

## **4. Discussion and Conclusions**

## **4. Discussion and Conclusions**

The aim of this chapter is to elaborate on the theoretical issues raised in chapter 1 on the basis of the results presented in chapter 3. The questions that are addressed are, in the first place, whether voicing assimilation is a gradient or a categorical process in each of the two languages studied, and secondly, whether there is a phonological rule for voicing assimilation in Catalan and English. I will discuss the mechanism that may underlie these patterns in section 4.2. Finally, I will summarize the conclusions (section 4.3).

#### 4.1. Discussion

The results of the present experiment provide evidence for categorical and gradient assimilation of voicing in Catalan. Categorical voicing assimilation was found in the sequences /t#g/ (realized as [d#g]), /s#d/ (realized as [z#d]), /z#t/ (realized as [s#t]) for the two speakers, and /d#k/ for speaker MJ (realized as [t#k]), as reported in chapter 3. The categorical behavior of assimilation may reflect a phonological rule of regressive voicing assimilation in Catalan. That is, C1 may take the voicing specification of C2 in obstruent sequences if no pause is present. The assimilation process seems to apply independently of speaking rate and articulatory overlap.

The Catalan results also show evidence for gradient assimilation, since for the sequence /d#k/ one of the speakers (AN) maintained voicing in C1 to an extent that made it different from the voiceless sequence /t#k/, so that regressive assimilation was partial. In this case, then, the neutralization of the voicing distinction is incomplete. Thus, voicing assimilation may also be an articulatorily gradient process in Catalan.

These results agree with previous experiments on voicing assimilation in Catalan, which found that obstruent sequences with different phonological specifications for voicing result in complete regressive assimilation of the voicing specification of C2 in most cases but that incomplete neutralization can also be found (Carbonell 1992, Cuartero 1998). As reported in chapter 1, Carbonell (1992) found that some speakers displayed more voicing in C1 in the underlyingly voiced sequences than in underlyingly voiceless – voiced sequences. Incomplete neutralization has also been reported for Russian (Burton *et al.* (1997)).

Additionally, the Catalan data show variability in the maintenance of vocal fold vibration in long obstruent sequences, *e.g.*, /t#g/ → [dd̥g̥], where voicing tends to die out due to aerodynamic factors. What the data seem to show is that, both for /t#g/ and

/d#g/, at least the first half of C1 must be voiced and that there has to be voicing at the release of C2.

In English obstruent sequences, the coordination of glottal and supraglottal gestures was different from that found in Catalan. Thus, in voiceless – voiced sequences such as /t#g/ and /s#d/, the general pattern is to partially or completely devoice C2, although regressive voicing of C1 may also occur at fast speaking rates (as found for speaker AL), reflecting anticipatory gestural overlap. In voiced – voiceless sequences such as /d#k/ and /z#t/, there is partial or complete devoicing of C1, but speakers may implement C1 as voiced, too. Thus, the English data showed large variability in the coordination of oral and glottal gestures in obstruent sequences, which is compatible with the fact that vocal fold vibration during the oral constriction is not a reliable cue for voicing in obstruents (Lisker and Abramson, 1964). The large variability found in the coordination of glottal and oral gestures in English obstruent sequences is compatible with data by other investigators (Westbury (1979), Docherty (1992) and Cuartero (1998)).

In sum, the greater stability of the timing of voicing in Catalan as opposed to the variability obtained in English suggests that the coordination of oral and glottal gestures is slightly more constrained in Catalan than in English obstruent sequences.

In English obstruent sequences, as opposed to Catalan ones, degree of overlap of the supraglottal articulators and speaking rate may affect the coordination of oral and glottal gestures. Thus, the English sequence /t#g/ may be implemented as voiced throughout when there is complete articulatory overlap and when the sequence is uttered at a fast speaking rate (speaker AL), suggesting complete anticipation of the C2 gesture due to time constraints. Conversely, at slow speaking rates the tendency is progressive devoicing of C2, suggesting inertial constraints. Thus, the speaker's articulatory

strategies to adjust to speaking rate differences result in qualitatively different patterns. In addition, for the English subject ME, the sequence /t#g/ was implemented with complete devoicing of C2 ([t#k]) if degree of articulatory overlap was higher than 50%, whereas there was partial devoicing of C2 if degree of overlap was smaller. In sum, these facts suggest that the assimilation of glottal gestures in English sequences is of a gradient nature, and depends on the degree of articulatory overlap and speaking rate (as predicted for phonetic effects, Solé 1992, 1995a). Unlike Catalan speakers, who plan the coordination of oral and glottal gestures during the obstruent closure in a constrained manner with the glottal gesture of C2 advanced to the onset of C1, English shows more variability for the organization of glottal and supraglottal gestures during the maximal constriction for the obstruents, although there are constraints on the variability that may take place. Either there is gradual anticipation of the voicing gesture for C2 (resulting in total or partial voicing/devoicing of C1), or there are inertial effects of the glottal gesture for C1 on C2 (resulting in partial voicing/devoicing of C2).

In sequences where voiceless obstruents combine with sonorants, the phonetic implementation of voicing is in accord with the phonological specification of the segment in both languages, but there is variability in the transition from C1 to C2. Thus, in the English and Catalan sequences /k#n/, /s#n/, /k#l/ and /s#l/ the second half of C1 may be voiced or the first half of C2 may be devoiced (consistent with anticipatory overlap and inertial effects, respectively). It seems, then, that the instructions for the change in the voicing gesture are coordinated with the onset of the oral constriction for C2, and that variability in the transition from C1 to C2 may occur. Thus, approximately half of the sonorant has to maintain its phonological specification for voicing whereas the portion adjacent to the obstruent allows variability due to speaking rate effects and articulatory overlap. In other words, there are constraints in the degree to which the

voicing gesture can penetrate into the adjacent consonant in this type of sequence. That is, variability can take place but with temporal restrictions.

Although the organization of oral and glottal gestures was fairly similar in Catalan and English obstruent – sonorant sequences, there was one difference: the Catalan data showed cases of complete regressive assimilation of voicing. Speaker AN showed complete voicing of /k#n/ and /k#l/ in a few cases. This optional process applies categorically in this Catalan speaker independent of speaking rate and articulatory overlap. Thus, it seems that the Catalan voicing assimilation rule, by which obstruents take the voicing specification of the immediately following consonant, may have been extended to obstruent – sonorant sequences for some speakers.

In the reverse sonorant – obstruent sequences the glottal gesture is also switched at the transition between the two consonants in the sequences /l#k/ and /l#s/, that is, when C1 was a lateral consonant, and the variability observed results from implementational factors. Again, there seem to be constraints on the variability that is allowed: in these sequences, at least the first half of C1 must show vocal fold vibration, and at least the second half of C2 must show vocal fold abduction in both languages. In nasal – obstruent sequences (/ #t/ and / #s/) voicing penetrated into C2 due to mechanical factors. Hayes and Stivers (1996) cite two mechanisms which favor the continuation of vocal fold vibration in nasal – obstruent sequences: firstly, the coarticulatory lowering of velum position during part of the obstruent consonant is sufficient to achieve “nasal leak”, which facilitates the continuation of vocal fold vibration (Ohala 1983). Secondly, when the velum is high enough to cut off nasal leak, it continues rising towards the pharynx, so the volume of the oral cavity expands and voicing is facilitated (Bell-Berti 1975). Coproduction of the obstruents with adjacent nasals may thus explain voicing continuation into the obstruent.

In nasal – stop sequences, voicing penetrated one to two thirds into C2, and in nasal – fricative sequences voicing penetrated significantly less than for stops. The smaller degree of voicing into C2 in nasal – fricative, vis-à-vis nasal stop sequences, most likely results from the difficulty to build up sufficient oral pressure to generate audible turbulence for fricatives with glottal resistance, that is, vibrating vocal folds (Ohala and Solé 1998).

Catalan sonorant – obstruent sequences, unlike obstruent – sonorant sequences, showed no cases of complete regressive assimilation of the voicing state of C2. This asymmetry may have a perceptual basis, since complete assimilation would yield a fully devoiced sonorant, which would endanger the correct perception of the consonant by the listener.

All in all, the data suggest that the phonology imposes constraints on the implementation of voicing in obstruent sequences in English, and that these constraints differ from the ones we find in Catalan. In English the constraints on the implementation of voicing during the consonant obstruction may not be as tight as in Catalan since vocal fold vibration during the constriction does not seem to be the primary cue for voicing in obstruents; rather, other cues such as the length of the vowel preceding C1 and the state of the glottis at the release of C2 seem to be the articulatory targets in English as suggested by Lisker and Abramson (1964) and Peterson and Lehiste (1960). Thus, variability is allowed in the implementation of voicing during the articulatory constriction in this language. In Catalan, on the other hand, there seem to be more severe temporal constraints in the coordination of oral and glottal gestures in obstruent sequences than in English, since the voicing patterns were more consistent and less variable than in English. In Catalan, the voicing gesture of C2 is, in most cases,

advanced to C1. However, it was also seen that this is not always the case, and the voicing specification for C1 may be maintained.



## 4.2 Phonological modeling

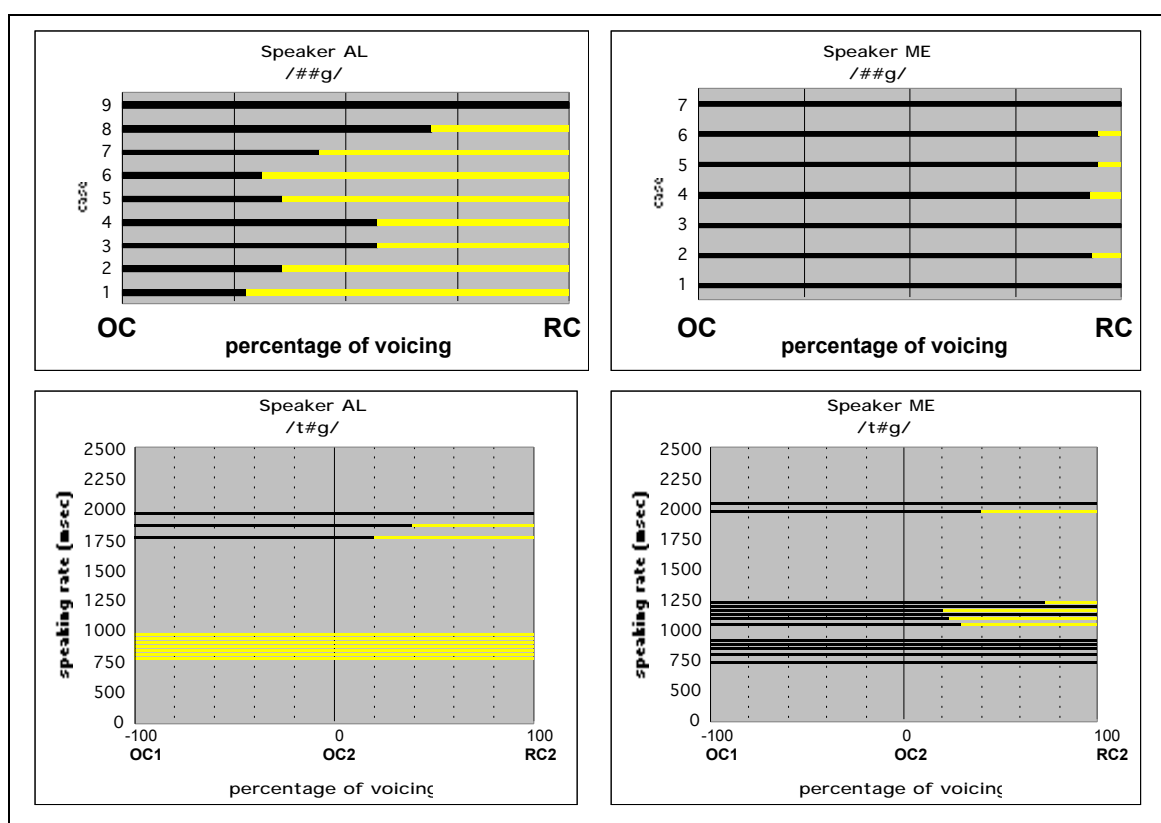
An adequate model of phonetic implementation should explain the variability observed, as well as the constraints that are at work in both languages. In addition, we have to establish how changes in glottal movements are coordinated in time in relation to supraglottal movements. Different models will be reviewed and it will be argued that Articulatory Phonology (Browman and Goldstein 1986, 1990) and Windows Theory (Keating 1988) may adequately explain the data observed.

In feature-based models like autosegmental phonology (Clements 1985), voicing assimilation in Catalan obstruents may be represented as linking the laryngeal node of C2 to that of C1. The problem with this formal representation is that it does not explain the direction of voicing assimilation and does not account for intermediate articulations. The same problem arises for English, where it is difficult to account both for the variability observed and for gradual, rather than categorical, assimilatory patterns.

In Articulatory Phonology, the process of voicing assimilation in Catalan may be described as perturbation of the glottal state for C1 due to total overlap of the competing configuration for the laryngeal gesture of C2. Partial overlap of competing configurations might account for the organization of gestures in English obstruent sequences. However, Articulatory Phonology would predict that regressive voicing assimilation would be a gradient process, co-varying with speaking rate and articulatory overlap both in Catalan and in English. Yet, the data in the present experiment showed no relationship between speaking rate/articulatory overlap and the coordination of oral and glottal gestures in Catalan, where the process was found to be categorical in most cases.

The results for English could be accounted for by this model in the following terms. The glottal behavior in English voiceless – voiced obstruent sequences could be

explained in terms of the implementation of voicing in *single* obstruents. Figure 4.0 below displays the timing of vocal fold vibration during the constriction for initial voiced stops (top) and for voiced stops following a voiceless obstruent (bottom) for the English subjects AL and ME. As the Figure shows, the English speaker AL displays voicing lead in initial voiced obstruents (top left panel). In consonant sequences, the vocal fold adduction gesture for /g/ might be advanced to the onset of the oral closure for C1, due to articulatory overlap, and result in fully voiced sequences for this speaker (bottom left panel). Speaker ME, on the other hand, shows little or no voicing lead in initial obstruents (top right panel). For this speaker, anticipation of the glottal gesture for /g/ in consonant sequences would result in a partially or fully voiceless C1 (bottom right panel).



**Figure 4.0.** Vocal fold vibration observed in the consonant /g/ in postpausal position for the English subjects AL and ME (top) and in the consonant sequence /t#g/ in ‘fat gap’ for the same speakers (bottom). The yellow lines represent vocal fold vibration and the black lines represent absence of vocal fold vibration. OC stands for onset of the oral constriction and RC stands for release of the oral constriction. OC1 stands for onset of C1, OC2 stands for onset of C2 and RC2 stands for release of C2. Each line represents one observation.

According to Articulatory Phonology, in English voiced – voiceless obstruent sequences the abductory glottal gesture for C2 would partially or completely overlap the adductory gesture for C1 in running speech, and this would result in partial or complete devoicing of C1. However, the data obtained showed that vocal fold vibration may be maintained during C1 in English sequences: partial or complete devoicing of C1 was observed in some cases, whereas in others C1 was fully voiced.

The Catalan data obtained cannot be explained as resulting solely from the inherent properties of the articulatory gestures; rather, the anticipation of the voicing gesture of C2 onto C1 seems to arise from higher level restructuring of conflicting consecutive motor commands in a single laryngeal gesture. In other words, complete voicing assimilation in Catalan seems to result from a phonological process, involving different motor instructions.

The range of assimilatory phenomena observed in Catalan and English may stem from the same source – gestural overlap and overlap of motor commands due to faster speaking rates or other time constraints – but may reflect two synchronically different processes. At one end, mechanical gestural overlap and increased speaking rate may result in varying degrees of voicing assimilation (including complete assimilation). At the other end, these phonetic tendencies may have been encoded in a higher-level reorganization of motor commands or a categorical process (as Nolan and Holst (1993) and Solé (1999) have argued for other assimilatory processes).

Now we will turn to an alternative account of the data obtained which may also satisfactorily explain the implementation of voicing in English and Catalan consonant sequences. Windows Theory (Keating 1988) is a model that takes discrete phonological features as input and produces a tracing of articulatory movement as output. Thus, it

aims at providing an interface between phonetics and phonology. In this model, the phonetic properties of segments along the different dimensions must be coordinated in time so that the listener perceives the correct segment. One of the main assumptions of Windows Theory is that phonetic dimensions are coordinated with respect to a small number of articulatory events, known as ‘articulatory landmarks’, which are both articulatorily and perceptually salient. The model also assumes that segments need not be specified for every feature. Feature specification results in consistency in the way a segment is phonetically implemented whereas variability suggests that a segment is not specified for that feature.

Keating (1988) suggests that articulatory targets are windows or ranges of allowable values along a phonetic dimension, so that contextual variation can be easily accounted for. Windows are assigned on the basis of feature specifications, and there may be cross-linguistic variation in the window width assigned to a particular type of segment. Besides, targets –or windows –have duration in time. The fact that windows have temporal width can explain fine coarticulatory effects in time that are a problem for analyses that are based on single target values.

The following assumptions, based on Huffman (1990), have to be made in order to account for the coordination of oral and glottal gestures:

- Segments are assigned laryngeal targets on the basis of feature specifications
- Targets are temporal windows of allowable values
- Interpolation connects targets by constructing a path through the available windows
- Target interpolation is variable but is constrained by a notion of economy, such as the goal of minimizing rate of change.

The data suggest that we need to specify certain states of the glottis and points in time when these states have to be achieved. The data also seem to indicate that there are targets for voicing gestures that are constrained in time. Voicing gestures are carefully controlled by speakers in relation to specific articulatory targets and variability is allowed as long as these targets are achieved. Glottal gestures may be coordinated with respect to three articulatory landmarks: onset of the consonant, middle of the consonant and release of the consonant for each consonant in the cluster. Temporal windows for voicing are mapped from the phonological specification with respect to these three articulatory landmarks.

For Catalan obstruents it could be hypothesized that voicing state is coordinated with the *middle* of the consonant (*i.e.*, vocal fold vibration – or lack thereof – has to be present (or absent) at the middle of the consonant constriction) whereas in English the glottal configuration might be tied to the *edges* of the obstruent (*i.e.*, vocal fold vibration has to be present or absent at or around consonant onset/release). Thus, it might be hypothesized that the voicing gesture may be targeted either at the *beginning* (for coda consonants) or at the *end* (for onset consonants) of the obstruent constriction in English. If the glottal abduction or adduction gesture is targeted at the beginning of the consonant, then the concomitant cues for voicing would be present in the immediately preceding segment (*e.g.*, preceding vowel length). When the glottal gesture is targeted at the end of the consonant, VOT values at consonant release would be the main cue for voicing. For sonorants, however, it may be hypothesized that vocal fold vibration is phased relative to the middle of the consonant in both languages. For vowels, vocal fold vibration would also be phased with the middle of the segment in both languages.

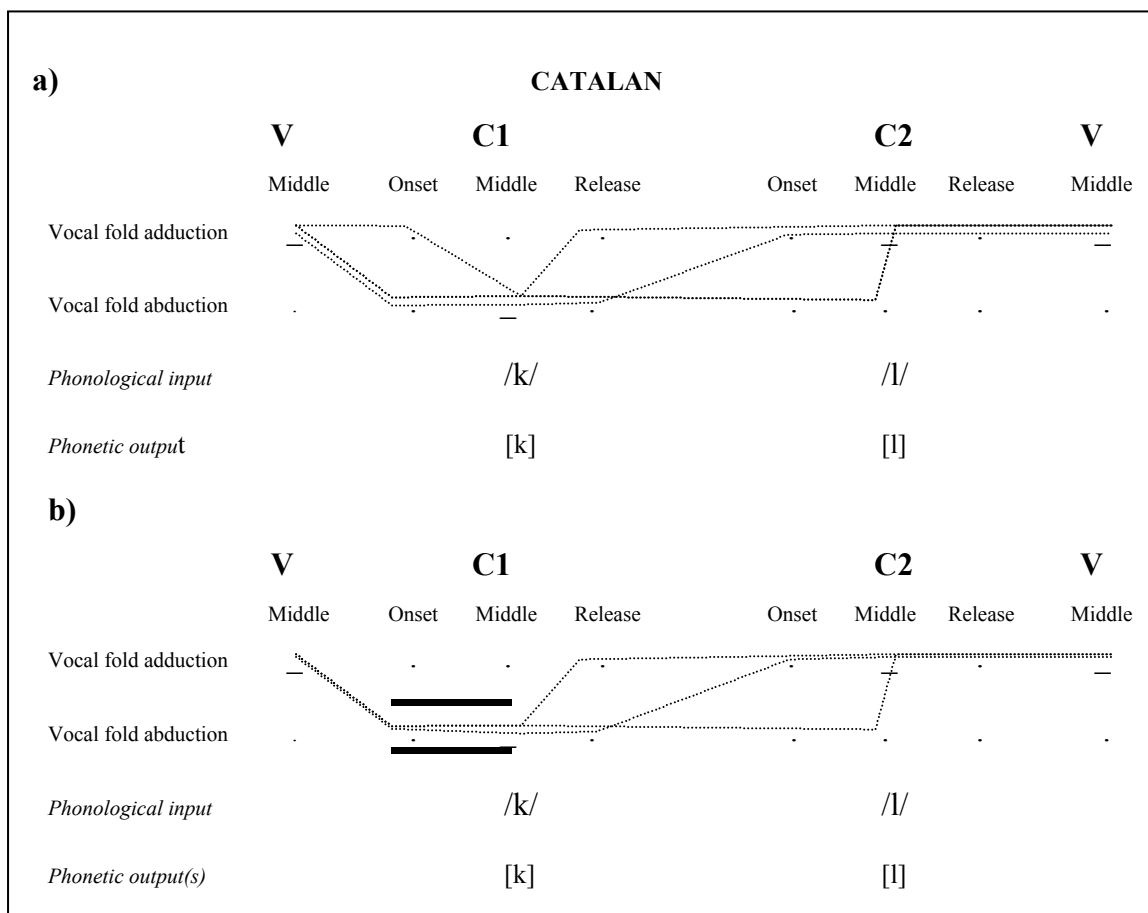
It has to be taken into account that vocal fold vibration has positioning, mechanical and aerodynamic constraints which are more severe than those required for voicelessness. Whereas there are different laryngeal configurations and pressure conditions that can lead to voicelessness, voicing requires a very precise laryngeal configuration and sufficient transglottal airflow. This is, however, not reflected in the diagrams below since they are an abstraction of laryngeal movements.

Figure 4.1 below represents the assignment of articulatory landmarks in Catalan *obstruent – sonorant* sequences. Each of the consonants contains, as observed above, three possible points – onset, middle and release – to which laryngeal targets can be associated. The small dots represent unassigned targets and the big dots represent assigned targets.

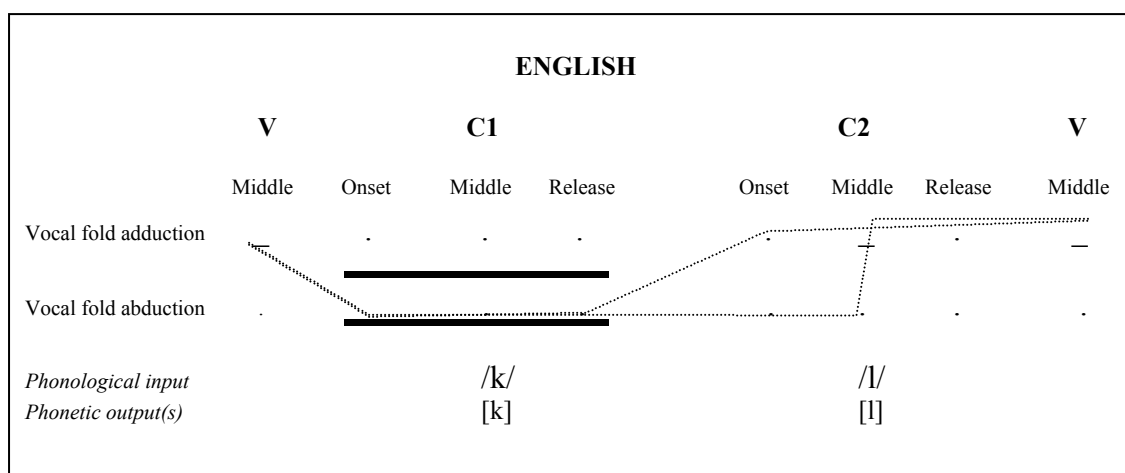
In the sequence in Figure 4.1, the middle of C1 would be targeted as voiceless and C2 would have a voiced target at the middle of C2. The representation in 4.1a would allow variability in the interpolation across laryngeal targets (indicated by a dotted line) for the first vowel and the laryngeal target for C1, which was not found in the data. Thus, it might be assumed, as shown in Figure 4.1b, that the laryngeal target for C1 has a temporal duration that extends to the onset of the consonant, as shown by the black lines in the Figure. This would ensure that C1 is voiceless from the onset to the middle of the consonant and variability would be allowed in the interpolation across the laryngeal targets for C1 and C2 as found in the data.

In English (Figure 4.2), vocal fold abduction for C1 would be targeted at the onset of C1 and the concomitant cues for voicing (*e.g.*, vowel length) would be present in the immediately preceding segment; the middle of C2 would be targeted as voiced. Since no cases were found where there was voicing in C1, the window for voicelessness in C1

may extend until the release of C1. Interpolation across targets allows variability to take place between the release and the middle of C2, as shown by the dotted line.

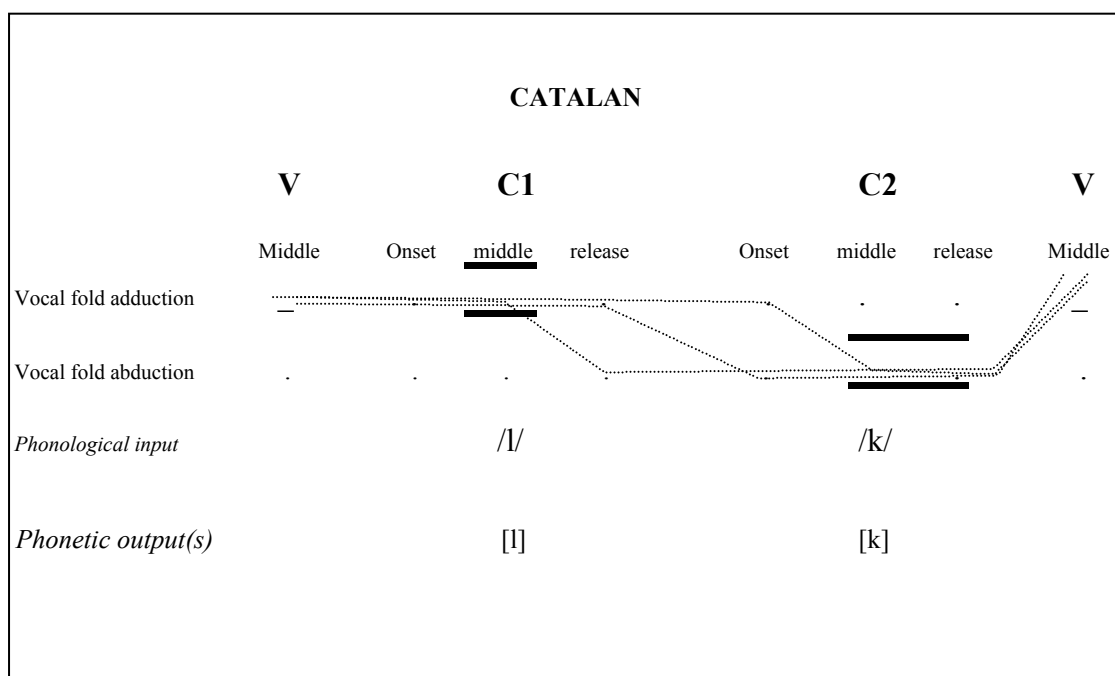


**Figure 4.1.** Windows Theory representation of voiceless obstruent – sonorant sequences in Catalan. The small dots represent possible articulatory landmarks and the big dots represent the laryngeal targets that speakers have to achieve at that landmark. Interpolation across targets is shown by the dotted line.



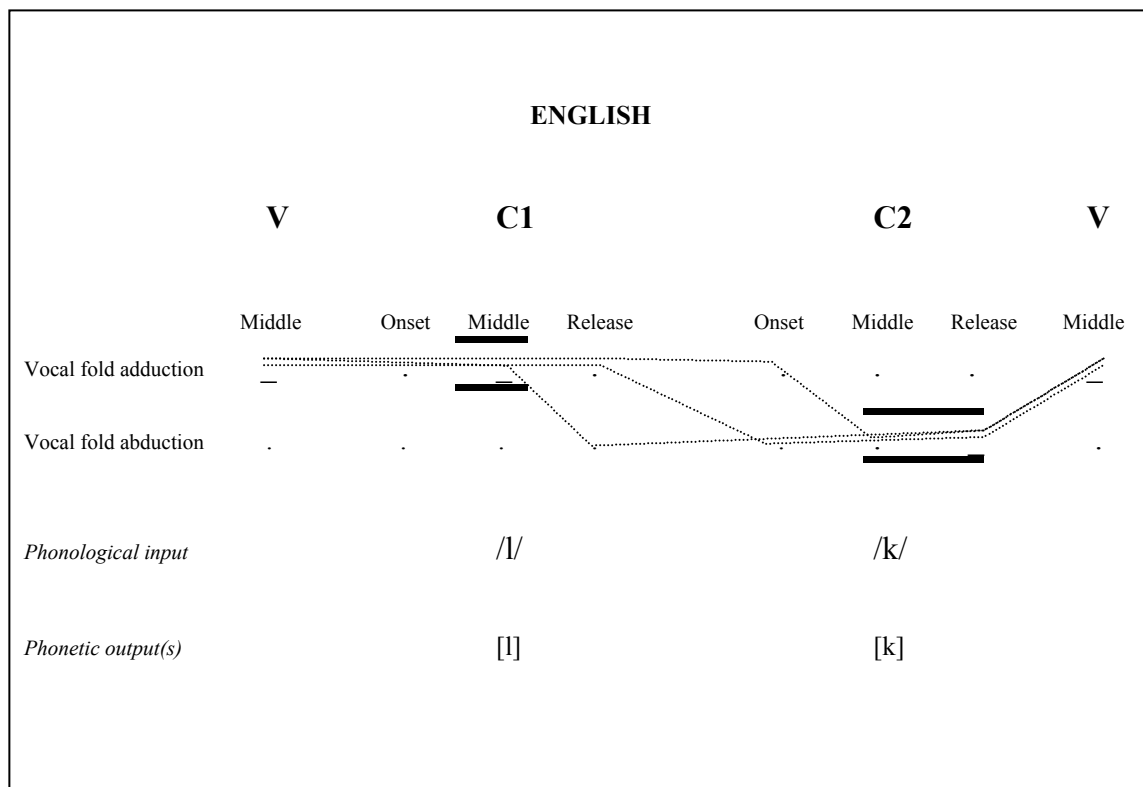
**Figure 4.2.** Windows Theory representation of voiceless obstruent – sonorant sequences in English. The small dots represent possible articulatory landmarks and the big dots represent the laryngeal targets that speakers have to achieve at that landmark. Interpolation across targets is shown by a dotted line.

In Catalan and English *sonorant – obstruent* sequences, the glottal gesture switched at the transition between the two consonants, and the variability observed seems to result from implementational variants resulting from the interpolation of the voicing transition. Such behavior can be modeled as shown in Figures 4.3 for Catalan and 4.4 for English. In both languages, the *middle* of the sonorant would be targeted with vocal fold adduction. The following obstruent would be targeted as voiceless at the middle of the consonant constriction in Catalan and at the consonant release in English as assumed above. The laryngeal target for C2 seems to spread from the middle to the release in Catalan and from the release to the middle in English, which would ensure absence of voicing in the second half of C2, as found in the data. Interpolation across targets (shown by the dotted line) allows variability at the transition between the two consonants. Slight anticipatory and inertial effects account for the variability observed in the data.



**Figure 4.3.** Windows Theory representation of sonorant – voiceless obstruent sequences in Catalan. The small dots represent possible articulatory landmarks and the big dots represent the laryngeal targets that speakers have to achieve at that landmark. Interpolation across targets is shown by a dotted line.

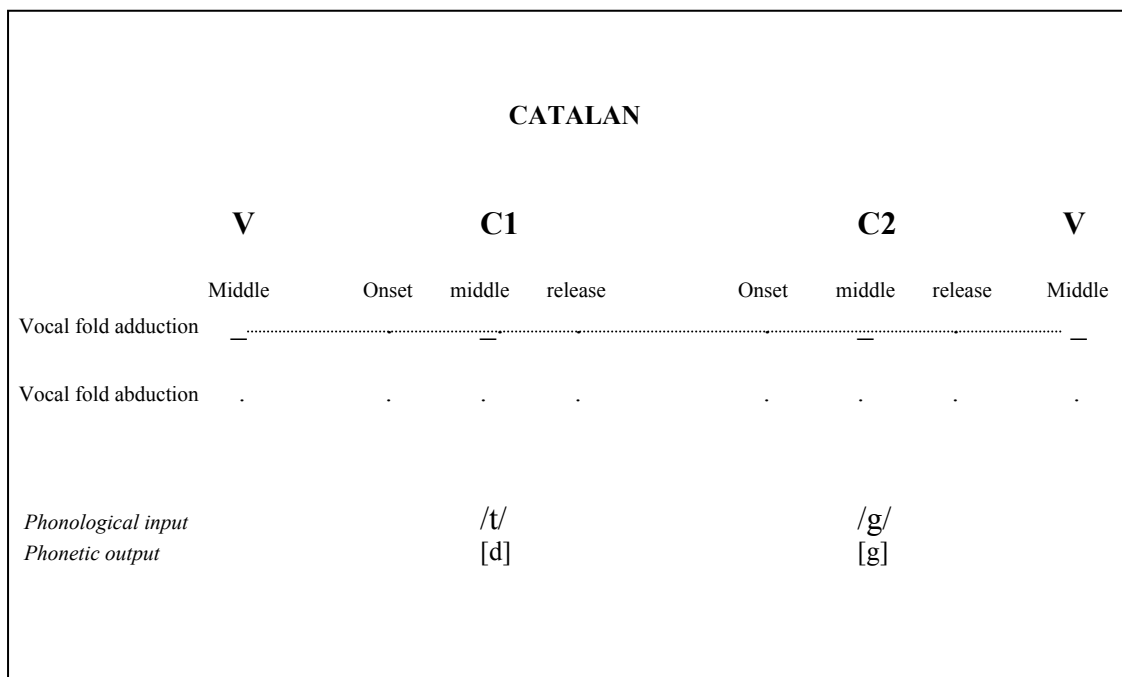




**Figure 4.4.** Windows Theory representation of sonorant – voiceless obstruent sequences in English. The small dots represent possible articulatory landmarks and the big dots represent the laryngeal targets that speakers have to achieve at that landmark. Interpolation across targets is shown by a dotted line.

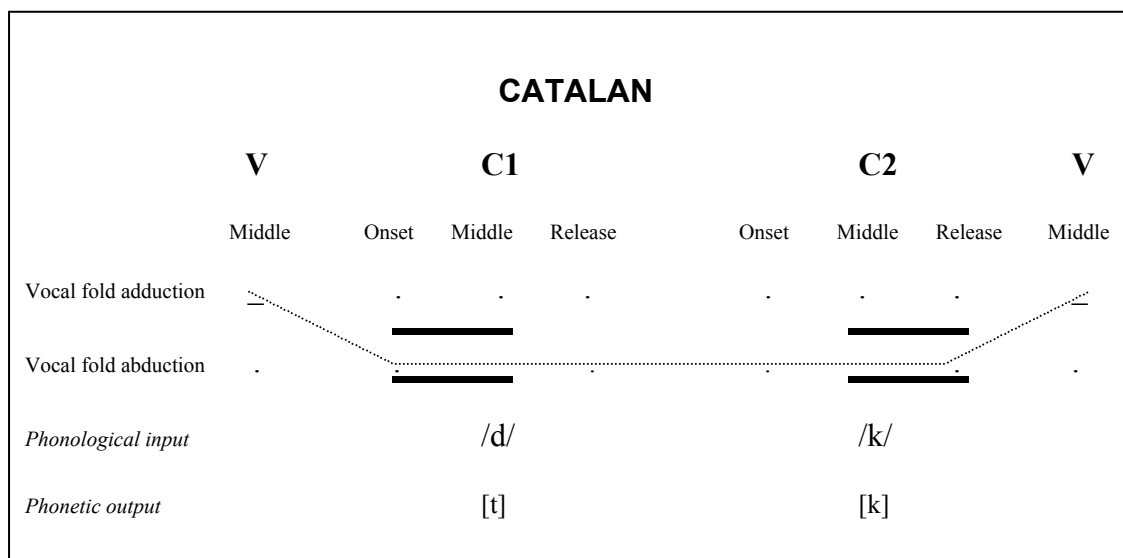
The modeling of the rule of regressive voicing assimilation found in Catalan voiceless – voiced obstruent sequences is presented in Figure 4.5. The middle of C2 would be targeted as voiced and the middle of C1 would also be targeted as voiced after copying the laryngeal target of C2 due to the application of the voicing assimilation rule. The fact that voicing may die out during the oral constriction, as observed in the data, is a phonetic effect. The fact that the middle of C2 is targeted as voiced ensures a negative VOT value, and therefore the correct perception of the consonant as voiced.

The rule of regressive voicing assimilation presented in Figure 4.5 may optionally apply in Catalan *obstruent – sonorant* sequences, at least for some speakers (subject AN).



**Figure 4.5.** Representation of voicing assimilation in Catalan voiceless – voiced obstruent sequences. The small dots represent possible articulatory landmarks and the big dots represent the laryngeal targets that speakers have to achieve at that landmark. Interpolation across targets is shown by a dotted line.

In Catalan voiced – voiceless sequences, the middle of C2 would be targeted with an abductory movement of the glottis and the middle of C1 would also be targeted as voiceless after copying the laryngeal target of C2 due to the application of the voicing assimilation rule, as shown in Figure 4.6 below. Thus, both consonants in the sequence would be implemented as voiceless. Since interpolation of laryngeal targets between the first vowel and C1 might result in the presence of voicing in the first half of C1 – which was not found in the data –, we need to assume that the laryngeal target for C1 spreads to the onset of the consonant, thus ensuring complete voicelessness in C1, as found in the data. In the same line, the laryngeal target for C2 should extend to the consonant release in order to ensure absence of voicing in the second half of the consonant.

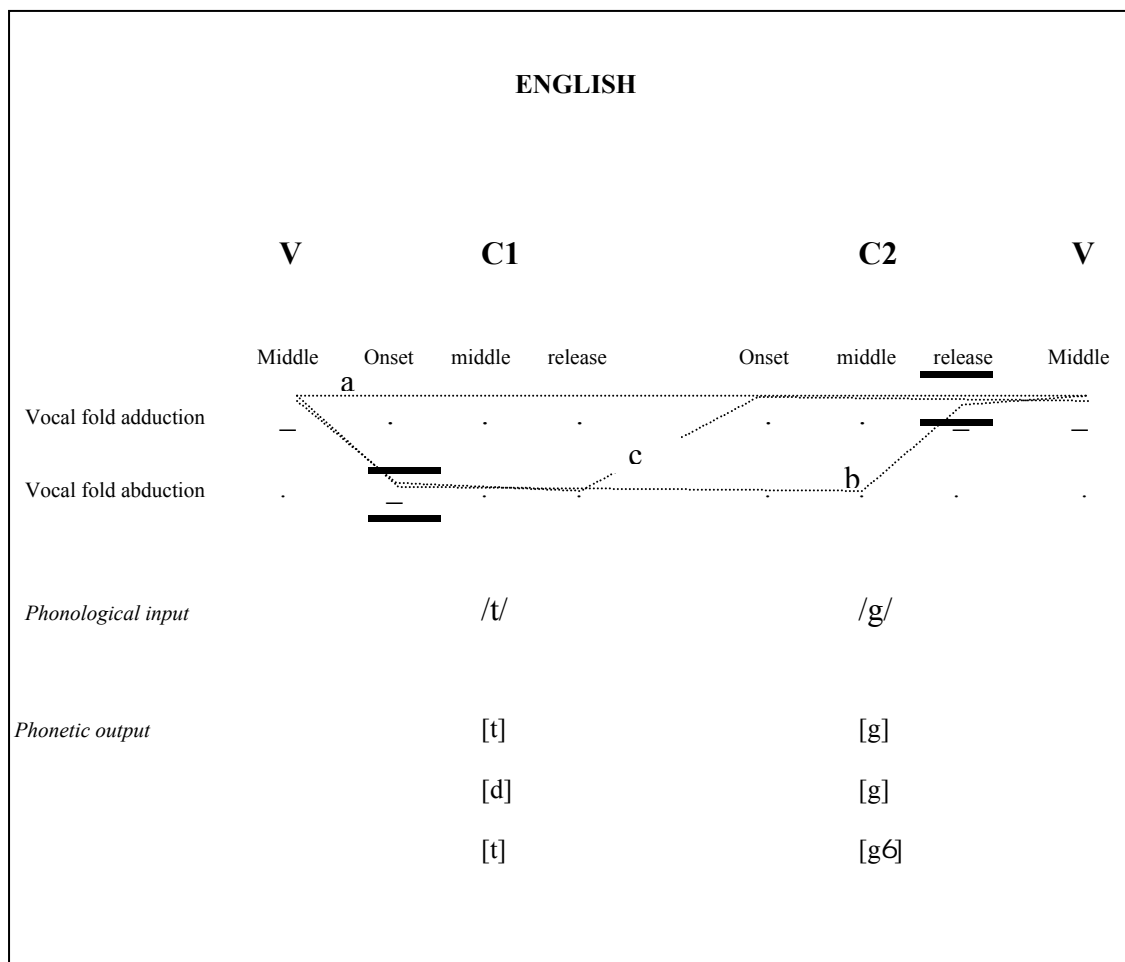


**Figure 4.6.** Representation of voicing assimilation in Catalan voiced – voiceless obstruent sequences. The small dots represent possible articulatory landmarks and the big dots represent the laryngeal targets that speakers have to achieve at that landmark. Interpolation across targets is shown by a dotted line.

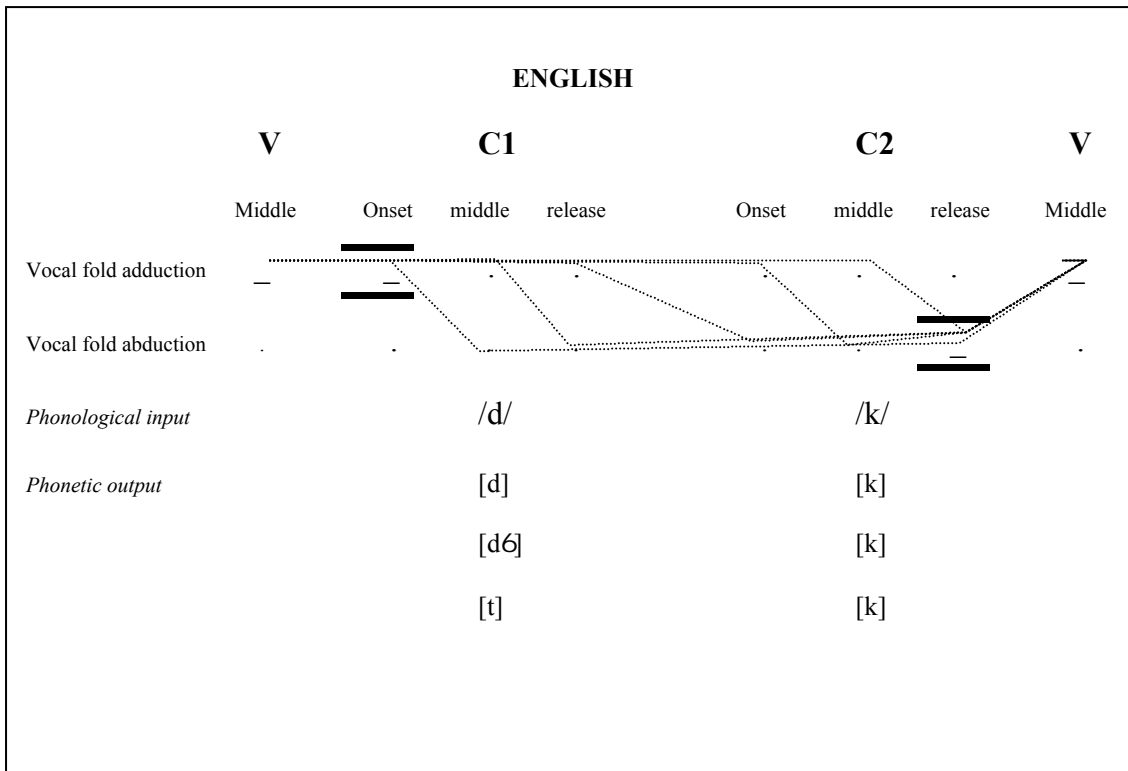
In English voiceless – voiced sequences like /t#g/ and /s#d/, the onset of C1 would be targeted as voiceless, as shown in Figure 4.7, and the concomitant cues for voicing – *e.g.*, vowel length – would show up in the preceding segment. The release of C2 would be targeted as voiced, as shown in Figure 4.7, which ensures a short negative or positive VOT value. Variability in the presence of vocal fold vibration is allowed during the consonant constriction because there is a wide time window of interpolation of laryngeal gestures, so that there can be complete voicing of C1 if there is complete articulatory overlap at faster rates (trace *a*); in this case, the target for C1 is not present because it is completely overlapped by that of C2. Alternatively, there may be partial or complete devoicing of C2 (trace *b*), or no devoicing of C2 (trace *c*). This representation would account for the data obtained in the present experiment, where great variability was found: if there was complete overlap of the supraglottal articulators the whole

consonant sequence could be voiced, whereas in other cases C2 was completely or partially devoiced.

In voiced – voiceless sequences in English, a similar representation might be proposed, but in this case the beginning of C1 would be targeted as voiced and the release of C2 would be targeted as voiceless, as shown in Figure 4.8 below. The wide time window for interpolation of laryngeal targets allows for variability to take place in voicing during the consonant constriction, and accounts for the fact that speakers may sometimes maintain vocal fold vibration in C1.



**Figure 4.7.** Windows Theory representation of voiceless – voiced obstruent sequences in English. The small dots represent possible articulatory landmarks and the big dots represent the laryngeal targets that speakers have to achieve at that landmark. Interpolation across targets is shown by a dotted line.



**Figure 4.8.** Windows Theory representation of voiced – voiceless obstruent sequences in English. The small dots represent possible articulatory landmarks and the big dots represent the laryngeal targets that speakers have to achieve at that landmark.

### 4.3 Conclusions

To summarize, it was found that in Catalan obstruent sequences that differ in their phonological specification for voicing, speakers tend to anticipate the voicing gesture of C2 to C1, both in stop sequences and in fricative – stop sequences. Thus, the process is regressive and categorical, which is congruent with a rule of voicing assimilation in Catalan. Evidence was also found that speakers can display partial anticipation of the voicing gesture of C2, which shows that voicing assimilation may also be a gradient process in this language. Thus, the voicing assimilation rule seems to be optional. The Catalan data thus seem to reflect two different processes. On one hand, complete regressive voicing assimilation in obstruent sequences seems to be the result of a rule involving higher-level reorganization of motor commands. On the other hand, cases of partial assimilation may result from phonetic implementation factors.

In English, it was found that there is no phonological rule of voicing assimilation in obstruent sequences. Rather, the coordination of oral and glottal gestures during the maximal constriction is a gradient process that may result from anticipatory overlap – sensitive to time constraints – and inertial effects .

In sequences of consonants where nasals and laterals combine with obstruents, the voicing gesture seems to be switched at the transition from C1 to C2 in both languages. In addition, evidence was found for complete assimilation of voicing in Catalan obstruent – sonorant sequences, suggesting the extension of the regressive voicing assimilation rule for obstruents to these sequences, at least for some speakers.

Finally, it has been suggested that Articulatory Phonology and Keating's Windows Theory account for the coordination of oral and glottal gestures in Catalan and English.

**REFERENCES**

- Abercrombie, D. (1967). *Elements of general phonetics*. Edinburgh: Edinburgh University Press.
- Amerman, J. D., Daniloff, R. and Moll, K. (1970). Lip and jaw coarticulation for the phoneme / l/. *Journal of Speech and Hearing Research*, 13, 147-161.
- Badia i Margarit, A. (1994). *Gramàtica de la llengua catalana*. Barcelona: Enciclopedia Catalana.
- Balise, R. and Diehl, R. (1994). Some distributional facts about fricatives and a perceptual explanation. *Phonetica*, 51, 99-110.
- Barry, M. (1985). A palatographic study of connected speech processes. *Cambridge Papers in Phonetics and Experimental Linguistics* 4.
- Barry, M. and Teifour, R. (1999). Temporal patterns in Syrian Arabic voicing assimilation. *Proceedings of the 14<sup>th</sup> International Congress of Phonetic Sciences*, 2429-2432, San Francisco.
- Bell-Berti, F. (1975). Control of pharyngeal cavity size for English voiced and voiceless stops. *Journal of the Acoustical Society of America*, 57, 456-461.

- Berg, J. van den (1958). Myoelastic-aerodynamic theory of voice production. *Journal of Speech and Hearing Research*, 1, 227-244.
- Berg, J. van den (1962). Modern research in experimental phoniatrics. *Folia Phoniatica*, 14, 81-149.
- Boyce, S. (1990). Coarticulatory organization for lip rounding in Turkish and English. *Journal of the Acoustical Society of America*, 88, 2584-2595.
- Browman, C. P. and Goldstein, L.M. (1986). Towards an articulatory phonology. In C. Ewan and J. Anderson (eds), *Phonology Yearbook*, 3, 219-252. Cambridge: Cambridge University Press.
- Browman, C. P. and Goldstein, L. M. (1989). Articulatory gestures as phonological units. *Phonology*, 6, 201-251.
- Browman, C. P. and Goldstein, L. M. (1990). Tiers in articulatory phonology, with some implications for casual speech. In J. Kingston and M. E. Beckman (eds), *Papers in Laboratory Phonology I. Between the grammar and the physics of speech* (pp. 341-376). Cambridge: Cambridge University Press.
- Browman, L. P. and Goldstein, L. M. (1992). Articulatory Phonology: an overview. *Phonetica*, 49, 155-180.



- Burton, M. W. and Robblee, K. E. (1997). A phonetic analysis of voicing assimilation in Russian. *Journal of Phonetics*, 25, 97-114.
- Byrd, D. (1996). A phase window framework for articulatory timing. *Phonology*, 13, 139-169.
- Carbonell, J. F. (1992). Final devoicing and voicing assimilation in Catalan: an acoustic experiment. Masters Dissertation, University College London, London.
- Catford, J. C. (1977). *Fundamental problems in phonetics*. Bloomington, IN: Indiana University Press.
- Charles-Luce, J. and Dinnsen, D. A. (1987). A reanalysis of Catalan devoicing. *Journal of Phonetics*, 15, 187-190.
- Clark, J. and Yallop, C. (1990). *An introduction to phonetics and phonology*. Oxford/Cambridge, MA.: B. Blackwell.
- Clements, G. N. (1985). The geometry of phonological features. *Phonology Yearbook*, 2, 225-252.
- Crystal, D. (1991). *A dictionary of linguistics and phonetics*. 3<sup>rd</sup> edn. Oxford: Blackwell Publishers.

- Cuartero, N. (1998). Voicing assimilation in stop sequences in Catalan and English. Masters Dissertation, Universitat Autònoma de Barcelona, Bellaterra.
- Cuartero, N. (1999). Voicing assimilation in stop sequences in Catalan and English. *Proceedings of the 14<sup>th</sup> International Congress of Phonetic Sciences*, 383-386, San Francisco.
- Dinnsen, D. A. and Charles-Luce, J. (1984). Phonological neutralization, phonetic implementation and individual differences. *Journal of Phonetics*, 12, 49-60.
- Docherty, G. J. (1992). *The timing of voicing in British English obstruents*. Netherlands phonetic archives. Berlin: Foris Publications.
- Fougeron, C., Meynadier, Y. And Demolin, D. (2000). 62 vs. 96 electrodes: a comparative analysis of Reading and Kay Elemetrics EPG pseudo-palates. *Proceedings of the SPS5 Seeon*, 309-312.
- Fujimura, O. (1990). Toward a model of articulatory control: comments on Browman and Goldstein's paper. In J. Kingston and M. E. Beckman (eds), *Papers in Laboratory Phonology I, Between the grammar and the physics of speech*. (pp. 377-381). Cambridge: Cambridge University Press.

- Fujimura, O. and Lovins, J. (1978). Syllables as concatenative phonetic units. In A. Bell and J. B. Hooper (eds), *Syllables and Segments*. Amsterdam: North Holland.
- Gibbon, F., Hardcastle, W. and Nicolaidis, K. (1993). Temporal and spatial aspects of lingual coarticulation in /kl/ sequences: a cross-linguistic investigation. *Language and Speech*, 36 (2, 3), 261-277.
- Gimson, A. C. (1970). *An introduction to the pronunciation of English*. London: Edward Arnold.
- Gósy, M. (1999). Predictability of voicing assimilation in speech production. *Proceedings of the 14<sup>th</sup> International Congress of Phonetic Sciences*, 1905-1908, San Francisco.
- Haggard, M. (1978). The devoicing of voiced fricatives. *Journal of Phonetics*, 6, 95-102.
- Hayes, B. (1992). Comments on the paper by Nolan. In G. J. Docherty and D. R. Ladd (eds), *Papers in Laboratory Phonology II. Gesture, segment, prosody*. (pp. 280-286). Cambridge: Cambridge University Press.
- Hayes, B. and Stivers, T. (1996). *A phonetic account of postnasal voicing*. Unpublished paper. University of California, Los Angeles.

- Holst, T. and Nolan, F. (1995). The influence of syntactic structure on [s] to [ʃ] assimilation. In B. Connell and A. Arvantini (eds), *Papers in Laboratory Phonology IV. Phonology and phonetic evidence*. (pp. 315-333). Cambridge: Cambridge University Press.
- Huffmann, M. K. (1990). Implementation of nasal: timing and articulatory landmarks. *UCLA Working Papers in Phonetics*, 75.
- Jones, D. (1960). *An outline of English phonetics*. Eighth edition. Cambridge: Heffer.
- Keating, P. (1984). Physiological effects on stop consonant voicing. *UCLA Working Papers in Phonetics*, 59, 29-34.
- Keating, P. (1988). Underspecification in phonetics. *Phonology*, 5, 275-292.
- Keating, P. (1990). The window model of coarticulation. In J. Kingston and M. E. Beckman (eds), *Papers in Laboratory Phonology I. Between the grammar and the physics of speech*. Cambridge: Cambridge University Press.
- Keating, P. (1996). The phonology-phonetics interface. *UCLA Working Papers in Phonetics*, 92, 45-60.

- Kenstowicz, M. (1984). *Phonology in generative grammar*. Oxford: Blackwell Publishers.
- Kerswill, P. (1985). A socio-phonetic study of connected speech processes in Cambridge English: an outline and some results. *Cambridge Papers in Phonetics and Experimental Linguistics 4*.
- Klatt, D. (1975). Voice Onset Time, frication and aspiration in word-initial consonant clusters. *Journal of Speech and Hearing Research*, 18, 686-705.
- Ladefoged, P. and Maddieson, I. (1996). *The sounds of the world's languages*. Oxford: Blackwell Publishers.
- Laver, J. (1994). *Principles of phonetics*. Cambridge: Cambridge University Press.
- Lisker, L. and Abramson, A. S. (1964). A cross-language study of voicing in initial stops: acoustical measurements. *Word*, 20, 384-422.
- Lombardi, L. (1999). Positional faithfulness and voicing assimilation in Optimality Theory. *Natural Language and Linguistic Theory*, 17.

- Maddieson, I. (1984). *Patterns of sounds*. Cambridge: Cambridge University Press.
- Mascaró, J. (1987). Underlying voicing recoverability of finally devoiced obstruents in Catalan. *Journal of Phonetics*, 15, 183-186.
- Menzerath, P. and Lacerda, A. de (1933). *Koartikulation, Steuerung und Lautabgrenzung*. Bonn: Dümmler.
- Mester, R. and Itô, J. (1986). The phonology of voicing in Japanese: theoretical consequences of morphological accessibility. *Linguistic Inquiry*, 17, 49-73.
- Müller, J. (1837). *Über die Kompensation der physischen Kräfte am menschlichen Stimmorgan*. Berlin: A. Hirschwald.
- Nolan, F. (1992). The descriptive role of segments: evidence from assimilation. In G. J. Docherty and D. R. Ladd (eds), *Papers in Laboratory Phonology II: gesture, segment, prosody* (pp. 261-280). Cambridge: Cambridge University Press.
- Nolan, F. and Holst, T. (1993). *Modelling [s] to [ʒ] assimilation*. Presented at the 2<sup>nd</sup> ACCOR Workshop (ESPRIT) on Lingual Data and Modelling in Speech Production, Barcelona.

- Norusis, M. J. (1998). *SPSS 8.0. Guide to data analysis*. New Jersey: Prentice-Hall.
- Ohala, J. J. (1976). A model of speech aerodynamics. *Report of the Phonology Laboratory (Berkeley)*, 1, 93-107.
- Ohala, J. J. (1983). The origin of sound patterns in vocal tract constraints. In P. MacNeilage (ed), *The production of speech* (pp. 189-216). New York: Springer Verlag.
- Ohala, J. J. (1990). The phonetics and phonology of aspects of assimilation. In J. Kingston and M. Beckman (eds), *Papers in Laboratory Phonology I: between the grammar and the physics of speech* (pp. 258-275). Cambridge: Cambridge University Press.
- Ohala, J. J. and Riordan, C. (1979). Passive vocal tract enlargement during voiced stops. In J. Wolf and D. Klatt (eds), *Speech Communication Papers presented at the 97<sup>th</sup> Meeting of the Acoustical Society of America*. Acoustical Society of America, New York: 89-92.
- Ohala, J. J. and Solé, M. J. (1998). The controversy of nasalized fricatives. *Proceedings of the 135<sup>th</sup> Meeting of the ICA/Acoustical Society of America*, 2923-2924, Seattle, Washington, USA.

Peterson, G.E. and Lehiste, I. (1960). Duration of syllable nuclei in English. *Journal of the Acoustical Society of America*, 32, 693-703.

Recasens, D. (1993). *Fonètica i fonologia*. (2nd edn). Barcelona: Enciclopèdia Catalana.

Recasens, D. (1998). Predicting the direction of assimilatory processes from coarticulatory data. *Labphon 6*, York.

Recasens, D. (1999). Predicting directionality trends in segmental assimilations and insertions. *Proceedings of the 14<sup>th</sup> International Congress of Phonetic Sciences*, 1847-1849, San Francisco.

Recasens, D., Fontdevila, J. and Pallarès, M. D. (1996). Linguopalatal coarticulation and alveolar-palatal correlations for velarized and non-velarized /l/. *Journal of Phonetics*, 24, 165-185.

Romero, J. (1995). Gestural organization in Spanish. An experimental study of spirantization and aspiration. Ph. Dissertation, The University of Connecticut.

Romero (1999). The effect of voicing assimilation on gestural coordination. *Proceedings of the 14<sup>th</sup> International Congress of Phonetic Sciences*, 1793-1796, San Francisco.



- Slis, I. H. (1986). Assimilation of voice in Dutch as a function of stress, word boundaries, and sex of speaker and listener. *Journal of Phonetics*, 14, 211-326.
- Smith, B. (1978). Effects of place of articulation and vowel environment on 'voiced' stop consonant production. *Glossa*, 12, 163-175.
- Smith, C. L. (1997). The devoicing of /z/ in American English: effects of local and prosodic context. *Journal of Phonetics*, 25, 471-500.
- Smith, H. Z., Allen, G. D., Warren, D. W. and Hall, D. J. (1978). The consistency of the pressure-flow technique for assessing oral port size. *Journal of the Acoustical Society of America*, 64, 1203-1206.
- Solé, M. J. (1992). Phonetic and phonological processes: the case of nasalization. *Language and Speech* 35 (1, 2), 29-43.
- Solé, M. J. (1995a). New ways of analyzing sound change. Speech rate effects. *Belgian Journal of Linguistics*, 9, 21-44.
- Solé, M.J. (1995b). Spatio-temporal patterns of velopharyngeal action in phonetic and phonological nasalization. *Language and speech*, 38 (1), 1-23.

- Solé, M. J. (1999). Production requirements of apical trills and assimilatory behavior. *Proceedings of the 14<sup>th</sup> International Congress of Phonetic Sciences*, 487-490, San Francisco.
- Solé, M. J. and Estebas, E. (1995). Phonetic and phonological phenomena: VOT. A cross-language comparison. *Actas del XVII Congreso de AEDEAN*. Universidad de Córdoba, Spain.
- Spencer, A. (1996). *Phonology: theory and description*. Oxford: Blackwell Publishers.
- Stevens, K., Blumstein, S., Glicksman, S., Burton, M., Kurowski, K. (1992). Acoustical and perceptual characteristics of voicing in fricatives and fricative clusters. *Journal of the Acoustical Society of America*, 91, 2979-3000.
- Stevens, K. and Klatt, D. H. (1974). Role of formant transitions in the voiced-voiceless distinction for stops. *Journal of the Acoustical Society of America*, 55: 653-659.
- Warren, D. W. (1996). Regulation of speech aerodynamics. In N. Lass (ed), *Principles of experimental phonetics* (pp. 46-92). Saint Louis: Mosby.

Westbury, J. R. (1979). Aspects of the temporal control of voicing in consonant clusters in English. *Texas Linguistics Forum*, 14. Department of Linguistics, University of Texas, Austin.

Westbury, J. R. and Keating, P. (1986). On the naturalness of stop consonant voicing. *Journal of linguistics*, 22, 45-166.