Articulatory constraints on stop insertion in consonant clusters*

DANIEL RECASENS

Abstract

This study claims that, in contrast with previous proposals in the literature, essentially all instances of stop epenthesis in two consonant clusters (e.g., [ml] > [mbl], [ls] > [lts], [wl] > [wgl]) may be attributed to the articulatory requirements and aerodynamic constraints involved in the production of the original cluster. The inserted stop results from the perceptual categorization of a transitional closure event. Several mechanisms may give rise to this momentary stoppage of air, and to an intraoral pressure rise which causes the stop burst to become prominent enough so that the emergent stop can be successfully perceived. Apparently exceptional cases such as [nl] > [ngl] and [sl] > [skl] are accounted for through direct epenthesis assuming that [l] is strongly dark and thus, produced with a back postdorsal constriction. Data on stop deletion in consonant clusters appear to be in support of this production-based explanation of stop insertion.

1. Introduction

Phonologists have formulated several explanatory hypotheses in order to account for stop epenthesis in two consonant clusters. The present investigation will show that, while making relevant predictions on several regularities about underlying stop insertion, these proposals fail to explain a good number of facts. Based on available experimental evidence and on descriptive data from different languages, the major claim of this paper is that stop epenthesis is triggered by the formation of an oral closure at the boundary between the two consonants in the cluster which results from the ways in which the articulatory gestures for the two consonants overlap in time. Consequently, an adequate understanding of the stop insertion processes occurring in consonant clusters can only be achieved through an analysis of the articulatory and aerodynamic mechanisms involved in their production. A central argument of this approach

Linguistics 49–5 (2011), 1137–1162
DOI 10.1515/LING.2011.031
0024–3949/11/0049–1137

is that the probability that the emergent closing phase be integrated as an independent stop consonant by listeners is to be sought in the degree to which the production mechanisms of interest render the oral stop perceptually prominent, which is also why stop epenthesis is expected to occur in some consonant sequences rather in others. Instances of variable epenthesis occurring synchronically may then become phonologized, thus giving rise to a completed sound change, and this phonologization process may start out with specific clusters and extend to other consonant sequences later on.

An illustrative example is [t] insertion in word final clusters ending in [s]. While the presence of [t] may be variable synchronically, the stop has acquired phonological status in the Yiddish lexical forms *gandz* and *haldz* derived from German *Gans* 'goose' and *Hals* 'neck', respectively (Wetzels 1985: 314). Differences in degree of variability in the application of the stop insertion process may be observed synchronically. Thus, in Valencian Catalan, an oral stop may be added systematically to the clusters with an alveolopalatal C1 [ʎs, ɲs] ([aʎtʃ] *alls* 'garlics', [aɲtʃ] *anys* 'years') but not to other clusters such as [ms, ns, ls, rs] ([pals] *pals* 'sticks', [fars] *fars* 'lighthouses') (Recasens, 1996: 274, 276, submitted)

The analysis of stop epenthesis will be carried out mostly with reference to the processes presented in Table 1 in the appendix. The table contains essentially all the clusters which may undergo stop epenthesis the author is aware of[1]. Those processes may have a synchronic or a diachronic status and, while being exemplified with data taken mostly from the Romance and Germanic languages, they could be assumed to be representative of stop insertion in general. The stop insertions in the table are organized according to the degree of anteriority of the first consonant in the cluster, i.e., labial [m], alveolar [n], alveolopalatal [ɲ] and velar [ŋ] regarding clusters with a nasal C1, and alveolar [l, n, s, z, r], alveolopalatal [ʃ, ʒ, ʎ] and labiovelar [w] in the case of clusters with a non-nasal C1. C2, i.e., the second consonant in the cluster, is also ordered from more anterior to more posterior.

2. Accounts of stop insertion

2.1. *Categorical and variable epenthesis*

Two types of stop insertion processes in consonant clusters were proposed in the 1980s depending on whether the second consonant in the cluster is a liquid or an obstruent (Wetzels 1985; Clements 1987). Illustrative examples are English *thunder* < Old English *thunrian* for the former insertion type (15 in Table 1) and English [sɛnts] *sense* for the latter (13 in Table 1). According to this proposal, epenthetic stops in consonant clusters can be accounted for through temporal mistiming of articulatory structures if C2 is an obstruent but not so if it is a liquid. The two insertion processes differ in other respects. In clusters with a liquid C2, stop insertion improves syllable structure by replacing a rising sonority slope by a falling one, i.e., C2 ranks higher in the sonority scale than C1 in the original cluster and the opposite applies after stop insertion, and the inserted stop may be unpredictable from phonetic context (as for [sl] > [skl]; see 34 in Table 1 and Section 3.4) and exhibits a relatively fixed duration very much like any underlying stop. In clusters with an obstruent C2, on the other hand, stop epenthesis may apply optionally, does not contribute to improve syllable structure in the original cluster, and generates an emergent stop whose duration is less than that for an underlying stop.

Experimental studies report contradictory findings regarding the frequency of occurrence, phonetic prominence and variability of epenthetic stops in clusters with a final lingual fricative, which questions a subdivision of stop epenthesis into two separate classes. In agreement with the two category approach, experimental data for American English show that inserted stops are clearly shorter than underlying stops (in words like *dense* vs *dents*), and that their frequency of occurrence may vary depending on the original consonants in the cluster (100% in *dense*, 10% or less in [lz, nz]) (Fourakis and Port 1986). Moreover, reaction times in a phoneme monitoring task performed on Dutch informants were slower for epenthetic vs underlying stops presumably because the former are not as acoustically prominent as the latter (Warner and Weber 2001). In disagreement with the subdivision of epenthetic stops into more than one class, however, it has also been shown for American English that underlying and epenthetic stops may exhibit no differences in closure duration (Lee 1991; Blankenship 1992). Also, emergent stops in clusters with a nonliquid C2 may occur systematically and, therefore, exhibit full segmental status, as for the Yiddish and Romansh forms in 13, 14, 27, 28 and 39 in Table 1, and for the Valencian Catalan forms in 19 and 47 where a stop has been inserted between the alveolopalatals [ʎ] and [ɲ] and the fricative [ʃ]. Along these lines, it should be admitted that the speakers' intuitions about whether an unexpected stop closure should be assigned segmental status or not are strongly influenced by the language orthographic conventions and thus, hard to ascertain. For example, *p* in English words such as *glimpse* and *Hampshire* could very well be considered an independent segment in its own right by English speakers even though the original cluster [ms] has no liquid C2 in it (Picard 1987a)[2].

Another relevant point to be made is that the likelihood that the emergent stop occurs may be influenced by the syllable affiliation of the two original consonants in the cluster rather than by the manner of articulation of the second consonant. Thus, less stability for clusters with a nonliquid C2 than for clusters with a liquid C2 could just be related to the fact that the epenthetic stop occurs in coda position in the former case (i.e., (C<u>C</u>C) and (C<u>C</u>)(C), as for

Landais Gascon [hemps] in 8 in Table 1 and for Old French *dampner* in 7) and in syllable onset position in the latter (i.e., (C)(C̲C), as for Catalan *semblar* in 6 in the table).

2.2. *Other proposals*

Other proposals handle partial aspects of stop epenthesis. The suggestion that stop epenthesis in clusters such as [nr, lr, ml, mr] occurs in order to reinforce weak syllable onsets (Hooper 1976: 221; Morin 1980) does not account for epenthesis in syllable final position. Moreover, a trend towards improvement of syllable contacts (Vennemann 1988) applies often to heterosyllabic sequences but not to homosyllabic clusters such as those occurring word initially in 34–36 in Table 1 ([sl] > [st/kl], [zl] > [zd/gl], [sn] > [st/kn]) and word finally in 23 and 27 ([ŋs] > [ŋks], [ls] > [lts]). This is so since, in spite of exhibiting a higher degree of consonantal strength, the inserted stop lies closer to the vowel nucleus than the fricative.

Another hypothesis claims that stop epenthesis is conditioned by the segmental composition of the available syllables in a particular language (Picard 1987b). This constraint accounts for most instances of stop epenthesis in the table but fails to explain the insertion of an alveolar stop in clusters such as [nl, zl] in Italian dialects and [nl] in Standard German and Middle English (see 12, 35), since [tl, dl] are ill-formed syllable onsets in the Romance and Germanic languages.

In view of the phonetic similarity between the inserted stop and one or the two original consonants in the cluster, stop insertion has also been considered to be an assimilatory adjustment between similar segments (Murray 1989: 312). There appears to be agreement among phonologists in that this similarity relationship occurs both in place of articulation, i.e., the inserted stop is generally specified for the same place as C1, and in voicing, i.e., the stop is voiced if the two consonants are voiced and voiceless if at least one of them is voiceless (Picard 1987b). In principle, the similarity relationship of interest appears to be at odds with the insertion of a velar, not an alveolar, stop in the sequences [nl, sl] (see 12, 34 in Table 1), and of a voiceless, not a voiced, stop in voiced clusters such as [mn] (see 7).

In order to cope with the unpredictable cases just reviewed, it seems plausible to consider stop insertion the outcome of the perceptual categorization as an independent segment of a transitional oral closing period resulting from the temporal overlap between the articulatory gestures for the consonants in the cluster (Millardet 1910; Mowrey and Pagliuca 1985; Browman and Goldstein 1991; Ohala 1983, 1997). At a later stage, phonetically variable epenthetic stops may occur in lexical underlying representations, not only in consonant groups with a liquid C2 but also in those where C2 is a fricative or a stop. According to this view, there would be not different types of epenthesis conditioned by the segmental composition of the original consonant cluster, but synchronic cases of phonetically variable epenthesis and diachronic cases where the epenthesis process has been completed and epenthetic stops have acquired a full segmental status (Page, 1997).

While the inception of stop epenthesis is phonetically conditioned, phonological, morphological and lexical factors may possibly play a role during the phonologization process. Experimental evidence suggests that the phonologization of epenthetic stops may be dialect dependent, i.e., stop closures in the clusters [ns, ls] have been reported to occur 100% of the time in American English and Dutch while being absent in Southern African English (Fourakis and Port 1986). Moreover, the stop closing phase has been found to be longer prepausally in homosyllabic clusters than utterance medially across a syllable boundary (American English: Yoo and Blankenship 2003; Valencian Catalan: Recasens submitted), and listeners are likely to interpret an unintended epenthetic stop as an occurrence of a stop phoneme if doing so does not violate a syllable structure constraint in the language (Warner and Weber 2001).

2.3. *Research goal*

The goal of this paper is to account for how transitional stop articulations may arise in a large number of consonant clusters by taking into consideration those production mechanisms involved in the realization of the consecutive consonants in the cluster. Section 3 will show how a detailed knowledge about the production constraints for the consonant clusters under analysis may account for the stop insertion processes presented in Table 1. Special attention will be paid to those emergent stops which are apparently phonetically unmotivated. Additional support for a production-based account of stop epenthesis will be provided in Section 4 dealing with stop elision in three-consonant clusters.

3. Stop insertion

The generation of an epenthetic stop in consonant clusters depends on two basic requirements, i.e., the formation of an oral stop closure (Section 3.1) and a sufficient intraoral pressure rise so that the stop burst may be intense and audible enough (Section 3.2). This section reviews those factors which contribute to the implementation of these articulatory and aerodynamic requirements.

3.1. *Oral stop closure formation*

3.1.1. *Basic mechanisms.* Two basic mechanisms have been proposed in order to account for stop closure formation depending on whether the velum is involved in the production of one of the consonants in the cluster or not.

In clusters with a nasal stop, an oral stop closure may occur whenever closure release and velic closing for the nasal do not occur simultaneously. In clusters with a nasal C1 (see 1–25 in Table 1), a premature raising of the velum may cause denasalization of the final portion of the nasal and a stoppage of the airflow once the oral and nasal passages are closed. Since the articulators are still placed in the articulatory configuration for C1, the air pressure is released at the C1 place of articulation thus giving rise to an oral stop which is homorganic with the nasal stop consonant (Ohala 1974; Busà 2007). Another source of stop insertion appears to be a delay in the onset of the fricative triggered by a prolongation of the nasal stop closure; in these circumstances, nasal flow and an intraoral pressure buildup occur during a silent period, after which the oral closure is released and the velum closes (Ali et al. 1979). Stop insertion through a delay in velic lowering may also take place in clusters with a nasal C2, as for [sm] > [spm], [sn] > [stn] (see 33 and 36 in Table 1).

It has been proposed that closure formation in clusters without a nasal stop is rendered possible through complementarity in tongue contact between the two meeting consonants. Thus, Ohala (1997) has attributed stop insertion in the sequences [ls, lz] (27, 28 in Table 1) to the superposition between the central contact area for [l] and the lateral contact area for the alveolar fricative. In Sections 3.1.2 and 3.1.3, we will argue that stop closure formation in these clusters may be achieved through the superposition between the two meeting consonants at both the central and lateral contact areas and that homorganicity plays a relevant role in this respect. Clusters not involving oral closure formation through articulatory superposition cannot give rise to stop insertion (e.g., [lf]).

3.1.2. *Homorganicity.* A look at the stop insertion cases listed in Table 1 shows that there is a basic difference between clusters with a nasal stop and those without it in that the two adjacent consonants in the cluster may be homorganic or heterorganic in the former while being essentially homorganic in the latter. Indeed, stop epenthesis in nasal clusters may occur in sequences 3–10 produced with the lips and the tongue front (also 33), in sequences 20–24 involving the tongue dorsum and the tongue front articulators, and also in the remaining clusters of the table where, as argued below, both consonants agree in place of articulation. Homorganicity contributes to closure formation in clusters with a non-nasal consonant and, as pointed out in Section 3.2, may also contribute to a rise in intraoral pressure in clusters with a nasal consonant thus rendering stop epenthesis feasible. Articulatory superposition at the central zone of the oral cavity (whether complete or partial) occurs basically in all clusters of interest. This is so since, among the consonants intervening in these clusters, oral and nasal stops are articulated with a full closure, laterals and rhotics with at least central contact, and fricatives with a narrow constriction and lateral contact at the alveolar zone.

In order to gain an appropriate understanding of how identity in place of articulation between the two consecutive consonants may be achieved, the production-based DAC ('degree of articulation constraint') model will be used (Recasens et al. 1997). This model has been elaborated with linguopalatal contact and acoustic data for Catalan in order to explain articulatory adaptation phenomena between phonetic segments in the speech chain. The model predicts that the extent to which the consonants in a cluster adapt to each other depends on the degree of articulatory constraint involved in their production. As for the tongue body for front lingual consonants, the trill [r], the two lingual fricatives and dark [l] are highly constrained, while dentals ([t, d]) and other alveolars and alveolopalatals ([n, ɲ, ʎ] and clear [l]) are less constrained. Moreover, place of articulation for all these consonants appears to be also conditioned by the degree of articulatory constraint: thus, in Catalan and other Romance languages, more constrained [s] and to a large extent the trill [r] are more posterior than less constrained [l, n], and the same applies to [ʃ] with respect to [ʎ, ɲ]. The reason why dark and clear [l] are front alveolar appears to be due to the need to let the airflow out of the mouth through lateral openings at one or both sides of the oral cavity.

Within this framework, two consecutive heterosyllabic consonants may reach the same closure or constriction location essentially through blending or assimilation (Recasens 2006a, in press, Recasens and Pallarès 2001b). Blending is a nondirectional process operating on clusters composed of consonants exhibiting a low degree of articulatory constraint and yielding an articulatory realization which is intermediate between C1 and C2 or else encompasses their closure or constriction areas. Assimilation, on the other hand, applies mostly at the regressive level whenever C2 is more constrained than C1, and causes C1 to acquire the C2 place of articulation since its very temporal onset. In clusters where C1 is more constrained than C2, the latter consonant adapts partially to the former through a carryover coarticulation effect proceeding from left to right.

Assimilation or blending render homorganic consonants with a nasal or lateral C1 and a second consonant produced at a close-by articulatory zone with the same or a contiguous articulator. As for the clusters in Table 1, the DAC model accounts for this consonant becoming labiodental in the clusters [ɱf, ɱv] (1, 2), dental in [nθ, lθ] (11, 26), centro-alveolar or postalveolar in [ns, nz, nr, ɲr, ls, lz, lr, ʎs, ʎr] (13, 14, 15, 18, 27–29, 45, 46) and alveolopalatal in [nʃ, nʒ, ɲʃ, lʃ, lʒ, ʎʃ] (16, 17, 19, 30, 31, 47). All these clusters undergo regressive assimilation since C1 happens to be less constrained than C2, and depalatalization takes place in the case of [ɲ, ʎ] before [s, r]. Laterality requirements account for why homorganicity in clusters with C1 = [l] may not be achieved until closure offset; indeed, electropalatographic data reveal that, during the closure period for the lateral, the tongue tip retracts a long way towards the place of articulation of C2 = [s, r, ʃ]. As for the sequence [nl] (12), C1 and C2 share the same closure location at the front alveolar zone (see above).

Even though the DAC model predicts that the cluster [ɲs] should become homorganic through regressive assimilation, [ɲʃ] has been included in the table while [ɲs] has not. The rationale for this decision lies on the fact that, since [ɲ, ʎ] exhibit a high degree of palatality, following [s] could undergo progressive assimilation thus becoming alveolopalatal ([ʃ]) after the nasal and the lateral. Moreover, dialectal data for the word endings [ɲs] and [ʎs] in Catalan are in support of this observation in so far as [s] palatalization may occur more systematically after [ɲ] than after [ʎ] (Recasens 1996). In case that progressive assimilation is not at work, stop insertion may take place before [s, r] after depalatalization and glide insertion of [ɲ] into [jn] (Old French [bajnts] *bainz* *BANIOS 'baths', [pujnts] *poinz* PUGNOS 'fists', *plaindre* PLANGERE 'to complain', *joindre* IUNGERE 'to join'; Pope 1934: 132–133). These cases do not differ essentially from those for [n] followed by [s, r] in Table 1 even though the starting point must be a palatalized alveolar C1 rather than an alveolar one.

As for clusters with C1 = [s], the DAC model also predicts that a higher degree of articulatory constraint for C1 than for C2 in the case of [sn] (36) and [sl, zl] (34, 35) ought to result in C1-dependent carryover coarticulatory effects on C2 which could yield the same or a close place of articulation for the two consecutive consonants and contribute to stop insertion. Indeed, these clusters keep the original place for C1, and may exhibit partial retraction of the C2 place of articulation or two independent targets for C1 and C2 mostly when the second consonant is [l] in view of the laterality requirements involved.

Alveolar stop insertion may also occur in combinations of highly constrained lingual fricatives and trills (see cases 37–41, 43, 44). Descriptive and experimental data on consonant clusters reported in studies on Spanish and Catalan such as those referred to above suggest that the trill [r] is more constrained than the two lingual fricatives [s, ʃ]. Effects exerted by the trill account for homorganicity at the back of the alveolar zone in all fricative + rhotic and rhotic + fricative combinations composed of these three consonants, which also explains why [sr, ʃr] may be realized [rr] while regressive assimilation does not operate on [rs, rʃ].

In principle, homorganicity does not seem to operate in consonant combinations with the glide [w], i.e., [ŋw, lw, rw, wl] (25, 32, 42, 48). However, the insertion of [g] in the cluster [ŋw] could be favored by both C1 and the labiovelar approximant sharing a back dorso-velar closure or constriction[3]. A homorganic relationship between the two consonants in the three remaining sequences [lw, rw, wl] may also occur at the back of the vocal tract, i.e., a dark realization of [l] and a trill-like realization of the rhotic share a postdorsal constriction with [w]. Data form the literature show indeed that these two consonants involve postdorsum retraction towards the upper pharynx and/or velar zone (Browman and Goldstein 1995; Proctor 2009). The insertion of [b] instead of [g] in the cluster [wɾ] (49) is consistent with the alveolar tap differing from the alveolar trill in not being articulated with a postdorsal constriction.

3.1.3. *Superposition of lateral contact.* The formation of a complete closure for an emergent stop depends on the two consecutive consonants sharing not only central contact at the place of articulation but also tongue contact at the sides of the oral cavity. Electropalatographic data reveal indeed the presence of lateral contact for essentially all dental, alveolar and alveolopalatal consonants intervening in the clusters of Table 1.

Several additional remarks need to be made in this respect. According to palatographic data, there is more lateral contact for the rhotic if realized as a trill or a trill-like sound than as a tap, and the alveolopalatal lateral [ʎ] often exhibits tongue contact at the sides of the palate surface in addition to a central closure, the lateral oral airflow exiting through openings located behind the palate in this case (Recasens and Pallarès 2001a). Moreover, in order to exhibit sufficient lateral contact, [l] is expected to be clear rather than dark since the production of clear [l] involves simultaneous central and lateral contact while this is not necessarily the case for dark [l] (Giles and Moll 1975; Recasens and Espinosa 2005).

3.2. *Intraoral air pressure buildup*

Closure formation is not the only requirement for an inserted closure to be categorized perceptually as an independent stop segment. In addition, both for clusters without a nasal stop and for those with a nasal, a sufficient air pressure needs to be created behind closure location so that the corresponding burst becomes intense enough to be heard by the listener. In clusters without a nasal consonant, closure formation through articulatory superposition ensures a pressure increase inside the vocal tract (see Sections 3.1.2 and 3.1.3 above). In clusters with a nasal C1, an increase in air pressure may take place during the oral stop closure when the velum is closed prematurely (Ohala 1974) and also during the nasal when velic closing is delayed after the stop release (Ali et al. 1979). Homorganicity appears to facilitate the emergence of an oral stop in these circumstances, as suggested by data for Valencian Catalan showing that the emergent stop burst occurs more often for [ns] (and for [ɲs]) than for [ms] where C1 and C2 are not homorganic and for [ls, ʎs] where homorganicity between C1 and C2 is not usually achieved until the end of the C1 closure period (Recasens submitted). Experimental evidence indicates that holding an oral closure at the same position for a long period of time causes indeed an increase in oral pressure to occur which should favor stop insertion (Westbury and Keating 1986). As discussed next, an oral pressure buildup and an increase in perceptibility of the stop burst (and thus, the implementation of stop epenthesis) are also favoured by the manner and place of articulation requirements for the consonants in the cluster.

An increase in intraoral pressure level appears to be facilitated by the presence of a fricative C2 in clusters (24 clusters in Table 1). Fricatives are endowed with a high pressure level in line with their production involving a high rate of oral airflow and a narrow oral constriction (Black 1950; Malécot 1955, 1968; Hixon 1966; Arkebauer et al. 1967). Oral pressure rise may also be favored by trilling in a rhotic C2 (9 clusters in the table), as suggested by experimental studies showing that trills require a high oropharyngeal pressure to maintain trilling (Solé 2002). This possibility is consistent with rhotics being realized as trills after a heterosyllabic consonant in most Romance languages (including Old French), and with electropalatographic data revealing that, in comparison to intervocalic trills and taps, postconsonantal trills involve more lateral tongue contact (Recasens and Espinosa 2007). Consequently, it may be hypothesized that, after the elision of word medial unstressed vowels in Proto-Romance, intervocalic [ɾ] had to become a syllable final trill or a trill-like articulation for stop insertion to apply, and that, later on, the outcoming heterosyllabic sequence [Cr] must have changed into the tautosyllabic sequence [Cɾ] through leveling with other syllable initial clusters with a tap. Thus, for example, the Catalan word [sem'bɾaɾ] 'to sow' may have been issued from [seme'naɾ] SEMINARE through the stages [sem'naɾ] > [sem'raɾ] > [sem'braɾ] and finally [sem'bɾaɾ] under the influence of words like [bɾew] BREVE 'brief' and [pɾat] PRATU 'prairie'. A possible reason as to why epenthesis may affect more often clusters with C2 = [r] than those with C1 = [r] (4 cases in Table 1) may be related to the weakness of syllable final [r] vis-à-vis the strong realization of the rhotic after a heterosyllabic consonant (in Romance, the alveolar rhotic is not realized as a well-defined trill but rather as a tap or as an approximant before a heterosyllabic consonant and word finally; see Navarro Tomás 1972: 115–116 for Spanish). Moreover, the conflicting aerodynamic requirements involved in tongue tip vibration for lingual trills and in the generation of an audible turbulence for lingual fricatives may account for why trilling and stop insertion are not prone to occur in clusters such as [rs] and [rʃ] (Solé 2002, Recasens submitted).

A rise in intraoral pressure level should also be facilitated by an increase in linguopalatal contact and a reduction of the cavity behind closure location for alveolopalatals and velars in comparison to more anterior lingual and labial consonants (11 clusters with C1 = [ʎ, ɲ, ŋ] in Table 1). This possibility is consistent with the stop burst being more prominent for the inserted oral stop closure in the case of the cluster [ŋs] than of the sequences [ms, ns] in Dutch (Warner and Weber 2001), and for stop insertion occurring systematically in the sequences [ʎs, ɲs] but not in the clusters [ms, ns, ls, rs] in Valencian Catalan (Recasens submitted).

Stop insertion is less likely to operate in sequences with a nasal, lateral, tap or approximant C2 than in those with a fricative or trill C2 since the consonants of the former group involve a relatively low oral pressure buildup, and the fact that the stop closure may be released nasally or laterally, i.e., whenever the air pressure build up is vented through the nose or the sides of the mouth, may render the burst in those clusters weak and not too audible. A perception-based explanation of stop epenthesis has been proposed for these consonant combinations: as for the clusters with both a nasal and a liquid, the insertion of an oral stop may be needed in order to prevent nasality from distorting the acoustic characteristics of the liquid (Ohala 1997); regarding the fricative + nasal sequences (e.g., [sm] > [spm], [sn] > [stn]), stop insertion could be triggered by a delay in velic lowering in order to preserve frication which would be seriously weakened if velar opening was anticipated in time (Solé 2007).

A click-based mechanism has also been proposed in order to explain stop epenthesis in clusters where the nasal consonant is followed by a nonhomorganic oral stop closure which is articulated more posteriorly, e.g., [mt, md, mn, ŋt] > [mpt, mbd, mpn, ŋkt] in 4, 5, 7 and 21 in Table 1 (Ohala 1997). A negative pressure is created inside the cavity between the places of articulation for the two consonants as the C1 closure is released which causes a stop-like click to be heard[4].

3.3. *Voicing*

Experimental data on stop insertion in American English indicate that the emerging closing period is regularly voiceless (Ali et al. 1979), though the continuation of voicing during the oral closure period is also possible (Fourakis and Port 1986). In theory, stop epenthesis is supposed to be less prone to occur in voiced than in voiceless consonant clusters the reason being that continuous voicing prevents less air pressure buildup from occurring which results into a less audible stop burst (Ohala 1974). The stop insertion processes presented in Table 1 show, however, that a voiced oral stop may be inserted as often as a voiceless stop and, more specifically, that the inserted stop is generally voiced if both C1 and C2 are voiced and voiceless if at least one consonant is voiceless (Picard 1987b). In agreement with this observation, experimental data on

Valencian Catalan stop insertion reveal frequent cases of complete or partial voicing during the closing phase of the inserted oral stop presumably when the intraoral pressure level is relatively low, i.e., more frequently utterance medially than prepausally, in nasal vs non-nasal clusters and for front vs back consonants (Recasens submitted).

Voicelessness in the inserted stop in clusters composed exclusively of voiced consonants could be associated with a rise in intraoral pressure level for [ml] > [mpl] (6) and [nl] > [ntl] (12), and with the aerodynamic characteristics of clicks for [mn] > [mpn] (7) (see Section 3.2). Clusters with a lingual fricative in C1 position deserve special attention. As shown in Table 1, the inserted stop appears to be voiceless or voiced depending on whether the fricative is voiceless or not, respectively (also Picard 1987b): [sl] > [stl, skl] (34), [zl] > [zdl, zgl] (35), [sr, ʃr] > [stɾ, ʃtɾ] (37, 43), [zr, ʒr] > [zdɾ, ʒdɾ] (38, 44). Examples taken from Romance indicate that the voicing status of the inserted stop in this case may be accounted for on the basis of the voicing status of the original fricative in Latin (Walker 1978; Pope 1934: 148). Thus, in French, the inserted stop in the clusters of interest is voiceless if the preceding fricative was originally voiceless whether because of being derived from geminate SS or being preceded by another consonant (*être* ESSERE 'to be', Old French *distrent* DIXERUNT 'they said'), or else voiced if the fricative was originally voiced because it was derived from S or NS (*coudre* CONSUERE 'to sew', Old French *misdrent* from MISERUNT 'they put (past)'). A possible problem with this explanation is that regressive voicing assimilation could have occurred in Romance at the time that the stop was inserted such that the alveolar fricative would have become voiced before a voiced consonant and voiceless before a voiceless one, thus rendering sequences such as [sl, sn] phonetically impossible (regarding the existence of a regressive voicing rule in heterosyllabic consonant clusters in Romance, see Pope 1934: 151 for Old French; Navarro Tomás 1972: 108 for Spanish; Herslund 1986: 510 for Portuguese; and Rohlfs 1966: 382 for Italian). Since stop epenthesis occurred after unstressed vowel syncope in Romance, traces of the original voiceless or voiced status of the fricative must have remained, which might have contributed to the insertion of a voiceless or voiced stop depending on the case. In insertion processes such as [sl] > [skl] (34) and [sn] > [skn] (36), devoicing could also be attributed to a rise in intraoral pressure triggered by the presence of a small back cavity behind a velar constriction (see Section 3.4).

3.4. *Special evolutions*

In several stop insertion cases in Table 1, the stop does not agree in place of articulation with any of the two original consonants in the cluster, i.e., [nl] >

[ngl] (12), [sl] > [skl] (34), [zl] > [zgl] (35) and [sn] > [skn] (36). Regarding the sequences with C2 = [l][5], since [t, d] may also appear instead of [k, g], it has been suggested that the first stop consonant to be inserted was a dentoalveolar oral stop, and that [t, d] must have been replaced by [k, g] at a later date in order to comply with the permissible syllable initial cluster structures, e.g., Fr. *épingle* < **espindla* < **espinla* SPINULA 'pin', Occitan *asclo* ASTULA < ASS(U)LA 'splinter' (Fouché 1927: 52–54; Morin 1980: 220; Grandgent 1991: 183–184). The same replacement appears to have affected [tl] in postvocalic position in Latin and Romance, e.g., It. *vecchio* VECLUS < Latin VET(U)LUS 'old', It. *capecchio* 'chapter' *CAPICLUS < CAPIT(U)LUS, Romansh ['tɛːglə] TITULAT 'he/she entitles', [aŋ'klikr] INTELLEGERE 'to understand' (Lutta 1923: 229). Menéndez Pidal (1968: 159–160) also mentions the Spanish lexical items *almeja* MITULU 'shellfish' and *arrojar* ADROTULARE 'to throw away' where the velar fricative [x], which is represented by the grapheme j in Spanish, goes back to Latin [kl] (e.g., ['oxo] *ojo* OCLU 'eye'). Other scholars suggest instead that [t, d] were not replaced by [k, g] in Romance but that the velar stop was appended directly to the original cluster, and that velar stop insertion was preferred to dental stop insertion for the same phonotactic reasons referred to above (Clements 1987: 40; Morin 1987). It has also been argued that a velar was inserted instead of a labial since the articulatory distance between [k] and [t] is smaller than that between [p] and [t] (Wetzels 1985: 308) or because [l] was velarized at the time that velar stop insertion occurred (Picard 1987a: 280).

Our position regarding this issue is that a velar oral stop may be inserted directly into the clusters [nl, sl] provided that the alveolar lateral is dark, not clear. A back postdorsal constriction for [l] could trigger some postdorsum narrowing at the pharyngeal or velar region in preceding [n] and [s] which may cause a stop to be heard at C1 offset. Moreover, X-ray data show that a lowered predorsum co-occurring with some tongue postdorsum backing is most prone to take place in apical, not laminal, realizations of the first alveolar consonant in the cluster (Dart 1991: 59). It seems that [l] must have been typically dark in most Romance languages judging from numerous instances of syllable final [l] vocalization into [w] such as Old Provençal *mout* MULTU 'a great deal' and Gascon *sau* SAL(E) 'salt' (Grandgent 1905: 70; Rohlfs 1970: 152). Also, if [l] was strongly dark, the darkness characteristic would have been present not only syllable finally but syllable initially as well, i.e., experimental data show that dialects with a strongly dark variety of [l] may exhibit this allophone in all positions (Recasens and Espinosa 2005).

Possible evidence for the direct epenthesis of a velar stop derives from alternating forms. As for the cluster [nl], phonetic alternations between [ll, nl, ŋl, ŋgl, gl, ŋg] in the lexical items below taken from Occitan (mostly Gascon) suggest that stop insertion was implemented through the derivation [nl] > [ŋl] >

[ŋgl] (see also Millardet 1910). The variant [nl] is the original form after unstressed vowel syncope in (2) and (4), and goes back to [ll] whether derived from [dl] in (1) and (5) or not in (3). The realizations [gl] in (1) and (3), and [ŋg] in (2), have probably been issued from [ŋgl].

(1)	MODULU	[ˈmollə], [ˈmu/ɔnlə], [ˈmwõŋglə], [ˈmuglə] 'mould' (Millardet 1910: 99–100; von Wartburg 1922– . . . , vol. 6(3): 15)
(2)	SPINULA	[esˈpillo], [ehˈpĩnlo], [ejˈpiŋgo], [esˈpĩŋglo] 'thorn' (Millardet 1910: 100, von Wartburg 1922– . . . , vol. 12: 183–186)
(3)	HABILIS	[aˈbillə], [aˈbinlə], [aˈbiglə] 'capable' (Millardet 1910: 188–189)
(4)	*HIRUNDULA	[aˈɾunlə], [aˈɾuŋglə] 'lark' (Millardet 1910: 99)
(5)	SPATULA	[esˈpallo], [esˈpanlo], [esˈpaŋlo] 'back' (von Wartburg 1922– . . . , vol. 12: 146; Ronjat 1930–1941, vol. 2: 151–152)

Regarding the cluster [sl], it may be that forms with and without velar stop epenthesis coexisted in Latin (e.g., *ISLA and *ISCLA, ASS(U)LA and *ASCLA, PESS(U)LU and *PESCLU), and that the present-day Romance languages exhibit phonetic outcomes issued from both nonepenthesized variants (see (6a) and (8a) below) and from epenthesized ones (see (6b), (7) and (8b) below) (Meyer-Lübke 1974: 439; Lausberg 1970: 416; Väänänen 1985: 126).

(6) a. Occitan [ˈiʎo], [ˈinlo], [ˈirle] *ISLA
'island'
(Ronjat 1930–1941, vol. 2: 242)

b. Occitan *isclo*, Catalan place names *Peníscola*, *Les Iscles*, Italian place name *Ischia* *ISCLA
'island'
(Ronjat 1930–1941, vol. 2: 242; Coromines, 1980–1991, vol. 4: 835; Rohlfs 1966: 351)

(7) Occitan *asclo*, Catalan *ascla* *ASCLA
'splinter'
(Ronjat 1930–1941, vol. 2: 241; Coromines, 1980–1991, vol. 1: 444)

(8) a. Old French *pesle*, Galician *peslo*, Occitan *pèile* *PESLU
'bolt'
(Molho 1958: 70; Ronjat 1930–1941, vol. 2: 242)
b. Lazio ['pɛskjo] *PESCLU, Vaux Francoprovençal ['peklɛt]
'bolt'
(Rohlfs 1966: 382; von Wartburg 1922– . . . , vol. 8: 308).

Further support for the possibility that [k] was inserted directly into the cluster [sl] derives from the adaptation of word initial [sl] as [skl] in Romance borrowings from Germanic languages (in (9a) and (9b)), from instances of [k] insertion in popular Romanian (in (10)), and from the alternate Middle English spellings *sl*, *scl* and *skl* in words exhibiting [sl] originally (in (11)). Moreover, Italian *schiavo* and Catalan *esclau* 'slave' go back to Old Slavic *sloveninu* through the Bizantin Greek form σχλάβος with an epenthesized velar. Finally, the coexistence of all three forms [sl, stl, skl, l] in word initial clusters derived from SL– in Latin in cases such as *stlis/slis/lis* 'trial' and *stlis/sclis* 'strife' (Phelps 1937; Lindsay 1894: 307) appears to be compatible with the independent insertion of [t] and [k] between [s] and [l] in the original cluster form.

(9) a. Catalan *esclet*, Italian *schietto* from Franconian *SLIHT
'pure, dry'
(Coromines 1980–1991, vol. 3: 523)
b. Catalan *esclatar*, French *éclater* from Franconian *SLAITAN
'to outburst'
(Coromines 1980–1991, vol. 3: 518–521)

(10) Romanian *iescle* < *iesle* 'cradle', *sklab* < *slab*
'weak'
(Nandris 1963: 196–197)

(11) Middle English *sclepen*, *scleue/skleves*, *sclauth* < Old English *sleep*, *sleeve*, *slaught*
(Minkova 2003: 231).

Cases such as those in (12a) and (12b) through (15), where Romance [skl] derives from the original cluster [stl], do not imply necessarily the substitution of [t] by [k] but could have been generated through [t] elision followed by [k] insertion.

(12) a. Occitan [fej'klio] FISTULA
'fistula'
(Ronjat 1930–1941, vol. 2: 241)
b. Italian *fischiare* FISTULARI
'to whistle'
(Cortelazzo and Zolli 1980: 439)

(13) Catalan, Occitan *esclop* STLOPPUS
'wooden show'
(Ronjat 1930–1941, vol. 2: 241; Coromines, 1980–1991, vol. 3: 528–530)

(14) Occitan *uscla*, Catalan *usclar*, dialectal Italian *uschiare* USTULARE
'to burn'
(Ronjat 1930–1941, vol. 2: 241; Coromines, 1980–1991, vol. 8: 997)

(15) Occitan *arescle* *ARISTULU 'beard of corn'
(Ronjat 1930–1941, vol. 2: 241)

4. Stop deletion

The hypothesis that stop epenthesis in clusters can be attributed exclusively to articulatory factors is consistent with the articulatory mechanisms involved in the reduction and elision of a stop consonant in two and three consonant clusters.

The elision of a stop C2 after a (quasi)-homorganic C1 in biconsonantal word final sequences may be attributed to the identity in place of articulation between the two adjacent consonants much in the same way as stop insertion is facilitated by homorganicity between the two consonants of the original cluster. Word final stop elision may be exemplified in Eastern Catalan where, in contrast with Valencian Catalan, an underlying oral stop drops after a homorganic nasal and an underlying dental stop is deleted in nonlearned words after [l] and in colloquial and/or fast speech after [s, r] (Eastern [kam], [al], Valencian [kamp], [alt] 'field', 'high, tall'; Recasens 1996).

As for three consonant clusters, the elision of a stop C2 may also take place next to a consonant exhibiting the same place of articulation at the bilabial (see (16)), alveolar (in (17)) or velar (in (18)) zone (see also Côté 2000: 43 regarding Hungarian clusters).

(16)	a.	[mpt, mps] > [nt, ns]	Catalan ['kontə] COMPUTU 'count' Catalan *cansar* CAMPSARE 'to tire out'
	b.	[rpm] > [rm]	Spanish *sarmiento* SARMENTUM < *SARPMENTOM (Niederman 1953: 157)
(17)	a.	[stm, stn] > [zm, zn]	Old French [ez'mer] AESTIMARE 'to evaluate' Old Bergamasco It. *pesnaga* PASTINACA 'carrot' (Pope 1934: 146; Rohlfs 1966: 384)

b. [nts, rts, lts] > [ns, rs, ls] Catalan [ʎən'sɔl] LINTEOLU 'sheet'
Catalan [di'mars] DIE MARTIS 'Tuesday',
Valencian Catalan [als] for [alts] 'high (pl.)'

c. [ndɾ, stɾ] > [nr, sr] dialectal Spanish [pon're] for [pon'dɾe] 'I will put',
Old Spanish ['nweso] < ['nwestɾo] 'our (masc.)'
(Menéndez Pidal 1968: 106, 145).

(18) [ŋkt] > [nt] Spanish *quinto* QUINTUS < QUINCTUS (Niederman, 1953: 73).

A good number of examples showing that the velar stop may drop from the original cluster [skl], thus yielding [sl], are in support of a direct [k] insertion process in the cluster [sl] (French *mâle* MASCULU 'male', *mêler* MISCULARE 'to mix', Spanish *muslo* MUSCULU 'thigh'). Likewise, French words with initial [skl] could be adapted as [sl] in Middle English, e.g., *slat* from *esclat*, *sluice* from *escluse* (Minkova 2003: 232). A related case could be the simplification processes [rgl] > [rl] and [gl] > [l] found in Old French *marle*, Occitan *marlo* MARGILA 'marl' (Molho 1958), Spanish *latir* GLATTIRE 'to beat', *landre* GLANDULA 'gland' (Menéndez Pidal 1968: 127), Campidanese Sardinian *landi* GLANDE 'acorn', [lɛa] GLEBA 'clod' (Virdis 1978: 69) and dialectal Catalan *ilésia* ECCLESIA 'church' (Recasens, 1996: 240). As argued for velar stop insertion in the sequence [sl] (see Section 3.4), the fact that [k, g] and dark [l] may share a velar closure or constriction may account for these changes to a large extent.

5. Conclusions

Experimental data for Dutch and Valencian Catalan referred to in the present paper show that stop epenthesis in consonant clusters is phonetically motivated and may occur systematically or highly frequently. This suggests that epenthetic stops are phonetically variable at first and may undergo phonologization later on. Moreover, as for many other processes (such as dark [l] vocalization), stop insertion appears to be conditioned by several contextual and positional factors which render inserted stop closures more prone to acquire segmental status in some clusters than in others. This theoretical proposal is supposed to account for cases of stop insertion which cannot be easily explained by other more formal proposals, e.g., [nl] > [ndl, ntl], [sl] > [stl] and [zl] > [zdl] violate constraints on well-formedness of syllable initial clusters, and [nl, sl] > [ŋgl, skl] (also voiceless stop insertion in clusters with two voiced consonants) the stipulation that the epenthetic stop should be similar to the two original consonants in the cluster.

It has been argued that stop insertion depends both on the formation of an oral closure and on a sufficient oral pressure rise so as to render the stop burst intense enough so that it may be accurately perceived. The former action is triggered by the anticipation or delay of the velic closing gesture with respect to the oral closure release in nasal clusters, and by (quasi-) complete tongue contact superposition between the two consonants in clusters without a nasal consonant. The DAC model has been called for in order to show that homorganicity applies to more clusters than previously assumed, and that the emergent stop closure formation is achieved by complete contact superposition in most cases. An increase in the intraoral pressure level should be favored by maximal articulatory superposition between C1 and C2 for clusters with non-nasal and nasal consonants, as well as by the presence of a fricative or trill C2, and by an increase in tongue contact and retraction of the place of articulation for C1.

Another contribution of the paper is that the inserted stop may be completely or partially voiced and that the absence or presence of voicing depends on several factors causing a higher or lower intraoral pressure level to occur during the emergent closing phase. Moreover, velar stop insertion in clusters with an alveolar consonant and dark [l] or [w] (e.g., [nl, sl, lw, rw]) may be attributed to C1 and C2 sharing a constriction at the velar or upper pharyngeal region. The fact that stop insertion and stop deletion may apply in the same or similar contextual conditions appears to be in support of the view that stop epenthesis is phonetically motivated.

The present work is relevant for the phonetics-phonology interface in that it shows that explanatory hypotheses in phonology need to be put to experimental testing, and that experimentally driven generalizations from a limited data set may prove inadequate. The latter remark applies to the assumption that emergent stops are most prone to be voiceless, or that stop epenthesis should apply independently of the articulatory and aerodynamic constraints for the consonants in the cluster to a large extent. Moreover, the experimental evidence adduced in the present investigation suggests that stop insertion and stop elision apply gradually through different clusters and presumably through the lexicon.

Further research should deal with the aerodynamic factors involved in the generation of a stop in different clusters including those with a liquid C2. Moreover, language data (both synchronic and diachronic) on the frequency of occurrence of inserted stops as a function of consonant cluster are needed in order to achieve a more thorough understanding of how stop epenthesis operates in different languages and dialects.

Received 22 February 2010
Revised version received 2 January 2011

Universitat Autònoma de Barcelona
Institut d'Estudis Catalans, Barcelona

Appendix

Table 1. *Stop epenthesis processes with examples*†.

I. Clusters with a nasal C1	
1. ɱf > ɱpf	Bergün Rosh. [aɱ'pfleːr] INFLARE 'to swell', Eng. [tɹaɪʌɱpf] *triumph* (Lutta 1923: 252, Page 1997: 176)
2. ɱv > ɱbv	S.It. [iɱ'bvɛrno] INVERNU 'winter' (Vincent 1988: 281)
3. mθ > mpθ	American Eng. [wɔɹmpθ] *warmth* (Ohala 1983: 208)
4. mt > mpt	Cat. *compte* COMITE 'count', Dut. [hɛmpt] for [hɛmt] 'shirt', Eng. *empty* < Old Eng. *æmtig*, [dɹɛmpt] *dreamt* (Warner 2002: 2; Murray 1989: 294)
5. md > mbd	Old Sp. *limbde* LIMITE 'border', Dut. ['hembden] *hemden* 'shirts' (Menéndez Pidal 1968: 156; Picard 1987a: 269)
6. ml > mbl, mpl	Cat. *semblar* SIMILARE 'to look like', Lat. *exemplum* < **exemlom* 'example', Eng. *thimble* < Old Eng. *thimle* (Niederman 1953: 152; Wetzels 1985: 287)
7. mn > mpn	Old Fr. *dampner* DAMNARE 'to hurt' , Middle Eng. *nempne* < Old Eng. *nemna* 'name' (Pope 1934: 148, Ohala, 1997)
8. ms > mps	Landes Gasc. [hemps] FIMUS 'manure', Eng. ['timpstəɹ] *teamster* (Millardet 1910: 95, Ohala 1983: 208)
9. mr > mbɾ	Cat. *sembrar* SEMINARE 'to sow', Old Eng. *timbran* next to Gothic *timrjan* 'to build' (Page 1997: 177)
10. mʃ > mpʃ	Eng. [ə'sʌmpʃən] *assumption* (Page 1997: 176)
11. nθ > ntθ	Eng. [naɪntθ] *ninth* (Page 1997: 176)
12. nl > ndl, ntl, ngl	Romagnol It. ['kondla] CUNULA 'little cradle', Standard Germ. *öffentlich* < *offen* + *lich* 'overt', Middle Eng. *spindle* < Old Eng. *spinle*. For velar stop insertion, see Section 3.4. (Rohlfs 1966: 355, Wetzels 1985: 302, Murray 1989: 300)
13. ns > nts	Bergün Rosh. [ɔnts] ANNOS 'years', Neapolitan It. [pen'tsaɾe] *pensare* 'to think', Eng. [sɛnts] *sense* (Lutta 1923: 244, Rohlfs 1966: 381, Page 1997: 176)
14. nz > ndz	Yid. *gandz* < German *Gans* 'goose' (Wetzels 1985: 314)
15. nr > ndɾ	Cat. *cendra* CINERE 'ashes', Eng. *thunder* < Old Eng. *thunrian* (Wetzels 1985: 287)
16. nʃ > ntʃ	Landes Gasc. ['mantʃə] < Fr. *manche* 'sleeve', Eng. *censure* ['sɛntʃəɹ] (Millardet 1910: 96, Page 1997: 176)

Table 1 (*Continued*)

I. Clusters with a nasal C1	
17. nʒ > ndʒ	XVIII c. Eng. *change*, Eastern Cat. ['men(d)ʒə] 'he/she eats' (MacMahon 1998: 479, Recasens 1996: 296–297)
18. ɲr > ɲdɾ	Valencian Cat. [plaɲ'dɾia] < *plany(e)ria* 'I would complain' (Alcover and Moll 1929, II: 46)
19. ɲʃ >ɲtʃ	Valencian Cat. [aɲtʃ] < [aɲʃ] ANNOS 'years' (Recasens 1996: 273–274)
20. ŋθ > ŋkθ	Eng. [lɛŋkθ] *length* (Page 1997: 176)
21. ŋt > ŋkt	Dut. [hɑŋkt] < [hɑŋt] 'he hangs' (Wetzels 1985: 288)
22. ŋl > ŋgl	Landes Gasc. [awɾaŋ'glɛɾə] from [awɾaŋ] *AULANA < ABELLANA 'hazelnut tree' (Millardet 1910: 99)
23. ŋs > ŋks	Landes Gasc. [maŋks] < [maŋs] MANUS 'hands', Eng. ['jʌŋkstəɹ] *youngster* (Millardet 1910: 95, Page, 1997: 176)
24. ŋʃ > ŋkʃ	Eng. ['æŋkʃəs] *anxious* (Page 1997: 176)
25. ŋw > ŋgw	Sp. placename *Yanguas* JANUAS, Old Prov. [veŋ'ges] < *[veŋ'gwes] VENUISSET 'he/she would come'. (Pensado 1986: 80, Grandgent 1905: 62)
II. Clusters without a nasal C1	
26. lθ > ltθ	Eng. [hɛltθ] *health* (Page 1997: 176)
27. ls > lts	Bergün Rosh. [tça'vɛlts] CAPILLOS 'hair (pl.)', Eng. [fɔlts] *false*, Yid. *alts* < *all(e)s* 'all' (Lutta 1923: 244, Picard 1987b: 136, Page 1997: 176)
28. lz > ldz	Yid. *haldz* < Germ. *Hals* 'neck' (Wetzels 1985: 314)
29. lr > ldɾ	Cat. *moldre* MOLERE 'to grind', Middle Eng. *alder* < Old Eng. *Alre* (Page 1997: 177)
30. lʃ > ltʃ	Eng. [wɛltʃ] *Welsh* (Page 1997: 176)
31. lʒ > ldʒ	s. XVIII Eng. [bʌl(d)ʒ] *bulge* (MacMahon 1998: 479)
32. lw > lgw	Old Prov. [val'ges] < *[val'gwes] VALUISSEM 'it would be worth' (Grandgent 1905: 62)
33. sm > spm	Sanskrit ['griʂpma] < ['griʂma] 'heat' (Ohala 1997)
34. sl > stl, skl	Old Norse person name *Ás(t)lákr*, Old Eng. *hwistlian* next to Old Norse *hvísl*a 'whistle'. For velar stop insertion, see Section 3.4 (Noreen 1903: 196l, Campbell 1959: 192).
35. zl > zdl, zgl	Marche It. [zdlon'gɛ] *slungare* "to lengthen", Rom. *zglobiu* < Old. Slav. *zlobivЪ* 'smart' (Rohlfs 1966: 263, Fouché 1927: 78).

Table 1 (*Continued*)

II. Clusters without a nasal C1	
36. sn > stn, skn	Old Norse *stniór* < *sniór* 'snow', Old Eng. *scnīcendan* < *snīcendan* 'to sneak, pres. part.' (Noreen 1903: 196, Murray 1989: 310)
37. sr > stɾ	Old Fr. ['estɾə] ESSERE 'to be', Old Eng. *stream* < IndoEuropean *sre–* 'flow' (Pope 1934: 148, Prokosch 1939: 85)
38. zr > zdɾ	Old Fr. ['kozdɾə] CONSUERE 'to sow' (Pope 1934: 148)
39. rs > rts	Bergün Rosh. [arts] ARSU 'burnt' (Lutta 1923: 245)
40. rʃ > rtʃ	Eastern Cat. [mər'(t)ʃa] Frankish *MARKON 'to go away' (Recasens 1996: 296–297)
41. rʒ > rdʒ	Eastern Cat. ['mar(d)ʒə] MARGINE 'boundary' (Recasens 1996: 296–297)
42. rw > rgw	Old Prov. [mɛrk] < *['mergwit] MERUIT 'he/she deserved' (Grandgent 1905: 62)
43. ʃr > ʃtɾ	S. Valencian Cat. [koneʃ'tɾe] < [koneʃ(e)'ɾe] 'I will know', Old High German *ʃtraube* < *ʃraube* 'screw' (Colomina 1985: 177, Fouché, 1927: 79)
44. ʒr > ʒdɾ	S. Valencian Cat. [ʎiʒ'ðɾia] < [ʎeʒ(i)'ɾia] *llegiria* 'I would read' (Colomina 1985: 177)
45. ʎs > ʎts	Old Fr. [fiʎts] < [fiʎs] FILIOS 'sons' (Pope 1934: 132)
46. ʎr >ʎdɾ	Old Fr. [mi'eʎdɾə] MELIOR, S. Valencian Cat. [kuʎ'dɾe] < [kuʎ(i)'ɾe] 'I will pick up' (Pope, 1934: 148, Colomina 1985: 177)
47. ʎʃ > ʎtʃ	Valencian Cat. [aʎtʃ] < [aʎʃ] ALIOS 'garlic, pl.' (Recasens 1996: 276)
48. wl > wgl	Landes Gasc. [aw'glaŋ] *AULANA < ABELLANA 'hazelnut' (Millardet 1910: 101)
49. wɾ > wbɾ	Landes Gasc. [aw'bɾeʎə] < [aw'ɾeʎə] AURICULA 'ear' (Millardet 1910: 101)

†Written forms taken from historical documents or the standard language are given in italics. Cat. (Catalan), Dut. (Dutch), Eng. (English), Fr. (French), Gasc. (Gascon), Germ. (German), It. (Italian), Lat. (Latin), Prov. (Provençal), Rom. (Romanian), Rosh. (Romansh), Sp. (Spanish), Yid. (Yiddish). The English phonetic transcriptions have been taken from Kenyon and Knott (1953).

Notes

* This research was funded by projects FFI2009-09339 and HUM2006-0374 from the Spanish Government and FEDER, and 2009SGR003 and 2005SGR864 from the Catalan Government. I would like to thank Yves-Charles Morin and two reviewers for very insightful comments on a previous version of the manuscript. Correspondence address: Departament de Filologia

Catalana, Edifici B, Campus de la UAB, 08193 Bellaterra (Cerdanyola del Vallès), Spain. E-mail: daniel.recasens@uab.es

1. A few stop insertions restricted to specific dialectal areas have not been included in Table I. In Romansh, [t] may be appended to heterorganic word final clusters with final [s] ([kle:fts] CLAVES 'keys', [nomts] NOMINES 'names', [krokʃts] CRUCES 'crosses', [maŋts] MANUS 'hands'; Lutta 1923: 246–248). The change [ft] > [fst] is also documented in Old Norse ([ofst] < [oft]; Noreen 1903: 195). On the other hand, the so called dissimilation processes /s##s, s##ʃ/ > [tts, ttʃ] which we find in Majorcan Catalan (*tres sabates* 'three shoes', *tres xinesos* 'three Chinese people') could also be accounted for through stop insertion followed by cluster simplification, i.e., /s##s, s##ʃ/ > [sts, stʃ] > [tts, ttʃ], as suggested by electropalatographic data revealing the presence of occluded realizations of preconsonantal [s] in this Catalan dialect (Recasens 2006b).
2. Additional support for the notion that the phonetic implementation of epenthetic stops in clusters with a final obstruent ought not to differ essentially from that of clusters with a final liquid should derive from experimental studies. To our knowledge, experimental data on stop insertion have only been collected for clusters with final [s] and, less so, for clusters with a final stop. A reason why stop epenthesis has not been investigated experimentally in clusters with a liquid C2 may be because these clusters typically occur word medially and inserted stops are less perceptible in this position than word finally (Yoo and Blankenship 2003; Arvaniti 2006; Recasens submitted).
3. In the example *Yanguas* of Table I (25), the sequence [ŋw] has been generated through regressive assimilation of [n] before [w], i.e., [nw] > [ŋw]. Preference for [g] over [b] insertion in this case may be attributed to the acoustic similarity between nasalized [w] and [ŋ] (Ohala & Lorentz 1977).
4. It should be noticed, however, that this stop epenthesis process would not correspond to a real phonetic event if the presence of an emergent oral stop in written forms such as those in 4, 5 and 7 in Table I were just an orthographic convention indicating that the two meeting consonants ought to be pronounced as clearly as possible (Grandgent 1991: 195, Lloyd 1993: 331).
5. According to Campbell (1959: 192), the evolutions [sm] > [skm] and [sn] > [skn] in word initial position were very rare in Old English.

References

Alcover, Antoni Maria & Francesc de Borja Moll. 1929–1932. La flexió verbal en els dialectes Catalans [The verbal inflection in the Catalan dialects]. *Anuari de l'Oficina Romànica de Lingüística i Literatura* 2–5.

Ali, Latif, Ray Daniloff & Robert Hammarberg. 1979. Intrusive stops in nasal-fricative clusters: An aerodynamic and acoustic investigation. *Phonetica* 36. 85–97.

Arkebauer, H. J., Thomas J. Hixon & J. C. Hardy. 1967. Peak intraoral air pressures during speech. *Journal of Speech and Hearing Research* 10. 196–208.

Arvaniti, Amalia. 2006. Stop epenthesis revisited. In *10th Conference on Laboratory Phonology (LabPhon 10) Book of abstracts*, 67–68. Paris, 29 June–1 July.

Black, John W. 1950. The pressure component in the production of consonants. *Journal of Speech and Hearing Disorders* 15. 207–210.

Blankenship, Barbara 1992. What TIMIT can tell us about epenthesis. *UCLA Working Papers in Phonetics* 81. 17–25.

Browman, Catherine P. & Louis Goldstein. 1991. Gestural structures: Distinctiveness, phonological processes, and historical change. In Ignatius G. Mattingly & Michael Studdert-Kennedy (eds.), *Modularity and the motor theory of speech perception*, 313–338. Hillsdale, NJ: Lawrence Erlbaum.

Browman, Catherine P. & Louis Goldstein. 1995. Gestural syllable position effects in American English. In Fredericka Bell-Berti & Lawrence J. Raphael (eds.), *Producing Speech: Contemporary Issues for Katherine Safford Harris*, 19–34. Woodbury, NY: American Institute of Physics.

Busà, Maria Grazia. 2007. Coarticulatory nasalization and phonological developments: Data from Italian and English nasal-fricative sequences. In Maria Josep Solé, Patrice Speeter Beddor & Manjari Ohala (eds.), *Experimental approaches to phonology*, 155–174. Oxford: Oxford University Press.

Campbell, Alistair. 1959. *Old English grammar*. Oxford: Clarendon Press.

Clements, George N. 1987. Phonological feature representations and the description of intrusive stops. In Anna Bosch, Barbara Need & Eric Schiller (eds.), *Papers from the parasession on autosegmental and metrical phonology*, 29–50. Chicago: Chicago Linguistic Society.

Colomina, Jordi. 1985. *L'alacantí. Un estudi sobre la variació lingüística*. [The Catalan dialect from Alacant. A study on linguistic variation]. Alcoi: Diputació Provincial d'Alacant.

Coromines, Joan. 1980–1991. *Diccionari etimològic i complementari de la llengua catalana*. [Ethymological and complementary dictionary of the Catalan language]. 10 vols. Barcelona: Curial.

Cortelazzo, Manlio & Paolo Zolli. 1980. *Dizionario etimologico della lingua italiana*. [Ethymological dictionary of the Italian language], vol. 2. Bologna: Zanichelli.

Côté, Marie-Hélène. 2000 *Consonant cluster phonotactics: A perceptual approach*. Cambridge, MA: MIT dissertation.

Dart, Sarah N. 1991. *Articulatory and acoustic properties of apical and laminal articulations*. UCLA Working Papers in Phonetics 79.

Fouché, Pierre. 1927. *Études de phonétique générale*. [Studies on general phonetics]. Paris: Les Belles Lettres.

Fourakis, Marios & Robert Port. 1986. Stop epenthesis in English. *Journal of Phonetics* 14. 197–221.

Giles, Stephen B. & Kenneth L. Moll. 1975. Cinefluorographic study of selected allophones of /l/. *Phonetica* 31. 206–227.

Grandgent, Charles Hall. 1905. *An outline of the phonology and morphology of Old Provençal*. Boston: Heath.

Grandgent, Charles H. 1991 [1970]. *Introducción al latín vulgar*. [Introduction to Vulgar Latin]. 5th edn. Madrid: CSIC. [Original edition: Grandgent, Charles Hall. 1907. *Introduction to Vulgar Latin*. Boston: Heath & Co.]

Herslund, Michael. 1986. Portuguese sandhi phenomena. In Henning Andersen (ed.), *Sandhi phenomena in the languages of Europe*, 505–518. Berlin & New York: Mouton de Gruyter.

Hixon, Thomas. 1966. Turbulent noise sources for speech. *Folia Phonatrica* 18, 168–182.

Hooper, Joan Bybee. 1976. *An introduction to natural generative phonology*. New York: Academic Press.

Kenyon, John Samuel & Thomas Albert Knott. 1953. *A pronouncing dictionary of American English*. Springfield, MA: G. & C. Merriam Company.

Lausberg, Heinrich. 1970. *Lingüística románica*. [Romance linguistics]. Madrid: Gredos. [Original edition: Lausberg, Heinrich. 1963. *Romanische Sprachwissenschaft*. Berlin & New York: De Gruyter.

Lee, S.-H. 1991. The duration and perception of English epenthetic and underlying stops. Paper presented at the 121st meeting of the Acoustical Society of America, Baltimore, MD.

Lindsay, Wallace Martin. 1894. *The Latin language: A historical account of Latin sounds, stems, and flexions*. Oxford: Clarendon Press.

Lloyd, Paul M. 1993. *Del latín al español*. [From Latin to Spanish]. Madrid: Gredos. [Original edition: Lloyd, Paul. 1987. *From Latin to Spanish*. Philadelphia: American Philosophical Society.]

Lutta, Corrado Martin. 1923. Der Dialekt von Bergün und seine Stellung innerhalb der rätoromanischen Mundarten Graubündens. *Beihefte zur Zeitschrift für Romanische Philologie* 71.
MacMahon, Michael K. C. 1998. Phonology. In Suzanne Romaine (ed.), *The Cambridge history of the English language*, vol. 4. Cambridge: Cambridge University Press.
Malécot, André. 1955. An experimental study of force of articulation. *Studia Linguistica* 9. 35–44.
Malécot, André. 1968. The force of articulation of American stops and fricatives as a function of position. *Phonetica* 18. 95–102.
Menéndez Pidal, Ramón 1968 [1904]. *Manual de gramática histórica española*. [A handbook of the historical grammar of Spanish]. 13th edn. Madrid: Espasa-Calpe.
Meyer-Lübke, Wilhelm. 1974. *Grammaire des langues romanes*. 4 vols. Geneva: Slatkine reprints. [Original edition: Meyer-Lübke, Wilhelm. 1890–1902. *Grammatik der romanischen Sprachen*. Leipzig: Reisland.]
Millardet, Georges. 1910. *Études de dialectologie landaise*. Toulouse: Édouard Privat.
Minkova, Donka. 2003. *Alliteration and sound change in Early English*. Cambridge: Cambridge University Press.
Molho, Maurice. 1958. Acerca de la evolución del grupo –SKL– > –SL– en romance. [On the evolution –SKL– > –SL– in Romance]. *Archivo de Filología Aragonesa* 8–9. 63–71.
Morin, Yves-Charles. 1980. Morphologisation de l'épenthèse en ancien français. [Morphologization of consonant epenthesis in Old French]. *Canadian Journal of Linguistics* 25. 204–225.
Morin, Yves-Charles. 1987. De quelques propriétés de l'épenthèse consonantique. *Canadian Journal of Linguistics* 32. 365–375.
Mowrey, Richard & Pagliuca, William. 1985. The reductive character of articulatory evolution. *Journal of Italian Linguistics* 7. 37–124.
Murray, Richard W. 1989. On epenthesis. *Folia Linguistica* 23. 293–316.
Nandris, Octave. 1963. *Phonétique historique du roumain*. Paris: Klincksieck.
Navarro Tomás, Tomás. 1972 [1918]. *Manual de pronunciación española*. [A handbook of Spanish pronunciation]. 17th edn. Madrid: CSIC.
Niederman, Max. 1953. *Précis de phonétique historique du latin*. Paris: Klincksieck.
Noreen, Adolf. 1903. *Altislandische und altnorwegische Grammatik unter Berücksichtigung des Urnordischen*. Halle: Max Niemeyer.
Ohala, John J. 1974. Experimental historical phonology. In John M. Anderson & Charles Jones (eds.), *Historical linguistics, II: Theory and description in phonology*, 353–389. Amsterdam: North-Holland.
Ohala, John J. 1983. The origin of sound patterns in vocal tract constraints. In Peter F. MacNeilage (ed.), *The production of speech*, 189–216. New York: Springer.
Ohala, John J. 1997. Emergent stops. In *Proceedings of the 4th Seoul International Conference on Linguistics*, 84–91. Seoul: Linguistic Society of Korea.
Ohala, John J. & James P. Lorentz. 1977. The story of [w]: An exercise in the phonetic explanation for sound patterns. *Proceedings of the Annual Meeting of the Berkeley Linguistics Society* 3. 577–599.
Page, B. Richard. 1997. Articulatory phonology as a tool for explanation in historical phonology: The case of stop epenthesis in Germanic. In Irmengard Rauch & Gerald F. Carr (eds.), *Insights in Germanic linguistics II: Classic and contemporary*, 175–188. Berlin & New York: Mouton de Gruyter.
Pensado, Carmen. 1986. El contacto de sílabas como origen de la evoluciones de las secuencias de consonante + wau en romance. [Syllable contact as trigger of the evolution of consonant + wau sequences in Romance]. *Revista de Filología Románica* 4. 73–110.
Phelps, John. 1937. Indo-European initial *sl*. *Language* 13. 279–284.
Picard, Marc. 1987a. L'épenthèse consonantique: contraintes phonologiques et syllabiques. *Revue Québécoise de Linguistique* 16. 267–287.

Picard, Marc. 1987b. On the general properties of consonant epenthesis. *Canadian Journal of Linguistics* 32. 133–142.
Pope, Mildred K. 1934. *From Latin to Modern French with special consideration of Anglo-Norman*. Manchester: Manchester University Press.
Proctor, Michael Ian. 2009. *Gestural characterization of a phonological class: The liquids*. New Haven, CT: Yale University dissertation.
Prokosch, Eduard. 1939. *A comparative Germanic grammar*. Philadelphia: The Linguistic Society of America, University of Pennsylvania Press.
Recasens, Daniel. 1996 [1991]. *Fonètica descriptiva del català*. [Descriptive phonetics of Catalan]. 2nd edn. Barcelona: Institut d'Estudis Catalans.
Recasens, Daniel. 2006a. Integrating coarticulation, assimilation, and blending into a model of articulatory constraints. In Louis M. Goldstein, Doug H. Whalen & Catherine T. Best (eds.), *Laboratory Phonology 8*, 611–634. Berlin & New York: Mouton de Gruyter.
Recasens, Daniel. 2006b. Gradient weakening for syllable-final /s, r/ in Majorcan Catalan consonant clusters. In Hani Camille Yehia, Didier Demolin & Rafael Laboissière (eds.), *Proceedings of the 7th International Seminar on Speech Production*, 11–18. Belo Horizonte: CEFALA.
Recasens, Daniel. In press. Adaptation du lieu d'articulation dans les groupes consonantiques du catalan à la lumière du modèle DAC. In Mohamed Embarki & Christelle Dodane (eds.), *La coarticulation: indices, direction et représentation*. Paris: l'Harmattan.
Recasens, Daniel. Submitted. The phonetic implementation of underlying and epenthetic stops in word final clusters in Valencian Catalan.
Recasens, Daniel & Aina Espinosa. 2005. Articulatory, positional and coarticulatory characteristics for clear /l/ and dark /l/: Evidence from two Catalan dialects. *Journal of the International Phonetic Association* 35. 1–25.
Recasens, Daniel & Aina Espinosa. 2007. Phonetic typology and positional allophones for alveolar rhotics in Catalan. *Phonetica* 64. 1–28.
Recasens, Daniel & Maria Dolors Pallarès. 2001a. *De la fonètica a la fonologia. Les consonants i assimilacions consonàntiques del català*. [From phonetic to phonology. Consonants and consonant assimilations in Catalan]. Barcelona: Ariel.
Recasens, Daniel & Maria Dolors Pallarès. 2001b. Coarticulation, assimilation and blending in Catalan consonant clusters. *Journal of Phonetics* 29. 273–301.
Recasens, Daniel, Maria Dolors Pallarès & Jordi Fontdevila. 1997. A model of lingual coarticulation based on articulatory constraints. *Journal of the Acoustical Society of America* 102. 544–561.
Rohlfs, Gerhard. 1966. *Grammatica storica della lingua italiana e dei suoi dialetti*. [A historical grammar of Italian and its dialects], vol. 1. Turin: Einaudi.
Rohlfs, Gerhard. 1970. *Le gascon: Études de philologie pyrénéenne*. 2nd edn. Tübingen: Max Niemeyer.
Ronjat, Jules. 1930–1941. *Grammaire (h)istorique des parlers provençaux modernes*. 4 vols. Montpellier: Société des Langues Romanes.
Solé, Maria Josep. 2002. Aerodynamic characteristics of trills and phonological patterning. *Journal of Phonetics* 30. 655–688.
Solé, Maria Josep. 2007. The stability of phonological features with and across segments: The effect of nasalization on frication. In Pilar Prieto, Joan Mascaró & Maria-Josep Solé (eds.), *Segmental and prosodic issues in Romance phonology*, 41–66. Amsterdam & Philadelphia: John Benjamins.
Väänänen, Veikko. 1985 [1970]. *Introducción al latín vulgar*. [Introduction to Vulgar Latin]. 2nd edn. Madrid: Gredos. [Original edition: Väänänen, Veikko. 1967. *Introduction au latin vulgaire*. Paris: Klincksieck.]
Vennemann, Theo. 1988. *Preference laws for syllable structure and the explanation of sound change*. Berlin & New York: Mouton de Gruyter.

Vincent, Nigel. 1988. Italian. In Martin Harris & Nigel Vincent (eds.), *The Romance languages*, 279–313. London: Routledge.

Virdis, Maurizio. 1978. *Fonetica del dialetto sardo campidanese*. [Campidanese Sardinian phonetics]. Cagliari: Edizioni della Torre.

Walker, Douglas C. 1978. Epenthesis in Old French. *Canadian Journal of Linguistics*, 23. 66–83.

Warner, Natasha. 2002. The phonology of epenthetic stops: Implications for the phonetics-phonology interface in optimality theory. *Linguistics* 40. 1–27.

Warner, Natasha & Andrea Weber. 2001. Perception of epenthetic stops. *Journal of Phonetics* 29. 53–87.

von Wartburg, Walther. 1922– *Französisches Etymologisches Wörterbuch*. Bonn & Leipzig: Schroeder, Tübingen: J.C.B. Mohr, Basel: R.G. Zbinden.

Westbury, John R. & Patricia A. Keating. 1986. On the naturalness of stop consonant voicing. *Journal of Linguistics* 22. 145–166.

Wetzels, Leo 1985. The historical phonology of intrusive stops. A non-linear description. *Canadian Journal of Linguistics* 30. 285–333.

Yoo, Isaiah WonHo & Barbara Blankenship. 2003. Duration of epenthetic [t] in polysyllabic American English words. *Journal of the International Phonetic Association* 33. 153–164.