2641	2570	2695
F4	3601	3581	3531
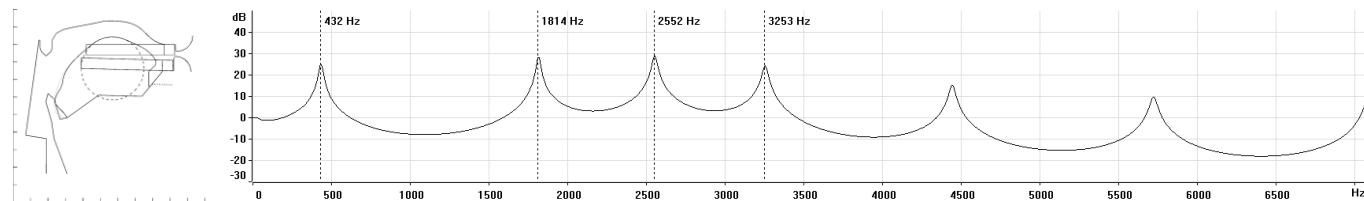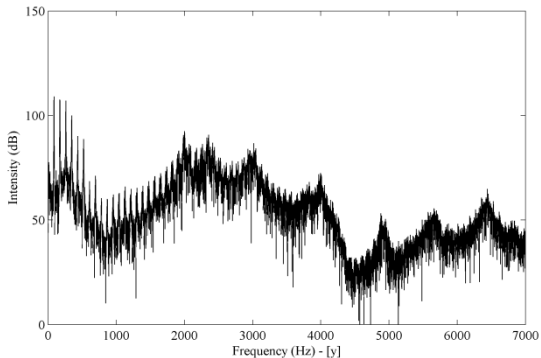
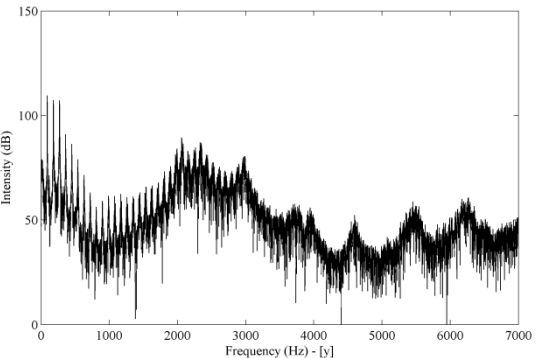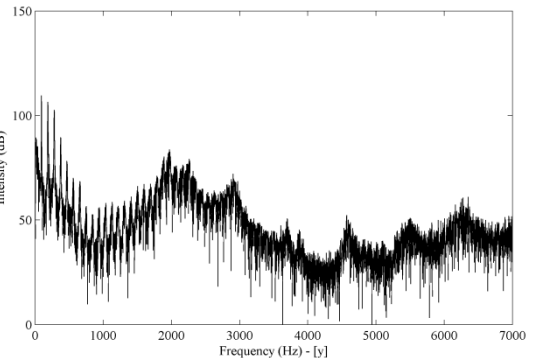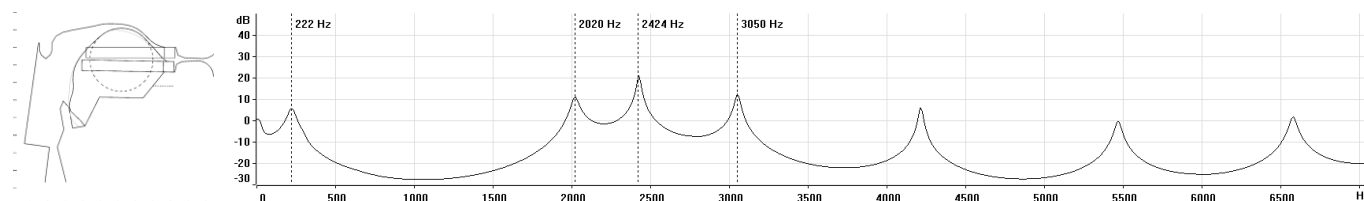|	AVG	VTL
F1	437	432
F2	1867	1814
F3	2635	2552
F4	3571	3253

VTL Params:
0.293142,-4.17471,-0.0143313,-1.48461,-0.548442,0.281444,0.5,-0.1,0,1.69956,-1.36696,3.64985,-0.946637,3.69956,-0.25731,-1.52746,-1.61766,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 3: y, [y]

	Example 1	Example 2	Example 3
F1	266	227	235
F2	2070	2048	1999
F3	2426	2404	2389
F4	3092	3094	2983
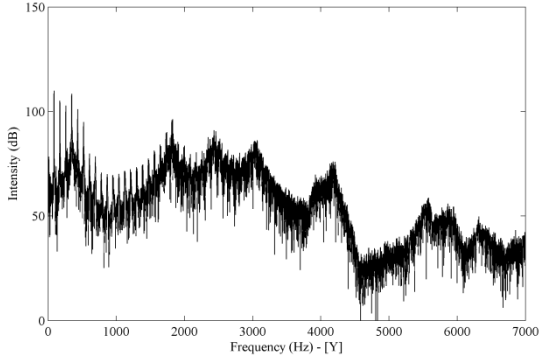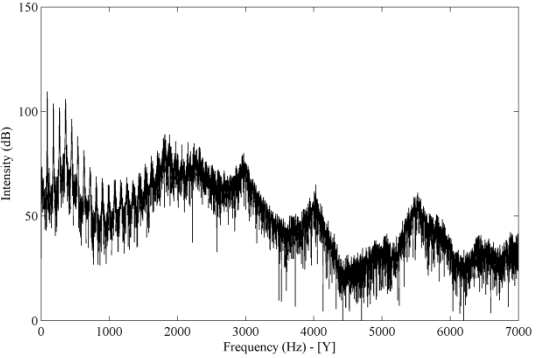
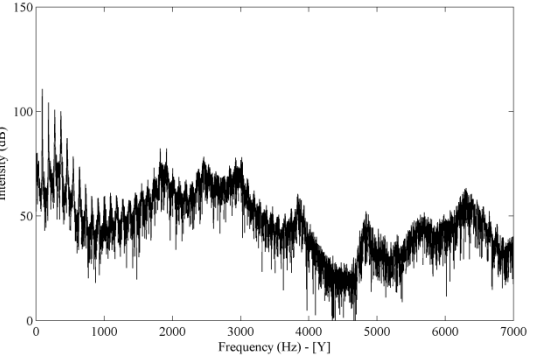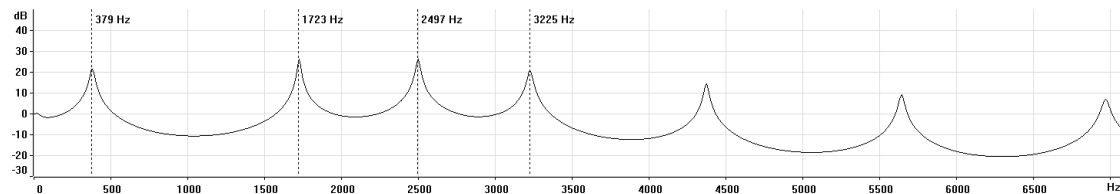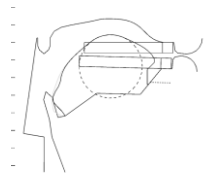|	AVG	VTL
F1	243	222
F2	2039	2020
F3	2406	2424
F4	3056	3050

VTL Params:
1,-4.47734,0,-1.03019,0.980548,0.122597,0.5,-0.1,0,2.20395,-0.711257,4.42325,-1.1652,3.76754,0.272148,-1.07634,-1.19852,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 4: Y, [ʏ]

	Example 1	Example 2	Example 3
F1	385	360	301
F2	1859	1898	1928
F3	2526	2549	2680
F4	3117	3208	3136

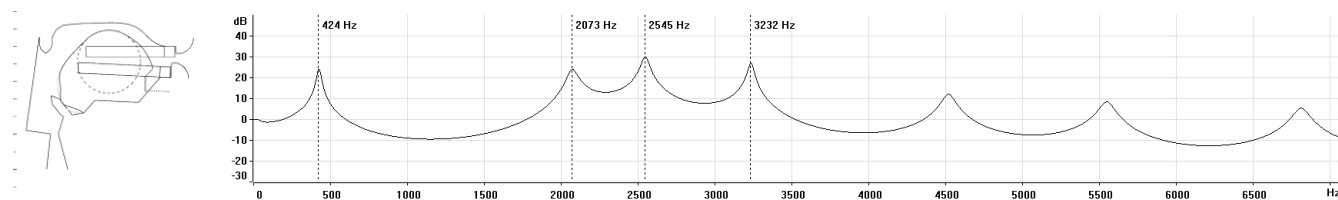|	AVG	VTL
F1	349	379
F2	1895	1723
F3	2585	2497
F4	3154	3225

VTL Params:
0.293142,-4.17471,-0.0143313,-1.48461,0.45689,0.111235,0.5,-0.1,0,1.69956,-1.36696,3.70029,-0.946637,3.70029,-0.290936,-1.52746,-1.61766,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 5: e, [e]

	Example 1	Example 2	Example 3
F1	446	416	390
F2	2051	2156	2092
F3	2690	2696	2677
F4	3580	3528	3384

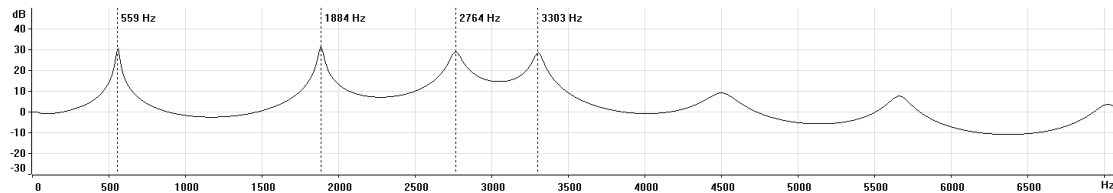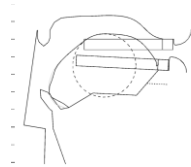|	AVG	VTL
F1	417	424
F2	2100	2073
F3	2688	2545
F4	3497	3232

VTL Params:
0.8958,-3.78801,-0.0982996,-2.88614,-0.548442,0.497186,0,-0.1,0,1.49781,-0.879386,3.38085,-1.11477,3.43129,0.0453216,-2.07018,-1.78532,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 6: E, [ɛ]

	Example 1	Example 2	Example 3
F1	595	595	539
F2	1843	1770	1810
F3	2599	2557	2651
F4	3548	3569	3463
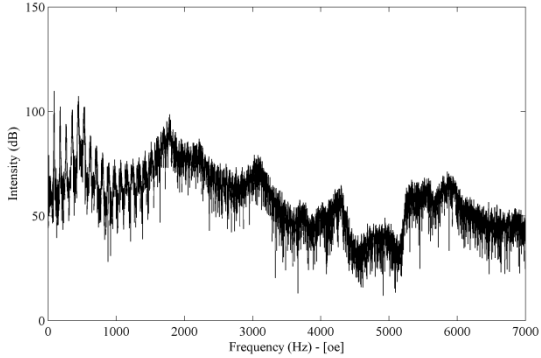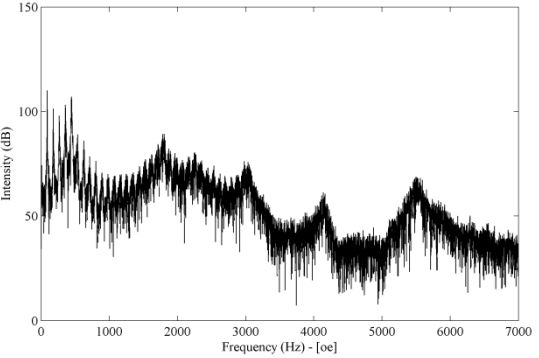
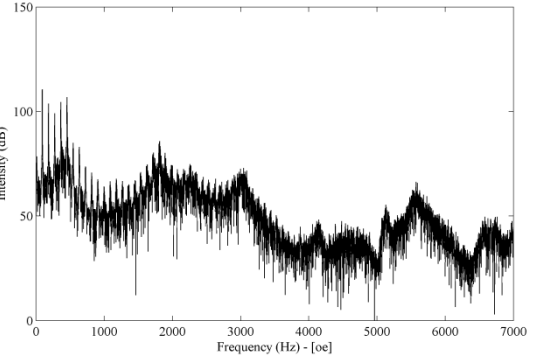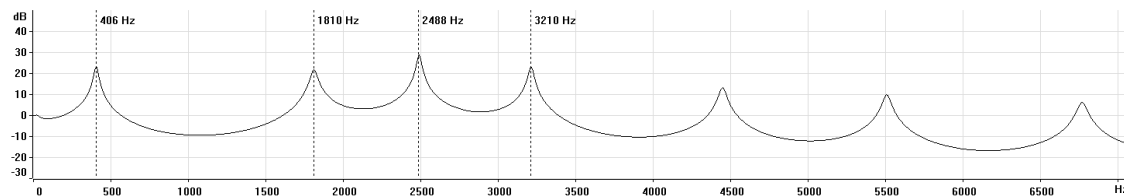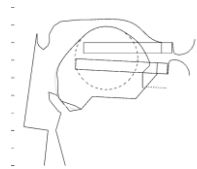|	AVG	VTL
F1	576	559
F2	1808	1884
F3	2602	2764
F4	3527	3303

VTL Params:
0.412074,-3.88889,-0.0982996,-2.88614,-0.548442,0.665315,0,-0.1,0,1.34649,-1.50146,3.81798,-1.33333,3.27997,0.263889,-2.17805,-1.91107,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 7: oe, [ø]

	Example 1	Example 2	Example 3
F1	480	436	411
F2	1779	1797	1840
F3	2226	2393	2478
F4	3159	3070	3061

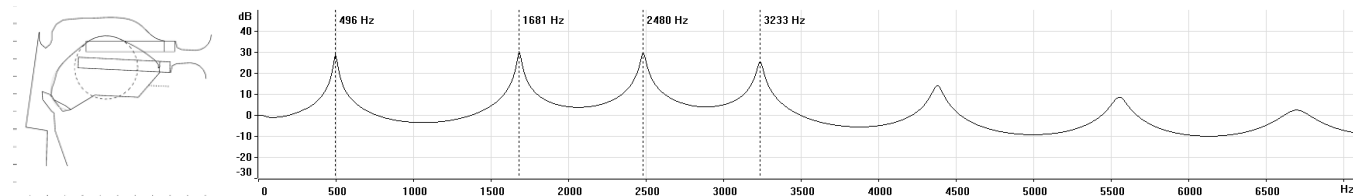|	AVG	VTL
F1	442	406
F2	1805	1810
F3	2366	2488
F4	3097	3210

VTL Params:
0.8958,-3.78801,-0.0982996,-2.88614,0.268533,0.272364,0,-0.1,0,1.49781,-0.879386,3.38085,-1.11477,3.43129,0.0453216,-2.07018,-1.78532,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 8: OE, [œ]

	Example 1	Example 2	Example 3
F1	524	509	477
F2	1658	1693	1757
F3	2359	2470	2270
F4	3203	3248	3048

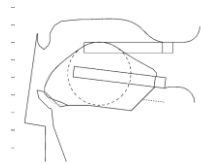|	AVG	VTL
F1	503	496
F2	1703	1681
F3	2366	2480
F4	3166	3233

VTL Params:
0.412074,-3.88889,-0.0982996,-2.88614,0.7824,0.714523,0,-0.1,0,1.34649,-1.50146,3.81798,-1.33333,3.3136,-0.442251,-2.17805,-1.91107,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 9: ae, [æ]

	Example 1	Example 2	Example 3
F1	735	685	653
F2	1710	1752	1794
F3	2568	2534	2644
F4	3625	3714	3536
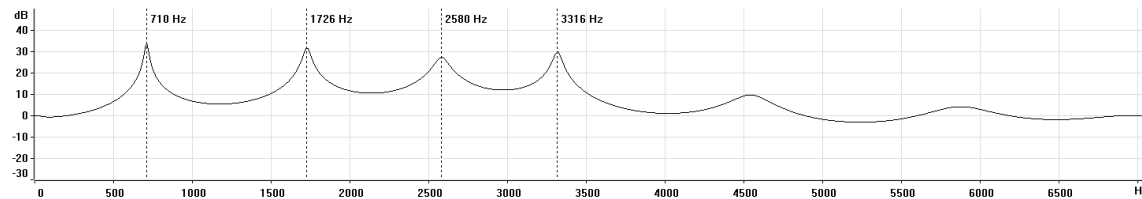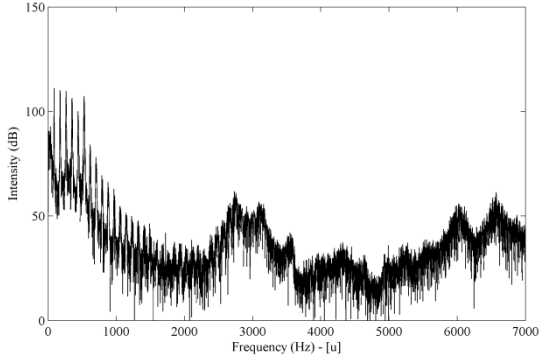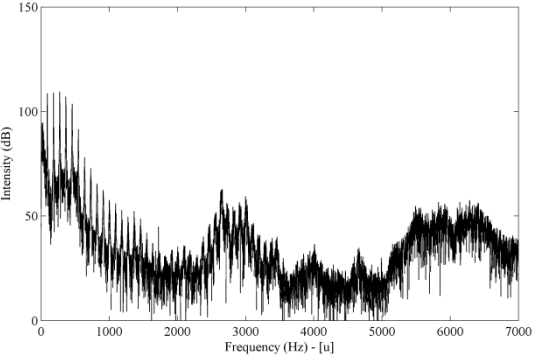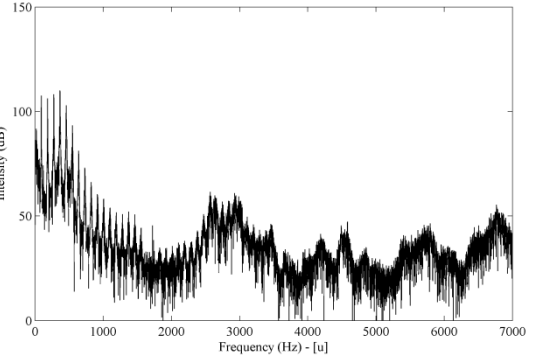
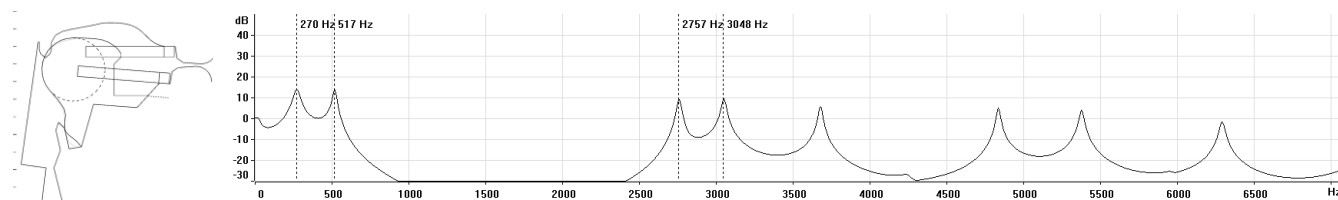|	AVG	VTL
F1	691	710
F2	1752	1726
F3	2582	2580
F4	3625	3316

VTL Params:
0.338712,-3.55263,0,-7,0.464261,2.54437,0,-0.1,0,1.06067,-2.05629,3.81798,-1.75365,2.82602,-0.828947,-2.53951,-2.14858,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 10: u, [u]

	Example 1	Example 2	Example 3
F1	285	290	326
F2	516	549	425
F3	2798	2764	2791
F4	3181	3092	3025
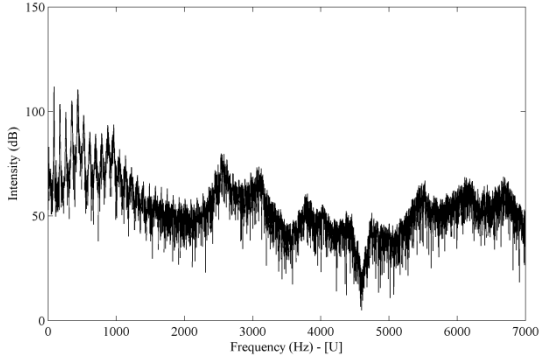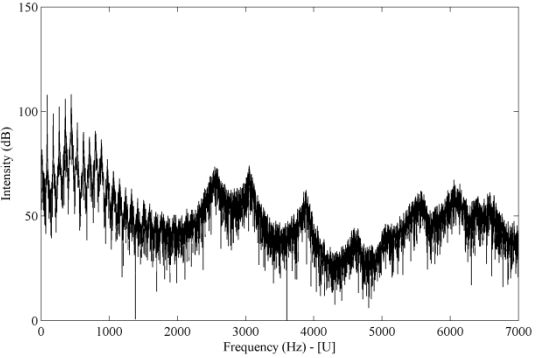
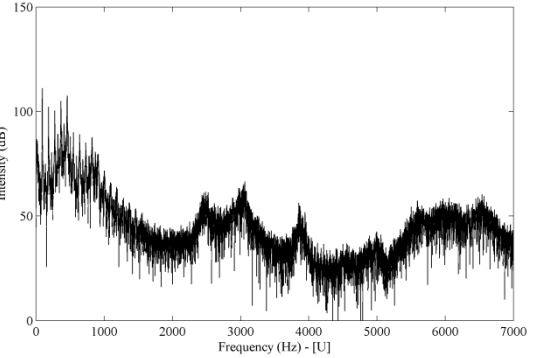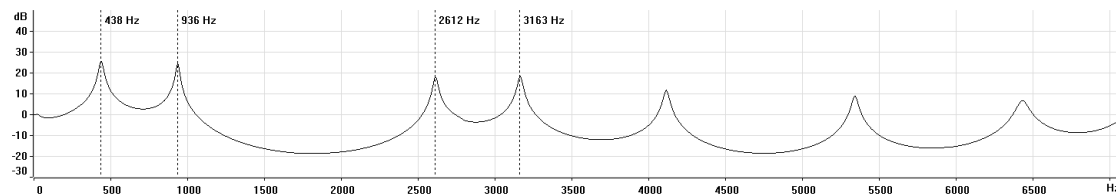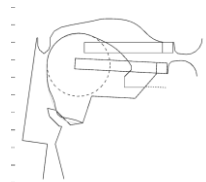|	AVG	VTL
F1	300	270
F2	497	517
F3	2784	2757
F4	3099	3048

VTL Params:
1,-5.70468,0,-4.56624,1,0.135107,0.5,-0.1,0,-0.502924,-1.31652,1.86769,-0.408626,1.39693,0.462826,-0.971494,-3.44793,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 11: U, [ʊ]

	Example 1	Example 2	Example 3
F1	452	493	430
F2	961	954	812
F3	2652	2626	2448
F4	3137	3048	3092
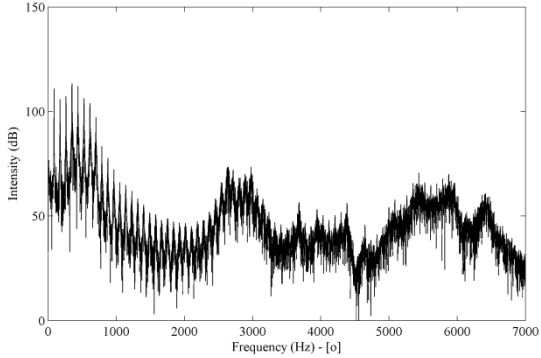
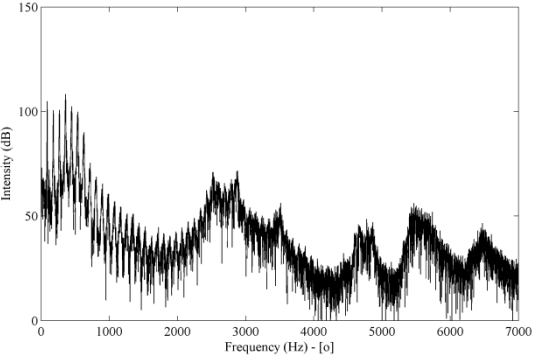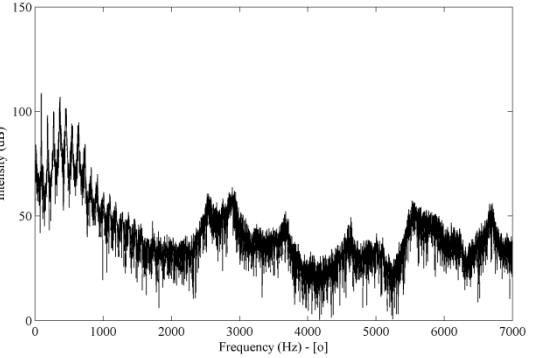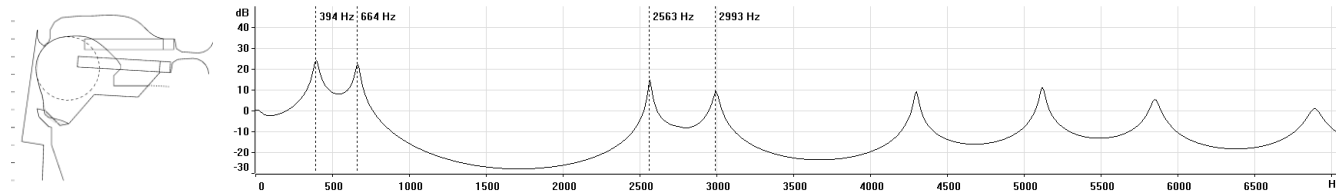|	AVG	VTL
F1	458	438
F2	909	936
F3	2575	2612
F4	3495	3163

VTL Params:
1,-4.59503,-0.180112,-2.92452,0.528148,0.342804,0.5,-0.1,0,-0.133041,-1.28289,2.48977,-1.36696,1.98538,-0.215425,-1.99476,-3.14056,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 12: o, [o]

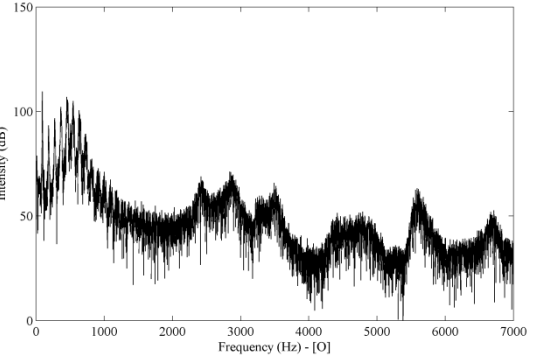|	Example 1	Example 2	Example 3
F1	402	356	423
F2	634	455	549
F3	2559	2581	2604
F4	3048	3048	3003
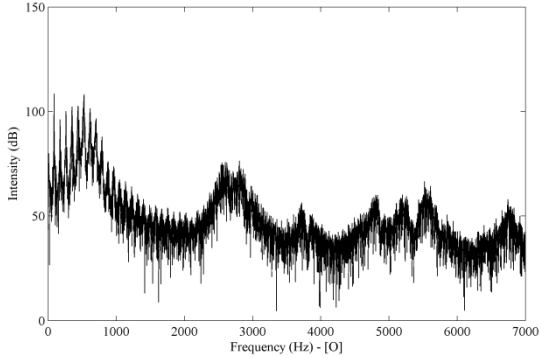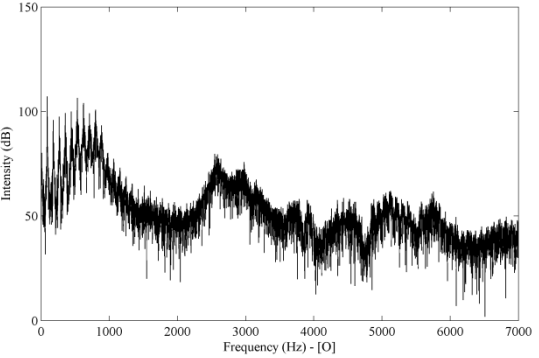
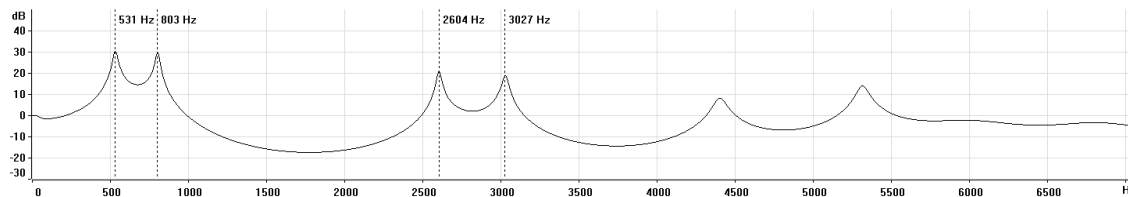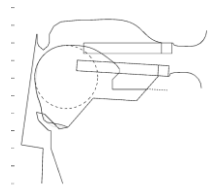|	AVG	VTL
F1	394	394
F2	546	664
F3	2581	2563
F4	3033	2993

VTL Params:
0.484355,-4.79678,0,-3.44047,0.879017,0.303481,0,-0.1,0,-0.755117,-1.66959,1.90132,-1.48465,0.623538,0.314327,-2.17606,-3.6575,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 13: O, [ɔ]

	Example 1	Example 2	Example 3
F1	405	485	509
F2	605	627	734
F3	2515	2516	2404
F4	3049	3070	2937
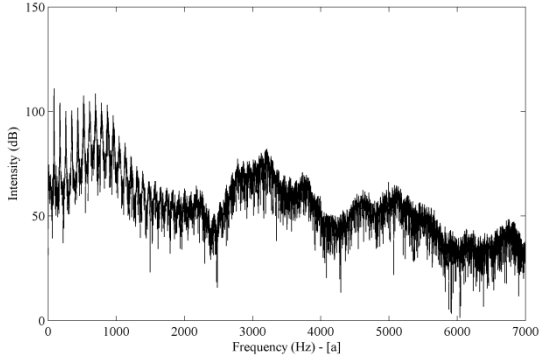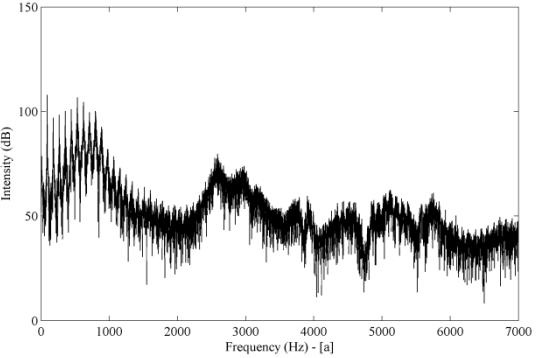
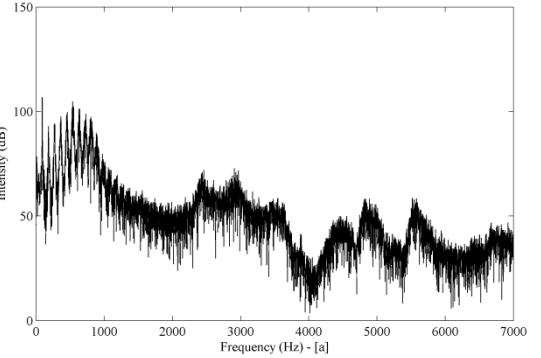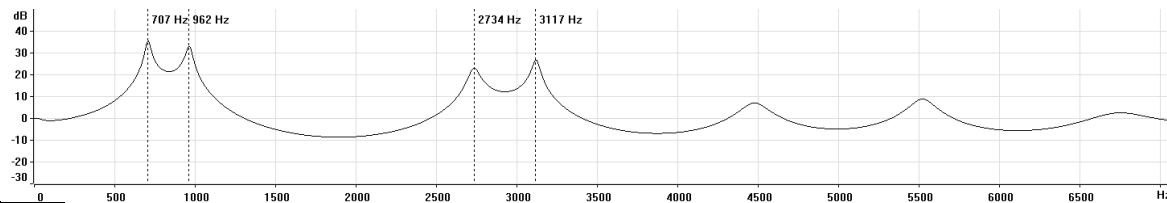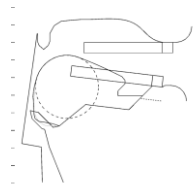|	AVG	VTL
F1	466	531
F2	655	803
F3	2590	2604
F4	3177	3027

VTL Params:
0.484355,-4.79678,0,-3.44047,0.685585,1.48038,0,-0.1,0,-0.788743,-1.9386,1.90132,-1.48465,0.707602,-0.105994,-2.42743,-3.68545,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 14: a, [ɑ]

	Example 1	Example 2	Example 3
F1	672	642	620
F2	860	728	861
F3	2737	2725	2752
F4	3314	3347	3323
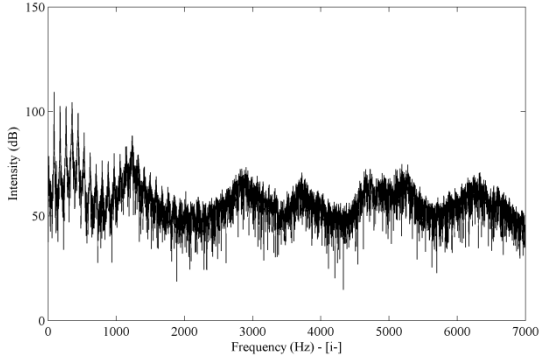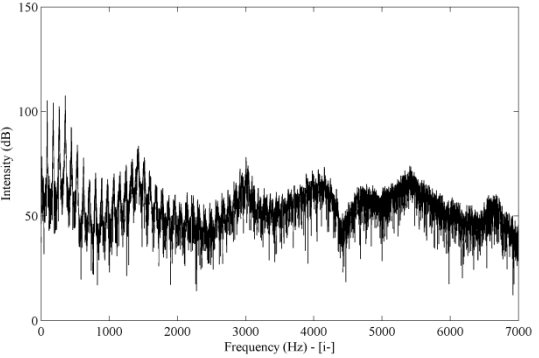
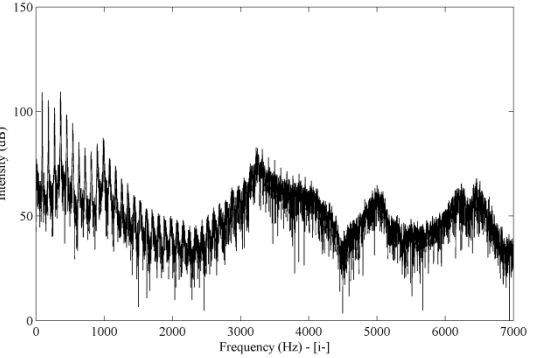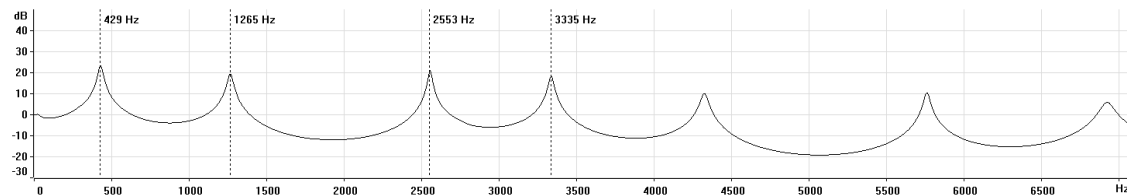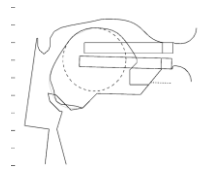|	AVG	VTL
F1	645	707
F2	816	962
F3	2738	2734
F4	3328	3117

VTL Params:
0.133738,-4.74635,-0.151519,-6.72855,0.224668,2.47503,0,-0.1,0,-0.77193,-2.52705,2.17032,-2.15716,1.01023,-1.28289,-2.9883,-3.67147,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 15: i-, [ɨ]

	Example 1	Example 2	Example 3
F1	354	337	390
F2	1264	1399	1060
F3	2848	3025	3314
F4	3825	3980	3892
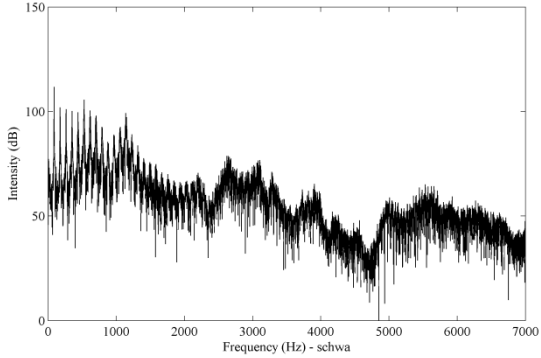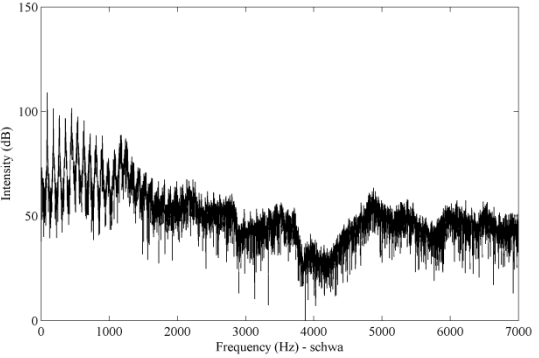
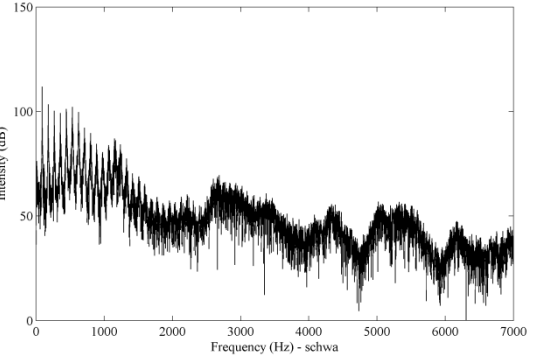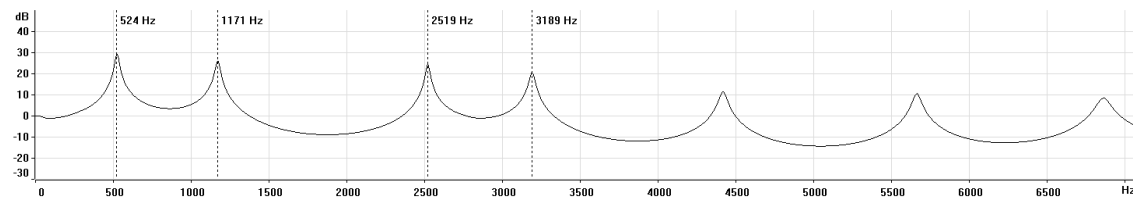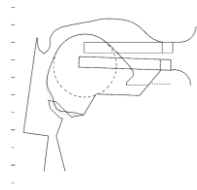
	AVG	VTL
F1	360	429
F2	1241	1265
F3	3062	2553
F4	3899	3335

VTL Params:
0.913492,-3.72076,0,-1.48077,0.242762,1.26209,0.5,-0.1,0,0.774854,-0.96345,2.72515,-0.946637,2.15351,0.793346,-2.44835,-2.3861,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 16: schwa, [ə]

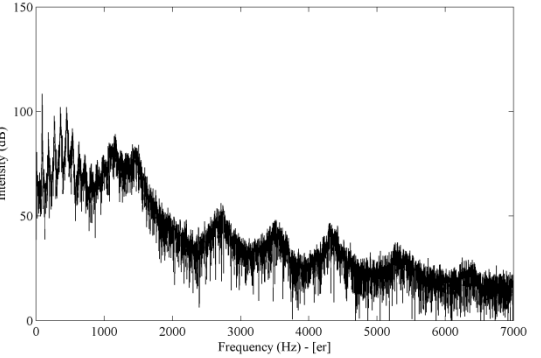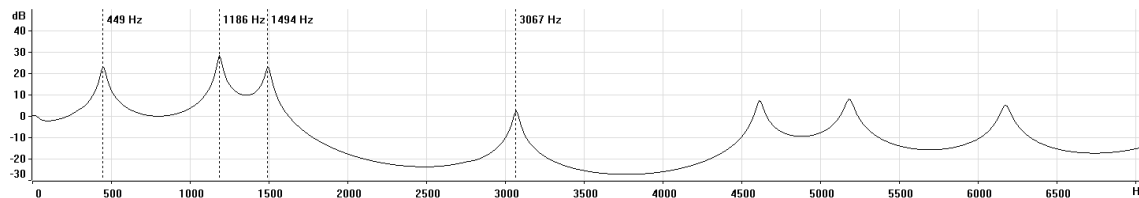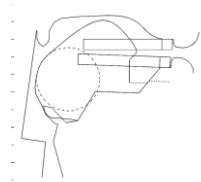|	Example 1	Example 2	Example 3
F1	599	524	512
F2	1167	1239	1147
F3	2626	2204	2617
F4	3181	2914	3225
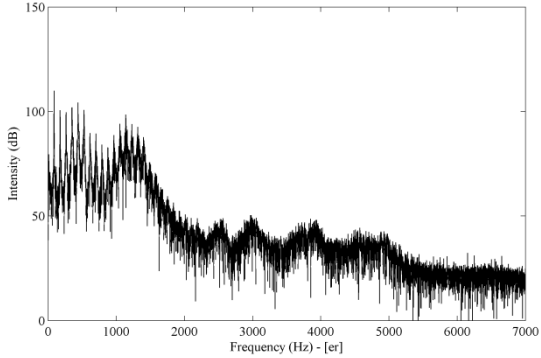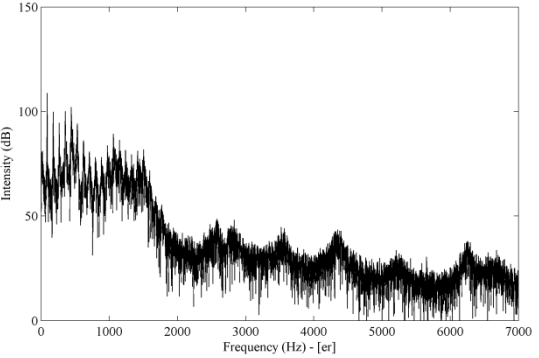
	AVG	VTL
F1	545	524
F2	1184	1171
F3	2482	2519
F4	3107	3189

VTL Params:
0.992982,-4.14108,-0.00452844,-1.93409,0.242762,1.66295,0.5,-0.1,0,0.236842,-1.33333,2.60746,-1.70322,2.00219,-0.475877,-2.47547,-2.83318,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 17: er, [ɚ]

	Example 1	Example 2	Example 3
F1	461	449	448
F2	1217	1218	1230
F3	1333	1458	1437
F4	2515	2626	2759
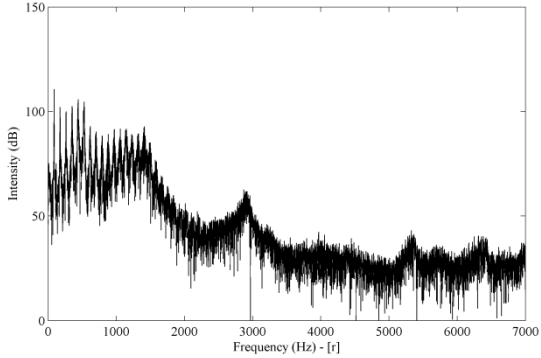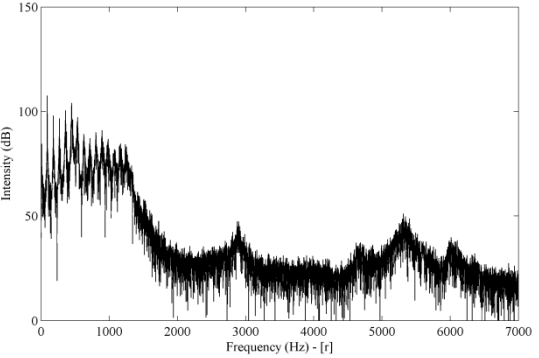
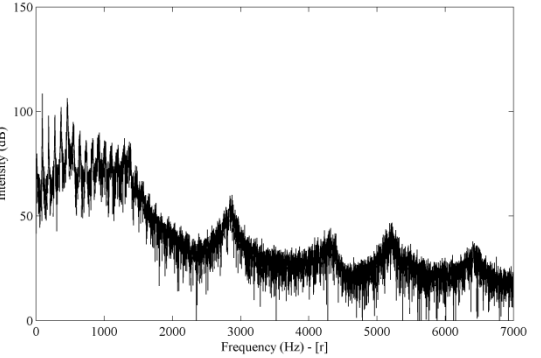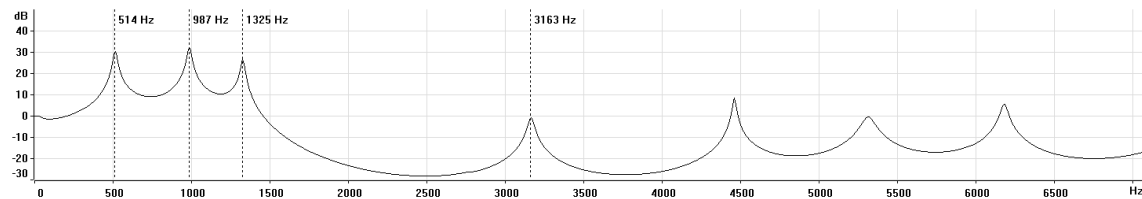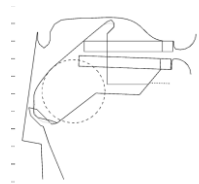|	AVG	VTL
F1	453	449
F2	1222	1186
F3	1409	1494
F4	2633	3067

VTL Params:
0.84006,-4.62865,0,-2.07149,0.363426,0.546444,0.0467836,-0.1,0,-0.671053,-2.27485,2.7924,-0.593567,1.46418,1.96199,-2.84519,-3.58764,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,

Vowel 18: r, [ɹ]

	Example 1	Example 2	Example 3
F1	531	509	502
F2	1161	928	985
F3	1480	1288	1342
F4	2975	2937	2892

	AVG	VTL
F1	514	514
F2	1025	987
F3	1370	1325
F4	2935	3163

VTL Params:
0.0361934,-4.66228,0,-2.07149,0.241554,0.514849,0,-0.1,0,-0.41886,-2.88012,1.5,1.00365,0.556287,0.342943,-3.2267,-3.37807,0,0,0,0,-0.05,-0.05,-0.05,2.3,4.7,3.5,2.3,4.9,3.5,3,0.726758,0.343016,0.200746,0.653359,0,0,