COARTICULATION IN VCV UTTERANCES

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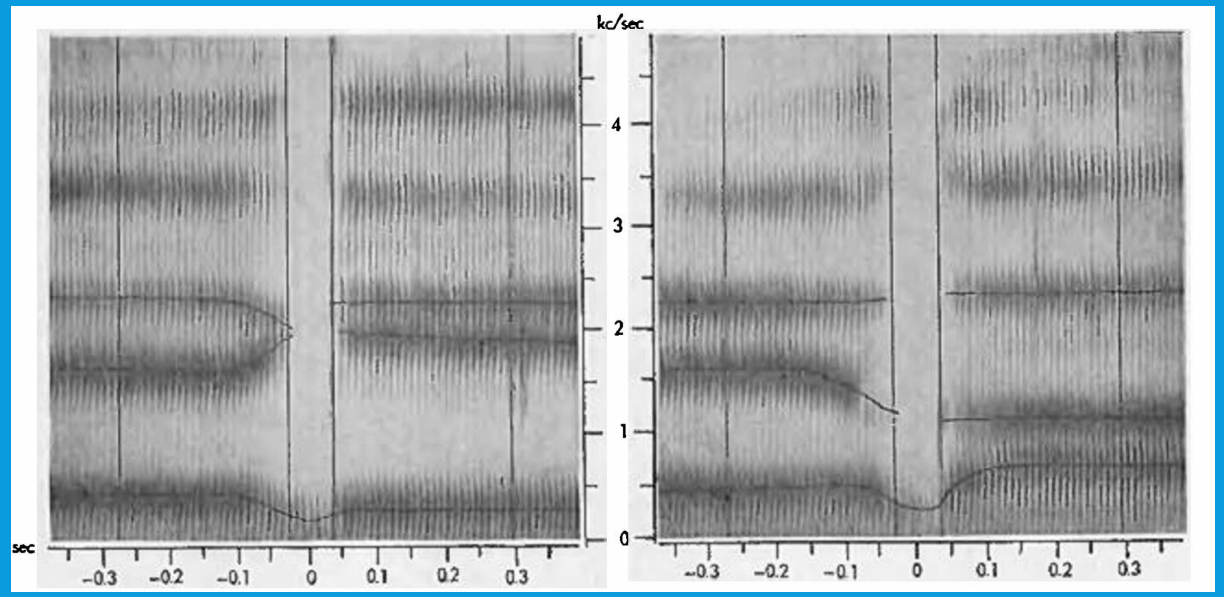
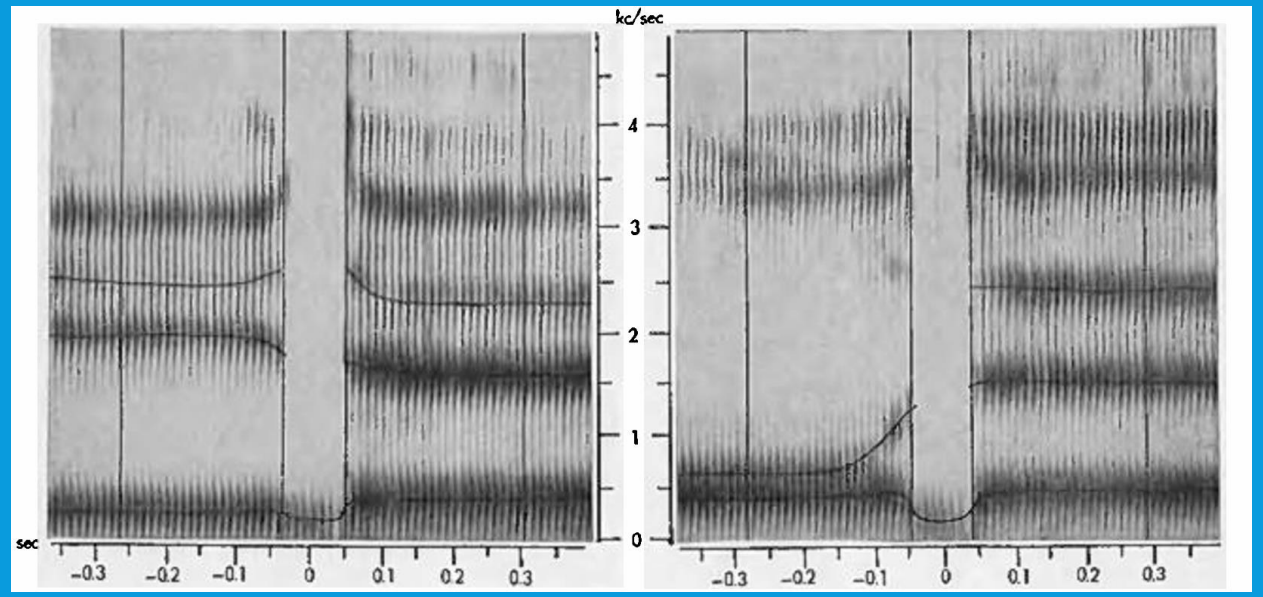
MOTIVATION



- /øgy/ vs. /øga/
- Second-formant transition of V1 is rising if V2 is /y/ and falling if V2 is /a/
- Variation in third formant

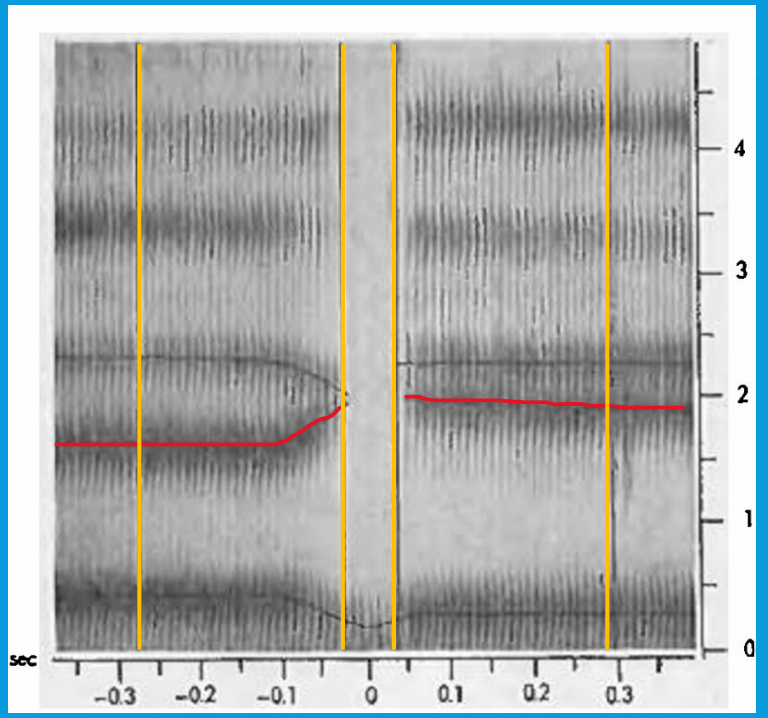


- /ydø/ vs. /odø/
- Second-formant transition of V2 is falling if V1 is /y/ and slightly rising if V1 is /o/
- Variation in third formant

EXPERIMENT 1: F2 TRANSITIONS OF AUTHOR'S SPEECH

MEASUREMENTS

- Stimuli: List of VCV non-words involving the vowels /y/, /ø/, /a/ and /u/, and the stop consonants /b/, /d/ and /g/
  - 4 x 3 x 4 possible combinations -> 48 stimuli (read three times)
- F2 frequencies are measured in stationary segments of V1 and V2, and at the beginning and end of the consonant's closure
- Thin horizontal lines are drawn to mark the F2 center
- Vertical lines are drawn to mark the stationary segments as well as the beginning and end of the stop closure
  - ➢Frequencies are measured at intersection of lines



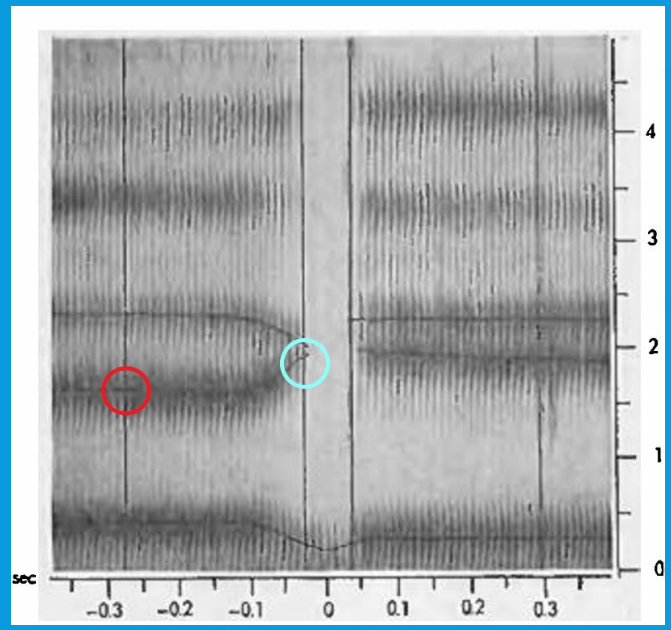
/øgy/

RESULTS

		VbV		VdV		VgV	
		VC	CV	VC	CV	VC	CV
y	y	−450	−350	−155	−130	−15	+140
	ø	−515	−370	−290	−200	−30	+55
	ɑ	−775	−370	−370	−280	−255	+115
	u	−650	−390	−200	−190	−325	+100
ø	y	−375	−65	−90	+75	0	+430
	ø	−415	−175	−200	−5	−25	+375
	ɑ	−465	−90	−340	−25	−275	+340
	u	−515	−140	−240	+40	−365	+315
ɑ	y	+100	+205	+265	+520	+175	+330
	ø	+25	+75	+240	+365	+125	+225
	ɑ	−100	−100	+165	+290	+30	+165
	u	−150	−55	+250	+315	−65	+80
u	y	+200	+255	+575	+940	+190	+115
	ø	+80	+325	+530	+840	+65	+255
	ɑ	+15	+200	+490	+370	+15	+190
	u	+5	−5	+490	+690	−50	−15

- Observed vowel specified in the first column, vowel to the opposite side specified in the second column
- Differences between F2 frequencies at the closure boundary and the stationary segments of the observed vowel (boundary – stationary)

  - Positive values: boundary frequency is higher than stationary frequency
  - Negative values: boundary frequency is lower than stationary frequency



/øgy/

INTERPRETATION

		VbV		VdV		VgV	
		VC	CV	VC	CV	VC	CV
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- F2 transition in every VC sequence depends on the final vowel
  - /ag/ rises by 175 cps if final vowel is /y/ and falls by 65 cps if final vowel is /u/
- F2 transition in almost every CV sequence depends on the initial vowel
  - /ba/ falls by 205 cps if initial vowel is /y/ and rises by 100 cps if initial vowel is /a/

➢ **Influence of transconsonantal vowel on observed vowel**

EXPERIMENT 2: F_1, F_2 AND F_3 TRANSITIONS OF A SWEDISH SPEAKER

MEASUREMENTS

- Repetition of first experiment on phonetically untrained Swedish male speaker
  - Avoid any bias of author's speech
- Enlarged set of stimuli: List of VCV non-words involving the vowels /y/, /ø/, /a/, /o/ and /u/, and the stop consonants /b/, /d/ and /g/
  - 5 x 3 x 5 possible combinations -> 75 stimuli (read five times)
- Annotation of spectrograms exactly as in the first experiment

RESULTS

Observed vowel	Transconsonantal vowel	VbV F_1 VC	VbV F_1 CV	VbV F_2 VC	VbV F_2 CV	VbV F_3 VC	VbV F_3 CV	VdV F_1 VC	VdV F_1 CV	VdV F_2 VC	VdV F_2 CV	VdV F_3 VC	VdV F_3 CV	VgV F_1 VC	VgV F_1 CV	VgV F_2 VC	VgV F_2 CV	VgV F_3 VC	VgV F_3 CV
y	y	−35	−90	−350	−265	−330	−235	−50	−115	−85	−85	245	255	−60	−75	130	145	−195	−120
	ø	−20	−20	−445	−235	−285	−85	−80	−95	−170	−185	150	265	−80	−125	95	185	−220	−15
	ɑ	−40	−45	−500	−325	−295	−95	−65	−95	−260	−290	250	320	−65	−70	−185	110	−300	−35
	o	−20	−20	−575	−320	−260	−115	−65	−110	−140	−290	180	220	−10	−55	−410	190	−310	−125
	u	−10	−90	−475	−390	−320	−130	−70	−65	−155	−235	165	135	−40	−55	−375	185	−245	−25
ø	y	−95	−130	−275	−50	−90	−155	−115	−170	−40	150	210	135	−130	−215	230	360	−300	−185
	ø	−95	−125	−190	−130	−110	−80	−145	−180	−55	65	205	255	−130	−175	115	300	−205	−195
	ɑ	−85	−150	−355	−160	−40	−110	−110	−135	−210	−25	280	240	−115	−150	−130	410	−155	−140
	o	−105	−140	−345	−235	−80	−65	−135	−135	−135	−115	245	165	−95	−130	−185	300	−180	−215
	u	−115	−150	−370	−270	−125	−115	−155	−180	−95	15	290	105	−90	−140	−240	340	−150	−175
ɑ	y	−300	−325	150	35	−290	−255	−335	−355	365	440	−95	−20	−320	−420	510	430	−315	−355
	ø	−220	−270	95	−15	−265	−280	−385	−390	310	480	−95	−50	−335	−370	400	405	−425	−275
	ɑ	−280	−330	−170	−55	−140	−210	−320	−350	125	225	−65	−50	−270	−325	225	110	−275	−145
	o	−260	−330	−155	−80	−140	−145	−385	−270	175	170	−20	−75	−275	−355	50	55	−200	−25
	u	−350	−300	−150	−185	−190	−225	−365	−375	280	220	−125	−65	−310	−300	110	20	−130	−80
o	y	−85	−105	290	255	···	−300	−80	−215	590	870	50	100	−100	−175	195	260	···	···
	ø	−120	−140	255	80	−250	−150	−85	−160	580	710	···	50	−105	−125	190	165	···	−190
	ɑ	−110	−105	−25	60	−50	−55	−50	−200	330	500	···	120	−115	−140	110	110	···	···
	o	−140	−95	−5	0	−10	···	−75	−95	365	475	···	40	−120	−135	35	10	···	···
	u	−100	−130	−10	−20	···	−125	−110	−175	425	520	···	30	−105	−120	15	−25	···	···
u	y	−60	−50	375	225	−130	−315	−65	−125	665	900	···	−50	−65	−135	105	280	···	−265
	ø	−60	−110	175	275	···	−135	−70	−110	665	800	···	···	−55	−125	60	180	···	−235
	ɑ	−90	−80	−135	170	···	−90	−60	−45	345	700	···	···	−75	−50	−60	135	···	···
	o	−80	−65	−50	5	···	···	−25	−35	430	650	···	···	−100	−95	−65	40	···	···
	u	−85	−90	−120	−25	···	−155	−60	−95	570	620	···	−50	−70	−95	−120	−50	···	···

- Differences between stationary and boundary segments as presented in first experiment
- Empty entries could not be measured from spectrogram
- Substantial variation in any VC or CV sequence depending on transconsonantal vowel
  - Range of variation: Largest difference between the observed vowel with any of the transconsonantal vowels

RESULTS

	VbV						VdV						VgV					
	F_1		F_2		F_3		F_1		F_2		F_3		F_1		F_2		F_3	
	VC	CV	VC	CV	VC	CV	VC	CV	VC	CV	VC	CV	VC	CV	VC	CV	VC	CV
y	30	70	225	155	70	150	30	50	175	205	100	185	70	50	540	80	115	110
ø	30	25	180	220	85	90	45	45	170	265	85	150	40	85	470	110	150	75
a	130	60	305	220	150	135	65	120	240	310	105	140	65	120	460	410	295	330
o	55	45	315	275	240	245	60	120	260	395	...	90	20	55	180	285	...	...
u	30	60	510	300	...	225	45	90	320	280	...	...	45	85	225	330	...	...

- Ranges depend on formant type:
  - F1: maximum: 130; average: 62
  - F2: maximum: 540; average: 280
  - F3: maximum: 330; average: 153

- Significant values for all formant types:
  - If values are exceeded, differences do almost certainly not occur by chance

	Level of significance	
Formant	0.01	0.05
F_1	57	44
F_2	118	93
F_3	115	87

RESULTS

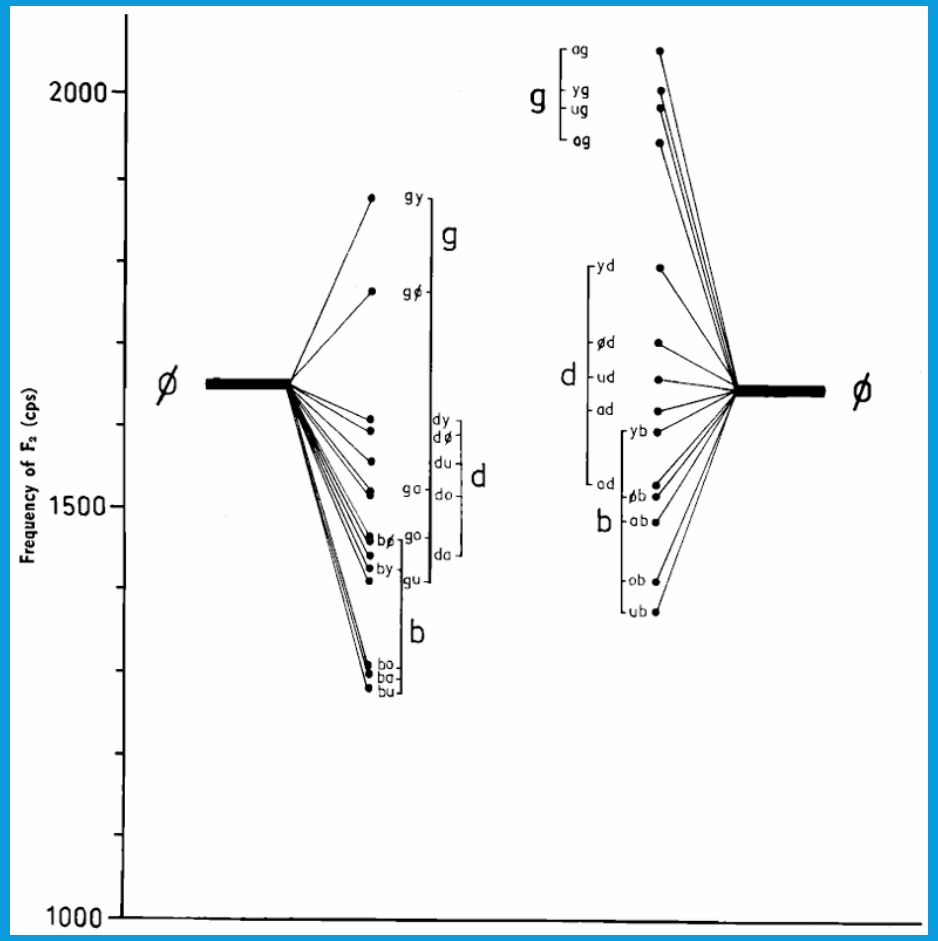
	VbV						VdV						VgV					
	F_1		F_2		F_3		F_1		F_2		F_3		F_1		F_2		F_3	
	VC	CV	VC	CV	VC	CV	VC	CV	VC	CV	VC	CV	VC	CV	VC	CV	VC	CV
y	30	70	225	155	70	150	30	50	175	205	100	185	70	50	540	80	115	110
ø	30	25	180	220	85	90	45	45	170	265	85	150	40	85	470	110	150	75
a	130	60	305	220	150	135	65	120	240	310	105	140	65	120	460	410	295	330
o	55	45	315	275	240	245	60	120	260	395	...	90	20	55	180	285	...	...
u	30	60	510	300	...	225	45	90	320	280	...	...	45	85	225	330	...	...

- All formant averages are significant
- All F2 measures except for /-gy/ are significant
- 50% of F1 and 50% of F3 are significant

➢ **Transconsonantal vowel influences formant frequencies of observed vowel**

	Level of significance	
Formant	0.01	0.05
F_1	57	44
F_2	118	93
F_3	115	87

INTERPRETATION

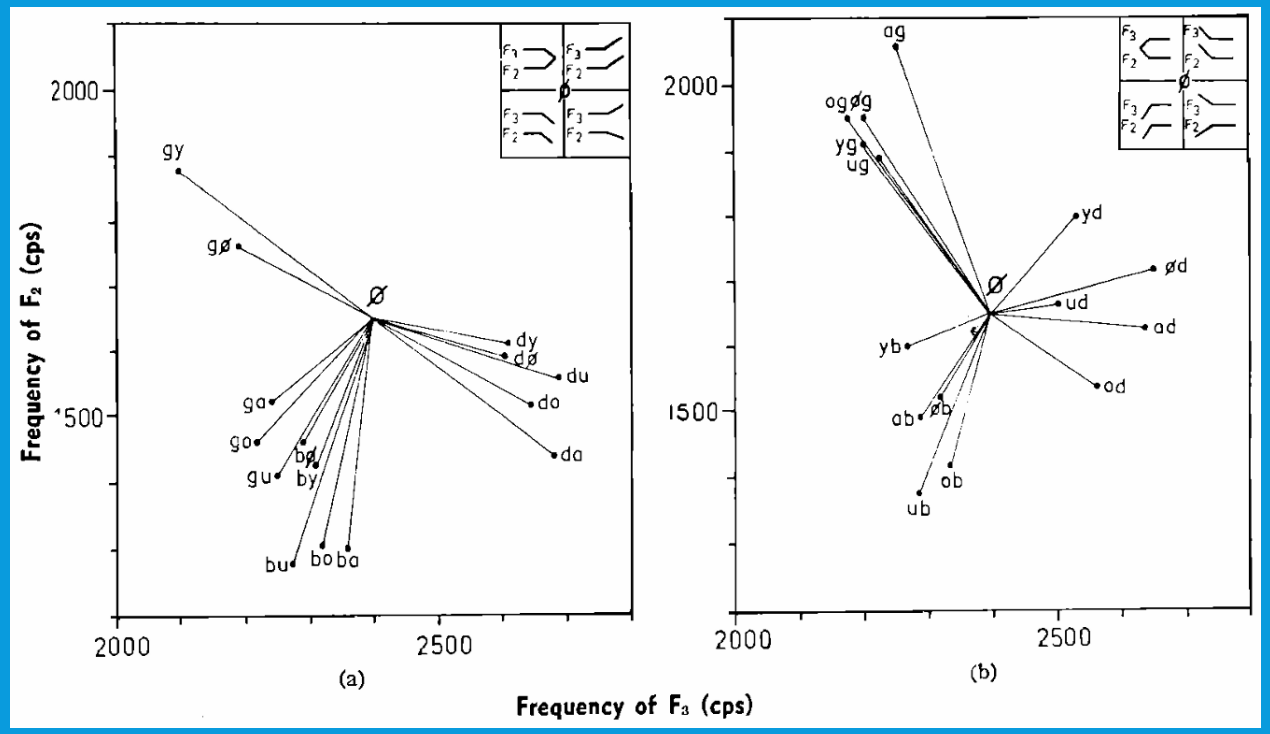


- F2 transitions in /øC-/ and /-Cø/ sequences
  - Difference between stationary /ø/ segment and boundary segment
  - Vertical lines: Ranges of variation for each consonant
- /øC-/:
  - /d/ transition range overlaps entirely with the /g/ transition range
  - Small region where a transition from /ø/ can be associated with any of the three consonants

➢Consonant's place of articulation cannot be determined by F2 only

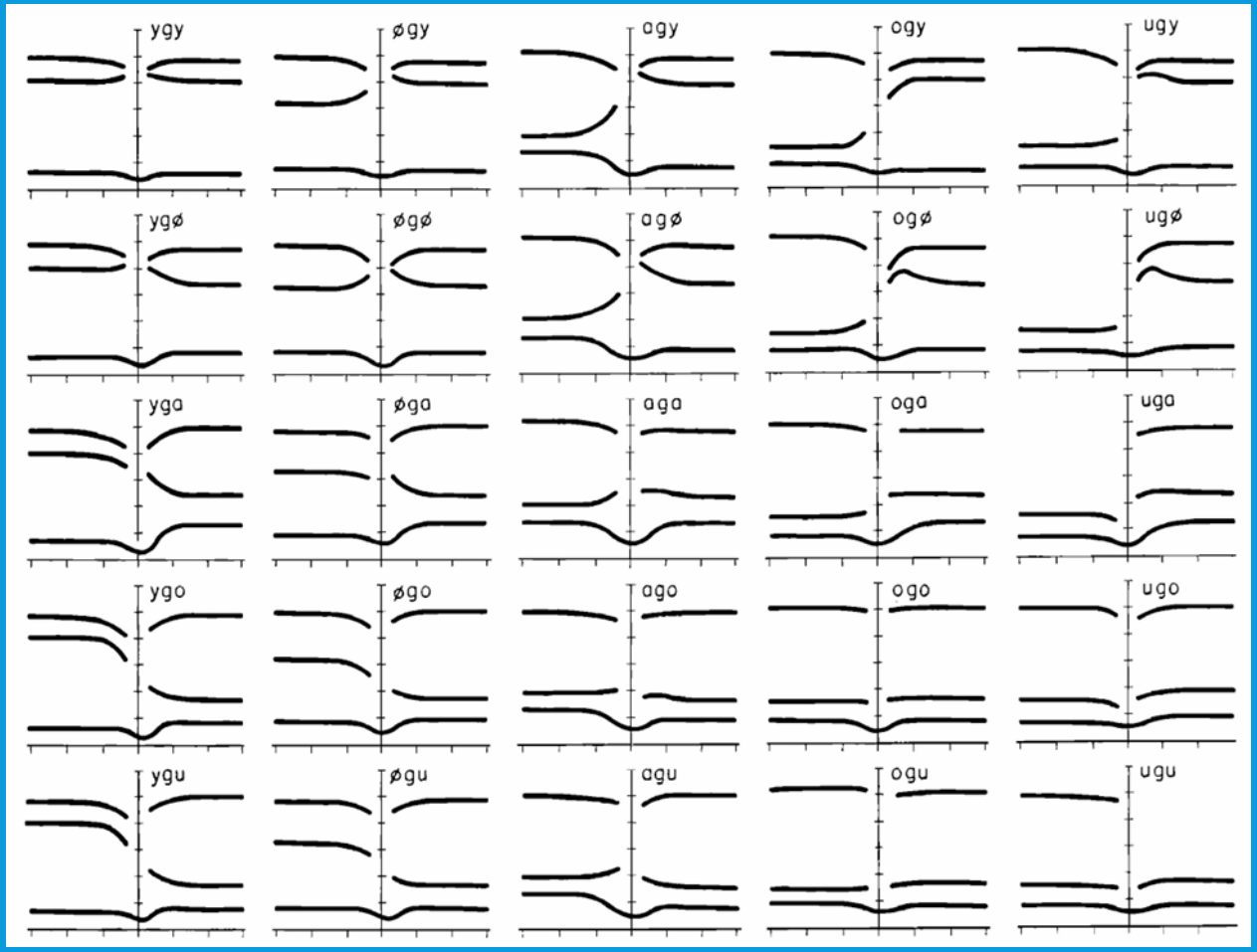
INTERPRETATION

Overlap can be reduced by additionally taking F3 into account:



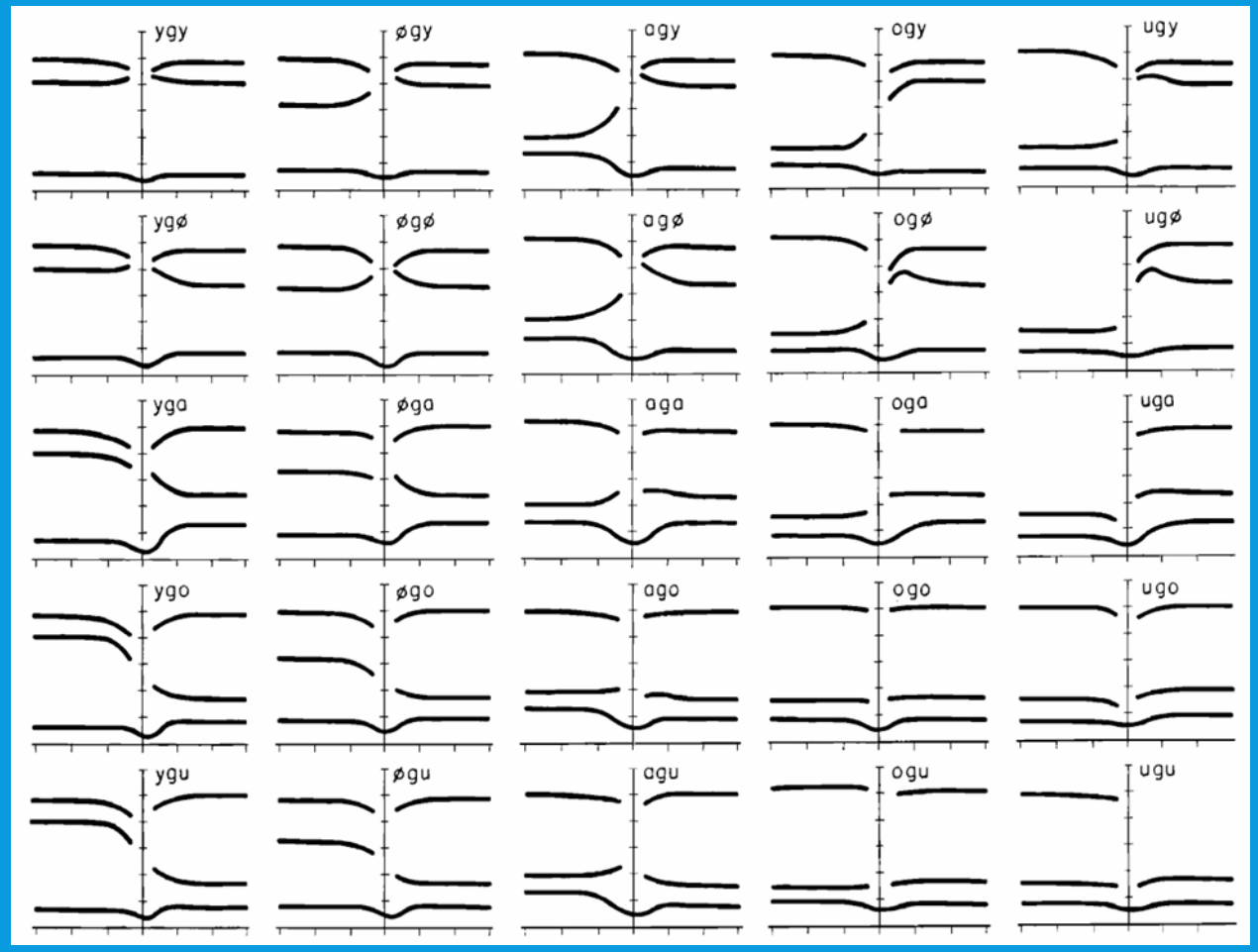
- /VCø/:
  - All /b/ transitions located lower-left, all /g/ transitions upper-left and all /d/ transitions right
  - ➢No overlap between /b/ and /g/
- /øCV/:
  - Some /g/ transitions located in the same area as /b/ transitions
  - ➢/øbø/ and /øgy/ very similar

INTERPRETATION



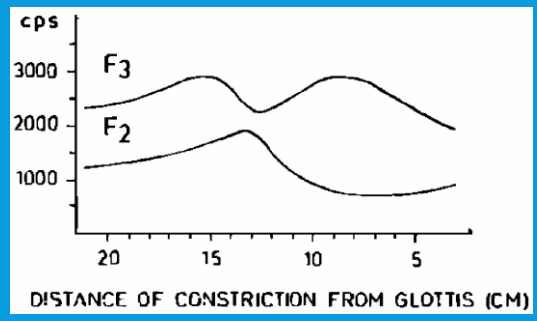
- Spectrograms of all VCV combinations
  - Averages of all five productions
  - ➢ Visible frequency shifts
  - ➢ Dependence on transconsonantal vowel

INTERPRETATION



- S-like shape of F2 transitions in the final vowel of some VgV productions
  - beginning with back vowel and ending with front vowel
  - Caused by place of constriction of vowels within the vocal tract

➢ Final vowel is anticipated and produced before target position is reached



EXPERIMENT 3: AMERICAN SPEAKER

AMERICAN SPEAKER

- Stimuli: List of VCV non-words involving the vowels /i/, /a/ and /u/, and the stop consonants /d/ and /g/
  - 3 x 2 x 3 possible combinations -> 18 stimuli (read five times)

		VdV		VgV	
		Initial	Final	Initial	Final
i	i	2260	2340	2290	2325
	a	2340	2280	2240	2280
	u	2290	2260	2280	2280
a	i	1180	1210	1200	1245
	a	1140	1200	1160	1175
	u	1130	1180	1120	1205
u	i	830	960	870	960
	a	830	950	860	930
	u	860	950	860	960

		VdV		VgV	
		VC	CV	VC	CV
i	i	−130	−380	+10	−65
	a	−190	−390	+100	−80
	u	−250	−370	−40	−20
a	i	+360	+550	+260	+825
	a	+275	+110	+160	+355
	u	+290	+420	+80	+165
u	i	+730	+820	+130	+640
	a	+630	+650	+90	+280
	u	+500	+650	0	+75

➢ **Same patterns as for the Swedish speaker**

EXPERIMENT 4: RUSSIAN SPEAKER

RUSSIAN SPEAKER

- Interesting because of distinction between palatalized and velarized consonants in Russian
- Stimuli: List of VCV non-words consisting of the vowel /ɛ/ followed by the stop consonants /b/, /d/, /g/ or their palatalized counterparts and ending in /i, ɒl/, /ɛ/, /a/, /o/ or /u/
  - 1 x 3 x 5 possible combinations -> 15 stimuli (read five times)
- Ranges of variation of the F2 transitions in the initial vowel under the different contextual conditions:

ɛb′–	ɛb–	ɛd′–	ɛd–	ɛg′–	ɛg–
120	90	80	60	45	570

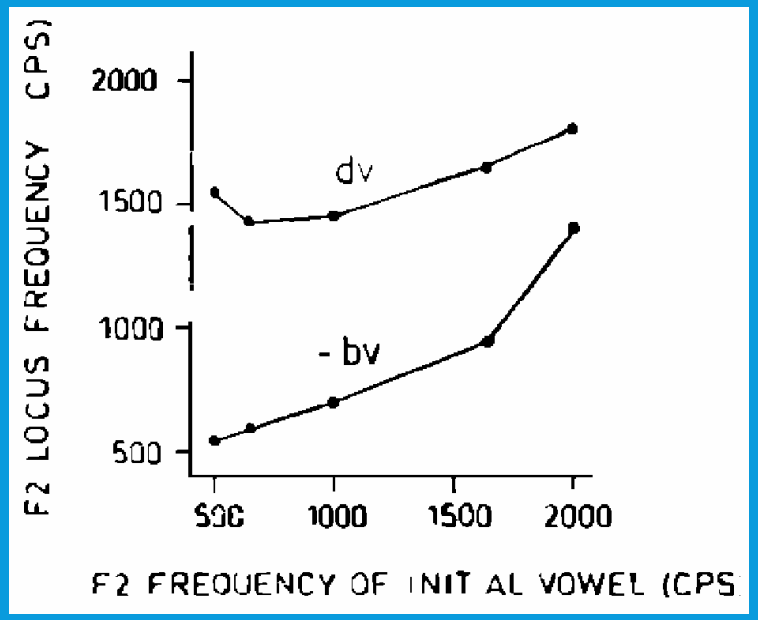
- No significant variation except for /g/
  - /g/ + front vowel not admissible in Russian morphemes -> might not be representative

➢ **Type of coarticulation in Swedish and English does not seem to be present in Russian**

DISCUSSION

LOCUS THEORY

- Liberman (1957): For each consonant there is a characteristic frequency position (locus) at which the formant transition begins or points to -> invariant consonant frequency
  - ➢Transitions as movements from loci to frequency levels of the next phone

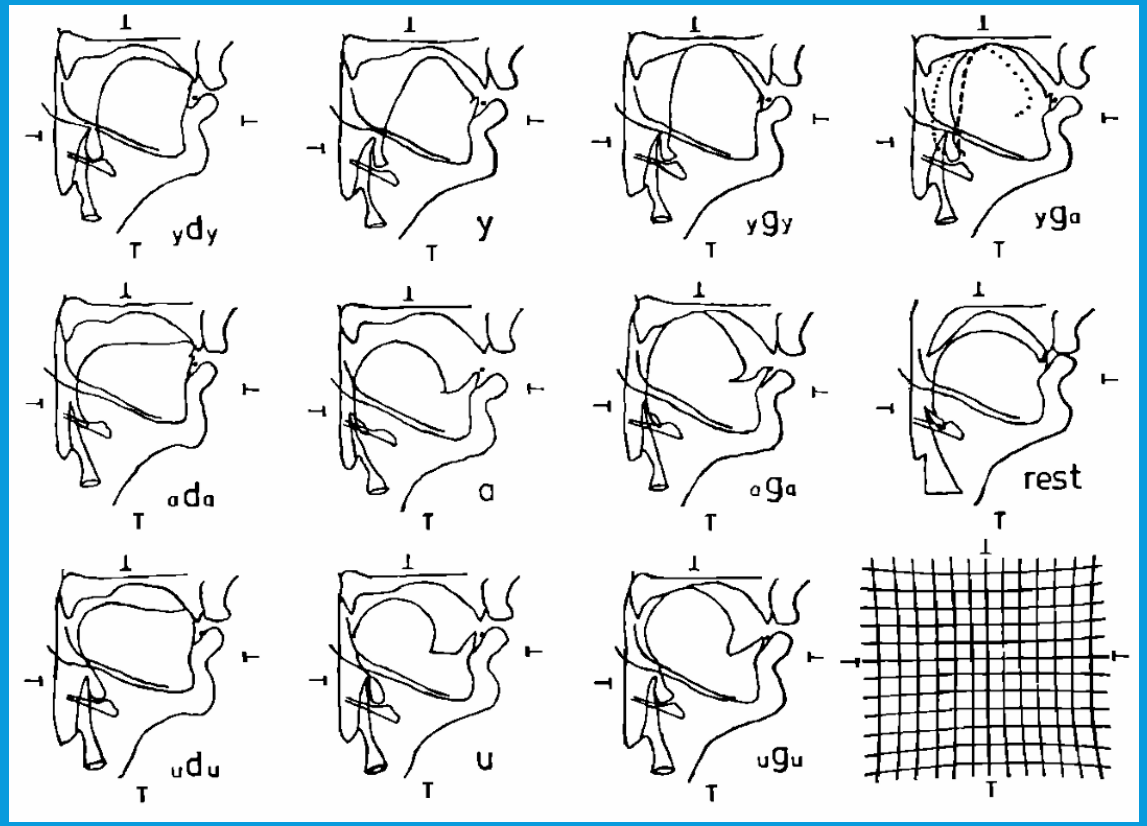


- F2 frequencies of transition loci of /b/ + V and /d/ + V for different transconsonantal vowels
  - /b/ and /d/ loci are not independent of the preceding vowel

➢**No constant formant-frequency cue for consonant perception, but analysis of the whole VCV production**

PHYSIOLOGICAL INTERPRETATION

- Findings suggest that variability in VC formant transitions is controlled by final vowel
  - Motion toward final vowel starts not much later or simultaneously with onset of consonant gesture
- Assimilation of the stop to the initial and final vowel impacts shape of unconstricted parts of the vocal tract
  - Dependence of constriction place on surrounding vowels
- /yga/: Tongue between places measured for /ygy/ and /aga/
  - Vowel gesture starts during production of stop consonant



PHYSIOLOGICAL INTERPRETATION

- Production of vowels and consonants involves activity of three sets of muscles that are partly overlapping
  - Might be controlled independently
  - However, neural commands of sets combine dynamically during speech production
  - Some languages might impose phonetic restrictions overruling freedom of control mechanisms
- In English and Swedish, stops are apparently produced through commands related to the apical and dorsal system
  - Subset of muscles is free to anticipate vowel production
- In Russian, "vowel channel" is additionally occupied during stop production
  - No free subset of muscles to anticipate vowel production

TIMING OF INSTRUCTION COMPONENTS

- Only three motor instructions are assumed: Initial vowel, consonant, final vowel
  - Instruction of V2 is already initialized during production of consonant

- However, only some components of vowel gestures are activated already at the onset of the consonant gesture
  - /ydu/: /d/ could not be produced if tongue would anticipate back vowel /u/ too early
  - Consonant gesture overrules vowel gesture if they are antagonistic

SUMMARY

- Terminal formant frequencies in VCV utterances depend not only on the consonant, but on the entire vowel context (English and Swedish)
  - Stop consonant loci are not unique
  - Simultaneous activation of neural commands for consonant and vowel production due to anticipation mechanisms
  - Certain components of V2 may be inhibited during consonant production because of anatomical limitations
- Freedom of coarticulation is smaller in Russian
  - Stops must always be coarticulated with either [i] (palatal) or [ɒl] (velar)
- Independent control of different subsets of tongue muscles
  - Dynamic interplay during production