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IMPLICATIONS FOR PHONOLOGY AND SOUND CHANGE

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1 Introduction

The phonetic realization of consonant clusters presents a challenge for studies on speech production. Differently from segmental sequences composed of vowels and consonants, the realization of consonant sequences offers a large variety of production scenarios which speakers may resolve through an array of articulatory mechanisms. These mechanisms are conditioned by the need to implement the place and manner of articulation and voicing characteristics for the consecutive consonants and may result in highly antagonistic situations. For example, in a sequence like /ɲr/ which may be found in the Catalan string *bany rus* "Russian bath", where /ɲ/ is an alveolopalatal nasal and /r/ is an alveolar trill, the need to anticipate the tongue body lowering and backing movement for the trill conflicts necessarily with the raised and fronted tongue body configuration for the preceding alveolopalatal nasal. Articulatory data show that speakers often solve this antagonistic situation by depalatalizing C1 rather than by palatalizing C2. There is no conflict in other consonant sequences where the lingual activity for C1 is more compatible with that for C2 as, for example, in the case of /nʃ/ where the tongue body raising and fronting movement for /ʃ/ is freely anticipated during the preceding alveolar nasal since the production of /n/ does not require a very precise lingual configuration partly due to the low manner of articulation-dependent production demands involved (see section 4.3.1.2).

A good reason for investigating the production mechanisms of consonant clusters is in order to be able to account for why certain consonant-to-consonant adaptations in place and manner of articulation take place more often than others. A production-motivated rationale for why these articulatory adaptations occur the way they do appears to be more acceptable than other approaches based on phonological principles such as the strength hierarchy, which runs opposite to the sonority hierarchy and proceeds in the progression stops (consonants with maximal strength) > fricatives > nasals > laterals > rhotics (consonants with minimal strength). According to this view, a CC syllable contact is favoured the higher the strength value of onset C2 relative to that of coda C1, and assimilation causes the stronger consonant to become less strong. Therefore, it is predicted that /ln/ and /rn/ should assimilate progressively into [ll] and [rr], respectively, while /nl/ and /nr/ ought to assimilate regressively into the same phonetic outcomes [ll] and [rr] (Maiden, 1995: 72, Vennemann, 1988: 50–51). A problem with this and similar hierarchies is that strength values are not independently motivated but are derived from the outcomes of the phonological and sound change processes themselves, which may lead to different hierarchies, especially among sonorant consonants, depending on which process is subject to analysis (see for a similar objection Cho, 1999: 205–211). Thus, for example,

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the relatively high strength value for nasals in the scale referred to above does not hold when we take into consideration the trend for /n/ rather than /t/ or /s/ to assimilate in place of articulation to the following syllable-onset consonant (chapter 4). Another problem with manner categories such as stop, fricative, nasal, lateral and rhotic is that they are far too general for making valid predictions about the range of adaptability processes which may apply to consonant sequences such as the ones analyzed in the present study. For instance, under the label *rhotic* we find manner classes as different as taps, trills and approximants, which operate very differently as coarticulation and assimilation triggers and targets, and a similar objection may be made regarding differences in adaptability between stops and nasals depending on the primary articulator and thus whether they are coronal or dorsal.

A similar criticism may be raised with respect to other phonological models based on features or gestures which consider place and manner of articulation characteristics independently of each other or attribute more relevance to gestural goals than to manner of articulation demands. Throughout this book we generally render consonantal assimilations dependent on the articulatory and aerodynamic requirements involved in the production of the two successive consonants in consonant clusters. The rationale behind this approach is that, in a good number of cases, place and manner of articulation properties account jointly for whether specific assimilatory processes apply or not.

A large number of recent studies on the realization of word-initial and word-final consonant sequences have tested several predictions about gestural overlap and articulatory cohesion at the syllable level formulated by Articulatory Phonology (Browman & Goldstein, 1992). Within this and other frameworks, much attention has been paid to the mechanisms of interarticulatory coordination for successive consonants produced with independent articulatory structures which may overlap in time, i.e., lips, jaw, tongue, velum and larynx, and tongue front and tongue body as well. The present book reviews citically the existing literature on the production of these two-consonant cluster structures, and provides some new insigths about the articulatory organization of heterosyllabic sequences which are (nearly)-homorganic and thus composed of consonants sharing essentially the same primary articulator. Moreover, it does not only deal with the place adaptation mechanisms between the two consonants in the cluster, but also with how the homorganic or heterorganic relationship between C1 and C2 as well as other articulatory and aerodynamic characteristics influence the implementation of manner assimilations (see section 2.4.3 for details) and the weakening of syllable-final consonants. These research topics are relevant in so far as they have been paid little attention in the literature. The study of manner assimilations will not deal with voicing adaptations or segmental insertions which may result from changes in glottal or articulatory timing between the consonants in succession.

A main goal of the present investigation is to show that attention to phonetic detail may contribute to unveil the causes of specific intersegmental adaptation processes. Sometimes what appears to be a categorical assimilation to the ear is not intended as such by the speaker. Even though in Chapter 5 we treat as categorical several apparently complete place and manner assimilations occurring in /sC/ and /rC/ sequences with a voiced or sonorant C2, we are aware that they often are not. Experimental research reveals that speakers may produce these consonant sequences through several C1 phonetic realizations which have been generated through different degrees of articulatory reduction and regressive adaptation. We believe that to the extent that these production mechanisms operate on certain coda consonants and consonant sequences rather than others, they ought to be modelled and accounted for by theories of phonology and sound change.

The book is structured as follows. Chapter 2 provides general information about the production characteristics of consonant sequences and consonant-to-consonant adaptation processes, and formulates a set of theoretical predictions to be tested in the following chapters. It deals with how articulatory gestures are organized in consonant clusters also as a function of syllable position, prosodic and lexical factors, as well as with the articulatory strategies which speakers use when producing the two consonants in succession, i.e., coarticulation, assimilation and blending.

Chapter 3 tests with articulatory data for Catalan consonant sequences a set of predictions made by the DAC model of coarticulation about place adaptation in (nearly)-homorganic clusters across a word boundary. This chapter has a much larger scope than previous publications (Recasens & Pallarès, 2001a, Recasens, 2006) in so far as it reports data for a larger subset of consonant combinations produced by a higher number of speakers from three different dialects and pays special consideration to the production strategies used by the individual subjects. Moreover, ample articulatory evidence is drawn in support of the predictions of the model with production data gathered not only by means of electropalatography (EPG) and acoustic analysis as in other publications but of ultrasound as well. The methodology for analyzing changes in closure or constriction location over time for consonants on the EPG record also differs from previous accounts. Descriptive and experimental data for other languages taken from literature sources are also included.

Chapter 4 reviews production data on the degree of gestural overlap in heterorganic consonant sequences composed of consonants of different place and manner characteristics, and evaluates the implications of these coproduction patterns for blending and regressive place assimilation processes. New ultrasound data are presented on changes in tongue configuration for sequences of overlapping consonants such as velars and dentals/alveolars. The chapter is also concerned with the c-center effect in syllable-onset and syllable-coda clusters.

Chapter 5 investigates, mostly for heterosyllabic consonant sequences, those phonetic factors (e.g., presence of voicing in C2, homorganic and heterorganic relationship between C1 and C2) which are directly involved in the implementation of regressive and progressive manner assimilations and in the weakening of consonants appearing preferably in syllable-final position. Among the weakening processes subject to analysis we have not only lenition and deletion but also rhotacism, vocalization and aspiration.

An aspect worth being mentioned is the crosslinguistic scope of the book. In chapters 2, 3 and 4, production data are presented for consonants and phonetic and phonological processes from not only the Romance, Germanic and Slavic languages but from languages spoken in Asia, Africa and Australia as well. Chapter 5 on manner assimilations in consonant sequences is centered mostly but not only in the Romance languages.

Some terminological concepts need clarification. Throughout the book we distinguish among the following tongue regions: tip and blade at the alveolar zone; front dorsum or predorsum at the palatal zone; back dorsum or postdorsum at the velar zone; back tongue body at the pharyngeal zone. The term ‘tongue front’ is also used to refer to either the tip and blade or else to the tongue tip, blade and front dorsum.

The following abbreviations are used throughout the book: Am. (American), Ar. (Arabic), Cast. (Castilian), Cat. (Catalan), Celt. (Celtic), coll. (colloquial), dial. (dialectal), E. (Eastern), EMA (electromagnetic midsagittal articulometry), Eng. (English), EPG (electropalatograhy), fem. (femenin), Fr. (French), Francoprov. (Francoprovençal), fut. (future tense), Ger. (Germanic), IE (Indo-European), It. (Italian), masc. (masculin), N. (Northern), Occ. (Occitan), pl. (plural), Port. (Portuguese), S. (Southern), Sard. (Sardinian), sing. (singular), Sp. (Spanish), Sw. (Swedish), W. (Western). An index of the languages and dialects is appended at the end of the book.

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2 Production constraints and articulatory adaptation mechanisms

Consonant sequences differ in interarticulatory organization and gestural overlap depending on whether they are tautosyllabic and thus placed within the same onset or coda syllable, or heterosyllabic and thus split by a syllable boundary which may coincide with a word boundary. Mostly in the case of heterosyllabic consonant sequences, interarticulatory organization and gestural overlap are also very much influenced by whether the two consonants are produced with the same or different articulators and are thus, homorganic or heterorganic. Sections 2.1 and 2.2 look into how the tautosyllabicity/heterosyllabicity and homorganicity/heterorganicity dichotomies shape gestural organization in consonant clusters. As discussed in sections 2.3, 2.4 and 2.5, gestural overlap may give rise to three articulatory adaptation processes, two of which appear to be phonetic (coarticulation, blending) and a third one is phonological (assimilation). The three latter sections deal with how these mechanisms of articulatory adaptation operate spatially and temporally on consonant sequences depending mostly on segmental composition. Section 2.6 is concerned with differences in gestural overlap as a function of prosodic, morphological and lexical factors as well as of speech rate. Sections 2.7 and 2.8 are central to the book. Section 2.7 introduces the basic principles of coarticulatory and assimilatory behaviour in consonant sequences formulated by the degree of articulatory constraint (DAC) model of coarticulation, which will be applied to the study of homorganic clusters in chapter 3 and of manner assimilation and weakening of coda consonants in chapter 5. Section 2.8 accounts for how differences in the direction of the articulatory adaptation effects in heterosyllabic consonant sequences may give rise to regressive and progressive assimilatory processes.

2.1 Tautosyllabic consonant sequences

Articulatory data reveal that syllable position influences interarticulatory timing in tautosyllabic consonant sequences, which happen to be more stable if placed syllable initially than syllable finally. An analogous situation holds for single consonants next to a vowel such as /m/ for the production of which, relative to the end of lip raising for the oral closure, velum lowering offset has been found to occur earlier in syllable-final position than syllable initially (as, for example, in *seam ore* vs *see more*; Krakow, 1999). Also, during the production of palatalized and velarized/pharyngealized consonants, tongue dorsum movement may precede the activation of the primary labial or lingual articulator provided that the

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consonant occurs syllable finally but not syllable initially. Thus, in the case of palatalized /p/ in Russian, the tongue dorsum may start moving upwards and frontwards before the labial closing gesture begins if the consonant appears in syllable-coda position while this anticipatory action is not at work if the consonant in question occurs in syllable-onset position (Kochetov, 2006). Kinematic data for American English dark /l/ exhibit comparable syllable-position-dependent differences in interarticulatory organization: tongue dorsum lowering and backing usually precedes the tongue tip raising gesture during the production of dark /l/ syllable finally, as in the word *peel*, while the two actions take place simultaneously or else tongue tip raising precedes tongue dorsum activation for a clearer variety of /l/ syllable initially, as in the word *leap* (Sproat & Fujimura, 1993).

Articulatory Phonology has shown that syllable-position-dependent differences in interarticulatory organization result from the way the consonants in sequence are coupled to the syllable vowel nucleus (Browman & Goldstein, 1988, Hoole & Pouplier, 2015). In syllable-onset position, the temporal midpoint of consonant clusters of different degrees of complexity (*c-center*) is hypothesized to be timed invariantly to the vowel; therefore, adding more consonants should not cause an increase of this temporal interval but the consonant adjacent to the vowel to shift towards the vowel (and the vowel to shorten) and the leftmost consonant to move away from it. In clusters occurring in syllable coda, on the other hand, the first consonant is hypothesized to be coupled with the preceding vowel nucleus and the following consonants each with the immediately preceding consonant but not with the vowel; consequently, adding consonants ought to yield an increase in the temporal distance from the c-center to the vowel but not in the distance between the postvocalic consonant with respect to the vowel itself. In addition, the successive consonants of the two cluster types are expected to differ regarding degree of overlap, which should be less in onset position than in coda position in agreement with the notion that consonantal gestures are more prominent and more precisely articulated in the former position than in the latter. Moreover, as a general rule, the lesser the degree of gestural overlap between the two consonants in onset position, the lesser the c-center effect and the further away C1 stays from the vowel.

It has also been claimed that the mode of articulatory organization of syllable-onset clusters just referred to could serve to preserve the phonemic information for C1 whose acoustic cues risk being masked by C2 in specific segmental combinations. An obvious scenario would be that of sequences where gestural overlap is prone to occur in the front-to-back order rather than in the back-to-front order. Thus, for example, in the case of the sequence /kt/ the burst for the (more posterior) velar stop will be inaudible if the tongue front closure for the following (more anterior) dentoalveolar stop is already formed during C1, while in the case of /tk/ closure formation for the dorsovelar stop before C1 is released should not prevent the burst for the dentoalveolar stop from being heard (Chitoran et al., 2002 and section 4.1.1.1).

As shown at length in chapter 4, not all syllable-onset consonant clusters conform to these principles of gestural organization however. Indeed, the degree of coupling between the successive consonants and the vowel nucleus as well as the extent to which they overlap among themselves have been found to depend on multiple factors among which the consonant place and manner of articulation and voicing characteristics. Other segmental properties may affect the degree of stability of the c-center effect for onset clusters such as an increase from two to three consonants (e.g., in contrast with /pl/- and /kl/-, no consistent c-center effect was found to occur for /spl/- and /skl/- in English; Waltl & Marin, 2010), the articulatory distance between the last consonant of the cluster and the vowel nucleus, and whether singleton voiceless stop consonants are aspirated or unaspirated (Brunner et al., 2014).

The syllable-position-dependent principles of articulatory organization just described may also be disallowed by language-specific trends in consonant grouping at the edges of words. In Moroccan Arabic and other Arabic dialects, where word-initial consonant clusters are parsed heterosyllabically, the temporal distance between the release of the last consonant in the cluster and an anchor point placed after the following vowel was found to be more invariant than the distance between the c-center and the same anchor point (Shaw et al., 2011). Also in Tashlhiyt Berber the rightmost consonant is not shifted towards the vowel when consonants are added to the consonant sequence, and this same behaviour has been reported to take place in Italian /sC/- sequences in addition to a considerable shift of /s/ towards the left (Goldstein et al., 2007, Hermes, 2013). Moreover, an intrusive schwa may be inserted between the consecutive consonants in the Berber language (Ridouane & Fougeron, 2011).

Another exceptional case is that of word-initial C*l*V and C*r*V sequences in languages such as Slovak where the liquid may be syllabic and thus occupies the syllable nucleus position. Data for Slovak clusters reveal that the liquid does not shift towards the vowel and that, due to C1 and C2 being timed far apart from each other, a long vocalic open transition arises between the two consonants, which happens to be associated with the early onset of the tongue body retraction motion for both dark /l/ and the alveolar trill /r/ (Pouplier & Beňuš, 2011). This vowel-like opening period is comparable to the one appearing optionally between the consonants in English word-final clusters with a syllabic liquid such as /tl̩/ in the word *bottle* (Roach & Miller, 1991).

2.2 Heterosyllabic consonant sequences

The coproduction patterns found to hold for a good number of word-initial consonant clusters appear to be also valid to a large extent for heterosyllabic consonant sequences occurring in word-medial position or across a word boundary, with aerodynamic and articulatory factors determining by far and large the degree of consonant-to-consonant overlap (see Kent & Moll, 1975 in this respect). Chapters 3 and 4 deal mostly with the production mechanisms of consonant sequences where C1 and C2 are split into two syllables and therefore occupy the syllable-final and syllable-initial position, respectively. In principle, consonants occurring in heterosyllabic clusters are expected not to be timed so much between themselves as coupled to the preceding and following vowel nuclei though other coupling options are also possible depending on language and the number of consonants involved (Goldstein & Pouplier, 2014). This leads to a rich array of consonant combinations than for either onset and coda clusters, which accounts for the application of a considerable number of phonetic and phonological processes such as assimilation and weakening operating mostly on syllable-final consonants.

Another difference between clusters located at the edges of words and across a syllable boundary is regarding sonority and homorganicity. As a general rule, sonority in onset and coda clusters decreases towards their edges, as for example /pl, ps/ at onset as in the Catalan words *pla* "flat" and *psalm* "psalm" and /lb, sp/ at coda as in Catalan *calb* "bold" and *cresp* "layer". Since this syntagmatic restriction does not play a role in consonant sequences located across a word boundary, the four sequences just referred to may occur equally often in this position: /pl/ *cap làmina* "no plate", /ps/ *cep solt* "loose stump", /lp/ *vol pomes* "(he/she) wants apples", /sp/ *vas ple* "full glass". On the other hand, homorganicity between the two consecutive consonants occurs less frequently in onset clusters than in heterosyllabic ones, i.e., the former are generally composed of consonants produced with (nearly)-independent overlapping articulators while this combinatory restriction does not apply necessarily to the latter. Indeed, homorganic or near-homorganic clusters such as /sn, rt, ls/ are sequential and thus less overlapping than heterorganic ones, and are prone to appear across a syllable boundary and only in specific cases syllable internally at the word edges.

A major research topic in speech production studies are the production mechanisms that speakers use for the realization of heterosyllabic consonant sequences and how these mechanisms contribute to the implementation of related phonological processes. In heterosyllabic two-consonant sequences, the syllable-final consonant is overlapped by the syllable-initial one rather than the other way around and this pattern of overlap is related to at least to two factors. First, syllable-final lingual consonants are known to shorten and undergo articulatory reduction more easily than syllable-initial consonants into phonetic realizations exhibiting a wider constriction at place of articulation, less tongue-to-palate contact and often a slightly more retracted tongue body position (Byrd, 1996, Recasens 2004). Articulatory reduction causes consonants to fall short of their targets and facilitates gestural overlap; if extremely shortened, reduced consonants may drop, as in Spanish dialects where stops may weaken into approximants and subsequently delete when occurring syllable finally before other consonants. Syllable-final weakening may be implemented through shortening rather than articulatory reduction, as in the case of front lingual fricatives which may be shorter without exhibiting a clearly different and more variable lingual position syllable finally than syllable initially in heterosyllabic two-consonant sequences (Recasens & Rodríguez, 2018). Secondly, there is a trend for the realization of phonetic segments to be anticipated rather than carried over in running speech, which is in line with phonemes being planned in advance of their actual temporal slot. Indeed, coarticulation studies show a tendency for anticipatory effects to occur more systematically than carryover effects and the onset of the former to be more temporally fixed than the offset of the latter (see section 2.8). Anticipatory planning accounts for why assimilations proceed from right to left and thus favour the regressive over the progressive direction in the world's languages, as in the case of discontinuous vowel harmony processes in VCV sequences and place, manner and voicing assimilations in heterosyllabic CC sequences.

The production characteristics of heterosyllabic consonant sequences are also closely related to whether the clusters of interest are homorganic or heterorganic. In heterorganic consonant sequences, the two consonants may be articulated with independent articulatory structures such as the lips and the tongue for oral consonants, and any of those structures and the velum for nasal stops. As for the tongue, the tongue front and the tongue body may move more or less independenty of each other. Therefore articulatory independence may be taken to occur in clusters composed of dentals or alveolars and dorsovelars (e.g., /kt, kn/) but not in those composed of consonants produced with the tongue front exclusively. The tongue front includes the tongue tip, the tongue blade and also the tongue predorsum, which means that sequences composed of dentals, alveolars and palatoalveolar or alveolopalatal consonants such as /st, ln, ɲt, sʎ/ may be treated generally as homorganic or, more strictly speaking, as either homorganic or nearly-homorganic depending on the precise articulators involved (see section 3.1.3 regarding the primary articulator for alveolopalatal consonants). Likewise, sequences composed of consonants articulated exclusively with the tongue dorsum at the palatal zone or at the velar zone, as for example /kj/, may also be considered to be homorganic. In the present book, the term *homorganic* will also be used to denominate two consonants which exhibit approximately the same closure or constriction location independently of whether they are articulated with the same or closeby primary articulators.

A relevant difference between homorganic and heterorganic clusters is that the implementation of the former depends closely on the closure or constriction location and size for the two consonants as well as on the speed at which their primary articulators travel in space, while that of the latter is primarily conditioned by the degree of overlap at articulatory regions which are not involved in constriction formation. Several examples may illustrate this difference. As to homorganic clusters, continuous contact fronting from an alveolar C1 to a dental C2 may proceed differently in the sequences /st/ and /rt/ in Spanish, Italian or Catalan since the apical rhotic is a faster articulation than the apical or laminal fricative /s/ (see section 3.3.2). Regarding heterorganic clusters, on the other hand, labial consonants allow for more overlap in lingual activity than lingual consonants since they do not involve the tongue in their production, and gestural superposition takes place mostly at the relatively unconstrained tongue front for /k/ in the sequence /kt/ (i.e., the tongue front is relatively free to raise in anticipation of /t/) and tongue dorsum for /t/ in the sequences /tk/ (i.e., tongue dorsum raising may occur during C1 in anticipation of /k/).

2.3 Coarticulation

Coarticulatory effects between adjacent phonetic segments occur whenever the articulatory gesture for one segment prevails over that for the adjacent segment without the target segment changing its place of articulation, manner of articulation and/or voicing characteristics. Coarticulation may operate not only at articulatory structures which are involved in closure or constriction formation but also at those which do not participate actively in the production of the target vowel or consonant. Thus, there may be changes in tongue front and tongue body position for dentoalveolar and alveolar consonants triggered by the adjacent vowels which do not alter the basic articulatory properties of the consonant. For example, closure location for /n/ is often more retracted next to /u/ than next to a front or a low vowel while occurring at the alveolar zone in all segmental combinations, and the tongue body (an articulatory structure which does not intervene in closure formation for /n/) occupies regularly a higher position in the context of /i/ than in the context of /a, u/. Coarticulatory effects also occur in consonant sequences, such as tongue body raising induced by an alveolopalatal or palatoalveolar consonant during a following dental or alveolar (/ɲt/, /ɲn/) or tongue front raising exerted by a dental or an alveolar consonant during a preceding velar (/kt/, /kn/).

Coarticulation effects may differ in size and temporal extent, and the two dimensions are often positively correlated. Regarding the temporal dimension, coarticulatory effects may be anticipatory or carryover depending on the articulatory characteristics of the triggering phonetic segment. Thus, for example, the depalatalization of an alveolopalatal consonant placed before the alveolar trill /r/ or dark /l/ may start relatively early in time since the manner requirements for these two alveolars require considerable tongue dorsum lowering and tongue body retraction (Recasens & Pallarès, 2001a). On the other hand, the palatalization of dentoalveolars next to alveolopalatal consonants may occur from left to right which is in line with the finding that tongue dorsum lowering at consonant release for consonants such as /ɲ/ and /ʎ/ proceeds more slowly and lasts longer than tongue dorsum raising at consonant onset (Recasens & Espinosa, 2010). An example of a left-to-right palatalizing effect occurs in the tautosyllabic word-final sequences /ʎs, ɲs, js/ in words like /aʎs/ *alls* "garlic, pl.", /aɲs/ *anys* "year, pl." and /rejs/ *reis* "king, pl." in Eastern Catalan, which may be purely coarticulatory rather than assimilatory and thus may yield an intermediate realization between /s/ and /ʃ/ instead of the phonetic outcome [ʃ]. In all these cases, an increase in the size of a given coarticulatory effect along one of the two directions tends to occur jointly with an increase in the temporal extent of the effect.

Coarticulatory prominence may differ from language to language. Thus, as reported by Solé (2007), the vowel nasalization span in VC sequences with a nasal stop in Spanish is relatively short and constant across rates since it is associated with the necessary time required by the velum to lower for the production of the nasal consonant; on the other hand, in American English, vowel nasalization is deliberate (planned) and timed relative to vowel duration and therefore may decrease or increase depending on whether speakers speak faster or slower. Likewise, differences in vowel duration as a function of the voicing status of the following obstruent consonant are small and remain stable across rates in the Romance languages, while in English they are greater and proportional to the duration of the vowel, larger for longer vowels at slower rates and smaller for shorter vowels at fast rates. Another piece of evidence in support of the language-dependent nature of the coarticulatory effects comes from studies showing that languages may differ regarding the extent of anticipatory and carryover vowel-to-vowel coarticulation and that listeners may be sensitive to these vowel coarticulation differences (Beddor et al., 2002). Other language-specific coarticulatory cases have been reported in the literature. Thus, lip movement for rounded vowels appears to be anticipated to a greater extent and more precisely by speakers of Swedish than by speakers of American English, which is in line with differences in the number of labial vowel phonemes between the two languages and in the accuracy with which the target articulatory position for the vowels in question is achieved (Lubker & Gay, 1982). In contrast to the Romance and Germanic languages, indigenous Australian languages exhibit limited C2-dependent anticipatory coarticulation in clusters with a coda nasal followed by a velar stop in syllable-onset position (Fletcher et al., 2008, 2014).

2.4 Assimilation

Assimilation may be said to apply whenever a consonant (the target) is overlapped completely by another consonant (the trigger) such that the two phonetic segments end up sharing the same closure or constriction location, manner of articulation and/or voicing status. In principle, a requirement for an articulatory adaptation process to be assimilatory is that it ought to apply systematically to all tokens of all lexical items in a given language much independently of speech rate.

Assimilations arise through the phonologization of coarticulatory effects, and by extension are regressive or progressive depending on whether they are associated with prominent anticipatory or carryover coarticulatory effects, respectively. By far and large assimilations in consonant sequences are regressive in the world's languages, as for place assimilation in the sequences /np/ ([mp]) and /nk/ ([ŋk]) where the closure location for C2 is prone to be anticipated during the alveolar nasal. An example of a progressive assimilatory process, which clearly arises from a carryover effect, is the palatalization of /s/ after a palatal consonant, as in the tautosyllabic word-final clusters /ʎs, ɲs, js/ in Western and Valencian Catalan where /s/ may be realized as [ʃ] systematically (see also section 2.3). It may be claimed that only coarticulatory effects which are most salient at the production and perception levels are prone to become phonologized, and that whether this applies or not varies from language to language, which may account for why specific sound changes and phonological processes take place in some languages but not others. A valid example is vowel nasalization in VC sequences with a syllable-final nasal which has given rise to distinctively nasalized vowels in some Romance languages (French, Portuguese) but not others (Spanish) presumably in line with language-dependent differences in degree of vowel nasalization at the time that the sound change took place. Present-day research pays much attention to the role that linguistic factors and individual speakers play in the phonologization of coarticulatory effects (Beddor et al., 2002, Grosvald & Corina, 2012, Yu, 2013).

Assimilations involving heterosyllabic consonants are more prone to occur word medially than across a word boundary, which follows naturally from differences in degree of gestural overlap between the two consecutive consonantal segments depending on their morphological affiliation. Thus, in Spanish, nasal + consonant sequences are always homorganic word medially ([mp] *impossible* "impossible", [ŋk] *banco* "bench") and may or may not undergo assimilation across a word boundary ([np], [mp] *són pocos* "they are few", [nk], [ŋk] *són cortos* "they are short"; Navarro Tomás, 1972). Moreover, whenever operating word medially, assimilation is expected to take place syllable internally rather than across a syllable boundary. In Russian, for example, regressive nasal place assimilation applies to /nkts/, which syllabifies /(nk)(ts)/ even at slow speech rates, but not to the heterosyllabic consonant sequences /ng, nk/ (Barry, 1991).

According to a perceptual account, place assimilations are mostly regressive since distinctive preconsonantal place cues are weaker and thus more difficult to perceive than prevocalic place cues (Ohala, 1990). In these circumstances hearers may attribute acoustic effects induced by the contextual consonant to inherent properties of the target consonant. The trend for place assimilation to affect coda nasals rather than coda oral stops has been attributed precisely to the lesser acoustic salience of the place cues for nasals than for stops in syllable-final position (Jun, 1995: 44, Kawahara & Garvey, 2014, Beddor & Evans-Romaine, 1995). A combination of articulatory and acoustico-perceptual characteristics seems to account adequately for why apical or apicolaminal stops and nasals undergo assimilation more easily than consonants of other place and manner characteristics (Hardcastle, 1992, Kohler, 1990): a short closure duration, relatively flat vowel formant transitions and a weak burst and, in the case of /n/, a weak nasal murmur as well.

The point needs to be made that assimilatory processes cannot be accounted for purely on descriptive grounds. Descriptive accounts may only handle those assimilations which are most salient perceptually. Thus, it has been generally noted that coda /n/ may assimilate to four places of articulation in the following syllable-onset consonant, i.e., bilabial, labiodental, alveolopalatal and velar, as for example in the case of the Spanish lexical sequences *un poco* "a bit", *son felices* "they are happy", *cien llaves* "one hundred keys" and *hacen cola* "they queue". Experimental data for coda /n/ provided in section 3.3.1.1 reveal however that in Catalan regressive place assimilation may also take place before other consonants exhibiting a more retracted alveolar constriction location than the alveolar nasal itself such as the trill /r/ and /ʃ/, which are postalveolar or palatoalveolar rather than alveolopalatal, as in the sequences *són russos* "they are Russian" and *són xinesos* "they are Chinese". Indeed, in these two contextual conditions, the tongue front articulator may retract its relatively front alveolar constriction to the back alveolar zone already at /n/ closure onset and thus all throughout C1. Therefore it is not appropriate to consider that, whenever place assimilation applies, the place of articulation for the target consonant ought to change necessarily from one traditional articulatory zone to another. This approach is consistent with the notion that the articulatory space is a continuum which is not delimited by precise anatomical boundaries. Knowledge of phonetic detail becomes thus crucial for determining whether articulatory adaptation phenomena are coarticulatory or truly assimilatory.

2.4.1 Categorical vs gradient assimilations

A difference needs to be made between whether assimilations are categorical or gradient (referred to also as complete and partial assimilations sometimes in the literature). Gradient assimilations leave a trace of the assimilated gesture and therefore do not involve a complete (categorical) segment replacement in a particular articulatory dimension. Thus, for example, regressive place assimilation in the cluster /nk/ may be considered to be complete when the tongue dorsum occludes the velar zone and the tongue front lies down inactive all throughout C1. Gradient /n/-to-C2 assimilation in the same sequence occurs whenever, as reported in several production studies, simultaneously to the formation of a dorsovelar closure the tongue front is raised but does not make a complete alveolar closure during the nasal. In contrast to categorical assimilatory processes, gradient ones are sensitive to rate effects and tend to apply postlexically across a word boundary.

The dichotomy between categorical and gradient assimilations is not accepted by Articulatory Phonology. Within this theoretical framework, assimilations in CC sequences are gradient by nature and therefore must leave a trace of the target consonant. Consequently, the so called *complete assimilations* should be viewed as cases of extreme gestural overlap and take place whenever overlap cooccurring possibly with gestural reduction exceeds some perceptual threshold and gives rise to realizations which are no longer perceptually ambiguous (Byrd, 1992, Browman & Goldstein, 1992). Thus, regarding stop clusters, both the absence of a C1 stop release and changes in the VC transitions approching C2 may cause listeners to hear these consonant sequences as assimilated even if the C1 gesture is still present though maximally reduced or hidden by the C2 gesture.

Recent experimental research summarized below shows that assimilatory processes may be gradient or categorical and that languages (and even speakers within a given language) may differ in this respect. It also reveals that, contrary to general assumptions hold in phonology, assimilations in languages which are supposed to have them do not operate across the board but may be sensitive to the individual speakers, the speech rate conditions and the lexical items taken into consideration.

In most Romance languages investigated so far, place assimilation in /n#C/ sequences is generally complete or categorical and therefore applies throughout the entire nasal consonant and results into no gestural residue of target /n/. In an EPG study dealing with /n#k, n#g/ produced by five Italian speakers at regular and slow speech rates, assimilated realizations of /n/ exhibiting a full postpalatal closure since C1 onset occurred 98% of the time; only in a few tokens produced at slow speech by a subset of speakers, the alveolar nasal showed a velar closure and lateral contact extending up to the postalveolar zone, which could indicate that a C1 gestural residue was present (Celata et al., 2013). According to another EPG study of the sequences /n#p, n#b, n#k, n#g/ produced by three Catalan speakers, in which /n/ could belong to regular and frequent words, cases of /n/ gestural residue occurred in only 4 out of 630 tokens; as for frequency of assimilation, /n/ assimilated all the time for two speakers and when it belonged to a frequent word in the case of the third subject (Recasens & Mira, 2015). Categorical nasal place assimilation has also been reported to occur in productions of /n#p, n#f, n#k, n#x/ by Castilian Spanish subjects (EPG, Martínez Celdrán & Fernández Planas, 2007: 131–134; EMA, Honorof, 1999) and by speakers of Argentinian and Cuban Spanish (EPG, Kochetov & Colantoni, 2011). In a paper on Sardinian, postlexical geminates generated through regressive assimilation in /t#C/ and /n#C/ sequences turned out not to differ in acoustic duration from lexical geminates, which was taken to indicate that complete assimilation was at work (Ladd & Scobbie, 2003). In another Romance language, French, however, the sequence /n#k/ has been found to show neither instances of categorical assimilation nor of partial assimilation with a gestural residue, but only instances of gestural overlap with two complete front and dorsal closures cooccurring at the most during about half of the nasal consonant period (EPG, Colantoni et al., 2016).

A similar scenario holds in Japanese and Korean. In Japanese, the sequence /ng/ has been reported to exhibit cases of residual gesture with an incomplete alveolar closure in only 3% or none of the tokens under analysis depending on speaker, which is in agreement with this language disallowing lexical heterorganic clusters (EPG, Stephenson & Harrington 2002). In another electropalatographic study performed on the Japanese clusters /n(t)s, n(t)ʃ, nkʲ/nç, nk/, the nasal assimilated fully to C2 as a general rule and its contact size at closure location was less before a fricative than before a stop (EPG, Kochetov, 2014). In the Korean sequences /tp, tk, pk/, which undergo regressive assimilation according to descriptive studies, the C2 articulatory gesture may be fully present throughout the entire C1 temporal period and the extent to which this occurs proceeds binarily, i.e., there is either presence or absence of the tongue tip or lip gestures for the first stop consonant; moreover, cluster duration was roughly the same for assimilated /tk/ and for the underlying geminate /kk/ though shorter for assimilated /tp/ than for /pp/ (EMA; Kochetov & Pouplier, 2008). Along the same lines, another speech production study with EMA data for the sequence /p(#)k/ uttered by three Korean speakers revealed that the frequency of occurrence of C1-to-C2 assimilation varied with speaker and rate of speech and that, judging from the degree of lip aperture, subjects produced either unassimilated or assimilated realizations of the cluster (Son et al., 2007).

In contrast to the Romance languages, Japanese and Korean, studies on English and German C#C sequences composed of the alveolars /t, n/ followed by a velar or a labial stop strongly suggest that so called *regressive place assimilations* tend to be phonetic and thus non-categorical in these languages. Indeed, assimilatory processes operate in a highly variable manner such that the corresponding phonetic outcomes may be completely or partially assimilated.

A considerable number of EPG studies on articulatory adaptation in English consonant sequences have been carried out by Hardcastle and colleagues. EPG data for /tk, tp/ produced by three speakers showed the complete absence of a linguopalatal contact trace of C1=/t/ only in 6 out of 96 tokens (Hardcastle & Roach, 1979). In a later EPG study carried out with productions of /d#k, n#g, n#k, nt#g/ read by seven speakers, the assimilated pattern was found to be far more common than the non-assimilated one, with nasals assimilating more than stops (94% *can go*, 71.3% *can't go*, 48% *Fred can*); moreover, there were instances of partial assimilation consisting of either an incomplete alveolar closure or of no closure and lateral contact up to the sides of the alveolar zone, and considerable speaker-dependent variability with the majority of speakers assimilating in the case of the sequences with C1=/n/ and showing a mixture of assimilated and non-assimilated patterns in the case of the sequences with C1=/d/ (Hardcastle, 1994 a, b). Another EPG investigation of /n#k/ produced in real sentences at fast speech rates by ten English speakers reported large speaker-dependent differences which could be classified into the following adaptation types: no assimilation or partial or complete assimilation depending on the sentence token (two speakers); either no assimilation or complete assimilation (two speakers); complete assimilation all the time (four speakers); no assimilation invariably (two subjects) (Ellis & Hardcastle, 2002).

Other scholars have also carried out articulatory research on place assimilation in heterosyllabic two-consonant sequences with an alveolar stop or nasal C1 using data for English, German or the two languages at the same time. With respect to English, EPG data on the sequences /tk, tp, nm, nk, ng/ across word and morpheme boundaries showed similar percentages of assimilated, non-assimilated and partially assimilated realizations across speakers, and large speaker-dependent differences regarding the frequency of occurrence of the three adaptation processes: one subject exhibited complete assimilation as a general rule, another subject did not fully assimilate, and a third speaker assimilated partially for the most part and thus had either partial closure or else no central closure and tongue contact fronting at the sides of the palate extending up to the alveolar zone (Barry, 1985). Evidence for cases of a C1 residual gesture has also been reported for tokens of the sequence /t#k/ in English, which happened to be perceptually ambiguous when asked to be categorized as /t/ or as /k/ by listeners (Nolan, 1992). EPG data for productions of /ng/ by Australian English speakers showed assimilation most of the time and rare cases of lateral contact fronting up to the alveolar zone and thus a residual alveolar gesture in the case of two subjects, and a more variable adaptation pattern for a third speaker (Stephenson & Harrington, 2002). This variable scenario may also be inferred from descriptive studies on nasal assimilation in English; thus, it is widely acknowledged that /n/ may assimilate in place of articulation or stay unmodified when occurring before a bilabial, labiodental or velar consonant word internally, as in derived lexical forms with the prefix *in* (*input*, *impossible*, *impolite*, *infrequent*, *incapable*).

Regarding German, EPG data for the sequences /n#k, n#g/ in noun compounds and particle verbs gathered from six speakers revealed above all the existence of partially assimilated cases exhibiting either weak central alveolar contact or else no central alveolar contact and lateral contact fronting during C1, though instances of categorical regressive assimilation also occurred for some speakers (Bergman, 2012). Two more studies dealing with regressive place assimilation in alveolar stop sequences using data for English and German should be mentioned as well. An EMA investigation on alveolar + velar stop sequences produced by three German speakers (/t#k/) and two English subjects (/d#k/) found that assimilations occurred very rarely for two speakers, about half of the time for two other subjects and most of the time for the fifth speaker, that they took place at fast speech rates as a general rule, and that all subjects had cluster tokens with some C1 residual movement (Kühnert, 1993). In a more recent EPG and EMA study for the sequences /d#k, t#k/ uttered at a fast speech rate, most English and German subjects favoured complete over partial assimilation with signs of a C1 residual gesture, and the residual gesture situation was clearly available at least some of the time for all speakers (Künhert & Hoole, 2004).

Segmental duration appears to be a less straightforward cue than degree and location of tongue-to-palate contact for determining whether complete assimilation, partial assimilation or no assimilation is at work, the reason being that it is not always obvious what the relationship between the duration of completely and partially assimilated consonant clusters and that of their underlying phonemic cognates ought to be. More work needs to be done in this area, as shown by the following examples taken from some of the studies referred to above. In Ellis & Hardcastle (2002), the presence of longer C1 realizations for underlying /ŋ#k/ in *bang comes* than for fully assimilated /n#k/ in *ban cuts* was considered to be compatible with the finding that assimilation, albeit partial, had occurred since velars should be longer than alveolars. In Stephenson & Harrington (2002), however, C1 and cluster duration turned out to be longer for tokens of /ng/ which were considered to be partially assimilated than for the underlying cluster /ŋg/.

To recapitulate, both for /tC/ and /nC/ sequences, speakers of English or German often show a residual C1 gesture and, as to the frequency of occurrence of place assimilation, they may favour assimilation, no assimilation or a mixed scenario. Speakers of Romance languages, Japanese or Korean, on the other hand, clearly disfavour gradual assimilations. For these subjects, /n/ tends to assimilate categorically and highly frequently to the following consonant, while frequency of place assimilation for /t, d/ varies substantially as a function of language, speaker and other factors (see sections 2.4.2 and 2.6).

2.4.2 Overlap/assimilation and reduction/elision

Consonant reduction involves typically segmental shortening and the failure for articulatory gestures to achieve a full-fledged constriction. When lenited, coda stop consonants shift to approximants, which are at the same time short and unconstricted, and a similar trend towards reduction in time and space accounts for other changes such as the replacement of preconsonantal /z/ by the apical tap [ɾ] (sections 5.2.3). As discussed below, an issue open to debate is whether coda consonants need to be maximally reduced for gestural overlap and regressive assimilation to apply. The relationship between the reduction of coda consonants and regressive assimilation appears to also be language-dependent in ways which are yet not fully understood.

There are languages where the two dimensions are positively correlated. In these languages, gestural overlap between two consecutive consonants may increase as the C1 gestural magnitude decreases at higher speech rates (see experimental evidence for this relationship in Byrd & Tan, 1996 and in section 2.6), and regressive assimilation is more prone to affect those coda consonants which are less prominent articulatorily such as front vs dorsal lingual stops and voiced vs voiceless obstruents (section 4.1.1). At the other extreme, syllable-final consonants in Russian consonant clusters turn out to undergo little or no articulatory reduction and tend to avoid regressive assimilation. Thus, EMA data on /kt, pt, kp/ within and across words revealed the presence of clearly positive C1/C2 lag values in Russian and negative or shorter positive lag values in Korean (negative for /pC/, positive for /kC/), which is consistent with /tp, tk, pk/ assimilating in Korean but not in Russian (Kochetov et al., 2007). Likewise EPG data on Russian heterosyllabic /tC, nC/ sequences showed no reduction of the coronal gesture for the oral stop with an increase in speaking rate while closure for /n/ could reduce in fast speech (Barry, 1991). Acoustic data also exhibited more frequent C1 releases in cross-boundary stop+stop sequences in Russian than in English (Zsiga, 2000). Another relevant example is that of the heterosyllabic sequence /sr/ in Italian and Spanish: more temporal separation between /s/ and the trill /r/ has been found to occur in the former language than in the latter, which accounts for why a short intrusive vocalic or consonantal segment may be inserted between the two consonants in Italian while regressive assimilation yielding [r(:)] applies frequently in Spanish (section 5.2.2.1).

Other sources of evidence show however that reduction of coda consonants and gestural overlap or regressive assimilation may proced independently from each other. Lingual kinematic data for /d#k/ in English and /t#k/ in German (Kühnert, 1993) and for /d#g, g#d, s#g, g#s/ in English (Byrd & Tan, 1996) reveal that, while C1 reduction may cooccur with assimilation, this dependency relationship is not obligatory. In Majorcan Catalan and most Occitan dialects coda oral stops never weaken but assimilate systematically in place to the following syllable-initial consonant; on the other hand, Valencian Catalan resembles several Spanish dialects in favouring weakening rather than assimilation of oral stops in coda position. Thus the sequence /kd/ in the lexical string *sac dur* "tough sack" is typically realized as [dd] in Majorcan and as [ɣð] in Valencian. Coda nasals assimilate in place to C2 in the two Catalan dialects.

A relevant research issue needs to be addressed in connection with the reduction/assimilation dichotomy, i.e., whether the single consonant outcome of a heterosyllabic consonant cluster has been generated through direct C1 elision or through regressive assimilation followed by simplification of the geminate outcome. Just to illustrate this problem, the outcome [t] of /kt/ may in principle result from lenition or maximal shortening and subsequent deletion of the velar stop (/kt/> [çt] > [t]; /kt/ > [^{k}t] > [t]) or else from shortening of a geminate realization after regressive place assimilation has taken place (/kt/ > [tt] > [t]). The latter development may be argued to apply whenever long and regular realizations of the assimilated outcome alternate in a given dialect (i.e., [tt] and [t] in the above example), and the former when alternations occur between the original unassimilated cluster and regular, not especially long productions of C2 (i.e., [kt] and [t] but not [tt]). Another possible way to ascertain whether cluster simplification has originated through assimilation or through straight C1 deletion is by comparing the duration of the simplified phonetic outcome (i.e., [t] < /kt/) with long phonetic realizations of an underlying geminate (i.e., [t:] < /tt/). If there is a difference between the two sound change processes, at least some tokens of the resulting stop [t] ought to be somewhat longer (and thus exhibit a comparable duration to the underlying geminate) if derived through shortening of an assimilated long realization than through elision of a weakened realization of the coda stop consonant.

Another interesting case which may serve to illustrate this point is that of the sequence /sʃ/. Long /ʃ/-like frication noises exhibiting a similar duration to a geminate rather than to a single consonant have been reported to occur for /sʃ/ in English and French meaning that some duration belonging to C1=/s/ has been articulated as C2=/ʃ/ and therefore that regressive assimilation has taken place (Niebuhr et al., 2011, Niebuhr & Meunier, 2011, Holst & Nolan, 1995, Nolan et al., 1996). The situation becomes more complicated when the noise portion of /sʃ/ becomes shorter and comparable to that of a single fricative under specific speech rate and positional conditions (English, Nolan et al., 1996; Catalan, Recasens & Mira, 2013). This is so since the short phonetic realization in question may result either from shortening of an assimilated realization or else from /s/ elision after severe articulatory reduction, which is most prone to occur whenever the alveolar fricative belongs to a frequent or function word. Also the sequence /s#r/ in Catalan may be assimilated into [r:] or else simplified into [r] through geminate shortening or C1 elision depending on factors such as speech rate, boundary strength and word frequency (section 5.2.2.1).

An alternative mechanism which could account for the presence of a short rather than a long phonetic outcome in consonant sequences like /sʃ/ is, as claimed by Articulatory Phonology, a maximal degree of gestural overlap between C1 and C2. According to this view, different durations of the coda fricative noise may result from different degrees of overlap between the articulatory gestures for the two fricatives in succession rather than from C1 deletion or complete regressive assimilation (see some support for this explanatory possibility in Pouplier et al., 2011). Again whether this production strategy applies or not could be language-dependent much like the scenario for regressive adaptation in heterosyllabic consonant sequences with coda /n/ and /t/ described in sections 2.4.1 and 2.6.

2.4.3 Manner assimilation

Complete regressive (C2-to-C2) or progressive (C2-to-C1) assimilation is achieved once the two successive consonants come to agree not only in place but also in manner of articulation. Thus, for example, the dental oral stop /t/ may become a bilabial nasal before /m/ and thus change its place and manner attributes in Catalan sequences like [sɛm ˈmɔrs] *set morts* "seven dead".

In contrast with the considerable attention which has been paid to the phonetic implementation of place assimilation, extensive research is lacking about the extent to which assimilations in manner of articulation operate more or less categorically in consonant clusters depending on segmental composition. Thus, for example, it has been shown that in Syrian Arabic the optional assimilation process /l#r/ > [rr] where the lateral belongs to the definite article may apply categorically or gradiently (Heselwood et al., 2011, Heselwood & Watson, 2013). Chapter 5 deals with this issue as well as with whether manner assimilations operate more frequently in consonant sequences which are homorganic (whether underlyingly or after place assimilation or blending has applied; see section 2.5) than in those which are heterorganic. The relationship between homorganicity and manner assimilation has been pointed out occasionally in the phonology literature. Rice & Avery (1991) claim that the spread of continuancy is conditioned by homorganicity, as in the case of the manner assimilations /nl/ > [ll] which may take place in Klamath, Toba Batak and Ponapean, /nr/ > [rr] (Toba Batak, Ponapean) and /rl/ > [ll] (Toba Batak), and also the regressive fricativization of labial stops before /f/ and dental stops before /s, ʃ/ in Sundanese Arabic. In an earlier study, Hutcheson (1973) formulated a Principle of Similarity condition according to which 'segments must be nearly identical in order to assimilate completely' without clearly specifying that the condition in question ought to operate on homorganic consonants and that assimilation ought to involve a complete adaptation in manner of articulation. Through the analysis of a wide range of manner assimilations we seek in chapter 5 to confirm that homorganicity facilitates manner assimilation, and argue that this may be the case since changes in manner often depend on slight changes in lingual configuration, as for example some contact loss at the tongue sides or at the center of the oral cavity when a dentoalveolar oral stop shifts into an alveolar lateral or an alveolar rhotic, respectively. It is less clear whether homorganicity plays any role in manner assimilations involving nasality since in principle velar lowering should not be conditioned by the placement and degree of the lingual constriction nor by the overall tongue configuration.

Another research issue which will be addressed in chapter 5 is the extent to which manner assimilation may be assisted by articulatory reduction and, therefore, whether it is prone to apply to coda consonants which have been subject to weakening and thus, have become lenited, aspirated, rhotacized or vocalized but have not assimilated in place of articulation to the following syllable-onset consonant. This assimilatory mechanism is prone to apply to consonants which are especially resistant to contextual coarticulation, and thus reluctant to adapt articulatorily to the following consonant, such as lingual fricatives and rhotics (sections 5.2 and 5.5).

Voicing assimilation will not be dealt with in detail in the present book among other things because its implementation differs qualitatively from assimilations in place and manner of articulation. This issue may be exemplified with data on regressive voicing adaptation for heterosyllabic consonant sequences composed of an obstruent followed by a voiced consonant in languages with a regressive assimilation voicing rule and voiced stops with negative VOT. In languages of the Romance family, the failure for voicing not to extend throughout the entire preceding coda obstruent could be considered to parallel cases of a gestural residue such as those referred to for place assimilation in section 2.4.1. The fact however is that whether this occurs or not does not appear to be controlled by the speaker but results rather from the aerodynamic constraints involved in the production of the target consonant such as the need to allow sufficient airflow through a relatively open glottis for fricatives or to increase the intraoral pressure level for stops or an alveolar trill. Analogous aerodynamic constraints may account for why in the languages referred to above voicelessness is more prone to occur in CC#C sequences with two coda obstruents and an underlying voiced C3 (/ks#d/ as in Catalan *sacs durs* "tough sacks") than in comparable C#C sequences with a single obstruent in coda position and an underlying voiced C2 (/k#d/ as in Catalan *sac dur* "tough sack"). In spite of these conditioning factors, it may be ascertained that regressive voicing assimilation is at work in both C#C and CC#C structures. This is strongly suggested by electroglottographic (EGG) data for Catalan VC#CV and VCC#CV sequences with word-final voiceless obstruents and an underlyingly voiced word-initial consonant showing invariably a voicing period at the onset of the first consonant of the consonantal sequence which is longer than the voicing lag induced by the preceding vowel and therefore must be associated with the voiced word-initial consonant (Recasens, 2014a: 342–349).

2.5 Blending

A significant contribution of Articulatory Phonology is the concept of gestural blending (Browman & Goldstein, 1989). Blending differs from assimilation and coarticulation in that the articulatory adaptation between the two consonants of a heterosyllabic consonant cluster does not result into the partial or complete prevalence of one consonant over the other but into a compromise realization between the two. As shown below, blending processes may be considered to be phonetic to the extent that the final articulatory outcome differs from C2 and their temporal domain does not extend throughout C1; on the other hand, however, they differ from purely coarticulatory effects in that the phonetic outcome in question may show a different place of articulation from that of the originary coda consonant.

For blending to apply the two meeting consonants need to be typically homorganic or nearly-homorganic, and thus articulated with the same or nearby articulatory structures such as tongue tip and blade or tongue blade and predorsum. Two main blending mechanisms have been shown to occur in heterosyllabic consonant sequences (Recasens & Pallarès, 2001a, b, Recasens, 2006), which will be analyzed in detail in chapter 3.3.4.

(a) Blending through intermediation gives rise to output realizations produced at an intermediate zone between the closure/constriction location for C1 and C2. Thus, for example, blending between the dorsovelar stop closing gesture for a back velar stop and the more anterior dorsopalatal gesture for a front vowel or glide gives rise to an intermediate stop realization which is articulated at the postpalate or postpalato-velar zone, as for [k̟] in English *quiche* as opposed to plain velar [k] in English *caught* (Frisch & Wodzinski, 2016). On the other hand, blending between the tongue blade for an alveolar consonant and the tongue dorsum for a truly palatal consonant may result into the formation of an intermediate palatalized postalveolar, palatoalveolar or alveolopalatal articulation, as for /sj/ > [sʲ], [ʃ] or /nj/ > [nʲ], [ɲ] in English (*miss you*, *onion*; Zsiga, 1995, 2000). As pointed out in section 4.6, blending through intermediation may also operate on closure or constriction places located futher apart provided that they approach each other sufficiently, as for example in the case of the endproduct [c] of the sequence /kt/ which may be achieved whenever the dorsovelar closure for C1=/k/ is sufficiently anterior and the cluster is articulated with considerable dorsopalatal contact.

(b) Blending through superposition applies when the closure area for the articulatory outcome is achieved by superimposing the closure areas for the two meeting consonants. Thus, sequences composed of a dentoalveolar or alveolar (e.g., /t, n, l/) and an alveolopalatal (e.g., /ʎ, ɲ/) such as /ɲn/ in the Catalan sequence *any nou* "new year" may be realized for the most part through a single closure event whose tongue contact area encompasses the closure areas for /ɲ/ and /n/ in intervocalic position and even surpasses them. Strictly speaking, the articulatory outcome of this blending mechanism is not produced at an intermediate location between C1 and C2 but results from overlaying the closure areas for two consonants in succession. Blending through superposition may also involve the bilabial closure for C1 and the labiodental constriction for C2 in the case of the clusters /mf/ or /nf/ (Eng. *ten folders*), which may account for the occasional insertion of an intrusive stop and thus the outcome [ɱᵖf].

A relevant issue is the temporal manifestation of blending, i.e., whether the compromise articulation of interest may be traced already at C1 onset or else at a later point in time during C1. To the extent that blending is a phonetic adaptation effect, the articulation in question is not required to occur since C1 onset and may last for a shorter or a longer period of time depending on the segmental composition of the consonant cluster, speech rate and other factors, as found by Zsiga (2000) for /sj/ in English. Moreover, given that blending does not convey the prevalence of one consonant over the other, its temporal domain may extend over the C2 temporal slot as well.

2.6 Prosodic, morphological and lexical factors, and speech rate

In addition to segmental factors, the degree of overlap and segmental duration characteristics in consonant clusters is also conditioned by boundary strength and word and utterance position, speech rate, stress and word frequency. Regarding word-initial clusters, the duration of the first consonant increases with boundary strength, as found for /kl, sp, sk/ in English (Byrd & Choi, 2010) and /kl, kn/ in German (Hoole et al., 2009, Bombien et al., 2010). Consonant overlap has also been reported to vary inversely with boundary strength, though this effect applies to clusters across a word boundary rather than to those placed word initially. Indeed, the inverse relationship in question has been shown to occur for /k#l/ and /s#ʃ/ in English (Hardcastle, 1985, Holst & Nolan, 1995) and for /s#r/ in Catalan (Solé, 1999), but only weakly or not at all for word-initial /kl/ in English and German (Byrd & Choi, 2010, Bombien et al., 2007) and word-initial /kl, kn, sk/ in German (Hoole et al., 2009, Bombien et al., 2010).

Consonant overlap also varies with position within the word and the utterance. Clusters show less consonant overlap word initially than word medially, as revealed by Georgian two-stop sequences (Chitoran et al., 2002) and by stop clusters starting with /t, k/ but not /p/ in Russian (Kochetov & Goldstein, 2005), and by differences in degree of anticipation of the apical raising gesture for /l/ during the dorsovelar closure period for /k/ in the cluster /kl/ in English (Hardcastle, 1985). Less overlap between C1 and C2 and/or lesser articulatory reduction of the alveolar fricative have also been reported to occur for /sk/ word initially than across a word boundary in English and German (Byrd, 1996, Brunner et al., 2014). On the other hand, cross-syllabic word-medial clusters exhibit more overlap than clusters across a word boundary, as reported for Korean /pC/ sequences (Kochetov & Pouplier, 2008), which is in line with the universal trend for regressive place assimilations to operate word internally rather than in C#C sequences. Thus, for example, according to descriptive studies, regressive place assimilation in /nC/ sequences applies obligatorily word internally and optionally across a word boundary in Catalan and Cairene Arabic (Youssef, 2013: 34–35). It is worth noting that the word-medial position may include the across morpheme boundary condition, as revealed by data taken from Spanish where the nasal of the prefix *in-* assimilates systematically to a following labial or velar (*imposible* "impossible", *incapaz* "incapable") and from English where /s/ palatalization before /j/ into [ʃ] takes place categorically in *confession* and gradiently in *miss you* (Zsiga, 1995, 2000). The position-dependent differences in degree of overlap just mentioned match to a large extent stability differences in the timing relationship between C1 and C2 which, according to simulation work carried out within the Articulatory Phonology framework, has been reported to be higher for onset clusters than for coda clusters and minimal for C#C sequences (Nam & Saltzman, 2003). In a similar vein, greater intergestural timing stability for Korean obstruent clusters with a labial and a lingual consonant has been found to hold across a word boundary inside a lexicalized compound than inside a non-lexicalized compound (Cho, 2001).

An increase in speech rate may cause an increase in gestural overlap, as shown for /kl/ and for consonant sequences composed of a nasal or an oral stop followed mostly by a stop in English (Hardcastle, 1985, Barry, 1992, 1991, Kerswill, 1985, Nolan, 1992, Ellis & Hardcastle, 2002, Künhert & Hoole, 2004), and for stop sequences which undergo assimilation according to descriptive accounts in Korean (Son et al., 2007, Kochetov & Pouplier, 2008). In a production study of English obstruent clusters, Byrd & Tan (1996) also found that an increase in speech rate caused gestural overlap to increase (though the effect was minimal for the maximally overlapped sequence /d#g/), as well as more or less articulatory reduction and shortening depending on position (coda consonants reduced more than onset consonants) and segment type (fricatives reduced less than stops). A less clear or no consistent effect of speech rate on frequency of consonant overlap has been reported for the English sequences /tk, tp, nm, nk, ng/ across word and morpheme boundaries (Barry, 1985) and for stop clusters in Korean and Russian (Kochetov et al., 2007).

Stress may also influence gestural overlap. According to several production studies on German consonant clusters, a trend was found for word-initial /kl/ and /kn/ to exhibit less overlap and more tongue-to-palate contact in stressed vs unstressed syllables (Bombien et al., 2007, 2010), and for the absence of sentence stress to also favour regressive adaptation and thus overlap in the case of the heterosyllabic sequences /nk, ng/ in noun compounds and particle verbs (Bergman, 2012). Other experimental studies report negative results for the stress effect in question. Data for the tautosyllabic word-initial sequences /kl, kn, sk/ in German reveal that the presence of lexical stress in the first syllable of the word renders C2 longer, which is consistent with this consonant being centered around the vowel nucleus, but does not affect the degree of overlap between the two consonants in the cluster, which was predicted to be greater in the unstressed vs stressed condition (EMA, Hoole et al., 2009). In a similar fashion, different degrees of sentence stress were found not to influence the frequency of occurrence of regressive place assimilation in Catalan /t#C, n#C/ sequences (EPG, Recasens & Mira, 2015).

Word frequency and morphological category may also bear upon the degree of overlap and frequency of occurrence of C1-to-C2 assimilations. Thus, regressive place assimilation in Catalan /t#C, n#C/ sequences turned out to operate more often when C1 was the last consonant of a grammatical particle (*un* "a", *set* "seven'") than of a less frequent noun (Recasens & Mira, 2015). In an EPG study dealing with regressive place assimilation in German /nk, ng/ sequences embedded in particle verbs and noun compounds, high frequency items, mostly if particle verbs, were especially prone to assimilate the alveolar nasal to the following consonant (*eingeben*, *Sinn krise*; Bergman, 2012). Likewise, according to EMA data for /n#k, n#p/ embedded in meaningful German sequences, word frequency had an effect on the degree of linguoalveolar contact reduction of coda /n/ and on the degree of consonant overlap between C1 and C2, mostly so when the nasal came after a low vs high front vowel (Jaeger & Hoole, 2011).

To recapitulate, intergestural timing is more stable in tautosyllabic vs heterosyllabic sequences and among the former clusters in onset vs coda position. In terms of gestural overlap, consonants overlap less word initially than across a syllable or word boundary and, as to heterosyllabic clusters, across a word boundary than word medially (though this latter relationship appears to be language-dependent; Yanagawa, 2006). Moreover, the presence of a major prosodic boundary such as a clause boundary causes minimal overlap in CC- and C#C sequences and the first consonant of a word-initial cluster to lengthen. Consonant overlap applies most often in frequent lexical items and is favoured by an increase in speech rate and, less so, by a decrease in stress level. Since the contribution of the former factor to the implementation of assimilatory processes has often been neglected in the literature, dissimilar results reported in several studies may be due to the fact that they were using words differing in frequency of occurrence and grammatical characteristics.

2.7 The DAC model of coarticulation

A central hypothesis of the present investigation is that the articulatory adaptation processes occurring in heterosyllabic consonant clusters are ruled to a large extent by the principles of the DAC model of coarticulation (Recasens et al., 1997). According to this model, which has been proposed to account mostly for lingual and jaw activity in speech, consonants differ in degree of articulatory constraint depending on the place and manner of articulation requirements involved in their production. The more constrained, the more resistant consonants are to the coarticulatory effects exerted by the adjacent phonetic segments, and the greater the effects that they exert on the adjacent segments in the speech chain. Consequently, a precise knowledge about the degrees of articulatory constraint for consonants should contribute to our understanding of the articulatory factors which render phonetic and phonological adaptation processes in consonant clusters possible.

Experimental studies on VCV lingual coarticulation such as those for Catalan (Recasens et al., 1997, Recasens & Espinosa, 2009, Recasens & Rodríguez, 2016) reveal that the coarticulatory resistance scale for consonants varies in the progression labials (least constrained, least resistant) > dentals and alveolars > (alveolo)palatals, palatoalveolars (most constrained, most resistant). The rationale underlying this coarticulation hierarchy is to be sought in specific properties of the lingual gestures involved: labials are most unconstrained since their production involves no lingual activity and (alveolo)palatals and palatoalveolars most constrained since raising the tongue dorsum and fronting the tongue body through genioglossus contraction prevents the entire tongue from adapting to the contextual vowels to a large extent; dentals and alveolars occupy an intermediate position given that the tongue body does not intervene in their closure/constriction formation but it is not entirely free to adapt to the contextual phonetic segments due to coupling with the primary tongue front articulator (presumably less free when the dentoalveolar consonant is laminal than when it is apical).

More fine-grained differences in degree of coarticulatory resistance among consonants have been found to hold. Among dentals and alveolars, the alveolar trill /r/ and somewhat less the alveolar fricative /s/ turn out to be most resistant due to stringent articulatory demands associated with manner of articulation: some predorsum and blade lowering and tongue body backing and enough lingual tension and airflow to generate the vibration cycle for /r/, and the formation of a central slit for the passage of the airflow required to generate turbulence when hitting against the front teeth in the case of /s/ (Solé, 2002a). Moreover, ultrasound data show that maximal coarticulatory resistance for these two consonants occurs at the tongue front and tongue predorsum rather than at the back of the tongue body located at the velar and pharyngeal zones. At the other extreme, the dental [ð], which is an approximant allophone of /d/ occurring intervocalically and in certain postconsonantal environments in Spanish and Catalan, is most variable and thus least resistant, which appears to be in line with its being articulated with a wide constriction and little tongue-to-palate contact. In principle, this coarticulation resistance characteristic for [ð] could be extended to other approximants such as [β] and [ɣ] with respect to [b] and [g], respectively. Other dentoalveolar and alveolar consonants such as /t/, /n/ and /ɾ/ exhibit intermediate degrees of coarticulatory resistance. The coarticulatory scenario for /l/ depends on darkness degree: the alveolar lateral is articulated more anteriorly and becomes more coarticulation resistant at the tongue body if strongly dark (as for /r/) than if clear (as for /ɾ/), which is in line with the production of the former variety involving some tongue predorsum lowering and tongue body backing. Even clear /l/ may oppose the vowel coarticulatory effects in tongue body positioning to some extent due to the requirement on laterals to lower the tongue sides for the passage of airflow; indeed, for all varieties of the alveolar lateral, transverse compression of the tongue may cause some tongue body backing and apicality, and these articulatory actions and a lowered predorsum and some jaw lowering may oppose the tongue body raising and fronting motion for front vowels (Linblad & Lunqvist, 2003). In principle, the articulatory configuration and coarticulatory resistance characteristics of retroflex and velarized/pharyngealized consonants parallel those of the alveolar trill and strongly dark /l/ (see section 3.3.1.3), while palatalized consonants should resemble alveolopalatals in this respect. Among palatals, on the other hand, the palatoalveolar fricative /ʃ/ is expected to be articulated somewhat more posteriorly and be more resistant than the alveolopalatals /ɲ, ʎ/ for essentially the same manner of articulation characteristics which cause /s/ to be more resistant than other non-rhotic front lingual consonants. Moreover, laterality requirements account for why, in comparison with /ɲ/, /ʎ/ is articulated at a fronter location and shows less dorsopalatal contact and therefore may be somewhat less resistant to tongue dorsum coarticulation.

The coarticulatory resistance scale for consonants just referred to is based on VCV coarticulatory patterns and therefore not necessarily identical to the coarticulatory resistance hierarchy operating in heterosyllabic CC sequences, the main reason being the higher degree of accuracy required for forming two constrictions in succession than for producing simple consonants in intervocalic position. This production requirement becomes especially relevant when the lingual gestures for the two consecutive consonants are antagonistic and thus implemented through opposite articulatory maneuvers such as tongue body raising/fronting and tongue body lowering/backing. In an EPG study on Catalan heterosyllabic C#C sequences (Recasens & Pallarès, 2001a), /s/, the alveolar trill and dark /l/ were found to be more coarticulation resistant not only than dentals and other alveolars but also than alveolopalatals; indeed, C1=/ɲ, ʎ/ turned out to be more sensitive to the anticipatory depalatalizing effect exerted by C2=/l, s, r/ (i.e., depalatalization involves some tongue dorsum lowering and thus a decrease in dorsopalatal contact) than C1=/l, s, r/ were to the anticipatory palatalizing effect exerted by an alveolopalatal or palatoalveolar C2 (i.e., palatalization involves an increase in tongue dorsum raising and dorsopalatal contact). Ultrasound data for C#C sequences next to /a/ also show more coarticulatory resistance for /s, r/ and to some extent /l/ than for /ɲ/ at the rear of the tongue body in front of the pharyngeal wall while all three consonants /s, r, ɲ/ happen to be more resistant than other dentals/alveolars at the palatal zone. In light of these data and at least for Catalan consonant sequences, the fricatives /s/ and /ʃ/ and the trill /r/ are clearly more constrained than the dental /t/, the alveolar /n/ and the alveolopalatals /ɲ, ʎ/. The alveolar lateral /l/ may be included with the former group if strongly dark or with the latter if clear though with some reservations associated with the requirements on laterality referred to above. A high degree of coarticulatory resistance for the rhotic irrespective of syllable position in C#C sequences could be related to its being realized as a trill syllable initially and with a trill-like configuration or a short and fast single apical contact in syllable-final position (see section 3.1).

Dorsovelar consonants differ from front lingual consonants regarding coarticulation in several respects. In contrast with (alveolo)palatals, they blend with the following vowel thus giving rise to two or even three closure locations at the postpalatovelar zone before front vowels and at the velar zone before low and back rounded vowels. In Catalan consonant clusters, velars undergo small changes in closure location unless occurring next to alveolopalatal consonants (see section 4.7.4) and allow more considerable coarticulatory effects in tongue front position since this lingual region is not involved in the dorsovelar closure or constriction formation. Moreover, much as for alveolopalatals, a decrease in dorsopalatal contact for /k/ may take place before the trill /r/ and dark /l/, which are articulated with a relatively low tongue dorsum position (Recasens & Pallarès, 2001b).

Differences in degree of articulatory constraint among consonants in heterosyllabic clusters are also correlated with syllable position though in complex ways due to the interaction with contextual effects exerted by the adjacent consonants and vowels (see regarding studies on the subject summarized next Byrd, 1996 and Byrd & Tan, 1996 for English obstruent C#C sequences, and

Recasens, 2004 and Recasens & Rodríguez, 2018 for several Catalan consonant combinations). Less constrained front lingual stops and nasals, and also alveolopalatals and to a large extent dorsovelars, tend to exhibit less tongue dorsum contact and a somewhat more posterior constriction and to be more sensitive to consonant-to-consonant coarticulation syllable finally than syllable initially though this positional and coarticulatory pattern may be counteracted by specific contextual coarticulatory effects (such as, for example, more prominent tongue body raising/fronting effects from alveolopalatals on other consonants at the anticipatory vs carryover level). Highly constrained front lingual fricatives and rhotics, on the other hand, do not show appreciable syllable-position-dependent differences in tongue configuration and contextual coarticulation; thus, front lingual fricatives are not more reduced in coda than in onset position though may show a wider constriction in the former position than in the latter. Other syllable-position-dependent characteristics may be determined by allophonic articulatory properties, as in the case of /l/ which tends to be somewhat darker in C1 (coda) than in C2 (onset) position and the alveolar rhotic which is generally less constricted and implemented with less apical contacts in the former position than in the latter.

2.8 Direction of segmental adaptation

In most cases, the direction of assimilatory processes conforms to that of the corresponding coarticulatory effects and may thus be said to be conditioned by the articulatory and aerodynamic requirements for the phonetic segments involved. This is so for specific vowel assimilations triggered by consonants. Thus, strongly dark /l/ and to a large extent the trill /r/ exert anticipatory tongue body lowering and backing effects on preceding front vowels and may cause them to shift to a lower vocalic segment. Moreover, the finding that the alveolar trill but not dark /l/ may trigger progressive vowel assimilations follows from the fact that the former consonant exerts more prominent carryover C-to-V coarticulatory effects than /l/ mostly on front vowels such as /i/ whose production involves an antagonistic tongue configuration to that for /r/ (Recasens, 2014b). It has been suggested that a plausible motivation for this coarticulatory and assimilatory behaviour for the alveolar trill is to be found in the manner requirements involved in the performance of apical trilling. The positive relationship between the direction of coarticulatory effects and assimilatory processes is consistent with the general principle of Articulatory Phonology that gestural overlap between consecutive phonemic units should be determined by the spatiotemporal properties of their articulatory gestures.

Other aspects about coarticulatory and assimilatory direction cannot be possibly attributed to the biomechanical properties of the articulatory gestures involved however. Thus, a tendency has been found for V-to-V anticipatory effects in VCV sequences to be less variable than V-to-V carryover effects, thus suggesting that the former reflect phonemic planning while the latter depend on the online state of the articulators (Whalen, 1990, Bell-Berti & Harris, 1981, Fowler & Saltzman, 1993). This asymmetrical relationship may explain why assimilatory processes such as vowel harmony in VCV sequences or place assimilations in heterosyllabic consonant sequences are regressive rather than progressive in the world's languages. Another valid example are low or mid vowel raising assimilations or cases of palatalization and closure retraction of front lingual consonants triggered by contextual (alveolo)palatal or palatoalveolar consonants, such as /ə/ > [i] before /ɲ, ʎ/ in Catalan *sinyor* for *senyor* "sir" and *millor* MELIORE "better" and /n/ > [n^j] before /ʃ, ʎ/ in English *ten ships* and Catalan *enllà* "far away". Indeed, these processes happen to operate mostly at the regressive level in the world's languages in spite of the fact that the tongue dorsum raising/fronting coarticulatory effects exerted by the (alveolo)palatal consonant trigger may be carryover rather than anticipatory and thus impinge on the following phonetic segment rather than on the preceding one.

It is sometimes hard to ascertain whether coarticulatory effects on coda consonants in heterosyllabic CC sequences are conditioned by the (co)articulatory requirements for both C1 and C2, by the expected trend for syllable-final consonants to be more reduced and to favour gestural overlap to a larger extent than syllable-initial ones, and/or by phonemic planning in speech. It may be argued in this respect that differences in lingual configuration between onset and coda consonants which cannot be attributed to the articulatory characteristics of the contextual consonants ought to be assigned to syllable position. As reported earlier in the literature (Recasens, 2004), this syllable position effect could account in principle for unconstrained lingual consonants showing less linguopalatal contact and being articulated more posteriorly syllable finally than syllable initially next to other relatively unconstrained consonants not requiring a specific tongue body configuration. Other articulatory configuration characteristics for syllable-final consonants appear to depend mostly on the patterns of coarticulatory direction for the syllable-onset consonant trigger, as for the presence of a more posterior and lower tongue body for /n/ in the sequence /nr/ than in the sequence /rn/ (which accords with the prominent anticipatory tongue lowering/backing effects exerted by the trill) and a higher tongue dorsum for /n/ in /ʎn/ than in /nʎ/ (which is in line with the prominent carryover tongue raising/fronting effects exerted by palatal consonants; see however section 3.3.4.1 (b)).

3 Homorganic clusters

This chapter investigates the C-to-C adaptation mechanisms in heterosyllabic consonant clusters composed of consonants articulated with the same or adjacent lingual regions at the same or a nearby place of articulation. The four former sections present EPG data for simple consonants and consonant sequences recorded by about fifteen speakers from three Catalan dialects, i.e., Majorcan, Valencian and Eastern, and ultrasound data acquired from five Eastern Catalan subjects. Section 3.1 deals with the articulatory characteristics of simple consonants in all three dialects. Sections 3.2, 3.3 and 3.4 are about heterosyllabic consonant sequences: the former section provides information about the data recording and analysis methods and the testing hypotheses; the two latter ones report the analysis results for sequences composed of tongue front consonants produced with the tongue tip, blade or predorsum and for sequences of dorsal consonants. Experimental and descriptive data on coarticulatory, blending and assimilatory processes for analogous consonant combinations taken from other languages are also presented and discussed.

3.1 Simple consonants

In order to investigate the interconsonantal adaptation mechanisms in Catalan consonant clusters, EPG linguopalatal contact data were recorded and analyzed for the following eight Catalan consonants embedded in symmetrical VCV sequences with the vowels /i, a, u/: the dental /t/; the alveolars /n/, /l/, /s/ and the trill /r/; the palatoalveolar /ʃ/; the alveolopalatals /ʎ, ɲ/. Data for the alveolar tap /ɾ/ were also collected in a different set of comparable vowel contexts by the same speakers. These articulatory data will serve as reference for checking changes in articulation for the same consonants which may occur as a function of the contextual consonant in consonant clusters. The VCV sequences were inserted in short meaningful sentences about four to six syllables long. Sentences were read about five to seven times by five adult speakers of Majorcan (AR, BM, MJ, ND, CA), Valencian (JM, VB, MS, VG, AV) and Eastern Catalan (DR, JP, JS, DP, JC), who speak Catalan on a daily basis. Linguopalatal contact patterns were acquired with the Reading electropalatographic system every 10 ms using artificial palates equipped with 62 electrodes (Hardcastle et al., 1989). Acoustic data were recorded simultaneously with the EPG data and digitized at 10 kHz.

The artificial palates worn by the fifteen subjects have 62 electrodes distributed into eight equidistant horizontal rows and four vertical columns at each side of the palate surface (see Figure 1). In the figure, electrodes are filled in black, grey or white depending on whether they have been contacted by the

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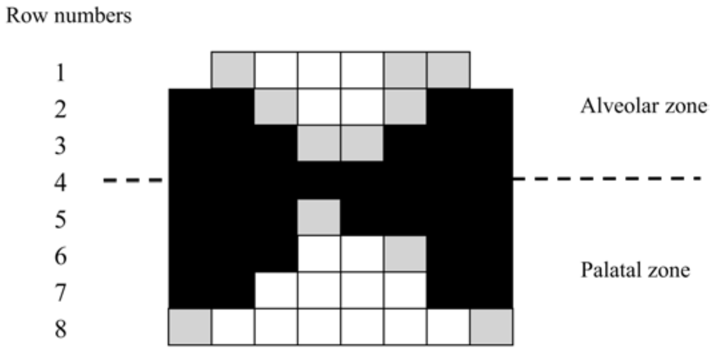

Figure 1: EPG contact configuration showing the distribution of electrodes into rows, columns, and alveolar and palatal articulatory zones. The electrodes have been assigned different shades depending on contact frequency across tokens: black (80–100% activation); grey (40–80%); white (0–40%).

tongue, respectively, more than 80% of the time, between 40% and 80% or less than 40% across tokens of the phonetic realization being displayed. Electrodes are grouped into two major articulatory zones: alveolar between the frontmost row 1 and row 4; palatal between row 5 and the backmost row 8. The separation between consecutive rows of electrodes at the palatal zone is greater than that at the alveolar zone, which follows from the fact that the latter zone is shorter than the former and the two zones include the same number of rows. Several articulatory subzones may be identified for better data interpretation, namely, dental (whenever closure location occurs exclusively at row 1, just behind the upper teeth), front dentoalveolar and back dentoalveolar (at rows 1–2, and 1–3 or 1–4, respectively), centroalveolar and postalveolar (at rows 2–3 and 3–4, respectively), alveolopalatal (whenever closure or constriction extends over a continuous contact area encompassing the alveolar and palatal zones), prepalatal (at row 5), mediopalatal (at rows 6–7) and postpalatal (at row 8).

Closure or constriction onset and offset were identified for all consonants in all VCV sequence tokens by placing a cursor on simultaneous EPG, spectrographic and waveform displays using the MultiSpeech 3700 program of Kay Pentax. Consonant onset and offset for /t/ were determined on the EPG record by the presence of a full closure located at one or more alveolar rows of electrodes starting at the offset of the preceding vowel and ending immediately before the stop burst. A similar criterion was applied to the segmentation of /n, l, ɲ, ʎ/ (sometimes the onset and offset of /l/ coincided with the beginning and end of a central alveolar contact area rather than of a complete closure). As for the two rhotic consonants, onset and offset were taken to occur at the beginning and end of a single short apicoalveolar contact in the case of the tap /ɾ/ and of several apical contacts in the case of the trill /r/. In some cases the consonant boundaries were determined based on inspection of the spectrographic and waveform displays: the boundaries of the fricatives /s/ and /ʃ/ were set at the onset and offset of a patch of frication noise, and those of nasal, lateral and rhotic consonants at the onset and offset of a period of weak and continuous formant structure whenever no clear instances of closure or central contact were available on the EPG displays.

The articulatory characteristics of the consonants under analysis were evaluated at the consonant midpoint on the corresponding linguopalatal contact patterns. Two values corresponding to maximal contact activation at the front and back closure or constriction borders were assigned to each consonant realization, e.g., 1–2 or 2–4 whenever full electrode activation occurred at rows 1 and 2 or at rows 2, 3 and 4 respectively. For a given row, maximal activation was considered to occur whenever there was lingual contact at all its electrodes, at all its electrodes except for one of the two central ones or just at its two central electrodes depending on the consonant subject to investigation. The former condition often applies to stops and the latter to alveolar rhotics and laterals. Both borders were assigned the same value if maximal activation turned out to be present at a single row. This criterion of place identification was preferred to other methods such as the center of gravity and the similarity indices which are based on an evaluation of overall contact areas rather than of tongue contact at specific rows of electrodes (Gibbon & Nicolaidis, 1999, Guzik & Harrington, 2007), or the contact index method which does not always discriminate between closure location and maximum contact fronting (Fontdevila, Pallarès & Recasens, 1994).

For all consonants and each Majorcan, Valencian and Eastern Catalan subject, Figure 2 plots closure or central constriction location and extent values on the eight rows of electrodes of the artificial palate for the intervocalic consonants referred to above. In this and other figures throughout the book, the edges of the vertical lines correspond to the upper and lower closure or constriction borders, as determined by applying the method described above, averaged across tokens of all VCV sequences with the vowels /i, a, u/. Each vertical line within each five line group corresponds to an individual speaker. Averages across contexts and tokens exhibit decimal numbers when the closure/constriction values are located between successive rows of electrodes. Thus, for example, the top constriction border for /ʃ/ for speaker AR (top graph, first vertical line) occurs at value 3.3 and thus between rows 3 and 4 since the fricative constriction could be located at rows 3 or 4 depending on vowel context and individual token.

The consonant closure or constriction can extend over several rows, as for the palatoalveolar /ʃ/ and the alveolopalatals /ʎ, ɲ/, or be located at a single

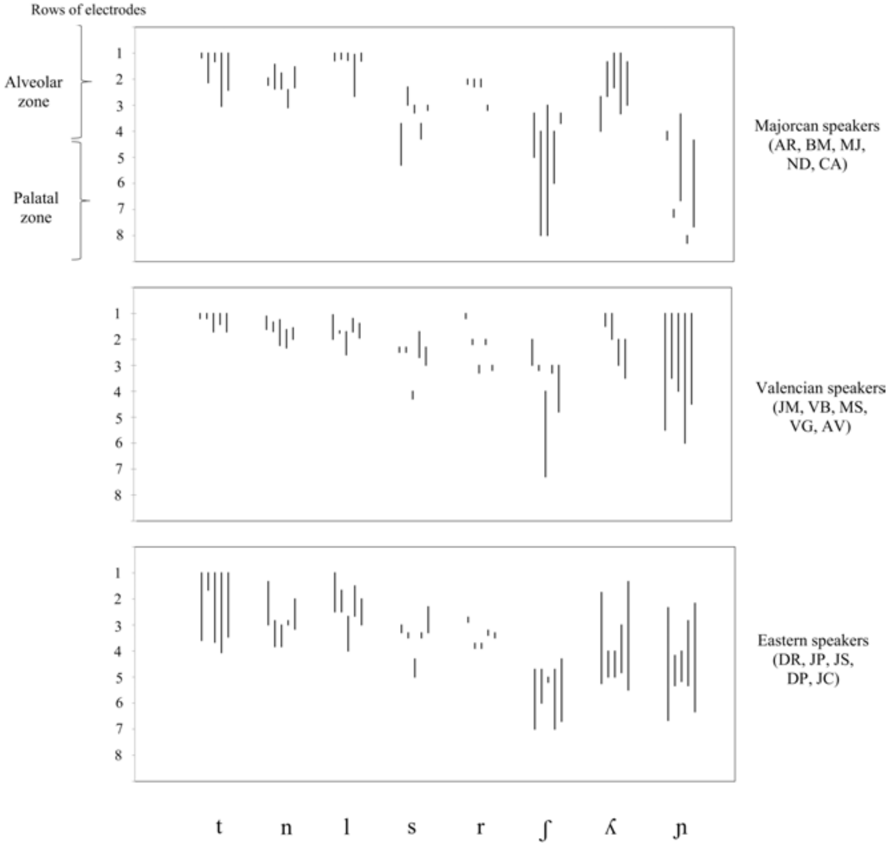

Figure 2: EPG closure or constriction location and extent values measured at the midpoint of several Catalan consonants placed in intervocalic position according to 15 speakers of three Catalan dialects. Data have been averaged across the contextual vowels /i, a, u/. The vertical lines extend from the upper to lower closure or constriction edges and within each five line group are laid in the same order as the speakers' names. Rows of electrodes proceed from the anteriormost row 1 at the top of each graph until the backmost row 8 at the bottom (see Figure 1).

row, as for /s/ and /r/ for all or most subjects. The general characteristics of place of articulation for the intervocalic consonants under analysis are discussed in the next subsections.

3.1.1 Dental or dentoalveolar?

The oral stop /t/, and also /d/ whenever realized as a stop, are said to be either dental or alveolar depending on the language taken into consideration. The former variety occurs in Spanish, Catalan and the other Romance languages where voiceless stops are unaspirated, and the latter in English and German where they are aspirated.

EPG data for Catalan /t/ plotted in Figure 2 reveal that the label *dental* may not be fully appropriate for characterizing closure location for this consonant. It is certainly the case that the tongue front makes dental contact during the articulation of /t/ since the row 1 of electrodes is fully contacted by all speakers. However, except for a few Majorcan and Valencian subjects, the /t/ closure extends over one or more alveolar rows behind row 1, namely, it occurs at rows 1–2 and 1–3 (Majorcan), 1–2 (Valencian) and 1–2 and 1–4 (Eastern). Assuming that purely dental articulations should show full tongue contact exclusively at row 1, it appears that /t/ is dentoalveolar rather than dental in Catalan though the fact that dental contact is always present may be taken in support of the descriptive label *dental*. Dialects differ regarding fronting degree at the back closure edge for /t/ in the progression Valencian (most anterior) > Majorcan > Eastern (most posterior). Based on EPG data for /VtV/ sequences showing different closure locations at rows 1–2, 1–3 and 1–4 depending on speaker, the stop /t/ has also been characterized as dentoalveolar rather than dental in Spanish (Martínez Celdrán & Fernández Planas, 2007: 86).

As for the tongue regions involved in closure formation, /t/ ought to be essentially apical if exhibiting a purely dental realization and apicolaminal, and thus produced with the tongue tip making contact at the upper incisors and the blade at the anterior portion of the alveolar zone, if being dentoalveolar. Several factors may cause the laminoalveolar contact size at /t/ closure location to increase such as word position (closure size may be larger postpausally and prepausally than intervocalically) and segmental context (in comparison to other vocalic contexts, /t/ next to /i, j/ often exhibits more dorsopalatal contact and expands its closure location towards the back while keeping the dental contact fixed). Closure placement for dental and dentoalveolar varieties of /t/ is not necessarily vowel-context dependent however: in comparison to the /a/ context, closure size in the context of /i/ may extend towards the palatal zone or remain constant at a relatively anterior location (Farnetani et al., 1989). Another relevant factor which affects closure location is voicing. Indeed, according to our EPG database, closure for intervocalic /d/ in Valencian and Majorcan Catalan, where the phoneme in question may be realized as [d] instead of as the approximant [ð], which is the preferred allophone in Catalan, is dental rather than dentoalveolar and therefore occurs exclusively at row 1 (eight speakers) or at rows 1 or 1–2 (two speakers). The presence of a smaller oral cavity behind closure location for [t] than for [d] may be associated with the higher intraoral pressure level needed to generate a longer and more intense burst in the case of the voiceless than the voiced stop cognate. Moreover, the consonant realization is purely apicodental and thus articulated exclusively at the upper incisors and exhibits barely any tongue contact at the alveolar and palatal zones if implemented as the approximant [ð] (see above). Indeed, ultrasound data for Catalan reveal that, in comparison with unconstrained alveolars such as /n/, dental [ð] is produced with a relatively posterior tongue body position mostly next to front vowels and some tongue dorsum/blade lowering mostly next to low and back rounded vowels. Tongue dorsum height and tongue contact size at the sides of the palatal zone for dental stop consonants may also vary with some of the factors referred to above: they are both often greater in prominent word positions, for voiceless /t/ than for voiced /d/ and in some vowel contexts rather than others (/i/ > /u/ > /a/).

Contact size at closure location for /t/ may change from closure onset to closure offset. Thus, speakers may exhibit a dental closure occurring exclusively at the frontmost row 1 of electrodes at consonant onset, midpoint and offset, or else a full closure at row 1 at onset, at row 1 and one or more posterior alveolar rows at midpoint, and at row 1 or at rows 2–4 at offset. In the case of the latter pattern there is then some increase in tongue contact at the alveolar zone towards the temporal midpoint of the closing phase and closure release proceeds either frontwards (for the dental release option) or backwards (for the alveolar release option).

3.1.2 Front and back alveolars

Figure 2 also shows that, at least in Catalan, the alveolars /n/, /l/, /s/ and /r/ differ not only in manner of articulation but also in closure/constriction placement. EPG data across vowel contexts reveal that the least contextually variable, more constrained consonants /s/ and /r/ are generally articulated further back than the more variable, least constrained ones /n/ and /l/. According to ultrasound data, /l, s, r/ are produced with more tongue body retraction and tongue dorsum lowering than the other alveolar and palatal consonants, most obviously in the context of front vowels.

The trill requires that central contact be made towards the postalveolar zone with the tongue tip (see Figure 2) and that the tongue predorsum and blade be lowered and the tongue body be retracted for a successful trilling performance. The faster alveolar tap /ɾ/, on the other hand, may be articulated somewhat more anteriorly than the trill and exhibits greater vowel-dependent effects in constriction location and dorsopalatal contact size and thus in tongue dorsum height (Recasens & Espinosa, 2007). As shown in Figure 2, the alveolar /s/, which is somewhat /ʃ/-like in Catalan, may be articulated with the apex and/or blade of the tongue at a constriction located at the central or posterior area of the alveolar zone. This realization of /s/ differs significantly from the laminodental or predorsodental variant which occurs in Andalusian Spanish and French. Moreover, also according to the figure, the two lingual fricatives /s/ and /ʃ/ have a somewhat more anterior constriction in Valencian than in Majorcan and Eastern. The lingual affricate /ts/, where the stop and frication phases are essentially homorganic at the alveolar zone, may be treated as /s/ regarding place of articulation (see section 3.3.1.1); some retraction from the stop closure placement to the fricative constriction location during /ts/ results not so much from differences in place of articulation between the two affricate phases but from the fact that the /t/ closure extends over a greater area (and thus covers more rows of electrodes on the artificial palate) than the /s/ constriction.

The alveolar nasal /n/ may be articulated with the tongue tip or with tip and blade. Continuous voicing and the passage of air through the nasopharyngeal passage during the closure period accounts for why this nasal consonant is produced with a low intraoral pressure level and a burst of little prominence, may lack a complete closure and, analogously to other apical consonants such as /ɾ/ and /l/, may show continuous tongue contact fronting at closure location from onset to offset. The alveolar /n/ exhibits a positive relationship between differences in dorsopalatal contact size and degree of closure fronting as a function of vowel context. It is highly sensitive to vowel coarticulatory effects in dorsopalatal contact size in the progression /i/ > /u/ > /a/, and also in constriction fronting in the progression /i/ > /a/ ≥ /u/ such that closure location may be dentoalveolar, front alveolar or back alveolar depending on the contextual vowel.

As for /l/, active fronting of the constriction location may serve to assist the passage of air through the lateral mouth openings and appears to depend on darkness degree such that the central closure is often more anterior for darker vs clearer realizations of the consonant (it may even be dental for strongly dark realizations). In Catalan, /l/ is often darker in Majorcan than in the Eastern dialect and least dark or clear in Valencian. The EPG data plotted in Figure 2 reveal that, as expected, the strongly dark realization of /l/ in Majorcan Catalan is articulated at the frontmost row of electrodes for most speakers of this dialect. Moreover, while /l/ darkness degree is high in all syllable and word positions in Majorcan, in Eastern Catalan the alveolar lateral may be darker syllable finally than syllable initially and thus when occupying the C1 than the C2 position in heterosyllabic consonant clusters. Dark realizations of /l/ involve tongue predorsum lowering and postdorsum retraction, and clearer ones some predorsum lowering for the passage of airflow through the sides of the oral cavity and a relatively anterior tongue body placement. A higher degree of articulatory constraint for dark /l/ than for clear /l/ explains why, in comparison to the latter variety, the former is more resistant to the same vowel coarticulatory effects in constriction fronting, tongue dorsum height and tongue body fronting referred to for /n/.

3.1.3 Palatal or alveolopalatal?

The term *palatal* is not fully appropriate for characterizing the place of articulation of the Catalan consonants /ʃ/, /ʎ/ and /ɲ/, and the allophones [c] and [ɟ] of front /k/ and /g/, which occur before a front vowel and word finally after any vowel in Majorcan Catalan. As shown in Figure 2, closure or constriction size is generally larger for the three former consonants than for the four alveolars whose articulatory characteristics have been described in section 3.1.2. Ultrasound data reveal that those alveolopalatal and palatoalveolar consonants are produced with a more anterior tongue body and a higher tongue dorsum than dentals and alveolars.

The fricative /ʃ/ is palatoalveolar and articulated at the postalveolar zone or simultaneously at the postalveolar and prepalatal zones with a raised tongue dorsum. As shown in Figure 2, the lingual constriction for this consonant may extend along the palatal zone as well. In parallel to /s/, /ʃ/ is especially anterior and thus plain alveolar in the case of some Valencian speakers. The lingual affricate /tʃ/ may be treated as /ʃ/ regarding place of articulation irrespective of small differences in closure/constriction placement which may occur between the stop and fricative phases (see also section 3.1.2 regarding /ts/). Analogously to other Romance languages, the nasal /ɲ/ is alveolopalatal, not palatal, in the Eastern and Valencian dialects. In Majorcan, where the allophones [c] and [ɟ] of /k/ and /g/ are also available (see above), speakers differ regarding the closure location for these stops and also for /ɲ/: as shown by the data for /ɲ/ in Figure 2, all these consonants are postalveolo-prepalatal for speaker AR, essentially palatal for BM and MJ, postpalatal for ND, and alveolopalatal or palatal for CA. Both /ʃ/ and /ɲ/ are highly resistant to vowel effects in tongue body fronting/raising which nevertheless can occur as a function of high vs low vowels.

The alveolopalatal lateral /ʎ/ is produced regularly at a more anterior location than the oral stop and nasal cognates due to the manner of articulation requirement to allow airflow through the sides of the oral cavity: it may be purely alveolar or alveolopalatal but not purely palatal and thus articulated at the palatal zone exclusively. It also exhibits less dorsal contact and more vowel coarticulation behind closure location than the alveolopalatal nasal and oral stops, which is in accordance with the notion that coarticulatory variability should vary inversely with tongue contact size.

3.1.4 Segmental complexity

It has been claimed that dark /l/ (also clear /l/ according to some scholars), the trill /r/ and (alveolo)palatal and palatoalveolar consonants are realized by means of two lingual gestures: a primary front lingual gesture which is responsible for closure or constriction formation at the alveolar, palatoalveolar or (alveolo)palatal zone; a secondary tongue body gesture which is implemented through tongue body backing for /l/ and /r/ and tongue body raising for palatal consonants (Sproat & Fujimura, 1993, Keating, 1988, Proctor, 2009).

Instrumental data show however that (alveolo)palatal consonants are articulated with a single tongue body raising and fronting gesture and therefore do not qualify for complex segments. Indeed, their realization involves an increase in tongue dorsum contact at the palatal zone as we proceed from closure onset to closure midpoint which does not reflect a separate activation of the tongue dorsum relative to the tongue front but results from an increase in tongue contact size as tongue pressure at closure location increases. Another phonetic characteristic which has been associated with segmental complexity, i.e., the /j/-like auditory impression at consonantal release, is associated instead with the duration and frequency extent of the vowel transitions; thus, in a sequence like /ɲa/ the greater the two dimensions whenever the alveolopalatal nasal is highly constricted, the higher the chances that the glide may be heard. This intrusive [j] segment is likely to occur since tongue contact release for laminodorso-alveolopalatal consonants proceeds from front to back as a general rule and, therefore, takes place earlier at the more anterior and flexible tongue blade than at the more posterior and sluggish tongue dorsum. To the extent that the dorsum of the tongue starts moving before the tongue blade during the vowel preceding the alveolopalatal consonant, a glide-like segment may also be heard at the onset of the consonant.

It may also be claimed that dark /l/ and the trill /r/ are produced with a single lingual mechanism involving the lowering of the tongue blade and predorsum and some tongue body backing as the tongue tip is being raised for closure formation. Indeed, this overall tongue configuration, as well as the fact that the tongue body starts moving before the tongue tip during the preceding vowel for both dark /l/ and /r/, could be attributed not to the activation of different tongue gestures but to the need to create the darkness percept for /l/ and to perform a successful trilling motion for the trill. Apicality appears to be a byproduct of these manner of articulation characteristics: in contrast to laminal realizations, apical ones require the formation of a /u/-like tongue body configuration.

In our opinion several phonetic changes such as the insertion of [w] before dark /l/ and of [j] before or after (alveolo)palatals and palatoalveolars are not associated with gestural complexity but result from the perceptual integration of salient VC or CV transitions as glides by the listener. The acoustic and perceptual prominence of these vowel transitions increases whenever there is a substantial delay between the motion of different tongue regions at consonant onset or consonant offset in ways specified above.

3.1.5 Summary

Based on the articulatory data presented in the preceding sections, Catalan front lingual consonants may be classified according to closure or constriction location as front and back. These consonant-dependent differences in place of articulation keep a certain relationship with differences in degree of articulatory constraint and manner of articulation: the highly constrained consonants /s/, /r/ and /ʃ/ are fixedly articulated at the central alveolar or postalveolar zone across contextual segments (though the lingual fricatives are more anterior in the Valencian dialect); the less constrained consonants /t, n, l, ɾ/ are dental/dentoalveolar (/t/), or may be articulated at the front, central or back alveolar zone depending on vowel context (/n, l, ɾ/); the lateral /l/ occupies an intermediate position regarding degree of articulatory constraint and is often more anterior if strongly dark and thus more constrained than if clear and thus less constrained; finally, /ʎ/ and /ɲ/ are produced with a large closure size either at the alveolar or alveoloprepalatal zone (the lateral) or mostly at the alveolopalatal zone but also at the palatal zone depending on dialect (the nasal), and are specified for a high degree of articulatory constraint. This hierarchy of degrees of articulatory constraint applies to VCV sequences and stays much the same in the case of consonant clusters except for alveolopalatals which become less constrained in C#C sequences than alveolars such as the trill /r/ and dark /l/ and /s/ (see section 2.7).

3.2 Consonant sequences

3.2.1 Methodology

Two methods have been used for investigating the production of consonant clusters, electropalatography (EPG) and ultrasound. Linguopalatal contact traces obtained with EPG are most suitable for uncovering changes in primary closure/constriction location that may occur in the transition from one consonant to the next, as has been shown already for simple consonants in section 3.1. The artificial palate covers the entire alveolar and palatal zones and therefore allows ascertaining whether a complete closure, central but not lateral contact or a central constriction occurs at place of articulation during consonant production. Ultrasound, on the other hand, provides images of the tongue predorsum at the palatal zone and of the back of the tongue body at the velar and pharyngeal zones and therefore is suitable for analyzing changes in overall tongue shape which occur in assimilatory, blending and coarticulatory processes. Whenever a palate trace is available, lingual profiles obtained with ultrasound may also be used for identifying closure/constriction location for palatoalveolar, alveolopalatal and velar consonants articulated behind the tongue tip/blade (see section 3.3.1.2 in this respect); the identification of closure/constriction location for apical and laminal consonants becomes however highly problematic due to the shade projected by the mandible on the ultrasound image (Stone, 2005).

3.2.1.1 Electropalatography

The filled cells in Figure 3 (top) correspond to the heterosyllabic C#C combinations which will be subject to investigation using electropalatography in the present chapter. The closure/constriction characteristics for the simple consonants appearing in the figure have been described in section 3.1.

The consonant sequences under analysis were placed generally across a word boundary except for the affricates /ts, tʃ/ and for /ns, nʃ/, which occurred word internally. The presence or absence of a word boundary between C1 and C2 should have no effect on the realization of the consonant cluster because in Catalan the syllabification rules are identical in the two cases. Moreover, the palatoalveolar fricative in the sequences /tʃ, nʃ, lʃ/ corresponds to the voiceless cognate /ʃ/ most of the time and sometimes to the voiced cognate /ʒ/; in Valencian, these two postconsonantal fricatives are realized as affricates and thus as [tʃ] and [dʒ], which in principle should make no difference with regard to [ʃ] and [ʒ] since the closing and frication phases of the affricate are homorganic. There are relevant allophonic differences between the coda and onset positions in the case of the alveolar rhotic in Catalan: the rhotic is realized as a trill after a consonant in syllable-onset position and with one or two fast apicoalveolar contacts at the most syllable finally; moreover, independently of the number of apical contacts and at least in Eastern Catalan, the tongue body configuration for the coda realization may approach that for the trill.

As revealed by the empty cells in Figure 3, several segmental combinations were not recorded and therefore could not be analyzed: most sequences with

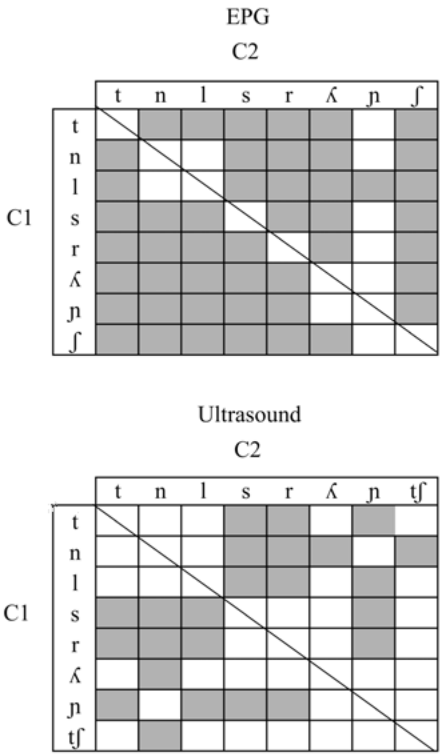

Figure 3: Grey squares indicate the heterosyllabic consonant sequences subject to EPG (top) and ultrasound (bottom) recording and analysis. Rows correspond to consonants occupying the syllable-final position and columns to consonants placed in syllable-onset position.

C2=/ɲ/ since /ɲ/ occurs rarely word initially in Catalan; /nl, ln, ɲʎ/ since no changes in closure location are expected to occur in this case. Several sequences were only recorded for Eastern Catalan, mainly /t/ + /n, l, ʎ/, /ʎ, ɲ/ + /t, n, l, s, r, ʃ/, and also /s, r, ʃ/ + /ʎ/, /s, ʃ/ + /r/ and /r/ + /s, ʃ/. Data for some of these and other consonantal combinations were lacking in Majorcan and/or Valencian often for specific reasons: in Majorcan, syllable-final /t/ and the nasal in the realization [jN] of syllable-final /ɲ/ assimilate to the following consonant, while preconsonantal /ʃ/ becomes [j]; in Valencian, preconsonantal syllable-final stops often lenite and thus, for example, /tr/ may be realized as [ðr].

Linguopalatal contact data for the consonant sequences of interest were collected with electropalatography (EPG) following the same recording procedure as for the VCV sequences (see section 3.1). The consonant clusters were read in short meaningful sentences about five to seven times by most speakers who recorded the single consonants, namely, AR, BM, MJ, ND, CA (Majorcan), JM, VB, MS, VG, AV (Valencian) and DR, JP, JS (Eastern Catalan). Cluster tokens were submitted to articulatory analysis after segmentation (see also section 3.1 regarding the segmentation criteria). Closure or constriction location was measured on the linguopalatal contact patterns at several points in time, i.e., at C1 onset, midpoint and offset and at C2 onset and midpoint, so as to explore possible changes in closure/constriction location during the cluster and to better evaluate the C-to-C adaptation effects. Analogously to the analysis of the intervocalic consonants, measurements were conducted by placing a cursor on simultaneous EPG, spectrographic and waveform displays using the MultiSpeech 3700 program of Kay Pentax.

3.2.1.2 Ultrasound

Ultrasound data were recorded for those C#C sequences with front lingual consonants given in Figure 3 (bottom): combinations of dentals/alveolars and alveolopalatals/palatoalveolars, i.e., /tɲ, ntʃ, nʎ, lɲ, sɲ, rɲ/ and the reverse clusters /ʎn, ɲt, ɲl, ɲs, ɲr, tʃn/; combinations of dentals and alveolars differing in degree of articulatory constraint, i.e., less constrained + more constrained (/ts, tr, ns, nr, ls, lr/) and more constrained + less constrained (/st, rt, sn, rn, sl, rl/). Among alveolopalatals, while /ɲ/ was used instead of /ʎ/, the pair /nɲ, ɲn/ had to be replaced by /nʎ, ʎn/ given that /nɲ/ would have resulted into the completely assimilated realization [ɲɲ]. The recording list also included C#C sequences with the bilabial /p/ and each of the consonants /t, n, l, s, r, ɲ, tʃ/, which were used as controls since labial consonants involve no tongue activation and therefore should not modify the tongue configuration for all these lingual consonants.

Consonant clusters were recorded in VC#CV sequences with the low vowel /a/ embedded in four to six syllable long phrases exhibiting the same stress pattern. Thus, for example, /t#s/ occurred in the phrase [un suldat ˈsart] *un soldat sard* ‘a Sardinian soldier’ where *soldat* is an oxytone bisyllable and *sard* is a monosyllable bearing lexical and sentence stress. Five native Catalan speakers, i.e., two men (DR, MO) and three women (ES, JU, IM), of 30–60 years of age read the list six times. Recordings were performed with an Echo Blaster unit type EB128CEXT from TELEMED and a microconvex Echo Blaster 128 CEXT transducer with a 2 to 4 MHz frequency range and a central curvature of 20 mm. The ultrasound images were acquired directly with a probe with a 90% field of view and a frequency of 2 MHz. The recording sampling rate was 57 frames per second, yielding one image every 17.54 ms. The ultrasound probe was attached to a transducer holder which was positioned under the subject’s chin in an Articulate Instruments stabilization headset. Image streams were recorded synchronously with the audio signal sampled at 22,050 Hz. Contours of the alveolar and a portion of the palatal zones were also recorded by asking speakers to press the tongue against the hard palate.

Tongue contours were tracked automatically at all temporal frames along each C#C sequence token using the Articulate Assistant Advanced (AAA) software and adjusted manually. Data points for all tongue contours were exported in an ASCII-file as *x-y* coordinates and acoustic files were also exported in *wav* format for segmentation and taking segmental duration measures. V1 onset and V2 offset were identified at the acoustic onset and offset of vowel-related formant structure, respectively. The boundary between the first and second consonants within each cluster was set as follows: in stop+consonant sequences, C1 offset was taken to occur at closure offset, and C2 onset after a stop burst in stop+stop sequences and at the onset of the frication noise for fricatives and of the voiced formant structure for nasals, laterals and rhotics. As to the remaining clusters, the segmental boundary was identified at the offset of the frication noise and of a period of formant structure in sequences with a fricative C1 and a nasal, lateral or rhotic C1, respectively. Whenever formants extended from C1 to C2 (as in nasal+lateral sequences), the boundary between the two consonants was established at a temporal point showing formant discontinuity. Visual inspection of the ultrasound image was also used for segmentation in cases where the spectrographic and waveform signals were unclear.

The palate traces shown in several figures displaying lingual configuration data throughout the book should be considered just an approximate reference frame for estimating closure/constriction location and tongue body position within the vocal tract for the consonants under analysis. The method for obtaining the palate trace is somewhat problematic (see above) which explains why, as revealed by Figures 36, 37, 39 and 40, the tongue surface may cross the palate trace occasionally whenever the tongue body is making contact at the hard palate.

In order to analyze changes in lingual position over time lingual spline data were processed at C1 onset, midpoint and offset and at C2 onset, midpoint and offset. There were different splines at C1 offset and C2 onset when C1 was a stop and showed a burst on the spectrographic displays or else a rhotic composed of a closing phase and a following vowel-like opening phase. Otherwise a single spline was available at these two temporal points. Spline data points were converted from Cartesian to polar coordinates by fronting the origin of the ultrasound field of view from the bottom-left corner of the ultrasound image to X = 86.7 mm and Y = 0 mm which is where the probe was located (Mielke, 2015). Next SSANOVA smoothed splines consisting of strings of points separated by 0.01 radians with the associated standard errors were computed for each C#C sequence using the R package gss to find a best fit curve (Davidson, 2006). In order to identify the front and left edges of the SSANOVA splines, we entered into the SSANOVA computation procedure the mean of the rightmost and leftmost angle values as delimited by the spline edges and the origin across all C#C tokens available.

In order to analyze changes in tongue position at different tongue locations, the SSANOVA splines displayed in Cartesian coordinates were divided into four portions which correspond to the alveolar, palatal, velar and pharyngeal zones by applying the following criteria separately for each speaker (see Recasens & Rodríguez, 2016, 2018 for details): the boundary between the alveolar and the dental zones was identified at an inflection point occurring at the spline front edge during dental /t/; the alveolar/palatal boundary was taken to occur at an inflection point placed at the back alveolar region for /r/, which is postalveolar in Catalan; the palatal/velar boundary was placed at the highest tongue dorsum location for /k/ next to /i/, which is postpalatal in Catalan; in order to identify the velar/pharyngeal boundary, the length of the velar zone was taken to be 1.26 and 1.51 times that of the palatal zone for male and female speakers respectively, as proposed by Fitch and Giedd (1999). Figure 4 plots an ultrasound image subject to analysis with the subdivision of the tongue contour into regions (top) and a SSANOVA lingual spline showing the same articulatory subdivisions (bottom).

For each C#C sequence and each subject distance values were measured between representative spline points within each articulatory zone and the origin of the ultrasound field of view. The distance values for the velar and palatal zones were obtained by averaging the distances across the five central points at each zone and the origin. In order to preserve the spatial information at the spline front edge where constriction location often occurs and given that the SSANOVA splines for the different C#C sequences could differ in length, the five distances subject to averaging at the alveolar and pharyngeal zones were gathered at the leftmost third of the former zone and the upper third of the latter zone. In order to evaluate changes in lingual position over time, differences regarding the distance between the tongue position and the origin of the ultrasound field of view were computed between consecutive points in time. Separate values were obtained for each articulatory zone, C#C sequence and speaker. In the case of those C#C sequences for which we had five splines, the four following differences (mp=midpoint, on=onset, off=offset) were calculated: C1 mp – C1 on; C1 off/C2 on – C1 mp (referred to as C2 on – C1 mp throughout the paper); C2 mp – C1 off/C2 on (referred to as C2 mp – C2 on throughout the paper); C2 off – C2 mp. As to those C#C sequences for which we had six splines, the five following differences were computed: C1 mp – C1 on; C1 off – C1 mp; C2 on – C1 off; C2 mp – C2 on; C2 off – C2 mp.

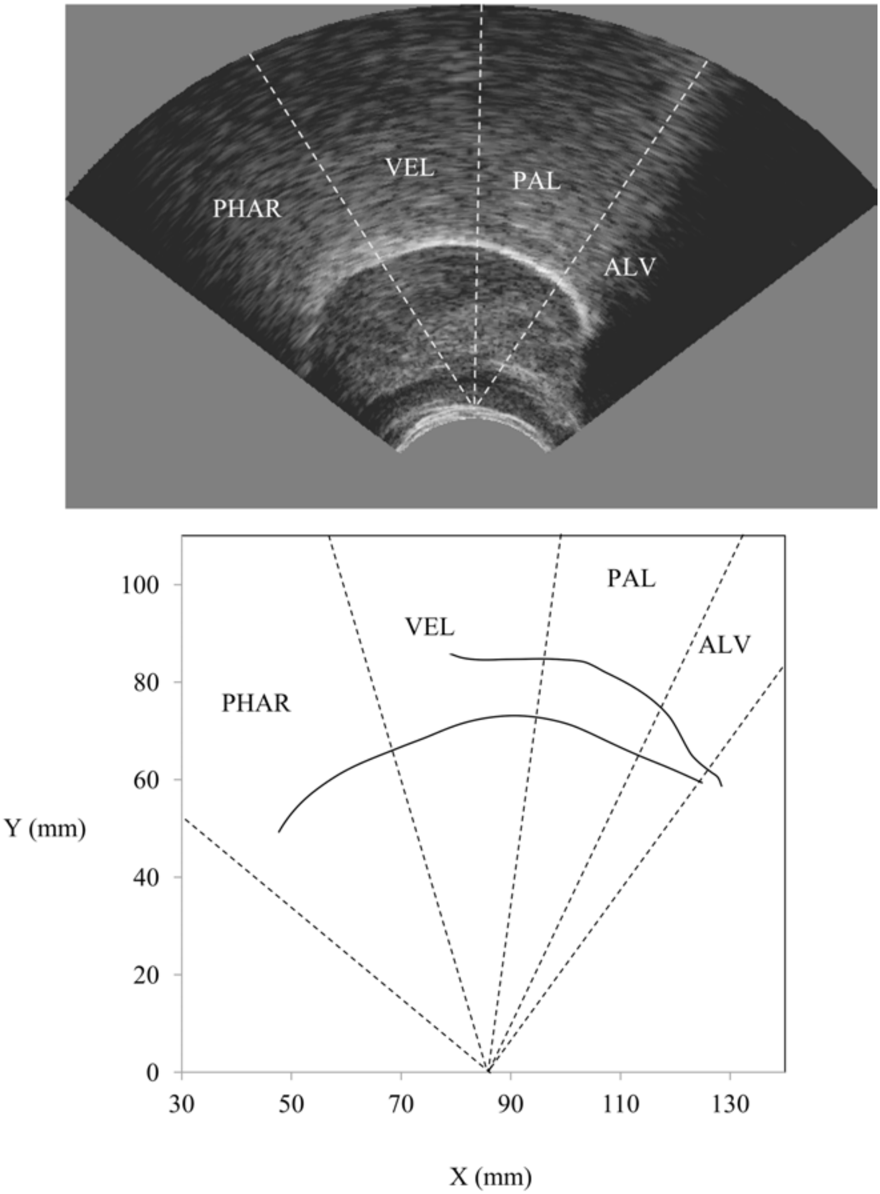

Figure 4: (Top) Ultrasound image of the tongue surface with subdivision into articulatory regions (ALV = alveolar, PAL = palatal, VEL = velar, PHAR = pharyngeal). The front of the mouth is on the right of the graph. (Bottom) SSANOVA lingual spline showing the same articulatory subdivisions with palate surface overimposed.

LMM (Linear Mixed Models) analyses were run on the ultrasound distance values. Separate tests were performed on sequences with dentals/alveolars and alveolopalatals/palatoalveolars, and on sequences with dentals and alveolars differing in degree of articulatory constraint. Moreover since ‘articulatory zone’ could not be entered as a factor due to convergence problems, separate analyses had to be performed on the data for each articulatory zone. In all tests we had ‘contextual consonant’ and ‘temporal period’ as fixed factors and ‘speaker’ as a random factor. Post-hoc comparisons and factor interactions were also analyzed statistically so as to find out whether there were significant differences between pairs of contextual consonants at each temporal period (e.g., C1 mp – C1 on) and across temporal periods, and between pairs of temporal periods for each contextual consonant and across contextual consonant conditions. The Tukey correction was applied to tests run on pairs of levels of a given variable. Statistical significance was established at $p < 0.05$. In this and other chapters of the book, ultrasound data will be provided mostly for those cases which yielded a significant statistical effect.

3.2.2 Testing hypotheses

Based on differences in degree of articulatory constraint among the consonants identified in sections 2.7 and 3.1, and on a general trend for anticipatory effects to prevail over carryover effects, the DAC model makes a number of predictions on closure/constriction adaptation for the (nearly)-homorganic clusters referred to in section 3.2.1.

(a) Unconstrained + constrained consonant sequences (/t, n, l, ʎ, ɲ/ + /s, r, ʃ/) ought to undergo regressive assimilation and therefore closure retraction from dental or alveolar to centroalveolar or postalveolar throughout the entire C1 duration. Regressive assimilation is expected to affect not only the dental or dentoalveolar stop /t/ but also the alveolar /n/ and even the alveolopalatals /ʎ/ and /ɲ/. Moreover, we expect C1 to exhibit a slightly more retracted location before /ʃ/ than before /s, r/ since the former consonant is palatoalveolar while the two latter ones are alveolar (Figure 2). In line with a trend for nasals to assimilate more than stops (section 2.4), it could also be the case that the degree of adaptability to C2 is higher for C1=/n/ than for the other unconstrained consonants. It also deserves to be seen the extent to which the regressive assimilation process operates on /l/ which, while being articulated at several locations over the alveolar zone, is supposed to be more constrained than other front lingual consonants due to laterality requirements. The alveolopalatal lateral /ʎ/ could also be reluctant to assimilate to a following highly constrained front lingual fricative and alveolar trill. Dialect-dependent differences in consonant production may also affect the final articulatory outcome of the consonant adaptation processes, such as especially anterior realizations of /s/ and /ʃ/ in Valencian, as well as a strongly dark variety of /l/ in Majorcan which should be less prone to assimilate than clearer realizations of the alveolar lateral.

(b) Constrained + unconstrained consonant sequences (/s, r, ʃ/ + /t, n, l, ʎ, ɲ/) should show two articulatory targets as a general rule, i.e., a more posterior one for C1 and a more anterior one for C2. Moreover, the scenario for /rC/ could differ from that for /sC, ʃC/ in that, since /r/ is realized as a fast tap rather than as a trill in coda position in Catalan, the C1-to-C2 constriction fronting excursion should be more extensive in the /rC/ sequences than in the /sC, ʃC/ ones; therefore, C2 is expected to achieve the dental target for /t/ and the front alveolar targets for /n/ and /l/ after /r/ rather than after the two lingual fricatives. For the rhotic to induce strong prominent carryover coarticulatory effects, it must be realized as a trill which, due to demands on trilling and thus manner of articulation requirements, could not only trigger regressive sound changes but progressive ones as well (Recasens, 2014b). Carryover coarticulatory effects and even instances of progressive assimilation (postalveolarization throughout the entire C2 period) are expected to occur most frequently when C1 is the palatoalveolar fricative /ʃ/ in so far as the tongue raising and fronting gesture for alveolopalatals and palatoalveolars is prone to trigger carryover coarticulation; therefore, C2=/t, n, l/ could be articulated more posteriorly after /ʃ/ than after /s, r/. There could also be some C1-to-C2 tongue fronting at constriction location in the case of the sequences /s, r, ʃ/ + /ʎ/ and perhaps /s, r, ʃ/ + /ɲ/, at least when C1 is /ʃ/ since this is the most posterior of the three consonant triggers (see Figure 2 regarding closure/constriction location for all these consonants in Catalan).

(c) Unconstrained + unconstrained consonant sequences (C1C2 combinations composed of /t, n, l, ʎ, ɲ/) are expected to exhibit blending of lingual gestures and thus a single closure location during most of the cluster duration (section 2.5). The articulatory implementation of gestural blending in sequences composed of unconstrained front lingual consonants is investigated essentially in two scenarios: in a palatalizing environment for sequences with /ʎ, ɲ/; in a dentalizing environment for sequences composed exclusively of /n/ and /l/, on the one hand, and /t/, on the other hand.

In clusters with C1=/t, n, l/ and C2=/ʎ, ɲ/ there should be some expansion at the back closure border during the dental, dentoalvolar or alveolar consonant yielding a blending through superposition or blending through intermediation scenario, as the tongue dorsum is being raised for the contextual alveolopalatal. Moreover, the front closure border ought to be maximally anterior, mostly so in sequences with a dental C1. It deserves to be seen whether gestural blending applies in the same way to the reverse clusters composed of C1=/ʎ, ɲ/ and C2=/t, n, l/.

The articulatory outcome for clusters made of C1=/n, l/ and C2=/t/ is not easy to ascertain. While it has been stated traditionally that /n, l/ ought to assimilate to following /t/ and thus become dental (see Navarro Tomás, 1972 for Spanish), the DAC model predicts that the two consonants should blend rather than undergo assimilation. It is hard to foresee whether the clusters /nt, lt/ should be resolved through regressive assimilation, blending through intermediation or blending through superposition: in the former event, /n, l/ ought to become dental throughout the entire closure period; in the second event, one or the two closure edges during the cluster ought to be located between those for the two simple consonants; in the latter case, the closure extent for the cluster should encompass the closure size for the two consonants.

Cluster scenarios blocking fully or partially the implementation of the blending process will also be paid attention to. Blending could be delayed or absent in clusters with /l/ due to the tongue predorsum lowering action involved in the passage of airflow through lateral channels (laterality) or the generation of a /w/-like percept (darkness). Moreover, failure for blending to apply in these circumstances is expected to take place in Majorcan (where /l/ is strongly dark) rather than in Valencian (where the lateral is essentially clear), the Eastern dialect (where /l/ is moderately dark) falling in between.

The predicted outcome for the scenarios 3.2.2 (a) and 3.2.2 (b) is based on the principle that highly constrained consonants should prevail upon less constrained ones either through an assimilatory action (in scenario (a)) or robust coarticulatory effects (in scenario (b)). There is also a directionality component involved in these two scenarios which has been referred to in section 2.2, namely, that anticipatory coarticulatory effects should be more systematic than carryover coarticulatory effects and thus assimilatory processes more prone to occur at the regressive than at the progressive level. This requirement accounts for why, in spite of being composed of the same consonants, the sequences in (a) are expected to undergo regressive assimilation and those in (b) either no coarticulation or carryover coarticulation instead of progressive assimilation which nevertheless could also operate under special conditions. A fourth scenario, i.e., constrained + constrained consonant sequences, only applies to the Catalan clusters /sʃ/ and /ʃs/ and will be dealt with in detail in section 3.3.5.

3.3 Results

3.3.1 Unconstrained + constrained

3.3.1.1 EPG data

(a) In order to investigate how often regressive assimilation applies in unconstrained+constrained consonant clusters, we will first look into the frequency of occurrence of the C1 closure patterns in Catalan C#C sequences composed of C1=/t, n, l/ and C2=/s, r, ʃ/ on a token-by-token basis using the EPG data. For the sake of determining whether closure location and extent varies from onset to offset of C1, the C1 articulatory realization will be characterized with reference to the 18 closure patterns listed in Figure 5, each of which includes three consecutive closure locations at C1 onset, midpoint and offset. In these 18 patterns, the labels D, DA and A correspond to different closure placement conditions as determined by the rows of electrodes where the front and back closure edges occur: D (dental) whenever closure is found exclusively at row 1; DA (dentoalveolar) when closure includes row 1 and one or more back alveolar rows; A (alveolar) when closure takes place at one or more rows placed at the alveolar zone excluding row 1.

	C1 onset	C1 midpoint	C1 offset
1	D	D	D
2	D	DA	D
3	D	DA	DA
4	D	DA	A
5	DA	D	D
6	DA	DA	D
7	DA	DA	DA
8	DA	DA	A
9	DA	A	D
10	DA	A	DA
11	DA	A	A
12	A	D	D
13	A	DA	D
14	A	DA	DA
15	A	DA	A
16	A	A	D
17	A	A	DA
18	A	A	A

Figure 5: 18 closure patterns indicating temporal changes in closure/constriction location during the coda consonant in heterosyllabic consonant clusters. Patterns are listed from frontmost to backmost. D = dental; DA = dentoalveolar, A = alveolar.

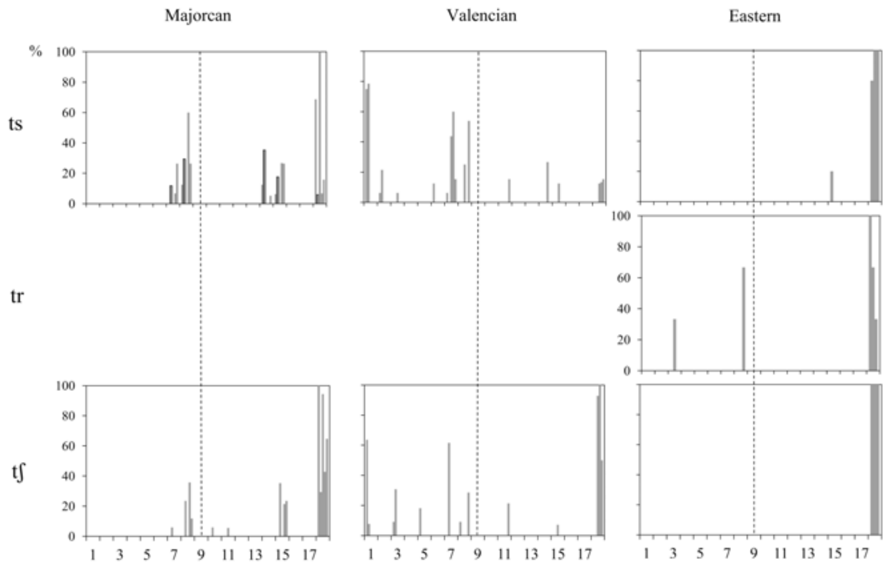

Figure 6: Frequency of occurrence of the 18 closure patterns listed in Figure 5 for /t/ in the sequences /ts, tr, tʃ/. Data have been plotted across speakers of each Catalan dialect.

Regressive place assimilation is clearly available in the case of pattern 18 and thus when the entire C1 shows an alveolar closure. Patterns 9 through 17 will also be considered to correspond to the alveolar place assimilation scenario in so far as they include the alveolar location at closure onset and/or at closure midpoint while differing among themselves as to whether the closure release is more anterior or more posterior. Indeed, patterns 9–11 present an alveolar closure at the midpoint of the consonant and a dentoalveolar closure at its onset; patterns 12–15, on the other hand, exhibit an alveolar closure at consonantal onset which extends regularly to the dentoalveolar zone at consonant midpoint; finally, patterns 16 and 17 show an alveolar closure from C1 onset until C2 midpoint. Closure release may occur at the dental, dentoalveolar or alveolar zone depending on the case.

Figures 6 and 7 plot the average frequency of occurrence of these 18 closure patterns for the consonant combinations /t/ + /s, r, ʃ/ and /n/ + /s, r, ʃ/. Bars displayed in each graph correspond to the closure location percentages for the 18 patterns identified in Figure 5 across speakers of each dialect (Majorcan, Valencian, Eastern). The figures reveal the presence of dialect-dependent differences: there is regressive place assimilation systematically in the Eastern dialect (rightmost graphs) since practically all C#C tokens exhibit the A-A-A pattern and,

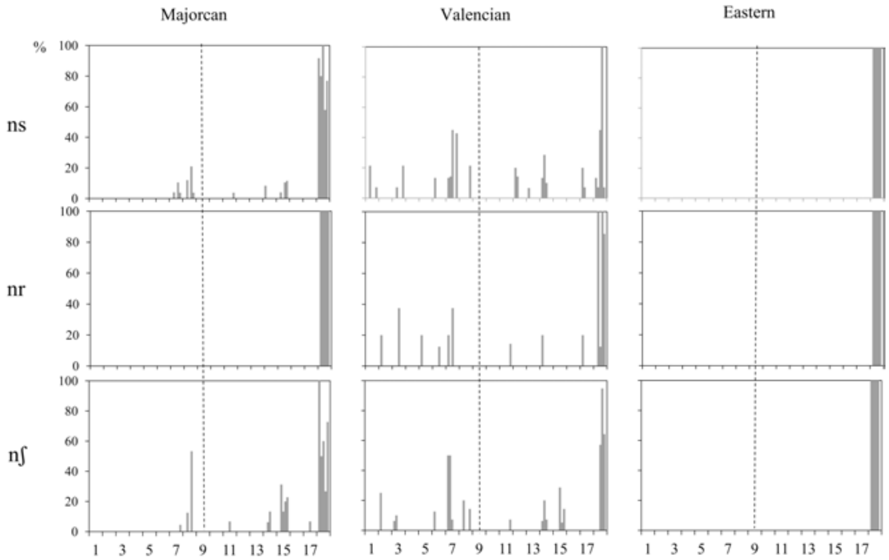

Figure 7: Frequency of occurrence of the 18 closure patterns listed in Figure 5 for /n/ in the sequences /ns, nr, nʃ/. Data have been plotted across speakers of each Catalan dialect.

judging from the frequency of occurrence of patterns 9–18, about 85% of the time in Majorcan (leftmost graphs) and about half of the tokens in Valencian (middle graphs). Moreover, these dialect-dependent differences parallel the closure fronting characteristics for the two lingual fricatives /s, ʃ/ and also for /t, n/ in intervocalic position, with Valencian exhibiting the most anterior articulations and Eastern the most posterior ones (Figure 2). The scenario for the /lC/ sequences (Figure 8) is similar to that for /tC/ and /nC/ except for the fact that this time the lowest percentage of alveolar realizations occurs in Majorcan (50%) followed by Valencian (about 75%) and Eastern (about 85%). This finding is in accordance with the fact that Majorcan has the darkest and most anterior realization of /l/ of all three Catalan dialects under study (Figure 2).

There are C1- and C2-dependent differences in assimilation degree across dialects. Thus, for a given C2 condition (essentially for sequences with C2=/s, ʃ/ since data for /tr/ are only available in Eastern Catalan), regressive assimilation percentages are generally higher when C1 is /n/ (about 80%) than when it is /t/ or /l/ (60%–65%). The alveolar nasal is thus more prone to assimilate than the stop and the lateral, which is in accordance with experimental and descriptive data for heterorganic clusters with C1=/t, n/ from other languages (section 4.3). Moreover, assimilation percentages turned out to be higher for sequences with

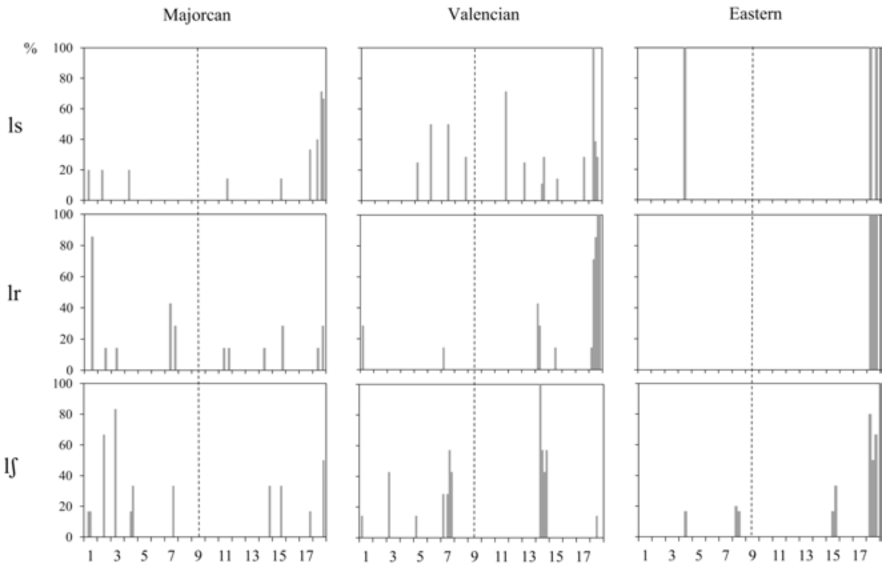

Figure 8: Frequency of occurrence of the 18 closure patterns listed in Figure 5 for /l/ in the sequences /ls, lr, lʃ/. Data have been plotted across speakers of each Catalan dialect.

C1=/n, l/ than for those with C1=/t/ when C2 is /s/ (80%, 71%, 56%) and for clusters with C1=/t, n/ than for those with C1=/l/ when C2 is /ʃ/ (77%, 80%, 54%), and were especially low for /ts/ in Valencian (19%) and for /lʃ/ in Majorcan (33%). As for clusters with C2=/r/, adaptation percentages are high in Valencian and Eastern (above 80%), and high for /nr/ and low for /lr/ in Majorcan (100%, 38%). These percentages reveal that regressive assimilation may be facilitated by the identity in lingual articulator between C1 and C2, i.e., it occurs most frequently between the apicals /l/ and /s/ and between the apicolaminal /t/ and the laminopredorsal /ʃ/, while /n/ assimilates to any following consonant highly often. Moreover, regressive assimilation may take place at a very anterior location for /ts/ in Valencian and is avoided in sequences with C1=/l/ when the alveolar lateral is especially anterior in the Majorcan dialect (see above).

The next step is to find out how the individual speakers produce these consonant clusters. For this purpose the graphs in Figures 9, 10 and 11 display changes in closure or constriction location throughout the entire cluster for the /tC, nC, lC/ sequences of interest across tokens according to each individual subject. Linguopalatal contact trajectories have been displayed over the five frontmost rows of electrodes of the artificial palate at five successive temporal points, i.e., C1 onset, midpoint and offset and C2 onset and midpoint. They

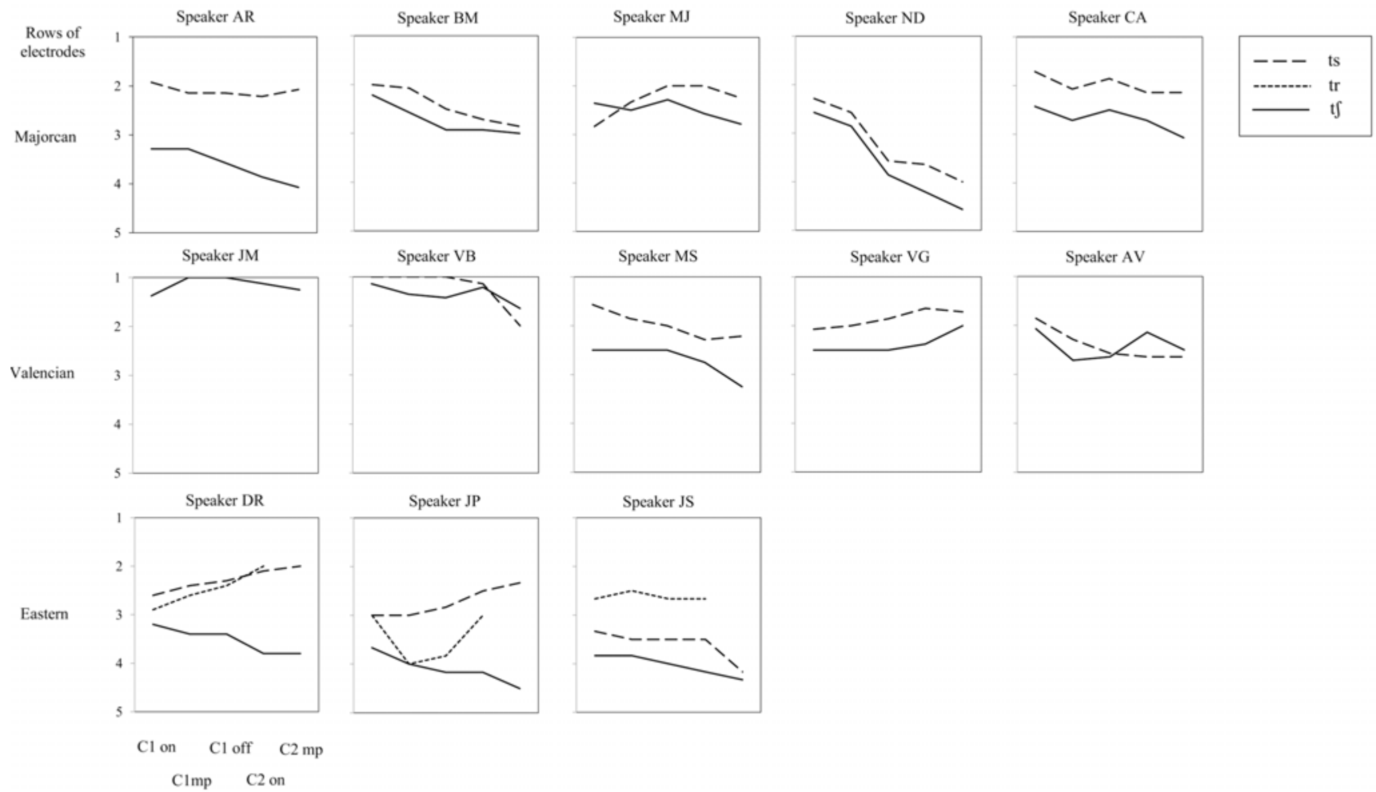

Figure 9: Closure/constriction location at C1 onset, midpoint and offset and at C2 onset and midpoint for the sequences /ts, tr, tʃ/ according to all Majorcan, Valencian and Eastern speakers. Linguopalatal contact trajectories travel halfway between the front and back edges of the consonant closure/constriction. See Figure 1 for the placement of rows 1–5 of electrodes on the artificial palate.

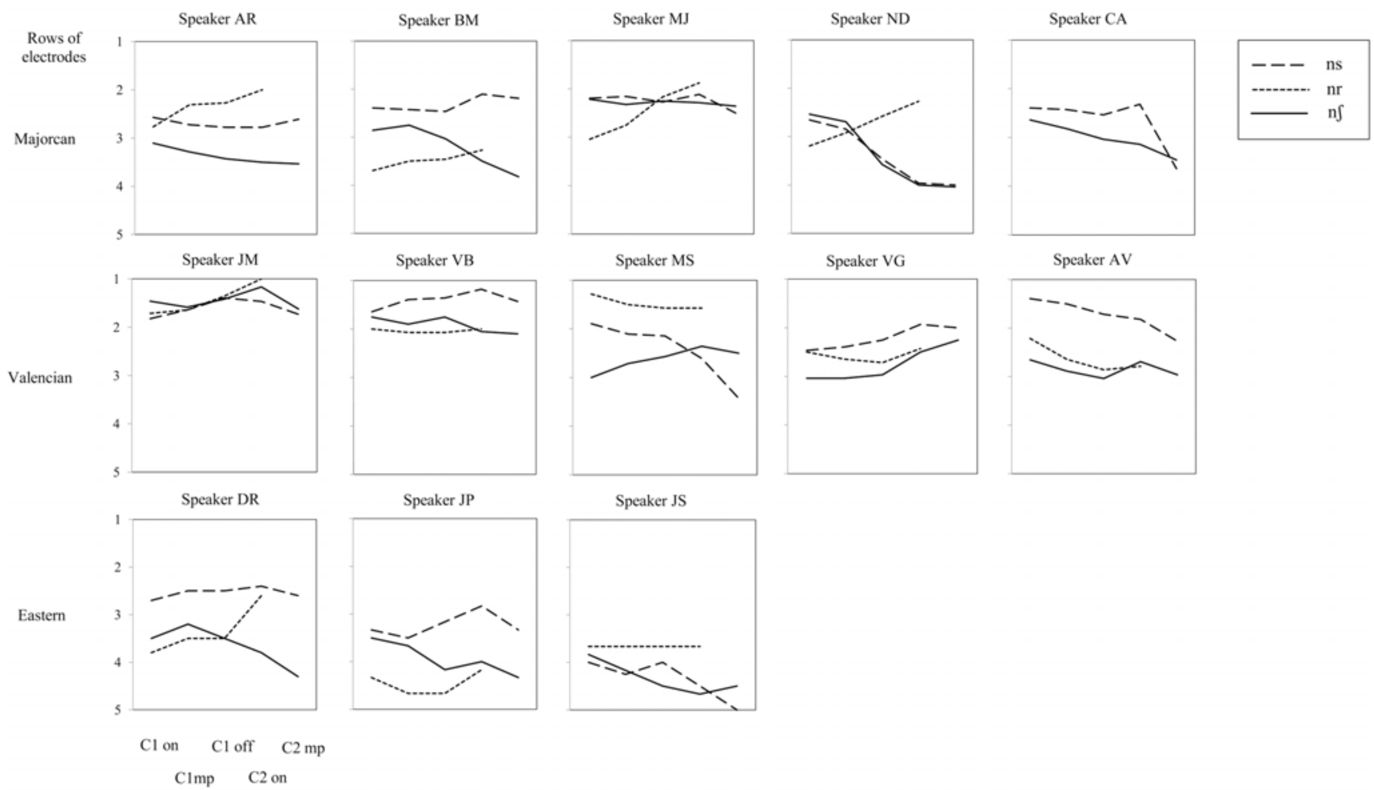

Figure 10: Closure/constriction location at C1 onset, midpoint and offset and at C2 onset and midpoint for the sequences /ns, nr, nʃ/ according to all Majorcan, Valencian and Eastern speakers. See the Figure 9 caption for details.

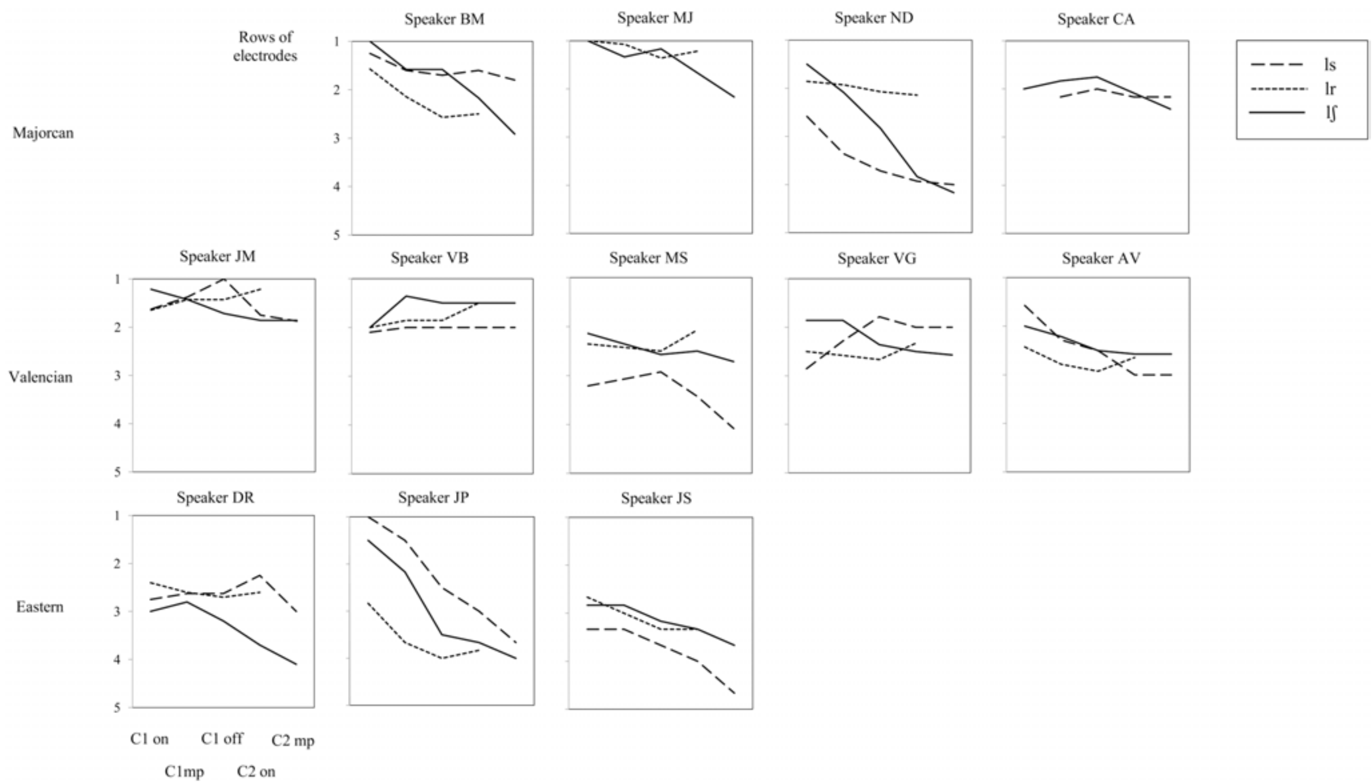

Figure 11: Closure/constriction location at C1 onset, midpoint and offset and at C2 onset and midpoint for the sequences /ls, lr, lʃ/ according to all Majorcan, Valencian and Eastern speakers. See the Figure 9 caption for details.

represent changes over time occurring halfway between the front and back closure or constriction borders. This representation procedure appears to be accurate to the extent that the two closure or constriction edges run parallel to each other throughout the clusters for the most part, the only exceptions being /ts, tʃ, ns, nʃ/ for speaker ND where closure backing during C1 occurs at the front border rather than the back border. In the figures, Majorcan Catalan data are lacking for the /Cr/ sequences in the case of speaker CA who has a uvular realization of the alveolar trill, and for the /lC/ sequences in the case of speaker AR who exhibits no central alveolar closure during syllable-final /l/ (also for /ls/ in the case of speaker MJ for the same reason). Closure/constriction location for /ts/ may occur (almost) exclusively at row 1 and is thus maximally anterior for the two Valencian speakers JM and VB, which explains why the traces for the former subject do not show up in the corresponding graph.

Simultaneous inspection of the graphs for /tC/ and /nC/ in Figures 9 and 10 reveals that in most cases C1 closure location proceeds either as a straight or nearly straight line at a given row of electrodes from onset to offset or, less often, it changes from a given row to the next row but not to a non-adjacent row. This is the expected outcome of a regressive assimilation process. This assimilatory behaviour is not at work for speaker ND, and may take place at the dental or dentoalveolar zone or at a maximally anterior alveolar location in the case of the Valencian subjects JM and VB. Moreover, the C1 assimilated outcome often matches the closure or constriction location for the C2 assimilation trigger. Indeed, the graphs in the two figures show a clear trend for the C1 closure to be more anterior before /s/ (discontinuous lines) than before /ʃ/ (continuous lines) for most subjects. The trajectories for /tr, nr/ are more variable and exhibit some C1-to-C2 contact fronting for some speakers, which may be associated with the formation of successive apicoalveolar contacts during the trill. In any case, for a considerable number of subjects, the C1 closure location for those two /Cr/ sequences is considerably retracted and occurs at a similar location to that for the /Cʃ/ sequences.

Data for the /lC/ sequences plotted in Figure 11 reveal the presence of assimilated outcomes mostly in the case of the Valencian subjects, who have a rather clear variety of the consonant. Speakers with a dark variety of /l/ such as those of Majorcan and to a lesser extent the Eastern dialect may show a closure backing motion extending for about two rows, mostly so when C2 is a fricative. It is thus the case that dark /l/ is reluctant to undergo regressive place assimilation at least when the following consonant is a highly constrained alveolar or palatoalveolar fricative.

According to the DAC model, also the alveolopalatals /ʎ, ɲ/ are expected to assimilate to a following highly constrained front lingual fricative or trill. EPG

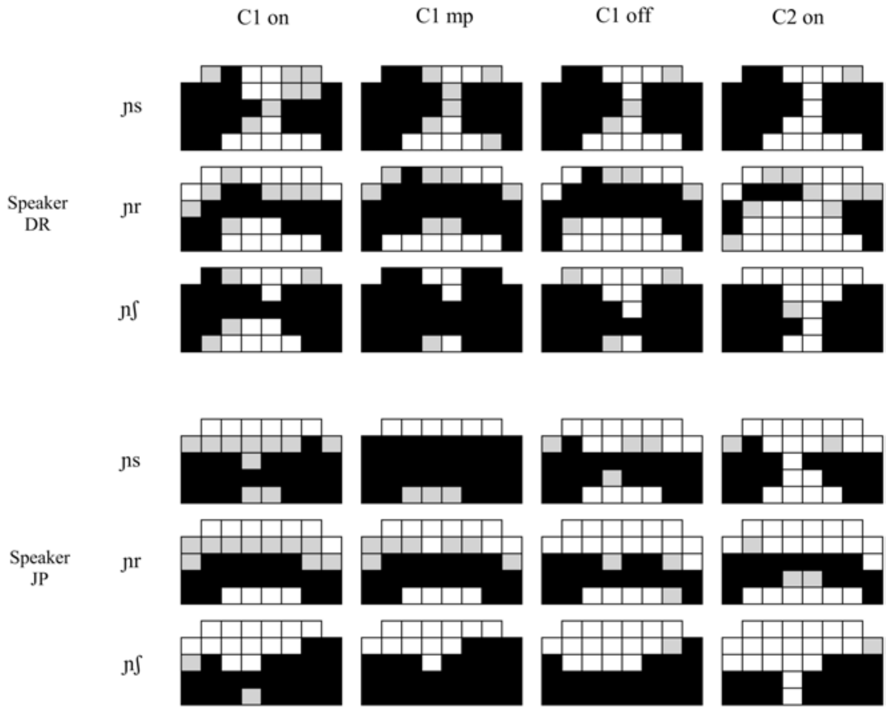

Figure 12: Linguopalatal contact patterns for the sequences /ɲs, ɲr, ɲʃ/ according to the Eastern Catalan speakers DR and JP. Contact patterns are displayed over the five front rows of electrodes at C1 onset, midpoint and offset and at C2 onset. The electrodes have been assigned different colour shades depending on contact frequency across tokens: black (80–100% activation); grey (40–80%); white (0–40%).

contact configurations displayed in Figure 12 reveal that C1=/ɲ/ may adapt to the constriction location of following /s, r, ʃ/ during its entire closing phase and therefore that it is articulated further back before /ʃ/ (at rows 3–4 for speaker DR and 4–5 for speaker JP) than before /s, r/ (at rows 2–3 for speaker DR and (2)3–4 for speaker JP). The degree of closure adaptation may be less for /ʎ/ than for /ɲ/. Indeed, the linguopalatal contact patterns for C1 in the sequences /ʎs, ʎr, ʎʃ/ plotted in Figure 13 show that the alveolopalatal lateral may either remain front alveolar before /r/ in the case of speaker DR or adapt to C2 and thus show differences in constriction fronting for /ʎs/ > /ʎr, ʎʃ/ in the case of speaker JP. The picture for subject JP is very different from that exhibited for /ls, lʃ/ by the same speaker, where the tongue front travels from a very front constriction location for /l/ to a postalveolar location for the following fricative and therefore regressive assimilation does not occur (see Figure 11, middle

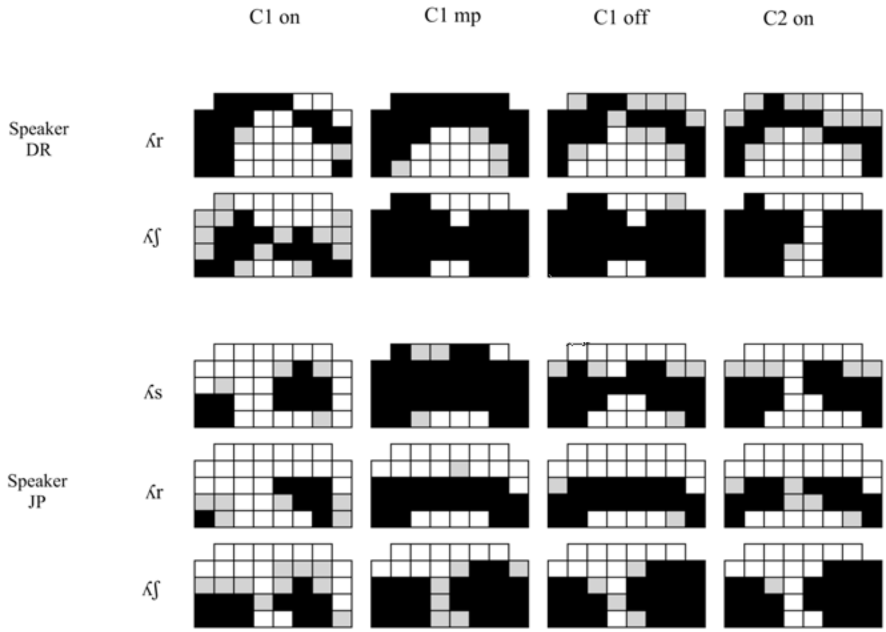

Figure 13: Linguopalatal contact patterns for the sequences /ʎs, ʎr, ʎʃ/ according to the Eastern Catalan speakers DR and JP. See the Figure 12 caption for details.

bottom graph). This difference is due to /l/ being dark and is in agreement with differences in flexibility between the primary articulators involved in the production of the two lateral consonants (the tip for /l/, the blade and possibly the predorsum for /ʎ/).

The EPG data reveal some aspects about tongue dorsum coarticulation for the clusters of interest which will also be referred to with regard to the ultrasound data in section 3.3.1.2. Closure retraction for /t, n, l/ before /ʃ/ takes place simultaneously with an increase in tongue dorsum contact at the palatal zone, which in the case of C1=/l/ holds much more noticeably when the lateral is clear than when it is dark. Judging from dorsopalatal contact data (Recasens & Pallarès, 2001b), the Catalan alveolopalatals /ɲ, ʎ/ (also /ʃ/) undergo more tongue dorsum lowering before /r/ and even before /l/ and /s/ than when occurring before /t, n/ or before the dorsal consonants /j, k/ during the production of which dorsopalatal contact achieves its maximum. Moreover, the anticipatory depalatalization effects exerted by /s, l, r/ on /ʃ, ʎ, ɲ/ last longer the larger they are, which is consistent with the remark that lingual gestures for the trill and for dark /l/ occur much in advance of their acoustic onset during a preceding antagonistic consonant.

(b) An apparent exception to the principle that C1 ought to assimilate to C2 in unconstrained + constrained sequences is the progressive palatalization of /s/ by a preceding front dorsal consonant. In Western Catalan dialects, the plural morpheme and 2nd person verbal morpheme /s/ may be realized as [ʃ] after a stem ending in /ɲ, ʎ, j/ (*anys* "year, pl.", *alls* "garlic, pl.", *reis* "king, pl."). The same assimilation process may take place across a word boundary in the case of these three consonant sequences and of /ʃ#s/ as well (/j#s/ *rei Sol* "Sun king", /ʃ#s/ *mateix sac* "the same sack").

This specific case should be attributed to the strong carryover effects exerted by the tongue dorsum gesture for (alveolo)palatal and palatoalveolar consonants on the following phonetic segment. Preference for carryover coarticulation is consistent with kinematic data for VCV sequences like /aɲa/ showing that the lowering of the tongue body after closure release (and thus during V2) proceeds more slowly than tongue body raising before closure onset (and thus during V1), which results into a higher tongue body position at V2 onset than at V1 offset (Recasens & Espinosa, 2010). This means that, if there is a direct relationship between coarticulation and assimilation, V2=/a/ ought to be more prone to raise to a mid front vowel than V1=/a/ whenever flanked by a front dorsal consonant. Consistently with this assumption, in the Catalan dialects referred to above, progressive /s/ palatalization may operate more often after /ɲ/ than after /ʎ/, which is in line with differences in tongue dorsum raising and dorsopalatal contact between the two alveolopalatal consonants.

3.3.1.2 Ultrasound data

Ultrasound provides data on overall tongue configuration rather than on closure/constriction location (see section 3.2.1) and therefore complements the EPG tongue contact data for the unconstrained + constrained consonant sequences given in section 3.3.1.1. Changes in tongue position will be reviewed separately for combinations of dentals and alveolars and of alveolopalatal and alveolars in sections (a) and (b) below.

(a) Figure 14 presents cross-speaker differences in tongue position between successive temporal periods for sequences of dental and alveolar consonants separately at the pharyngeal (PHAR), velar (VEL), palatal (PAL) and alveolar (ALV) zones. The tongue position data plotted in this and other bar figures throughout the book correspond to distances between representative lingual spline points located at a given articulatory zone and the origin of the ultrasound field of view (see section 3.2.1.2). Four sets of bars have been included in each graph for the temporal periods C1 mp – C1 on, C2 on – C1 mp, C2 mp – C2

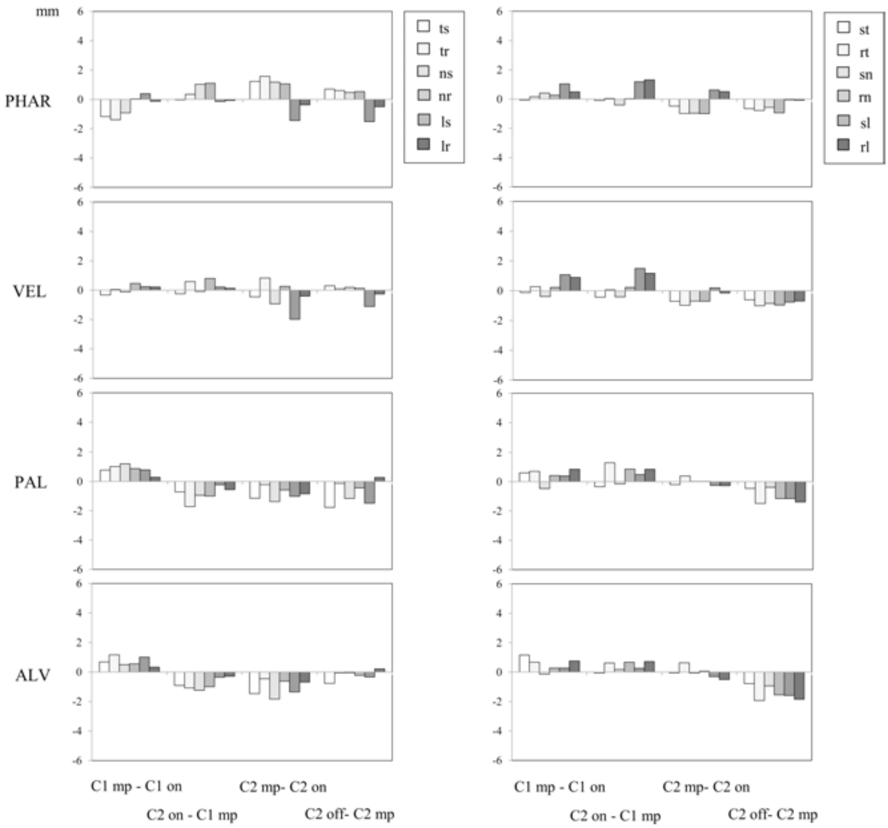

Figure 14: Cross-speaker differences in tongue position between successive temporal points for unconstrained + constrained (left) and constrained + unconstrained (right) C#C sequences composed of dentals and alveolars. They are plotted separately for the four temporal periods C1 mp – C1 on, C2 on – C1 mp, C2 mp – C2 on and C2 off – C2 mp (on = onset, mp = midpoint, off = offset) at the alveolar (ALV), palatal (PAL), velar (VEL) and pharyngeal (PHAR) articulatory regions.

on and C2 off – C2 mp, where on=onset, mp=midpoint and off=offset. The C2 on – C1 mp period includes the two shorter C1 off – C1 mp and C2 on – C1 off periods whenever C1 is a stop and is released into a visible burst or it is a rhotic and shows a vocalic period before C2 begins. Bars are positive when a given distance between a lingual spline and the origin occurring at a particular temporal point is greater than that taking place at the preceding temporal point (e.g., at C1 mp than at C1 on in the case of the C1 mp – C1 on period) and negative if the reverse applies.

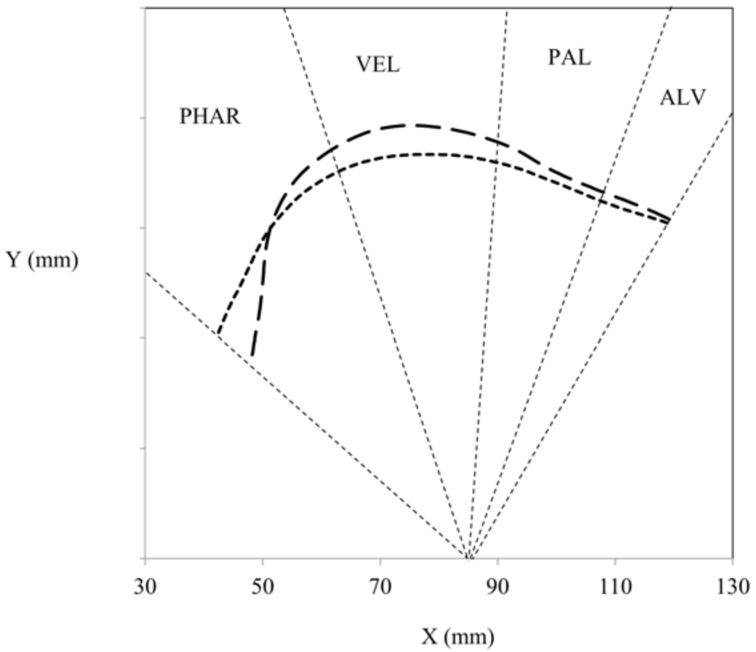

Figure 15: SSANOVA lingual splines obtained at two successive temporal frames, namely, at onset (dotted spline) and midpoint (discontinuous spline) of /l/ in intervocalic position.

Two successive lingual splines, i.e., a dotted spline at /l/ onset and a subsequent discontinuous spline at /l/ midpoint, are plotted in Figure 15 for exemplification. In the graph the origin of the ultrasound field of view is located at X= 86.7 mm and Y=0 mm. At the pharynx, the C mp – C on difference is positive at the upper pharynx since the back of the tongue body is located more posteriorly at the midpoint of the consonant than at its onset, and negative at the lower pharynx since the tongue body is more anterior at C midpoint than at C onset. At the velar, palatal and alveolar zones, on the other hand, the C mp – C on difference is positive since the tongue is higher at consonant midpoint than at consonant onset in all cases. In sum, positive bars in Figure 14 indicate that changes in tongue position over time (e.g., from the onset to the midpoint of the consonant) involve tongue retraction at the pharynx and tongue raising at the alveolar, palatal and velar zones, while negative bars that the tongue proceeds anteriorly at the pharynx and downwards at the other three zones.

Compared to analogous bar graphs such as the ones presented in Figure 17 the bars in Figure 14 are relatively small (the mm distance scale has been kept the same in all bar figures appearing throughout the book), thus meaning that changes in tongue displacement occurring during C1 and C2 and also consonant-to-consonant coarticulatory effects in sequences composed exclusively of dentals and alveolars are also small.

Ultrasound data for sequences composed of unconstrained /t, n, l/ followed by constrained /s, r/ (Figure 14, left graphs) often showing regressive assimilation at closure location according to the EPG data reveal the following scenario during C1. At the C1 mp – C1 on period, positive bars at the alveolar and palatal zones indicate that the front dorsum and blade raise, and negative bars at the pharynx for some sequences that the back tongue body shifts to a more anterior position, during the formation of the C1 closure or constriction. At the C2 on – C1 mp period the bars shift direction, i.e., those at the palatal and alveolar zones are now negative and those at the pharynx may be positive, which is related to C2-dependent anticipatory effects in tongue body retraction and in front dorsum and blade lowering during the second half of C1. These effects are less obvious for /ls, lr/ than for /ts, tr, ns, nr/ presumably since C1=/l/ is already articulated with a relatively low and retracted tongue configuration. At the C2 mp – C2 on period and thus towards C2 onset, the tongue front and front dorsum keep lowering for all sequences (mosty for those with C2=/s/), and there is some back tongue body retraction at the pharynx for /ts, tr, ns, nr/ but not for /ls, lr/ which again is in support of C1=/l/ being produced with some tongue body lowering/backing.

Figure 16 compares lingual configuration data for /tr/ for all individual speakers plotted at five successive time points (left graphs) with those gathered at the midpoint of syllable-final /t/ and syllable-initial /r/ next to /p/ and thus, in the same syllable position as /t/ and /r/ in the cluster /tr/ and adjacent to a consonant involving no tongue activation (right graphs). The right graphs of the figure reveal that the tongue position at the front spline edge where place of articulation occurs is more retracted for /r/ than for /t/ in the neutral labial consonant context. On the other hand, data for /tr/ in the left graphs indicate that, except perhaps for speaker JU, the front spline edge occurs essentially at the same location during C1=/t/ and during C2=/r/, and a comparison between the left and right graphs that this front spline edge location coincides with that for C2=/r/ after C1=/p/, which is in agreement with the regressive assimilation account. Changes in predorsum height and back dorsum fronting in the transition from C1=/t/ to C2=/r/ in the cluster /tr/ (left graphs) often mirror differences in tongue body position between /t/ and /r/ next to /p/ (right graphs) and therefore are associated with differences in manner of articulation between the two consonants. Regarding the sequences /ls, lr/, which may show closure retraction rather than regressive assimilation according to the EPG data (Figure 11), the tongue body position exhibits essentially no changes during C1.

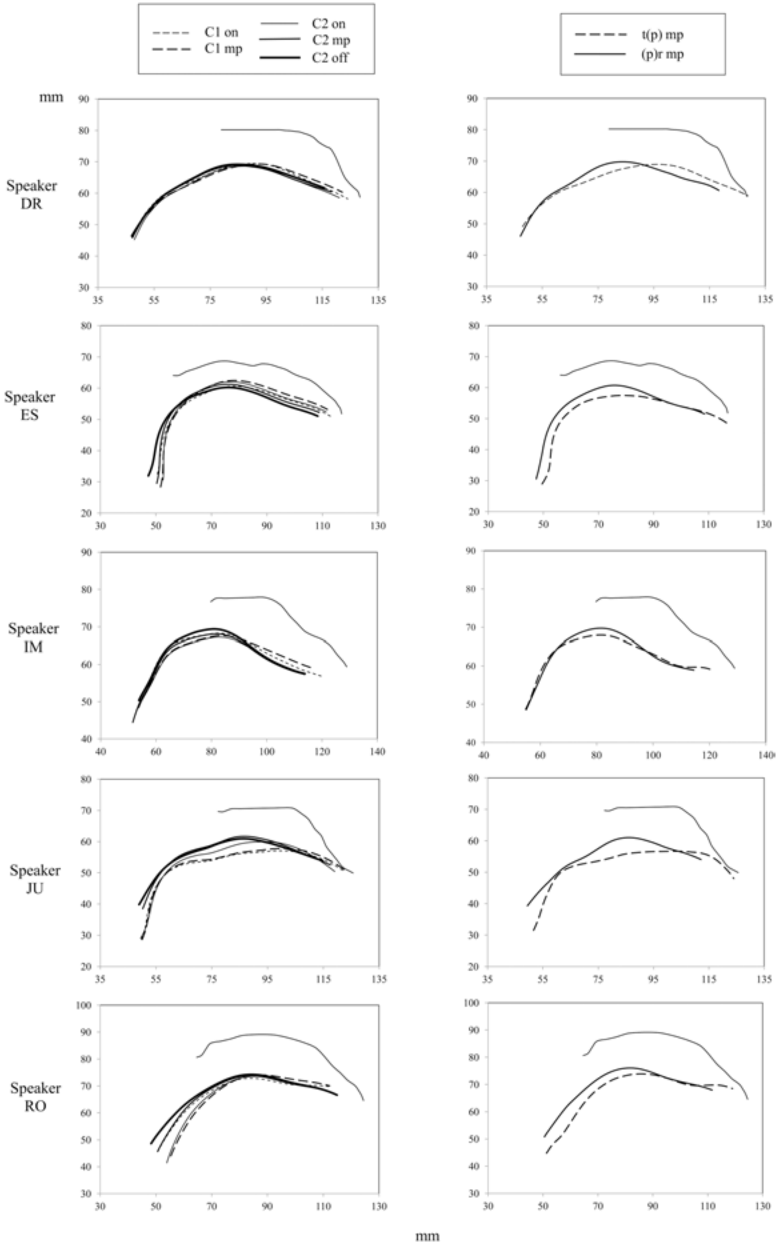

Figure 16: (Left) Lingual configurations for /tr/ plotted at five time points throughout the cluster for all individual subjects. (Right) Lingual configurations at the midpoint of C1=/t/ and C2=/r/ in the sequences /tp/ and /pr/, respectively. A palate trace is provided for all speakers.

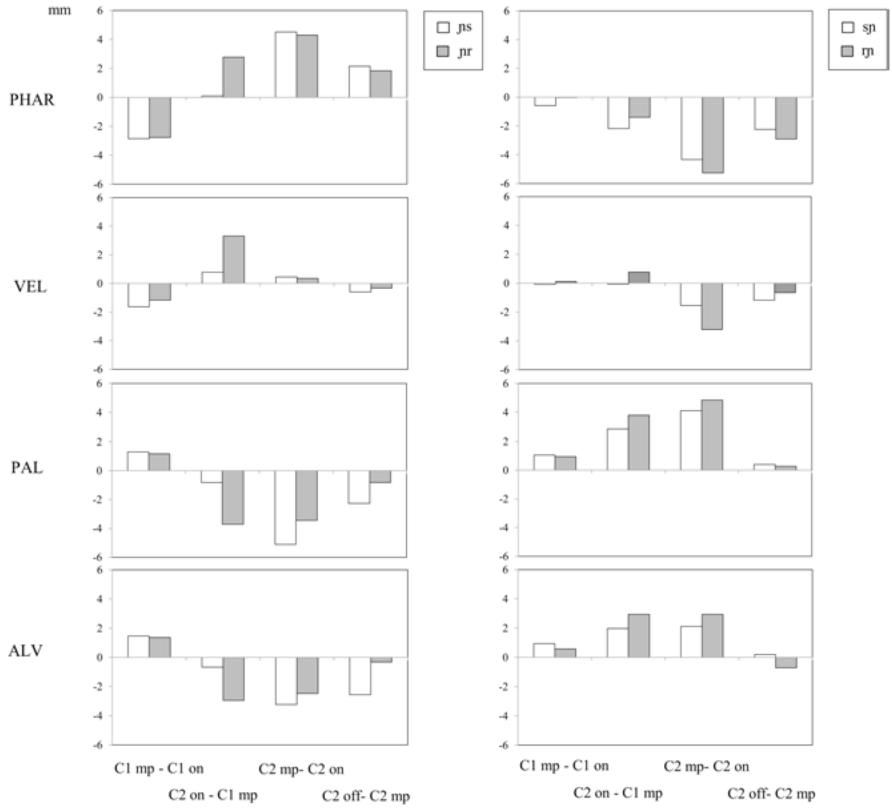

Figure 17: Cross-speaker differences in tongue position between successive temporal points for C#C sequences composed of unconstrained alveolopalatal and constrained alveolar consonants. See the Figure 14 caption for details.

(b) Changes in tongue position in sequences with a relatively unconstrained alveolopalatal C1 and a constrained alveolar C2 may be analyzed by focusing on the ultrasound data for /ɲs/ and /ɲr/ displayed in the left graphs of Figure 17. In parallel to the unconstrained + constrained sequences with dentals and alveolars (see Figure 14, left graphs), there is a change in the direction of the tongue motion during C1 which may be taken in support of a tongue repositioning mechanism. The C1 mp – C1 on bars towards C1 onset indicate the presence of some tongue dorsum raising and tongue back fronting during the formation of the alveolopalatal consonant. The second set of bars corresponding to the C2 on – C1 mp period show, mostly for /ɲr/, some tongue front and dorsum lowering at the alveolar and palatal zones and, less systematically, some back dorsum raising and backing at the velar and pharyngeal zones, which are clearly associated with

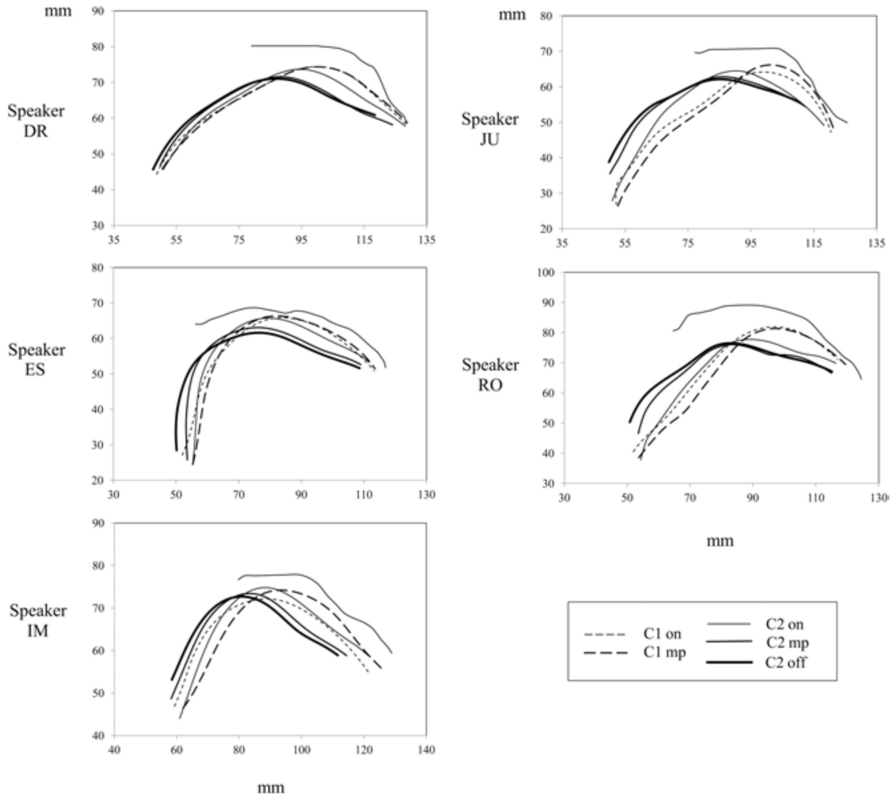

Figure 18: Lingual configurations for /ɲr/ plotted at five time points throughout the cluster for all individual subjects. A palate trace is provided for all speakers.

the C2-dependent anticipatory effects. At the C2 mp – C2 on period and thus during the first half of C2, the tongue travels backwards at the pharynx and downwards at the palatal and alveolar zones; this tongue motion may be related both to the articulatory characteristics of C2 and to those of the following low vowel /a/ and, as revealed by the fourth set of bars towards the C2 release, may continue until C2 offset.

The scenario for sequences composed of an alveolopalatal C1 followed by /s, r/ just described differs from that of unconstrained + constrained sequences with dentals and alveolars in that changes in tongue configuration over time are much larger since C1 and C2 are articulated with more distant lingual positions. This contrast may be seen by comparing differences in tongue location between successive time periods at the palatal and pharyngeal zones in the case of the sequences /ɲr/ (Figure 18) and /tr/ (Figure 16, left graphs). Indeed, changes in tongue position from C1 midpoint to C2 onset and from C2 onset to C2 midpoint are much larger for /ɲr/ than for /tr/ for all speakers, while place of articulation may occur at a similar location for C1 and C2 in the two sequences.

3.3.1.3 Other languages

Articulatory data for unconstrained + constrained consonant sequences in other languages besides Catalan show a similar intersegmental adaptation behaviour to that described in sections 3.3.1.1 and 3.3.1.2. This section reviews instances of regressive place assimilation in heterosyllabic CC sequences where a relatively unconstrained dental or alveolar is followed by a front lingual fricative or an alveolar trill or else by a retroflex or velarized/pharyngealized dental or alveolar, which as argued below are considered to be highly constrained consonants in view of their lingual configuration characteristics and coarticulatory behaviour.

As to the sequences with a front lingual fricative C2, EPG data for /nʃ/ and /ntʃ/ in Italian show that the nasal retracts its closure location in the case of two or all three speakers subject to analysis though a sequential realization is also allowed to occur when C2 is a palatoalveolar fricative (Farnetani & Busà, 1994). There may also be regressive assimilation in sequences composed of C1=/n/ and a following front lingual fricative in Argentinian and Cuban Spanish. Indeed, EPG data for speakers of these two Spanish dialects reveal that the nasal is articulated more anteriorly before /s/ (at about rows of electrodes 1–2 or 2–3 at the alveolar zone; see Figure 1) than before the realizations [ʃ, ʒ] of /ʎ/ (at about rows 2–3), which matches the presence of comparable constriction locations for the two fricatives in intervocalic position (Kochetov & Colantoni, 2011). In Japanese, significant differences in closure fronting were also found to occur between /n/ before /(t)s/ and before /(t)ʃ/ (EPG; Kochetov, 2014). Cinefluorographic data for English clusters also reveal that apical /t, d, n, l/ become laminal before laminal /s, z/ in word-internal position (Bladon & Nolan, 1977). The regressive alveolarization of dental /t/ before alveolar /s/ may account presumably for the palatalization of the affricate /ts/ into [tʃ] in Sardinian areas (Sulcis, Désulo; Wagner, 1984: 297), Valencian Catalan ([totʃ] *tots* “everybody”, [ˈdodʒe] *dotze* “twelve”) and Occitan dialects ([grantʃ] *grands* “big, pl.” [kurtʃ] *courts* “short, pl.”; Ronjat, 1930–1941, 2: 276).

It may also be contended that /t, d, n/ assimilate to the purely dental fricative /θ/, as in the English sequence *ten things* (Gussenhoven & Jacobs, 1998: 74), rather than that the two consonants blend as suggested by Browman & Goldstein (1991a). This assimilatory analysis appears to be consistent with EPG data for English showing that C1 is realized more anteriorly in the sequences /d#θ, n#θ/ than in intervocalic position, some constriction retraction during the transition from C1 to C2 in these two sequences being related presumably to the fact that the closure for /d/ and /n/ extends over a larger tongue contact area than the lingual constriction for /θ/ (Solé & Estebas, 1995).

Analogously to Catalan, /t/ and /n/ may undergo regressive place assimilation before the heterosyllabic alveolar trill /r/ in other languages. EPG data for /n#r/ produced by several Cuban, Argentinian and Castilian Spanish-speaking subjects show that, depending on speaker, closure location for the nasal may occur at rows 2–3, 3 or 3–4 and, less often, at rows 1–3 (*digan rato* “say ‘while’, 3rd person plural”), which is in agreement with the constriction placement for the trill occurring at rows 2 or 3 and occasionally 1–2 in intervocalic position for the same subjects (*diga rato* “say ‘while’, 3rd person singular”) (Kochetov & Colantoni, 2013). Also in Spanish dialects, dental /t/ may become postalveolar when followed by tautosyllabic /ɾ/ in syllable-onset position, after which the rhotic may devoice and assibilate (*otro* “another one”; Penny, 2000: 157–158; Malmberg, 1950: 134).

Evidence for regressive assimilation in unconstrained + constrained consonant sequences also derives from clusters in which dentoalveolar stops and nasals become retroflex before retroflex consonants which, in parallel to the Catalan trill /r/, are articulated at the postalveolar zone or even further back and exhibit some tongue lowering behind the primary articulator and a low jaw position, which renders them highly constrained. In an MRI study performed on Tamil liquids (Narayanan et al., 1999), retroflex and non-retroflex laterals and rhotics differed in that, in comparison to the non-retroflex cognates, the retroflex consonants were produced with a more posterior constriction, a somewhat more concave lingual configuration behind the primary constriction and a lower tongue dorsum roof. Also, when compared to clear /l/, the Malayalam darker retroflex lateral was found to be articulated with a faster apical motion, a less anterior and higher tongue blade position and more tongue predorsum lowering (Scobbie et al., 2013). It remains still unclear whether back tongue body retraction towards the pharyngeal wall is an articulatory characteristic of retroflex consonants, several aspects such as manner of articulation and the contextual vowels contributing presumably to the degree of lingual fronting at the pharynx in this case. Tongue body retraction has been considered to cooccur with tongue middle lowering during the production of retroflex consonants by some scholars (Hamann, 2002, 2003). Data on back tongue body position show indeed that the Malayalam dark retroflex lateral is as posterior and stable as the alveolar trill (ultrasound, Scobbie et al., 2013), and that the Tamil non-retroflex apicodental voiced stop and apicoalveolar lateral and rhotic are less retracted than the corresponding retroflex cognates in the context /a__a/ (MRI, Proctor et al., 2009). In contrast with these lingual configuration data, however, the Kannada retroflex geminate /ʈʈ/ has been reported to be articulated with a more anterior tongue body than other geminates such as the dental /tt/ in the /a/ context condition perhaps in order to assist the flapping-out movement of the tip during and after the consonantal constriction (ultrasound, Kochetov et al., 2012, 2014). It ought to be kept in mind regarding this issue that ultrasound images may fail to capture the minimal tongue-to-pharynx distance for retroflex consonants if it occurs at the lower pharynx rather than at the upper pharynx.

Regarding coarticulatory sensitivity, several studies have found that, in comparison to non-retroflex dentoalveolars, retroflex dentoalveolars are more resistant to vowel coarticulation at the tongue body which is in line with differences in articulatory constraint between the two consonant types (Malayalam, Scobbie et al., 2013, Irfana & Sreedevi, 2016; Tamil, Wiltshire & Goldstein, 1998). On the other hand, however, the apical constriction location for retroflexes varies considerably with vowel context. Thus, MRI data for Tamil retroflex stops, nasals and rhotics show a more retracted apico-postalveolar closure with a curled back of the tongue tip in the /a, u/ contexts and a more anterior laminal articulation and some tongue dorsum bunching in the /i/ context (Smith et al., 2013).

Patterns of regressive assimilation in consonant clusters with a retroflex C2 appear to be in agreement with the strong anticipatory effects in tongue tip retraction and tongue body positioning exerted by retroflexes on less constrained dentals and alveolars. Regarding consonant sequences with a retroflex rhotic, /t/ has been reported to shift to [ʈ] before tautosyllabic [ɽ] in Sicilian ([ʈɽ]*i* "three", *pa*[ʈɽ]*i* "father") and in S. Italian dialectal areas such as Calabrese and Salentino (Millardet, 1925, 1933, Rohlfs, 1966: 264, 371). The most characteristic realization of *tr* in these dialects appears to be the postalveolar affricate [t(:)ˢ], which suggests the earlier existence of the realizations [tɹ] or [ʈɻ] with a rhotic approximant (Celata, 2004–2005). In S.W. British English, the alveolar /t/ is realized at the postalveolar zone when occurring before the tautosyllabic postalveolar approximant [ɹ], as in the words *try* and *straw*, and thus exhibits a closure location which parallels that for /tʃ/ and is more posterior than the one for /ts/ (Jones, 1976: 165–166). Preference for [ɹ] being a regressive place assimilation trigger appears to be consistent with a trend for the American English rhotic to exert anticipatory rather than carryover effects on vowels (Boyce & Espy-Wilson, 1997). Assimilation to a following retroflex flap also accounts for the realizations [ʈɽ, ɖɽ] in Lugamba, which must have been the regular outcomes in the Indo-Aryan language Sindhi in the past, for the affricate realization of *tr* in Vietnamese, and for the variant [ɳɖ] of /nr/ in the Dravidian language Tamil (Bhat, 1973: 36, 44–45, Hamann, 2003: 86).

Regressive assimilation of dentals and alveolars before a heterosyllabic non-rhotic retroflex is also attested. Again, this is so since retroflex consonants may be considered to be highly constrained articulatorily, as proven by the similarity in lingual configuration with the alveolar trill. Regressive retroflexion is exerted by /ʈ/, /ɖ/ and/or /ɳ/ on the dental stops in Telugu and /t, d, n, s/ in Sanskrit (Hamann, 2003: 121, Cho, 1999: 60), /n/ in Kharia, Baluchi, Koya and Bengali, /l/ in Bengali and Kharia, /s/ in Koya, and the rhotic /r/ in Kannada which, after becoming retroflex, shifts to /ɳ/ (Bhat, 1973: 44–45). Likewise, /nɖ/ is implemented as [ɳɖ] in large Sardinian areas (Blasco, 1986: 39, Wagner, 1984: 293, Contini, 1987: 160).

Regressive deretroflexion, i.e., assimilation of a retroflex to a non-retroflex, is more rare than regressive retroflexion, which may be related to the notion that less constrained consonants ought to assimilate to highly constrained ones rather than viceversa. It occurs in Punjabi and Tamil where deretroflexion applies before /n/ and non-coronals, respectively (Punjabi /ɳn/> [nn], Tamil /ʈk/ > [kk]; Hamann, 2003: 122), and also in Sicilian where [ɳ] cannot show up before /t/ ([nd] *canda* from Latin CANTAT "he/she sings", *vendu* VENTU "wind"; Millardet, 1925: 732).

Velarized and pharyngealized dentals and alveolars resemble the alveolar trill and dark /l/ in being produced with active tongue body retraction and more or less tongue predorsum and jaw lowering, and also in that this lingual activity is mostly anticipatory and may cause place assimilation in a preceding non-velarized dentoalveolar to occur (Giannini & Pettorino, 1982, Watson, 2002: 277, Altairi et al., 2017). In view of these (co)articulatory characteristics, the consonants of interest may be considered then to be highly constrained as well. This assimilatory behaviour may be exemplified with descriptive data for Cairene Arabic where syllable-final /t, d, s, z, l, r/ shift to emphatic [tˤ, dˤ, sˤ, zˤ, rˤ] before /tˤ, dˤ, sˤ, zˤ, rˤ/ across a word boundary, and /l, r/ and /s, z, ʃ, ʒ/ totally assimilate to /rˤ/ and /sˤ, zˤ/, respectively (Youssef, 2013: 37). EPG data on Irish C#C sequences composed of palatalized and velarized /t/ (also /k/) reveal that the velarization gesture for a velarized stop overrides the palatalization gesture for the preceding palatalized stop rather than the other way around, and that the final outcome may be a reduced C1 gesture or regressive assimilation (Chasaide & Fritzpatrick, 1995). This finding is in contrast with descriptive reports for Irish consonant sequences composed of /t, d, n, l, s/ indicating that a velarized and palatalized C1 may assimilate to a palatalized and velarized C2, respectively (Ó Cuív, 1986: 403). Prevalence of velarization onto palatalization appears to be analogous to coarticulation data for Catalan consonant sequences such as /ɲr/, where the trill may cause the alveolopalatal consonant to undergo constriction retraction and tongue dorsum lowering while contextual palatalization of a rhotic is less common (section 3.3.1.1).

3.3.2 Constrained + unconstrained

3.3.2.1 EPG data

Data on closure or constriction location for sequences composed of C1=/s, r, ʃ/ and C2=/t, n, l/ plotted in Figures 19, 20 and 21 allow studying the realization of constrained + unconstrained consonant combinations. Analogously to the data

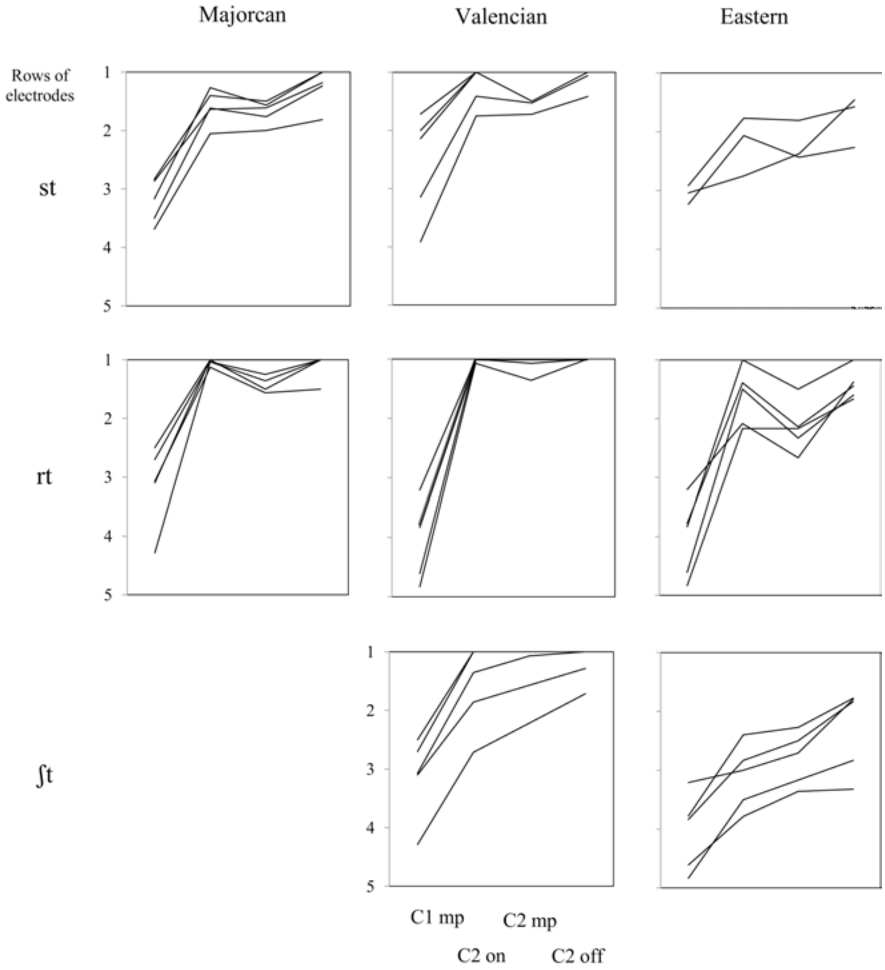

Figure 19: Closure/constriction location at C1 midpoint and at C2 onset, midpoint and offset for the sequences /st, rt, ʃt/ according to all three Catalan dialects. Linguopalatal contact trajectories travel halfway between the front and back edges of the consonant closure/constriction. Each trajectory corresponds to an individual speaker.

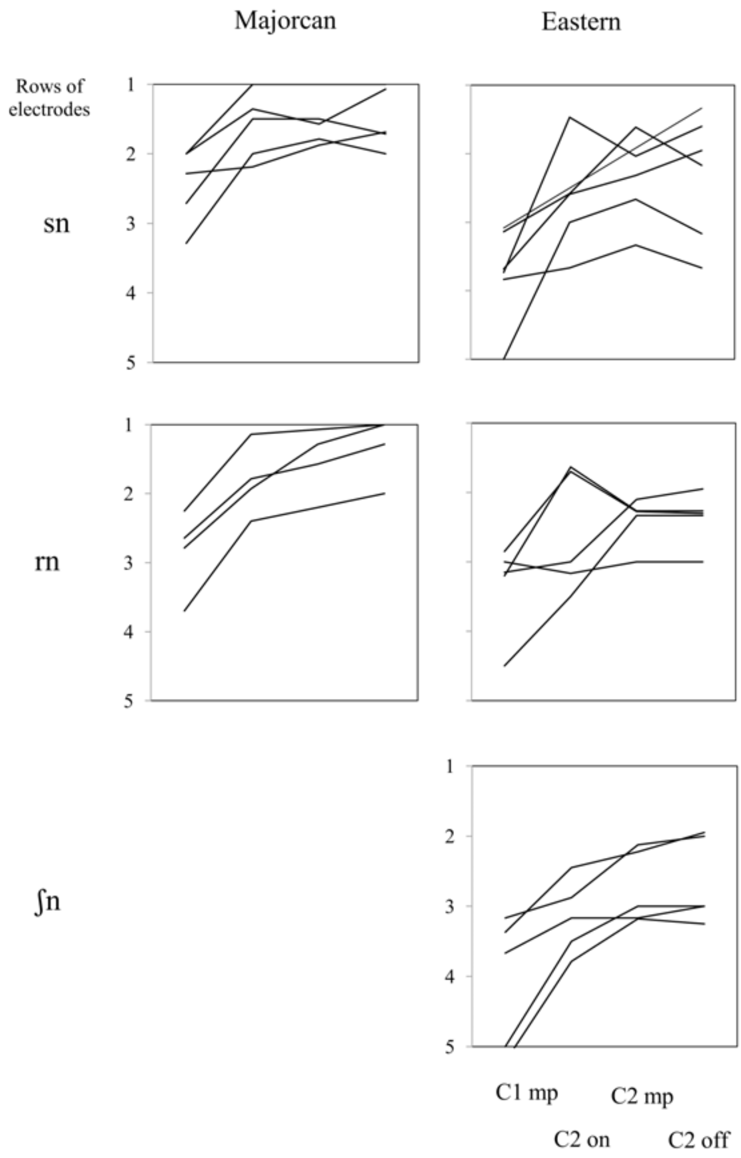

Figure 20: Changes in closure/constriction location during the clusters /sn, rn, ʃn/ for Majorcan and Eastern Catalan. See the Figure 19 caption for details.

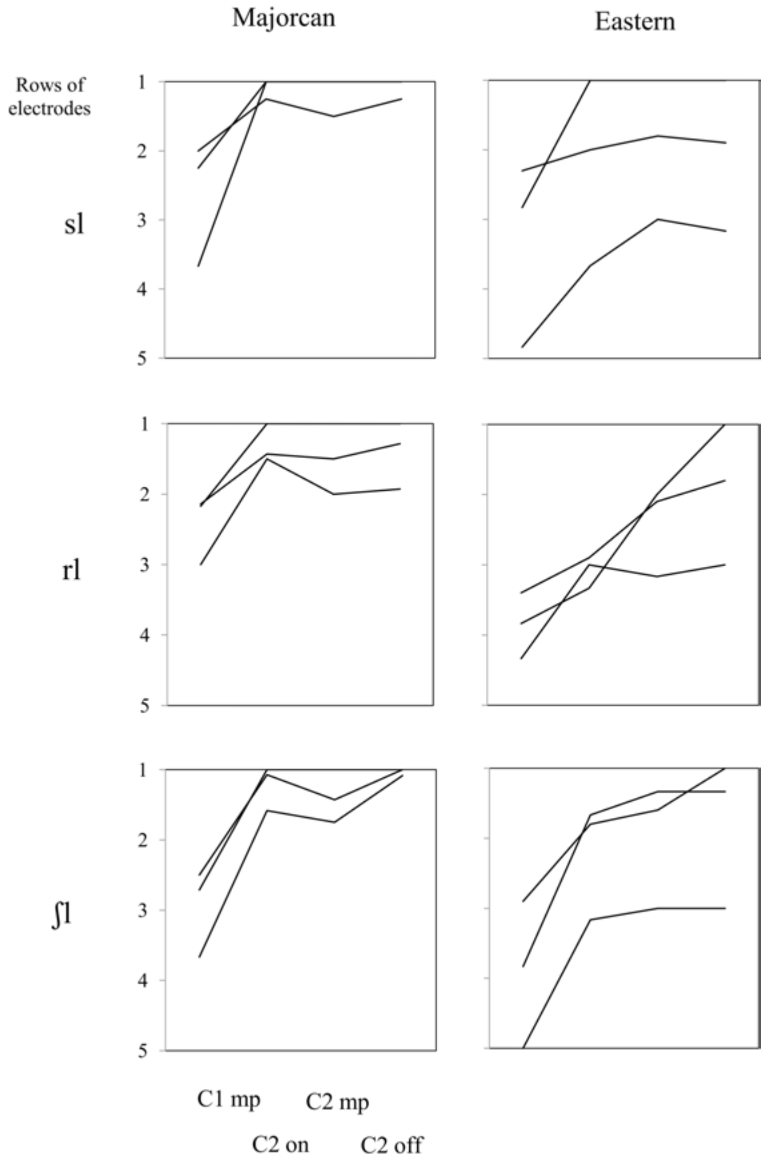

Figure 21: Changes in closure/constriction location during the clusters /sl, rl, ʃl/ for Majorcan and Eastern Catalan. See the Figure 19 caption for details.

plotted in Figures 9, 10, and 11, the lines in the graphs proceed halfway between the front and back closure/constriction borders at four consecutive temporal points during the cluster, i.e., C1 midpoint and C2 onset, midpoint and offset. The trajectories in each graph correspond to different speakers and have been averaged across cluster tokens. They are displayed for sequences with C2=/t/ in all three dialects and for sequences with C2=/n, l/ in Majorcan and Eastern Catalan. Available data for the sequences /Cn, Cl/ in the Valencian dialect are scarce, which is why they have not been represented in Figures 20 and 21.

A quick look at the graphs reveals that the tongue front travels from a relatively back constriction location for C1 to a more anterior closure location for C2, not only when C2 is dental or dentoalveolar (/t/, Figure 19) but also when it is alveolar (/n, l/, Figures 20 and 21). This scenario is radically different from that for the unconstrained C1 + constrained C2 sequences presented in Figures 9, 10 and 11 in that, as a general rule, C1 and C2 keep their own place of articulation and therefore C2 does not assimilate to C1. The consonant sequences of interest are thus implemented essentially through a two-target mechanism. EPG data for these and other consonant clusters reported elsewhere also reveal that the effect of C2 on C1=/s, ʃ/ may be in constriction degree rather than in constriction location, i.e, the two fricatives are articulated with more constriction narrowing before /n, l/ (/s/) and /n, l, t, ʎ/ (/ʃ/) than before the dorsal consonants /j, k/ (Recasens & Pallarès, 2001a).

A closer inspection of the closure/constriction trajectories for the constrained + unconstrained consonant sequences of interest shows finer differences regarding the extent to which C1 affects C2. The degree of carryover coarticulation depends on cluster composition, as revealed by the frequency of occurrence of patterns 1–18 during C2=/t/ in the case of the clusters /st, rt, ʃt/ displayed for all dialects in Figure 22 and during C2=/n, l/ in the case of the sequences /sn, rn, ʃn, sl, rl, ʃl/ displayed for the Majorcan and Eastern dialects in Figure 23 (regarding the absence of data for /ʃt/ in Majorcan, see section 3.2.1.1).

As to the sequences with C2=/t/ (Figure 22), instances of progressive assimilation yielding plain alveolar realizations of C2=/t/ occur more often after /ʃ/ than after /s/ mostly in Eastern Catalan, and are practically absent in the case of the cluster /rt/. Differences in constriction fronting between the two lingual fricatives account for differences in closure placement for /t/ after /s/ and /ʃ/ in the Eastern dialect, and the fact that preconsonantal /r/ is articulated with a short and fast apicoalveolar contact may explain why /t/ achieves the dental or dentoalveolar place of articulation after the rhotic in all dialects as a general rule.

A similar scenario to that for the sequences with C2=/t/ just described applies to the clusters /sd, rd/ in Majorcan, Valencian and Eastern Catalan (not

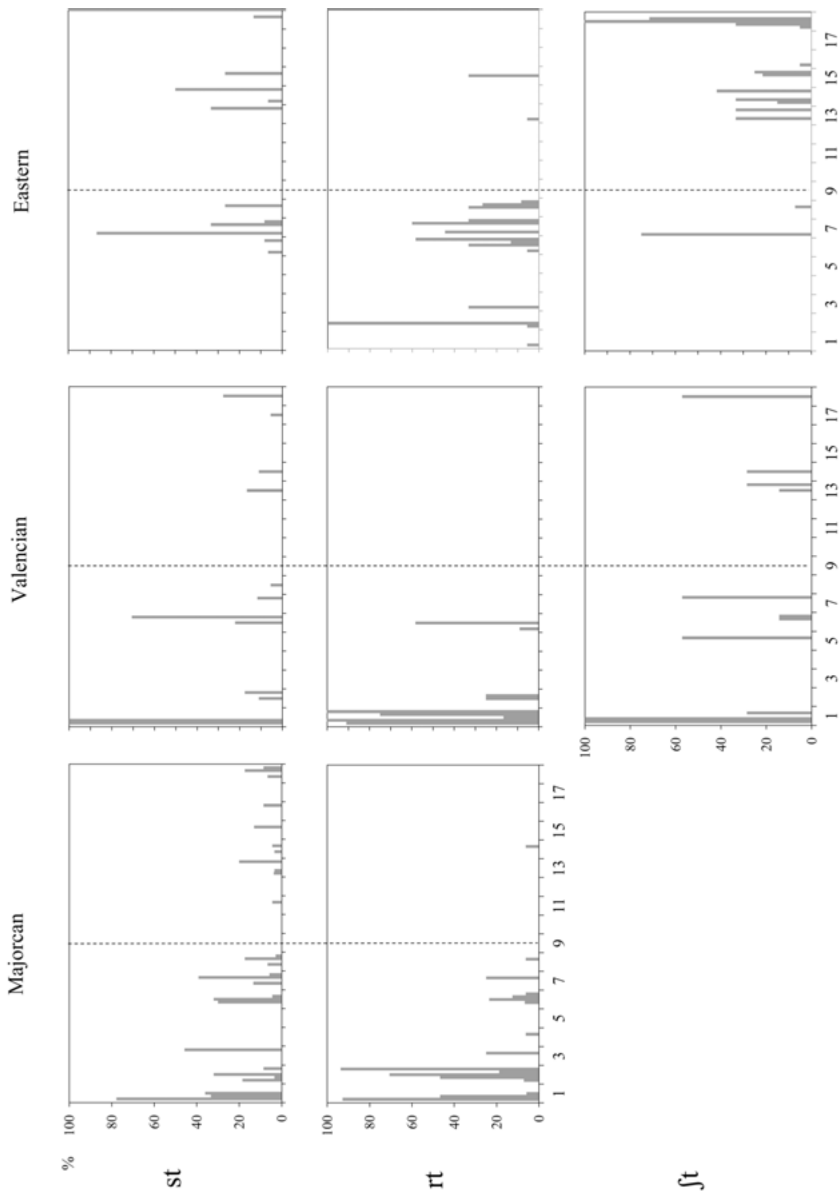

Figure 22: Frequency of occurrence of the 18 closure patterns listed in Figure 5 for C2=/t/ in the sequences /st, rt, ʃt/. Data have been plotted across speakers of each Catalan dialect.

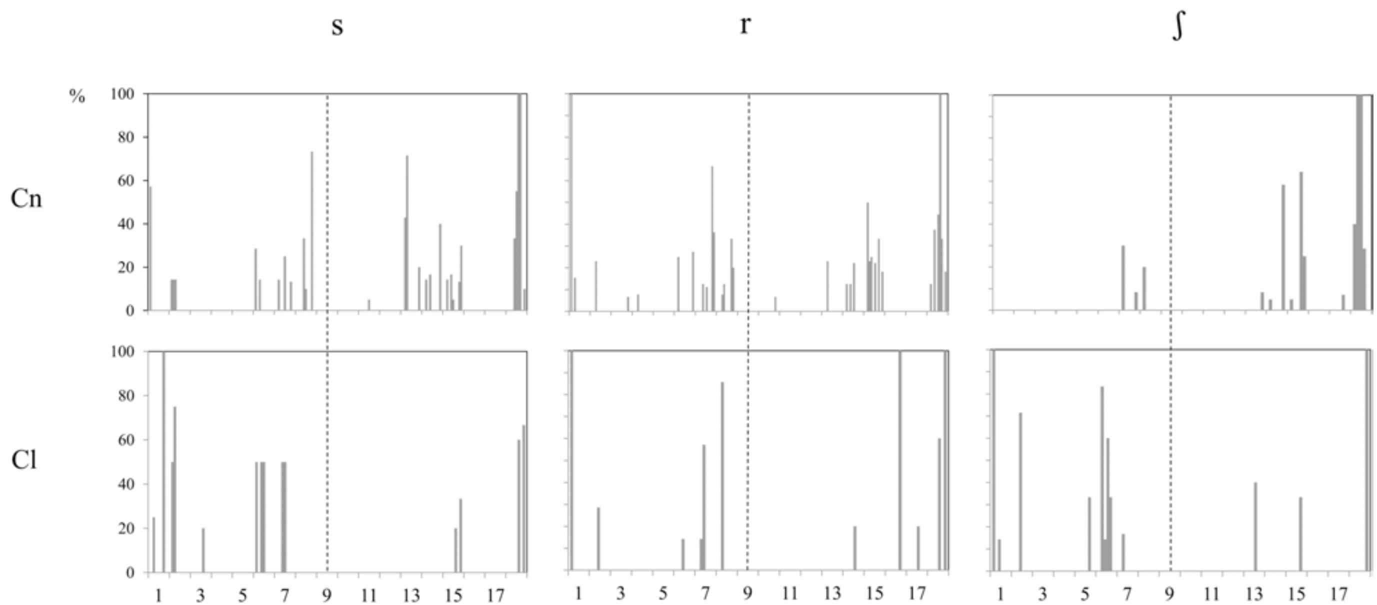

Figure 23: Frequency of occurrence of the 18 closure patterns listed in Figure 5 for C2=/n, l/ preceded by /s, r, ʃ/ in the sequences /sn, rn, ʃn, sl, rl, ʃl/. Data have been averaged across speakers of the Majorcan and Eastern dialects.

shown), where /d/ is realized typically as the approximant [ð] though [d] is also possible. Thus, C2=/d/ shows a dental realization in most tokens of these consonant sequences and therefore a much more frequent closure or constriction at row 1 (70%–80% of the time for /sd/, 90–100% for /rd/) than at rows 1+2 (about 10% for both /sd/ and /rd/). These electropalatographic data are consistent with EMA data for /sd, rd, ʒd/ in Eastern Catalan showing a sequential C1-to-C2 realization for all three sequences, and a lower and more anterior apical constriction for C2=/d/ after the rhotic, which is comparable to the constriction location for intervocalic [ð], than after the two fricatives (Recasens, 1995). Similar EMA data have been reported for /sd, rd/ in Spanish (Romero, 1996).

Data on the frequency of occurrence of patterns 1–18 for /n, l/ preceded by /s, r, ʃ/ in Figure 23 (see also Figures 20 and 21) reveal the presence of a more posterior realization for the nasal (mostly alveolar) than for the lateral (often dental or dentoalveolar). A more anterior realization for /l/ than for /n/ ought to be associated with the requirement for the lateral to allow airflow through the mouth sides and, in Majorcan, with a strongly dark realization articulated at row 1 and therefore at the dental zone (see Figure 2).

Sequences composed of C1=/s, r, ʃ/ and C2=/ʎ/ in Eastern Catalan (not shown) parallel the combinations /s, r, ʃ/ + /t, n, l/ in that they are implemented through closure fronting in spite of the fact that closure or central contact for the alveolopalatal lateral may occur at the alveolar zone (Figure 2). EPG data also reveal that the alveolopalatal lateral is articulated at a more posterior realization after /ʃ/ than after /s, r/, which is reminiscent of the coarticulatory scenario for C#C sequences with C1=/s, r, ʃ/ and a dentoalveolar or front alveolar C2 (see above). Moreover, progressive depalatalization yielding a purely alveolar realization of the (alveolo)palatal stop allophone of /k/ may take place in the Majorcan Catalan sequences [lc, sc, rc] (Recasens, 2014a: 312).

3.3.2.2 Ultrasound data

Lingual configuration data for constrained + unconstrained consonant sequences will be given and discussed next for combinations of dentals and alveolars (section (a)) and of constrained alveolars followed by alveolopalatals (section (b).

(a) The bar graphs on the right of Figure 14 allow studying changes in tongue position over time at each articulatory zone during consonantal sequences composed of highly constrained C1=/s, r/ and less constrained C2=/t, n, l/. The four bar groups in each graph plot changes occurring between C1 onset and midpoint, C1 midpoint and C2 onset, C2 onset and C2 midpoint and C2 midpoint and C2 offset. Regarding sequences with C1=/r/, the C2 onset – C1 midpoint period includes two shorter periods, i.e., C1 offset – C1 midpoint and C2 onset – C1 offset such that the former occurs during the second half of C1 and the latter during the vowel-like opening period following the rhotic release. Regarding the sign and size of the bars, see section 3.3.1.2.

Bars for the C2 on – C1 mp period and thus before C2 onset displayed in the graphs of the figure indicate some back tongue body raising and retraction at the velar/pharyngeal zones in the case of /sl, rl/ but not /st, rt, sn, rn/, which may be associated with the C2–dependent anticipatory effects. They also reveal the presence of some front dorsum and tongue front raising at the palatal and alveolar zones mostly for sequences with C1=/r/ (/rt, rn, rl/), as the tongue tip travels from the C1 to the C2 constriction location. Past C2 onset, there is some back tongue body fronting and lowering for /st, rt, sn, rn/ and some front dorsum and tongue front lowering towards C2 closure release for all six consonant clusters, which at least in part may be related to the low tongue position for the following vowel /a/.

Lingual splines for /rt/ at all time points plotted in Figure 24 (left graphs) reveal the existence of a fronting movement from C1 (discontinuous lines) to C2 (continuous lines) at the front lingual edge which parallels the EPG data (Figure 19). Therefore, in contrast with /tr/, C1 does not assimilate to C2 in the sequence /rt/ but the two consonants are realized at two separate places of articulation. Moreover, as shown by the right graphs displaying lingual configurations for the same sequence at C1 midpoint, C1 offset and C2 onset, the /r/-to-/t/ tongue fronting movement occurs essentially during the vocalic period following the release of the rhotic (i.e., between C1 offset and C2 onset) rather than during the rhotic constriction period; during this /r/-to-/t/ apical frontig movement the tongue body stays fixed and there may be some raising of the tongue region located immediately behind the tip. This scenario differs from that for the sequences /sl, rl/ for the production of which the back tongue body retracts during the C1-to-C2 constriction fronting movement (see EPG data in Figure 21 and ultrasound data in Figure 14, right graphs).

(b) As revealed by Figure 17 (right graphs), the production of sequences composed of constrained C1=/r/ and unconstrained C2=/ɲ/ shows considerable front dorsum and tongue front raising at the palatal and alveolar zones and back tongue body fronting at the pharynx in anticipation of C2 during the C2 on – C1 mp period. Moreover, the same lingual raising and fronting activity continues during C2 presumably until the alveolopalatal closure for the nasal is completed (see the third set of bars for the C2 mp – C2 on period). The fourth set of bars shows no obvious change in tongue position at the alveolar and palatal zones which is where the alveolopalatal closure for /ɲ/ occurs while the tongue

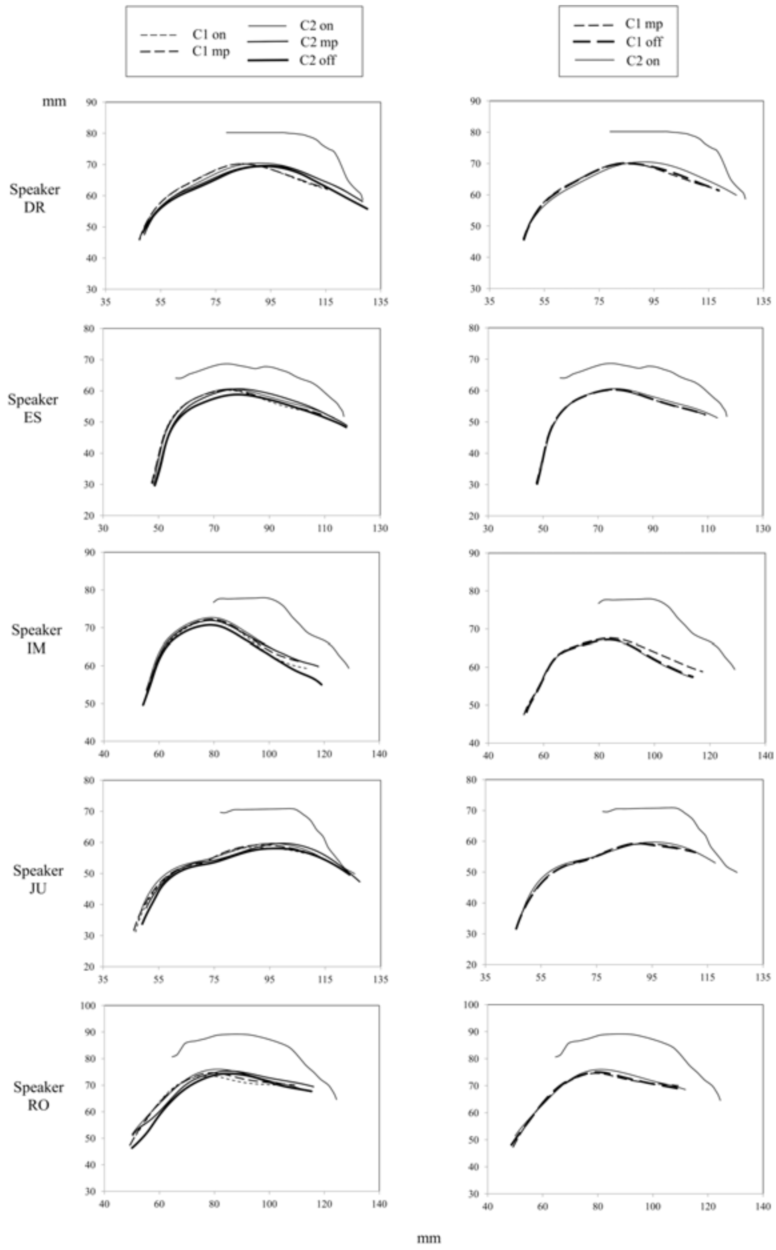

Figure 24: Lingual configurations for /rt/ plotted at five time points throughout the cluster (left) and at three time points around the C1C2 boundary (right) for all individual subjects. A palate trace is provided for all speakers.

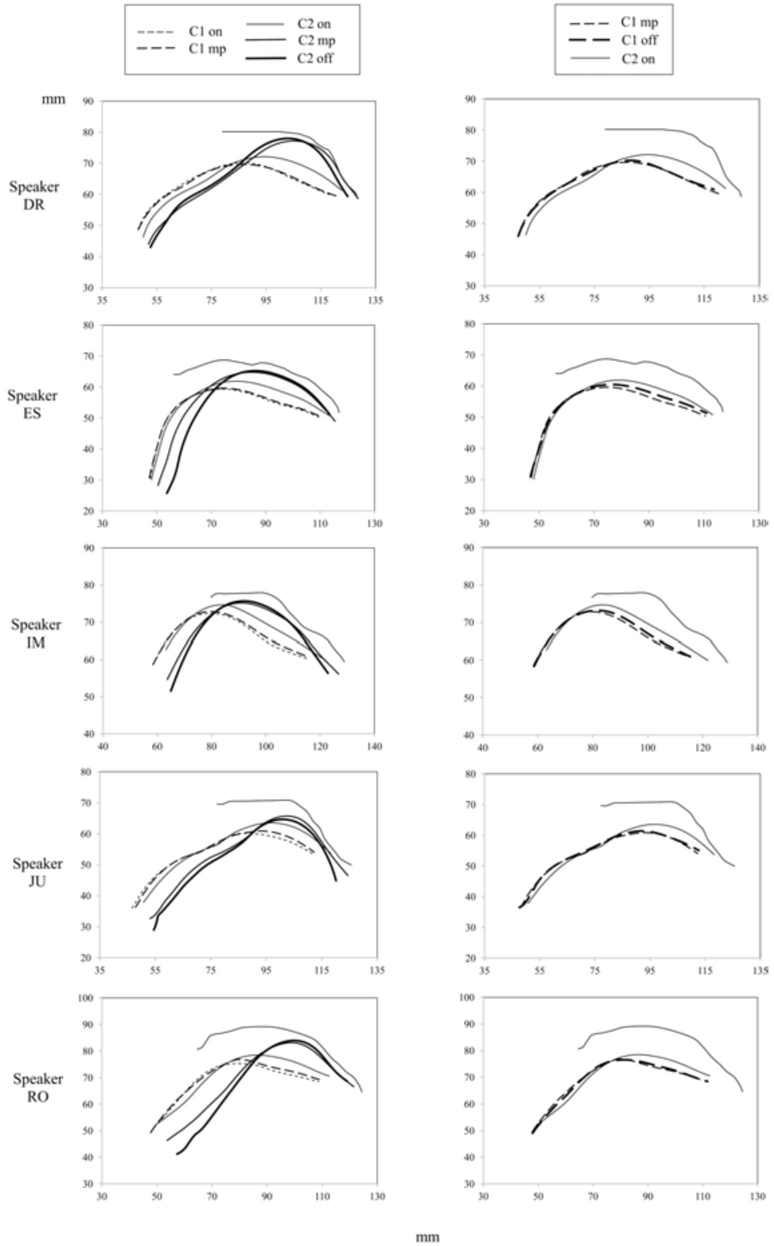

Figure 25: Lingual configurations for /rɲ/ plotted at five time points throughout the cluster (left) and at three time points around the C1C2 boundary (right) for all individual subjects. A palate trace is provided for all speakers.

back is still being fronted presumably as a preparation for the nasal stop closure release.

Lingual configuration data for /rɲ/ (also /sɲ/) in Figure 25 exhibit considerable tongue dorsum raising and back tongue body fronting throughout the cluster, which according to the right graphs of the figure displaying the tongue contours at C1 midpoint, C1 offset and C2 onset occur during the vocalic period following the rhotic release to a large extent. Indeed, there are no visible changes in lingual configuration during the constriction period for C1=/r/ that may be ascribed to C2=/ɲ/, which is in contrast with the considerable anticipatory tongue lowering and backing effects exerted by the trill during C1=/ɲ/ in the case of the sequence /ɲr/ (see Figure 18).

3.3.2.3 Other languages

Progressive place assimilation of dentals and alveolars may be triggered by a preceding rhotic, which parallels the constriction retraction of unconstrained dentoalveolars before an alveolar trill (section 3.3.1.1). However, as revealed by the Catalan data, to the extent that the syllable-final rhotic may be less constrained than the syllable-onset trill both regarding number of apical contacts and overall tongue body configuration, the place assimilation in question is not expected to apply as often at the progressive level as it does at the regressive level. EPG data for Italian (where the allophonic distribution of the alveolar rhotic is essentially the same as in Catalan) show indeed that the sequence /rn/ is implemented through two separate articulatory targets, a more posterior one for /r/ and a more anterior one for /n/ (Farnetani & Busà, 1994).

For the postalveolarization of a dental stop or a front alveolar consonant to occur in /rC/ sequences, the rhotic needs to exhibit a trilled and even fricated realization, or else be retroflex. Postalveolarization after /r/ may apply on a dental stop and the alveolars /n, s/ in Spanish from Paraguay, Chile and other American dialects (Malmberg, 1971: 436, Eliasson, 1986: 293), and /t, d/ may shift to a palatoalveolar affricate after /r/ word medially in some French and Franco-provençal dialects: Franche Comté [potʃ] Fr. *porte* “door”, [kwodʒ] Fr. *corde* “string” (Dondaine, 1972: 126–127); Vosges [puˈʃa] Fr. *porter* “to carry” (Bloch, 1917: 17, 142); Bourgogne (Taverdet, 1975–1980, maps 433, 1400). Progressive assimilation occurs more commonly when the rhotic is retroflex, as for the sequences /ɽt, ɽd, ɽl/ in Sicilian (/ɽt/ *pa*[ɽʈ]*i* “part”, /ɽl/ *pa*[ɽɭ]*u* “I speak”; Millardet, 1925:737). A particular case is that of Cuban Spanish from La Havana where coda /l, r/ may be realized as [ɽ] and retroflexion is propagated from these consonant realizations to following /t(ʃ), d, n, l/ and also /s/ (*go*[ɖɖ]*o* Sp. *gordo* “fat”, *Ca*[ɭɭ]*os* Sp. *Carlos* “Charles”), while complete regressive assimilation in [ɽC] sequences occurs before non-homorganic labials and velars ([pp] Sp. *ser pobre* “to be poor”) (Guitart, 1976).

Regarding languages which do not belong to the Romance family, /t, d, n, l, s/ become retroflex and thus [ʈ, ɖ, ɳ, ɭ, ʂ] after /r, ɽ/ across morpheme and word boundaries in Norwegian, after which the rhotic is deleted (Kristoffersen, 2000: 88). (In this section we include rhotic + lingual fricative sequences, which strictly speaking belong to section 5.5.1.1). Also in Norwegian, the phonemes /ʈ, ɖ, ɳ, ɭ, ʂ/ originated historically from the clusters /rt, rd, rn, rl, rs/ through progressive assimilation. In Faroese, on the other hand, /rs/ assimilates into [ʂ] (Bhat, 1973: 44). In a similar fashion, in Swedish, progressive retroflexion causes /t, d, n, l, s/ to shift to [ʈ, ɖ, ɳ, ɭ, ʂ] after /r/ obligatorily morpheme internally and optionally across a word boundary and to a lesser extent across a word internal boundary, and applies recursively in three-consonant sequences starting with /r/ (*harts* “rosin”); moreover, in addition to [ɭ], /rl/ may be realized as either [rl] or unassimilated [l], which follows from the reluctance on the part of the alveolar lateral to undergo place assimilation (Eliasson, 1986: 277–282). Also in S.W. British English dialects, the retroflex rhotic causes a following alveolar to become retroflex after which the rhotic may be deleted (*reade(r)s*; Hamann, 2003: 121). Progressive retroflexion or postalveolarization triggered by a rhotic also operates in the combinations /r/ + /t, n, l, r/ in Australian languages, /r/ + /t, d, n, ʃ/ in Iranian languages, and /r, ɽ/+ /n, s/ in Sanskrit where /s/ does not become retroflex before /r, ɽ/ (Bhat, 1973: 43–44, Whitney, 1889: 64, Burrow, 1973: 80, 97).

Highly constrained front lingual fricatives may also trigger strong carryover effects or progressive place assimilation on less constrained and more anterior dentoalveolar or alveolar consonants. Thus, in parallel to the regressive adaptation scenario (section 3.3.1), /t/ has been reported to become alveolar after /s/ in Finnish (Suomi et al., 2008: 35), and apical /t, d, n, l/ to shift to a laminal realization after laminal /s, z/ word internally in English (Bladon & Nolan, 1977). In agreement with the latter finding, static palatographic data for English show that the alveolar stop /d/ is articulated at the postalveolar location if preceded by stem-final /ʃ, ʒ, tʃ, dʒ/ in the past tense of verbs (*mashed*, *matched*), while remaining more anterior at the alveolar zone when occurring after /s, z/ (*missed*) (Baković & Kilpatrick, unpublished).

A non-rhotic retroflex consonant may also trigger progressive retroflexion of a following dental or alveolar. As to the Romance languages, /ɳd/ may turn to [ɳɳ] through place and manner assimilation in Sicilian (*u*[ɳɳ]*i* UNDE “where”; Millardet, 1925: 732), and the sequences /ɭt, ɭd/ may be realized as [ɭʈ, ɭɖ] in

Andalusian Spanish in lexical variants like *goldo* and *alto* for Sp. *gordo* “fat” and Sp. *alto* “high” (Llorente Maldonado de Guevera, 1962: 239). In Norwegian and Swedish, on the other hand, there is progressive assimilation of a dental or alveolar consonant after a rhotic and iterative retroflexion of C3 if available ([ʈʂ] /rts/ Sw. *harts* “rosin”, [ɳʂʈ] /rnst/ Sw. *Ernst*). In Swedish, this iterative application has an exception in sequences with the alveolar lateral, which again is in accordance with the particular behaviour of this consonant regarding place assimilation: /l/ becomes retroflex after a retroflex non-lateral ([ɖʂɭ] for /rldsl/, as in *världslig* “wordly”), while non-laterals do not after a retroflex lateral ([ɭs] for /rls/, as in *pärlsocker* “crushed loaf sugar”) (Eliasson, 1986: 280).

Progressive retroflexion after non-rhotic retroflexes has also operated historically in several Sanskrit consonant sequences: /ʂ, ɳ/ + /t, n/ (> [ʂʈ, ʂɳ, ɳʈ, ɳɳ]) and possibly /ɭt/ as for *pa*[ʈ]*a* derived from **palta*-, and also /ʂ, ɳ/ + /s/ but not /ʈs/ (Burrow, 1973: 80, 93, 97, Hamann, 2003: 121, Whitney, 1889: 61–69, Cho, 1999: 74–75). In other Dravidian and Australian languages, /ʈ, ɖ, ɳ, ɭ/ may induce retroflexion in a following dentoalveolar or alveolar: Tamil /ʈt/>[ʈʈ]; Malayalam /ɳt/ > [ɳʈ], /ʈt, ɭt/ > [ʈʈ]; Telugu /ɖl/> [ɭɭ], /ɖn/ > [ɳɳ]; E. Arrernte /ɭt/ > [ɭʈ]; Kannada /ɭl/> [ɭɭ], /ɳd/ > [ɳɖ] (Steriade, 2001: 245–246, Hamann, 2003: 120).

3.3.3 Trends in assimilatory direction

The trend for place assimilation as a function of a non-retroflex alveolar rhotic to operate at the regressive rather than at the progressive level is in line with the different manner characteristics of the rhotic in the syllable-coda and syllable-onset positions. Thus, as already pointed out in section 3.3.2.3, for the rhotic to induce progressive assimilation (and thus retroflexion), it has to have a trill-like realization or else, as suggested for Norwegian and Swedish by Eliasson (1986: 292–294), be realized as a fricative or approximant. The flap or tap realizations are excluded. Front lingual fricatives, on the other hand, may also favour the two assimilatory directions perhaps since they do not undergo much articulatory reduction syllable finally and their lingual configuration does not change much as a function of syllable position. As for the target consonant and in line with the predictions of the DAC model, retroflex assimilation in consonant sequences has been found to affect more often the relatively unconstrained consonants /n/ and /t, d/ than the more constrained ones /s, l/.

Several hypotheses have been proposed in order to account for the directionality pattern of place assimilation triggered by retroflex consonants in consonant clusters. It has been argued that this process is essentially progressive

(Steriade, 2001: "since C2 in a VC1C2V sequence lacks the VC transitions and C1 possesses them, assimilation for any features cued by VC transitions should target C2"). According to this view, preference for the VC acoustic cues results from the fact that the tongue tip slides forward during the closing phase of retroflexes (at least if the retroflex consonant is a stop or a liquid). Indeed, this tongue tip sliding movement towards the front causes the acoustic distinction between cognates such as /t/ and /ʈ/ to lie primarily in the VC transitions, i.e., at the VC transition endpoint the F3 locus is located at 1800 Hz for retroflex dentoalveolars and at 2700 Hz for the non-retroflex cognates while the consonant release and CV transition spectral characteristics are very similar for the two consonant classes. Indeed, the fact that the F3 resonance for retroflex consonants depends inversely on the size of the cavity in front of the constriction explains while the F3 frequency locus is so much lower for the VC transition than for the CV transition. According to Steriade, regressive place assimilations induced by retroflex consonants on a preceding syllable-coda consonant may be accounted for on other grounds, i.e., they may operate across a word boundary due to the articulatory and acoustic prominence of word-initial consonants (as in Sanskrit and Punjabi) and in nasal-stop clusters since the F3 transition is attentuated by the nasal zeroes thus rendering it not too perceptually prominent (as in Sanskrit and Malayalam).

This proposal appears to be not too consistent with the facts. As shown in section 3.3.1.3, retroflex consonants are prone to induce not only progressive place assimilations but regressive ones as well since tongue tip retraction and tongue body lowering and retraction for their implementation occur primarily at consonant onset and are anticipated in time during the preceding phonetic segment if available (Bhat, 1974). Thus, instances of both regressive and progressive retroflexion induced by a retroflex rhotic have been reported to occur in several languages and dialects (S.W. British English, Sicilian) and the same remark may apply to non-rhotic retroflexes (Sanskrit, Telugu). Moreover, it may be that specific languages or language families favor one direction or the other, i.e., the regressive direction by the Tibeto-Burman languages and the progressive direction by the Dravidian, Indo-Aryan and Australian languages (Arsenault, 2012). Retroflexes also parallel the alveolar trill in that both trigger right-to-left and left-to-right coarticulatory effects and assimilatory processes (Recasens, 2014b), which in the case of /r/ may be attributed to specific manner of articulation requirements. More attention needs to be paid in future work to differences in the coarticulatory and assimilatory behaviour among retroflex consonants of different manners of articulation.

3.3.4 Unconstrained + unconstrained

3.3.4.1 Palatalizing environment (EPG data)

(a) In order to analyze the implementation of gestural blending in alveolar+ alveolopalatal consonant sequences, Figures 26 and 27 plot the front and back closure border trajectories for the sequences /nʎ, lʎ, lɲ/ where blending is expected to occur (thick lines) and for each of the two consonants of each cluster in intervocalic position (discontinuous straight lines for C1, continuous straight lines for C2). Data correspond to the Majorcan, Valencian and Eastern dialects in the case of /nʎ/, to Majorcan and Eastern for /lʎ/ and to Valencian and Eastern for /lɲ/, and are presented at C1 onset, midpoint and offset and C2 onset and midpoint. EPG contact trajectories for /lɲ/ in Majorcan have not been included in Figure 27 since, given that the nasal is prone to be purely palatal in this dialect (Figure 2), the consonant sequence may be implemented through two independent targets rather than a blending mechanism.

Whether occurring as C1 or as C2 in consonant clusters, the EPG data for the intervocalic consonants show that /n/ and /l/ are generally articulated at the central alveolar area except for strongly dark /l/ in Majorcan which is often produced at row 1 only and therefore is dental rather than alveolar. As for /ʎ/ and /ɲ/, the lateral is alveolar in Valencian and Majorcan and alveolopalatal in Eastern, while the nasal exhibits an alveolopalatal closure in Valencian and an alveolopalatal or prepalatal closure in Eastern (see also Figure 2).

Data for the consonant sequences of interest reveal that closure location at C1 onset is relatively restricted and fairly front, and resembles those for the alveolars /n/ and /l/ rather than the ones for the alveolopalatals /ɲ/ and /ʎ/. Indeed, dialect-dependent differences in closure anteriority at C1 onset match those found for the same consonants in intervocalic position, i.e., closure fronting at this temporal point decreases in the progression Valencian > Majorcan > Eastern in the case of /n/ and with darkness degree in the progression Majorcan > Valencian, Eastern in the case of /l/. Past C1 onset and as pointed out below, closure location undergoes much expansion at the back border as C2 is approached.

Regarding the sequence /nʎ/ (Figure 26), data for the Majorcan and Valencian dialects reveal that the location of the back closure border, and to a lesser extent that of the front closure border as well, exceeds the closure border placement for intervocalic C1 and C2. Data for /nʎ/ in Eastern Catalan show that the front closure border for this cluster runs often more anteriorly than those for intervocalic /n/ and /ʎ/, while the corresponding back closure border may exceed the one for intervocalic /n/ and parallel that for intervocalic /ʎ/ (speaker DR) or else occurs somewhere between the front and back closure borders for

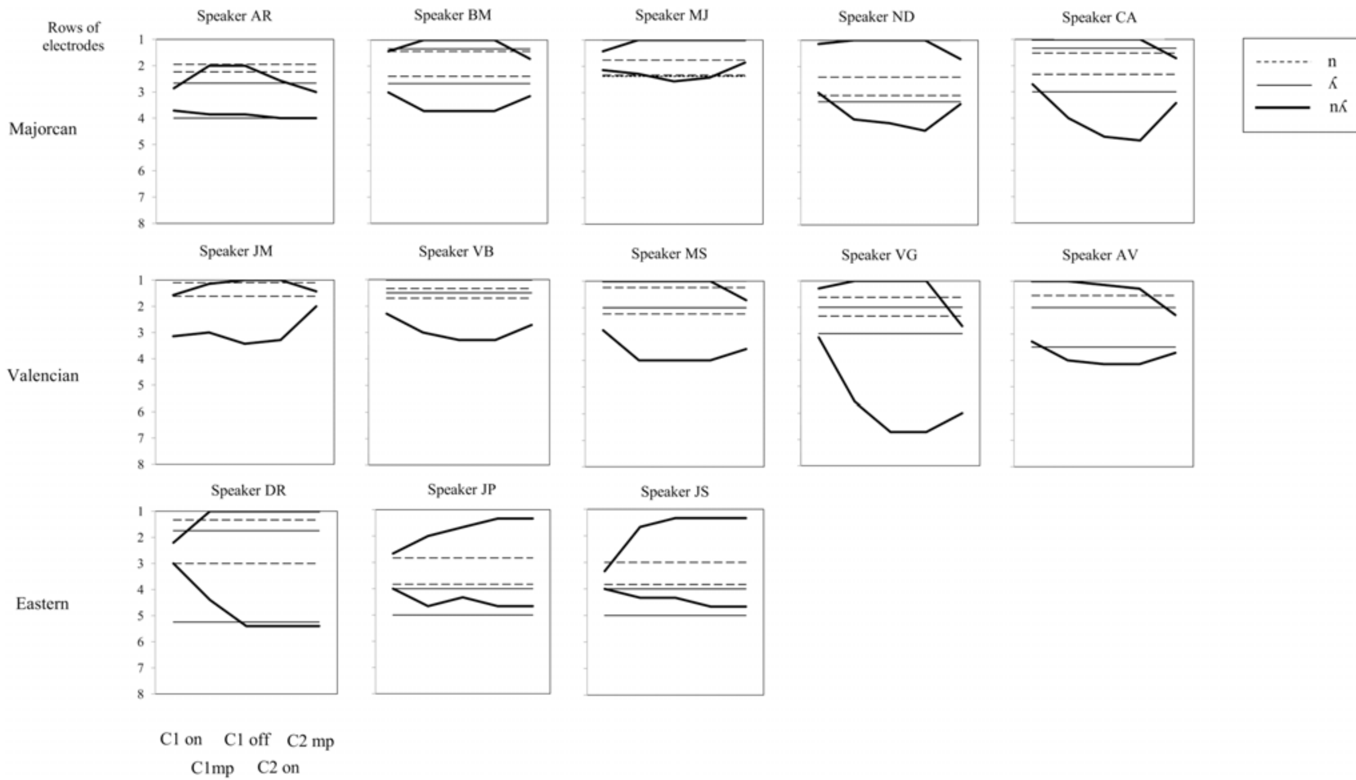

Figure 26: Closure edges for the cluster /nʎ/ at C1 onset, midpoint and offset and at C2 onset and midpoint, and for intervocalic /n/ and /ʎ/ at consonant midpoint, according to speakers of Majorcan, Valencian and Eastern Catalan.

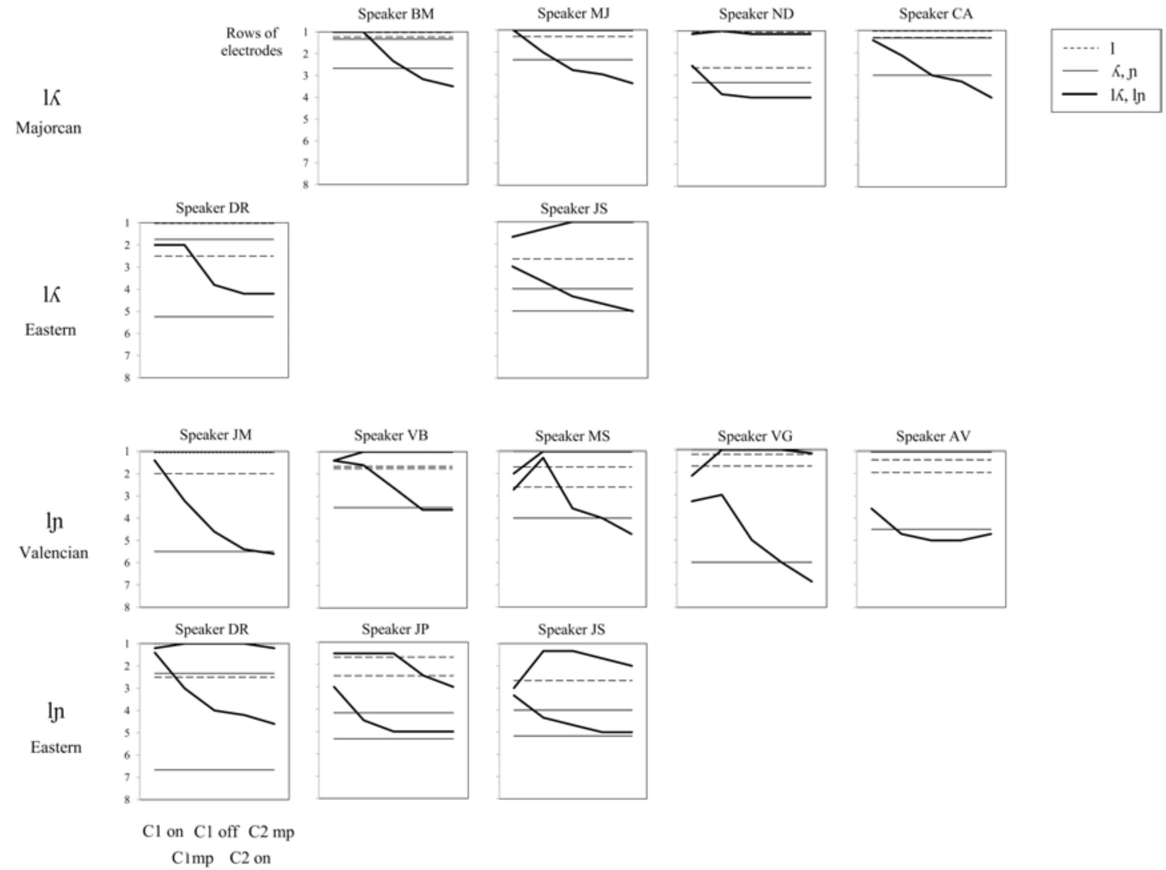

Figure 27: (Top) Closure edges for /lʎ/ at C1 onset, midpoint and offset and at C2 onset and midpoint, and for intervocalic /l/ and /ʎ/ at consonant midpoint, according to speakers of Majorcan and Eastern Catalan. (Bottom) Closure edges for /lɲ/ and for intervocalic /l/ and /ɲ/ at the same temporal points according to speakers of Valencian and Eastern Catalan.

/n/ and /ʎ/ in intervocalic position (speakers JP and JS). Therefore, closure extent for this cluster may equal or overcome that predicted by blending through superposition in most cases, and conforms less often to a blending through intermediation scenario. Inspection of the graphs in the figure also reveals that the closure outcome of the blending process extends generally into the second consonant of the cluster. An analogous blending mechanism operates in productions of the sequences [nc, nɟ] in Majorcan Catalan in which the alveolopalatal stop is an allophone of /k, g/ (not shown); in this case, there is an /n/-like alveolar closure at the onset of the cluster followed by contact spread at closure location yielding an alveolopalatal articulation from C1 midpoint onwards.

Regarding the clusters with C1=/l/ (Figure 27), data on the location of the back closure border for /lʎ/ in Majorcan suggest the presence of a blended outcome which is implemented through a blending through superposition mechanism and is achieved at about C1 offset (speakers BM, MJ, CA) rather than at C1 midpoint (speaker ND). Also judging from the location of the back closure border, blending for /lʎ/ in Eastern and /lɲ/ in Valencian and Eastern is not achieved until C1 midpoint or C1 offset and gives rise to an intermediate closure location between the two consonants fairly often. In all cluster productions, the front closure border reaches maximal fronting at row 1 early in the cluster as a general rule.

In sum, the tongue contact expanding motion at closure location proceeds earlier in clusters with C1=/n/ than in those with C1=/l/, and often yields a comparable closure area to that for the alveolopalatal C2 at about C1 midpoint when this consonant is /n/ and at about C1 offset when this consonant is /l/. Moreover, blending in the consonant sequences with C1=/l/ is delayed or even blocked when the alveolar lateral is strongly dark as in Majorcan rather than when it is clear as in Valencian or moderately dark as in Eastern. Front closure expansion often reaches row 1 during the first half of C1 in all consonant combinations.

An increase in tongue contact at the back closure location of a dentoalveolar or alveolar consonant triggered by a following alveolopalatal consonant coccurs with some raising of the tongue dorsum in sequences with C1= /t, n, l/ and C2=/ʎ, ɲ/ (see also section 3.3.4.1 (b)). In any case, the degree of dorsopalatal contact for /n/ before those alveolopalatal consonants is still less than that for /ɲ/ in intervocalic or word-initial position, which indicates that /n/ palatalization does not cause the alveolar nasal to become alveolopalatal regarding tongue dorsum raising degree. Anticipatory palatalization may yield regressive place assimilation when the palatalized consonant target cannot be distinguished from the alveolopalatal consonant trigger because the two share the same manner of articulation, as for /nɲ/ > [ɲ:] (Catalan *bon nyap* “a good fudge”), /lʎ/ > [ʎ:] in dialects where the alveolar lateral is clear rather than dark (Valencian Catalan

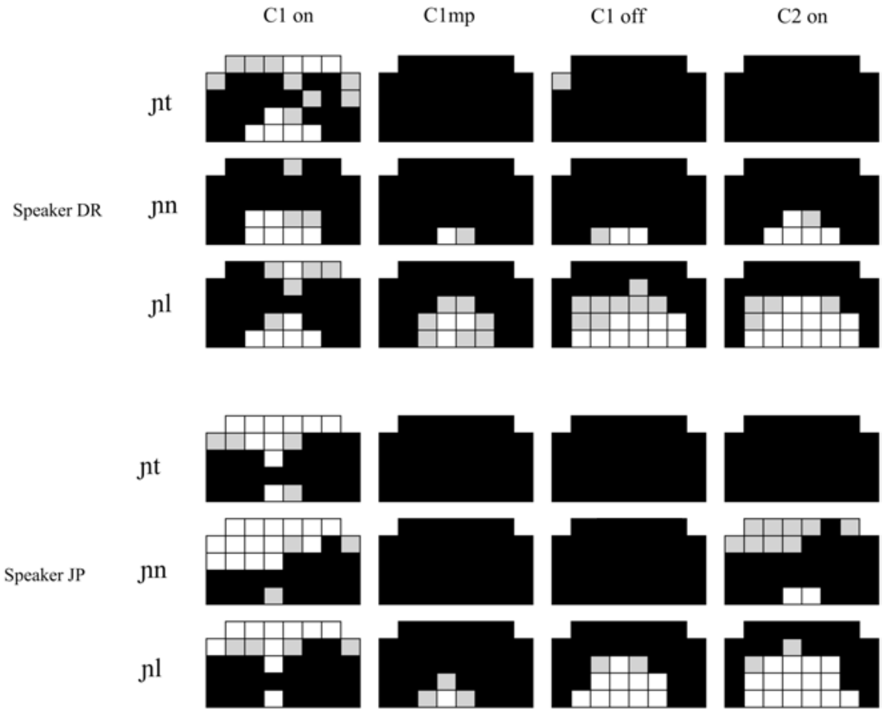

Figure 28: Linguopalatal contact patterns for the sequences /ɲt, ɲn, ɲl/ according to the Eastern Catalan speakers DR and JP. Contact patterns are displayed over the five front rows of electrodes at C1 onset, midpoint and offset and at C2 onset. The electrodes have been assigned different colour shades depending on contact frequency across tokens: black (80–100% activation); grey (40–80%); white (0–40%).

mal llamp "dangerous thunder") and /t, d/+ [c, ɟ] > [cː, ɟː] in Majorcan Catalan. In Valencian Catalan, an increase in closure size towards the back alveolar zone and much tongue dorsum raising for the clear variant of /l/ may also give rise to the realization [ʎ] when the lateral is followed by a non-lateral alveolopalatal or palatoalveolar consonant ([ʎdʒ] *aljub* "tank", [ʎtʃ] place name *Elx*).

(b) So far, blending in the palatalizing environment has been investigated for sequences composed of C1=/n, l/ and C2=/ʎ, ɲ/. The question is whether, as predicted by the DAC model, the reverse combinations /ʎ, ɲ/ + /t, n, l/ exhibit blending as well. Figures 28 and 29 display EPG linguopalatal contact patterns at successive time points for the clusters of interest produced by the two Eastern Catalan speakers DR and JP.

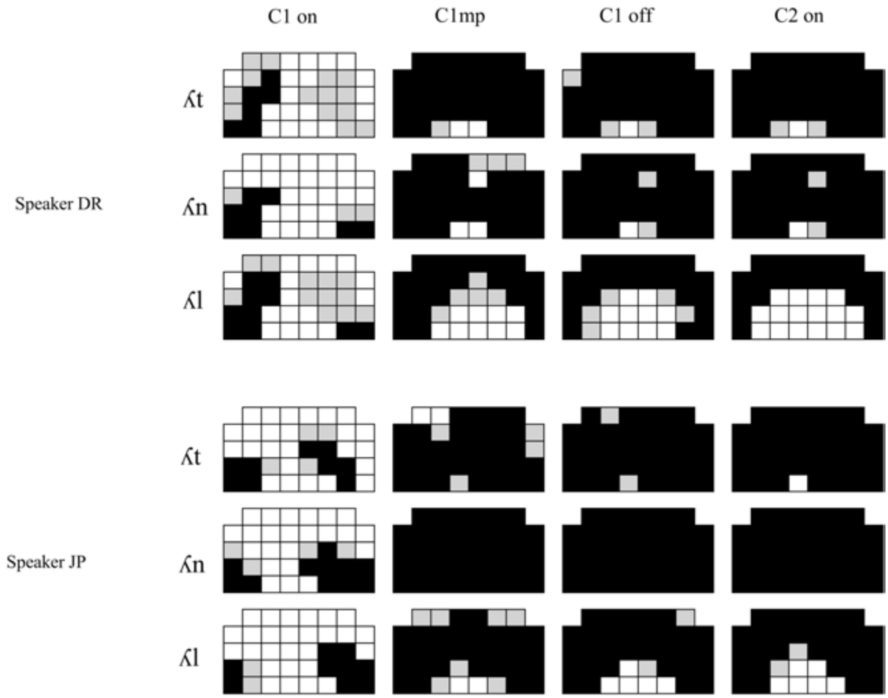

Figure 29: Linguopalatal contact patterns for the sequences /ʎt, ʎn, ʎl/ according to the Eastern Catalan speakers DR and JP. See Figure 28 for details.

Analogously to /nʎ/ and for both Eastern Catalan subjects, closure for the sequences /ɲt/ and /ɲn/ embraces the entire alveolar zone and prepalate and therefore is implemented through a blending through superposition strategy (Figure 28). Also in parallel to the phonetic realization of /nʎ/, this blending mechanism is achieved about C1 midpoint with full contact over the entire alveolar zone extending into C2 (not shown). The scenario for /ɲl/ differs from that for /lɲ/ and /lʎ/ (Figure 27) in that blending is not allowed to occur not even at C1 offset. Indeed, in this particular case closure at C1 midpoint and offset occurs at rows 1–2 or 1–3 and, therefore, at a more anterior location than C1 for the sequences /ɲt, ɲn, lɲ, lʎ/. The final realization of C1 in /ɲl/ is very much /l/-like, as indicated by the fact that intervocalic /l/ is articulated at about rows 2–4 and intervocalic /ɲ/ at about rows 3–6 in Eastern Catalan (Figure 2). In sum, while /lɲ/ may undergo blending, /ɲl/ undergoes anticipatory depalatalization and no blending. This finding is in accordance with the notion that anticipatory tongue predorsum lowering and tongue body retraction effects for dark /l/

may override the tongue dorsum raising and fronting gesture for alveolopalatal consonants.

The EPG contact configurations for /ʎt, ʎn, ʎl/ in Figure 29 look very similar to those for /ɲt, ɲn, ɲl/, respectively, with again the presence of a full closure at about the entire alveolar and prepalatal zones which is achieved through blending in sequences with a stop or nasal C2, and regressive depalatalization involving a decrease in dorsopalatal contact and no blending in sequences with C2=/l/. In parallel to the EPG data for /ʎt/ and in accordance with the blending account, EMA data for an Eastern Catalan speaker show a single closure location throughout the entire consonantal sequence /ʎd/, which is as anterior as the closure placement for dentoalveolar /t/ in intervocalic position and more anterior than or equally anterior to the closure placement for intervocalic /ʎ/ (Recasens, 1995).

A comparison between the sequences /ʎn/ (Figure 29) and /nʎ/ (Figure 26) reveals that at least for speaker DR /n/ is articulated with more dorsopalatal contact when occurring as C1 than as C2 and therefore is subject to more anticipatory than carryover palatalization. This finding is somewhat unexpected since alveolopalatals are predicted to exert more carryover than anticipatory coarticulation on dentals and alveolars, and could be attributed, at least in part, to a tendency for coarticulatory and assimilatory processes to operate from right to left rather than the reverse (section 2.8). Another plausible interpretation, which applies to analogous sequence pairs such as /sʃ/ and /ʃs/, is that the production of /nʎ/ is less complex than that of /ʎn/ for reasons pointed out in the next section 3.3.4.2.

3.3.4.2 Palatalizing environment (ultrasound data)

Figure 30 represents changes in tongue position between consecutive time points during the production of sequences composed of unconstrained dental/alveolar and alveolopalatal/palatoalveolar consonants.

According to the left graphs of the figure, the dental/alveolar + alveolopalatal/ palatoalveolar sequences /tɲ, ntʃ, nʎ, lɲ/ show much anticipatory lingual activity for C2 during C1. In particular, the second group of bars corresponding to the C2 on – C1 mp period reveals the existence of considerable anticipatory effects in tongue dorsum and tongue front raising at the palatal and alveolar zones and in back tongue body fronting and lowering at the pharyngeal and velar zones (mostly in sequences with C1=/l/). This anticipatory action is to a large extent concomitant with that involved in the formation of the closure or constriction for the dental/alveolar C1 at the C1 mp – C1 on period. This same tongue dorsum raising and tongue body fronting movement may continue during C2=/ɲ/ presumably until the alveolopalatal closure is completed (see third set of bars corresponding to the C2 mp – C2 on period).

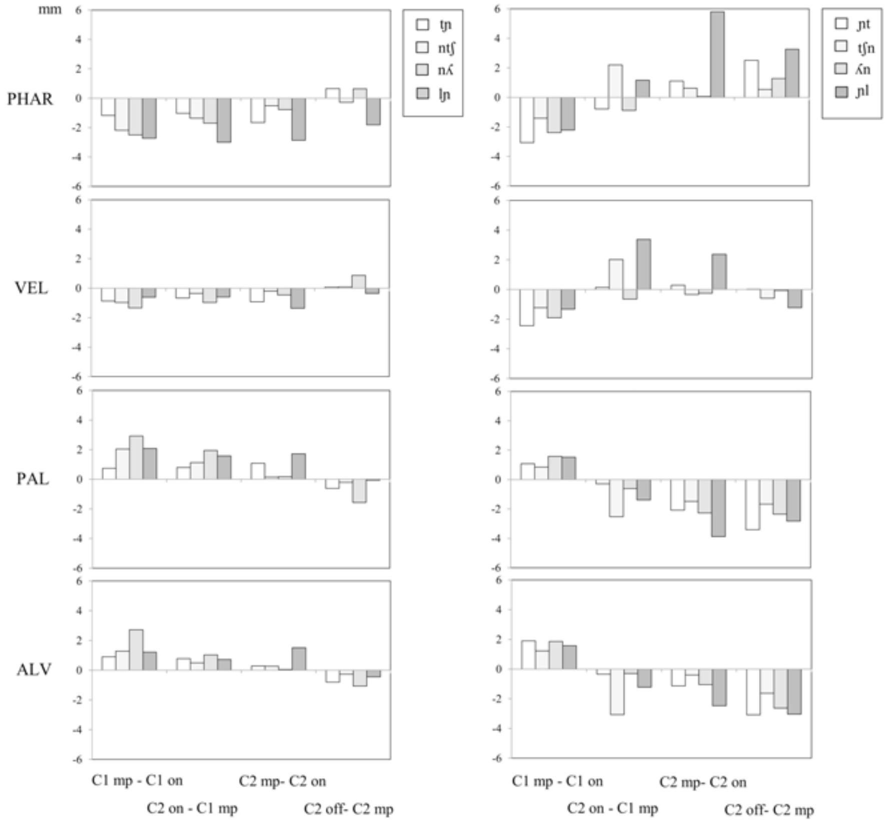

Figure 30: Cross-speaker differences in tongue position between successive temporal points for C#C sequences composed of alveolopalatal/palatoalveolar and unconstrained dental/alveolar consonants. See the Figure 14 caption for details.

Overall changes in lingual configuration over time are less for /tɲ, ntʃ, nʎ, lɲ/ than for /sɲ, rɲ/ (Figure 17), mostly so during C2 and thus past C2 onset. The reason for this difference is apparent in Figure 31 where lingual configuration data for /nʎ/ are being displayed for all individual speakers. These data (as well as those for /tɲ, ntʃ/) show that Catalan subjects blend the two consonants into a single articulatory realization mainly by fronting the back tongue body and raising the tongue dorsum during C1. Blending is manifested by the lack of articulatory activity all throughout the consonant cluster; indeed, compared to the bars for /sɲ, rɲ/ in Figure 17 (right graphs), those for /tɲ, ntʃ, nʎ/ in Figure 30 are relatively small meaning that changes in tongue position over time are also small. Regarding /lɲ/, there is blending essentially for subjects ES, JU and

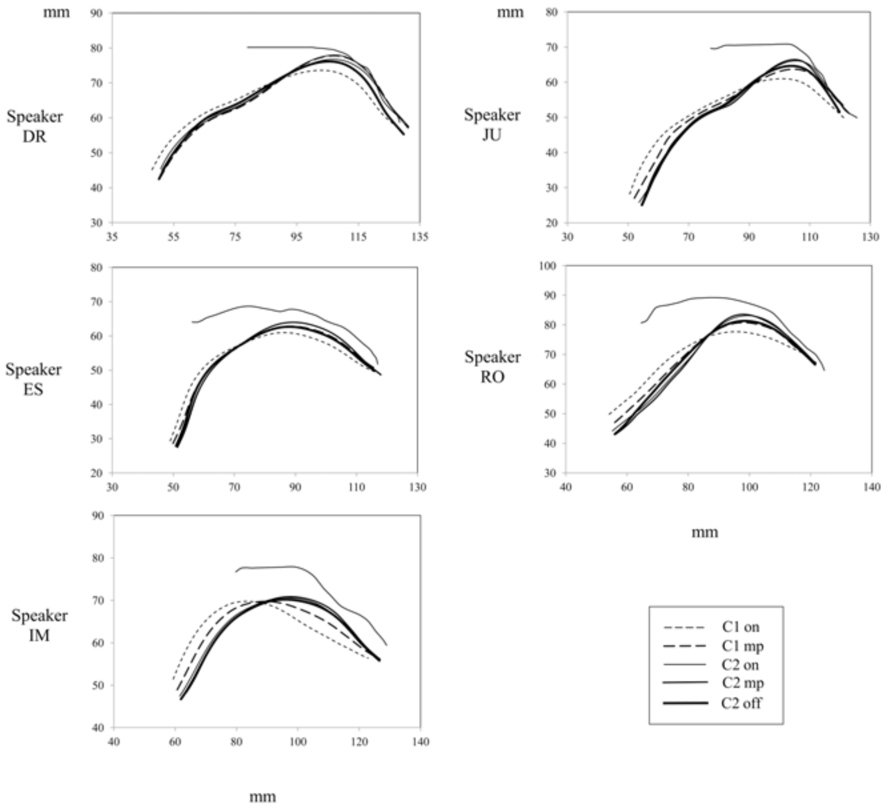

Figure 31: Lingual configurations for /nʎ/ plotted at five time points throughout the cluster for all individual subjects. A palate trace is provided for all speakers.

RO while DR and IM exhibit considerable tongue raising/fronting from C2 onset to C2 midpoint and to a lesser extent during the second half of C1.

Let us shift to the unconstrained alveolopalatal/palatoalveolar+dental/alveolar sequences /ɲt, tʃn, ʎn, ɲl/. Bars for these sequences plotted in the right graphs of Figure 30 show a change in tongue motion direction during C1. At the C1 mp – C1 on period and thus towards C1 onset the tongue dorsum raises and the tongue back fronts for the alveolopalatal C1 closure formation. At the C2 on – C1 mp period and thus later on during C1, /ɲt/ and /ʎn/ show almost no changes in lingual configuration which may be indicative of blending (see below), while /tʃn, ɲl/ exhibit some C2-dependent tongue front and dorsum lowering at the alveolar and palatal zones and some back tongue body raising and backing at the velar and pharyngeal zones. At the C2 mp – C2 on period and thus during the first half of C2, there is some additional tongue lowering/

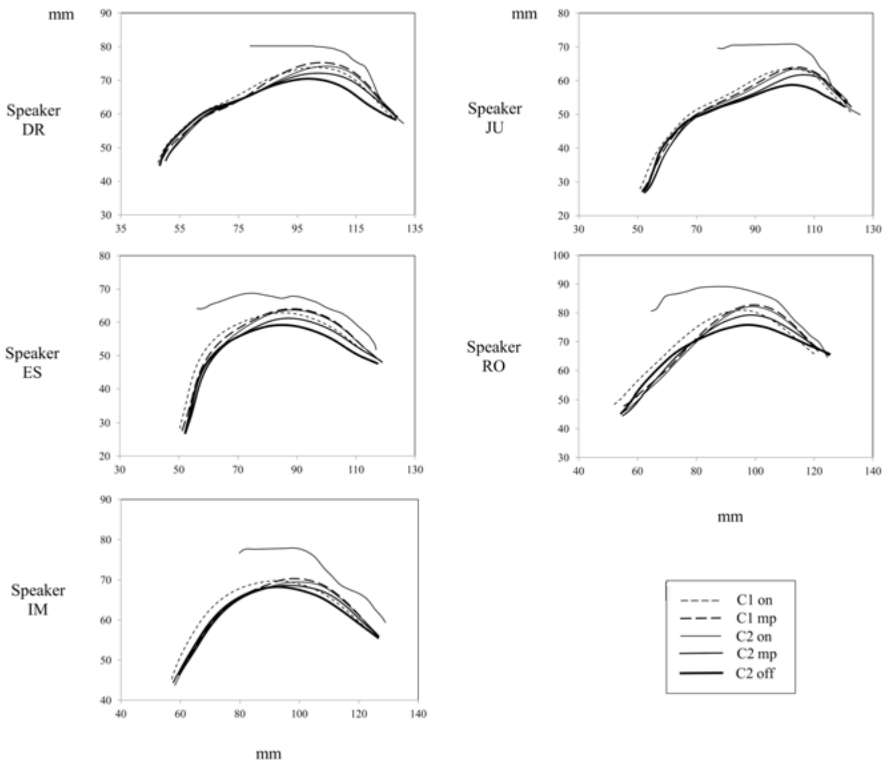

Figure 32: Lingual configurations for /ʎn/ plotted at five time points throughout the cluster for all individual subjects. A palate trace is provided for all speakers.

backing movement for /ɲl/ and few changes in tongue position for /ɲt, tʃn, ʎn/ thus suggesting that, at least for /ɲt, ʎn/, /t, n/ blend with C1 into a palatalized realization. The tongue lowering/backing motion for all sequences at the C2 off – C2 mp period and thus towards C2 offset may be related at least in part to the presence of following /a/.

A blended articulatory outcome achieved through a shift of the alveolar /n/ towards the closure location for alveolopalatal /ʎ/ may be observed in the case of both sequences /nʎ/ and /ʎn/ in Figures 31 and 32 (also /tɲ, ɲt/, not shown). Data for /ɲl/ on the other hand resemble those for /ɲs, ɲr/ (compare the bar graphs for the three C#C sequences in Figures 30 and 17), while those for /lɲ/ may or may not resemble those for /sɲ, rɲ/ in the same figures depending on whether blending applies to /lɲ/ or not. Regarding /tʃn/, there is no blending but C1-to-C2 changes in tongue configuration occurring mostly during the affricate frication period. Both /tʃn/ and /ɲl/ (see also comments on /ɲs, ɲr/ in section

3.3.1.2) appear to be implemented through a tongue repositioning strategy involving some tongue dorsum lowering during C1 after the C1 closure has been formed so that the tongue tip and blade may be adequately raised for the production of C2. This scenario differs from that for reverse clusters such as /ntʃ/ where the lack of tongue body activity for the alveolar nasal facilitates anticipatory tongue dorsum raising and an increase in laminoalveolar contact, which is complementary with the tongue dorsum raising movement involved during the C1 closure formation at the onset of the consonant.

3.3.4.3 Dentalizing environment

EPG data on closure location and size for /nt/ and /lt/ and for intervocalic /n/, /l/ and /t/ reported in Figures 33 and 34 allow investigating whether the two clusters undergo assimilation or blending. As referred to in section 3.1 and indicated by the discontinuous lines in the graphs, intervocalic /n, l/ are plain alveolar except for dark /l/ in Majorcan which is either dental or dentoalveolar. As for intervocalic /t/, the continuous straight lines show that the front closure border reaches row 1 at the teeth while the back closure border varies in degree of fronting according to dialect in the progression Valencian > Majorcan > Eastern (see also Figure 2).

Three different predictions regarding the articulatory outcome for these two-consonant sequences may be made which are more specific than the general hypotheses elaborated on in section 3.2.2 (c):

(a) Regressive assimilation should apply whenever closure location is more anterior for /t/ than for /n/ and /l/ in intervocalic position and the back closure border during C1 in the cluster does not occupy a more retracted location than that for intervocalic /t/. In case that closure location is not more anterior for intervocalic /t/ than for intervocalic /n/ and /l/, we cannot be sure whether assimilation applies since frontmost contact during C1 in the clusters /nt/ and /lt/ could be associated with the alveolar consonants.

(b) Blending through intermediation should take place when the back closure border for the cluster occurs somewhere between the back closure border for C1 and that for C2 in intervocalic position.

(c) Blending through superposition is expected to occur when the closure area for the cluster exceeds that for the two meeting consonants in intervocalic position, or else equals the largest closure area of the two.

In order to determine whether blending applies or not, a comparison between closure location and extent for the clusters /nt, lt/ and for intervocalic /n, l, t/ needs to be carried out at C1 midpoint and offset rather than at C1 onset since

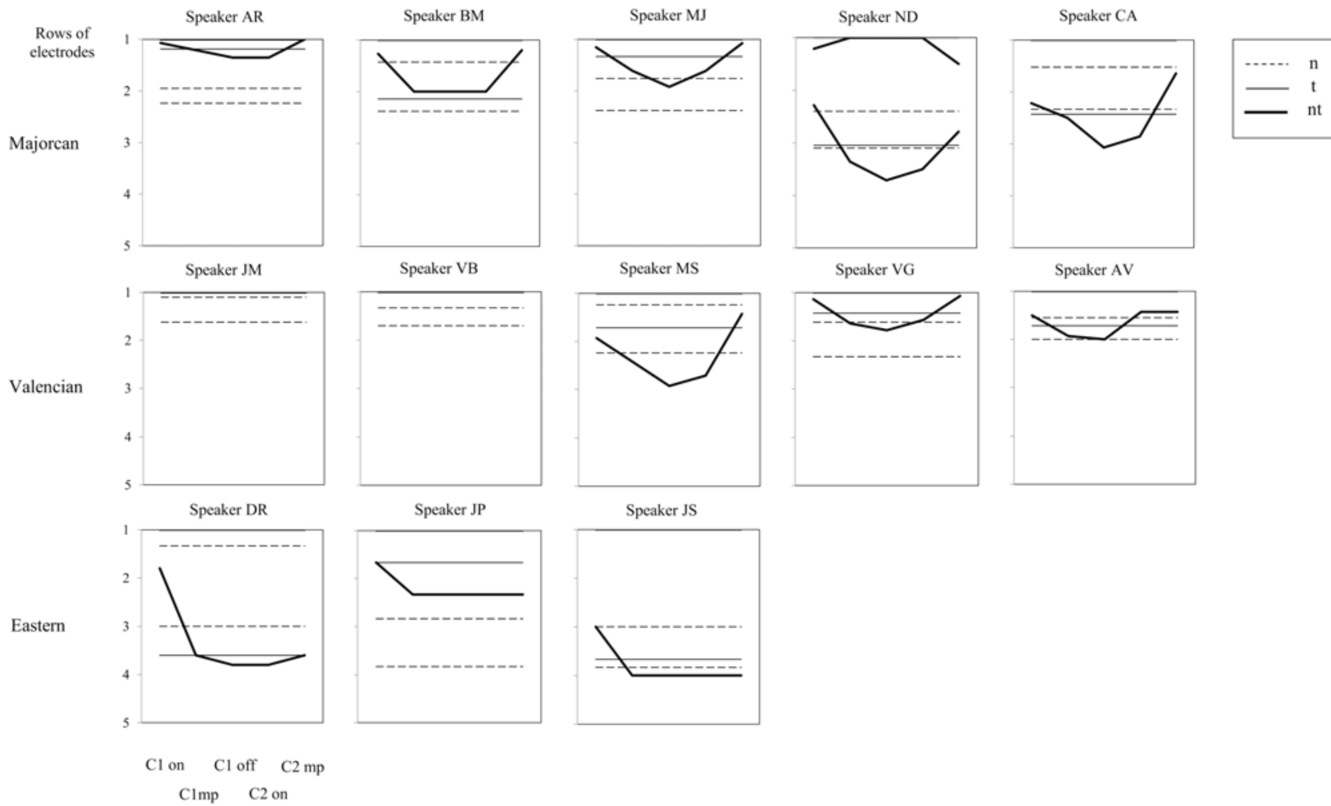

Figure 33: Closure edges for the cluster /nt/ at C1 onset, midpoint and offset and at C2 onset and midpoint, and for intervocalic /n/ and /t/ at consonant midpoint, according to speakers of Majorcan, Valencian and Eastern Catalan.

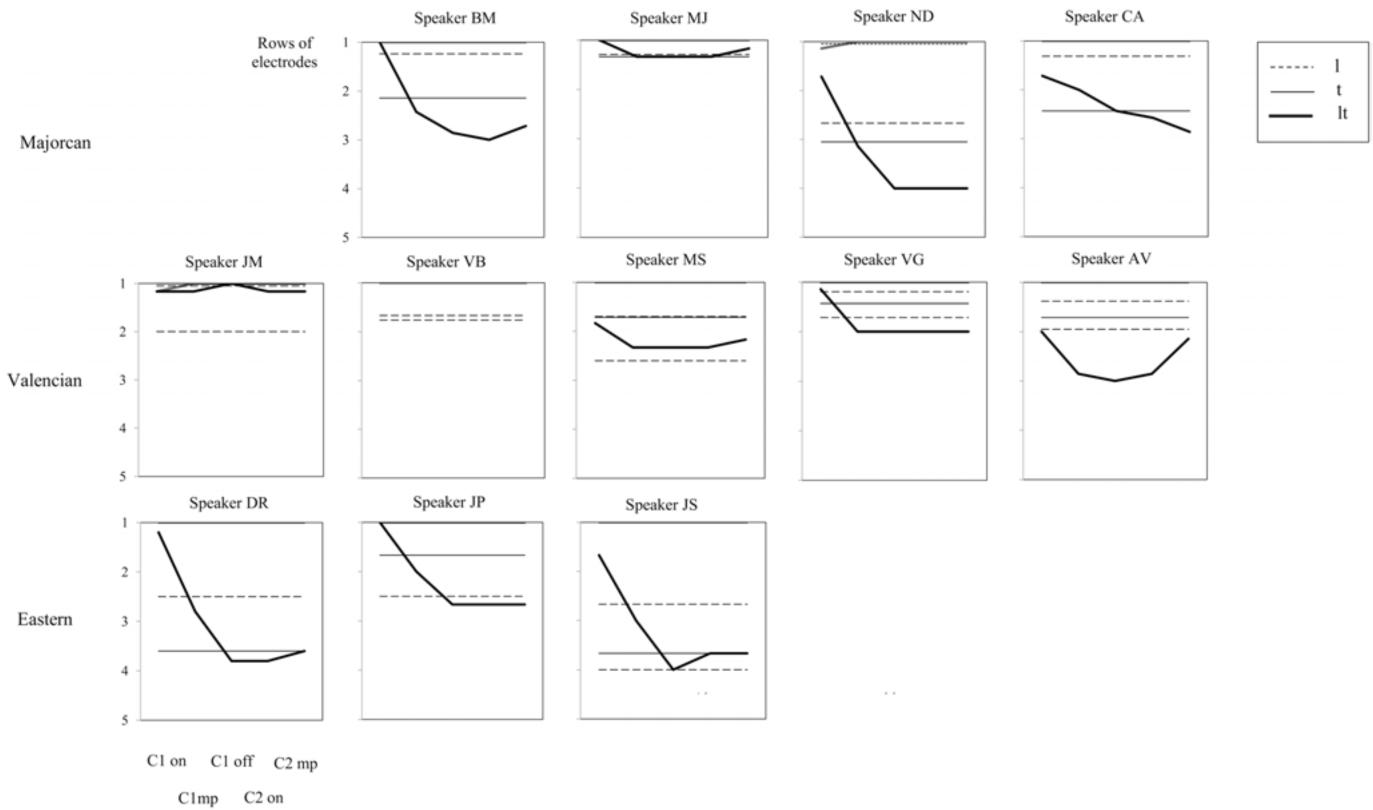

Figure 34: Figure 34. Closure edges for the cluster /lt/ at C1 onset, midpoint and offset and at C2 onset and midpoint, and for intervocalic /l/ and /t/ at consonant midpoint, according to speakers of Majorcan, Valencian and Eastern Catalan.

blending ought to be at work at the two former points rather than at the latter. This is done in Figures 33 and 34 which parallel Figures 26 and 27 in displaying the location of the front and back closure border for the two clusters and the intervocalic consonants. Regarding the front closure border, data in Figures 33 and 34 reveal the presence of an anteriormost closure location at row 1 all throughout C1 and C2 for the two clusters and in the case of all speakers; indeed, subjects show one thick horizontal line for /nt, lt/ which corresponds to the back closure border, the front closure border occurring at row 1. In principle, this maximal closure fronting characteristic could be indicative that regressive assimilation is at work (maximal fronting is also found for C2=/t/ in intervocalic and other positions) but also of a blending through superposition mechanism. Relevant variations in contact placement over time occur at the back closure border. There is often some backward expansion from C1 onset to C1 midpoint or C1 offset which may reflect a general trend for the consonant closure to increase its contact area as consonant midpoint is approached. More specifically, most subjects favour a blending through superposition strategy and therefore show a closure area which encompasses that for the two consecutive consonants in intervocalic position and may even exceed it; this production mechanism holds for /nt/ in the case of speakers ND, CA, MS, VG, AV, DR and JS, and for /lt/ for speakers BM, ND, CA, VG, AV, DR, JP and JS. Blending through intermediation and regressive assimilation applies less often: the former process may operate in the clusters /nt/ (speakers AR, BM, MJ, VG and JP) and /lt/ (speaker MS), and the latter may be available in productions of speakers exhibiting a very front realization of /t/ and other alveolar consonants (/nt/, speakers AR, JM, VB; /lt/, speakers JM, VB and perhaps MJ). It may be seen in this respect that not only the front closure border but the back border as well occurs at row 1 and is maximally anterior in the case of /nt/ for speakers JM and VB and /lt/ for speaker VB.

In comparison with the scenario for the clusters /nt, lt, ɲt, ʎt/ where blending is the favoured strategy, speakers appear to prefer to produce the reverse sequences /tn, tl, tɲ, tʎ/ (not shown) by means of a progressive dentalization mechanism by placing the tongue front at the juncture of the teeth and the alveolar zone until the end of the cluster (Recasens & Mira, 2015). This production strategy holds of course whenever C1 is realized as an oral stop and therefore does not assimilate to C2 in manner of articulation. This asymmetrical behaviour could be associated with a higher degree of articulatory constraint at the closure or constriction location for C1 whenever this consonant is an oral stop (in the /tC/ clusters) than when it is an alveolar nasal or a lateral (in the /nC, lC, ʎC/ clusters).

3.3.4.4 Other languages

Regarding the palatalizing environment, blending has been reported to occur for the sequence /n#tʃ/ (*digan chata*) in Argentinian Spanish such that closure location is at rows 1–4 and encompasses the closure area for intervocalic /tʃ/ at rows 1–4(5) and for intervocalic /n/ at the central alveolar zone (Kochetov & Colantoni, 2011). Since the palatoalveolar affricate is articulated essentially as /ʃ/, regressive assimilation involving closure retraction towards the postalveolar zone could also be argued to occur in this case (section 3.3.1). As pointed out for Catalan in section 3.3.4.1, complete assimilation rather than blending and anticipatory palatalization is prone to take place obligatorily in the dental, alveolar + alveolopalatal sequences /t, d#c, ɟ/ and /n#ɲ/ in Hungarian given that C1 and C2 agree in manner of articulation (Siptár & Törkenczy, 2000: 180).

In agreement with the Catalan ultrasound and EPG data, X-ray data for French show differences in C1 lingual configuration between /ɲ#t, ɲ#n/ and /ɲ#l/ (Rochette, 1973: 71–72, 158). The sequence /ɲ#t/ (*est-ce que tu grognes toujous* "are you grumbling all the time?"), and also /ɲ#n/, is realized sequentially: it exhibits an alveolopalatal closure during C1 and some tongue contact loss at closure location during the transition from C1 to C2 in order to assist the formation of the dentoalveolar closure which is complete by the time C2 begins. It is not clear whether blending applies to these two-consonant sequences. As to /ɲ#l/ (*le médecin soigne l'athlète* "the doctor treats the athlete"), on the other hand, the nasal is realized not as an alveolopalatal but as a postalveolar with a flat blade and predorsum, and the transition from C1 to C2 involves some tongue blade and predorsum lowering and back tongue body retraction.

Palatoalveolars and alveolopalatals may trigger progressive palatalization when followed by dentals and alveolars (see also section 3.3.5 for /ʃs/), which is in line with the blended outcomes reported in section 3.3.4.1 and with the prominence of the carryover effects exerted by consonants articulated with a tongue dorsum raising and fronting gesture. Thus, in Basque from Ondarroa and Gernika, /d, t/ palatalize into [c, ɟ] after /ɲ, ʎ/ (Hualde, 1991: 198).

With regard to the dentalizing environment, blending rather than regressive assimilation operates in the sequences /nt, nd, lt, ld/ in languages where /t/ and /d/ are dental or dentoalveolar in intervocalic position. A blended outcome has been reported to occur in the case of /nt/ in Italian (EPG, Farnetani & Busà, 1994), Catalan (EPG, Solé & Estebas, 1995) and Spanish (EMA, Honorof, 1999), sequences composed of the alveolars /n/ or /l/ and the dentoalveolar /t/ in Finnish (Suomi et al., 2008: 35), and also the cluster /ld/ in Peninsular Spanish for the production of which maximal tongue front raising/fronting occurs at an intermediate location between the displacement maxima for /l/ and for /t, d/ in intervocalic position (EMA, Romero, 1996). Other cluster productions are more ambiguous, as revealed by /nt/ in Argentinian and Cuban Spanish showing a closure location which coincides with that for intervocalic /t/ at rows 1–2 or 1–3 and is somewhat more anterior than that for intervocalic /n/ (EPG, Kochetov & Colantoni, 2011).

3.3.5 Constrained + constrained

In principle, sequences composed of highly constrained front lingual consonants ought to include /sʃ, ʃs, rs, rʃ, sr, ʃr/ and thus all combinations of the two front lingual fricatives and the alveolar rhotic. Instead, only production data for /sʃ/ and /ʃs/ will be reviewed in this section. Intersegmental adaptation mechanisms occurring in the sequences /rs, rʃ, sr, ʃr/ will be dealt with in sections 5.2.2.1 and 5.5.1.1 since they involve changes in manner of articulation rather than in constriction location (in Catalan, /s/, /r/ and /ʃ/ exhibit a centroalveolar or postalveolar constriction though /ʃ/ may also be articulated somewhat further back than /s/ and /r/; see Figure 2).

The articulatory implementation of /sʃ/ (as in *this shoe*) and /ʃs/ (and in *fresh soil*) has been paid much attention in the phonetics literature. Indeed, there are EPG and acoustic studies on the phonetic realization of those consonant sequences across a word boundary in English, German and Catalan and acoustic studies on the same C#C sequences in French (Perkell et al., 1979, Holst & Nolan, 1995, Nolan et al., 1996, Niebuhr et al., 2011, Niebuhr & Meunier, 2011, Pouplier et al., 2011, Recasens & Mira, 2013). In principle, /sʃ/ and /ʃs/ could be implemented through the following articulatory adaptation mechanisms: regressive or progressive assimilation and therefore complete adaptation in constriction location throughout the first or second fricative, respectively; blending which, in parallel to sequences like /sj/ or /kj/, should yield an intermediate realization between the two fricatives which in addition could be more /ʃ/-like or more /s/-like; a two-target sequence and thus a change in constriction location from /s/ to /ʃ/ or from /ʃ/ to /s/ depending on whether the cluster into consideration is /sʃ/ or /ʃs/, respectively. Moreover, the DAC model predicts that /ʃ/ ought to overcome /s/ rather than the other way around since only the palatoalveolar fricative involves considerable activation of the dorsum of the tongue.

According to experimental data for Engish and Catalan as well as descriptive accounts for other languages, regressive assimilation is the preferred production strategy for the sequence /sʃ/. In Catalan, /sʃ/ assimilates into [ʃ(:)] and /ts#ʃ/ behaves articulatorily like /sʃ/ and therefore is realized as [tʃ]. Spectral data for the same cluster produced by twelve English speakers also reveal a clear preference for regressive assimilation to yield a fricative outcome whose noise has a canonical /ʃ/ quality (Holst & Nolan, 1995). However, in German, /sʃ/ may be realized not only through regressive assimilation but also through blending and thus may exhibit an intermediate realization between C1 and C2 (Pouplier & Hoole, 2016).

The phonetic implementation of the sequence /ʃs/ is more variable than that of /sʃ/ and thus subject to a larger array of production mechanisms.

(a) Spectral and EPG data for Catalan reveal that /ʃs/ may show an intermediate realization between the two fricatives which often approaches one or the other, and a two-target realization as well. Moreover, analogously to the relationship between /sʃ/ and /ʃs/, the frication noise of /tʃ#s/ has a higher central of gravity (COG) than that of /ts#ʃ/ and is thus acoustically sharper. Also in English, regressive intersegmental adaptation occurs less frequently and to a lesser degree for /ʃ#s/ than for /s#ʃ/, and the former sequence often yields articulatory realizations which are intermediate between C1 and C2 (Pouplier et al., 2011). A blending strategy with a more /ʃ/-like than /s/-like noise spectrum appears to be also characteristic of German (Pouplier & Hoole, 2016).

(b) /ʃs/ may also undergo progressive assimilation into a palatoalveolar fricative outcome. It does in Western Catalan and in Swiss German where /s, z/ become palatoalveolar both before and after /ʃ, ʒ/ (Moulton, 1986: 389), and more or less often in French as in the sentence *elle remâche sa viande* "she broods over her meat" (Niebuhr et al., 2011). In Portuguese, progressive assimilation may also account for the realization [ʃs] or [ʃ(:)] of the sequence /s(#)s/ in dialects where coda /s/ is produced systematically as [ʃ] (*dois sapatos* "two shows", *nascer* "to be born"; Leite de Vasconcellos, 1987: 77, Mateus & Andrade, 2000: 145). As mentioned above, this progressive assimilation process does not operate in English and Eastern Catalan and occurs only rarely in German.

(c) Descriptive accounts indicate that both /s(#)ʃ/ and /ʃ(#)s/ undergo regressive assimilation into [ʃ:] and [s:] obligatorily in Hungarian and Cairene Arabic (Youssef, 2013: 32, Watson, 2002: 240).

Another relevant issue is whether cluster duration decreases with gestural overlap in the lingual fricative sequences of interest. According to Articulatory Phonology, assimilatory processes should be viewed as instances of maximal gestural overlap which are likely to operate in fast speech and word positions of little prominence (Browman & Goldstein, 1992). Data for /sʃ/ referred to in section 2.4.2 support the alternative view that C1 assimilates completely to C2 since the corresponding phonetic outcome may be a long frication noise whose duration parallels that for an underlying geminate. This long fricative realization may shorten at fast or regular speech rates. Moreover, it may be argued that the direct elision of C1=/s/ is prone to occur whenever the alveolar fricative belongs to a frequent or function word, as in Catalan *dos xals* "two shawls".

A possible reason why the palatoalveolar fricative /ʃ/ tends to prevail over /s/ in the regressive and progressive directions is because it is more constrained articulatorily. Indeed, according to the DAC coarticulation model, the tongue dorsum raising and fronting gesture for a palatal, alveolopalatal or palatoalveolar consonant constrains the entire tongue body to a large extent, which is in accordance with the trend for /ʃ/ to exert prominent carryover effects on following dental and alveolar consonants and on preceding dentals and alveolars as well. However this cannot explain why regressive assimilation in the sequence /sʃ/ is so much more frequent than progressive assimilation in /ʃs/. It may be argued that this asymmetrical behaviour follows from assimilatory processes operating typically at the regressive level in the world's languages since their execution reflects the planning component in speech. Another relevant piece of evidence, which is also applicable to sequence pairs like /tk/-/kt/ (section 4.1.1.1), is that it is simpler to anticipate C2 in the sequence /sʃ/ than in the sequence /ʃs/: while the anticipation of /ʃ/ during preceding /s/ involves a single articulatory action, i.e., some tongue dorsum raising in addition to an increase in tongue contact immediately behind the alveolar constriction, the anticipation of /s/ during preceding /ʃ/ requires the execution of two non-complementary actions, i.e., tongue dorsum lowering in conjunction with the raising of the tongue tip and blade after the tongue dorsum has been raised for the /ʃ/ gesture formation. This articulatory repositioning mechanism may explain why the central constriction for /ʃ/ is wider before /s/ than before other front alveolars and dentals such as /t, n/ (Recasens & Pallarès, 2001b). A complementary explanation to the one just given has also been proposed (Perkell et al., 1979): once the lingual groove has been created, the production of /ʃ/ in the sequence /sʃ/ involves just pushing the tip-blade upward and forward while that of /s/ in the sequence /ʃs/ requires a more precise tongue front positioning along the front-back dimension.

Other factors play a role in the phonetic output of /ʃs/. In Western Catalan progressive assimilation accords with a trend available in this dialect to assimilate /s/ to a preceding palatoalveolar, alveolopalatal or palatal consonant mostly so if the two consecutive consonants occur in syllable-final position (/ɲs, ʎs, js/; section 3.3.1.1). Lexical factors and the frequency of occurrence of consonants in specific word positions ought to be taken into consideration as well. Thus, in English, the sequence /sʃ/ could be especially prone to undergo regressive assimilation because, given that word-final /s/ is more frequent than word-final /ʃ/ in this language, the alveolar fricative may be more easily dispensed with than the palatoalveolar fricative (Pouplier et al., 2011). Along the same lines, the assimilation /ʃs/ > [ʃ(:)] would take place more often in French than in English since, given that sequences of front lingual fricatives including one or two instances of /ʃ/ or /ʒ/ occur rarely in the former language, prevalence of the palatoalveolar over the alveolar fricative at the regressive and progressive levels should not create risk of lexical ambiguities or misunderstandings (Niebuhr et al., 2011). Stress appears to be an influencing factor as well such that its presence favours an increase in dorsopalatal contact and thus the chances that the fricaton noise in the sequence /ʃs/ has a /ʃ/-like quality.

3.4 Blending involving dorsal consonants

Blending resulting from gestural overlap operates regularly in sequences composed of (nearly)-homorganic dorsal consonants articulated at the palatal and velar zones. In principle, this blending mechanism ought to be more prone to apply whenever the velar consonant has a front realization. Indeed, as pointed in section 2.5, velars differ from (alveolo)palatals in that, while being produced with the dorsum of the tongue, they adapt considerably to the contextual vowels: velars blend with the following vowel such that two or even three closure locations may occur, at the palatovelar zone before front vowels and at one or different locations at the velar zone before low and back rounded vowels. The influence of the preceding vowel in closure location for the velar appears to be less relevant though still noticeable; indeed, back velars followed by a back vowel may be articulated at a somewhat more anterior location when preceded by /i/ (/ika, iku/) than when preceded by /a, u/ (/aka, aku, uku, uka/).

This blending scenario applies to the consonantal sequence /kj/ where the stop shows a purely dorsopalatal realization in Catalan as well as in other Romance languages, and may also operate in clusters where /k/ is articulated further front when occurring next to a purely dorsopalatal realization of /ɲ/, which may be found in Majorcan Catalan (regarding blending in sequences with /k/ and an alveolopalatal consonant, see section 4.6.2).

3.5 General summary

Data for Catalan and other languages provided in chapter 3 are consistent with the predictions of the DAC coarticulation model to a large extent. This section summarizes the main findings reported in the chapter for sequences of consonants exhibiting the same or different degrees of articulatiory constraint.

3.5.1 Sequences with consonants differing in degree of articulatory constraint

Articulatory and acoustic data for unconstrained+constrained and constrained +unconstrained consonant sequences lend support to the prediction that place adaptation should depend on the degree of articulatory constraint for the two consecutive consonants and also that it ought to proceed more frequently and categorically in the leftward than the rightward direction.

As for the unconstrained + constrained sequences, regressive assimilation may apply to the sequences /t, n, l/ (also /ʎ, ɲ/) + /s, r, ʃ/, and approaches categoricalness in some dialects and for some speakers more than others. Full adaptation is most prone to affect target /n/ and least often strongly dark /l/, and to occur in consonant sequences where C1 and C2 share the same lingual articulator, i.e., apical /l/ and /s/ (/ls/) and apicolaminal /t/ and laminopredorsal /ʃ/ (/tʃ/). Moreover, the Catalan data show that the precise closure location of the C1 assimilated outcome may vary as a function of the degree of constriction fronting for C2 in the progression /s, r/ > /ʃ/. Regressive assimilation may also operate on the sequences /t, n/ + /θ/, the tautosyllabic onset cluster /tɾ/ provided that the rhotic is produced with a postalveolar constriction, and /t, n, l, s/ followed by retroflex or velarized/pharyngealized consonants, which are articulated with a similar overall tongue configuration to that for the alveolar trill and dark /l/ and whose lingual gesture is strongly anticipated during the preceding phonetic segment. Large degrees of adaptation at constriction location cooccur with changes in tongue body configuration, which are related to differences in manner of articulation between C1 and C2 and occur in sequences with C1=/t, n/ rather than in those with C1=/l/ in line with the reluctance of the alveolar lateral to assimilate. Thus, the two consonants /t/ and /n/ allow some tongue dorsum lowering in anticipation of /r/, /n/ palatalizes before the palatoalveolar /ʃ/ and (alveolo)palatal consonants without yielding /ɲ/, and /ɲ/ undergoes depalatalization before the trill /r/ without yielding /n/. Moreover, it may be argued that the tongue body needs to be repositioned during C1 in sequences like /ɲr/ but not /nʃ/: while in the case of /nʃ/ the tongue dorsum raises and the tongue body fronts continuously during C1 for closure formation and in anticipation of C2, C1=/ɲ/ in the sequence /ɲr/ is realized through two opposite actions: tongue dorsum raising and tongue body fronting at onset followed by tongue dorsum lowering and tongue body retraction in anticipation of C2=/r/. The strong carryover effects associated with (alveolo)palatals and palatoalveolars account for why /s/ may be realized as [ʃ] after /ʃ, ɲ, ʎ, j/.

Constrained+ unconstrained sequences with /s, r, ʃ/ followed by /t, n, l/ (also by alveolopalatals such as /ʎ/) are realized most often through a two-target mechanism. Closure/constriction fronting from the first to the second consonant in these clusters occurs not only when C2 is dental (/t/), and is thus articulated at a different articulatory zone from C1, but also when it is front or central alveolar (/n, l/ and even /ʎ/). The degree of progressive adaptation varies with dialect and also with the precise constriction location and manner of articulation characteristics for C1 and C2. It is greater for /ʃt/ than for /rt/ whenever /r/

is articulated as a fast one-contact tap, /st/ falling in between. Trill-like and fricated realizations of /r/ are prone to cause following /t/ to retract to the post-alveolar zone. Clusters with C2=/l/, on the other hand, exhibit continuous closure/constriction fronting from C1 to C2 rather than progressive adaptation due to the general requirement for /l/ to allow the passage of air through the mouth sides and for dark /l/ to be articulated more anteriorly than clearer varieties of the consonant. Finally, most front lingual consonants occupying the C2 position in the combinations just referred to may become retroflex after /ɽ/ and other retroflex consonants, with again /l/ being less prone to assimilate.

The place adaptation behaviour for unconstrained + constrained and constrained + unconstrained sequences summarized above indicates that place assimilation occurs more often at the regressive than at the progressive level, which could be taken in support of the principle that categorical assimilations reflect the planning component of speech.

3.5.2 Sequences with unconstrained consonants

The notion of articulatory blending has proved useful for dealing with the articulatory outcome of clusters composed of unconstrained front lingual consonants.

Sequences composed of a relatively unconstrained dental or alveolar followed or preceded by an alveolopalatal favour blending through superposition, with contact size at closure location equalling or exceeding that for the two individual consonants in most cases. This blending outcome is generally achieved at C1 midpoint, as in the case of /nʎ, ʎn, ɲt/ and also the sequence /n/+[c]. Complete assimilation rather than blending applies in analogous sequences composed of consonants agreeing in manner of articulation such as /nɲ/. Blending and regressive palatalization are less prone to take place in clusters with C1=/l/ and a following alveolopalatal consonant, mostly if the alveolar lateral is dark; in this case, while the front closure border achieves maximal fronting early during C1, the back closure border may either fall somewhere between the two consecutive consonants or reach a more retracted closure location than theirs not earlier than C1 offset. Blending also operates on sequences composed of dorsopalatal and dorsovelar consonants.

Gestural blending is also sensitive to coarticulatory direction. Thus, there are less chances that it operates in sequences composed of an alveolopalatal consonant followed by dark /l/ than in the reverse combinations (e.g., in /ɲl/ than in /lɲ/) since much anticipatory tongue dorsum lowering and retraction for /l/, mostly if dark, overrides the high front dorsum position for the preceding alveolopalatal. This coarticulation scenario is in support of (alveolo)palatal consonants being specified for a lower degree of articulatory constraint than consonants involving active tongue body lowering and retraction such as dark /l/ and the trill /r/. There is a complementary account of differences in articulatory adaptation between the two sequences of cluster pairs like /lɲ/-/ɲl/, which is in accordance with the scenario for /tk/-/kt/ and /sʃ/-/ʃs/ (section 4.1.1.1): blending becomes feasible for /lɲ/ since there is still room for raising the tongue dorsum after it has been raised more or less during the C1 closure formation, but less so or not at all for /ɲl/ due to tongue repositioning which must take place during C1. The need to reposition the tongue body could also justify why /n/ may be articulated with less dorsopalatal contact in the sequence /ʎn/ than in the sequence /nʎ/.

It looks as if regressive place assimilation should not be considered the most natural adaptation process for the sequences /nt, lt/ unless speakers articulate the dental stop at a very front location and thus as truly dental. The two sequences appear to involve most often blending through superposition somewhere after C1 onset where closure location is basically the same as for C1 in intervocalic position. As for the reverse unassimilated sequences /tn, tl/ (also /tʎ/), speakers favour progressive dentalization over blending perhaps since the stop /t/ is more constrained articulatorily than the sonorants /n, l/ when occupying the C1 position in the consonant sequences of interest.

3.5.3 Sequences with constrained consonants

Articulatory data for /sʃ/ and /ʃs/ show that regressive assimilation is prone to apply to /sʃ/, while /ʃs/ is realized through two separate targets or else undergoes blending or progressive assimilation depending on the language or dialect taken into consideration. Once assimilation or blending has applied, the outcoming long fricative realization may shorten. Moreover, /s/ may delete in the sequence /sʃ/ if it belongs to a frequent or function word. A higher degree of tongue dorsum constraint for /ʃ/ than for /s/ cannot account for why assimilation applies so much more often at the regressive level in the sequence /sʃ/ than at the progressive level in the case of /ʃs/. Several explanations have been proposed in order to explain this assimilatory asymmetry such as tongue repositioning for /ʃs/ vs /sʃ/ and a universal tendency for place assimilations to operate at the regressive level. Non-phonetic factors may also be involved.

4 Heterorganic articulators

This chapter deals with patterns of articulatory adaptation in sequences of consonants produced with separate articulatory structures, namely, the lips and the tongue, and the tongue front (tip, blade, predorsum) and the tongue dorsum. These consonant sequences may exhibit different degrees of gestural overlap and yield complete place assimilation. In fact, a positive relationship is expected to occur between overlap and assimilation such that consonant sequences which allow more overlap (e.g., /tk/) should assimilate more often than those which exhibit less overlap (e.g., /kt/). A related issue is whether place assimilations apply categorically or gradiently and therefore whether a trace of the originary consonant subject to assimilation remains in the articulatory signal or not (section 2.4.1).

Sections 4.1–4.5 deal with gestural overlap in tautosyllabic and heterosyllabic clusters composed of consonants produced at distant places of articulation. The two cluster types differ in interarticulatory organization: in tautosyllabic sequences, onset and coda clusters are coupled differently to the only vowel nucleus available (section 2.1), while in heterosyllabic consonant sequences each consonant is coupled to its corresponding vowel nucleus. In spite of this syllable-position related difference, the same or similar articulatory and aerodynamic requirements facilitate or disallow gestural overlap in the two cluster types. Manner of articulation characteristics appear to play a relevant role in the implementation of gestural overlap which is why consonant sequences have been grouped according to their manner properties as follows: section 4.1 deals with stop+stop sequences, and sections 4.2, 4.3, 4.4 and 4.5 with sequences with a fricative, a nasal, a lateral and a rhotic, respectively. Section 4.6 is about gestural blending in clusters composed of heterorganic consonants.

In addition to EPG linguopalatal contact and EMA lingual movement data from several languages published elsewhere, this chapter reports for the first time ultrasound data for Catalan C#C sequences composed of /k/ and a front lingual consonant (dental, alveolar, palatoalveolar, alveolopalatal), which were recorded and analyzed applying the same methodological procedure described in section 3.2.1.2. The recording list includes /tk, nk, lk, sk, rk, ɲk, tʃk/ and the reverse clusters /kt, kn, kl, ks, kr, kɲ, ktʃ/. Speakers were instructed not to assimilate /t, n/ to C2 in place of articulation when reading meaningful sentences with the clusters /tk/ and /nk/.

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4.1 Stop clusters

4.1.1 Onset and heterosyllabic C(#)C sequences

Stop+stop sequences are reluctant to show the c-center effect in word-initial position (section 2.1), and therefore to exhibit an invariant duration between the cluster midpoint and the vowel nucleus while differing in degree of gestural overlap depending on consonant composition. As demonstrated next by sequences composed of lingual stops and of lingual and labial stops, articulatory and aerodynamic factors may account for why overlap occurs more often in some clusters than others whether placed word initially within the same syllable or across a word boundary.

4.1.1.1 Lingual

Greater gestural overlap has been reported to take place in dentoalveolar+velar than in velar+dentoalveolar sequences, as revealed by articulatory data for English (/d#g/ > /g#d/, Byrd, 1996; /tk/ > /kt/, Hardcastle & Roach, 1979), Georgian (/dg/ > /gd/, word initially and word medially; Chitoran et al., 2002) and Moroccan Arabic (/dg/ > /gd/, word medially; Zeroual et al., 2014). Little gestural overlap for velar+dentoalveolar sequences has also been found to hold in Korean (/kt/, word initially and across a word boundary; Kochetov et al., 2007) and Romanian (/kt/, word initially; Marin, 2013). Moreover, the data for word-initial /kt/ in Romanian show little compression of the vowel nucleus following the consonant cluster with respect to the CV condition, thus suggesting, as for coda clusters, the existence of a right-edge rather than a c-center organization (Marin, 2013 and also section 2.1). In Russian, the same consonantal sequence appears to show more gesture superposition word initially while /k#t/ is not much overlapped (Kochetov et al., 2007, Pouplier et al., 2015).

This asymmetrical relationship in degree of gestural overlap between dentoalveolar+velar and velar+dentoalveolar sequences is consistent with the principle that velars should be better assimilation triggers and worse assimilation targets than front linguals (Jun, 1995). Indeed, regressive place assimilation may operate on /tk, tp/ but not on /kt, kp/ in languages like Catalan (/tk/ > [kk] in *set cases* "seven houses", /kt/ > [kt] in *rec tort* "crooked ditch"). Also in Korean, /tk/ but not /kt/ may undergo regressive assimilation, as revealed by EMA data exhibiting different degrees of consonant-to-consonant overlap and reduction of the C1 lingual gesture between the two sequences depending on speaker and rate of speech (Kochetov & Pouplier, 2008). Other languages may also allow assimilation for dentoalveolar stops but not velars: in Cairene Arabic,

/t, d/ may assimilate to a following labial or velar optionally in C#C sequences, and the detransitivizing verbal prefix *t-* assimilates optionally to /k, g/ and the uvular /q/ (Youseff, 2013: 28–29, 38); in Sardinian, the 3rd person singular verbal ending /t/ assimilates optionally to any word-initial consonant though there is also an alternative analysis according to which the geminate outcome is generated through C1 elision followed by C2 lengthening (Campidanese, Bolognesi, 1998: 47–48). An exception to the general assimilation principle just referred to is the regressive place assimilation of Latin /kt/ into [tt] in word-medial position, as revealed by lexical forms of present-day Italian (*latte* LACTE "milk", *otto* OCTO "eight") as well as Sardinian where the geminate may simplify into [t] (*latte* LACTE, *fatu* FACTU "fact"; Jones 1988: 325).

An articulatory rationale may be given in order to explain the coarticulatory and assimilatory behaviour of interest: on the one hand, tongue dorsum activation for a velar is expected to take place during a preceding dentoalveolar since the production of dentoalveolars involves the activation of the flexible tongue front articulator and a low degree of tongue dorsum constraint; on the other hand, anticipatory tongue front raising and tongue dorsum lowering for /t/ is less prone to occur during a preceding velar since the activation of the sluggish tongue dorsum articulator constrains the whole body of the tongue to a greater or lesser extent. Thus, while tongue front raising for C1=/t/ leaves the tongue body relatively free to coarticulate with following /k/, tongue dorsum raising for C1=/k/ may prevent much front lingual movement for following /t/ from occurring. The fact however is that, as shown below, anticipatory tongue front raising occurs quite freely during C1 in the sequence /kt/ and analogous velar + alveolar sequences. According to a complementary explanation, /k/ would be reluctant to assimilate to following /t/ since a rise in intraoral pressure during the velar stop should cause a delay in the anticipatory tongue front raising motion for C2.

Differences in interarticulatory organization may also be adduced in order to account for the dissimilar coarticulatory and assimilatory behaviour between /tk/ and /kt/: while tongue body raising may be anticipated without any noticeable changes at C1 closure location in the case of the sequence /tk/, for /kt/ to allow gestural overlap there must be tongue body repositioning during C1 and thus tongue body raising for the dorsovelar closure formation followed by tongue body lowering as the tongue front is being raised in anticipation of C2=/t/. Different degrees of gestural overlap in the case of the cluster /kt/ appear to be correlated with the duration of the velar stop burst, which reflects the temporal delay between the closure release for the velar stop and the achievement of a complete closure for the following dental stop (Greek, Yip, 2013: 92–93). X-ray data for French reveal analogous cluster-dependent differences in

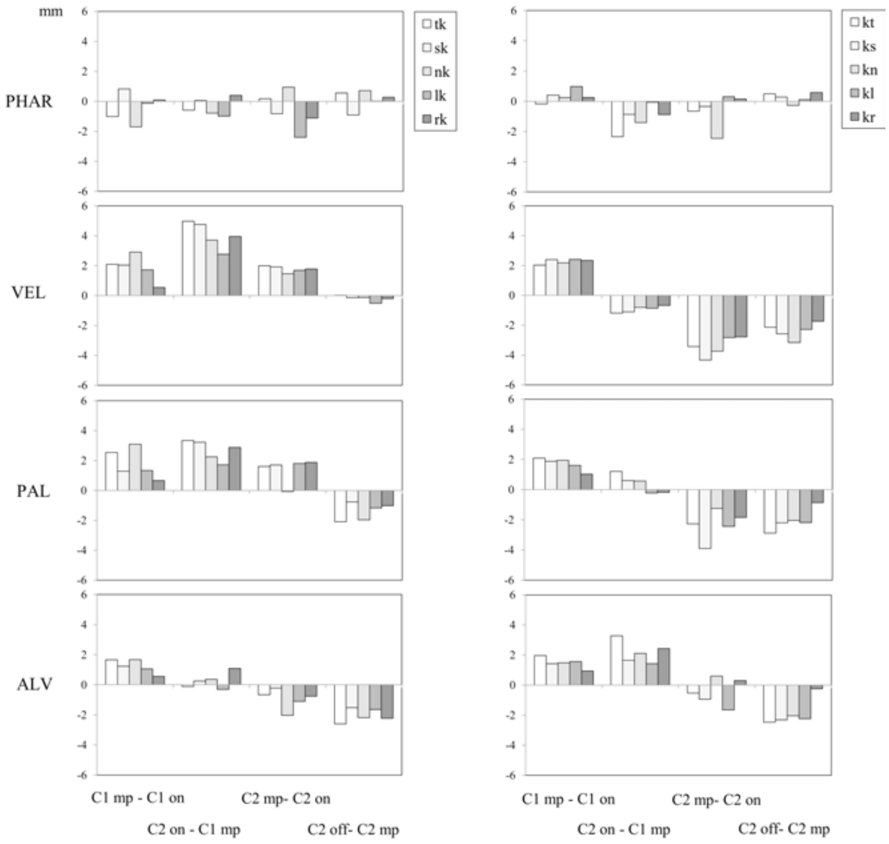

Figure 35: Cross-speaker differences in tongue position between successive temporal points for sequences composed of velar and dental/alveolar consonants. See the Figure 14 caption for details.

interarticulatory organization (Rochette, 1973: 61, 66–69): in the case of /d#k, t#k/, as in the sentence *prends le trousseau de clefs* "take the set of keys", the tongue dorsum raises during C1 and the dorsovelar closure is achieved immediately after the /t/ release and acoustic burst; during /k#t/, as in *on prend un bock de bière* "we drink a glass of beer", there may be some tongue body fronting during C1 as the tongue front is being raised in anticipation of C2=/t/, and a complete /t/ closure is formed either before or after the /k/ release which should have an effect on the perceptibility of the velar stop burst.

A more accurate picture of differences in articulatory organization between /tk/ and /kt/ may be achieved from inspection of ultrasound data for these and other sequences with /k/ in Catalan. The bar graphs in Figure 35 represent temporal changes in tongue position at different articulatory zones for clusters with a dental or an alveolar consonant followed by /k/ (left) and for /k/ followed by a dental or an alveolar (right) (see section 3.3.2.2 for how to interpret the bar graphs). Data for /tk/ and /kt/ correspond to the first (unfilled) bar in each bundle of five bars appearing in each graph of the figure.

Regarding /tk/, the positive sign of the bars at the C1 mp – C1 on period and thus towards C1 onset indicates the presence of some tongue front and dorsum raising as the dentoalveolar closure for /t/ is being formed. During the second temporal interval C2 on – C1 mp the tongue keeps raising considerably at the velar and palatal zones in anticipation of C2=/k/, and there is little activity at the alveolar zone where the /t/ closure occurs. According to the third set of bars for the C2 mp – C2 on period, the back tongue body and front dorsum continue to raise as the dorsovelar closure is being completed. Finally, during the C2 off – C2 mp period towards C2 offset the tongue body stays fixed at the velar zone while the front dorsum and the tongue blade lower at the alveolar and palatal zones presumably in order to assist the stop release.

Some additional information about changes in tongue position over time for /tk/ may be inferred from the lingual configuration data for all Catalan speakers displayed in Figure 36. The left graphs in the figure show some C2-dependent anticipatory tongue body raising and fronting proceeding from C1 midpoint to C2 onset; indeed, the lingual configuration at C2 onset (thin continuous line) lies higher up at the palatovelar zone and may run more anteriorly at the pharynx than the lingual configuration at the temporal midpoint of C1 (dashed line). Moreover, the lingual splines at C1 midpoint, C1 closure offset and C2 onset after the stop burst reproduced in the right graphs of the figure reveal that the anticipatory tongue body raising movement just referred to occurs just before the stop closure is released into the stop burst in the case of all subjects. It thus appears that the tongue dorsum for C1=/t/ is free to raise in anticipation of C2=/k/ before the dentoalveolar stop release.

Data for /kt/ plotted Figure 35 (right graphs) show a quite different picture from that for /tk/. According to the first set of bars, the tongue front and dorsum raise for the formation of the velar stop closure at C1 onset. The second set of bars exhibits several articulatory actions during C1=/k/ in anticipation of C2=/t/ which may run opposite to the tongue dorsum raising motion occurring at C1 onset: some tongue blade raising at the alveolar zone and, less so, front dorsum raising at the palate; some tongue body lowering at the velar zone and back tongue body fronting at the pharynx. During C2 (see the third and fourth set of bars), the tongue keeps lowering at the velar, palatal and to a large extent alveolar zones all the way until the consonant release. Lingual configuration data at all temporal frames for /kt/ displayed Figure 37 (left) show some tongue body raising at C1 onset and C1 midpoint followed by some antagonistic tongue

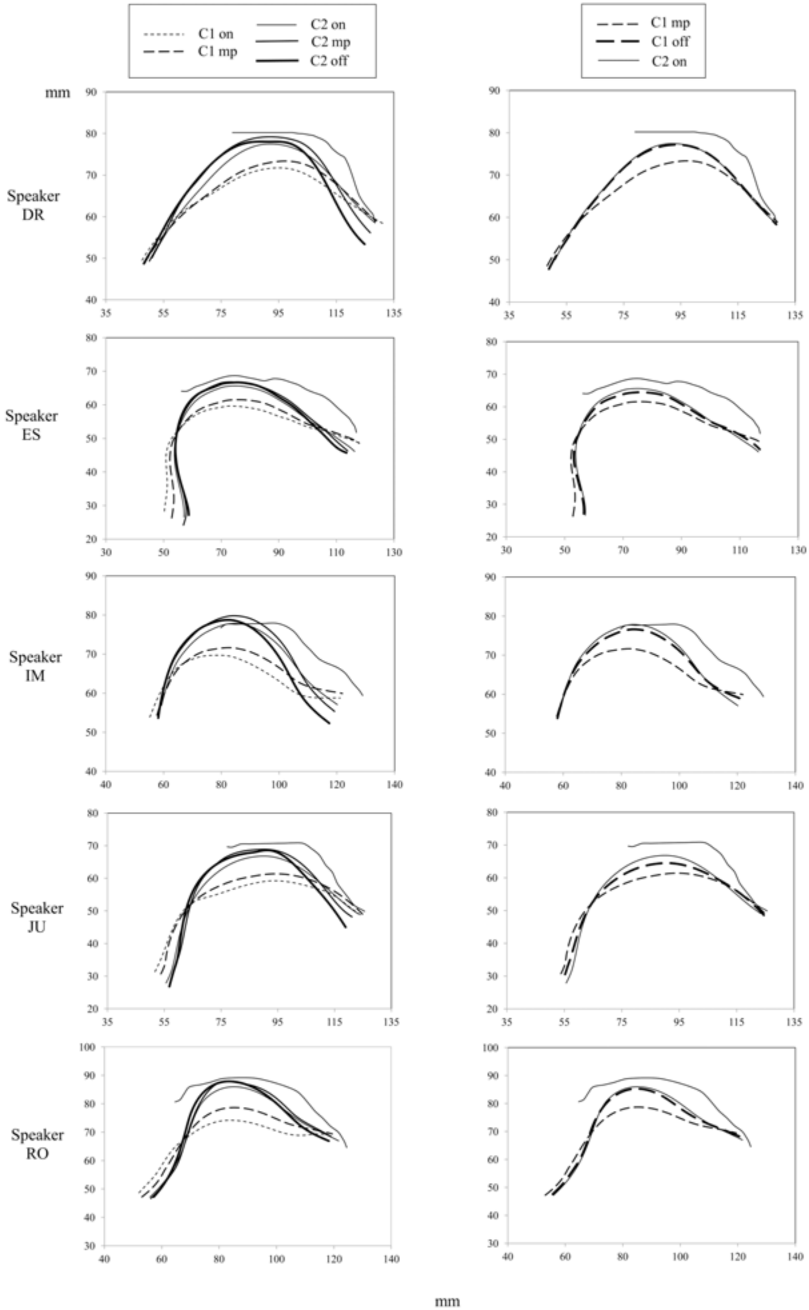

Figure 36: Lingual configurations for /tk/ plotted at five time points throughout the cluster (left) and at three time points around the C1C2 boundary (right) for all individual subjects. A palate trace is provided for all speakers.

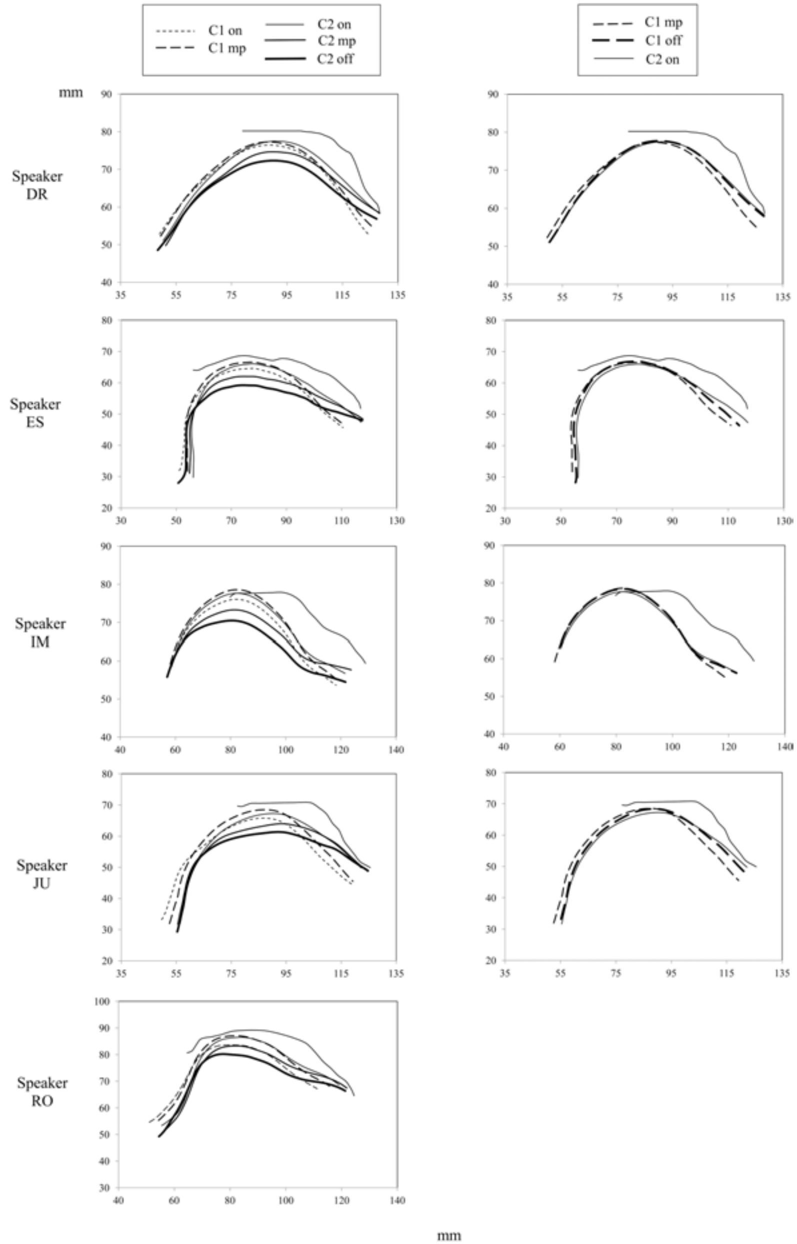

Figure 37: Lingual configurations for /kt/ plotted at five time points throughout the cluster (left) and at three time points around the C1C2 boundary (right) for all individual subjects. A palate trace is provided for all speakers.

body lowering starting during C1 and continuing during C2. Moreover, according to the right graphs of the figure (no graph is available for speaker RO here since his productions of the sequence /kt/ had a weak or no apparent velar stop burst on the spectrographic displays), tongue repositioning appears to assist the tongue front raising motion for C2=/t/ which is already apparent towards the midpoint of C1=/k/.

Perceptually-based interpretations have also been proposed in order to account for the asymmetrical assimilatory behaviour between /tk/ and /kt/ and analogous front lingual+velar and velar+front lingual sequences. It has been suggested that regressive assimilation is prone to take place in sequences like /tk/ because there is little motivation for speakers to preserve the weak acoustic cues for the dentoalveolar stop (Byrd, 1996, Ohala, 1990). Another explanation is based on the C1 perceptual recoverability principle: consonant overlap ought to be less in clusters with a C1 articulated at a place posterior to C2 than in clusters showing the opposite order as a means to recover the C1 percept whose audible release could be jeopardized by too much C2-to-C1 superposition (Chitoran & Goldstein, 2006).

Voicing may also affect degree of overlap and thus frequency of assimilation. In Eastern Catalan, regressive place assimilation for C1=/t/ has been reported to apply more frequently before /g/ than before /k/ and, therefore, whenever the dental becomes voiced than when it remains voiceless after regressive voicing assimilation applies (EPG, Recasens & Mira, 2015). This finding supports the notion that, given that voiced obstruents are more prone to reduce than voiceless ones, place assimilation and thus gestural overlap may be facilitated by gestural reduction in the coda stop consonant (see section 2.4.2). Descriptive data for Valencian Catalan also reveal than coda stops are more prone to lenite before voiced consonants than before voiceless ones and therefore when they become voiced (Recasens, 2014a: 323–324).

4.1.1.2 Labial and lingual

Differences in degree of overlap and assimilation have been reported to occur between sequences composed of labial and lingual stop consonants as well.

In agreement with the coarticulatory resistance hierarchy, greater overlap has been found to occur in sequences with a labial C1 than in those with a velar C1 whenever C2 is a dentoalveolar stop. This difference in gestural overlap holds for /pt/ > /kt/ in Greek (word initially and word medially; Yip, 2013) and in Korean and Russian (word medially and across a word bounday in the former language and in C#C sequences in the latter; Kochetov et al., 2007), and for /p^ht^h/ > /gd/ in Georgian (word initially and word medially according to Chitoran et al., 2002 and word initially according to Goldstein et al., 2009). The reverse relationship, i.e., more overlap for /kt/ than for /pt/, has been reported to take place in Portuguese (word medially, Cunha, 2014), though this apparent exception could be attributed to the fact that /kt/ was embedded in longer words than /pt/: (/pt) *captar* "to catch", *captador* "catcher"; (/kt/) *compactado* "compacted", *compactador* "compactor".

Regarding stop cluster pairs showing a reverse place combination, a comparison between labial + velar and velar + labial sequences show the expected differences in degree of overlap, namely, /bg/ > /gb/ in Georgian (see above) and in Moroccan Arabic (word medially; Zeroual et al., 2014). More overlap for /bg/ than for /gb/ could be associated with the fact that C1 is labial in /bg/ and velar in /gb/ and also that C2 is velar in the former sequence and bilabial in the latter. Differences in degree of overlap between labial+velar and velar+labial sequences have implications for assimilatory patterns, as revealed by Korean where /pk/ but not /kp/ undergoes regressive assimilation. As to the pairs of sequences with a dentoalveolar and a labial, more overlap has been reported to take place in labial+front lingual clusters than in front lingual+labial ones in Georgian (/p^ht^h/ > /t^hb/, word initially and word medially; Chitoran et al., 2002) and Moroccan Arabic (/bd/ > /db/, word medially; Zeroual et al., 2014). This difference in degree of gestural overlap is not consistent with the trend for /t/ to assimilate to following /p/ and for /p/ to not assimilate to following /t/ in languages like Korean and Catalan (see also descriptive data for Cairene Arabic in section 4.1.1.1), and could be associated with the fast motion of the tongue front articulator for the production of apical and apicolaminal consonants.

The predicted patterns of gestural overlap are also consistent with production data for cluster pairs where C1 remains constant. Thus, in sequences with a labial C1 the consonant is more overlapped by a following velar stop than by a following dentoalveolar stop, as revealed by data taken from Moroccan Arabic (/bg/ > /bd/; Zeroual et al., 2014) and marginally from English (/p#k/ > /p#t/; Gao et al., 2011). In agreement with this pattern of gestural overlap, regressive assimilation in clusters with C1=/p/ applies only when the labial stop precedes /k/ in Korean (Kochetov & Pouplier, 2008, Son et al., 2007). The opposite trend, i.e., more anticipatory overlap during /p/ before /t/ than before /k/ in English (Hardcastle & Roach, 1979) and Taiwanese (Gao et al., 2011), parallels instances of greater overlap in labial+front lingual clusters (/pt, bd/) than in front lingual +labial ones (/tb, db/) reported above and may be attributed to the faster tongue movement associated with the lingual gesture for the dentoalveolar vs dorsal and labial stops. This argument could also explain why /pt/ has assimilated into [tt] historically in Italian (*scritto* SCRIPTU "written", *sette* SEPTE "seven") and Sardinian (['sɛtɛ]/['sette]; Jones, 1988: 325). A perceptual motivation, i.e., a strategy seeking to avoid an audible release for coda stops, has been proposed in order to account for why /p#t/ and /p#k/ show more overlap in Taiwanese than in English.

More gestural overlap has also been reported to occur in clusters with C1=/t/ before a velar stop than before a labial stop in Korean, which is consistent with the principle that velars should be better assimilation triggers than labials and front linguals. Indeed, based on articulatory duration measures, /t/ was found to assimilate to following /k/ and to reduce rather than assimilate to following /p/ in the Korean language (Kochetov & Pouplier, 2008).

4.1.1.3 Summary

Data on gestural superposition for stop clusters referred to in the preceding sections reveal differences in degree of overlap for /pk/ > /pt, kp/, /pt/ > /kt/ and /tk/ > /tp, kt/ (and for the corresponding voiced stop sequence cognates), which are consistent with the predicted trend for regressive assimilation to be triggered by velars rather than by labials and front linguals and being targeted in the progression front linguals, labials > velars (Jun, 2004, Surprenant & Goldstein, 1998). An articulatory account may be given regarding the role of velars as triggers and targets: of all three stop places of articulation, dorsals are produced with the most extensive lingual gesture and at the same time are most resistant to coarticulation and overlap. This place of articulation hierarchy is also compatible with /t/ being more prone to lenite than /p/ and /k/ in syllable-coda position in heterosyllabic consonant clusters (see supporting evidence for Valencian Catalan in Recasens, 2014a: 323–324). Moreover, higher frequency of assimilation percentages for /tg/ than for /tk/ agree with the notion that regressive place assimilation may depend on C1 reduction degree, which is expected to be greater when the consonant is voiced than when it is voiceless.

Regarding clusters composed exclusively of lingual consonants, differences in tongue dorsum-tongue front coordination between /kt/ and /tk/ (as well as between analogous sequence structures; see sections 4.2–4.5) appear to also play a relevant role in gestural overlap and regressive assimilation.

As mentioned above, one case requires a detailed scrutiny. The finding of more overlap for /pt/ than for /tp/ is not entirely consistent with the expected trend for /t/ to exert less anticipation on /p/ than /p/ on /t/ and for regressive assimilations to occur in sequences with C1=/t/. It has been suggested in this respect that much anticipation for /pt/ could be related to the fast motion of the tongue front. Another possible reason why /pt/ overlaps more than /tp/, which could also explain why overlap is greater for /pt/ vs /kt/, /tk/ vs /kt/ and /pk/ vs /kp/, lies in differences in intraoral pressure among stops of different places of articulation occurring in C1 position: a higher intraoral pressure level for C1=/k/ than for C1=/t/ and for C1=/t/ than for C1=/p/ (intraoral pressure is inversely related to back cavity size) could account for why the degree of C2 anticipation varies in the inverse progression.

It is worth being noted that, contrary to the initial expectation, the cluster-dependent differences in gestural overlap just referred to are not inversely related to the frequency of occurrence of the C1 stop burst in English stop+stop sequences, which has been found to decrease in the progression /tk, pk/ (85–90%) > /kt, pt/ (67–73%) > /tp, kp/ (8–25%) (Henderson & Repp, 1982; see also Zsiga, 2000). This progression, which is clearly dependent on the place of articulation of the consonant occupying the C2 position in the cluster, could change at fast speech rates and needs to be further investigated with data from other languages.

4.1.2 Coda sequences

Data for stop+stop sequences such as /kt, pt/ in Romanian (Marin, 2013) and /kt, bt/ in German (Pouplier, 2012) are consistent with the predicted temporal organization of coda clusters, namely, that the interval between the onset consonant and the preceding vowel should be stable while the c-center value ought to increase with the number of consonants available (section 2.1).

4.2 Obstruent clusters with a fricative

4.2.1 Sequences with a stop and a fricative

4.2.1.1 Onset and heterosyllabic C(#)C sequences

EPG data for English reveal the presence of more gestural overlap in stop+stop sequences composed of a velar and a dentoalveolar than in fricative+stop and stop+fricative sequences exhibiting the same segmental composition regarding place of articulation and, therefore, in /g#d/ than in /g#s/ and in /d#g/ than in /s#g/ (Byrd, 1996). Coarticulation data for Catalan clusters also show less overlap in the case of the clusters /ps, ks/ than in sequences in which /p, k/ are followed by other front lingual consonants such as /t, d, l, n, ʎ/ (EPG, Recasens, 2014a: 316–318). It thus appears that /s/ is more resistant to coarticulation than /t, d/ in coda position, which appears to be related to the strict requirements involved in fricative production both regarding airflow volume and constriction width, and also perhaps to the fact that the alveolar fricative needs to have a minimal duration of at least 50 ms in order to be identified perceptually (Jongman, 1989). The finding that the lingual gesture for syllable-onset /s/ is less prone to be anticipated than that for /t, d/ during a preceding coda stop consonant is harder to explain and could be accounted for assuming that the manner requirements for the lingual fricative render the tongue front not only less adaptable but also less movable.

In any case this is not to say that /s/ may not trigger regressive place assimilation in the preceding stop. In addition to the historical assimilation processes /ks, ps/ > [ss] documented in Italian and Sardinian (Italian *osservare* "to observe", *cassa* CAPSA "case", Sardinian *issa* IPSA "this one, fem."; Rohlfs, 1966: 338–339), the word endings /ps/ and /ks/ are realized as [ts] systematically in Alguerese Catalan, and in several Catalan words /ks/ and /gz/ may be pronounced as [ts] and [dz] in casual speech (*e*[dz]*èrcit* "army" and *a*[ts]*és* "access" for *e*[gz]*èrcit* and *a*[ks]*és*). Also in Greek, contrary to the expected trend, /ps, ks/ (and also /ft, xt/) do not show less overlap than /pt, kt/ in word-initial and word-medial position, which may be related to the fact that those two stop+fricative clusters may appear word initially in this language (*psari* "fish", *ksero* "to know"; Yip, 2013).

Gestural overlap in consonant sequences with a stop and a fricative may vary depending on the segmental composition of the consonant cluster. There is more overlap in /s#g/ than in /g#s/ in English, which parallels the scenario for /tk/ and /kt/, and may be attributed to a tendency for the tongue dorsum raising gesture for a velar to be anticipated more easily during a preceding dentoalveolar/alveolar than for tongue body repositioning to occur during C1 in the cluster /kt/ (Byrd, 1996). Inded, ultrasound data reported in the bar graphs of Figure 35 and also lingual splines gathered at successive time points show analogous changes in tongue configuration over time between /sk/ and /tk/ and between /ks/ and /kt/. However, no differences in degree of overlap were found to occur between word-initial /sk/ and /ks/ in Romanian (Marin, 2013) and German (Bombien et al., 2010). On the other hand, gestural overlap for Greek word-initial clusters was reported to be less for /ks/ than for /ps/ (and to some extent for /xt/ than for /ft/ as well), which matches the existence of more overlap for /pt/ than for /kt/ in stop consonant clusters (section 4.1.1.2; Yip, 2013).

A related aspect which has been subject to considerable research is the c-center effect for word-initial clusters with a fricative consonant. The effect in question has been shown to operate in fricative + stop sequences (English, Romanian /sp, sk/, German /sk/, Polish /sp, sk, ʃp/) but not in stop + fricative sequences (Romanian /ps, ks/, Polish /ps, pʃ, ks/, German /kv/) (Marin, 2013, Pastätter & Pouplier, 2015, Marin & Pouplier, 2010, Pouplier, 2012, Honorof & Browman, 1995, Brunner et al., 2014). Moreover, among fricative + stop sequences allowing the c-center effect, C2 has been reported to shift towards the vowel nucleus for /sp/ rather than for /sk/ in American English and Romanian (Marin & Pouplier, 2010, Marin, 2013). The referred asymmetrical behaviour between fricative + stop and stop + fricative sequences has been attributed to differences in degree of gestural overlap between C2 and the vowel nucleus: when occupying the C2 position in the cluster, sibilants are less prone to overlap with the following vowel than consonants of other manners of articulation (Pastätter & Pouplier, 2015). Other language-specific factors such as the frequency of occurrence of the cluster and the phonetic characteristics of the consonants involved may also play a role. Thus, the trend for the c-center effect to hold in /sC/- vs /Cs/-sequences in Romanian could be related to the fact that the former clusters occur more frequently than the latter in word-initial position in this language. Another factor may account for why /sC/ sequences show the c-center effect in English and German but not in French or Italian: a greater shift towards the vowel as the number number of cluster consonants increases is expected to occur in languages where voiceless stops are aspirated in CV sequences and unaspirated in /sC/ clusters than in languages where voiceless stops are always unaspirated (Brunner et al., 2014).

4.2.1.2 Coda sequences

Articulatory data for the sequences /ps, sk, ks/ in Romanian (Marin, 2013), /ps, sp(s), sk, ks/ in English (Marin & Pouplier, 2010, Honorof & Browman, 1995), /ks/ in German (Pouplier, 2012) and /ps, pʃ, ks/ in Polish (Pastätter & Pouplier, 2015) reveal that fricative+stop and stop+fricative sequences exhibit the predicted c-center organization in coda position (see sections 2.1 and 4.1.2). Moreover, gestural overlap turns out to be less for /ks/ than for /sk/ word finally (Byrd, 1996), a difference which has also been reported to occur word internally and across a word boundary for this same cluster pair and for the analogous pair /kt/-/tk/ and the corresponding voiced consonant cluster cognates in section 4.1.

4.2.2 Two-fricative sequences

Regarding sequences of lingual fricatives, a parallel may be drawn between the regressive assimilation /sx/ > [xx], where /x/ derives from /k/, in Sardinian zones (['paxxa] It. *Pasqua* “Easter”), and the assimilatory process /tk/ > [kk] discussed in section 4.1.1.1.

The voiceless glottal fricative /h/ is highly sensitive to overlap from lingual fricatives since it lacks a lingual constriction. When placed word initially after a word-final lingual fricative, /h/ undergoes progressive assimilation in Nuorese Sardinian ([sa(ʃ) ˈʃeminasa] < [saʃ ˈheminasa] < /sas ˈfeminasa/ “the women”; Contini, 1987: 320, 493–494) and drops in Gascon ([aˈs ami] /as ˈhami/ “are you hungry?”, [etʃ ˈ(h)wek] “the fire”; Bec, 1968: 123, Rohlfs, 1970: 146). Also in Cairene Arabic, /h/ assimilates to preceding or following /x, ɣ, ħ, ʔ/ in C#C sequences (Youssef, 2013: 39). Place assimilation triggered by a lingual fricative may also operate on a glottal stop, which lacks a supraglottal constriction, in specific Sardinian regions; this development accounts for the derivation /sk/ > [sʔ] > [ss] as in [ˈmuska] *musca* “fly” > [ˈmusʔa] > [ˈmussa].

As to sequences composed of labial and lingual fricatives, research on gestural overlap reveals different scenarios depending on segmental ordering. EPG data for German show C2-dependent lingual anticipatory activity during the labiodental fricative /f/ in the sequences /f#s, f#ʃ/ (more so when C2=/ʃ/ than when C2=/s/), which has few acoustic consequences due to the prevalence of the labiodental constriction in the C1 acoustic spectrum; as for the reverse sequences /s#f, ʃ#f/, there is, as expected, some progressive overlap for /ʃf/ but not for /sf/ due to the involvement of the tongue dorsum in the production of /ʃ/ and the associated carryover effects (Pouplier & Hoole, 2016). In Sardinian zones, the sequence /s(#)f/ may undergo regressive assimilation ([isfaˈʃarɛ] > [i(f)faˈʃarɛ] “to demolish”, [if ˈfɛrrus] “the iron pieces”).

4.3 Clusters with a nasal

4.3.1 Onset and heterosyllabic C(#)C sequences

4.3.1.1 Non-nasal C1

As to word-initial clusters composed of a lingual fricative and a nasal, the c-center effect has been found to comply with the initial expectations in fricative + nasal sequences but not in nasal + fricative sequences, which parallels the behaviour for /s/+stop and stop+/s/ sequences (section 4.2). Therefore, /sm/ exhibits the c-center effect in English and Romanian, and /ʃm/ does while /mʃ/ does not in Polish (Marin, 2013, Pastätter & Pouplier, 2015, Marin & Pouplier, 2010). Data for American English also show a greater C2 shift towards the vowel nucleus for /sm/ than for /sp, sk/ (Marin & Pouplier, 2010). The presence of a c-center effect in sequences with a nasal C2 appears to be related to coupling of the velar lowering gesture with the vowel and also of the labial constriction gesture whenever the nasal consonant is the bilabial /m/ (Marin & Pouplier, 2010).

Word-initial stop + nasal sequences are, however, reluctant to exhibit the c-center effect as well as gestural overlap, as reported for /kn/ in Romanian, German and French (Bombien et al., 2010, Künhert et al., 2006, Marin, 2013). Overlap has also been found to be less for /pn, kn/ than for /pl, kl/ word initially in French (Kühnert et al., 2006) and for /kn/ vs /kl/ in the same word position in German (Bombien et al., 2010). In any case, while exhibiting little C2-to-C1 overlap, the c-center effect appears to hold for /km/ (also for /gm/) in German (Pouplier, 2012). EPG data for three Catalan speakers also show more overlap for /k#l/ than for /k#n/; thus, the percentage of overlap over C1 duration turned out to be 27% for /k#l/ and 18%, for /k#n/ for one subject, 43% vs 20% for the second speaker and 52% vs 13% for the third one (Recasens, 2014a: 317).

Also regarding stop+nasal sequences, the degree of consonant-to-consonant superposition is conditioned by the specific segmental make up of the consonant cluster. Thus, it happens to be higher for /pn/ than for /kn/ in word-initial position in French, which parallels differences in degree of gestural overlap for obstruent clusters varying in the progression /pt/ > /kt/ (section 4.1.1.2) and /ps/ > /ks/ (section 4.2.1) (Kühnert et al., 2006). EPG and acoustic data for Catalan heterosyllabic stop + nasal sequences exhibit a similar scenario, with segmental overlap as well as regressive manner and voicing assimilation being less for /k#m, k#n/ than for /p#m, p#n, t#m, t#n/ (Recasens & Mira, 2015). EPG data for Italian /kn/ also reveal that the front lingual raising gesture for /n/ does not begin until about the release of /k/ (Farnetani & Busà, 1994). Voicing also matters: less gestural overlap and more C1 departure from the vowel nucleus has also been found to occur for /km/ than for the corresponding voiced cognate /gm/ in word-initial position in German (Pouplier, 2012).

Several arguments have been proposed in order to account for the reluctance for stop+nasal sequences to undergo gestural superposition and why this is especially the case for clusters with a velar C1. A possible reason is that the high intraoral pressure buildup for an oral stop may conflict with velar lowering and lingual anticipatory activity, and also that anticipatory velar opening could mask the oral stop release thus rendering the preceding oral stop non-recoverable. The two anticipatory maneuvers should be harder to apply when the stop C1 is a velar, mostly so if voiceless, due to the particularly high intraoral pressure level and little vocal-tract wall compliance involved during the production of velar stops. There are other reasons why /kn/ may prevent tongue front raising anticipation from occurring thus allowing less gestural superposition than /pn, tn/: the fact that, in parallel to /kt/, the tongue needs to be repositioned during C1; the high demands associated with the tongue dorsum raising gesture for the velar; clusters like /kn/ are not frequent in word-initial position in languages like Romanian, German and French. In support of the former hypothesis, ultrasound data reported in Figure 35 (and also lingual splines gathered at successive time points) reveal changes in lingual configuration over time for /nk/ and /kn/ which are analogous to those for /tk/ and /kt/ and /sk/ and /ks/, respectively (see sections 4.1 and 4.2). In addition, C2 anticipation may be more prone to occur in the cluster /kl/ than in /kn/ since the tongue tip gesture proceeds faster for the apico-alveolar lateral than for the more lamino-alveolar nasal, and the tongue dorsum configuration for /k/ is more compatible with that for /l/ than with that for /n/ (see also section 4.4). The two factors also predict that tongue repositioning during C1 should be less obvious for /kl/ than for /kn/.

Greater gestural overlap has been found to occur for /fn/ than for /pn/ and /kn/ word initially in French perhaps since the low intensity fricative noise for the labiodental consonant may still be perceptually robust against some degree of velar opening induced by the following nasal consonant (Kühnert et al., 2006).

4.3.1.2 Nasal C1

Compared to the dentoalveolar oral stops /t, d/, coda /n/ exhibits more gestural overlap and is more prone to assimilate to a following heterosyllabic labial or velar consonant. Thus, according to EPG data for three Catalan-speaking subjects, regressive place assimilations in C#C sequences with a labial or velar C2 were more than twice for C1=/n/ (73%) than for C1=/t/ (33%), and reached up to 100% when the word-final nasal belonged to a frequent word (Recasens & Mira, 2015). EMA data for the sequences /t#p, t#k, n#p, n#k/ in German also showed more overlap between the primary gesture for C2 and that for C1 in the nasal clusters than in the stop clusters (Jaeger & Hoole, 2011). Other instances of complete and frequent place assimilation in /n#C/ sequences taken from the Romance and Germanic languages may be found in section 2.4.1.

In line with these speech production data, descriptive accounts indicate that coda /n/ is a place assimilation target in many languages, often obligatorily word internally and optionally across a word boundary: in Spanish, English and German, as well as in Swedish and Norwegian (Eliasson, 1986: 276, Kristoffersen, 2000: 319–327), Icelandic (Einarsson, 1945: 18–19), Dutch (Booij, 1995: 64–65), Polish (Gussmann, 2002: 83–89), Frisian (van der Meer and de Graaf, 1986: 310–311), Irish (Ó Cuív, 1986: 404–405), Finnish (Suomi et al., 2008: 43), Malayalam, Korean, Japanese and Hindi (Jun, 1995: 44–49, 51–52, 57–59), Cairene and San'ani Arabic (Watson, 2002: 235), Hungarian (Kenesei et al., 2010: 438), Lithuanian (Baković, 2007: 344), and also Sardinian where word-final /n/ in the morphological particles *in*, *non* and *cun* assimilates to a following word-initial labial or velar consonant (Pittau, 1972: 36). The coronal oral stop may also undergo assimilation in some of these languages (e.g., Catalan, English, German, Japanese) but not in others (e.g., Malayalam, Hindi).

There is common agreement that /n/ is prone to assimilate since it requires a low intraoral pressure level, and is endowed with a nasal murmur, a stop burst and vowel transitions of little salience. The trend for coda nasals to undergo assimilation may also be associated with the introduction of extra formants and a broadening of formant bandwidths in the preceding nasalized vowel, which may lead to an obscuration of the VC formant transitions and thus the most relevant place of articulation cue (Nolan & Kerswill, 1990: 312, and also section 2.4).

Analogously to stop+stop sequences, a factor facilitating regressive place assimilation in coda /n/ is voicing in the C2 assimilation trigger. According to EPG data for /n#g/, /n#k/ and /nt#g/ uttered by seven English subjects reported by Hardcastle (1994a), complete/partial assimilation percentages were higher for the former cluster (about 90%, *can go*) than for the two latter ones (about 70–80%, *Susan can't*, *can't go*). It appears then that a lower intraoral pressure level for C2 if voiced than voiceless renders gestural superposition and thus regressive assimilation more feasible.

Regressive place assimilation occurs less often in the sequences /mC/ and [ŋC] in which, as shown by the following lexical variants, the assimilation of the labial and the velar is favoured when the following consonant is front lingual. (In the lexical forms mentioned next, a two-consonant cluster may result from the fall of an unstressed vowel in a CVC sequence or of a consonant in a CCC sequence, as in *senda* < SEMITA and *cansar* < CAMPSARE respectively. Moreover, the velar nasal [ŋ] may correspond to the first consonant of the graphemes NG and GN in Latin and *nc/ng* in Romance).

(/mt, md/) Spanish *senda* SEMITA "path", *pronto* PROMPTU "soon"; Catalan *contar* COMPUTARE "to count", *llindar* LIMITARE "doorstep".

(/mn, ms, mr/) Sardinian *sonnu* SOMNU "dream", *dannu* DAMNU "damage"; S.W. Lengadocian ending *-ms* > *-ns* (Ronjat 1930–1941, 2: 214, 286); Spanish *cansar* CAMPSARE "to tire"; coll. Catalan *so*[nr]*iure* for *somriure* "smile".

([ŋt, ŋn, ŋs, ŋr]) coll. Catalan *santraït* for *sangtraït* "bruise"; Calabrese [ˈlinnə] LIGNU "wood", Sardinian [ˈmannu] MAGNU "big" (Trumper, 1997: 357, Blasco, 1984: 227); coll. Catalan *dons* for *doncs* "then"; Occitan [ˈʒunrə] JUNGERE "to yoke" (Ronjat 1930–1941, 1: 241).

4.3.2 Coda sequences

The predicted c-center organization for coda consonant clusters has been found to be at work in the case of sequences composed of nasals exclusively (Romanian /mn/; Marin, 2013) and of a nasal and a fricative (English /ms/, Romanian /sm/, Polish /ʃm/; Marin & Pouplier, 2010, Marin, 2013, Pastätter & Pouplier, 2015) (see sections 2.1 and 4.1.2).

4.4 Clusters with a lateral

4.4.1 Onset and heterosyllabic C(#)C sequences

Word-initial sequences composed of a stop followed by /l/ tend to show the c-center effect, as reported for Italian /pl/ (Hermes, 2013), English /pl, kl/ (Marin & Pouplier, 2010, Honorof & Browman, 1995) and Romanian /pl, bl, ml, fl, kl, gl/ (Marin & Pouplier, 2014), but not for /pl/ in German (see below). It is hard to see what is the motivation for this language-dependent difference since the alveolar lateral has a clear variety not only in German but also in Romanian and Italian.

As to gestural superposition, a crucial factor appears to be segmental composition. Thus, overlap has been reported to be less for /kl/ than for /pl/ word initially in American English (Marin & Pouplier, 2010), French (Kühnert et al., 2006) and Georgian (Chitoran & Goldstein, 2006), and also in Greek word initially and word medially (Yip, 2013). EPG data for Catalan show the same trend towards less overlap for /k#l/ than for /p#l/ at least in the case of two out of three subjects (27% vs 45%; 52% vs 93%) and for /k#ʎ/ than for /p#ʎ/ for the three of them (7% vs 31%; 5% vs 40%; 13% vs 28%) (Recasens, 2014a: 317). This finding is in accordance with gestural anticipation being favoured to a larger extent by labials, which do not involve tongue activity, than by velar stops, which require a holistic tongue motion which tightly constrains the body of the tongue. A greater lag for /kl/ than for /pl/ in Georgian cannot be attributed to perceptual recoverability being at risk since, given that the liquid C2 does not involve a complete closure, the stop release is not in danger of being obscured by a high degree of overlap (Chitoran & Goldstein, 2006). On the other hand, more overlap for /fl/ than for /pl/ and /kl/ word initially in French has been attributed to the low intensity noise for the labiodental fricative tolerating more coarticulation with the following lateral than the high intraoral pressure buildup for an oral stop (Künhert et al., 2006).

It deserves to be seen whether degree of overlap is favoured by a greater gestural affinity between /k/ and dark /l/ than between the velar stop and clear /l/ in line with the fact that dark /l/ but not clear /l/ is produced with some tongue predorsum lowering and tongue body retraction. In agreement with this possibility, consonant overlap for the tautosyllabic cluster /kl/ in word-medial intervocalic position was found to be greater in Catalan where /l/ is dark than in other European languages where the alveolar lateral is clear (Gibbon et al., 1993). Also ultrasound data for the same five Catalan speakers who recorded speech material for other C#C sequences reveal more articulatory affinity between /k/ and /l/ than between /k/ and other dental/alveolar consonants. Indeed data for /lk/ in the left bar graphs of Figure 35 show that anticipatory back tongue dorsum raising at the velar zone during C1=/l/ is less than for other dental/alveolar + /k/ sequences, and those for /kl/ in the right bar graphs of the figure that there is very little back tongue body and tongue dorsum activity during C1 at the pharynx, velar zone and palate in anticipation of C2=/l/. The prediction is that an analogous tongue body position for /k/ and dark /l/ in the cluster /kl/ should facilitate anticipatory tongue tip raising and presumably less of a shift of the lateral towards the following vowel nucleus. This prediction appears though not to be too consistent with data for American English showing less overlap for /kl/ than for /pl/ word initially in this language, which calls for further research on the subject involving other languages where /l/ is strongly dark.

The stop voicing status also matters, as revealed by the German onset clusters /bl/ and /pl/: even though the two sequences show similar degrees of gestural overlap, /l/ shifts towards the vowel when preceded by /b/ but not by /p/, and /p/ but not /b/ shifts away considerably from the vowel nucleus (Pouplier, 2012). Less consonant overlap for voiceless /pl, kl/ than for the voiced cognates /bl, gl/ has been reported to occur also in German whether word initially (Hoole et al., 2009, Bombien & Hoole, 2013) or word initially and word medially (Brunner et al., 2014), presumably in order to counteract the fact that the timing of peak glottal opening for voiceless plosives is close to the time-point of the oral release. Voiced consonant clusters in languages with negative VOT are expected to exhibit considerable gestural overlap since the presence of glottal fold vibration should lower the intraoral pressure level during the stop and favour /l/ anticipation, as suggested by data for word-initial /bl/ in Russian showing much superposition between the two consonants (Pouplier et al., 2015). In parallel to German voiceless stop clusters, however, a low degree of overlap was found to occur for word-initial /bl, gl/ in French, which was attributed to another factor: since stops are distinctly released in this language, this production strategy allows for the C1 release while at the same time causing an oral pressure drop which prevents a rise in intraoral pressure and voicing termination during the stop consonant (Bombien & Hoole, 2013).

4.4.2 Coda sequences

In agreement with the c-center hypothesis for coda clusters, the VC interval has been reported to remain more or less constant and the c-center to increase with the number of consonants in /lC/ sequences with clear /l/ such as /lb, lm, lf, lk, lg/ in Romanian (Marin & Pouplier, 2014) and /lp, lm/ in German (Pouplier, 2012). However, dark /l/ turned out to shift towards the vowel in the American English sequences /lk/ and /lp/, which is in disagrement with the initial prediction that the VC interval should hold invariant (Marin & Pouplier, 2010). This leftward shift follows from the fact that the dark variety of the alveolar lateral is implemented through anticipatory tongue dorsum lowering and tongue body retraction, mostly when the preceding vowel has a palatal constriction. In these circumstances, the articulatory transition from C1 to C2 during the cluster /lk/ is expected to involve tongue tip lowering but little tongue dorsum raising since the tongue dorsum is already in place for /k/ during preceding /l/. Ultrasound data for /lk/ in Catalan show indeed that the tongue body is located at a relatively high back position already at cluster onset and keeps raising during C1 until it achieves the palatovelar closure for /k/ by the time that the tongue tip closure for /l/ is released (see Figure 35 and section 4.4.1).

4.5 Clusters with a rhotic

4.5.1 Onset and heterosyllabic C(#)C sequences

Tautosyllabic onset clusters with a stop followed by an alveolar rhotic show the expected c-center behaviour, as revealed by data for Italian /pɾ/ (Hermes, 2013), Romanian /pɾ, bɾ, mɾ, kɾ, gɾ/ (Marin & Pouplier, 2014), German /tʀ/ rather than French /bʀ/ (Hoole et al., 2013) and Georgian /k’r/ except when a vowel is epenthesized between C1 and C2 (Goldstein et al., 2007).

The articulatory mechanisms involved in the production of the heterosyllabic clusters /rk/ and /kr/ parallel those for other sequences with a velar stop and a dentoalveolar stop consonant (see ultrasound data in Figure 35 in this respect). Moreover, consonant overlap has been found to be less for word-initial C*r*- clusters than for C*l*- ones in several languages largely independent of the articulatory realization of the rhotic, i.e., in Romanian where the rhotic is realized as an alveolar tap and in German and French where it is uvular (Marin & Pouplier, 2014, Hoole et al., 2013). This difference may be related to the fact that since it proceeds more rapidly for the rhotic than for the lateral, the apical gesture for the former consonant does not need so much preparation in order to be implemented successfully. Consequently, in languages such as Spanish, Italian or Catalan, vowel intrusion has ben reported to occur in tautosyllabic C*r* sequences with an alveolar tap /ɾ/ but much less so or not at all in tautosyllabic C*l* clusters (e.g., in Spanish words like *prado* “prairie” and *creer* “to believe” but not in *plata* “silver” and *pleito* “lawsuit”). The perceptual identification of a short vowel-like segment in these circumstances corresponds to the open configuration of the vocal tract during the time elapsing between the C1 release and the closure or central contact for the tap. The fast closure release for the alveolar rhotic also accounts for vowel intrusion in heterosyllabic *r*C sequences where the rhotic exhibits more often one contact than two (Spanish *hierba* "herb", *arder* "to burn"). No intrusive vowel occurs however when the rhotic is realized as a trill in heterosyllabic C*r* sequences (Spanish *honra* "honour"). It has also been suggested that the rhotic needs to be realized as a flap rather than as a tap for vowel insertion to occur based on the assumption that the inserted vowel would be too short to be heard if the consonant was produced with a ballistic tongue tip raising gesture (Romero, 2008, Recasens, 1995). The flapped realization in question may be observed during productions of *r*[ð̞] (/rd/) in Spanish and Catalan exhibiting continuous tongue tip fronting from the constriction location for the rhotic to that for the following dental approximant (section 3.3.2.1).

Data for several languages reveal that the formant structure of the inserted vowel segment is conditioned by the quality of the following vowel in syllable-onset C*r* clusters and the preceding vowel in heterosyllabic *r*C sequences, as well as by the articulatory characteristics of the consonant flanking the rhotic in both cases. Moreover, the inserted vocalic segment in question is often longer than the rhotic itself and, as pointed out in (a) and (b) below, has a more variable duration which depends on the place, manner and voicing characteristics of the flanking consonant and on stress and syllable and word position (Greek, Baltazani & Nicolaidis, 2013; Spanish, Bradley & Schmeiser, 2003, Colantoni & Steele, 2005; Romanian, Savu, 2012).

(a) The vowel is longer if the rhotic and the adjacent consonant are heterorganic than if they are homorganic and thus, if the rhotic occurs next to a labial or a dorsal consonant than if it appears next to a front lingual consonant. This is consistent with the fact that syllable-initial C*r* and heterosyllabic *r*C sequences with heterorganic consonants exhibit partial gestural overlap which favours vowel insertion. Moreover, as found for Spanish /Cɾ/ and /rC/ sequences, the duration of the intrusive vowel is maximal when the rhotic appears next to a dorsovelar stop since the slow excursion of the tongue body for velars is most compatible with the generation of an open interval immediately before or after the apical contact(s) for the rhotic (Colantoni & Steele, 2005: 86, Schmeiser, 2011: 189). A greater lag for /k'r/ than for /pr/ word initially in Georgian appears to be associated precisely with this articulatory factor rather than with perceptual recoverability being at risk since the stop release is not in danger of being obscured by a high degree of consonant overlap in this case (Chitoran &

Goldstein, 2006, and see section 4.4.1 for clusters with an alveolar lateral regarding this issue).

As to the effect of manner of articulation, the intrusive vowel turns out to be longer before an approximant than before a stop or a nasal in Spanish and Catalan *r*C sequences, which may be related to the fact that the lingual movement from the rhotic to the following consonant proceeds more slowly if C2 is unobstructed than if it is articulated with an oral closure (Schmeiser, 2011: 189). The intrusive vowel duration also increases when the consonant appearing before the rhotic in /Cɾ/ sequences and after the rhotic in /rC/ sequences is voiced rather than voiceless, which is in line with differences in the speed of the closing/opening gesture between the two contextual consonant types.

(b) Data for Spanish /Cɾ/ sequences reveal that the inserted vocalic segment and the entire syllable which contains the rhotic are longer if the syllable is stressed than if it is unstressed (Colantoni & Steele, 2005: 86). Syllable affiliation also matters. Thus, the vocoid and the rhotic are often longer in /rC/ than in /Cɾ/ sequences (Greek, Baltazani & Nikolaidis, 2013; Catalan, Recasens, 2014a: 227), which matches other cases of loose gestural coordination for consonants and consonant clusters placed in syllable-final position. Moreover, according to these and other studies (Bradley, in press), the inserted vowel may also be especially long and occurs frequently in word-initial clusters, which is consistent with tautosyllabic consonants occurring in this word position being least susceptible of undergoing gestural overlap.

Vowel insertion appears to be subject to language-dependent effects as well. In French, where the rhotic is uvular, vowel epenthesis in tautosyllabic /Cʀ/ sequences occurs least often next to velars and the inserted vowel is longer after /t, d/ than after labials and velars (Colantoni & Steele, 2005: 84–85). This contextual restriction is in support of the notion that vowel insertion is favoured by heterorganicity and in agreement with X-ray data for the French sequences /kʀ, gʀ/ showing that the tongue dorsum lowers only slightly during the transition from the velar stop to C2=/ʀ/ (French *je crois* “I believe”, *sac rouge* “red sack”; Rochette, 1973: 137–138). Moreover, according to data on vowel insertion in French /Cʀ/ sequences reported in Colantoni & Steele’s study, the intrusive vowel occurs after a voiced stop rather than after /p, t, k, f/ (see also above for Spanish) independently of whether the cluster appears word initially or word internally and in stressed or unstressed position. Vowel insertion is less prone to apply in German voiced onset clusters such as /bʀ/ perhaps since phonological voiced stops are substantially devoiced in this language (Hoole et al., 2013).

4.5.2 Coda sequences

The predicted c-center organization for coda clusters was found not to apply to /rp, rb, rk, rg/ in Romanian presumably because, in parallel to dark /l/ (see section 4.4.2), the production of the rhotic, which is realized as a trill in syllable-final position in this language, involves some anticipatory tongue body retraction (Marin & Pouplier, 2014).

4.6 Blending scenarios

Gestural blending may not only affect consecutive consonants articulated with the same or a closeby lingual region but also heterorganic lingual consonants provided that their closure/constriction locations approach each other spatially so that they may give rise to a single consonant articulation. As described next, this particular instance of blending may occur in sequences composed of front lingual and dorsovelar or dorsopalatal consonants.

4.6.1 Sequences with a dental or an alveolar consonant, and the dorsopalatal /j/

A typical blending scenario is that of consonant sequences composed of /t, d, n, l, s/ and the dorsopalatal /j/. A trend for /j/ rather than the vowel /i/ to trigger regressive palatalization in a preceding dental or alveolar is in line with the approximant being articulated with a more anterior and narrower constriction than the vowel, which also accounts for why /t, d/ affrication and thus the generation of a long and intense frication noise at stop release may occur before /j/ rather than before /i/ (Hall et al., 2004). Blending for /tj, dj, nj, lj, sj/ is achieved through shortening of the temporal lag between the front lingual gesture for C1 and the dorsal gesture for C2, as gestural overlap between the two consonants increases, cooccurring with some C1 closure or constriction retraction towards the postalveolar zone and an increase in dorsopalatal contact. The resulting consonantal outcomes of the blending process, i.e., [c] (/tj/), [ɟ] (/dj/), [ɲ] (/nj/), [ʎ] (/lj/) and [ʃ] (/sj/), are articulated typically at the alveolopalatal or palatoalveolar zone depending on manner of articulation. Regressive palatalization and thus blending before /j/ is not prone to affect consonants requiring a low and back tongue body position such as dark /l/ and the trill since this tongue configuration is antagonistic to that for /j/ (Iskarous & Katviskaya, 2010), nor the rhotic /ɾ/ presumably due to the fast articulation and extremely short duration of the apicoalveolar tap.

The regressive palatalization process of interest took place in Vulgar Latin or Early Romance where all or most consonant sequences referred to above yielded alveolopalatal or palatoalveolar consonants, which are nowadays part of the phonemic system of languages like Italian, Spanish or Catalan. Thus, for example, the Latin words *pa*[lj]*a* PALEA "straw" and *monta*[nj]*a* MONTANEA "mountain" gave rise to the present-day Catalan words *pa*[ʎ]*a* and *munta*[ɲ]*a*. Alveolopalatal consonants like /ʎ/ and /ɲ/ are not complex segments but simple segments articulated with a single laminodorsal gesture at the alveolopalatal zone (section 3.1.4). In present-day Catalan, this blending process has ceased to apply whether word internally or across a word boundary, as shown by the fact that a sequence like /n(#)j/ may show some anticipation of the dorsopalatal gesture for /j/ but cannot be pronounced as [ɲ] not even at fast speech rates (*unió* "union", *un iogurt* "a iogurt"; Recasens & Pallarès, 2001b).

In English, palatalization and blending apply to /sj/ in a gradient fashion at the postlexical level (*confess you)*. Thus, the realization of this cluster exhibits considerable token-to-token variation, and the corresponding linguopalatal contact patterns may show a change from a /s/-like to a /ʃ/-like contact configuration, and the acoustic record an intermediate spectrum proceeding from more /s/-like to /ʃ/-like throughout the frication noise (EPG, Zsiga, 1995). Word internally, /sj/ is realized as [ʃ] categorically in English (*impression*), and the same categorical scenario accounts for the realizations [dʒ], [tʃ], [ʃ] and [ʒ] of /d, t, s, z/ in the derived words *gradual* from *grade*, *habitual* (*habit*), *pressure* (*press*) and *usual* (*use*) (Zsiga, 2011). A similar blending mechanism yielding different phonetic outcomes ranging from [nʲj] to [ɲ] applies to the sequence /nj/ in words like *onion* in some English varieties.

Regressive palatalization through blending in sequences with a front lingual consonant followed by /j/ may operate in other languages as well. It does optionally across words and obligatorily within words in the case of /tj, dj/ and to some extent /nj/ in Hungarian and of /sj, zj, tj, nj/ in Dutch, the final outcome being [c, ɟ, ɲ] in the former language and [ʃ(j), ʒ(j), c(j), ɲ(j)] in the latter (Siptár & Törkenczy, 2000: 180, Booij, 1995: 95, 151). In Russian, however, acoustic data reveal that /sj/ shows gestural overlap but no blending (Zsiga, 2000), which is reminiscent of the failure for heterosyllabic stop consonant sequences to undergo regressive assimilation in this language (section 2.4.2).

Blending may also operate at the progressive level in sequences composed of /j/ and a following dental or alveolar consonant, which is in line with (alveolo)palatal and palatoalveolar consonants triggering prominent carryover effects onto the following phonetic segment (section 2.3 and 2.8). Progressive palatalization yielding the outcomes [c], [ɲ] and [ʎ] of /t/, /n/ and /l/ occurs in Basque under certain conditions (Hualde, 1991: 108, 114, 120): after /i, j/ in the case of /t, n, l/ in Ondarroa and Gernika, and /n, l/ and optionally /t/ in Donostia; after /j/ but not /i/ when the target consonant is /n/ or /l/ but not /t/ in Baztan. Progressive palatalization of /s/ after /j/ but not after /i/ may also take place word finally and, less often, across a word boundary in Western Catalan ([jʃ] in *reis* "kings" and *rei Sol* "Sun king"; section 3.3.1.1).

4.6.2 Sequences with front lingual and velar consonants

The clusters /tk/ and /kt/ are usually implemented through a two-target mechanism and much tongue contact at the sides of the hard palate even during the velar stop (section 4.1.1.1). Another production mechanism is gestural blending yielding a single laminopredorso-alveoloprepalatal articulation with, therefore, a closure location which extends more towards the back than for intervocalic or word-initial /t/ and more towards the front than for intervocalic or word-initial /k/ (Recasens et al., 1993). In parallel to other blending processes (section 2.5), this blended realization occurs at about the midpoint of the cluster rather than at C1 onset and C2 offset.

Evidence for the blending outcome of the cluster /kt/ comes from sound change. Several evolutionary paths have been proposed in order to account for the phonetic endproducts of Latin /kt/ in the Romance languages. According to one explanatory hypothesis, /k/ underwent lenition and vocalization into [j] (i.e., /kt/ > [çt] > [jt]), after which two successive changes could apply: progressive palatalization and blending between [j] and following [t] gave rise to [c]; the (alveolo)palatal stop burst was integrated as the frication phase of the palatoalveolar affricate [tʃ] (Menéndez Pidal, 1968: 143). Languages have chosen outcomes corresponding to earlier or later stages of this phonetic development: [jt] in Occitan, Old Catalan, Old French and Portuguese (Port. *leite*, Occ. [lajt], [lɛjt] LACTE "milk"); [c] in Rhaetoromance dialects (Sutselvan [lac]); [tʃ] in Spanish and Lombard and [jtʃ] in Occitan dialectal zones (Sp. [ˈletʃe]). An alternative explanatory hypothesis states that the final outcomes [jt] and [tʃ], which may be found in several Romance languages and dialects, were derived independently from a blended realization [c] of /kt/ through perceptual integration of either the VC transitions (/kt/ > [c] > [jt]) or the stop burst (/kt/ > [c] > [tʃ]). There is still a third explanatory hypothesis according to which [jt] and [tʃ] came to exist through entirely different evolutions: [jt] from a lenited realization of C1=/k/ (/kt/ > [çt] > [jt]); [tʃ] from the endproduct [c] of /kt/ derived through blending between the dorsal gesture for the velar and the front lingual gesture for the dentoalveolar (/kt/ > [c] > [tʃ]).

A greater reluctance for consecutive consonants to overlap in clusters with a lingual fricative than in sequences composed exclusively of two stop consonants (section 4.2) ought to have implications for the interpretation of the causes of sound change. Thus, the fact that the two consonants of the sequence /ks/ barely overlap suggests that Latin /ks/ yielded [ʃ] in the Romance languages (Latin [ˈakse] AXE “axis” > Eastern Catalan [eʃ]) not through blending between the front gesture for the alveolar consonant and the dorsal gesture for the velar but through coda stop weakening. A possible development may thus have been /ks/ > [çs] > [js] > [jʃ] > [ʃ], the intermediate stage [jʃ] being still available in Romance dialects such as Western Catalan ([ejʃ] AXE). According to a blending account, /ks/ became [ʃ] after which the segmental integration of the VC transitions as [j] gave rise to [jʃ]. It is commonly agreed that the French outcome [js] (*laisser* LAXARE “to leave”) must have been issued through [ʃ] depalatalization whenever originary /ks/ was realized as [jʃ].

The Romance languages also show instances of historical palatalization achieved presumably through blending in sequences composed of a velar nasal followed by a dental or alveolar consonant: [ŋt] NG/KT > [ɲc] > [ɲtʃ] (Old Occitan *sanch* SANCTU “saint”, Alpine Occitan *luench* LONG(I)TU “far away”; Appel, 1918: 85, Ronjat, 1930–1941, 2: 188); [ŋn] GN > [ɲ] (Tuscan [ˈlɛɲɲo] LIGNU “wood”, Old Provençal *estanh* STAGNU “pond”, *ponh* PUGNU “fist”; Appel, 1918: 80–81). In any case, the two derivations are problematic for a blending account since [ŋ] is realized with even less dorsal contact than [k] or [g] and therefore is expected not to merge easily with following /t/ or /n/ into an intermediate alveolopalatal articulation.

Blending appears to have also yielded the realizations [kʎ] and [gʎ] of /kl/ and /gl/ in dialects such as Ribagorçan Catalan ([kʎaw] CLAVE “key”, *un(g)lla* UNGULA “nail”). For this blending outcome to occur, /l/ must be clear and thus articulated with a high and front position of the dorsum of the tongue. Under these circumstances and analogously to the sequence /kt/ (see above), the velar and alveolar consonants could yield an alveolopalatal lateral by approaching their closure/constriction location in space and time.

Another potential blending scenario is that of sequences composed of a velar and the palatoalveolars/alveolopalatals /ʎ, ɲ, tʃ/, though probably not /kʃ, ʃk/ due to the high manner of articulation requirements involved in the production of /ʃ/ (see the above dicussion on /ks/). In order to ascertain whether the sequences in question undergo blending or not, ultrasound data for /tʃ#k, ɲ#k, k#tʃ, k#ɲ/ recorded in meaningful short sentences by the Catalan speakers DR, ES, IM, JU and RO will be reported next.

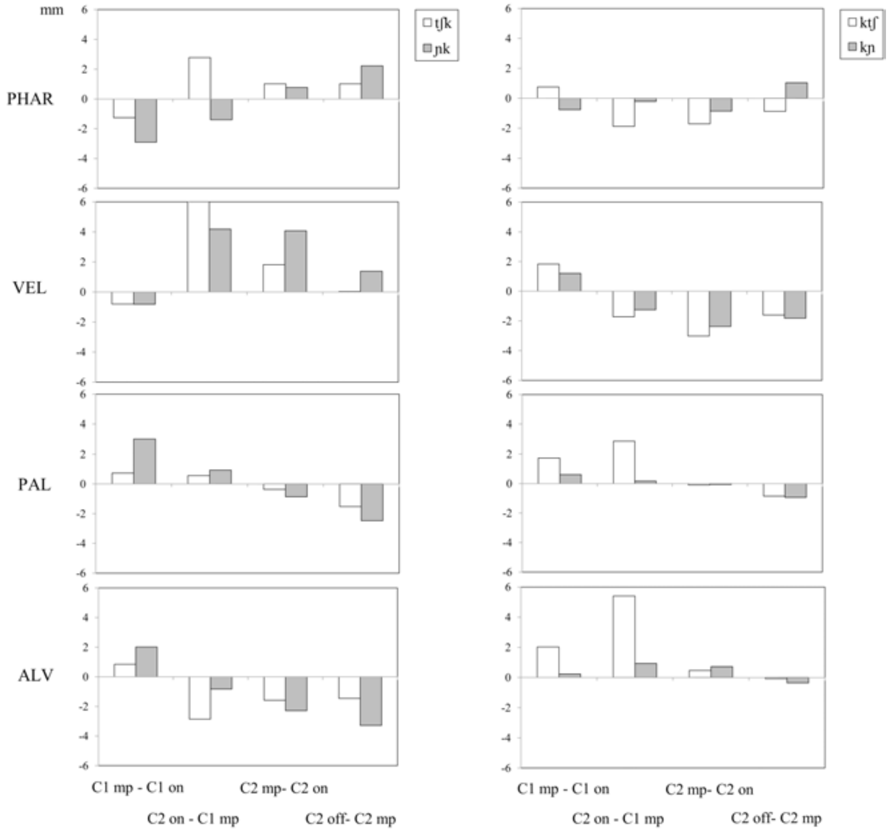

Figure 38: Cross-speaker differences in tongue position between successive temporal points for C#C sequences composed of velar and alveolopalatal/palatoalveolar consonants. See the Figure 14 caption for details.

Regarding the sequences /tʃk, ɲk/ (Figure 38, left graphs), bars for the C1 mp – C1 on period show some predorsum and tongue front raising and back tongue body fronting as the palatoalveolar or alveolopalatal closure for /tʃ/ and /ɲ/ is being formed. From C1 midpoint to C2 midpoint (see second and third sets of bars), the front dorsum remains largely fixed at the palatal zone while the tongue body raises considerably at the velar zone and the tongue front lowers at the alveolar zone; moreover, there is some tongue body retraction at the pharynx for /tʃk/ but not for /ɲk/. Finally, both front dorsum and blade lower at the palatal and alveolar zones during the C2 off – C2 mp period and thus towards C2 closure offset.

Figures 39 (left) and 40 display tongue configurations at C1 onset and midpoint and at C2 onset, midpoint and offset for those two sequences /tʃk/ and /ɲk/. In parallel to the graphic displays for sequences like /kt/ and /rɲ/, the right graphs of Figure 39 allow tracing changes in lingual configuration occurring from C1 midpoint until C1 closure offset before the frication noise begins and from C1 closure offset until C2 closure onset during the affricate frication noise. Data for /tʃk/ plotted in Figure 39 (left graph) reveal the existence of a clearcut shift in closure location proceeding backwards from the front palate for the affricate to the back palate for the velar which, as shown by the right graphs of the figure, takes place during the frication phase and thus between C1 closure offset and C2 closure onset. Data for /ɲk/ displayed in Figure 40, on the other hand, show that in this particular case the transition from C1 to C2 may achieved by sliding the tongue dorsum articulator backwards and thus moving it gradually from the more anterior alveolopalatal closure location for /ɲ/ to the more posterior palatovelar closure location for /k/. This sliding movement is especially apparent for speakers IM, JU and RO, and continues during C2 as the formation of the velar closure is completed. In parallel to the realization of velar consonants before a front vowel or glide, closure location for /k/ in the two sequences /tʃk/ and /ɲk/ does not occur at the soft palate but at the rear of the hard palate; therefore, in both cases the velar stop is not purely velar but exhibits a postpalatal or postpalato-velar realization. The production mechanisms for /tʃk/ and /ɲk/ just described mirror those for /tk/ and other sequences with a dental or alveolar C1 and C2=/k/, in so far as the back tongue dorsum gesture for /k/ may be anticipated during C1 without disrupting the alveolopalatal or palatoalveolar closure for the first consonant in the cluster. In sum, there is no blending between the two closures into a single closure location though something close to a blending strategy is available for /ɲk/ in the case of speaker ES.

Bars in Figure 38 (right graphs) allow exploring changes in tongue configuration for the reverse sequences /ktʃ/ and /kɲ/. At C2 on – C1 mp and thus after the velar stop closure has been formed, /ktʃ/ and less so or not at all /kɲ/ shows anticipatory tongue front and dorsum raising at the alveolar and palatal zones, some tongue body lowering at the velar zone and tongue body fronting at the pharynx. The tongue front and front dorsum are kept fixed during C2 for both clusters while the tongue body keeps lowering at the velar zone until the release of the consonant. Lingual configuration data for /ktʃ/ and /kɲ/ for the individual speakers displayed in Figures 41 and 42 reveal two different production strategies which are in agreement with the bar data displayed in Figure 38 just described. As regards to /ktʃ/, there is a gradual change in place of articulation from the (post)palatal zone to the prepalatal or alveoloprepalatal zone which, according to the right graphs, takes place essentially during the second half of the velar

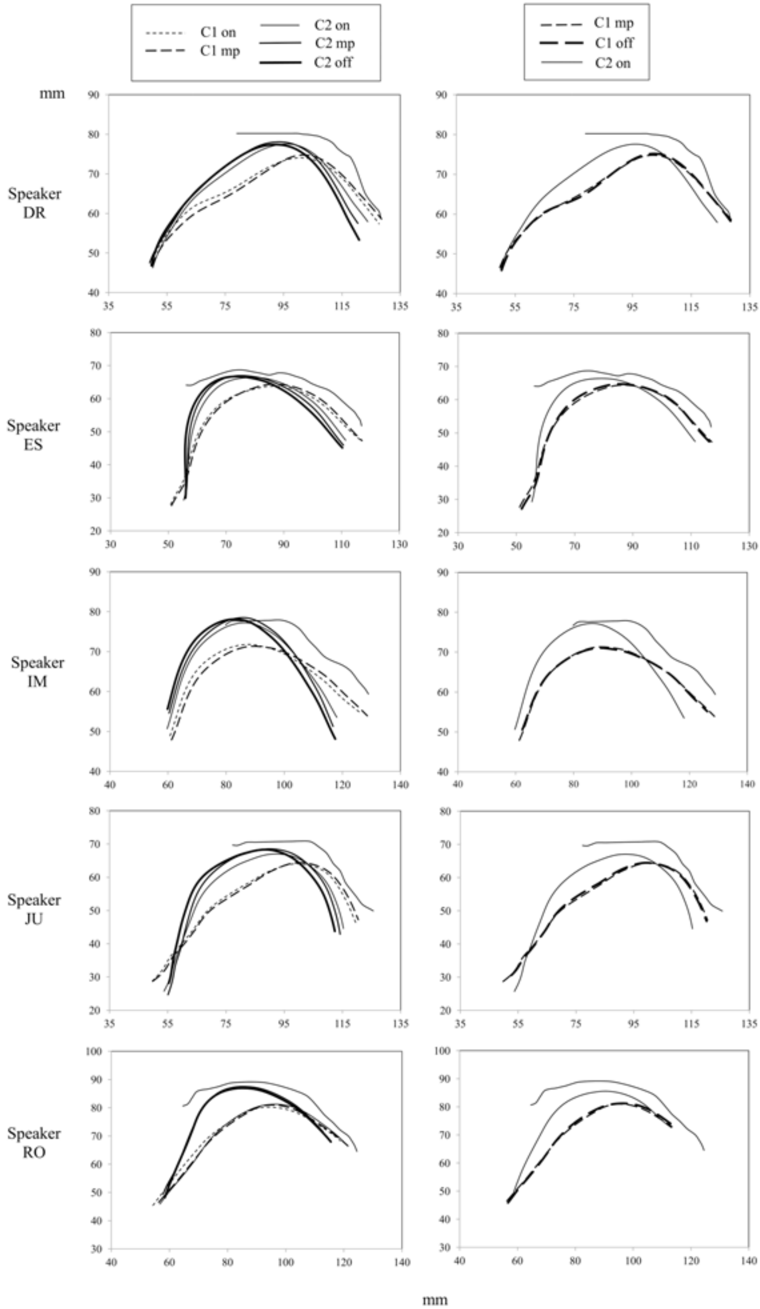

Figure 39: Lingual configurations for /tʃk/ plotted at five time points throughout the cluster (left) and at three time points around the C1C2 boundary (right) for all individual subjects. A palate trace is provided for all speakers.

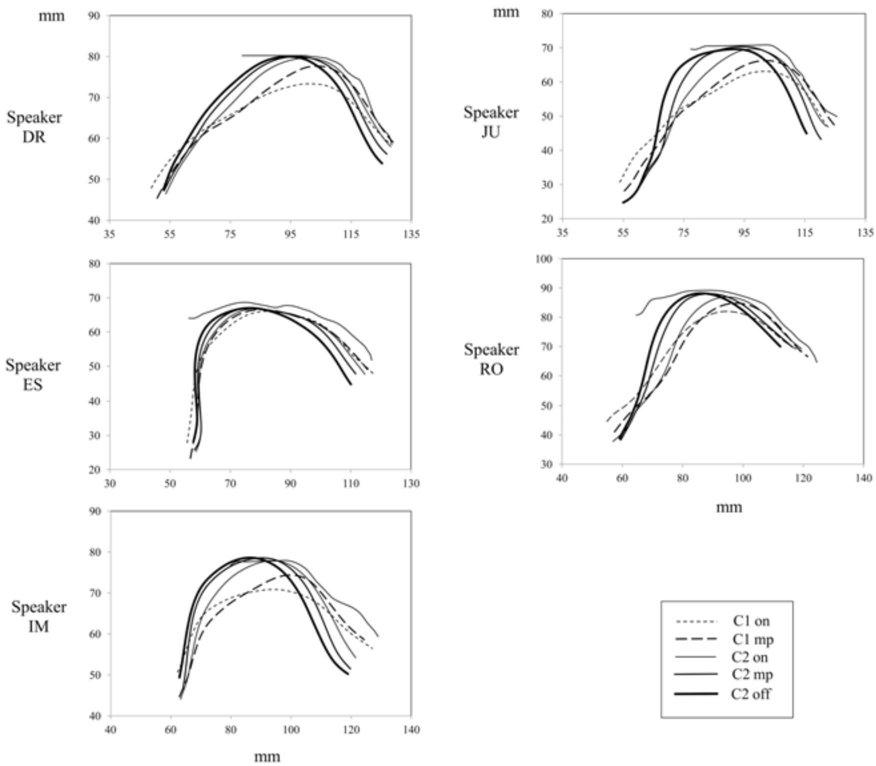

Figure 40: Lingual configurations for /ɲk/ plotted at five time points throughout the cluster for all individual subjects. A palate trace is provided for all speakers.

stop closure. On the other hand, /kɲ/ is realized through a single closure location for most subjects, and therefore a blending mechanism which is achieved essentially by fronting the velar stop closure; the transition from C1=/k/ to C2=/ɲ/ in this case may involve a reduction of the closure area and some lowering of the back dorsum rather than a change in closure location.

EPG data for Catalan show that alveolopalatals acquire maximal tongue dorsum contact before the dorsal consonants /j, k/. In line with the ultrasound data just referred to, they also reveal that blending is most prone to operate on the sequences /kʎ/ and /kɲ/ for the production of which a complete closure encompassing much of the alveolar and palatal zones occurs throughout much of the entire consonant sequence or else the back closure for the velar is maintained passed the formation of the tongue front closure for C2 (in both cases, the stop consonant release occurs at the alveolopalatal zone) (Recasens & Pallarès, 2001b, Recasens, 2014a: 318). A sequential realization of the sequences /kʎ, kɲ/

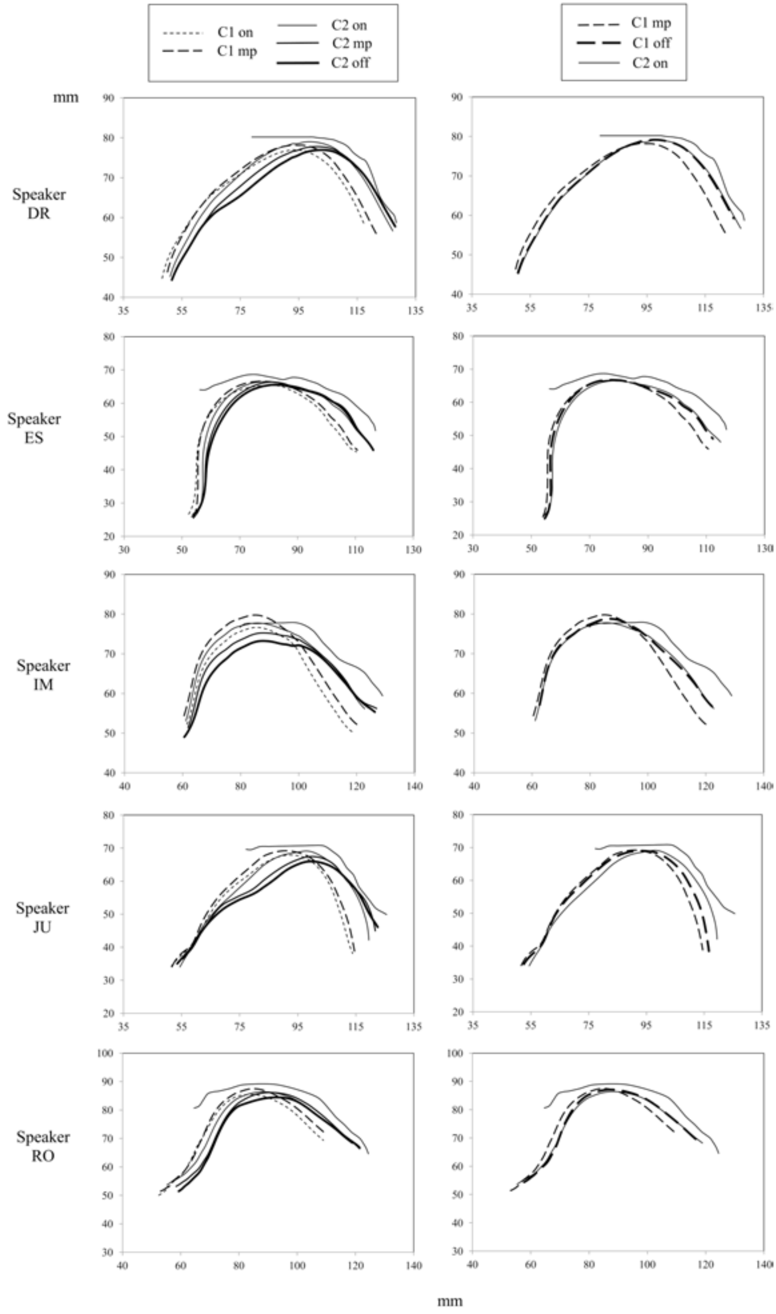

Figure 41: Lingual configurations for /ktʃ/ plotted at five time points throughout the cluster (left) and at three time points around the C1C2 boundary (right) for all individual subjects. A palate trace is provided for all speakers.

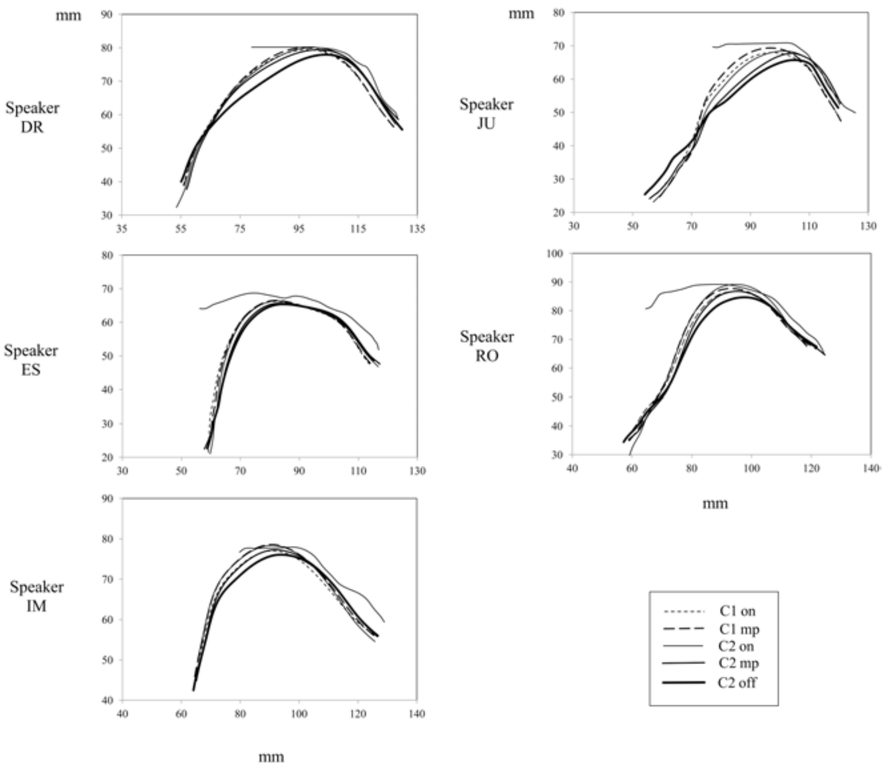

Figure 42: Lingual configurations for /kɲ/ plotted at five time points throughout the cluster for all individual subjects. A palate trace is provided for all speakers.

should not be excluded however. According to X-ray data for French, closure sliding has been reported to occur for /ɲ#k/ and /g#ɲ/ (*il grogne quan elle rit* "he grumbles when she is laughing" and *il m'a servi de vagues gnocchi* "he has served me lots of gnocchi"; Rochette, 1973: 65–66, 72); thus, closure slides forward (/kʎ, kɲ/) or backwards (/ʎk, ɲk/) during C1 while the tongue front or tongue dorsum raises depending on the case, and a complete alveolopalatal closure (/kʎ, kɲ/) or velar closure (/ʎk, ɲk/) is formed by the time C2 begins.

4.7 General summary

As summarized in sections 4.7.1–4.7.4, the degree of gestural superposition in heterorganic consonant sequences is conditioned by several factors which are mostly associated with the segmental composition of the cluster, and appears to keep a direct relationship with the frequency of occurrence of related place assimilations.

4.7.1 Manner of articulation

Degree of overlap is very much influenced by the manner of articulation of the consonants in succession. Syllable-final /n/ and voiced consonants are prone to overlap with and assimilate in place of articulation to the following heterosyllabic consonant since they exhibit a low intraoral pressure level and a burst of little prominence. In sequences with a dental/alveolar and /k/, there is less overlap when the former consonant is /s/ than when it is /t, d/; thus, the high manner demands involved in the production of /s/ cause the fricative to be at the same time highly resistant when appearing in syllable-coda position and also less flexible at the tongue front and thus less aggressive when occurring in syllable-onset position. It should be noticed that the latter claim runs against the notion that more resistant phonetic segments should be more aggressive and thus, most prone to affect other contextual segments at the coarticulatory level (Fowler & Saltzman, 1993). Stop+nasal sequences, on the other hand, are reluctant to undergo gestural superposition presumably in order to prevent nasality from masking the stop release and also since this anticipatory production mechanism is disallowed by the pressure buildup for the oral stop. Moreover, gestural overlap is less for /Cr, rC/ than for /Cl, lC/ probably since, as revealed by instances of vowel intrusion, the apical gesture proceeds more rapidly for the rhotic than for the lateral. The sequence /kl/ (also /lk/) exhibits greater interconsonantal gestural overlap at the back of the vocal tract when /l/ is dark than when it is clear in view of the affinity in tongue body configuration between the velar stop and dark /l/, the question being the extent to which tongue body compatibility interacts with degree of tongue tip anticipation for the alveolar lateral during the velar C1. The available phonetics literature on consonant clusters also reports more overlap for /fn/ than for /pn, kn/ and for /fl/ than for /pl, kl/ in word-initial position, which appears to be in line with the little acoustic salience of the frication noise for the labiodental fricative.

As to the role of consonant voicing, more gestural overlap has been reported to occur for /bl, gl/ than for /pl, kl/, for /gm/ vs /km/, for /tg/ vs /tk/, and also in sequences of /n/ followed by a voiced vs voiceless consonant. Voicing in the consonant flanking the rhotic also determines the duration of the intrusive vocalic segment showing up between C1 and C2 in /Cr/ and /rC/ sequences, i.e., the segment in question is longer whenever the rhotic is flanked by a voiced stop than by a voiceless stop and by an approximant than by a stop or a nasal.

4.7.2 Place of articulation

The degree of adaptation between the two successive consonants also depends on place of articulation and the primary articulator. Overlap decreases in the progression velars > labials, front linguals for the triggering consonant and front linguals > labials > velars for the target consonant. Consequently, dorsals are at the same time coarticulation resistant and produced with extensive lingual gestures and thus coarticulation aggressive, while the tongue front gesture for /t, d/ is most sensitive to coarticulation and articulatory reduction. These consonant hierarchies are in agreement with several cluster-dependent differences in gestural overlap, which are directly associated with C2 when C1 is kept constant (/pk/ > /pt/; /tk/ > /tp/), with C1 when C2 is kept constant (/pt/ > /kt/; /ps/ > /ks/; /p, t/+nasal > /k/+nasal; /pl/ > /kl/), or with both C1 and C2 in symmetrical sequences (/tk/ > /kt/; /pk/ > /kp/; /sg/ > /gs/; /nk/ > /kn/). More overlap for /pt/ than for /tp/ runs against the initial prediction and could result from the fast tongue front anticipatory movement for the dentoalveolar stop during the preceding labial. Other factors disfavouring overlap in clusters with C1=/k/ are tongue repositioning and a high oral pressure level for the velar stop. Tongue repositioning occurs for velar + front lingual sequences but not for front lingual + velar sequences: the latter involve a single tongue body raising action from C1 onset until C2 midpoint, while the former are implemented through two opposite lingual actions, i.e., tongue body raising for the velar stop closure formation at C1 onset followed by tongue body fronting and lowering as the tongue front is being raised in anticipation of C2. As to the /Cɾ, rC/ sequences, overlap is less when the consonant adjacent to the rhotic is dorsal than when it is non-dorsal and when the consonant sequence is heterorganic than when it is homorganic.

4.7.3 C-center effect

Manner of articulation constraints determine the extent to which the c-center effect operates in word-initial clusters and thus, whether the interval between the midpoint of the consonant sequence and the following vowel nucleus stays invariant as more consonants are added to the onset cluster. The c-center effect appears to be favoured by the degree of gestural overlap between C2 and the vowel, and occurs when C2 is a stop rather than a lingual fricative (/sk/ vs /ks/), a nasal, a lateral and a rhotic rather than an obstruent (/sm, ʃm/ vs /sp, sk, mʃ/), and a labial rather than a lingual consonant (/sp/ vs /sk/; /km, gm/ vs /kn/). While ending in a nasal, stop+nasal clusters do not favour the c-center effect however (see section 4.3.1). As to the sequence /kl/, the c-center effect is expected to be less obvious when /l/ is dark than when it is clear since the former lateral variety ought to overlap more easily with /k/ at the velar zone.

Several word-final consonant sequences, i.e., /pt, bt, kt/, /ps, sp, sk, ks/, /mn, ms, sm/ and /lp, lb, lm, lf, lk, lg/ with clear /l/, conform to the initial prediction that there should be a constant interval between the vowel nucleus and the first consonant of the cluster and an increase in the temporal distance between the c-center and the vowel as cluster complexity increases. Clusters starting with consonants involving tongue body retraction such as the trill /r/ and dark /l/ in sequences like /lp, lk, rp, rb, rk, rg/ do not exhibit an invariant VC interval since the two liquids coarticulate strongly with the preceding vowel.

4.7.4 Blending

Gestural superposition may yield a blended realization towards cluster midpoint but not at cluster onset in the following scenarios:

(a) Sequences composed of /t, d, n, l, s/ and the dorsopalatal approximant /j/ may blend into the laminodorsal alveolopalatal realizations [c], [ɟ], [ɲ], [ʎ] and [ʃ], respectively.

(b) Sequences made up of a dental or alveolar and a velar may also blend into [c] in the case of /tk, kt/ and into [kʎ] in the case of /kl/ whenever /l/ has a clear variety (among other reasons, the cluster /lk/ cannot undergo blending due to the retracted position of the tongue body throughout the entire cluster). Other blending scenarios are less obvious whether because the two consonants are not prone to overlap (/ks/ > [ʃ]) or because one of them is articulated with little dorsal contact ([ŋt] > [ɲc], [ŋn] > [ɲ]).

(c) Blending may also operate on sequences composed of palatoalveolar/alveolopalatal and velar consonants such as /ʎk, ɲk, kʎ, kɲ/, though less clearly so /kʃ, ʃk/ due to the high manner requirements involved in the production of /ʃ/. Moreover, blending through intermediation and thus yielding a closure located about half way between C1 and C2 is more prone to occur for /kɲ/ than for /ɲk/ (during /ɲk/, closure placement slides backwards from the alveolopalatal zone to the postpalatal or palatovelar zone). Consonant strings with a velar and a palatoalveolar affricate show a change in closure location with the distance travelled being larger for /tʃk/ than for /ktʃ/.

Differences in the production mechanisms used by speakers for the realization of alveolopalatal/palatoalveolar + velar and velar + alveolopalatal/palatoalveolar sequences may be attributed to the primary articulator involved for C1, i.e., the blade and front dorsum in the case of the former sequence structure and the back dorsum in the case of the latter. Velars are articulated with a massive portion of the tongue which moves slowly and can hit the palate at several locations, while alveolopalatals and palatoalveolars are realized more precisely at a more restricted location which includes the back portion of the alveolar zone and the front portion of the hard palate for the most part. During the production of /tʃk, ɲk/ enough space is left at the back dorsum during C1 so that the dorsal gesture for C2 can be anticipated over time. As to the reverse sequences /kɲ/ (and less so for /ktʃ/), it appears to be more economical to attempt to blend the two lingual gestures by fronting the dorsal closure for the velar stop during C1 than to perform two successive closures at the palatal and alveolopalatal zones by sliding the tongue dorsum frontwards.

5 Manner assimilation and weakening

This chapter deals with those articulatory factors which render manner assimilation and weakening of preconsonantal coda consonants possible. From a methodological viewpoint, we will assume that place assimilation and segmental weakening may occur independently of each other: assimilation may be triggered by gestural overlap without articulatory reduction of the coda consonant being necessarily available, while weakening and elision may take place without much gestural overlap being necessarily present. This notion is supported by dialects where consonants in coda position assimilate pervasively to onset consonants but do not reduce and other dialects where the consonants in question may exhibit lenition and delete without undergoing regressive assimilation (section 2.4.2).

Several working hypotheses will be tested against data for the relevant phonological and sound change processes. Firstly, we hypothesize that, whether underlying or achieved through either place assimilation or blending, homorganicity, i.e., the agreement in constriction location between the two consonants in a cluster, ought to play a relevant role in the implementation of regressive manner of assimilation (see also section 2.4.3). It may be assumed indeed that specific changes in tongue configuration for the acquisition of a new manner characteristic may be easier to perform once the two consonants have come to share the same closure or constriction location, as in the case of the shift of /l/ or /n/ into a rhotic before an alveolar trill which requires the formation of a central constriction opening for the passage of airflow. Through manner assimilation, two consonants sharing the same place of articulation become identical (provided that they agree in voicing as well) and thus give rise to a geminate realization, which may stay as such or shorten into a single consonant. Strictly speaking, geminate simplification after complete assimilation is not to be treated as a case of segmental deletion but of shortening of a long segment.

Another expected outcome is that the weakening of coda consonants should be facilitated by specific C2 phonetic characteristics (section 2.4.3). The shortening and undershoot of syllable-final consonants are triggered most especially by voicing and sonorancy in C2, which should cause the intraoral pressure level for C1 to lower, as well as by heterorganicity and thus the existence of a different constriction location between C1 and C2, which may contribute to contact loss at the C1 closure/constriction location. Through articulatory reduction, coda consonants may undergo lenition, aspiration, rhotacism or vocalization and even get deleted. The fact that lenition/elision and rhotacism affect most often coda dentals and alveolars appears to lend support to this articulatory explanation since these consonants are relatively short and produced with little

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contact at closure location and a relatively unconstrained tongue body configuration. Once weakened through one of those mechanisms, C1 is prone to assimilate to C2 completely.

The present chapter will review manner assimilation and consonantal weakening strategies in clusters with coda consonants differing in manner of articulation, i.e., oral stops (section 5.1), lingual fricatives (section 5.2), nasals (section 5.3), laterals (section 5.4) and rhotics (section 5.5). As pointed out above, special consideration will be given to those contextual effects which cause manner adaptation and articulatory reduction to occur. Most lexical variants included in the chapter belong to the Romance languages and derive from Latin etymons given in capitals.

5.1 Stops

5.1.1 Assimilation/elision

5.1.1.1 Nasal context

Even though nasalization operates independently of the lingual configuration, it may be argued that regressive nasality assimilation in heterosyllabic two-consonant sequences is most prone to occur when the two consonants are homorganic. Indeed, EPG and acoustic data for Catalan reveal that this manner assimilation process operates more often on /p#m, t#n, t#ɲ/ ([bm, mm] < /p#m/ *cap mort* "no dead people", [dn, nn] < /t#n/ *set nois* "seven kids", [dʲɲ, ɲɲ] < /t#ɲ/ *set nyaps* "seven fudges") than on /p#n, t#m/ ([bm, mn] < /p#n/ *cap noi* "no kids", [dm, mm] < /t#m/ *set morts* "seven dead") (Recasens & Mira, 2015). It should be recalled that, in Catalan, the two consonants are homorganic underlyingly in the case of /p#m/ and become homorganic obligatorily through blending in the case of /t#n, t#ɲ/ (see section 3.3.4), while homorganicity can only be achieved through optional regressive place assimilation for /t#m/ and under no circumstances for /p#n/. The role of homorganicity in the implementation of regressive nasal assimilation in Catalan stop + nasal clusters could also account for why /t#m/ may be realized as [mm] (*se*[m m]*ort*s "seven dead") but not as [bm] (**se*[b m]*orts*). Thus, once C1 and C2 become homorganic (and thus /t/ becomes bilabial before /m/ in the example just cited), the most natural strategy appears to be for C1 to assimilate to C2 in manner of articulation. Homorganicity also accounts for the assimilation of /ɖn/ into [ɳɳ] in Telugu (section 3.3.2.3). In Korean, however, homorganicity is not required for oral stops to assimilate in nasality to a following nasal consonant (e.g., /km/ > [ŋm], /pn/ > [mn]; Cho, 1999: 88).

Table I: Progressive stop nasalization (top) and oral stop elision (bottom) in nasal + voiced oral stop sequences. In this and the other tables throughout the book, the phonetic variants of interest (3rd colum) are provided together with their dialectal provenance (2nd column), the Latin etymological form or the corresponding form in the standard language (4th column), an English gloss (5th column) and the bibliographical source (6th column).

Progressive stop nasalization					
/mb/	Sardinian	*tùmma*	'It. tomba'	"tomb"	(Contini, 1987: 133)
	Romanesco	*piommo*	PLUMBU	"lead"	(Rohlfs, 1966: 360)
		m mettó	'It. un bottone'	"a button"	íd.
	Napoletan	*nom mòglio*	'It. non voglio'	"I do not want"	íd.
	Calabrese	*sammucu*	'It. sambuco'	"elser"	íd.
	Sicilian	*mmintari*	'It. inventare'	"to invent"	(Guarnerio, 1918: 493)
/nd/	Romanesco	*monno*	MUNDU	"world"	(Rohlfs, 1966: 357)
		mannare	MANDARE	"to order"	íd.
	Sicilian	*un niri*	'It. non dire'	"not to say"	íd.
		u[ɳɳ]*i*	UNDE	"where"	(Millardet, 1925: 732)
	Sardinian	*tu*[ɳɳ]*u*	'It. tondo'	"round"	(Contini, 1987: 160)
		annare	ANDARE	"to walk, to go"	(Jones, 1988: 325)
/ŋg/	Sicilian	[ˈlɔŋŋu]	'It. lungo'	"long"	(Rohlfs, 1966: 361)
		[uŋ ˈŋattu]	'It. un gatto'	"a cat"	íd.
Oral stop elision					
/mb/	Spanish	*lomo*	LUMBU	"back, noun"	
	Argentinian Sp.	*tamién*	'Sp. también'	"also"	(Malmberg, 1950: 68)
	Occitan	*camo*	CAMBA	"leg"	(Ronjat, 1930–1941, 2: 216)
	Portuguese	*imora*	'Port. embora'	"away"	(Leite de Vasconcellos, 1987: 100)
/nd/	Catalan	*manar*	MANDARE	"to order"	
	Gascon	*grano*	GRANDE	"big"	(Rohlfs, 1970: 155).
		préne	PRENDERE	"to take"	íd.

Regressive manner of assimilation occurs less often in segmental sequences which are reluctant to undergo gestural overlap such as /k#m, k#n/ due to the articulatory and aerodynamic requirements pointed out in section 4.3.1. Among these we should mention a high intraoral pressure buildup, a low vocal-tract wall compliance and the high demands associated with the tongue dorsum raising gesture for the velar stop, which ought to conflict with velar lowering in general and with the anticipation of the front lingual raising gesture for C2=/n/ in particular.

Progressive nasalization of a voiced oral stop appears to be also favoured by homorganicity. Consonant gradation in Finnish allows for nasal + stop (strong grade)/ nasal + nasal (weak grade) alternations only when C1 and C2 are homorganic, i.e., [mp]/[mm], [nt]/[nn] and [ŋk]/[ŋŋ] (Hutcheson, 1973: 24). Other relevant examples taken from S. Italian and Sardinian are listed in Table I (top). The fact that the instances of progressive nasality assimilation in the table apply in sequences with a voiced C2 (/mb, nd, ŋg/) is clearly related to aerodynamic conditioning factors: a lower intraoral pressure level for voiced stops than for their voiceless cognates allows velar lowering to be maintained for a longer period of time during C2 in the former vs latter contextual condition. The same progressive assimilatory process may account for instances of the change /ɲɟ/ > [ɲ(:)] in Early Romance (Catalan *vergo*[ɲ]*a* VERECUNDIA "shame", *estrè*[ɲ]*er* STRINGERE "to tighten"), in which the input (alveolo)palatal stop /ɟ/ was generated from the Latin sequences /dj/ and /ge, gi/ through blending between the dental or velar stop and the following front vocalic segment.

As revealed by other examples in Table I (bottom), the homorganic Latin sequences /mb, nd/ have also yielded the single nasals [m] and [n] in several Romance languages whether through simplification of the geminate nasal outcome issued from progressive assimilation (e.g., /mb/ > [mm] > [m]) or through deletion of a weakened realization of the oral stop (e.g., /mb/ > [m]).

5.1.1.2 Lateral context

Homorganicity is required for regressive manner assimilation to occur in stop + lateral sequences, as for /tl/ > [ll] and /tʎ/ > [ʎʎ] in Catalan ([ll] *set làmines* "seven plates", [ʎʎ] *set llums* "seven lights"), /ɖɭ/ > [ɭɭ] in Telugu, /tl/ > [ll] in Korean and Sanskrit, and /dl/ > [ll] in Latin forms like *sella* < **sed-la* "seat". In all cases, the fact that the two consonants have come to share the same closure location through blending or progressive dentalization (section 3.3.4) appears to facilitate some lowering at the tongue sides for the passage of airflow during the stop and, therefore, the implementation of the stop lateralization process. In Early Romance, stop lateralization also applied to the sequences /tl, dl/ derived from Latin /tVl, dVl/ through elision of the intermediate unstressed vowel, as in the case of the Old French forms [esˈpallə] SPAT(U)LA "back, noun" and [ˈmɔllə] MOD(U)LU "mold" (Pope, 1934: 149).

Stop lateralization may also take place at the progressive level in clusters which have become homorganic whether through place assimilation or blending. In Romance, this change may have operated on /ld/ and also on /lɟ/ where /ɟ/ corresponds to Latin /ge, gi/. Thus, /ld/ shifted to [ll] in Old Romanesco *callo* CAL(I)DU "hot, masc. sing." and *sollati* "soldiers" and in Old Catalan forms like *sollos* SOL(I)DOS "pennies" and *Arnallus* ARNALDUS (Rohlfs, 1966: 340), while the outcome [ʎʎ] of /lɟ/ accounts for the Italian verbal form [ˈkɔʎʎere] *cògliere* COLL(I)GERE "to pick". Other examples may be found in Latin (*sallo* < **saldo* "to salt"), and in Finnish where consonant gradation shows the alternation [lt]/[ll] as in the word pair *silta* "bridge" (strong grade)/*sillan* (weak grade) (Hutcheson, 1973: 24).

5.1.1.3 Fricative and rhotic context

Homorganicity is also involved in the regressive manner assimilation processes /ts/ > [ss] and /tʃ/ > [ʃʃ], which may apply after the dentoalveolar stop /t/ becomes alveolar before /s/ and /ʃ/ through regressive place assimilation (section 3.3.1.1). Regressive fricativization in the sequence /ts/ is found in Latin (*messui* < **met-sui* "I mowed", *assimilare* < *ad-simulare* "to assimilate"), and operates on the detransitivizing verbal prefix *t-* in Cairene Arabic, which turns optionally into an alveolar fricative when followed by /s, z/ and into a palatoalveolar fricative before /ʃ, ʒ/ (Youssef, 2013: 28–29). In Korean compounds and in Sino-Japanase vocabulary elements of Japanese, /t/ assimilates fully to following /s/ in addition to other consonants (Japanese *bessitu* < *bet+situ* "separate room"; Cho, 1999: 51, 88). Regressive manner assimilation also accounts for the historical change /ps, ks/ > [ss] in Italian and Sardinian lexical items presumably after the two sequences became homorganic and thus shifted to [ts] (Italian *osservare* OBSERVARE "to observe", *asse* AXE "axis", *cassa* CAPSA "box", Sardinian *íssu* IPSU "the same, masc. sing.", [lasˈsarɛ] LAXARE "to leave"; Rohlfs, 1966: 338–339, Jones, 1988: 325).

Regressive fricativization may operate on clusters with homorganic consonants sharing a labial or velar constriction location. In Cairene Arabic, /b#f, v/ and /k, g#x, ɣ/ may be realized as [ff, vv] and [xx, ɣɣ], respectively (Youssef, 2013: 38–39). Moreover, in an Italian word like *affamare* derived from AD+FAME "to starve", regressive manner assimilation must have been preceded by a change in place of articulation by which the dental stop C1 turned into a labiodental stop (Rohlfs, 1966: 338).

As the following lexical items show, the voiced dental stop /d/ may also assimilate in manner of articulation to a following homorganic rhotic in syllable-onset clusters, presumably whenever the rhotic has a trill or trill-like realization and is thus prone to trigger regressive assimilation in constriction location in a preceding unconstrained dental or alveolar consonant (section 3.3.1.1). Thus, *dr* became [r] in Italian *quarra* QUADRA "square sail", Old Lombard *verrâ* It. *vedrà* "he/she will see" (Rolhfs, 1966: 338, 371), Occitan *nurri* *NUTRIRE "to feed" (Ronjat, 1930–1941, 2: 222) and Alguerese Catalan *llarre* LATRO "thief" and *perra* PETRA "stone". An analogous manner assimilation may also operate on the tautosyllabic sequence *gr* perhaps since tongue body retraction for the alveolar trill renders this consonant nearly-homorganic with the preceding velar stop at the back of the vocal tract (see section 5.1.2.2 for an alternative account). Thus, *gr* has become [r] in Sicilian *rappa* It. *grappa* and *ranni* It. *grandi* "big, masc. pl." (Dulcibella, 1934: 298) as well as in the dialectal Catalan forms *arro* for *agre* "sour" and *rapat* for *grapat* "handful".

5.1.2 Lenition/elision

5.1.2.1 Syllable-final position

In dialects favouring coda stop lenition and elision (dial. Spanish [(β)t] *obtener* "to obtain"; Penny, 1986: 494–495), stop weakening in preconsonantal syllable-final position operates on the apicolaminal /t/ rather than on the longer labial and velar cognates /p/ and /k/. If shortened considerably, the former consonant may be deleted without undergoing lenition. Straight elision applies to word-final /t/ before several consonants in Frisian frequent words (van der Meer & de Graaf, 1986: 316–317) and to word-final /d/ placed in an unstressed syllable when followed by any word-initial consonant in Breton (Dû, 1986: 446). Likewise, in Sardinian, word-final /t/, which is the 3rd person singular marker in verbal forms, drops before a word-initial consonant and causes this consonant to lengthen (Lausberg, 1970: 434–435).

A related issue is whether in dialects where syllable-final stops may lenite preconsonantally, the simplification of a heterosyllabic stop + consonant sequence occurs through coda stop lenition or through simplification of a geminate realization generated through regressive assimilation. Data for Valencian Catalan suggest that whether one mechanism or the other applies depends on the segmental composition of the cluster: C1 elision after weakening is prone to operate in the sequences /tg, td, tr/, which may also be realized as [ðC], while geminate simplification affects mostly /tl, tʎ, tn, tm/, which may exhibit regressive manner assimilation rather than C1 lenition (Recasens, 2014a: 325). A rationale for this double behaviour is to be sought in the fact that the articulatory mechanisms associated with nasality and laterality are most prone to be anticipated during a preceding homorganic oral stop.

5.1.2.2 Syllable-onset position

Progressive lenition may apply to a syllable-onset voiced stop whenever the immediately preceding coda consonant allows the passage of airflow through the location where C2 is articulated. Therefore, the heterorganicity condition between C1 and C2 may contribute to widen the C2 constriction and thus to replace the syllable-initial stop by a fricative or an approximant. This contextual change is at work in language scenarios such as the following.

– (Catalan) /b, d, g/ are realized as the approximants [β, ð, ɣ] after a fricative, a lateral or a rhotic except if occurring in the homorganic sequences /fb, ld, ʎd/ where /b/ and /d/ are realized as [b] and [d], respectively. Examples: [ˈerβə] *herba* "weed", [əzðəβəˈni] *esdevenir* "to become", [ˈmurɣə] *murga* "street noise".

- (N. W. Logudorese, Nuorese) /l, s, r/ + /k, g, b/ yield [xx], [ɣɣ] and [vv], respectively, through progressive lenition followed by regressive fricativization. Examples: [ˈpixxɛ] PISCE "fish", [ˈpoxxu] PORCU "pig", [kaxˈxandzu] CALCANEU "heel", [ˈlaɣɣa] LARGA "long", [ˈaɣɣa] ALGA "alga" (Contini, 1987: 303, 493, Jones, 1988: 326).
- (Francoprovençal from Freiburg and Vaud) /p, t, k/ shift to [f], [θ, ç] and [x, h], respectively, when preceded by [ç] derived from /s/, after which the consonantal sequence may reduce to a single consonant. Examples: [ˈvefa] VESPA "wasp", [ehuˈta] AUSCULTARE "to listen to", [ˈkuθa] COSTA "coast", [viˈθi] VESTIRE "to put cloathes on" (Rousselot, 1891, Guarnerio, 1918: 517).
- (Andalusian Spanish) /b, d, g/ are realized as voiced fricatives when preceded by the voiced aspirate [ɦ] derived from coda /s, θ/, after which progressive devoicing and cluster simplification may occur, i.e., /sb, sd, sg/ [ɦβ, ɦð, ɦɣ] > [ɦɸ, ɦθ, ɦx] > [ɸ, θ, x]. Examples: *la* [ɸ]*otas*, *lo* [θ]*ientes*, *de*[θ]*e*, *novia*[x]*o* and *lo* [x]*atos* for *las botas* "the boots", *los dientes* "the teeth", *desde* "from", *noviazgo* "engagement" and *los gatos* "the cats" (Torreblanca, 1984).

Stop lenition and elision may also occur in homorganic syllable-onset clusters, mostly so if the consonant subject to weakening has a velar place of articulation. Thus, in several Romance dialects, C1 may drop in the sequence /kl/ through the development /kl/ > [kʎ] > [çʎ] > [ʎ] and thus the three following successive changes: the stop /k/ and the lateral /l/ blend into [kʎ] and thus become homorganic at the alveolopalatal place of articulation (section 4.6.2); the velar stop lenites into the palatal fricative [ç] before [ʎ]; [çʎ] simplifies into the alveolopalatal [ʎ] in line with the (nearly)-homorganic relationship between C1=[ç] and C2=[ʎ]. Moreover, the phonetic development for the originary voiced cluster cognate /gl/ should be /gl/> [gʎ]> [ɣʎ] > [ʎ]. The intermediate outcome [çʎ] is still found in Francoprovençal from Forez ([çʎu] CLAVU "nail", [çʎo] CLAVE "key"; Jeanjaquet, 1931: 40, Gardette, 1941: 74–77), and the final alveolopalatal lateral outcome [ʎ] occurs in Ribagorçan Catalan forms such as *esllésia* ECCLESIA "church", *llera* GLAREA "grape variety" and *lleva* GLEBA "lump of earth" where the digraph *ll* corresponds to [ʎ]. Homorganicity also accounts for the elision of /g/ before several tautosyllabic consonants with which the velar shares or may share a back dorsal constriction: /w/ (dial. Catalan (*g*)*uarda* "he/she keeps", *i*(*g*)*ual* "the same"); a rhotic (Catalan *peresa* PIGRITIA "laiziness", Italian *nero* NIGRU "black", Calabrese *ranne* It. *grande* "big", Logudorese [ˈruɣe] CRUCE "cross"; Rohlfs, 1966: 251, Guarnerio, 1918: 474, Blasco, 1984: 236); /l/ (Spanish *latir* GLATTIRE "to beat", Sardinian *lómuru* GLOMURU "wool ball", Friulian [dʒ/zeˈnoli] GENUCULU "knee"). A lenited realization of /d/ may also drop before (nearly)-homorganic *r* in syllable-initial position, as revealed by

Spanish *cuarenta* QUADRAGINTA "fourty" and *cadera* CATHEDRA "hip" and by the Piedmontese lexical form *pare* which may be traced back to *padre* PATRE "father" (Rohlfs, 1966: 370).

5.1.2.3 Word-final elision

The elision of a stop C2 in word-final clusters is also conditioned by the homorganic relationship between the two consonantal segments in succession. In several Catalan dialects, oral stops drop after a homorganic nasal: /mp/ > [m] as in *camp* CAMPU "field", /nt/ > [n] as in *vent* VENTU "wind", [ŋk] > [ŋ] as in *cinc* CINQUE "five" (Ronjat, 1930–1941, 2: 289). Among the three places of articulation, the stop drops less often when it is a velar than a bilabial or a dental which may be due to several articulatory and acoustic factors associated with the production of velar stops, namely, the slow motion of the tongue dorsum articulator, the high perceptual salience of the dorsovelar release as well as a high intraoral pressure level which may prevent the velum from occupying a low position during the /k/ closure. Also in Gascon, word-final cluster simplification operated historically on /mp/ and /nt/ but not on [ŋk] (Sampson, 1999: 155). As to other word-final consonant sequences, in present-day Catalan, /t/ drops after homorganic /l/ obligatorily in frequent words (*alt* "high", *dalt* "upstairs") and optionally in less frequent lexical items (*indult* "indult"), and only in colloquial speech when it belongs to the sequences /rt, st/ which may become homorganic through progressive assimilation in constriction location (*port* "port", *gust* "taste"; section 3.3.2.1).

In addition to other factors, (near)-homorganicity may also play a role in the deletion of a postconsonantal stop in word-final position in other languages (Côté, 2000: 194, 244–248, 264). In Farsi, the coronal stop deletes optionally after a homorganic nasal or front lingual fricative provided that the two consecutive consonants share the same voicing specification, as for example /t/ after /s, ʃ/ and /d/ after /n/. A similar rule applies in Québec French, where French and English borrowings delete /t/ after /s/ and /d/ after /n, l/. In Philadelphia English, on the other hand, the alveolars /t, d/ have been reported to drop after the (near)-homorganic alveolars /s, n/ and less so /l/ but not after /r/ (*wrist*, *tend*, *tent*, *cold*, *colt*; *cart*), as well as after a non-coronal stop and less frequently a non-coronal fricative or nasal (*act*, *draft*, *summed*).

5.1.3 Rhotacism and vocalization

As hypothesized at the beginning of this chapter, coda stop weakening is facilitated by voicing and sonorancy in C2. Thus, a lenited realization [ð] may shift

Table II: Vocalization of syllable-final stops of different places of articulation.

Dental	[j]	Occitan	*dème*	DECIMU	special tax	(Ronjat, 1930–1941, 2: 189)
			lèido	LICITA	special tax	íd.
			caire	QUADRU	"edge"	íd.: 226
			pèiro	PETRA	"stone"	íd.
		Portuguese	*cadeira*	CATHEDRA	"chair"	(Williams, 1938: 78)
		Argentinian Spanish	*maire*	MATRE	"mother"	(Malmberg, 1950: 135)
		dial.Catalan	*doize*	'Cat. dotze'	"twelve"	
			tois	'Cat. tots'	"all, masc.pl."	
	[w]	Catalan	*creure*	CREDERE	"to believe"	
			coure	COCERE	"to cook"	
Labial	[w]	Catalan	*roure*	ROBORE	"oak"	
			ciutat	CIVITATE	"city"	
		Occitan	*coude*	CUBITU	"elbow"	(Ronjat, 1930–1941, 2: 167)
		Old Occitan	*deuta*	DEBITA	"debt"	íd.: 166
		dial. Spanish	*receución*	'Sp. recepción'	"reception"	(Malmberg, 1950: 68)
			conceuto	'Sp. concepto'	"concept"	íd.
	[j]	Occitan	*joine*	JUVENE	"young"	(Ronjat, 1930–1941, 2: 256)
		Old Occitan	*coide*	CUBITU	"elbow"	íd.: 166
			caitiu	CAPTIVU	"captive"	íd.: 165
		dial. Spanish	*receición*	'Sp. recepción'	"reception"	(Malmberg, 1950: 68)
			conceito	'Sp. concepto'	"concept"	íd.
			aceitar	'Sp. aceptar'	"to accept"	íd.
Velar	[w]	Occitan	*pers*[ɛw]*re*	PERSEQUERE	"to chase"	(Ronjat, 1930–1941, 2: 228)
		Portuguese	*outubro*	OCTOBRE	"October"	(Williams, 1938: 85)
			noute	NOCTE	"night"	íd.
		Calabrese	[ˈniuru]	NIGRU	"black"	(Rohlfs, 1966: 372)
			[ˈliunu]	LIGNU	"wood"	íd.: 368
		Catalan	*Jaume*	JACOMU	"James"	
		Old Catalan	*saumera*	SAGMARIA	"donkey,fem."	
		dial. Spanish	*afeuto*	'Sp. afecto'	"affection"	(Malmberg, 1950: 79)
			auto	'Sp. acto'	"act"	íd.
	[j]	Occitan	*flairo*	FLAGRAT	"(s)he smells"	(Ronjat, 1930–1941, 2: 227)
		Portuguese	*noite*	NOCTE	"night"	(Williams, 1938: 84)
			inteiro	INTEGRU	"whole"	íd.
		Calabrese	[ˈajnə]	AGNU	"lamb"	(Rohlfs, 1966: 368)
		Abbruzzese	[ˈnajrə]	NIGRU	"black"	íd.: 372
		Catalan	*lluita*	LUCTA	"fight"	
		dial. Catalan	*sainia*	'Cat. sagnia'	"bloodletting"	
		dial.Spanish	*aición*	'Sp. acción'	"action"	(Malmberg, 1950: 79)

into a short alveolar rhotic articulation when followed by the voiced sonorants /l, n/ and also a voiced obstruent, as shown by Romansh [rurˈle:r] ROTULARE "to mark" and [tarˈle:r] TITULARE "to title" (Lutta, 1923: 201), colloquial Romanian *logornă* "engagement" and *povirlă* "marmalade" (Nandris, 1963: 128) and dialectal

Catalan *corna* *KÚTENA "crust, peel" and *surja* *SUDIA "soot". The change [ð] > [l] may apply in the same C2 context conditions presumably after rhotacism has taken place. Thus, the dialectal Catalan form *colna* *KÚTENA should derive from *corna*, and the development [ð] > [ɾ] > [l] may account for dialectal Spanish phonetic variants such as *almirar* "to admire", *alvertir* ADVERTERE "to warn", *portalgo* PORTATICU "special tax" and *julgar* JUDICARE "to judge" (Malmberg, 1950: 415, Zamora Vicente, 1989: 152).

Weakening may also give rise to vocalized realizations of coda stops, the issue being under which contextual conditions these realizations are prone to occur. Table II illustrates the phonetic outcomes of stop vocalization in the Romance languages. The vocalization of [ð] into [j] and less so into [w] is favoured by a following voiced consonant, with the outcome [j] occurring mostly next to alveolars also when [ð] occupies the syllable-initial position (Occitan *caire* "edge", Chilean Spanish *maire* "mother"). The vocalization of coda labials and velars, on the other hand, may apply before a voiced or voiceless C2: labials yield [w], and also [j] before dentals and alveolars (Catalan *roure*, Occitan *joine*); the final outcome for velars is [w] before consonants favouring tongue predorsum lowering such as labials (Catalan *Jaume*), and may be [j] or [w] before dentals and alveolars (Occitan *flairo*, *perseure*, Portuguese *noite*, *noute*). In sum, analogously to [ð] rhotacism, voicing in the following consonant favours [ð] vocalization; on the other hand, anticipatory coarticulatory effects in tongue body raising and fronting may account for why labials and velars, which ought to yield [w] due to their articulatory configuration and grave acoustic spectra, happen to vocalize into [j] before heterorganic dental and alveolar consonants.

5.1.4 Summary

Homorganicity between a coda stop and the following syllable-onset consonant appears to facilitate several regressive manner assimilation processes involving laterality, nasality, rhoticity and fricativization. Sound changes associated with segmental weakening such as lenition, rhotacism and vocalization operate on coda stops, especially if the target consonant is dentoalveolar and is followed by a voiced consonant mostly if it is also a sonorant. Heterorganicity with respect to the following syllable-onset consonant appears to also play a role in the vocalization of lenited stops placed in syllable-final position. Coda stops may be effaced through geminate simplification after regressive assimilation has applied or else may lenite or delete when considerably shortened. In word-final clusters, a dentoalveolar stop is prone to delete after a homorganic consonant.

As to syllable-onset consonants, when voiced, a syllable-onset stop may assimilate to a preceding homorganic lateral or nasal consonant in the case of the sequences /ld, mb, nd/. On the other hand, a lenited stop (mostly if a velar) may delete before a (nearly)-homorganic lateral, rhotic or back rounded glide, and a voiced stop may lenite after a lateral, rhotic or fricative, mostly if heterorganic. As to the sequences /md, nd/, the final outcome [m, n] may be achieved either through direct elision of the stop C2 or else through simplification of a nasal geminate after progressive nasality assimilation has applied.

5.2 Lingual fricatives

5.2.1 Aspiration

The aspiration of syllable-final /s/ in preconsonantal position may be accounted for through contact loss at constriction location and thus, gestural reduction. As analyzed in some detail below, two contextual factors appear to be especially involved in the implementation of this reduction process, namely, voicelessness in C2 and the heterorganic relationship between the two successive consonants. These contextual factors render the articulatory account of /s/ aspiration preferable to or as feasible as a perception-based explanation according to which /s/ aspiration is triggered by the categorization of anticipatory glottis opening and breathiness on the margin of the preceding vowel such that, when /s/ is much shortened, this devoiced vowel portion is perceived as an aspiration by listeners (Ohala, 1993, Widdison, 1995, 1997).

Aspiration of coda /s/ has been reported to apply before voiceless stops rather than before voiced consonants in Andalusian Spanish. Indeed, according to the Ethnographic and Linguistic Atlas of Andalucía (ALEA), when followed by a voiceless stop, coda /s/ becomes [h] 79% of the time while deleting and undergoing regressive assimilation 10% and 4%, respectively ([lo^{h} ^{p}pa^{t}ˈtoɾɛh] Sp. *los pastores* “the shepherds”, [ˈmɔhka] Sp. *mosca* “fly”; Moreno, 1996–1997). These percentages are very much in contrast with those occurring before a voiced consonant: 31% for aspiration ([ˈdehðe] Sp. *desde* “from”), and 28% and 17% for elision and assimilation, respectively. The interdental fricative /θ/ may also be realized as [h] before a voiceless stop ([oˈɾohko] Sp. *Orozco*; Zamora Vicente, 1989: 72). Moreover, the Eastern and Western Andalusian dialects differ regarding the phonetic outcome of /s/ aspiration in that, while the stop closing phase cooccurring with aspiration may lengthen in the two dialects, the former dialect favors preaspiration over postaspiration and the latter postaspiration combined optionally with preaspiration (Torreira, 2006, 2007: 78–79). Moreover, Latin American Spanish dialects such as Porteño and Puerto Rican resemble Eastern Andalusian except for the fact that the outcome [hC] of /sC/ does not show a long closure.

Coda /s/ aspiration or fricativization operates before voiceless stops in other non-Spanish speaking dialectal regions within the Romania: in Occitan areas ([eçˈpawlə] SPATULA "back, noun", [eçˈkolə] SCHOLA "school"; Fleischer, 1912: 41), the Vosges region in North Eastern France ([vɛ(ç)ˈti] VESTIRE "to put on clothes"; Bloch, 1917: 68), North Eastern Walloon and Judeo-Spanish (see below), and the Bergamasque dialect in Northern Italy where /s/ aspiration may take place before a voiced consonant as well ([ˈvɛhpa] It. *vespa* "wasp", [pehˈka] It. *pescare* "to fish", [dihˈna] It. *desinare* "to dine"; Rohlfs, 1966: 380, 382). /s/ aspiration occurs exclusively before a voiced sonorant in a few dialectal domains: in Old Walloon before /l, n/ (*ahnesse* "donkey"; Dámaso Alonso, 1962: 49) and in Gascon Garonnais before /l, m, n/ (Allières, 1955; [lah ˈbɛhtis] "the beasts", Ronjat, 1930–1941, 2: 279).

The final outcome of /s/ aspiration is complete elision. In Old French, /s/ deletion appears to have taken place in the XII-XIIIth century whenever the endproduct [h] was followed by a voiceless consonant, while weakened or assimilated outcomes of the alveolar fricative were also effaced before a voiced consonant as exemplified by *mêler* "to mix" which may be traced back to the variant *medler* of the older form *mesler* *MISCULARE (Dámaso Alonso, 1962: 51–52). In Spanish, the zero outcome is found in dialects such as Puerto Rican and Miami Cuban where the two members of a minimal pair like /pásta/ "mush" – /páta/ "leg" are set in contrast by means of vowel duration and are thus realized as [ˈpa:ta] and [ˈpata], respectively (Torreira, 2007: 79).

The aspiration of coda /s/ is also favoured by a following heterorganic velar, which is compatible with an articulatory reduction account since velars do not involve front lingual activity. Indeed, /s/ aspiration operates exclusively or for the most part before /k/ in Judeo-Spanish (Walsh, 1985: 240), and may take place also before the voiceless velar stop word medially in North Eastern Walloon ([ˈh(j)ale] SCALA "staircase", [ˈmohe] MUSCA "fly"; Remacle, 1972: 323, 1953, 1: chart 61) and before /p, k/ in Occitan zones (Drôme [ˈvɛ(h)pre] VESPERU "evening", [ra(h)ˈkla] Fr. *racle* "to scrape", [ˈma(h)kle] Fr. *mâle* "male"; Bouvier, 1976: 200). In other dialectal zones the final endproduct is a back lingual fricative: [ç, x] before /k/ and [ɣ, ɦ] before /g/ across a word boundary in Logudorese Sardinian areas (Contini, 1986: 539 and section 5.1.2.2); [ç, x] before /k/ in the Vosges region (Bloch, 1917: 77). There are articulatory data in support of the hypothesis that /s/ aspiration is favoured by undershoot at constriction location triggered by a non-overlapping contextual consonant. Indeed, EPG data show that /s/ may be articulated with less front lingual contact before labials and dorsals (/b, k/) than before front linguals (/t/) (Colantoni & Kochetov, 2011). It has also been argued that /s/ aspiration is prone to operate before a velar stop because tongue contact loss at the /s/ constriction location may cooccur with some tongue predorsum lowering and tongue body retraction and thus an analogous overall lingual configuration to that of /k/ (Straka, 1964, Walsh, 1985).

5.2.2 Assimilation/elision

5.2.2.1 Before a trill

Regressive manner assimilation may occur in sequences composed of /s, ʃ/ and a following alveolar trill, which are all highly constrained lingual consonants sharing essentially the same centroalveolar or postalveolar constriction location. From a gestural point of view this adaptation process is related to the early onset of lingual movement for the trill perturbing the articulatory trajectory for the fricative as well as the critical constriction area for friction and thus, the fricative becoming rhotic-like when not fully assimilated (Ohala & Solé, 2010: 57).

In Catalan, /sr/ yields [rː] as a general rule, the alternative outcome [r] being generated either through simplification of the geminate or direct elision of the alveolar fricative most often when /s/ belongs to a function morpheme or a frequent word (*dos reis* "two kings", *estàs rebentat* "you are exhausted"; section 2.4.2). Moreover, EPG and acoustic data for /sr/ in the same language reveal that prosodic prominence and/or the strength of the morphological boundary located between the fricative and the trill may affect the degree of C1-to-C2 adaptation, which may be correlated with several articulatory characteristics: constriction location, which is typically more anterior for /s/ than for /r/; manner of articulation, i.e., frication may be present or absent, and precede the rhotic or be overlaid onto the outcoming trill realization; segmental duration, i.e., the outcoming trill realization may be longer than or as long as an underlying alveolar trill (Solé, 1999, 2002b). As to the sequence /ʃr/, the final outcome is regularly [r(ː)] and also [jr] in Catalan dialects where intervocalic /ʃ/ is realized as [jʃ] (*mateix rotllo* "the same roll"). Moreover, whenever /ʃ/ stays, it undergoes some tongue dorsum lowering and constriction opening resulting from the anticipatory coarticulatory effect exerted by the trill (Recasens & Pallarès, 2001b). The sequences /ts#r/ and /tʃ#r/, on the other hand, exhibit the phonetic outcomes [dr] and [d^{j}r] (or [jdr]), respectively, which are analogous to those for /s#r/ and /ʃ#r/ (*soldats russos* "Russian soldiers", *boig rematat* "completely crazy").

Also in Spanish, the fricative may be phonetically absent in realizations of the sequences /sr/ (*la(s) rojas* "the red ones, fem.", *I(s)rael*) and /θr/ (*vo(z) ronca* "hoarse voice", *Cru(z) Roja* "Red Cross"). In Eastern Portuguese, on the other hand, [ʒʀ] stays word internally (*Israel*) and may be realized as [ʀ] across a word boundary apparently through deletion of the fricative consonant (*dois requerimentos* “two requests”, *os rapazes* “the boys”; Herslund, 1986: 510–511). Another relevant case is the word-initial cluster /str/ ([s̺t̺ɾ]) in Sicilian which is realized as [ɽɽ] through assimilation of [s̺] to following [ɽ] after [t̺] effacement (Dulcibella, 1934: 306–307).

The regressive manner assimilation process under discussion is not general across languages. According to Busà (2013), Italian speakers do not assimilate /s/ to following /r/ in manner of articulation but insert [d] or else a schwa-like vowel about 30–50 ms long which may be endowed with the quality of the following vowel (*Is*[d]*raele*, *autobus*[ə] *rosso* “red bus”). The insertion of these transitional segments could be a consequence of the trill having a tap-like realization after /s/ or else of /sr/ and other heterosyllabic consonant sequences exhibiting less gestural overlap in Italian than in languages like Spanish or Catalan. An alternative strategy to regressive manner assimilation is C1 or C2 lenition, as in Finnish where the sequence /sr/ with a syllable-onset trill is realized as [xr] or [sɹ] at least word medially in lexical items such as *Israel* (Suomi et al., 2008: 35).

5.2.2.2 Assimilation in other consonantal contexts

There is a clear trend for regressive assimilation in [hC] sequences derived from /sC/ to be conditioned by the presence of voicing in C2. In the Spanish-speaking town of Villena located in the Alicante province, where coda /s/ (also /θ/) is realized as [h], the fricative may assimilate to a following consonant and most especially to /m, d, n, l, g/: [ˈmullo] *muslo* “thigh”, [ˈdɛððe] *desde* “from”, [ˈmimmo] *mismo* “the same”, [ˈneɣɣa] *nesga* “piece of cloth”, *noviaggo* for *noviazgo* “engagement” (Torreblanca, 1976: 135–137). In other regions of Southern Spain (see section 5.2.1), percentages of assimilation and deletion of aspirated /s/ are also higher before voiced consonants than before voiceless ones and some remnant of aspiration may occur in the contextual voiceless stop condition ([aˈβiʰppa] Sp. *avispa* “wasp”, [gaʰpˈpatʃo] Sp. *gazpacho*; Dámaso Alonso, 1962: 51, Penny, 2000: 123, Catalán, 1971: 86).

The path from aspiration to assimilation is through intermediate coarticulated realizations. As a result of coarticulation, listeners may perceive a weak version of the [h] noise as a regular fricative agreeing in place with the following consonant and, therefore, as /f/ before labials and labiodentals, as /s/ or /ç/ before coronals and as /x/ before dorsals (Silverman, 2003, Colantoni & Kochetov, 2011). These fricative realizations are heard in Spanish dialects such as Andalusian and Argentinian ([ˈbuxko] Sp. *busco* “I look for”, [ˈkaxko] Sp. *casco* “helmet”; Malmberg, 1950: 160, Marrero, 1990), as well as in Gascon areas where /sp/

and /sk/ may yield respectively [fp] and [xk, hk] and words beginning with FL in Latin may be produced with [hl], [zl] and the assimilated outcome [ll] ([ɛh/zˈlamo], [ɛlˈlamo] FLAMMA "flame"; Séguy, 1954, Fleischer, 1912: 49).

Coda /s/ aspiration is however not a necessary precondition for regressive assimilation to apply, as shown by the Majorcan Catalan and Sardinian behaviour described next. In Majorcan Catalan, where /s/ never weakens into [h] in coda position, the alveolar fricative may assimilate to a following nasal or lateral mostly if it belongs to a frequent or function word ([m:] *es moro* "the moor", [ʎ:] *es llit* "the bed"; Recasens, 2014a: 329–330). In a large Sardinian area, C2 voicing has also been reported to play a determinant role in coda /s/ assimilation both word internally and across a word boundary when the alveolar fricative belongs to a function word like the article *is* or the numeral *tres* ([immentiˈɣaɾɛ] "to forget", *im manus* "the hands", *tred dentis* "three teeth"; Wagner, 1984: 307, Blasco, 2002: 76, Contini, 1987: 134). More especifically, regressive /s/ assimilation has been reported to occur before /b, m, f, v, d, n, l, g/ in Campidanese, /m, n, l, r/ in Logudorese and /f, n, l/ in Nuorese (Lorenzo, 1975: 121, Dâmaso Alonso, 1962: 53, Pittau, 1972: 33–34). In a more restricted Sardinian area, the assimilatory process may also operate before voiceless /p, t, k/ (also before /f, ʃ, x/), after which the outcoming geminate may shorten or stay long ([ˈɛp(p)ɛ] VESPA "wasp", [i kˈkanizi] "the dogs"; Contini, 1987: 55, 218, 298, 493). This assimilatory account is however uncertain since, as suggested by several scholars, the geminate outcome in question could also be generated through C1 elision followed by C2 lengthening (Virdis, 1978: 62, and sections 4.1.1.1 and 5.1.2.1). Regressive assimilation of /s/ before a voiced consonant also occurs in the frequent English forms *doesn't* and *wasn't* when the ending -/znt/ is pronounced as -[nn̩t] (Gimson, 1962: 296).

5.2.2.3 Deletion in other consonantal contexts

In dialects where coda /s/ has shifted to [h], consonant effacement may occur through geminate simplification after regressive manner assimilation has applied preconsonantally. This is the case for language scenarios where /s/ aspiration took place before a voiced consonant mostly if a sonorant such as Old Picard (*val(l)et*; Gossen, 1970: 107) and presumably Old French (*blâmer* "to blame", *île* "island"; section 5.2.1), and perhaps for present-day Gascon where [h] derived from /f/ may drop if it belongs to the word-initial clusters /fr, fl/ ([ˈryjta] FRUCTA "fruit", [raj] FRATRE "brother", [ˈlamo] FLAMMA "flame", [lu] FLORE "flower"; Bec, 1968: 119). The Spanish form *lacio* FLACIDDU "flaccid" must have had an analogous development.

In dialectal areas without /s/ aspiration, /s/ may drop through direct elision after undergoing extreme reduction. This reduction process is expected to take place before /m, n/ due to the encroachment of velar opening and the consequent fricative noise source pressure drop (Haggard, 1972, Ohala & Solé, 2010: 64). In addition to the nasal context, /s/ elision has been reported to apply syllable finally before syllable-onset /b, d, l, g/ in Majorcan Catalan (EPG, Recasens, 2014a: 329–330). Therefore, as shown by the following examples, voiced consonants, and sonorants in particular, appear to act as /s/ deletion triggers.

- (Contextual nasal) Balearic Catalan *quare(s)ma* "Lent", *mo(s) n'anam* "we are leaving", *enfalimar* < Cat. *enfurismar* "to upset"; Occitan regions *ane* AS(I)NU "ass", *dinar* < *disnar* "to dine" (Grandgent, 1905: 53), Basse-Auvergne *deme* < *desme* "special tax", *omono* ELEMOS(Y)NA "alms" (Dauzat, 1938: 179); Spanish *levantémonos* < *levantémos-nos* "let us stand up" (Lausberg, 1970: 430); Latin *grāmen* "fodder" < IE **gras-men*.
- (Contextual lateral) Portuguese *ama-lo* < *amas-lo* "love him" (Herslund, 1986: 515); Basse-Auvergne *valet* *VASS(E)LLITTU "kid" (Dauzat, 1938 179).

5.2.3 Rhotacism

As the examples listed in Table III show, rhotacism of coda /s/ operates most often under similar contextual conditions to those favouring /s/ assimilation and elision, namely, before a voiced consonant where, in comparison to other consonantal contexts, the fricative, mostly if apical, is prone to shorten and become voiced and articulated with a wider and less defined constriction and with less tongue-to-palate contact (Romero, 2003). According to literature sources, /s/ rhotacism is prone to apply before a nasal, lateral and /b, d, g/ in dialectal Spanish (Torreblanca, 1976: 135–136), /g/ and less so /b, m, d/ in Majorcan Catalan (Recasens, 2014a: 329–330), /b, m, f, d, z, dz, r, j, g/, but not /n, l/ which trigger assimilation, in Nuorese Sardinian (Pittau, 1972: 33–34), /b, f, v, d, dz, g/ in Logudorese Sardinian (Lorenzo, 1975: 121), and /m, d, g/ and less so /n, l/ in a Western Logudorese Sardinian area (Contini, 1986: 536). An open issue, which is also relevant to /s/ assimilation and deletion, is whether rhotacism is prone to be triggered by sonorancy rather than by voicing and consequently takes place before nasals and laterals due to anticipatory mechanisms, i.e., lowering of the velum and of the tongue sides, which jeopardize the aerodynamic requirements for the generation of turbulence (Ohala & Solé, 2010: 64–65).

It is hard to ascertain whether the fact that coda /s/ and the following consonant share the same primary lingual articulator or not plays any role in /s/ rhotacism. It could be that, analogously to other weakening processes such

Table III: Rhotacism of syllable-final /s/ in preconsonantal position.

/sb/	Majorcan Cat.	*birbe*	ESPISCOPU	"bishop"	
		derbocat	'Cat. desbocat'	"runaway"	
/sd/	Occitan	*derdire*	DISDICERE	"to take back"	(Lorenzo, 1975: 127)
		cordura	*CONSUTURA	"good sense"	íd.
	S. American Sp.	*quierde*	'Sp. que es de'		íd.:132
	S. Spanish	*derde*	'Sp. desde'	"from"	(Torreblanca, 1976: 136)
	dial. Catalan	*aumorda*	Arabic *al-muzda*	"alms"	
		donarda	**donasda*	"agave"	
		ordilles	UTENSILIA	"tools"	
		Ordal	HOSPITALE	place name	
	Old Catalan	*preborde*	PRAEPOSITU	"provost"	
/sm/	Occitan	*esparme*	SPASMU	"spasm"	(Lorenzo, 1975: 127)
		abirme	*ABYSSIMU	"abyss"	íd.
		blarmé	from *BLASTEMARE	"blamed"	íd.
	Lengadocian	*rejerme*	Old Occ. *regesme*	"kingdom"	íd.
	Old Occitan	*carerma*	QUADRAGESIMA	"Lent"	íd.
		ermenda	'Occ. esmena'	"amendment"	íd.
	Asturian	*arma*	'Sp. asma'	"asthma"	(Lorenzo, 1975: 130)
	Galician	*lerma*	LIMACE	"slug"	íd.:136
		parmón	'Sp. pasmón'	"halfwit"	íd.
		pantarma	'Sp. fantasma'	"ghost"	íd.
	Portuguese	*mermo*	'Sp. mismo'	"the same"	(Leite de Vasconcellos, 1987: 98)
	dial. Catalan	*Corme*	'Cat. Cosme'	given name	
		fantarma	'Cat. fantasma'	"ghost"	
		armolls	'Cat. esmolls'	"tongs"	
		erma	'Cat. esma'	"judgement"	
		sancugerma	QUINQUAGESIMA	"Whitsunday"	
		germil	'Cat. gessamí'	"jasmine"	
	Old Roussillonnais	*armaut*	'Cat. esmalt'	"enamel"	
/sn/	Ligurian	*dirná*	DISJEJUNARE	"to dine"	(Rohlfs, 1966: 382)
	Old Picard	*arne*	ASINU	"donkey"	(Gossen, 1976: 107)
		porterne	*posterne*	"secondary gate"	íd.
	Occitan	*aumorno*	ELEEMOSYNA	"alms"	(Ronjat, 1930–1941, 2: 194)
	Lengadocian	*irnelament*	Old Occ. *isnelament*	"promptly"	(Lorenzo, 1975: 125)
	Asturian	*limorna*	ELEEMOSYNA	"alms"	íd.:130
	S. American Sp.	*dernudo*	'Sp. desnudo'	"naked"	íd.:133
	Majorcan Cat.	*aneu-vor'n*	'Cat. aneu-vos-en'	"go away"	
/sl/	Old Picard	*varlet*	Celt.*VASSELITOS	"boy"	(Gossen, 1976: 107)
		merler	*MISCULARE	"to mix"	íd.
		marle	MASCULU	"male"	íd.
	Occitan	*arluciado*	'Occ. esluciado'	"lightning"	(Lorenzo, 1975: 125)
		barlugo	'Sp. vislumbre'	"glimpse"	íd.
	Asturian	*irla*	INSULA	"island"	(Lorenzo, 1975: 130)
	S.American Sp.	*murlo*	MUSCULU	"thigh"	íd.:133
	dial. Catalan	*xirlot*	'Cat. sislot'	"plover"	
		Xirles	SILICES	place name	
		les Irles	INSULAS	place name	
	Old Catalan	*carlà*	CASTELLANU	"castellan"	

/sg/	Asturian	*ergranar*	'Sp. desgranar'	"to enumerate"	(Lorenzo, 1975: 130)
		rielgar	'Sp. rasgar'	"to rip"	íd.
	Galician	*murjo*	'Sp. musgo'	"moss"	íd.:136
	S. Spanish	*nerga*	'Sp. nesga'	"piece of cloth"	(Torreblanca, 1976: 136)
	Occitan	*dumergue*	DOMESTICU	"domestic"	(Ronjat, 1930–1941, 2: 160)
	dial. Catalan	*murga*	MUSICA	"drag"	
		targa	TRANSICA	"thong"	
/sp/	Limousin Occ.	*arpri*	'Fr. esprit'	"spirit"	(Lorenzo, 1975: 127)
/sf/	S. American Sp.	*fórforo*	'Sp. fósforo'	"matchstick"	íd:133
	dial. Catalan	*mòrfora*	'Cat. atmosfera'	"atmosphere"	
/st/	Limousin Occ.	*jurte*	'Fr. jusque'	"until"	(Ronjat, 1930–1941, 2: 200)
		verto	'Fr. veste'	"jacket"	(Lorenzo, 1975: 127)
		murtacho	'Fr. moustache'	"moustache"	íd.
/sθ/	Castilian Sp.	*arcenso*	'Sp. ascenso'	"rise"	(Lorenzo, 1975: 129)
		erceso	'Sp. exceso'	"excess"	íd.

as stop vocalization and /s/ aspiration (sections 5.1.3 and 5.2.1), the change in question is facilitated by contact loss at constriction location when occurring before the heterorganic consonants /b, m, f, g/. (Near)-homorganicity could also contribute to the implementation of the sound change of interest before apical consonants such as /θ/ and the lenited realization [ð] of /d/ in dialectal Spanish (see some relevant examples in Table III) as well as some of the contextual consonants referred to for Logudorese-Nuorese above.

Several examples of rhotacism occurring across a word boundary need to be added, in which target /s/ belongs to a function or high frequent word and the following word-initial consonant is voiced or a dental fricative: dialectal Spanish *már gastos* "more expenses", *lar* [θ]*ejas* "the eyebrows", [lɔɾ ˈmoɾɔ] Sp. *los moros* "the moors"; Logudorese and Nuorese Sardinian *sar dentes* "the teeth", *er medzus* "it is better"; Portuguese *mair dinheiro* "more money" (Lorenzo, 1975, Leite de Vasconcellos, 1987: 98). The realization [l] of word-final /s/ before a word-initial consonant in Sardinian, which should be traced back to an intermediate alveolar rhotic, has been reported to occur mostly before a voiced consonant and /f/ ([trɛl ˈmanɔzɔ] "three hands"), and more especifically before /b, f, v, d, g/ in Western Logudorese (Contini, 1986: 538).

5.2.4 Vocalization

In parallel to other weakening processes affecting syllable-final /s/ such as rhotacism and elision and as revealed by data for the Romance languages presented in Table IV, /s/ vocalization through tongue contact loss at constriction location is prone to take place before a voiced consonant or a sonorant. In addition to the general outcome [j], it may yield [w] mostly before /m, n/ (also before

Table IV: Vocalization of syllable-final /s/ in preconsonantal position.

/sb/	[j]	dial. Catalan	*aibre*	**asbre* ARBORE	"tree"	
			maibre	**masbre* MARMORE	"marble"	
			escaibre	**escasbre* SCALPRU	"chisel"	
/sm/	[j]	Catalan	*esblaimat*	BLASTEMARE	"pale"	
		Old Catalan	*raima*	Ar. *razma*	"ream"	
			eymina	*ESMINA	measurement	
		dial. Catalan	*espaimat*	from SPASMU	"astonished"	
			aimari	*asmari* ARMARIU	"cupboard"	
			escaimat	*SCATTIMARE	"lost"	
		Occitan	*blaimá*	*BLASTIMARE	"to blame"	(Ronjat, 1930–1941, 2: 157)
			deime	DECIMU	special tax	íd.: 189
			baime	BALSAMU	"balsam"	íd.: 159
			èime	from ADAESTIMARE	"judgement"	íd.: 201
			espaime	SPASMU	"spasm"	íd.
			carèimo	QUADRAGESIMA	"Lent"	íd.
	[w]	Occitan	*espaume*	SPASMU	"spasm"	(Ronjat, 1930–1941, 2: 201)
			fantaumo	PHANTASMA	"ghost"	íd.
/sd/	[j]	dial. Catalan	*broidar*	Germ. *BRUZDON	"to embroider"	
		Old Catalan	*preboyde*	PRAEPOSITU	"provost"	
/sn/	[j]	Catalan	*dinar*	DISJEJUNARE	"to dine"	
			almoina	ELEEMOSYNA	"alms"	
			mainada	MANSIONATA	"children"	
		dial. Catalan	*rebeinét*	from NEPTU	"great-great-grandson"	
			roinejar	from ROS	"to sprinkle"	
		Old Catalan	*raina*	rasna	fish type	
		Occitan	*aine*	ASINU	"donkey"	(Ronjat, 1930–1941, 2: 194)
	[w]	Auvergnat	*omouno*	ELEEMOSYNA	"alms"	(Dauzat, 1938: 179)
/sl/	[j]	Occitan	*pèile*	PESSULU	"bolt"	(Ronjat, 1930–1941, 2: 242)
		Catalan	*vailet*	Celt. *VASSELITOS	"boy"	
			illa	INSULA	"island"	
			guilla	Germ. WIHSELA	"fox"	
/sr/	[j]	Old Catalan	*preyron*	PRESERUNT	"they caught"	
			respoyren	RESPONDERUNT	"they answered"	
/sg/	[j]	Catalan	*iglésia*	**eiglésia* 'església'	"church"	
		dial. Catalan	*traiga*	TRANSICA	"thong"	
/sp/	[j]	Francoprov.	[ˈvɛjpa]	VESPA	"wasp"	(Rousselot, 1891)
/st/	[j]	Francoprov.	[ˈfejta]	FESTA	"feast"	(Rousselot, 1891)
			[ˈkrɛjtə]	CRISTA	"crest"	íd.
			[ejˈtela]	STELLA	"star"	íd.
		Perigordian	[ˈbejtjɔ]	BESTIA	"beast"	(Marshall, 1984: 25)
	[w]	Haute Loire	[ˈkrowtə]	'Fr. croûte'	"crust"	(Nauton, 1974: 227)
			[ˈkowta]	COSTA	"coast"	íd.
/sk/	[j]	Limousin	[ˈejkɔlo]	SCHOLA	"school"	(Lafont, 1983: 51)

/t/) whenever the preceding vowel is low or back rounded. The outcome [j] may also be issued from [ç]-like realizations whether derived from /s/ in Limousin Occitan forms such as [e(j)ˈkɔlo], [exˈkɔlo] SCHOLA “school” (Lafont, 1983: 51) or from /f/ in Gascon phonetic variants like [ejluˈɾi], [(ɛ)hluˈɾi] FLORIRE “to blossom” (Fleischer, 1912: 49).

Across a word boundary, the vocalization of the alveolar fricative into [j] operates exclusively before a voiced consonant in Gascon (*erai duoi rodos* ILLAS DUAS ROTAS “those two wheels”; Rohlfs, 1970: 145), and in this same context as well as before /f, s, tʃ/ in Lengadocian Occitan areas: [ej ˈmɔrt] *es mòrt* “he is dead”, [laj bɛloj ˈbakos] *las bèlos vacas* “the nice cows”, [bunoj ˈsɛgos] *bonas sègas* “good harvests”, [laj ˈfennos] *las femnas* “the women” (Wheeler, 1988: 252, Michel, 1955: 103).

5.2.5 Palatalization

Another change which could be associated with weakening, albeit not too convincingly, is the palatalization of preconsonantal /s/ into [ʃ]. As pointed out in section 2.2, some form of lingual retraction in addition to contact loss at constriction location may characterize the articulatory reduction of coda consonants.

In the Romance languages, this sound change operates preferably before one or more voiceless stops depending on the dialect taken into consideration. In Italy, /s/ palatalization may apply word internally either before any voiceless stop, before /p, k/ in Northern and Southern dialects (*mo*[ʃ]*ca* “fly”, *ve*[ʃ]*pa* “wasp”), or just before /k/ in Calabria and Lucania whenever /sk/ derives from the Latin cluster /skl/ (*mas*[ʃ]*cu* MASC(U)LU “male”) (Rohlfs, 1966: 379–380). In Sardinian, /s/ palatalization operates mostly before /p, k/ in S. Logudorese (Contini, 1987: 487, 1986: 536), while in the Barbagia region /s#f/ yields [(ʃ)ʃ] through the intermediate realization [ʃɸ], as proved by coexisting variants of *duas fem(m)inaza* “two women” such as *dua*([ʃ]) [ʃ]*eminaza* and *dua*[ʃˈɸ]*eminaza* (Contini, 1986: 539–540). Regarding the Iberian Peninsula, /s/ may turn into [ʃ] before /k/ more or less often in Old Spanish and Judeo-Spanish (*moxca*, *cáxcara* “shell” where *x* corresponds to [ʃ]; Zamora Vicente, 1989: 356) and in Valencian Catalan as well (*vixc*, *merexcut*, *moxca* and *foxc* for the standard forms *visc* “I live”, *merescut* “deserved”, *mosca* “fly” and *fosc* “dark”). /s/ palatalization before a voiceless stop occurs in language domains as diverse as Rhaeto-Romance from Engadine, Slovenian and several Iranian languages (Grammont, 1971: 207).

The reason why preconsonantal /s/ may shift to [ʃ] is probably not due to constriction retraction since lingual fricatives are known to be highly resistant to coarticulatory effects in constriction fronting (Recasens & Pallarès, 2001a, b). A more plausible triggering factor may be an increase in sublaminal cavity size, which is prone to occur in apical realizations of the alveolar fricative and contributes to some lowering of the /s/ spectral peak frequency (/ʃ/ has a lower spectrum frequency than /s/). This explanatory hypothesis is consistent with the sound change in question operating most often before the velar stop /k/, which is articulated with a low jaw position and may cause some jaw lowering and enlargement of the sublingual cavity during the fricative.

The same /s/ palatalization process may take place word initially before a tautosyllabic consonant in Standard German and in the case of the sequence *str* (/stɹ/) in English dialects where it could be attributed to tongue bunching anticipation associated with the rhotic (Mielke et al., 2010). It has been found in this respect that /s/ has a lower spectral center of gravity before /t/ than before a vowel in German (*Liste*, *Kiste* vs *wisse*) and American English (*steam* vs *seem*, *sane*) and that, as a consequence of this contextual difference, German listeners may hear /s/ as more /ʃ/-like before /t/ than before a vowel (Stevens et al., 2015).

5.2.6 Summary

Regressive manner assimilation of coda /s/ is prone to apply before a voiced consonant and is associated primarily with weakening whether it takes place after /s/ aspiration (as in Southern Spanish dialects) or not (as in Majorcan Catalan). Moreover, in contrast to manner assimilations affecting other coda consonants, this assimilatory process does not seem to be related to homorganicity except perhaps for the change of /sr/ into [(r)r] which appears to also be determined by the antagonistic manner of articulation requirements for C1 and C2.

The weakening of coda /s/ may yield aspirated, rhotacized, vocalized and perhaps palatalized realizations of the fricative consonant. /s/ rhotacism and /s/ vocalization mostly into [j] parallel the scenario for coda stops in that they occur most frequently before a voiced consonant (see section 5.1.3). /s/ aspiration, on the other hand, is achieved through constriction loss and is prone to operate before voiceless obstruents since it involves glottal opening, though it may take place before voiced nasals, laterals and approximants as well. /s/ palatalization is also favoured by the presence of a following voiceless consonant. Analogously to coda stops, the aspiration, rhotacism and palatalization of coda /s/ may also be facilitated by heterorganicity and thus the presence of a following labial or dorsal, while homorganic apical consonants could also contribute to the rhotacism of preceding /s/.

The alveolar fricative may drop in coda position after undergoing aspiration into [h], or else reduction into [ˢ] mostly before a voiced C2 preferably if it is a sonorant. /s/ deletion may also take place through simplification of an assimilated geminate issued from the realizations [hC] or [ˢC] of /sC/.

5.3 Nasals

5.3.1 Assimilation/elision

5.3.1.1 Contextual fricative

Historical grammarians often assume that the single fricative outcome of consonantal sequences composed of a nasal and a following homorganic fricative is achieved through simplification of a geminate issued through a regressive manner assimilation process (e.g., /ns/ > [ss] > [s]). There are however reasons to believe that, in most cases, the fricative outcome in question has come to exist through deletion of the nasal rather than through geminate simplification. Moreover, it may be argued that homorganicity between the two adjacent consonants, which is prone to occur in /nC/ sequences in the world's languages, facilitates nasal deletion.

There are several signs of reduction and deletion of coda nasals before a homorganic fricative. On the other hand, /n/ has often been found to lack a complete linguoalveolar closure before alveolar and palatoalveolar fricatives, as revealed by EPG data for Japanese and also for South American Spanish dialects where [ʃ]/[ʒ] may correspond to /ʎ/ (Kochetov & Colantoni, 2011, Kochetov, 2014). Straight deletion after articulatory reduction accounts for phonetic variants in which the nasalization property has been trasferred to the preceding vowel (dial. Spanish [lõxa] Sp. *lonja* "market"). It may also explain the occasional simplification of the ending *-ns* into *-s* in function and frequent words in dialects where vowels are barely nasalized before a coda nasal, as for *us* < *uns* "indefinite article, masc. pl.", *tes* < *tens* "you have", *mos* < *mons* "our, masc. pl." and *ges* < *gens* "not at all" in dialectal Catalan. The elision of a nasal consonant before a fricative has also been attributed to a hypercorrecting action by which listeners misinterpret the nasal as a kind of spurious element that they have come to expect in this contextual environment and thus discount it (Ohala & Busà, 1995).

Specific languages and dialectal zones are most favourable to the nasal deletion process. In N. Italian, the nasal of the clusters /nf, ns, nʃ/ as in *infimo* "negligible", *penso* "I think" and *conscio* "aware" is weak articulatorily, which explains why it may be missed by the listener and causes the preceding vowel to lengthen and become more heavily nasalized than when occurring before the more complex cluster /nts/ as in *pinza* "clamp" (Busà, 2007). A good exemplifying form is [mũ:(ŋ)ˈʒa] MULGERE "to milk" from the Piedmontese dialect of Val d'Antrona in which the vowel lengthens and becomes fully nasalized after the nasal consonant is deleted (Tuttle, 1991). Whenever occurring before a fricative, the alveolar nasal becomes [w̃] in Polish (Gussmann, 2002), and drops and causes the preceding vowel to become nasalized across a word boundary in Frisian (van der Meer & de Graaf, 1986: 318–319) and in fast speech in Dutch ([ɔ̃zekər] *on-zeker* "uncertain"; Booij, 1995: 148). /n/ also drops before a fricative in Zoque if acting as a pronominal prefix (Padgett, 1994), in Finnish in fast speech (Suomi et al., 2008: 43) and in Lithuanian prior to preceding vowel lengthening (Baković, 2007: 344).

Historical data also shed light on the evolution of homorganic nasal + fricative sequences. There are reasons to assume that the replacement of Latin /ns/ by [z] in intervocalic position in the Romance languages (Catalan *pe*[z]*ar* PENSARE "to weigh", Old Spanish *me*[z]*a* MENSA "table") occurred through nasal stop deletion rather than through regressive assimilation followed by geminate simplification. Indeed, in parallel to other Latin voiceless obstruents, the endproduct [z] of /ns/ was achieved through voicing of the intermediate stage [s]; in case /ns/ had assimilated into [ss], the final outcome in Romance would have been [s] since Latin geminates underwent simplification but not voicing in the Romance languages. It should be noticed however that, as to the Latin nasal + labiodental fricative sequences, nasal consonant loss may account for the outcome [v] of /nv/ (NV) but not for the outcome [f] of /nf/ (NF) which ought to have been [v] instead: (/nv/) Old Catalan *(a)covidar* *CONVITARE "to invite", dial. Occitan *cumbent*, *cuvent* "convent" (Ronjat, 1930–1941, 2: 213); (/nf/) dial. Occitan [ˈuflo] INFLO "I swell", *e/ufant* INFANS "infant", Catalan *botifló* for *botinfló* "fat person", Old Spanish *i(n)fante*, Old Portuguese *iferno* INFERNU "hell" (Ronjat, 1930–1941, 2: 211, Menéndez Pidal, 1968: 137, Williams, 1938: 76).

Whenever regressive assimilation applies, the nasal turns into a nasalized fricative as in the case of the realization [f̃f] (also [ɱf]) of /n#f/ in Spanish sentences like *són felices* "they are happy" (Honorof, 1999). Geminate fricatives generated through regressive assimilation and the corresponding simplified realizations occur word medially in Sardinian, most especially in Logudorese: *cossolare* < *consolare* "to comfort", *ifferru* INFERNU, [laθˈθare] LANCEARE, Nuorese [leˈθolu] LINTEOLU (Sampson, 1999: 285, Contini, 1987: 139, Wagner, 1984: 296, 300). Also in Sardinian, /ns/ is realized as [s:] across a word boundary whenever the nasal belongs to the prepositions *in*, *non* and *cun* ([kũs:uˈvraðɛ] /kun su fráde/ "with his brother", [is:aˈiɖ:a] < /in sa bíɖɖa/ "at the village";

Ladd & Scobbie, 2003). This cross-word boundary assimilation process, which may also apply before /f/ (*nof facas* for It. *non fare*! "do not do it!"; Pittau, 1972: 36), remains unclear since there are reasons to believe that the geminate is generated through C1 elision followed by C2 lengthening (see also section 5.2.2.2).

5.3.1.2 Contextual liquid

Whether achieved through place assimilation or blending, homorganicity appears to also play a relevant role in the regressive manner assimilation and deletion processes /nr/> [rr], [r] and /nl/ > [ll], [l] (section 3.3.1.1). Regarding manner assimilation, it is hypothesized that the identity in constriction location between the two successive consonants in the two originary sequences ought to facilitate the lowering of the front central lingual region or the tongue sides and thus the replacement of /n/ by the alveolar trill or the alveolar lateral, respectively. As to /n/ elision, the long duration of the alveolar trill renders it difficult to elicit whether the replacement of /nr/ by [r] in dialectal forms such as those listed in Table V (top) has been achieved through elision of the alveolar nasal (/nr/ > [r]) or through regressive manner assimilation followed by geminate simplification (/nr/ > [rr] > [r]). In support of the elision account, EPG data for /nr/ uttered by Italian speakers show the absence of any trace of /n/ and thus maximal reduction of the tongue front gesture for the alveolar nasal (Farnetani & Busà, 1994). Straight nasal deletion ought to also apply in Frisian and Lithuanian followed by the same changes in the preceding vowel which occur after /n/ elision before /l/ (see below in this section). On the other hand, regressive manner assimilation probably applied to the prefixes *con* and *in* before a stem-initial trill in Latin as suggested by present-day English lexical forms like *correspond* and *irresponsible*, and explains the presence of the long rhotic in Nuorese Sardinian which could also be accounted for through C1 elision followed by C2 gemination (*nor rugas* for It. *non cadere*! "do not fall"; Pittau, 1972: 36).

Homorganicity also contributes to progressive manner assimilation of /n/ after /r/ provided that progressive assimilation in constriction location has previously applied (section 3.3.2). As revealed by the examples given in Table V (top), this progressive manner assimilation process occurs less often than regressive manner assimilation of /n/ before /r/. Moreover, the deletion of the alveolar nasal in the word ending /rn/ in some examples listed at the bottom of the table may also be attributed to the homorganic relationship between C1 and C2 after progressive assimilation in place of articulation has taken place.

Homorganicity may also contribute to the anticipatory lateralization of /n/ before /l/ and, in the long run, to the change of /nl/ into [ll]. Examples of

Table V: Assimilation and elision of /n/ in the context of /r/.

Nasal assimilation or elision next to /r/					
/nr/	Umbrian	*la marritta*	'It. la mano ritta'	"upright hand"	(Rohlfs, 1966: 339)
	Senese	*ur ramo*	'It. un ramo'	"a branch"	íd.
	Old Sicilian	*tirrò*	TENIRE, fut.	"I will have"	(Dulcibella, 1934: 402)
		convirrà	CONVENIRE, fut.	"he/she will agree"	íd.
	Italian	*verrò*	VENIRE, fut.	"I will come"	(Maiden, 1995: 72)
	Old Tuscan	*orrare*	'It. onorare'	"to honour"	íd.
	Old French	*durrai*	'Fr. donerai'	"I will give"	(Pope, 1938: 148)
	Old Catalan	*perrets*	*PRENDERETIS	"you will seize"	
	Old Portuguese	*marrei*	*MANERE AIO	"I will remain"	(Williams, 1938: 105)
	Old Picard	*engerra*	'Fr. engendra'	"(s)he will create"	(Gossen, 1970: 117)
		terront	'Fr. tiendront'	"they will have"	íd.
/rn/	Campidanese	*fòrru*	FURNU	"oven"	(Virdis, 1978: 60)
		kòrru	CORNU	"horn"	íd.
		torrái	TORNARE	"to come back"	íd.
	Abruzzese	[ˈkarə]	'It. carne'	"flesh, meat"	(Rohlfs, 1966: 340)
		[ˈjurə]	DIURNU	"day"	íd.
Nasal elision in word-final /rn/					
	Occitan	*car*	CARNE	"flesh, meat"	(Ronjat, 1930–1941, 2: 356)
		ibèr	HIBERNU	"winter"	íd.
		[dʒur], [ʒun]	DIURNU	"day"	(Lafont, 1983: 60)
	Old Occitan	*cor(n)*	CORNU	"horn"	(Grandgent, 1905: 46)
		tor(n)	TORNU	"lathe"	íd.
	French	*four*	FURNU	"oven"	

this regressive assimilation process may be found in Italian (Old Italian *nolla* < *non la*, Tuscan *culla* < *con la*, *spilla* SPINULA, *mallevare* MANU LEVARE "to guarantee"; Rohlfs, 1966: 339, 355), in specific Old Basque lexical items (Michelena, 1961: 366), and in Sardinian where, in parallel to the scenario described in section 5.3.1.1, the nasal consonant of the particles *in*, *non* and *cun* undergoes regressive assimilation or else elision followed by C2 gemination when occurring before word-initial /l/ ([il ˈletu] "in bed"; Jones, 1988: 326, Pittau, 1972: 36). In Cairene Arabic and other Arabic dialects such as Lybian, the assimilation process of interest may apply within and between phonological words ([kal lu] /ka:n lu/ "he had"; Youssef, 2013: 30, Elramli, 2012: 86, Watson, 2002: 237–238). Also in Korean, Sanskrit and Old Irish, /nl/ assimilates into [ll] (Cho, 1999: 46, 58–59, 212), and the same regressive change operated on the prefixes *in* and *con* before a stem starting with /l/ in Latin, which accounts for present-day English forms like *collaborate* and *illegal*. The progressive lateralization process /ln/> [ll], on the other hand, is available in Korean, Old Irish and Old Finnish (Cho, 1999: 212, Hutcheson, 1973: 96–97), Latin (*collis* < **col-nis* "hill"), and less often than regressive lateralization in other language domains (Old Romanesco *alla* ALINA, *giallo* < Old French *jalne*; Rohlfs, 1966: 340).

The sequence /n#l/ undergoes direct elision of the alveolar nasal in Frisian and Lithuanian, after which the preceding vowel becomes nasalized in the former language (van der Meer & de Graaf, 1986: 318) and lengthens in the latter (Bakovic, 2007: 352). In Zoque, the pronominal prefix /n/ deletes before laterals and rhotics (Padgett, 1994).

5.3.1.3 Contextual stop

There may also be regressive manner assimilation in sequences composed of a nasal consonant followed by a homorganic voiceless labial, dentoalveolar or velar stop, in which identity in place of articulation between the two adjacent consonants may be achieved through place assimilation or blending depending on closure location: /mp/ > [pp] (Romanesco *roppe* for It. *rompere* "to break"; Rohlfs, 1966: 365); /nt/ > [tt] (Salentino *cuttente* for It. *contento* "happy, masc. sing.", Cairene Arabic [bint], [bitt] /bint/ "girl"; Rohlfs, 1966: 339, Elramli, 2012: 97); [ŋk]> [kk] (Sardinian *ma*[kk]*ai* and [afˈfiku] for *mancari* "even though" and *affinku* "care"; Wagner, 1984: 301).

The nasal may also drop before a homorganic stop or affricate, as exemplified by the phonological process /nt/ > [t] in Swahili (Pater, 2001) and by lexical variants such as *tapoc* < *tampoc* "neither" in dialectal Catalan and *ma*[t:ʃ]*a* < *man*[tʃ]*a* MANTICE "bellows" in the S. Sardinian region of Sárrabus (Wagner, 1984: 301). The motivation for nasal deletion in this case may be sought in the high air pressure level needed for the production of the voiceless stop, which may cause the velum to raise prematurely and the nasal murmur for the preceding nasal consonant to shorten and cease to be perceived. In these circumstances, nasality may be cued perceptually not by the nasal consonant but by the preceding nasalized vowel, as shown by the minimal pair [kæ̃p] *camp*/[kæp] *cap* in American English (Malécot, 1960).

Nasals are longer and thus more perceptible and more prone to be maintained when followed by a voiced obstruent, as revealed by American English where /n/ typically stays in *send* and *pined* and may be deleted in *sent* and *pint* (Greenlee & Ohala, 1980, Fujimura & Lovins, 1978). In any case the nasal consonant may also delete before a voiced stop, as exemplified by the variant *tabé* of the frequent word *també* "also" in dialectal Catalan.

5.3.2 Rhotacism

The change of /n/ into an alveolar rhotic is achieved through tongue contact loss at closure location and, in parallel to /s/ rhotacism, may take place before a voiced consonant. There are examples of /n/ rhotacism before another nasal in which the rhotic outcome may have shifted to [l] (coll. Tuscan *auturno* for It. *autunno* "autumn", Old Occitan *mermar* MIN(I)MARE "to lessen", Spanish *alma* AN(I)MA "soul", dial. Catalan *colna* for /'konnə/ "crust, peel"; Rohlfs, 1966: 461, Ronjat, 1930–1941, 2: 216, Grandgent, 1905: 84). Rhotacism of the alveolar nasal may also occur before a voiced stop, as in the case of the Occitan forms *morgue* MONICU "monk" and *margue* MANICA "sleeve" (Ronjat, 1930–1941, 1: 244, Grandgent, 1905: 83).

5.3.3 Summary

Manner assimilation in nasal + consonant sequences is facilitated by homorganicity and thus place assimilation of syllable-final /n/ to the following syllable-onset consonant. It may involve a change into a trill or /l/ at the regressive and progressive levels, and into a voiceless stop or fricative at the regressive level. Homorganicity may also contribute to the elision of a coda nasal, mostly when followed by a fricative, /l/, a trill or a voiceless stop or affricate. The rhotacism of /n/ is associated with articulatory reduction and operates before voiced consonants.

5.4 Laterals

5.4.1 Assimilation/elision

5.4.1.1 Contextual trill

For analogous reasons to those mentioned in section 5.3.1.2, it is hard to ascertain whether the trill outcome of the sequences /lr/ and /rl/ in the examples listed in Table VI has been achieved through direct elision of /l/ or through simplification of the geminate [rr] after the lateral has assimilated to the rhotic. Both manner assimilation and /l/ elision may be facilitated by homorganicity between the two consecutive consonants, which may be achieved through assimilation in constriction location rendering /l/ postalveolar (see sections 3.3.1 and 3.3.2).

At the phonological level, regressive manner assimilation applies to /lr/ in Hungarian and in Cairene Arabic and other Arabic dialects such as Lybian and Syrian, both word internally and across a word boundary: Hungarian [bɔrˈroːl] *bal-ról*, [ˈteːrrɛ] *tél-re* (Kenesei et al., 2010: 438); Arabic [waːkir riɣiːf] /waːkil riɣiːf/ "eating a loaf" (Youssef, 2013: 30, Elramli, 2012: 86, Watson, 2002: 238, Heselwood et al., 2011, Heselwood & Watson, 2013).

Table VI: Assimilation of /l/ to /r/.

/lr/	Italian	*torre*	TOLLERE	"to take off"	(Rohlfs, 1966: 338)
	Old Picard	*mourre*	MOLERE	"to grind"	(Gossen, 1970: 117)
		sorre	SOLVERE	"to solve"	íd.
	Old French	*purrə*	PULVERE	"dust"	(Pope, 1934: 148)
	Catalan	*forrat*	'Cat. folrat'	"covered"	
		Torrà	'Cat.Tolrà' TOLOSANU	family name	
/rl/	Campidanese	*feúrra*	FERULA	"birch"	(Virdis, 1978: 60)
		meúrra	MERULA	"blackbird"	(Blasco, 1984: 228)
	Old Senese	*Orrando*	'It. Orlando'	given name	(Rohlfs, 1966: 340)
	Calabrese	*scarratina*	'It. scarlatina'	"scarlet fever"	íd.
	Sicilian	*Ca*[ɽɽ]*u*	'It. Carlo'	"Charles"	(Millardet, 1925: 737–738)
		pa[ɽɽ]*u*	'It.parlo'	"I speak"	íd.

5.4.1.2 Contextual stop, nasal and fricative

The alveolar lateral may assimilate in manner of articulation to other consonants sharing the same constriction location through some slight change in tongue configuration.

In sequences composed of /l/ followed by a dental stop or an alveolar affricate, the lateral may shift to a stop after blending has taken place and thus the cluster has come to be realized through a single closure location (section 3.3.4.3). This regressive manner assimilation process may be exemplified with lexical variants taken from Spanish and Italian dialects: Chilean Spanish *mutta* < *multa* "fine", Antillian Spanish *fadda* < *falda* "skirt"; Calabrese *caddu* and *fadda*, Salentino [ˈud:zu], Velletri [aˈd:za] and Abbruzzese [ˈfad:zə] for It. *caldo* "hot", *falda* "slope", *bolso* "purse", *alzare* "to raise"and *falso* "false", respectively (Alonso, 1967: 228, Rohlfs, 1966: 344, 348, 381). In Malayalam, regressive occlusivization of /ɭ/ before /t/ occurs after the stop becomes homorganic with C1 and thus retroflex (/ɭt/ > [ʈʈ]).

Homorganicity appears to be also involved in the implementation of the regressive and progressive manner assimilations /ln/ > [nn] and /nl/ > [nn]. The replacement of /l/ by [n] is in line with production data showing that velic position is lower for liquids than for obstruents and that velar lowering for C2=/n/ is anticipated during C1=/l/ in the sequence /ln/ (Bell-Berti, 1993, Moll & Daniloff, 1971). The regressive change /ln/ > [nn] operates in Cairene Arabic in fast speech (Watson, 2002: 238–239), in specific lexical items in other languages (Catalan anthroponym *Monner* MOLINARIU), and across a word boundary in Logudorese Sardinian if we assume that the nasal geminate has not been generated through /n/ strengthening after /l/ deletion ([sa nˈnuεzε] "the clouds"; Contini, 1986: 538). The progressive change /nl/ > [nn], on the other hand, may take place across a word boundary in Marchegiano ([n ˈnume] and [n ˈna] for It. *un lume* "a light" and *in là* "in there"; Rohlfs, 1966: 340) and Alguerese Catalan ([n:] in Cat. *fan lo forat* "they dig the whole", *con la dona* < *com la dona* "like the woman"). Progressive nasalization may also operate on the alveolopalatal lateral, as exemplified by the change /nʎ/ > [ɲɲ] (dial. Catalan *co*[ɲ:]*oga* < *conlloga* "consortium", *e*[ɲ:]*oc* < *enlloc* "nowhere") and the phonetic derivation /ngl/ > [ŋgʎ] > [ɲʎ] > [ɲ] (Sp. [ˈuɲa] *uña* UNGULA "nail").

Homorganicity may also contribute to the elision of a preconsonantal alveolar lateral. The lateral may drop before dentoalveolar /t/ or the alveolar stop component of an affricate after blending has taken place, as shown by phonetic variants taken from Roussillonnais Catalan (*cutiu* *CULTIVU "crops", *cotell* CULTELLU "knife", *escotar* AUSCULTARE "to listen to") and dialectal Italian (Calabrese *atu* ALTU "high", *fa*[ts]*u* FALSU "false", Castro dei Volsi in Lazio *vota* for It. *volta* "time", [ˈatə] ALTERU "another one"; Rohlfs, 1966: 344, Pensado, 1991: 77–78). It is worth pointing out that /l/ deletion before /t/ cannot take place through alveolar contact loss since the alveolar lateral is articulated with as much tongue contact at closure location as the oral stop in the sequence /lt/; therefore, in this contextual condition the lateral may only cease being perceived after shortening considerably in fast speech or in frequent lexical items such as those for dialectal Italian given above. On the other hand, the elision of /l/ before /s/ may be triggered by alveolar contact loss in line with the fact that the fricative is articulated with no central contact at constriction location: Spanish *soso* INSULSU "tasteless", Castro dei Volsi in Lazio [ˈpusə] PULSU "wrist" (Pensado, 1991: 77–78); Old Picard -ALIS > *-es*, as in *tes* and *ques* for Fr. *tel* "such" and *quel* "which one" (Gossen, 1970: 52); Old regional French *ostes* HOSPITALIS "hospitable" (Pope, 1934: 155); dialectal Catalan *vos* and *des* for *vols* "you want" and *dels* "of the, masc. pl.".

5.4.1.3 Contextual velar and labial

As shown by the examples listed in Table VII (top), the alveolar lateral may also undergo regressive occlusivization before /k, g/, which may be facilitated by near-homorganicity at the rear of the vocal tract where the two consonants in the cluster may share a tongue body closure or constriction (section 4.4.1). The assimilation of the alveolar lateral to a following labial is however not associated with homorganicity but results from the superposition between the lip closing gesture for the labial and the apical gesture for /l/. Some examples included in the table require a special justification: /l/ assimilation to a following stop in dialectal Spanish and perhaps other dialectal domains may have taken place after the lateral has shifted to *r* and perhaps the rhotic has become aspirated (section 5.5.2); the Sardinian geminate outcomes [xx, ɣɣ] of /l/ + /k, g/

Table VII: Assimilation of coda /l/, and elision of the alveolar lateral in the preconsonantal and postconsonantal positions.

/l/ assimilation					
Labial	Florentine	*ip pane*	‘It. il pane’	“the bread”	(Rohlfs, 1966: 338)
	Lucanian	*upp*	‘It. volpe’	“fox”	íd.
	Dominican.	[ˈamma]	‘Sp. alma’	“soul”	(Malmberg, 1971: 391)
	Republic Sp.	[ˈpuppo]	‘Sp. pulpo’	“octopus”	íd.
	N.Logudorese	*cuppa*	CULPA	“fault”	(Jones, 1988: 326)
Velar	Salento	[ˈfagge]	FALCE	“sickle”	(Rohlfs, 1966: 348)
	Lucanian	[sukk]	‘It. solco’	“furrow”	íd.: 339
		[kakˈkaɲ]	‘It. calcagno’	“heel”	íd.
	Cuban Sp.	[ˈaggo]	‘Sp. algo’	“something”	(Lipski, 1996: 257)
	N.Logudorese	[kaxˈxandzu]	CALCANEU	“heel”	(Contini, 1987: 295)
		[ˈmuɣɣɛrɛ]	MULGERE	“to milk”	(Jones, 1988: 326)
/l/ elision					
Preconsonantal position					
Labial	Catalan	*pam*	PALMU	“handspan”	
		cop	COLAPHU	“blow”	
		om	ULMU	“elm”	
		pop	POLYPU	“octopus”	
	Lombard	*tap*	TALPA	“mole”	(Pensado, 1991: 77–78)
		savia	SALVIA	“sage”	íd.
	Old Picard	*mavaise*	MALIFATIA	“bad,fem.sing.”	(Gossen, 1970: 115)
		saf	SALVU	“safe”	íd.
		savage	SILVATICU	“wild”	íd.
		pamier	PALMARIU	“palm tree”	íd.
		amosne	ELEEMOSYNA	“alms”	íd.
	English	[kɑːm]	‘Eng. calm’		
		[ˈsɑːmən]	‘Eng. salmon’		
Velar	Old Picard	*acun*	*ALICUNU	“a few”	(Gossen, 1970: 115)
	S. French	*quequefois*	‘Fr.quelquefois’	“sometimes”	(Coustenoble, 1945: 125)
	dial. Catalan	*foguera*	‘Cat. falguera’	“fern”	
		soc	‘Cat. solc’	“furrow”	
		cogar	‘Cat. colgar’	“to hang“	
	English	[wɔːk]	‘Eng. walk’		
Postconsonantal position					
Labial	dial. Catalan	*pus*	PLUS	“more”	
		dobbés	DUPLARIOS	“money”	
		fabiol	‘Cat. flabiol’	“shepherd’s flute”	
	Vosges	[trɛf]	‘Fr. trèfle’	“clover”	(Bloch, 1917: 39)
	Ardennes	[tab]	‘Fr. table’	“table”	(Bruneau, 1913: 379)

Velar	dial.Catalan	*rescum*	'Cat. resclum'	"stink"	
		giscar	'Cat. xisclar'	"to scream"	
		cofoll	'Cat. clofoll'	"shell"	
		onque	'Cat. oncle'	"uncle"	
	Occitan	*cerque*	cercle	"circle"	(Ronjat, 1930–1941, 2: 375)
	Calabrese	[ˈmaʃku]	MASCULU	"male"	(Rohlfs, 1966: 351)
	Neapolitan	[ˈiʃka]	*Ischia* *ISCLA	place name	íd.
	Ardennes	[sɛk]	'Fr. cercle'	"circle"	(Bruneau, 1913: 379)

must have been generated through C2 lenition followed by regressive fricativization of the alveolar lateral (see also section 5.1.2.2).

The reduction of the apical gesture may account for instances of /l/ elision next to a heterorganic consonant whose articulation does not involve the tongue front, and thus before a velar or a labial in syllable-coda position and after the same consonants in syllable-onset position (Table VII, bottom). The motivation for /l/ elision in this case may also be acoustic since dark /l/ shares similar grave spectral properties with labials and velars and therefore may be missed by listeners when occurring in sequences like /lp, pl, lk, kl/.

5.4.2 Rhotacism

The change /l/ > *r* may occur syllable finally before a syllable-onset consonant and after a stop or /f/ in tautosyllabic onset clusters. In both cases, it is prone to affect a clear variety of the lateral since both clear /l/ and an alveolar tap or a short trill-like realization share similar articulatory characteristics (an apical constriction and a fronted tongue body) and spectral properties (a high F2 frequency towards 1800 Hz).

Whenever occurring syllable finally, the replacement of /l/ by an alveolar rhotic appears to be favoured by a following heterorganic labial or velar consonant. Rhotacism occurs more or less often before consonants of these two places of articulation in Italian dialects (Ligurian *vurpe* VULPE "fox", *surcu* SULCU "furrow", Piedmontese *vurp*, *surk*, Sicilian *arba* ALBA "dawn", *sipurcru* SEPULCRU "tomb"; Grammont, 1971: 208, Rohlfs, 1966: 342–344), and mostly before labials in Francoprovençal dialects (Gardette, 1941: 129, Dondaine, 1972: 212) and other languages (dial. Catalan *parpella* PALPEBRA "eyelid", *vàrvula* "valve", *escarpra* SCALPRU "chisel", *sorc* "furrow"). In other dialectal domains the replacement of /l/ by the alveolar rhotic may take place before any consonant: vulgar Florentine (*cardo* CALDU "hot", *morto* MULTU "much"; Rohlfs, 1966: 342), Sardinian apart from some varieties of Logudorese and Campidanese (*artu* ALTU "high"; Jones, 1988: 322–323), and Andalusian and Canarian Spanish (*arquiler* "renting"; Lapesa, 1980: 521, 575).

/l/ rhotacism may also apply after a heterorganic labial or a velar in tautosyllabic onset clusters. This phonetic replacement occurs highly systematically in Sardinian (*prenu* PLENU "full", *crau* CLAVU "nail"; Lausberg, 1970: 332), Portuguese (*cravo* CLAVU "nail", *fraco* FLACCU "thin"; Williams, 1938: 63) and Alguerese Catalan (*prat* < *plat* "dish"), and more occasionally in other dialectal zones: Leonese Spanish (*igrésia*, *branco* and *praça* for Sp. *iglésia* "church", *blanco* "white" and *plaça* "square"; Menéndez Pidal, 1968: 199), dialectal Catalan (*frabiol* "shepherd's flute", *gràndula* "gland", *frèvol* FLEBILE "weak"), Sicilian (*brancu* "white"; Rohlfs, 1966: 242).

In principle, the fact that the change *r* > *l* may apply in similar conditions to *l* > *r*, and thus preconsonantally and after a tautosyllabic consonant, is in support of an acoustico-perceptual interpretation of /l/ rhotacism based on the spectral affinity between the two consonant sounds. Examples of the change *r* > *l* are *albre* "tree", *golfa* "loft", *flare* "friar" and *clossa* "crutch" in dialectal Catalan and *reflán* "saying", *cuelpo* "body", *talde* "late" and *calne* "flesh, meat" in dialectal Spanish (Menéndez Pidal, 1968: 199). However, *l* > *r* happens to occur more often than *r* > *l*, which at least in specific dialects is more in accordance with the hypothesis that rhotacism is a production-based sound change triggered by articulatory reduction.

5.4.3 Vocalization

The vocalization of syllable-final dark /l/ into [w] is favoured by the presence of a following heterorganic labial or velar consonant in some dialectal domains (Gévaudan, Australian and New Zealand English; Camproux, 1962: 315–316, Horvath & Horvath, 2002) or of just a following labial or labiodental in other dialects (Catalan *aubarca*, *pauma* and *taup* for Cat. *albarca* "sandal", *palma* "palm" and *talp* "mole"). This contextual restriction is consistent with articulatory data showing that the apical closure for dark /l/ is frequently lacking before consonants produced with no front lingual closure or constriction, thus supporting the notion that /l/ vocalization should be considered a case of articulatory reduction (see Hardcastle & Barry 1985, Scobbie & Wrench, 2003 and Lin et al., 2014 for English). The vocalization of /l/ into [w] before a dental or an alveolar consonant in other dialectal scenarios ought to be attributed to other factors.

The replacement of clear /l/ by [j] may also be favoured by heterorganic labials and velars, as revealed by data taken from Italian dialects (Romagnol *eiba*, [sojk] and Emilian *aibre*, [dojk] for It. *alba* "dawn", *solco* "furrow", *albero* "tree" and *dolco* "fraud", respectively; Rohlfs, 1966: 346) and from Andalusian Spanish and other Spanish varieties where the change /l/ > [j] appears to apply before velars for the most part (*aigo* < *algo* "something"; Penny, 2000: 151). Heterorganicity is also involved in the replacement of /l/ by [j] in tautosyllabic onset clusters whether after a labial or a velar in Tuscan (*stabbio* STAB(U)LU "manure", *tempio* TEMPLU "temple", *maschio* MASCULU "male", *unghia* UNGULA "nail") or just after a velar in Romanian (*unghie* UNGULA, *ochiu* OCULU "eye"; Lausberg, 1970: 376–377). Two vocalization cases of /l/ into [j] deserve special attention: after a back rounded vowel and before a dentoalveolar in, among other lexical forms, Portuguese *muito* MULTU "a lot"; alternating forms such as [ˈɛjlva], [ˈɛjvva] and [ˈɛvva] HERBA "herb" or [ˈmajltʃu] and [ˈma(j)ʃu] MASCULU "male" in Northern Logudorese, which suggest that forms such as [ˈɛjva] and [saj ˈmanɔzɔ] *sal manos* < *sas manos* "the hands" have been generated through on-glide insertion followed by assimilation of /l/ to the following consonant or /l/ deletion (Contini, 1986: 223, 538, 1987: 370–372; Wagner, 1984: 312–313).

There are also some indications that the vocalization of preconsonantal /l/ into [w] is most prone to occur when the following consonant is voiced, which parallels other instances of articulatory reduction of coda consonants before a voiced consonant (sections 5.1.3, 5.2.3, 5.2.4 and 5.3.2). Indeed, according to data for Catalan dialects collected by the author, out of 66 cases of /l/ vocalization into [w] before labials and labiodentals, 53 occur before a voiced consonant (28 before /b/, 17 before /m/, 8 before /v/) and only 13 before a voiceless consonant (5 before /p/, 8 before /f/). Also in Logudorese areas, word-final /l/ derived from /s/ through an alveolar rhotic becomes [j] most frequently when followed by word-initial /b, m, v/ and less often /p, f, n, l, r/.

5.4.4 Summary

Homorganicity appears to facilitate the regressive and progressive manner assimilation of /l/ to an adjacent rhotic or nasal in the sequences /lr, rl/ and /ln, nl/, and the regressive occlusivization in the sequences /lt, ld, lk, lg/. Homorganicity cannot possibly account, however, for instances of /l/ assimilation before a labial consonant. After shortening considerably, /l/ may also drop before consonants sharing a front lingual constriction with the alveolar lateral, namely, a dental stop and /s/. As expected, changes related to /l/ weakening are prone to operate in the context of a heterorganic consonant; this is so for rhotacism, elision and vocalization into [j] before and after a labial or a velar, and for vocalization into [w] before consonants of those two places of articulation. Moreover, C2 voicing appears to favour the replacement of preconsonantal dark /l/ by [w].

5.5 Rhotics

5.5.1 Assimilation/elision

5.5.1.1 Contextual fricative

Regressive fricativization is not likely to occur in the sequences /rs, rʃ/ (Catalan [rs] *mar santa* "holy sea", [rʃ] *bar Xaló* "Xaló bar"), where the two successive consonants are (nearly)-homorganic. This appears to be the case since the fast excursion of the ballistic apical movement for the syllable-final rhotic, mostly if showing a trill-like realization, is likely to prevent gestural overlap from occurring. Even though the rhotic is regularly maintained, the antagonistic requirements between lingual fricatives and rhotics account for why, as shown by EPG data for /rθ/ in Greek, preconsonantal /r/ may exhibit a wider central constriction and thus weaken into an approximant realization and acquire frication which could lead to deletion in the end (Baltazani & Nicolaidis, 2013). If realized as a trill, rhotic fricativization may take place whenever the requirements for trilling are not met whether because some resistance at constriction location causes a decrease in aiflow to occur or, conversely, there is an increase in constriction width and air velocity (Solé, 2002a, Widdison, 1998).

Regressive manner assimilation in the sequence /rs/ applies in languages allowing geminates, as for Italian dialects (Old Padovan *travesso* "across", Sicilian *ussu* URSU "bear", Abbruzzese [sənˈdissə] It. *sentirsi* "to feel onself"; Rohlfs, 1966: 339, Hastings, 1997: 324), and Sardinian dialects such as Logudorese where geminates may also correspond to /rθ, rx/ and Nuorese where rhotic+ fricative sequences may assimilate across a word boundary ([ˈkussu] CURSU "course", [ˈbussa] BURSA "bag", [ˈpoxxu] PORCU "pig", *battof fizos* "four sons"; Sampson, 1999: 286, Wagner, 1984: 281, Pittau, 1972: 34, and section 5.1.2.2). In Classical Latin, homorganic /rs/ could become [rr] and thus undergo progressive maner assimilation (infinitive form *ferre* < **fer-se* "to carry").

Whenever /rs/ has yielded a simple fricative, it often remains unclear whether the sound in question has originated through direct elision (/rs/ > [s]) or through geminate simplification after manner assimilation has occurred (/rs/ > [ss] > [s]). The latter development may account for the outcome [s], not [z], of intervocalic /rs/ (RS) during the transition from Latin to Romance (see relevant comments regarding /ns/ in section 5.3.1.1), and the former for the same outcome through cluster simplification in lexical items from the Romance languages at a time when intervocalic obstruent voicing was not a productive process any longer. Here are some illustrative examples of the change /rs/> [s] with intervocalic *ss* standing for [s]: Portuguese *pessoa* PERSONA "person", *pêssego* PERSICU "peach" (Williams, 1938: 75); Occitan *cusso* CURSU, *busso* BURSA "bag", *fosso* FORTIA "strength" (Ronjat, 1930–1941, 2: 204, Alibèrt, 1976: 36); dial. Catalan *armossar*, *fassir* and *escasser* for Cat. *esmorzar* "to have breakfast", *farcir* "to stuff" and *escarser* "odd". Rhotic elision is even more clearly the only possible account in other cases:

(a) *-rs* > *-s* in plural nouns and adjectives, as for Occitan *madu(r)s* "ripe, masc. pl." and *escu(r)s* "dark, masc. pl." (Ronjat, 1930–1941, 2: 299). Rhotic deletion in analogous Old Catalan plural forms appears to be responsible for why *r* fails to show up in absolute word-final position in the singular cognates in most Catalan dialects nowadays; thus, for example, the simplification [məˈðurs] > [məˈðus] must have caused the Old Catalan form [məˈður] to be replaced by present-day Eastern Catalan [məˈðu].

(b) *-r* > Ø in infinitive forms before an enclitic pronoun starting with /s/ (Dominican Republic Spanish *ise* 'Sp. irse' "to go away"; Alonso, 1967: 247, Malmberg, 1971: 391).

(c) /rs/ > [rʃ] > [ʃ] in the Ardennes, Lorraine and Franche Comté dialectal domains ([pɛˈʃon] Fr. *personne* "person", [eˈkoʃ] Fr. *écorce* "peel, crust", [peʃ] Fr. *perche* "stick", [puˈʃe] PORCELLU "pilet"; Bloch, 1917: 17, 54, Duraffour, 1932: 245; Lahner et al., 1978–1988, maps 133, 241, 472, 543, 807; Bruneau, 1913: 397, Remacle, 1972: 323).

The incompatibility between frication and trilling may also cause the rhotic to become a sibilant after /s, ʃ/, as for /s̺r/ > [s̺] in the Iranian languages Pashto and Yidgha (Hamann, 2003: 86, Bhat, 1973: 34). The same assimilatory development may apply to the cluster *str* after /t/ elision has taken place, whether word initially and word medially in Sicilian ([s̺ʈɽ] > [s̺ɽ] > [s̺], [ʃ]; Dulcibella, 1934: 299–301, 402–403), or just word medially in S. Italian dialects (Salentino [ˈnɔʃʃa] It. *nostra* "our, fem. sing.", Calabrese [jiˈnɛʃʃa] It. *ginestra* "broom"; Rohlfs, 1966: 380) and presumably in the Old Spanish lexical forms pronounced with [s] *nueso* NOSTRU "our, masc. sing.", *maese* MAGISTRU and *vuesa merced* < *vuestra merced* "sir" (Menéndez Pidal, 1968: 145). The progressive fricativization process under analysis is consistent with syllable-initial *r* being often realized as a tap, a fricated rhotic or an approximant rather than as a trill when occurring after a syllable-final front lingual fricative in Italian and Latin American Spanish dialects (Busà, 2013, Bradley, 2006).

5.5.1.2 Other contextual consonants

Regressive manner of assimilation may operate on syllable-final /r/ before /t, d, n, l/, which may become homorganic with the rhotic through progressive assimilation in constriction location (section 3.3.2). As revealed by the examples listed in Table VIII, this manner assimilation process is prone to occur in dialects which allow geminates (Nuorese Sardinian *battol litros* < *battor litros* "four

Table VIII: Regressive assimilation of /r/.

/t, d/	dial. Spanish	*puetta*	'Sp. puerta'	"door"	(Alonso, 1967: 234)
		vedde	'Sp. verde'	"green"	íd.
	S. Italian	*pe ttía*	'It. per te'	"for you"	(Rohlfs, 1966: 429)
	Sicilian	*muottu*	'It. mortu'	"dead,masc.sing."	(íd.: 339)
		schedda	'It. scherda'	"fishbone"	íd.
	Abbruzzo	[luʃˈʃettələ]	*[la ˈtʃɛrtola]	"lizard"	(Hastings, 1997: 324)
	Vosges	[pɛdˈdi]	'Fr. perdrix'	"partridge"	(Bloch, 1917: 126)
	Campidanese	*attu*	*artu* 'It. alto'	"high"	(Wagner, 1984: 299–300)
		caddu	*cardu* 'It. caldo'	"hot"	íd.
		mattsu	*Martsu* MARTIU	"March"	íd.
		o[dːʒ]*u*	*o*[rdʒ]*u* HORDEU	"barley"	íd.
/n/	Sicilian	*funnu*	FURNU	"oven"	(Rohlfs, 1966: 376)
	Majorcan Cat.	*to*[nː]*ar*	'Cat. tornar'	"to come back"	
		inte[nː]	'Cat. intern'	"internal"	
	Occitan	*pen Nadal*	'Occ. per Nadal'	"for Christmas"	(Alibèrt, 1976: 38)
	dial. Spanish	*canne*	'Sp. carne'	"meat"	(Alonso, 1967: 243)
		tienno	'Sp. tierno'	"tender"	íd.
/l/	Nuorese Sard.	[aˈulla]	ARULA	"small altar"	(Wagner, 1984: 283)
	Sicilian	[ˈmɛlla]	'It. merla'	"blackbird"	(Rohlfs, 1966: 339)
	Vosges	[sɛlˈla]	'It. salera'	"he/she will salt"	(Bloch, 1917: 125)
	Majorcan Cat.	*pal.lar*	'Cat. parlar'	"to speak"	
		al.lot	'Cat. arlot'	"kid"	
		fèl.lera	FERULA	"birch"	
	dial. Spanish	[ˈbulla]	'Sp. burla'	"mockery"	(Lapesa, 1980: 505)

liters", *batton nukes* < *battor nukes*' "four weddings"; Pittau, 1972: 34), and in other dialectal domains where preconsonantal /r/ becomes aspirated (S. Spanish [ˈkanne], [ˈkahne] Sp. *carne* "flesh, meat", [ˈpella], [ˈpehla] Sp. *perla* "pearl"; García Martínez, 1986: 92–93).

The assimilation process of interest may also apply in sequences composed of an infinitive followed by a clitic pronoun and across a word boundary, mostly so if the rhotic belongs to a function word: Romanesco *guardal.lo* "to keep it", *vedel.lo* "to see it" (Rohlfs, 1966: 339); Majorcan Catalan *vorel.ló* "to see it", *visital.lós* "to visit them"; dialectal Spanish *decin.nos* "to tell us", *trael.lo* < *traerlo* "to bring it"; Occitan *pel lo* < *per lo* (Ronjat, 1930–1941, 2: 424). In Cairene Arabic, /rl/ may be realized as [ll] within and between phonological words (Watson, 2002: 237–238).

Regressive manner assimilation may also take place before a velar consonant, which is in line with rhotics and velars sharing a back dorsal constriction and thus being nearly-homorganic, and also before a labial mostly if voiced where homorganicity cannot be possibly involved. Assimilation examples of these characteristics may be found in Sardinian ([ˈkakki] < [ˈkarki] It. *qualche* "a few", [ˈlaɣɣa] LARGA "long", [ˈɛvva] HERBA "herb"; Wagner, 1984: 300, Contini, 1987: 223, 371, and section 5.1.2.2), Italian dialects (Sicilian *babba* and *cuccatu* for

Table IX: Elision of /r/.

Word medially					
/rt/	Lorrain	[mwaˈte]	MARTELLU	"hammer"	(Grammont, 1971: 209)
/rn/	dial. Spanish	*una*	'Sp. urna'	"vase"	(Alonso, 1967: 252)
Word finally					
/rt/	Vosges	*kwa/ot*	CHARTA	"chart"	(Bloch, 1917: 31)
	Franche Comté	[po/utʲ], [po/utʃ]	'Fr. porte'	"door"	(Dondaine, 1972: 130)
/rd/	Franche Comté	[kudʒ]	'Fr. corde'	"rope"	íd.: 127
/rn/	Majorcan Cat.	*can*	'Cat. carn'	"flesh, meat"	
		ton	'Cat. torn'	"lathe"	
	Bourgogne	[kɔn]	'Fr. corne'	"horn"	(Taverdet, 1975–1980, maps 912, 1035)
/rl/	Bourgogne	[mal]	'Fr. merle'	"blackbird"	íd.
Across a word boundary					
/rd/	dial. Occitan	*per ana(r) dansar*		"to go dance"	(Sánchez Miret, 2012)
/rl/	Portuguese	*pelo*	'Port. por lo'	"for the, masc. sing."	(Herslund, 1986: 514)

barba "beard" and *coricato* "retired"; Rohlfs, 1966: 339), dialectal Catalan ([kː] *cercar* "to look for", *ce(r)cle* "circle", [mː] Majorcan *entornam-mos* < *entornar-mos* "to go back, 1st person pl."), and dialectal Spanish after /r/ aspiration or retroflexion as a possible option (*cagga* < *carga* "load", *sibbe* < *sirve* "he/she serves"; Malmberg, 1971: 391).

It may become hard to ascertain whether the simplified outcome of a cluster /rC/ has been issued through direct elision of the rhotic or through geminate simplification after regressive assimilation has applied. Rhotic loss appears to be favoured by homorganicity, as exemplified by the lexical forms with /rt, rn, rl/ listed in Table IX, and according to descriptive sources stating that /r/ deletion may take place before /n, l, k/ in Majorcan Catalan (Recasens, 2014a: 332–333), before /t, d/ and possibly /n, l/ in Vosges and Bourgogne (Bloch, 1917: 17, Taverdet, 1975–1980, maps 189, 433, 855, 912), before /n, l/ in Franche Comté (Grammont, 1971: 209), and word finally before alveolars rather than before other consonants in Frisian (van der Meer & de Graaf, 1986: 317–318) and mostly before /l/ in Spanish from Panamá (Terrel, 1976).

It may also be argued that (near)-homorganicity contributes to the deletion of the rhotic in syllable-onset clusters whenever occurring after /t/ and also after a velar and even [h] whith which *r* may share a back lingual constriction: Occitan *quate* "four", *mete* "to put" (Ronjat, 1930–1941, 2: 232); Campidanese Sardinian *nostu* < *nostru* "our, masc.", *unga* < *ungra* UNGULA "nail", [oˈriɣ(ɾ)a] AURICULA "ear", [ˈoɣ(ɾ)u] OCULU "eye" (Bolognesi, 1998: 57, Blasco, 1984: 236);

Neapolitan [feˈnɛsta] It. *finestra* “window”, Como province [h(ɾ)eˈga] It. *fregare* “to rub” (Rohlfs, 1966: 249, 380).

The elision of the rhotic before or after /t/ may be facilitated by the effect of a dorsal constriction on the aerodynamic conditions involved in the production of *r*, and also by a devoicing effect triggered by the stop, which is in agreement with segmental duration data showing that the alveolar rhotic is shorter before voiceless stops than before voiced stops (Haggard, 1972, Hoole et al., 2013). Rhotic devoicing may also account for the deletion of *r* word finally when preceded by (nearly)-homorganic /t/ and other obstruents (Ardennes [mɛt] Fr. *mettre* “to put”, [tʃãb] Fr. *chambre* “room”, Montreal French [pov] Fr. *pauvre* “poor”; Bruneau, 1913: 358, Hooper, 1976: 228).

5.5.2 Vocalization, aspiration and uvularization

In parallel to clear /l/, the rhotic may vocalize into [j] in coda position before heterorganic labial and velar consonants, which favour apicoalveolar contact loss at constriction location. This vocalization process may occur in dialectal Italian and dialectal Spanish, also before other consonants: Ligurian *baiba*, [ˈajku], Palermitano [ˈsujddu] for It. *barba*’ “beard”, *arco* “arch” and *sordo* “deaf”; Spanish *poique* < *porque* “because”, *cueipo* < *cuerpo* “body”, *pueico* < *puerco* “pig”, *pueita* < *puerta* “door”, *caine* < *carne* “flesh, meat” (Rohlfs, 1966: 376, Malmberg, 1971: 391, Alonso, 1967: 239, Lapesa, 1980: 521, 575, Penny, 2000). An alveolar tap may also vocalize into [j] syllable initially after a labiodental consonant in Sicilian areas ([fj]*ati* FRATRE “brother”; Ruffino, 1997: 373).

In dialectal Spanish, the alveolar rhotic may weaken into [h] before the homorganic sonorants /l, n/ rather than before other consonants after which regressive assimilation and geminate simplification may occur ([ˈkahne] *carne* “flesh, meat”, [ˈbuhla] *burla* “mockery”, [ˈpehla] *perla* “pearl”, [ˈbjehnes] *viernes* “Friday”; Malmberg, 1971: 391, 1950: 138, Quilis-Sanz, 1998: 147, Lorenzo, 1975: 134). In a Logudorese Sardinian area, the same homorganicity condition may be invoked in order to account for why C1=*r* (and also *l* and *s*) may assimilate to the fricative realizations [ç, x] of C2=/k/ and [ɣ, ɦ] of C2=/g/ (section 5.1.2.2; Contini, 1986: 539).

The velarization or uvularization of apical *r* into [ʀ], a dorsal articulation which may be found in present-day French, appears to have originated through apical contact loss and simultaneous back tongue body raising in syllable-final position (Straka, 1965: 488, Straka & Nauton, 1947, Lorenzo, 1975: 123). This interpretation is in line with productions of the apical rhotic in utterance-final position showing a primary tongue tip gesture and an additional dorsouvular or dorsopharyngeal constriction (Morin, 2013). The elevation of the postdorsum towards the soft palate and hollowing of the tongue predorsum may be viewed as a strategy to reduce tongue tip tension for trilling (Widdison, 1998). Data are lacking as to whether, analogously to /s/ palatalization (see section 5.2.5), the change *r* > [ʀ] in syllable-final position may be favoured by the presence of following syllable-onset velars and other consonants involving no front lingual contact.

5.5.3 Summary

Homorganicity or quasi-homorganicity appears to be involved in several changes affecting the alveolar rhotic, namely, regressive manner assimilation and C1 elision in the sequences /rt, rd, rn, rl, rs, rʃ/ and even /rk, rg/, progressive assimilation in the case of /sr, ʃr/, and rhotic elision in the syllable-onset clusters *tr*, *gr* and even [h]*r*. This conditioning factor does not intervene in assimilatory and other changes occurring next to labial consonants. The coda rhotic may vocalize into [j] before heterorganic labials and also velars. Homorganicity may also play a role in rhotic fricativization in Sardinian developments such as *r* > [ç, x] before /k/ and *r* > [ɣ] before /g/, though less clearly in Spanish dialects where, among other contexts, *r* aspiration may occur before alveolar sonorants.

5.6 General summary

Data presented in chapter 5 reveal several major articulatory adaptation trends in consonant clusters which are summarized in sections 5.6.1 and 5.6.2 below. Section 5.6.1 deals with the role of homorganicity in manner assimilation and elision of one of the two consonants in the cluster, and section 5.6.2 with the effect of the manner and place of articulation characteristics for the contextual consonants on articulatory reduction and related changes affecting mostly coda C1 in heterosyllabic consonant sequences.

5.6.1 Homorganicity

Homorganicity between two consonants in a cluster, which includes the co-occurrence of the back lingual closure/constriction for a velar and dark /l/ or the alveolar trill, has been found to facilitate assimilation of manner of articulation. The rationale underlying this assumption is that slight changes in articulatory

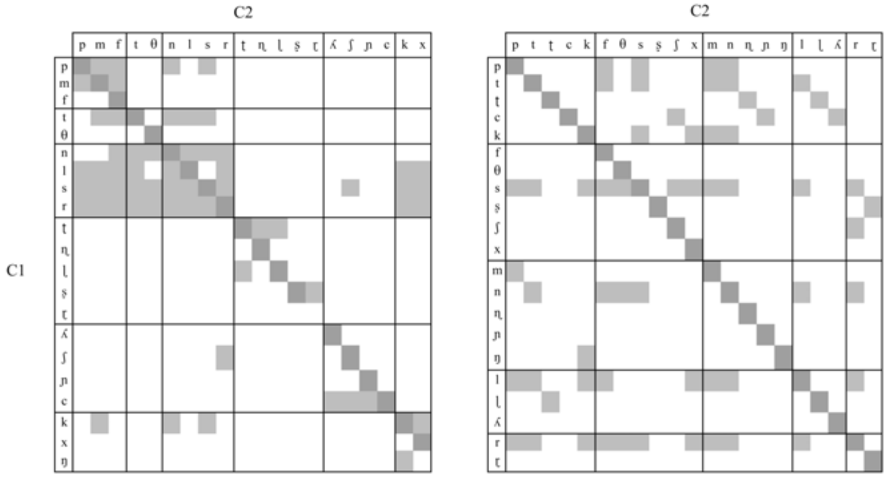

Figure 43: Consonant combinations reported to undergo regressive manner assimilation in heterosyllabic consonant sequences, grouped by place of articulation (left graph) and by manner of articulation (right graph).

configuration for the implementation of the manner adaptation process should be easier to perform if the two consonants share the same closure/constriction location than if they do not.

In order to summarize the regularities underlying manner assimilation in clusters, Figures 43 and 44 show those consonant combinations which have been reported to undergo regressive and progressive manner assimilation in heterosyllabic consonant sequences, independently of whether the assimilatory process applies more or less often in the world's languages. Cells corresponding to CC sequences undergoing a manner assimilation are filled in light grey. Each figure includes two graphs with consonants grouped by place of articulation in the left graph and by manner of articulation in the right graph. Place categories are labial/labiodental, dental, alveolar, retroflex, alveolopalatal/palatoalveolar and velar, and manner classes are stop, fricative, nasal, lateral and rhotic. In the two graphs of each figure, the obstruents occupying the C1 and C2 position may be in principle voiceless or voiced though they are transcribed with the phonetic symbols for one of the two voicing categories depending on frequency of occurrence of the relevant assimilatory processes. The figures do not include unusual assimilatory processes (e.g., /hl/- > [ll]- in Gascon) nor assimilatory processes involving consonants placed in tautosyllabic onset sequences (*dr*, *gr*).

A comparison between Figures 43 and 44 (left graphs only) reveals that, as expected, regressive assimilations are more numerous than progressive ones,

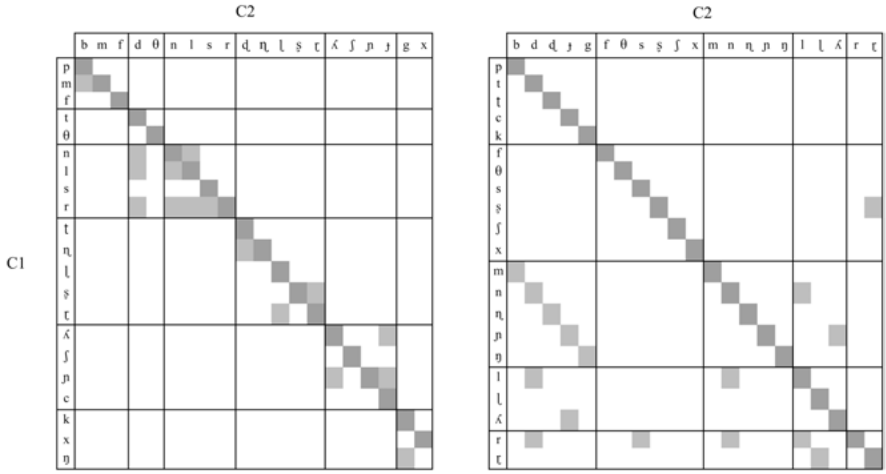

Figure 44: Consonant combinations reported to undergo progressive manner assimilation in heterosyllabic consonant sequences, grouped by place of articulation (left graph) and by manner of articulation (right graph).

and that in the two cases homorganicity plays a crucial role as indicated by the fact that the light grey cells occur next to the cells filled in dark grey for the most part. Target dentoalveolar/alveolar consonants show a high number of regressive assimilations which, in contrast with the progressive assimilation scenario, may also involve the presence of non-homorganic contextual labials and velars. In any case, homorganicity may be considered to be at work in the case of regressive manner assimilations operating on C1=/l, r/ before C2=/k, g, x/.

Progressive assimilations also apply more restrictively than regressive assimilations when evaluated as a function of the manner of articulation characteristics of the two successive consonants. Indeed, according to Figure 43 (right graph), consonants of all manners of articulation may act as assimilation triggers and targets at the regressive level, i.e., regressive assimilation of essentially all manner of articulation characteristics may apply to alveolar fricatives, nasals, laterals and rhotics and to all places of articulation in the case of the oral stops. As to the progressive assimilations (Figure 44, right graph), on the other hand, C2 may assimilate to a preceding sonorant but not to a preceding obstruent, and a fricative or rhotic C2 does not change its manner of articulation except when preceded by a rhotic or a fricative, respectively.

Data reported in chapter 5 also reveal that homorganicity may contribute to shorten and delete syllable-final consonants. Figure 45 displays those heterosyllabic consonant combinations allowing C1 elision classified according to

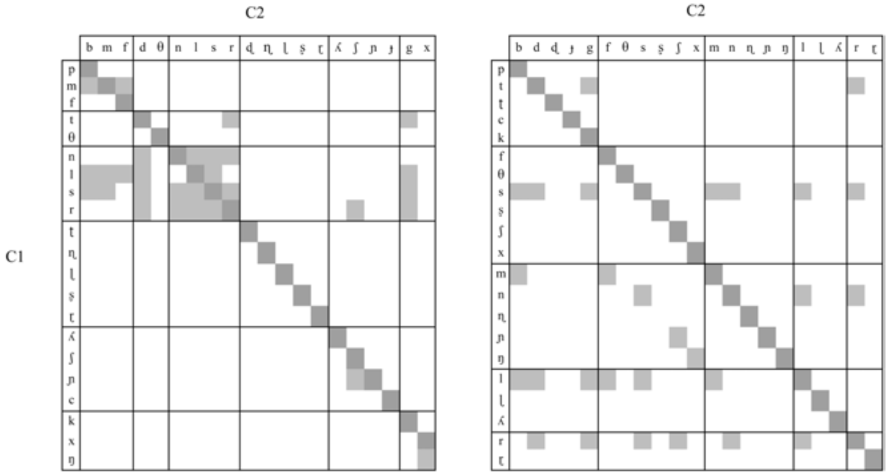

Figure 45: Consonant combinations reported to undergo C1 elision in heterosyllabic consonant sequences, grouped by place of articulation (left graph) and by manner of articulation (right graph).

consonant place of articulation (left graph) and manner of articulation (right graph). The figure shows that nasal, lateral, fricative and rhotic alveolars delete most often, and that most frequently this deletion process takes place before consonants of other manners of articulation agreeing in place of articulation with the target coda consonant. Occasionally the second consonant of a homorganic consonant sequence may be deleted, as in the case of the clusters /mb, nd/.

Consonant elision may also operate in syllable-initial and word-final clusters whenever the two consonants in succession are (nearly)-homorganic. As to syllable-initial clusters, C1=/d, g, h/ may drop before /l, ɾ/ (/g/ also before /w/), and C2=/l/ and C2=/ɾ/ may delete after a velar, and after a dental, a velar or /h/, respectively. Regarding word-final clusters, stops may drop after a homorganic nasal, the dentoalveolar stop after /l, s, r, ʃ/, /n/ after /r/, and the alveolar rhotic after /t/.

5.6.2 Weakening

Shortening and articulatory undershoot may generate lenited, aspirated, rhotacized and vocalized realizations out of consonants placed in coda position whenever followed by a voiced consonant. The target consonant is mostly dentoalveolar/

alveolar and the trigger consonant mostly a sonorant. In these circumstances, there may be lenition, rhotacism and vocalization of dentoalveolar stops, rhotacism, aspiration and vocalization of /s/, rhotacism of /n/, vocalization of /l/ and aspiration of /r/. The rhotic may also weaken into an approximant before /s/. A special case is that of /s/ aspiration (also /s/ palatalization), which is more likely to operate before voiceless obstruents than before voiced ones through contact loss and simultaneous glottal opening. Once lenited, aspirated or rhotacized, the coda consonant may either drop or assimilate completely to C2, as suggested by alternations between the realizations [hC] and [C:] of /sC, rC/ in dialectal Spanish (['muhlo]/['mullo] Sp. *muslo* "thigh", ['bulla]/['buhla] Sp. *burla* "mockery"). The corresponding geminate outcomes, no matter their source, may then shorten into a simple consonant.

In addition to voicing and sonorancy in the consonant causing weakening to occur, heterorganicity between the two adjacent consonants may also play a role. Thus, rhotacism, lenition, vocalization and also elision have been reported to operate on coda dentoalveolars before labials or velars, as well as on liquids preceded by labials or velars in a syllable-onset cluster. More especifically, in these circumstances weakening accounts for the rhotacism of coda /s/, the vocalization, elision and rhotacism of onset and coda /l/, and the vocalization of onset and coda rhotics and of coda velars. Also, syllable-final /s/ is prone to undergo aspiration and palatalization before velar consonants. Gestural overlap may explain why /l/ and /r/ may delete before or after a labial and before a labial, respectively. Heterorganicity is also often involved in the fricativization or approximantization of a syllable-onset stop after a non-homorganic coda consonant allowing continuous airflow and thus a liquid, rhotic or fricative.

6 Recapitulation and discussion

The major goal of this book has been to investigate the production mechanisms involved in the realization of consonant sequences differing in segmental composition, and how these mechanisms may account for segmental adaptation and weakening in consonant clusters. Of special relevance is to ascertain whether the observed articulatory adaptation effects are consistent with patterns of consonant assimilation. The present chapter summarizes and evaluates critically the main findings reported in the book, both regarding articulatory adaptation and place assimilation in homorganic and heterorganic consonant sequences (sections 6.1 and 6.2), as well as manner assimilation and weakening processes acting mostly but not only on syllable-coda consonants (sections 6.3 and 6.4). Section 6.5 identifies several research issues to be explored in the future.

6.1 Homorganic sequences

Special attention has been paid to the mechanisms of articulatory adaptation, i.e., coarticulation, assimilation and blending, between heterosyllabic consonants produced with the same or a closeby front lingual articulator. As predicted by the DAC model of coarticulation, the application of these adaptation mechanisms is strongly conditioned by the place and manner of articulation characteristics of the consonants involved. Moreover, by and large, the coarticulatory, assimilatory and blending patterns detected in the Catalan articulatory data have been shown to also hold for other languages. A production-based theory of place assimilations appears to be crucial for rendering the term *homorganicity* precise enough and for investigating the extent to which regressive and progressive manner assimilations are conditioned by whether the two successive consonants are homorganic or not (see section 6.3 below).

Let us refer to sequences composed of highly constrained and unconstrained consonants in the first place. Consonants produced with tongue body lowering and backing such as the alveolar trill, exert considerable anticipatory coarticulatory effects in lingual activity and may trigger regressive place assimilations in less constrained dentoalveolar, alveolar and alveolopalatal consonants. Moreover, consonants exhibiting this lingual configuration appear to be more constrained than those produced with a high and front tongue body position, as revealed by the fact that coda (alveolo)palatals may assimilate in constriction location and depalatalize before syllable-onset trills while coda rhotics often remain postalveolar and are reluctant to palatalize before (alveolo)palatals and palatoalveolars. Front lingual fricatives are also highly constrained and thus

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may trigger regressive place assimilation due to a requirement on overall tongue configuration associated with the generation of frication. The reverse constrained + unconstrained sequences, on the other hand, are generally implemented through a two-target production mechanism such that intersegmental adaptation effects happen to be coarticulatory rather than assimilatory in this case. Moreover, the prominence of these coarticulatory effects varies with the articulatory characteristics of the trigger C1 in the progression fricative, trill > tap and the target C2 in the progression non-lateral > lateral.

Several remarks need to be made in regard to the segmental adaptation patterns operating in these unconstrained + constrained and constrained + unconstrained consonant combinations. On the one hand, the fact that categorical assimilations occur in the leftward rather than the rightward direction are in agreement with the more categorical nature of the anticipatory vs carryover coarticulatory effects, and appears to be in support of the notion that the former are planned while the latter are conditioned to a large extent by the peripheral properties of the speech production system. Indeed, while adaptable to context, anticipatory effects in lingual coarticulation and velar lowering have been reported to be less variable than carryover effects (see for example Bell-Berti & Harris, 1981). A second remark is that categoricalness does not hold across the board but differs in degree depending on speaker and dialect (some speakers are more prone to assimilate than others) and on segmental composition (e.g., contextual adaptability was generally greater for target /n/ than for target /l/).

Other findings appear to be in support of the coarticulatory motivation of place assimilatory processes. Thus, prominent carryover coarticulation effects and progressive assimilations are triggered mostly by (alveolo)palatal and palatoalveolar consonants on dentoalveolars and alveolars, which is in accordance with the spatiotemporal characteristics of the tongue dorsum raising/fronting gesture. Moreover, retroflex consonants parallel the alveolar trill in that they exert considerable anticipatory and carryover effects, while also causing the preceding and following dentoalveolars and alveolars to assimilate in place of articulation (see supporting evidence for Sicilian, English dialects, Tamil, Telugu and Sanskrit in sections 3.3.1.3 and 3.3.2.3). Regarding /rC/ sequences, C1-to-C2 effects may be assimilatory rather than coarticulatory whenever the rhotic is produced as a trill. This behaviour is in partial contrast with that for velarized/pharyngealized dentoalveolars of languages like Irish and Arabic, which behave more like dark /l/ in exerting anticipatory rather than carryover coarticulation effects and triggering regressive rather than progressive assimilatory processes (Watson, 2002).

As predicted by the DAC model of coarticulation, blending in sequences composed of relative unconstrained consonants (and thus not including the alveolar trill and the alveolar and palatoalveolar fricatives) yields a single articulatory realization whose closure extends over a variable period of time and encompasses the closure areas for C1 and C2 (blending through superposition) or, less often, occurs at an intermediate location between them (blending through intermediation). Blending through superposition has not been paid too much attention in the speech production literature and is in fact the preferred solution in the case of consonant sequences composed of an alveolopalatal and a dentoalveolar/alveolar. In parallel to the assimilation scenario in sequences with constrained and unconstrained consonants, the alveolar lateral, mostly if dark, is reluctant to blend with an alveolopalatal consonant. The same blending through superposition mechanism may be argued to operate in /n, l/ + /t, d/ sequences, which have been traditionally considered to undergo regressive dental assimilation in the Romance languages.

A relatively unexpected finding was that blending may be sensitive to coarticulatory direction (see also section 6.2). Thus, it applies to both /nʎ/ and /ʎn/ and to /lɲ/ but not /ɲl/, the reason being that, during the production of /ɲl/, the tongue dorsum must lower and retract in anticipation of C2=/l/. Mutual adaptation between the two consonants is also subject to a directionality effect in the cluster pairs /nt/-/tn/ and /lt/-/tl/: /nt/ and /lt/ exhibit blending and /tn/ and /tl/ progressive dentalization perhaps due to differences in degree of articulatory constraint among those consonants which occupy the C1 position, namely, nasals and laterals in the two former sequences and stops in the two latter ones.

Articulatory data for sequences with highly constrained /s/ and /ʃ/ reveal a trend for /sʃ/ to exhibit regressive assimilation and for /ʃs/ to favour blending, a two-target realization and also progressive assimilation. Differences in intersegmental adaptation between these two-consonant sequences may be related to the fact that the tongue needs to be repositioned during C1 for /ʃs/ but not for /sʃ/ or else to a universal trend for assimilations to favour the regressive over the progressive direction.

6.2 Heterorganic sequences

Data for heterosyllabic consonant sequences reveal that, as a general rule, those coda consonants which are prone to overlap with the following onset consonant in heterorganic clusters are also prone to undergo regressive place assimilation, which supports the view that phonological process involving successive segments have a phonetic basis. As pointed out below, degree of gestural overlap is determined by the consonant place and manner characteristics.

Manner of articulation appears to play a relevant role in gestural overlap: stop+nasal sequences may exhibit little gestural superposition due to the incompatibility between anticipatory nasality, and oral pressure rise and burst production for oral stops; /nC/ sequences show considerable overlap in line with the little salience of the articulatory and acoustic cues for nasals in general and for the alveolar nasal in particular; there is less overlap in sequences with front lingual fricatives than in those with front lingual stops in accordance with the strict articulatory and aerodynamic requirements involved in the production of the former; C*r*/*r*C sequences show less overlap than C*l*/*l*C sequences due presumably to differences in the speed of the apical movement between the alveolar rhotic and the alveolar lateral. Voicing requirements also matter. Thus, there is more gestural overlap in sequences with a voiced stop than in those with a voiceless stop whether placed in C1 or in C2 position, which suggests that overlap could be facilitated by gestural reduction whenever the target voiced stop is syllable final. Clusters with *r* however exhibit less overlap when the consonant occurring next to the rhotic is voiced than when it is voiceless and an approximant than a stop or a nasal.

Degree of gestural overlap is also influenced by the place of articulation and primary articulator for the two consonants in succession: overlap decreases in the progression velar > labial, front lingual for the triggering consonant and front lingual > labial > velar for the target consonant. These consonant-dependent differences are consistent with the related assimilatory patterns and appear to be in line with several articulatory characteristics: dorsovelars exhibit a high intraoral pressure level and are produced with extensive lingual gestures which constrain the entire tongue body to a large extent; apicolaminals are realized with a flexible articulator and are prone to undergo reduction at constriction location. In particular, overlap is disfavoured in sequences composed of a velar stop followed by a dental or alveolar consonant due presumably to the need to reposition the tongue for performing the C2 gesture. An exceptional finding, i.e., more overlap for /pt/ than for /tp/, is not consistent with the trend for /t/ to undergo regressive assimilation and could result from the fast apicolaminal raising gesture for /t/ being easily anticipated during a preceding labial consonant.

Articulatory data provided in the book also reveal that, as argued for homorganic sequences above, assimilations do not always proceed categorically. Thus, traces of syllable-final /t, d, n/ occur regularly in English and German in cases in which the coda consonant is perceived as fully assimilated to the following syllable-onset consonant. Whether complete or partial, assimilation applies or fails to apply depends on speaker, lexical item, speech rate and segmental composition not only in those languages but also, albeit to a much lesser extent, in languages where categorical assimilation is more frequent (Spanish, Japanese). A third group of languages exhibit gestural overlap between the coda and onset consonants rather than complete or partial assimilation (French, Russian).

Blending may take place in heterosyllabic sequences composed of heterorganic lingual consonants whenever they approach each other sufficiently in space and over time. It may result into a laminodorso-alveolopalatal realization in the case of sequences with a dental or alveolar consonant and /j/ (mostly so if /j/ is the second consonant in the cluster), and also in those with /k/ and /t, l, ʎ, ɲ/ (most often if the velar occupies the first position in the cluster). Alternative mechanisms such as closure sliding or partial gestural superposition are also possible. Again, as discussed in section 6.1, blending may be sensitive to coarticulatory direction and thus more prone to apply, among other sequence pairs, to /kɲ/ than to /ɲk/.

Research on the c-center effect and gestural overlap in word-initial and word-final clusters has also been referred to. As to word-initial clusters, manner of articulation constraints determine whether the temporal interval between the midpoint of the consonant cluster and the following vowel nucleus stays constant irrespective of cluster complexity. Thus, the c-center effect is likely to be favoured by an increase in degree of overlap between the successive consonants and between the last consonant in the cluster and the vowel. The effect in question has been reported to occur for stop+lateral, stop+rhotic and fricative + nasal sequences and less so or not at all for stop+fricative, nasal+fricative and stop+nasal sequences, fricative+stop and stop+stop sequences falling in between. On the other hand, word-initial clusters ending with a stop conform to the c-center effect when the stop is labial rather than when it is dorsal. As to word-final clusters, a trend has ben reported for the interval between the vowel and the first consonant in the cluster to stay constant and for the duration of the c-center effect to increase with the number of consonants; this principle of segmental organization has been found to hold for stop+stop, stop+fricative, fricative+stop, fricative+nasal, nasal+nasal and nasal+fricative sequences, as well as for /l/+stop and /l/+nasal sequences whenever the lateral is clear. However, the VC interval does not stay invariant if the first consonant in the coda cluster is prone to overlap with the preceding vowel, as for dark /l/ and the trill /r/.

6.3 Manner assimilation and weakening

Homorganicity contributes to regressive/progressive manner assimilation, the assumption being that changes in tongue configuration for the implementation of the outcoming manner of articulation characteristic should be easier to achieve whenever the two successive consonants share the same constriction location and main articulator. Manner assimilation operates preferably on dentoalveolar/ alveolar consonants whenever flanked by other consonants of the same place of articulation (at the regressive and progressive levels) and by non-homorganic labials and velars as well (at the regressive level only). Cases of manner assimilation involving target /l/ or the alveolar rhotic and a contextual velar consonant may also be attributed to (nearly)-homorganicity in view of the fact that the two consonants in succession may share a closure or constriction at the back of the vocal tract in this case; on the other hand, manner assimilation and the deletion of a dentoalveolar/alveolar next to a labial can only be triggered by gestural overlap since the two adjacent consonants are heterorganic in this case. Moreover, while all manner features may migrate regressively irrespective of the C1 manner of articulation, a sonorant C2 does not assimilate in manner to a preceding obstruent and progressive manner changes affecting a fricative or rhotic C2 are rare.

Homorganicity also contributes to the shortening and elision of coda nasal, lateral, fricative and rhotic alveolars before front lingual consonants, and to the elision of C2 in the sequences /mb, nd/. It may also account for the lenition and elision of a velar or a dental stop before an alveolar liquid in syllable-initial clusters and for the elision of the liquid C2 in the same syllable-onset sequences, as well as for the elision of an absolute-final dentoalveolar stop in word-final two-consonant clusters.

Several processes triggered by weakening, i.e., lenition, aspiration, rhotacism, vocalization and elision, have been found to be also contextually determined. Coda dentoalveolars may undergo any of these processes when followed by a voiced consonant or a sonorant placed in the following syllable after which they may assimilate completely or drop. The aspiration and palatalization of coda /s/ are special in that they occur most typically before a voiceless stop though may take place before a voiced consonant as well. Heterorganicity in the context of a labial or a velar may also contribute to the implementation of the processes in question whether affecting dentoalveolars in syllable-final position and alveolar liquids occupying the C2 position in syllable-onset clusters. Heterorganicity is also involved in the lenition of onset stops after consonants allowing the passage of airflow at the C2 constriction location, as for the change /b, d, g/ > [β, ð, ɣ] after coda fricatives, laterals and rhotics in Spanish.

6.4 General conclusions and topics for future work

The book has shown that articulatory adaptation mechanisms in homorganic consonants sequences (coarticulation, assimilation, blending) may be modelled quite successfully when related to considerations about gestural displacement, constriction degree and aerodynamic constraints. The asymmetry between the direction of these articulatory adaptation processes in clusters with unconstrained and constrained front lingual consonants, i.e., the fact that the leftward direction favors assimilation in a sequence like /ts/ while the rightward direction favours a two-target realization in the reverse cluster /st/, goes beyond the prediction of the DAC model and may be associated with the phonemic planning component in the leftward case and with peripheral constraints of the speech production system in the rightward case. It is also interesting to realize that consonants which share analogous tongue body configurations such as the alveolar trill and retroflex consonants may exhibit analogous trends in coarticulatory and assimilatory direction.

The articulatory and aerodynamic factors which contribute to gestural overlap and place assimilation in heterorganic sequences are only partly understood. Thus, for example, the reasons why a limited degree of gestural overlap is available in velar+front lingual and word-initial stop+nasal sequences need to be explored in more detail by providing better arguments for notions like coarticulatory resistance and aggressiveness, gestural antagonism and tongue repositioning. Moreover, in parallel to similar remarks made for homorganic sequences, it remains unclear whether the preference for regressive over progressive assimilations in heterorganic clusters (also in the case of the sequence pair /sʃ/-/ʃs/) should be attributed to the cognitive component or must be assigned a production-based explanation.

In general terms, we are in need of more information about the sources of variability involved in assimilatory processes. Articulatory data reveal that regressive place assimilation in /nC/ sequences (also in /tC/ sequences) does not apply systematically not even in languages which favor regressive place assimilations like Spanish, Catalan and Italian. Moreover, languages like Spanish and English differ not so much in regard to whether assimilations apply systematically or not as to whether they are gradient/partial (as in English) or complete (as in Spanish) and therefore may or may not show a trace of the originary target gesture. The extent to which segmental, prosodic and lexical factors bear upon the frequency of occurrence of complete/partial place assimilation processes should be subject to further investigation.

A relevant contribution of the book is that patterns of manner assimilation and of weakening of coda consonants do not occur at random but are conditioned mostly by homorganicity the former process and C2 voicing and heterorganicity the latter. Moreover, the finding that manner assimilations take place at the regressive level rather than at the progressive level could again be due to the planning component of the anticipatory effects and the physico-mechanical nature of the carryover effects, though there could also be production-based explanations for why some manner features migrate rightward while others do not. The weakening of coda consonants before voiced and heterorganic consonants is associated with a decrease in intraoral pressure level with respect to the voiceless cognates (voicing condition) and with contact loss at constriction location (heterorganicity condition).

Other aspects need to be looked into more thoroughly such as the relationship between articulatory reduction of coda consonants and regressive assimilation. Regarding regressive manner assimilations, data reported in the present study reveal that these assimilatory processes may operate both in homorganic clusters in which the coda consonant is not strongly reduced and on coda consonants which have become lenited, aspirated or rhotacized and are thus prone to be strongly overlapped. This double possibility is in agreement with the existence of languages and dialects which do not lenite coda stops nor favour regressive place assimilations (Russian) and with others where coda stops do not lenite and undergo place assimilation as a general rule (Majorcan Catalan). Along the same lines, future work ought to explore whether the simplification of heterosyllabic consonant clusters is more likely to operate through geminate shortening after assimilation has applied or through direct elision of a severely reduced coda consonant. Based on experimental data it seems that the former option, i.e., shortening after assimilation, is most appropriate for the simple consonant outcomes [ʃ] and [r] of /s#ʃ/ and /s#r/ in languages like Catalan.

More research is also needed in order to ascertain whether assimilations can be justified entirely by the characteristics of the triggering and target consonants or may be conditioned, at least in part, by other factors. Among these, one may mention positional constraints which cause certain consonants to be more reduced in syllable-coda than in syllable-onset position, a universal trend for coarticulatory effects to be anticipatory and for assimilations to be regressive, and production mechanisms for specific two-consonant sequences such as the need to reposition the tongue during C1 in anticipation of the lingual gesture for C2. Thus, for example, it still remains unclear the extent to which tongue dorsum lowering during /ɲ/ in a sequence like /ɲr/ ought to be attributed exclusively to the anticipatory effects exerted by the following trill or also to the universal tendency for certain consonants to be articulated with less dorsopalatal contact in syllable-final vs syllable-initial position.

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