3.4. Sequences of nasal and obstruent consonants

In this section, the sequences where nasals combine with obstruent consonants in C1 and C2 position will be analyzed. Section 3.4.1 presents the results for obstruent – nasal sequences and section 3.4.2 presents the results for nasal – obstruent sequences. Sections 3.4.3 and 3.4.4 analyze the effect of speaking rate and degree of overlap on voicing in these sequences.

3.4.1. Obstruent – Nasal sequences

We will first address stop/fricative – nasal sequences in Catalan, and then we will turn to the English sequences. The results for the stop – nasal sequence /k#n/, and the control sequence /g#n/ for Catalan (top) and English (bottom) are shown in Figure 3.26. In the Catalan sequence /k#n/, both speakers mostly implemented C1 with no vocal fold vibration and a voiced C2, with devoicing of the initial portion of C2 probably due to inertial effects. Speaker AN also displayed complete regressive assimilation, *i.e.*, [gn]. The control sequence /g#n/ showed the same voicing patterns as the test sequence /k#n/: complete voicing throughout and devoicing of C1. As shown in Table XI below, no significant difference was found between the mean percentage of voicing in the sequence /k#n/ and the voiced control sequence /g#n/ for speaker AN, and the difference did not reach significance for speaker MJ.

Thus, concerning the direction and extent of voicing assimilation, the data seems to show that onset of vocal fold vibration in the sequence /k#n/ was coordinated with the onset of the oral constriction for C2, and that complete regressive assimilation applied optionally in a categorical fashion.

Table XI. Results of one-way ANOVA comparing percentage of voicing in sequences where nasals combined with obstruents. * = $p<.05$, ** = $p<.01$

Language	Sequence type	Mean	SD	N	Speaker	Sequences	ANOVA	*p*	Sig.
Catalan	/g#n/	-53	55	9	AN	/g#n/-/k#n/	F(1,21)=0.608	0.443	
	/k#n/	-33	62	14					
	/g#n/	3.5	73.2	13	MJ		F(1,22)=3.348	0.080	
	/k#n/	44.4	11.4	11					
	/z#n/	-27.3	28.1	8	AN	/z#n/-/s#n/	F(1,20)=9.694	0.005	**
	/s#n/	-2.5	8.3	14					
	/z#n/	8.5	28.7	12	MJ		F(1,18)=0.086	0.771	
	/s#n/	4.9	23.5	8					
	/N#d/	100	0	9	AN	/N#d/-/N#t/	F(1,20)=101.61	0.0001	**
	/N#t/	33.7	19.5	13					
	/N#d/	90.5	19.7	10	MJ		F(1,17)=116,68	0.0001	**
	/N#t/	8.7	11.8	9					
	/N#z/	80.2	33.8	7	AN	/N#z/-/N#s/	F(1,17)=60.04	0.0001	**
	/N#s/	3.9	6.2	12					
	/N#z/	22.8	25.5	10	MJ		F(1,19)=52.09	0.0001	**

	/N#s/	-44.8	17	11					
English	/g#n/	-100	0	10	AL	/g#n/-/k#n/	F(1,19)=19.377	0.0001	**
	/k#n/	-55	32	11					
	/g#n/	-55.5	55	14	ME		F(1,26)=32.030	0.0001	**
	/k#n/	30.8	15.3	14					
	/z#n/	-100	0	9	AL	/z#n/-/s#n/	F(1,18)=126.08	0.0001	**
	/s#n/	39.6	18.2	10					
	/z#n/	22.6	11.6	14	ME		F(1,27)=4.804	0.037	*
	/s#n/	31.1	9.3	15					
	/N#d/	100	0	9	AL	/N#d/-/N#t/	F(1,16)=24.08	0.0001	**
	/N#t/	65.3	21.2	9					
	/N#d/	94.5	13.7	12	ME		F(1,23)=69.24	0.0001	**
	/N#t/	36.1	20.3	13					
	/N#z/	100	0	10	AL	/N#z/-/N#s/	F(1,17)=220.88	0.0001	**
	/N#s/	13.7	18.4	9					
	/N#z/	65	28.4	11	ME		F(1.21)=45.75	0.0001	**
	/N#s/	8.8	4.1	12					

In the Catalan sequence /s#n/, shown in Figure 3.27, onset of vocal fold vibration coincided with the onset of C2 for both speakers. There were no cases of regressive voicing assimilation. The control sequence /z#n/ showed lack of voicing during over three fourths of the fricative constriction (reflecting the difficulty to maintain voicing in fricatives). Table XI shows that, percentage of voicing did not differ significantly in the sequences /z#n/ and /s#n/ for speaker MJ, whereas there was significantly more voicing in the voiced control sequence for subject AN.

Figure 3.26 shows that, in English, the sequence /k#n/ was produced with a voiceless C1 and glottal vibration in C2 by subject ME, although the initial portion of C2 was frequently devoiced. Speaker AL, on the other hand, tended to advance the voicing gesture to C1 partially or completely, so that in some cases C1 was fully voiced, a process that was also observed in this subject in the obstruent sequence /t#g/. For the sequence /s#n/, in Figure 3.27, both subjects displayed partial devoicing of the initial portion of C2, [σν6ν].

Thus, in English obstruent-nasal sequences, onset of voicing seemed to be coordinated, as in Catalan, with onset of C2. Similarly to Catalan, one of the speakers (AL) showed regressive assimilation of voicing into C1. Table XI above shows that the mean percentage of voicing in the control and in the test sequences differed significantly for both speakers.

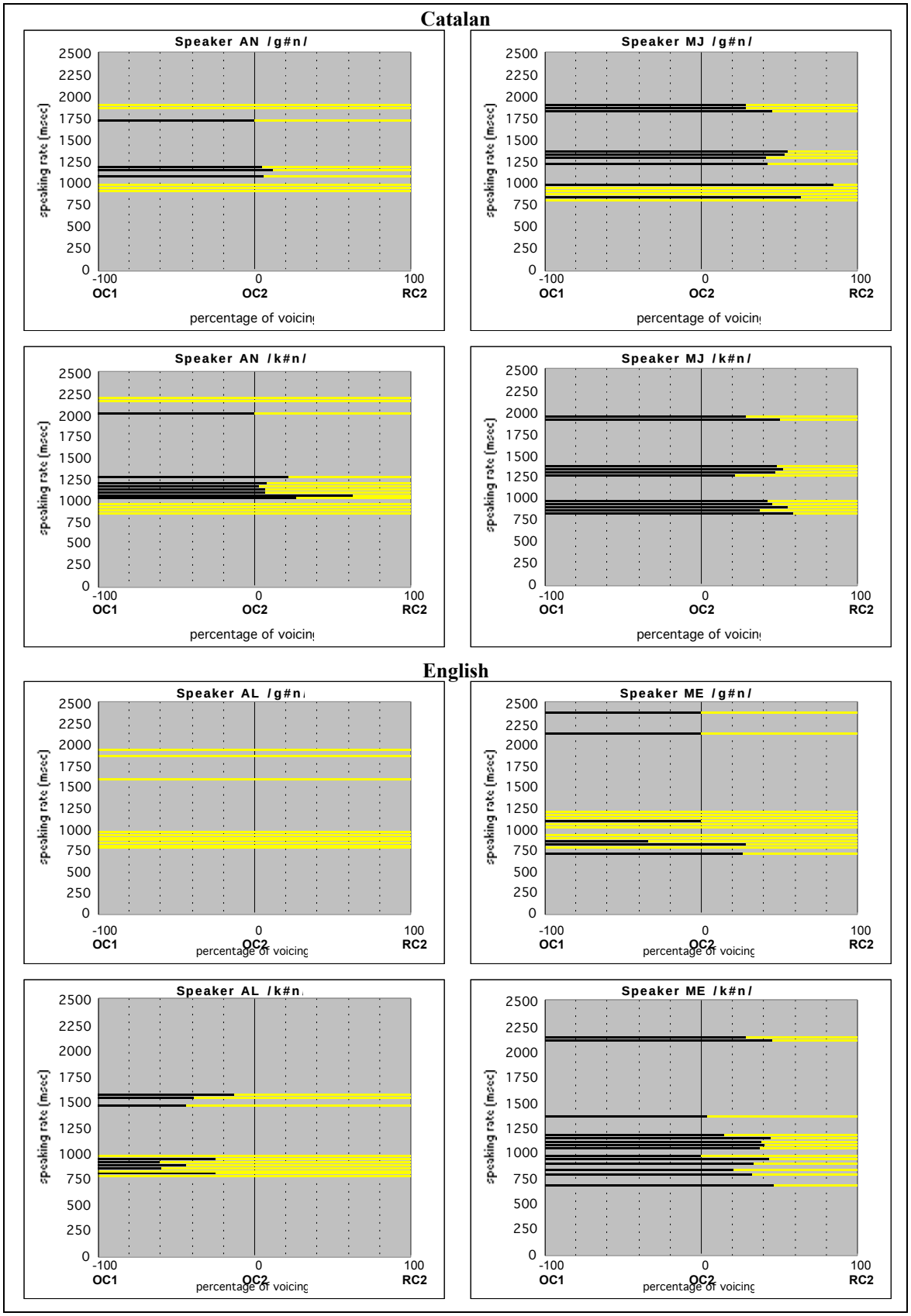

Figure 3.26. Vocal fold vibration in the consonant sequences in 'mag nou, big nut' (/g#n/) and 'Mac nou, thick nut' (/k#n/) in Catalan and English. The yellow lines represent vocal fold vibration and the black lines represent absence of vocal fold vibration. Speaking rate appears on the ordinate and percentage of voicing in relation to supraglottal gestures appears on the abscissa. OC1 stands for onset of C1, OC2 stands for onset of C2 and RC2 stands for release of C2. Each line represents one observation.

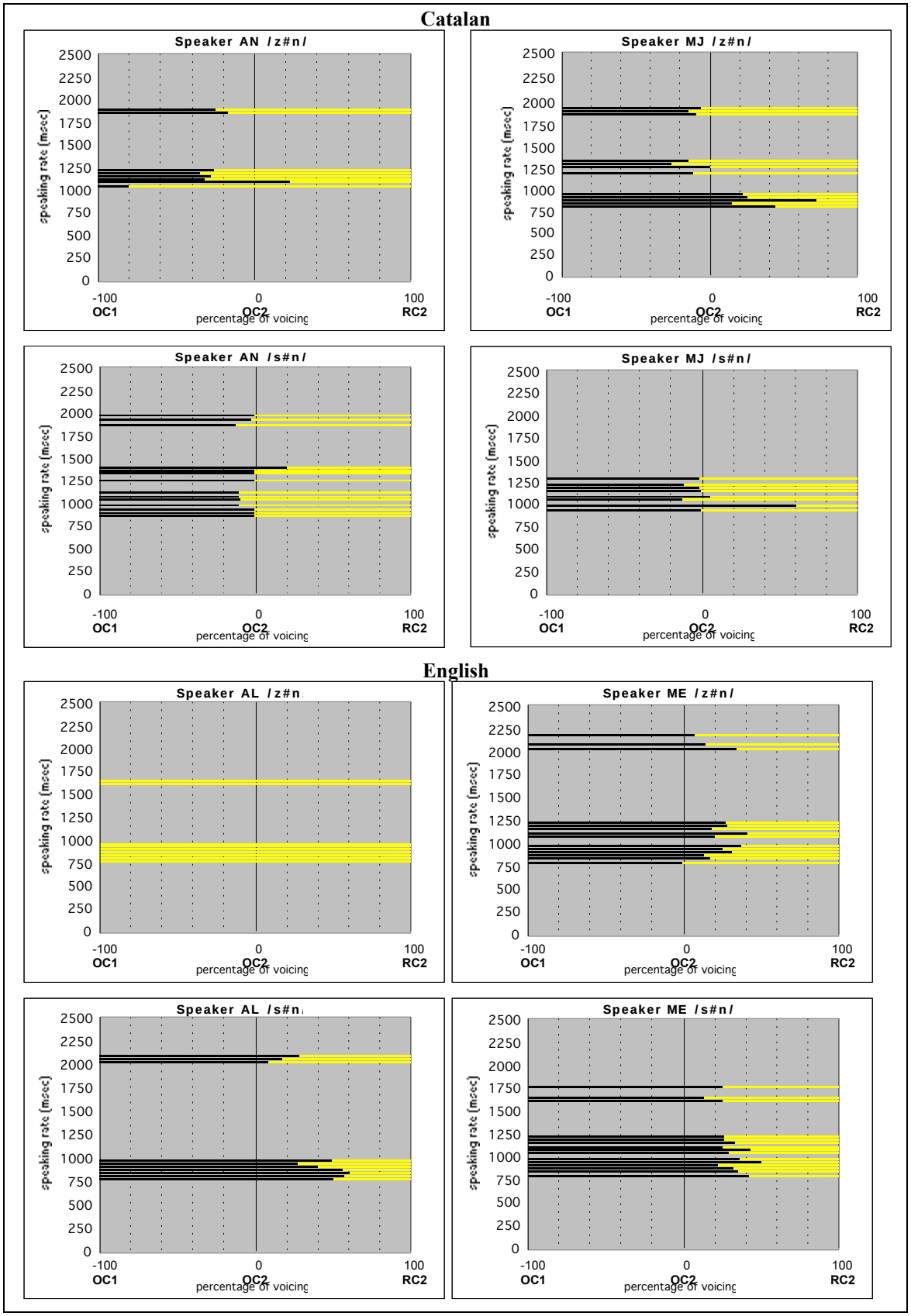

Figure 3.27. Vocal fold vibration in the consonant sequences in 'ga**s n**ou, hi**s n**ut' (/z#n/) and 'pa**s n**ou, thi**s n**ut' (/s#n/) in Catalan and English. The yellow lines represent vocal fold vibration and the black lines represent absence of vocal fold vibration. Speaking rate appears on the ordinate and percentage of voicing in relation to supraglottal gestures appears on the abscissa. OC1 stands for onset of C1, OC2 stands for onset of C2 and RC2 stands for release of C2. Each represents one observation.

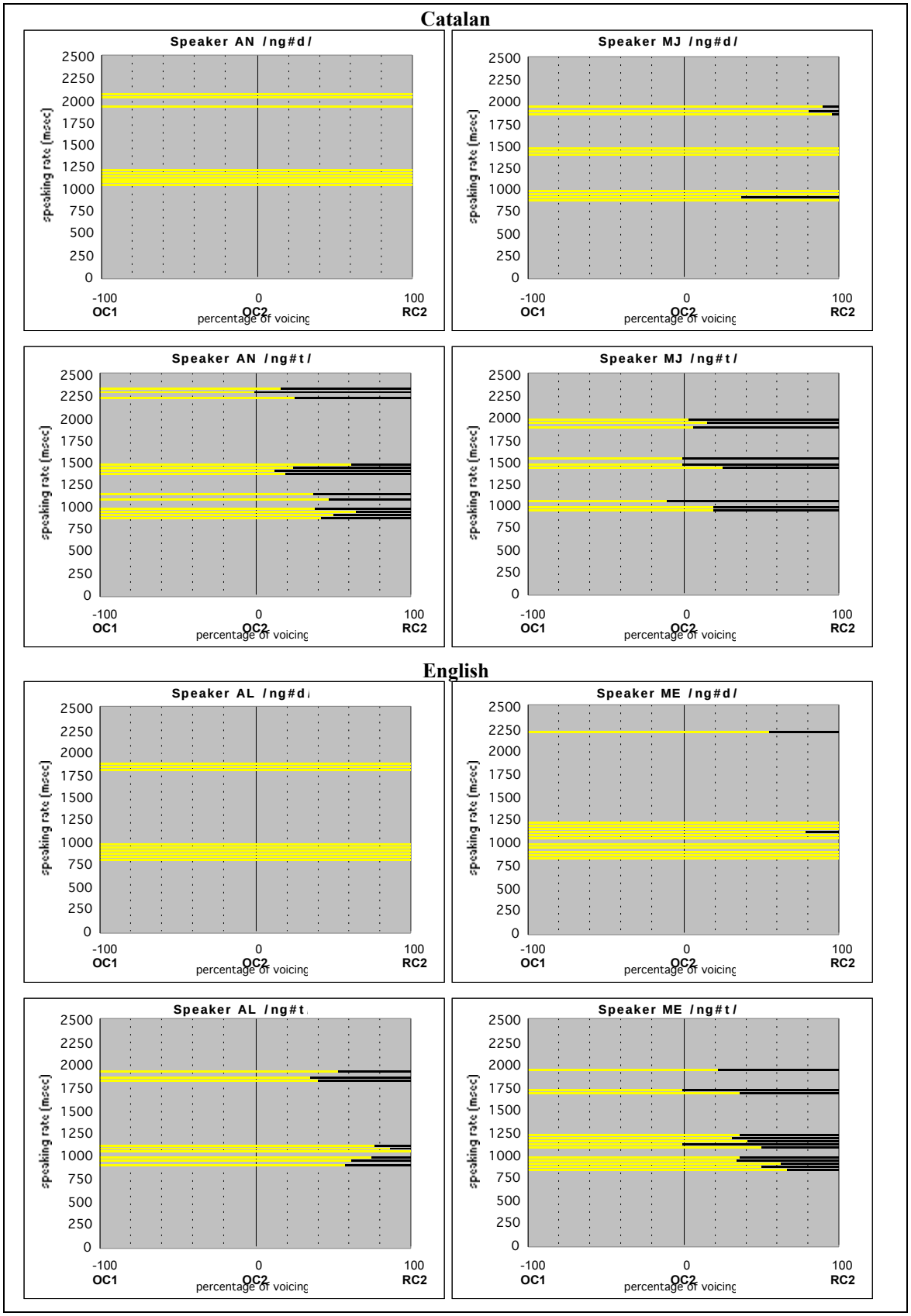

Figure 3.28. Vocal fold vibration observed in the consonant sequences in 'fon**g d**ur, lo**ng d**oll' (/N#d/) and 'fo**ng t**urc, lo**ng t**oll' (/N#t/) in Catalan and English. The yellow lines represent vocal fold vibration and the black lines represent absence of vocal fold vibration. Speaking rate appears on the ordinate and percentage of voicing in relation to supraglottal gestures appears on the abscissa. OC1 stands for onset of C1, OC2 stands for onset of C2 and RC2 stands for release of C2. Each line represents one observation.

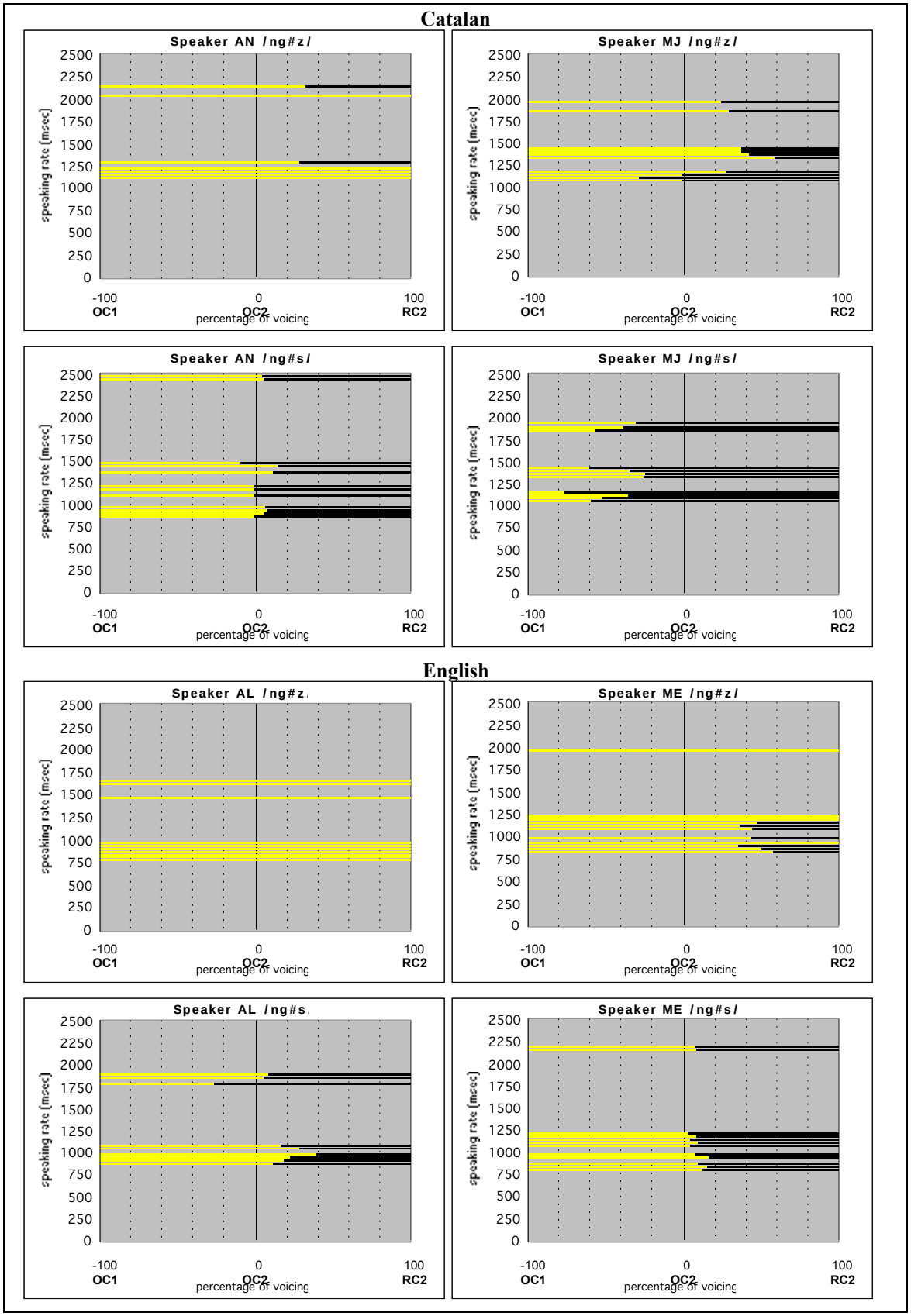

Figure 3.29. Vocal fold vibration in the consonant sequences in 'fo**ng z**íngar, lo**ng z**ip' (/N#z/) and 'fo**ng s**imple, lo**ng s**ip' (/N#s/) in Catalan and English. The yellow lines represent vocal fold vibration and the black lines represent absence of vocal fold vibration. Speaking rate appears on the ordinate and percentage of voicing in relation to supraglottal gestures appears on the abscissa. OC1 stands for onset of C1, OC2 stands for onset of C2 and RC2 stands for release of C2. Each line represents one observation.

3.4.2. Nasal – Obstruent sequences

The percentage of voicing in the sequences /N#t/ and /N#s/, together with the voiced control sequences /N#d/ and /N#z/ is presented in Figures 3.28 and 3.29 respectively. Catalan and English showed a similar pattern: C1 was implemented with vocal fold vibration throughout and C2 was implemented as voiceless. Offset of voicing appeared to be coordinated with the onset of the oral closure for C2 in the test sequences. In the control sequences, both consonants were implemented as voiced, with voicing dying out before the release of C2 due to mechanical devoicing (mostly for the Catalan speaker MJ and the English speaker ME). One-way-ANOVAs (see Table XI above) showed that, in all cases, the voiced control sequences /N#d/ and /N#z/ showed significantly more voicing than the test sequences.

For the sequence /N#s/, shown in Figure 3.29, Catalan and English speakers showed vocal fold vibration in C1 and absence of vocal fold vibration in C2. The Catalan speaker MJ displayed devoicing of the last third of C1 in all cases, most likely due to the advancement of the glottal abductory gesture for C2. In most cases, though, over 50 per cent of C1 was voiced.

The data suggest that, in /N#t/ and /N#s/ sequences in both languages, offset of vocal fold vibration was targeted at the onset of the oral constriction for C2, and mechanical anticipatory or progressive movements were possible. In sum, nasal – obstruent and obstruent – nasal sequences in Catalan and English exhibited vocal fold vibration relatively synchronic with their phonological specification.

In nasal – stop sequences such as /N#t/ it can be observed that the glottal vibration for the nasal penetrated into C2 in both languages. In the sequence /N#s/ voicing also penetrated into C2 in English but less so than in /N#t/. We will return to this question in the discussion section.

3.4.3. Speaking rate effects

In order to explore the relationship between speaking rate and degree of voicing in obstruent – nasal and nasal – obstruent in Catalan and English, the percentage of voicing for each individual sequence was plotted as a function of rate of speech. Figures 3.30 and 3.31 below display the results for obstruent – nasal test and control sequences in both languages for both speakers. The reverse nasal – obstruent sequences are shown in Figures 3.32 and 3.33. The data in the scattergrams cluster around 0 regardless of rate of speech. Similarly, the values for voicing onset/offset in the control sequences do not correlate with speaking rate effects. The results of Pearson's correlation tests, reported in Table XII below, show no significant values for effect of speaking rate on degree of voicing.

Table XII. Results of Pearson's correlation exploring the effect of speaking rate on percentage of voicing in sequences where nasals combined with obstruents in Catalan and English. * = $p<.05$, ** = $p<.01$

Sequence	Speaker	r^2	p.	Sequence	Speaker	r^2	p.
Catalan				English			
/k#n/	AN	0.004	0.882	/k#n/	AL	0.246	0.119
	MJ	0.100	0.341		ME	0.0001	0.980
/s#n/	AN	0.006	0.787	/s#n/	AL	0.004	0.659
	MJ	0.203	0.261		ME	0.013	0.388
/N#t/	AN	0.248	0.120	/N#t/	AL	0.019	0.562
	MJ	0.008	0.809		ME	0.035	0.342
/N#s/	AN	0.004	0.837	/N#s/	AL	0.036	0.486
	MJ	0.083	0.387		ME	0.125	0.257

3.4.4. Effect of degree of overlap

In order to explore the relationship between degree of overlap and the amount of voicing in stop – nasal and nasal – stop sequences, the percentage of voicing for each individual sequence was plotted as a function of overlap indexes OIACO and OIOC. Figures 3.34 and 3.35 display the results for the sequences /k#n/ and /N#t/, respectively, in Catalan and English. The data in the scattergrams show that in Catalan the test sequences clustered around 0 in most cases regardless of articulatory overlap. In English, speaker AL showed more voicing into C1 in the sequence /k#n/ the greater the degree of overlap, whereas for speaker ME C2 was more devoiced the greater the degree of overlap in this sequence. Thus, the English speakers exhibited inverse tendencies. The results of Pearson's correlation tests analyzing the relationship between degree of overlap and percentage of voicing are reported in Table XIII below for OIACO and in Table XIV below for OIOC. Pearson's correlation showed that there was a significant correlation between degree of overlap and degree of C2 devoicing for subject ME, and that there was a significant correlation between degree of articulatory overlap and degree of voicing into C1 for subject AL. No significant correlation was found in any of the Catalan speakers.

Table XIII. Results of Pearson's correlation exploring the effect of overlap index OIACO on % of voicing in sequences where nasals combined with obstruents in Catalan and English. * = $p<.05$, **=$p<.01$.

Sequence	Speaker	r^2	p.	Sequence	Speaker	r^2	p.
Catalan				English			
/k#n/	AN	0.101	0.268	/k#n/	AL	0.122	0.292
	MJ	0.019	0.679		ME	0.688	0.0002**
/N#t/	AN	0.161	0.173	/N#t/	AL	0.0003	0.963
	MJ	0.011	0.304		ME	0.056	0.433

Table XIV. Results of Pearson's correlation exploring the effect of overlap index OIOC on % of voicing in sequences where nasals combined with obstruents in Catalan and English. * = $p<.05$, ** = $p<.01$.

Sequence	Speaker	r^2	p.	Sequence	Speaker	r^2	p.
Catalan				English			
/k#n/	AN	0.007	0.762	/k#n/	AL	0.472	0.019*
	MJ	0.026	0.069		ME	0.757	0.00005**
/N#t/	AN	0.091	0.314	/N#t/	AL	0.00001	0.994
	MJ	0.304	0.120		ME	0.175	0.153

Catalan

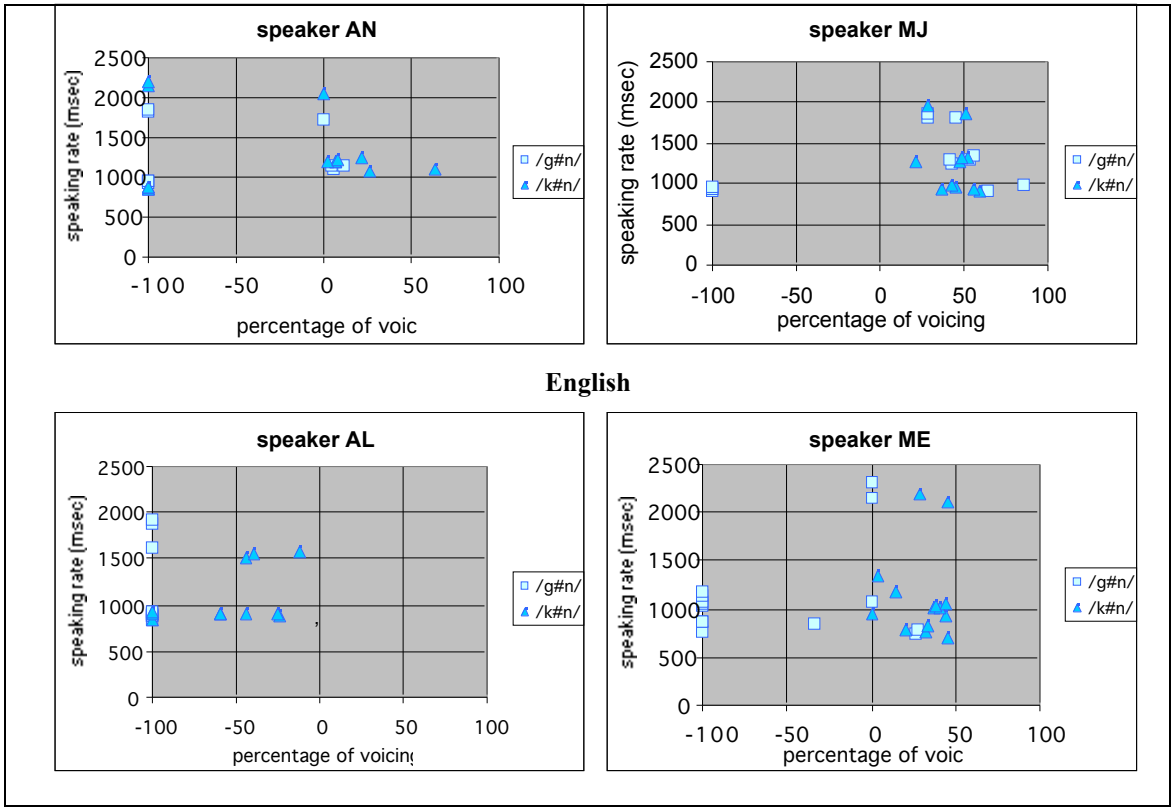

Figure 3.30. Scattergrams of percentage of voicing (horizontal axis) plotted as a function of speaking rate (vertical axis) in the Catalan and English sequences 'mag nou, big nut' (/g#n/) and 'Mac nou, thick nut' (/k#n/), with higher values indicating slower speaking rates. Each dot represents one observation.

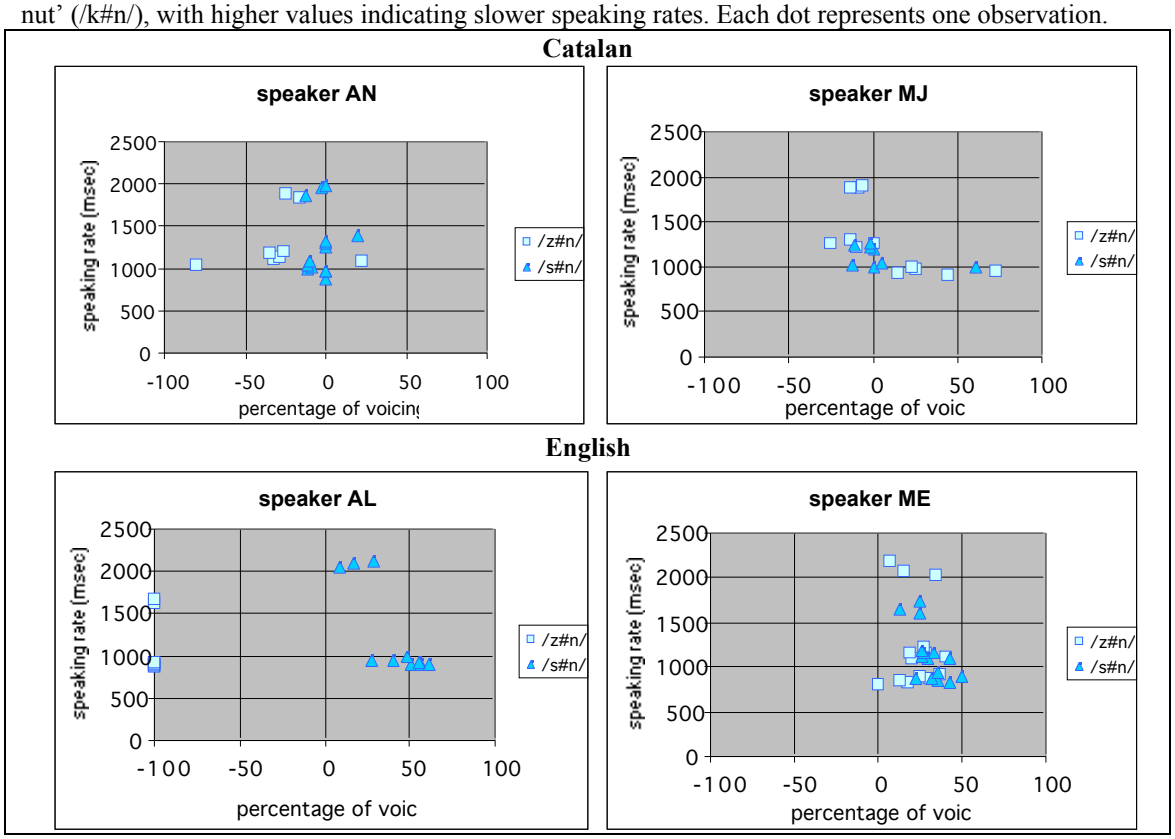

Figure 3.31. Scattergrams of percentage of voicing (horizontal axis) plotted as a function of speaking rate (vertical axis) in the Catalan and English sequences 'gas nou, his nut' (/z#n/) and 'pas nou, this nut' (/s#n/), with higher values indicating slower speaking rates. Each represents one observation.

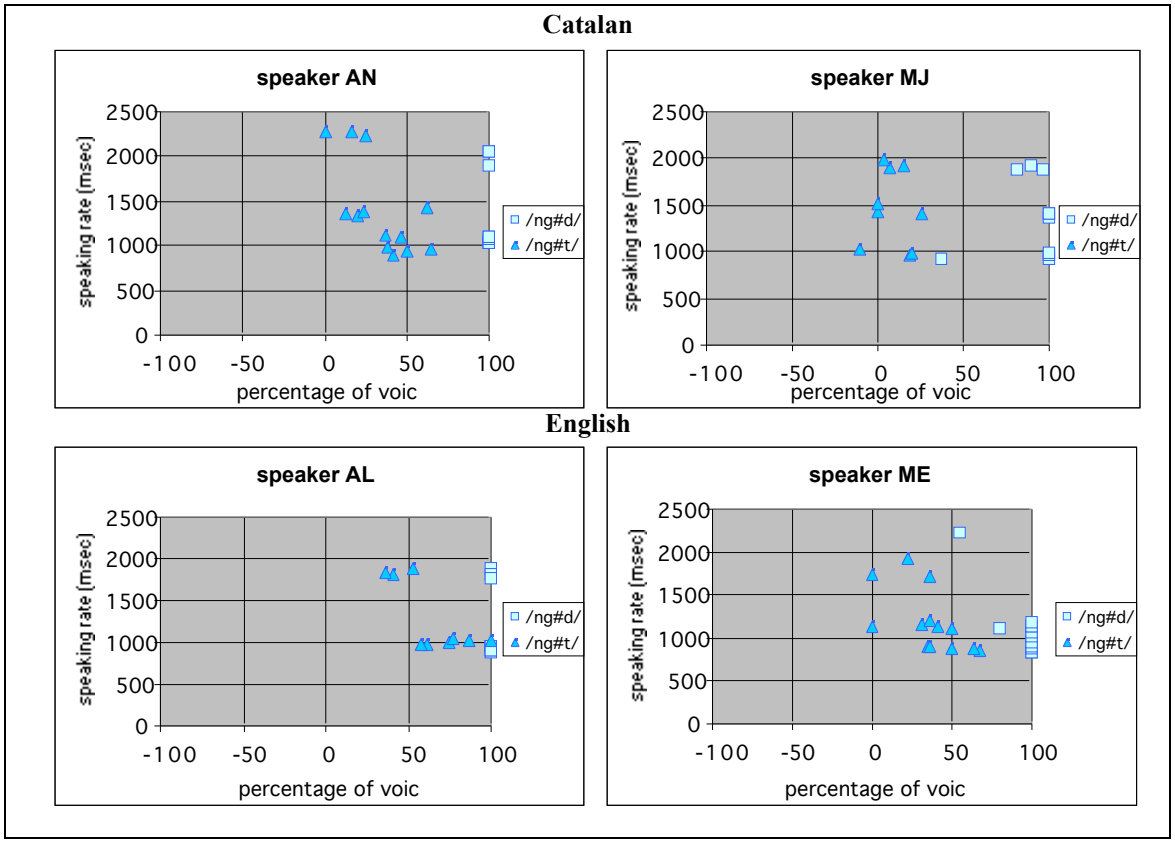

Figure 3.32. Scattergrams of percentage of voicing (horizontal axis) plotted as a function of speaking rate (vertical axis) in the Catalan and English sequences 'fong dur, long doll' (/N#d/) and 'fong turc, long toll' (/N#t/), with higher values indicating slower speaking rates. Each dot represents one observation.

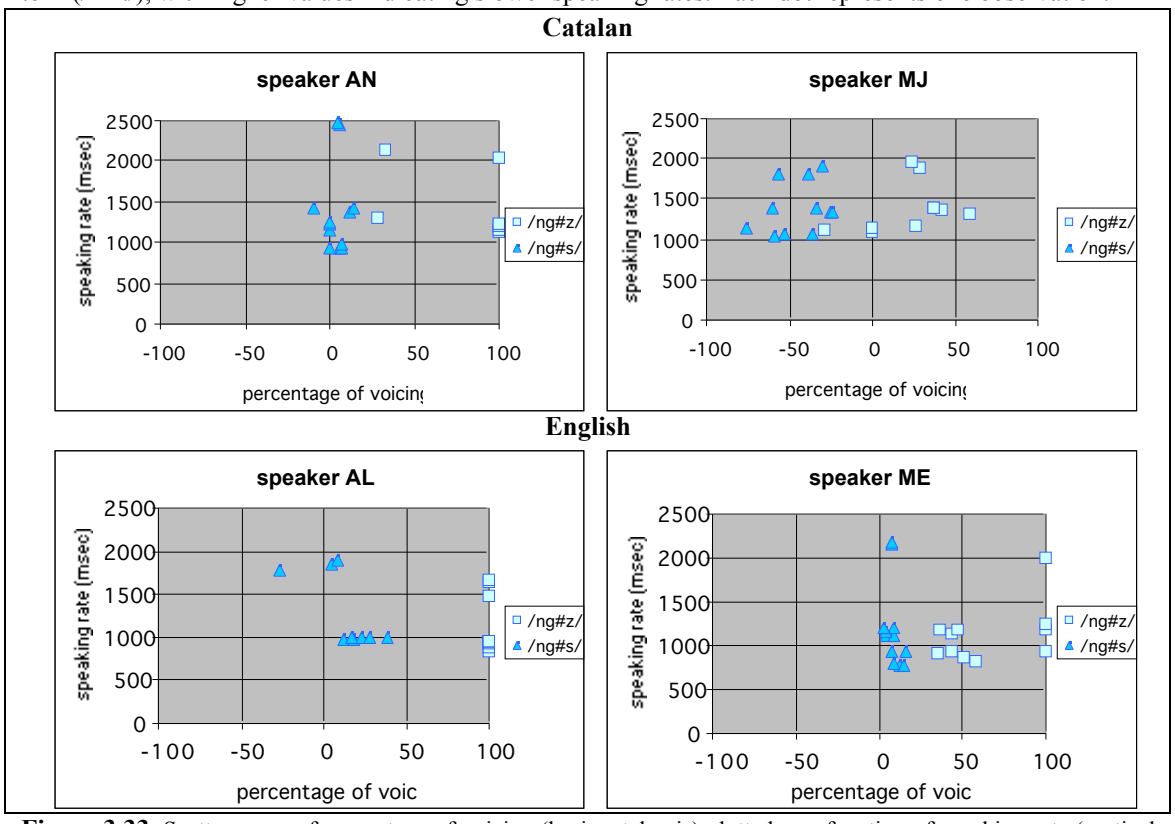

Figure 3.33. Scattergrams of percentage of voicing (horizontal axis) plotted as a function of speaking rate (vertical axis) in the Catalan and English sequences 'fong zíngar, long zip' (/N#z/) and 'fong simple, long sip' (/N#s/), with higher values indicating slower speaking rates. Each dot represents one observation.

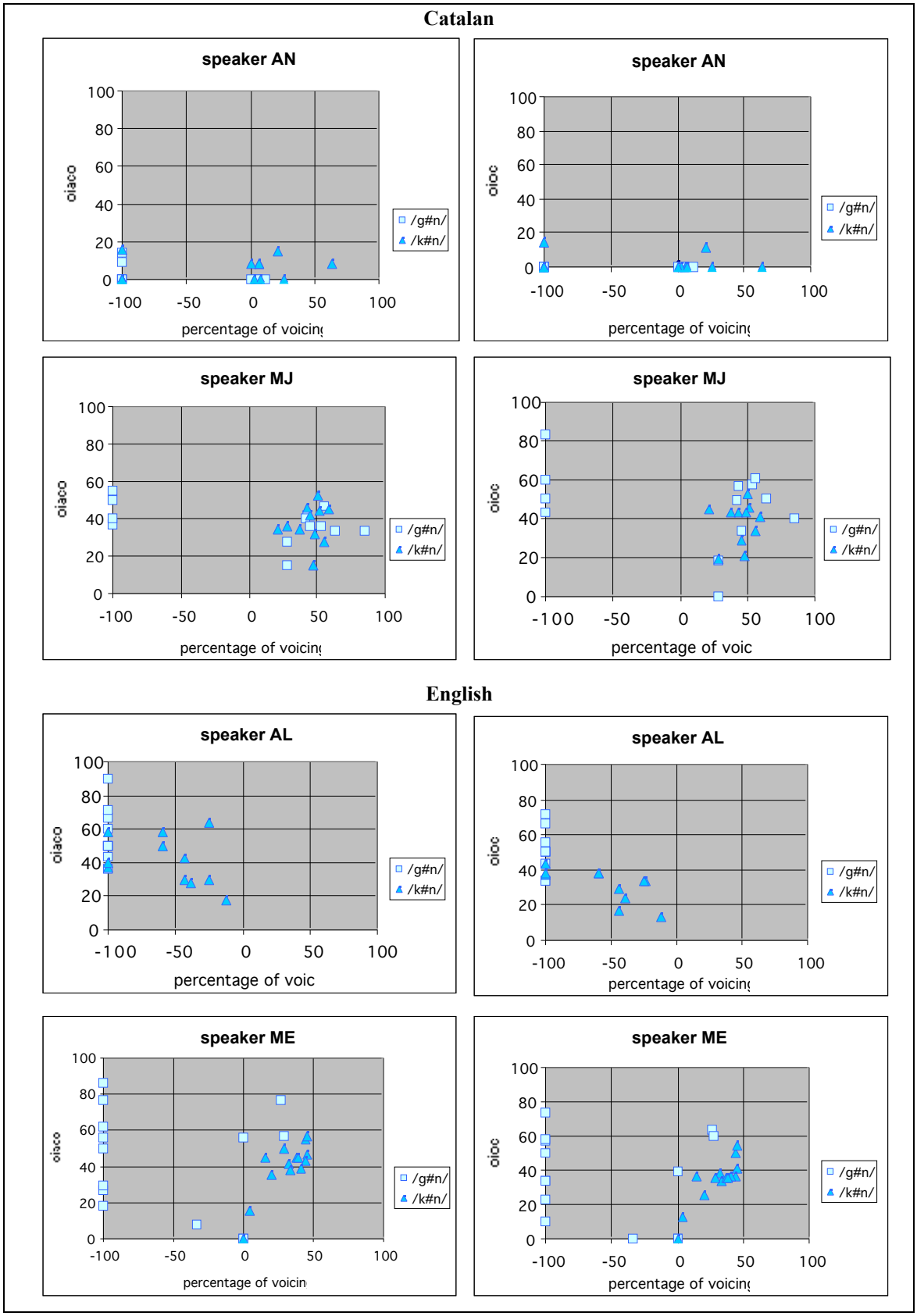

Figure 3.34. Scattergrams of percentage of voicing (horizontal axis) in the individual tokens plotted as a function of overlap indexes OIACO and OIOC (vertical axis) in the Catalan and English sequences 'mag nou, big nut' (/g#n/) and 'Mac nou, thick nut' (/k#n/). Each dot represents one observation.

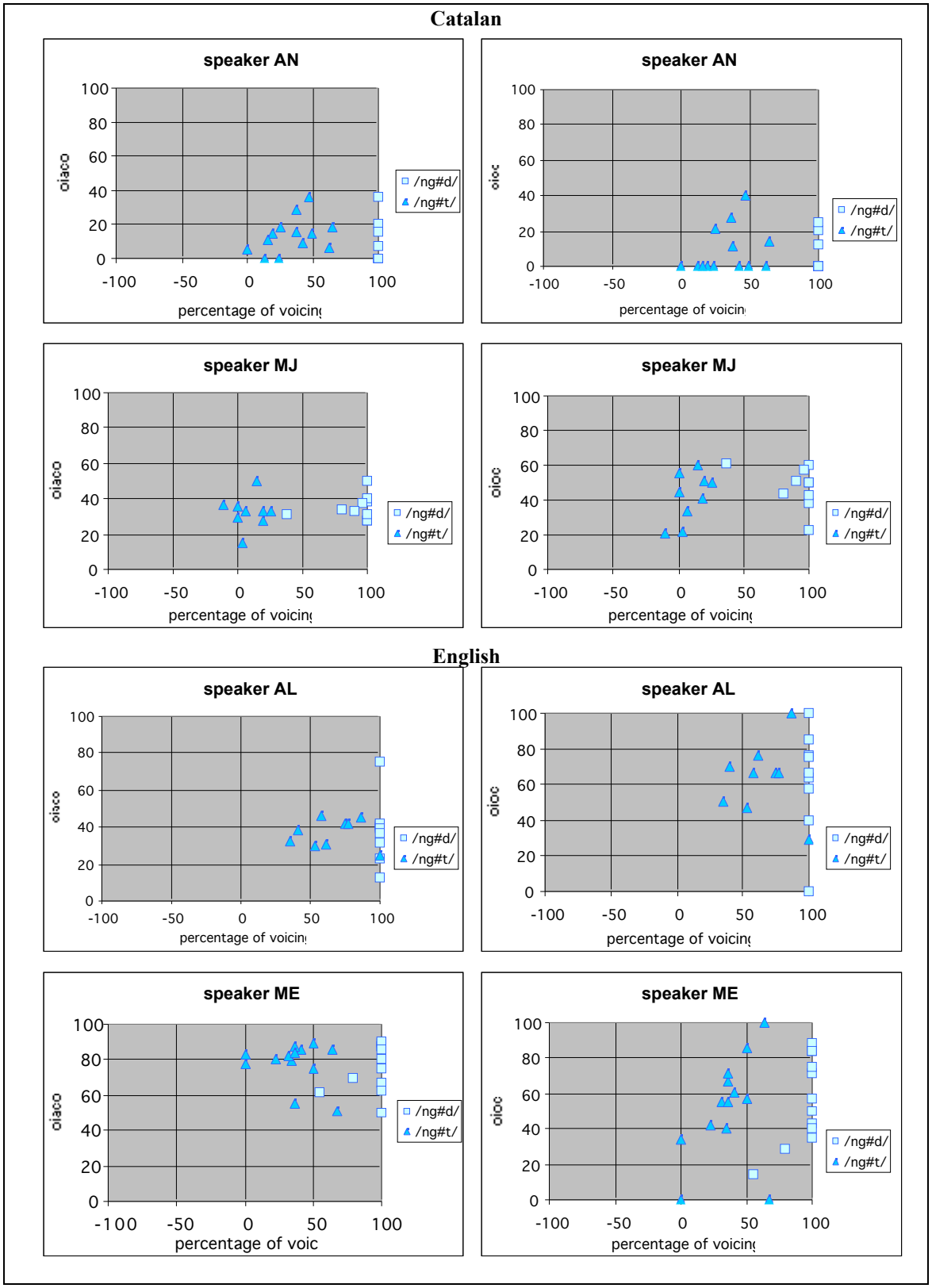

Figure 3.35. Scattergrams of percentage of voicing (horizontal axis) in the individual tokens plotted as a function of overlap indexes OIACO and OIOC (vertical axis) in the Catalan and English sequences 'fong dur, long doll' (/N#d/) and 'fong turc, long toll' (/N#t/). Each dot represents one observation.