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*A phonetically based account of phonological stop assibilation**

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This paper proposes a phonetically based account of phonological stop assibilation. We first review evidence for the phonological representation of sibilants proposed by Jakobson *et al*. (1951) and others. An examination of cross-linguistic data involving phonological assibilation reveals two asymmetries: (a) only high vocoids constitute assibilation triggers; (b) only following vocoids, not preceding vocoids, constitute assibilation triggers. It is then shown that high vocoid-conditioned phonological stop assibilation is motivated by the brief period of turbulence that sometimes occurs at the release of a plosive into a high vocoid. We argue that this turbulence is interpreted in phonology as the insertion of the feature [+strident] into the representation of the plosive, with the loss of the feature [−continuant] in the case of frication. Not only does this phonetic analysis explain the phonetic origin of assibilation, it also correctly reflects the cross-linguistic conditions on high vocoid-conditioned phonological assibilation.

1 Introduction

This paper proposes a phonetically based account of phonological stop assibilation. Phonological assibilation – the creation of sibilants (affricates and/or fricatives) from non-sibilant plosives – is analysed as having its phonetic origin in the brief period of turbulence which occurs at the release of a plosive into a high vocoid.[1] It is also proposed that this turbulence is interpreted in the phonology as the insertion of the feature [+strident] into the representation of the plosive, with the loss of the feature [−continuant] in the case of frication.

As a common case of phonological plosive assibilation, we may cite a process whereby the alveolar plosives /t d/ are affricated to [t^{s} d^{z}] or fricated to [s z] before the high front vocoid /i/ in a specific morphological

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[1] Throughout the paper we use the term 'plosive' to refer exclusively to non-affricated stops, 'affricate' to strident or non-strident affricates and 'stop' as a cover term for plosives and affricates.

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context, as in Axininca Campa and Finnish.[2] For instance, in Axininca Campa (Spring 1992), the root-final /t/ affricates to [t^{s}] when followed by the non-future tense marker /i/, as shown in (1a). When a vowel-final root to which the non-future tense marker /i/ is attached undergoes epenthesis, the epenthetic [t] also undergoes affrication, as in (1b).[3]

(1) *Axininca Campa Affrication* (Spring 1992)

		epenthesis	*affrication*	
a.	no-kant-i I-say-NF	—	[nokant^{s}i]	'I said'
	no-ant-i I-do-NF	—	[nant^{s}i]	'I did'
b.	no-misi-i I-dream-NF	no-misi-t-i	[nomisit^{s}i]	'I dreamed'

Affrication, however, does not apply in a non-derived environment, e.g. /t^{ʃ}okori-ti/ → [t^{ʃ}okoriti] 'armadillo-POSS' in Axininca Campa.

Another similar case to Axininca Campa affrication is the lexical frication process in Finnish (Kiparsky 1973), where a stem-final plosive /t/ is changed into [s] before /i/ across a morpheme boundary. As shown in (2a), the underlying stem-final plosive /t/ is changed into [s] before the suffix /i/, and when the underlying stem-final /e/ is changed into /i/ by an independent process in word-final position, the plosive /t/ also becomes the fricative /s/, as in (2b). However, such a frication process does not apply to a morpheme-internal /ti/ sequence, as in (2c).

(2) *Finnish Frication* (Kiparsky 1973)

a. *across a morpheme boundary*
   /halut + i/ → [halusi] 'wanted' cf./halut + a/ 'want'
   /hakkat + i/ → [hakkasi] 'hewed'
   /turpot + i/ → [turposi] 'swelled'
   /avat + i/ → [avasi] 'opened'

b. *morpheme-internally*, *with derived* /i/
   /vete/ → (veti →) [vesi] cf. [vete + nä] 'water (ESS)'

c. *morpheme-internally*, *with underlying* /i/
   /tila/ → [tila] 'place, room'
   /kartio/ → [kartio] 'cone'
   /tippa/ → [tippa] 'drop'
   /vaatia/ → [vaatia] 'demand'
   /tiivis/ → [tiivis] 'dense, tight'
   /itikka/ → [itikka] 'mosquito'
   /äiti/ → [äiti] 'mother'

[2] See further data in Slavic (Chomsky & Halle 1968), Gbe (Capo 1991) and Akan (Schachter & Fromkin 1968), which have synchronic assibilation processes that change alveolar plosives into affricates before the high front vowel /i/.

[3] Throughout this paper, IPA transcription is used unless otherwise noted. Affricates are represented with a superscripted second element.

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Phonological plosive assibilation in the languages where either affrication or frication occurs before a high vocoid is perhaps the most common type of assibilation, but not the only type. There are other sources of sibilants which do not necessarily involve the presence of a high vocoid as a trigger (e.g. Clements 1999). One important source of sibilant affricates is assibilation of palatalised ('soft') coronal plosives, as in Russian and Polish. As shown in (3), the stem-final consonants /t d/ in Polish (Rubach 1984) are affricated into the alveolo-palatals [t^{ϵ} d^{z}] when followed across a morpheme boundary by the locative singular /ɛ/, verbalising /e i/ or the feminine suffix /it^{ϵ}+a/, by virtue of Coronal Palatalisation.

(3) *Polish Coronal Palatalisation* (Rubach 1984)

	nom sg				
a.	brat	'brother'	*loc sg* /ɛ/	brac+ie	[$brat^{\epsilon}$+ɛ]
	cud	'miracle'		cudz+ie	[cud^{z}+ɛ]
b.	lot	'flight'	*verbalising* /e/	lec+ie+ć	[let^{ϵ}+e+t^{ϵ}]
c.	brud	'dirt'	*verbalising* /i/	brudz+i+ć	[$brud^{z}$+i+t^{ϵ}]
d.	kot	'cat'	*fem* /it^{ϵ}+a/	koc+ic+a	[kot^{ϵ}+it^{ϵ}+a]

Another source of sibilant affricates is Strident Assimilation, as in Polish (Rubach 1994). The anterior obstruents /t d/ in Polish are optionally affricated before sibilant fricatives or affricates within a lexical item or across word boundaries, as shown in (4).[4]

(4) *Polish Strident Assimilation* (Rubach 1994)

od soboty	[t s] ~ [t^{s} s]	'since Saturday'
twardszy	[t ʃ] ~ [$t^{ʃ}$ ʃ]	'harder'
odcedzić	[t t^{s}] ~ [t^{s} t^{s}]	'drain'
świadczyć	[t $t^{ʃ}$] ~ [$t^{ʃ}$ $t^{ʃ}$]	'witness'
odznaczyć	[d z] ~ [d^{z} z]	'distinguish'
budżet	[d ʒ] ~ [$d^{ʒ}$ ʒ]	'budget'
przed dzwonkiem	[d d^{z}] ~ [d^{z} d^{z}]	'before the bell'
oddzielić	[d $d^{ʒ}$] ~ [$d^{ʒ}$ $d^{ʒ}$]	'separate'

As a further source of assibilation of plosives, we can cite a sound change in German that occurred in the sixth and seventh centuries. At this period, the Old High German /t/ was assibilated to the affricate [t^{s}] or the

[4] One reviewer raised the question of how we could distinguish free variants between a plosive+strident and an affricate+strident in (4), except by electropalatography or some similar technique. While the difference between these pairs of realisations might seem very subtle and a matter of degree, it should be noted that Polish is well known for distinguishing sequences of plosive+strident from affricates (cf. minimal pairs such as *czy* [$t^{ʃ}$] 'if' *vs. trzy* [t ʃ] 'three'). Polish phoneticians therefore readily and reliably transcribe such sequences as clearly distinct. See Rubach (1984) and the references therein for discussion.

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fricative [s], whereas the stop consonant /t/ remains unchanged in English and Dutch, as shown in (5). In this assibilation it did not matter which vowel followed or preceded the plosive /t/, or where the consonant was placed in a stem (Penzl 1972, Sonderegger 1979).[5]

(5)	*Old High German*	*English*	*Dutch*
a.	[t^{s}]unga	tongue	tong
	se[t^{s}]en	set	zetten
	her[t^{s}]a	heart	hart
	swar[t^{s}]	swart	zwart
b.	e[s]an	eat	eten
	wa[s]er	water	water
	fuo[s]	foot	voet
	wa[s]	what	wat

Another possible source of sibilant fricatives from plosives is intervocalic frication. For instance, the survey of Lavoie (1996, 2000) shows that the plosive /t/ in Pengo changes into [z] intervocalically (Burrow & Bhattacharya 1970) and that Ancient Greek intervocalic /t/ is weakened to the fricative [s] when followed by a high front vowel (Sommerstein 1973).

However, the most common type of assibilation found in the literature is the high vocoid-conditioned plosive assibilation, as shown in Axininca Campa and Finnish. This paper proposes that high vocoid-conditioned phonological assibilation is motivated quite specifically by the brief period of turbulence that sometimes occurs at the release of a plosive into a high vocoid. It also proposes that the turbulence is interpreted in the phonology as the insertion of the feature [+strident] into the phonological representation of a plosive, with loss of [−continuant] in the case of frication. Not only does this phonological interpretation do justice to the phonetic origin of assibilation, it correctly reflects the cross-linguistic conditions on high vocoid-conditioned phonological plosive assibilation.

In order for a phonetically based phonological account to go through, it is first assumed that strident affricates are stops specified as [−continuant, +strident], in line with Jakobson *et al.* (1951), LaCharité (1993), Rubach (1994), Kim (1997) and Clements (1999). Two asymmetries in the process are identified and explained. First, assibilation is normally triggered only by high vocoids. We will examine articulatory data that show that stridency is generated when the tongue moves from the oral closure of a plosive consonant toward a high vocoid. Second, phonological plosive assibilation occurs before a high vocoid, but not after it. It is argued that this asymmetry has an acoustic and aerodynamic explanation. In order to confirm that the conditions that create transient frication in the vicinity of

[5] This sound change is called the second German consonant shift, in comparison with the first German consonant shift occurred in prehistoric Germanic wherein the voiceless stop consonants /p(h) t(h) k(h)/ were fricated into /f θ χ/, respectively, and the voiced ones /b d g/ were devoiced.

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plosives are present in plosive consonant + high vocoid sequences, acoustic experiments on the Korean plosive consonant /t/ were carried out and the aerodynamics of egressive plosive formation is considered.

We state phonological processes in terms of a serial constraint-based framework. While the adoption of a parallel constraint-based framework would require some revision of the details of the analyses in this paper, it would not impinge upon the argument for a phonetically based approach to assibilation, which is the central point of the paper.

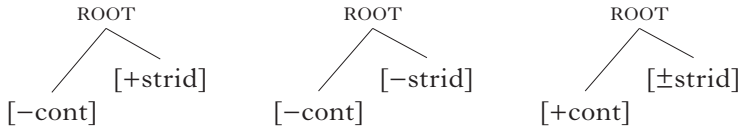
This paper is organised as follows: §2 offers an argument that affricates are stops which do not bear a specification [+continuant], §3 establishes the context in which assibilation applies, §4 provides a phonetically based account of phonological plosive assibilation, §5 discusses a phonological representation of high vocoid-conditioned plosive assibilation and §6 is the conclusion.

2 Some arguments that affricates are stops

As a necessary basis for evaluating competing phonetic accounts of assibilation in the later discussion, this section examines the linguistic data supporting the stop analysis of affricates. In line with Jakobson *et al.* (1951) and others (see above), affricates are shown to be stops which do not bear a specification for [+continuant] at any point in phonology.

In the stop analysis, strident affricates are specified as [−continuant, +strident], whereas non-strident plosives and affricates are specified as [−continuant, −strident] and fricatives as [+continuant, ±strident], as in (6).[6]

(6) *strident affricate* *plosive* *fricative*



In the stop analysis, it is expected that affricates and plosives will pattern together with respect to the feature value [−continuant] on both 'edges'. However, affricates never pattern together with fricatives in terms of the [+continuant] value. It is by virtue of the feature [+strident], not [+continuant], that affricates and fricatives pattern together.

For instance, in English plural formation, when an English word ends in one of the non-coronal or non-strident fricatives /f v θ ð/, as in (7a), it does not take the plural form [əz], but takes [z] or [s] depending on its voicing. On the other hand, when a word ends in one of the strident

[6] In the stop analysis of affricates, non-strident affricates are differentiated from plosives by other features such as [anterior], [distributed] and [lateral]. See Clements (1999) for a detailed discussion.

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palato-alveolar affricates /tʃ dʒ/ or the strident fricatives /s z ʃ ʒ/, it takes the plural form [əz], as in (7b).

(7) a.

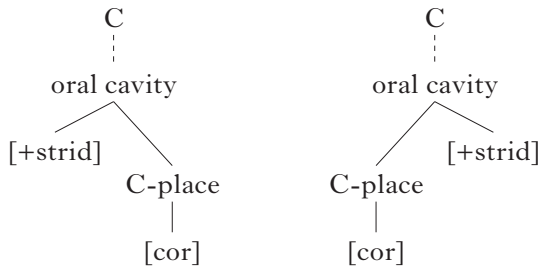
[rufs]	*[rufəz]	'roofs'
[keɪvz]	*[keɪvəz]	'caves'
[bæθs]	*[bæθəz]	'baths'
[leɪðz]	*[leɪðəz]	'lathes'

b.

[bʌsəz]	'buses'
[veɪsəz]	'vases'
[bʊʃəz]	'bushes'
[keɪdʒəz]	'cages'
[tʃɝtʃəz]	'churches'
[bædʒəz]	'badges'

If we use [−continuant] for both affricates and plosives, as in the stop analysis of affricates, we can use the feature [strident] and [coronal] to group the consonants which take the plural form /əz/; only after coronal strident consonants is the plural form [əz] allowed, whereas after other consonants the plural forms [s] and [z] are required. Under this analysis, the presence of schwa in (7b) can be attributed to preventing an OCP violation on both the [coronal] tier and the [strident] tier. Assuming the underlying form of the plural suffix to be /-əz/, the deletion of schwa is blocked if it creates a sequence of two adjacent coronal [+strident] segments, as shown in (8).[7]

(8)



On the other hand, affricates, like plosives, fail to pattern with fricatives on their right edge. Rubach (1994) provides Polish Fricative Assimilation as an example. As shown in (9a), the fricatives /s z/ assimilate to the following plosives in terms of the place of articulation after the plosives and fricatives have undergone Coronal Palatalisation.[8] For instance, in /ost+e/ → [oɕtᵉ+e] 'thistle (LOC SG)', the stem-final plosive /t/ is first palatalised to the alveolo-palatal affricate /tᵉ/ by Coronal Palatalisation (3), and then the fricative /s/ assimilates in place to [ɕ] before the alveolo-palatal affricate [tᵉ]. In /sn+i+tᵉ/ → [ɕɲitᵉ] 'to dream' and also in /zɬ+i/ → [ʑlʲi] 'evil' (ADJ, NOM PL), the fricatives /s z/ assimilate in place to the alveolo-palatal sonorants, which have undergone Coronal Palatalisation

[7] See Borowsky (1986), Yip (1988) and Lombardi (1990) for discussion of the OCP effect on the [strident] tier in English plural formation. Here we assume that the schwa is underlyingly present, following the deletion analysis of Borowsky (1986) and Lombardi (1990), among others. In an insertion analysis taking /-z/ as basic (e.g. Yip 1988), the OCP would trigger schwa insertion to remove OCP violations.

[8] The sonorants /n l r/ also undergo Coronal Palatalisation, yielding alveolo-palatal sonorants (Rubach 1984).

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before the high front vowel /i/.[9] However, affricates do not undergo this process, as shown in (9b).[10,11]

(9) *Polish Fricative Assimilation* (Rubach 1994)

a.	*UR*	ost+e	sn+i+t$^{\text{ɕ}}$	zɬ+i
	Cor Pal	ost$^{\text{ɕ}}$+e	sɲ+i+t$^{\text{ɕ}}$	zl$^{\text{j}}$+i
	Fric Assim	oɕt$^{\text{ɕ}}$+e	ɕɲ+i+t$^{\text{ɕ}}$	ʑl$^{\text{j}}$+i
		[oɕt$^{\text{ɕ}}$e]	[ɕɲit$^{\text{ɕ}}$]	[ʑl$^{\text{j}}$i]
		'thistle (LOC SG)'	'to dream (DAT SG)'	'evil (ADJ, NOM PL)'
b.	*UR*	ot$^{\text{s}}$t+e	t$^{\text{s}}$n+i+t$^{\text{ɕ}}$	t$^{\text{s}}$ɬ+i+t$^{\text{ɕ}}$
	Cor Pal	ot$^{\text{s}}$t$^{\text{ɕ}}$+e	t$^{\text{s}}$ɲ+i+t$^{\text{ɕ}}$	t$^{\text{s}}$l$^{\text{j}}$+i+t$^{\text{ɕ}}$
	Fric Assim	—	—	—
		[ot$^{\text{s}}$t$^{\text{ɕ}}$e]	[t$^{\text{s}}$ɲit$^{\text{ɕ}}$]	[t$^{\text{s}}$l$^{\text{j}}$i+t$^{\text{ɕ}}$]
		'vinegar (LOC SG)'	'to hanker'	'to impose duty'
		never *[t$^{\text{ɕ}}$t$^{\text{ɕ}}$]	*never* *[t$^{\text{ɕ}}$ɲ]	*never* *[t$^{\text{ɕ}}$l$^{\text{j}}$]

If affricates are assumed to be stops, and Polish Fricative Assimilation applies to [+continuant] sounds, then Fricative Assimilation will affect fricatives to the exclusion of plosives and affricates.

As Rubach points out, in the contour segment analysis (where affricates are represented as two ordered values of [continuant], as in Sagey 1986), the [+continuant] edge of an affricate, which is adjacent to a following non-continuant, constitutes a target for assimilation. Thus it is incorrectly predicted that, just like a fricative, an affricate should undergo the process. In the complex segment analysis (where affricates are represented by two *unordered* values of [continuant], as in Hualde 1987, 1988, Lombardi

[9] According to Rubach (1984, 1994), Polish Fricative Assimilation cannot be collapsed with Coronal Palatalisation as a single process. First, Coronal Palatalisation is cyclic, so that morpheme-internal consonants cannot be affected by it. In contrast, Fricative Assimilation can apply within morphemes before consonants that have not undergone Coronal Palatalisation. The surface fricatives [ʃ] in *szczegół* [ʃt$^{\text{j}}$-] 'detail' and [ɕ] in *ściana* [ɕt$^{\text{ɕ}}$-] 'wall', are derived from the underlying fricative /s/ by virtue of Fricative Assimilation, when followed by an underlyingly palato-alveolar and alveolo-palatal affricate, respectively, morpheme-internally (Rubach 1994). Second, Fricative Assimilation is not always fed by Coronal Palatalisation. It is also fed by Yer Deletion, which is postcyclic (Rubach 1984, 1994). Fricative Assimilation does not apply across word boundaries, as in *czas#niewoli* [s#ɲ] 'time of captivity' (Rubach 1994). Thus, compared to Coronal Palatalisation, which is cyclic, Fricative Assimilation is postcyclic, not postlexical (Rubach 1994). Finally, the targets of Fricative Assimilation are only /s z/, whereas those of Coronal Palatalisation include anterior coronal stops.

[10] Unrealised yers, which do not interact with the phenomena under discussion here, are omitted here.

[11] In /zɬ+i/ 'evil' in (9a) and /t$^{\text{s}}$ɬ+i+t$^{\text{ɕ}}$/ 'impose duty' in (9b), the liquid undergoes further processes such as Liquid Spell-out and Surface Palatalisation after Coronal Palatalisation (Rubach 1984). We will not discuss these processes here, in order not to unnecessarily complicate our presentation.

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1990), the [+continuant] value of an affricate is also adjacent to a following non-continuant value. Hence it is the target of the assimilation process. Both of these analyses incorrectly predict that affricates and fricatives should undergo assimilation. The Polish data therefore indicates that by characterising affricates as [−continuant] only, and not as [+continuant], we can correctly predict the patterning of fricatives to the exclusion of plosives and affricates.

Before closing this section, we consider another alternative, the analysis of Steriade (1993). In her analysis, [continuant] is no longer an autosegment assigned to a separate tier, but is a feature of the root node, that is, the A_o, A_f or A_{max} aperture nodes. But the issue of whether [continuant] is a property of the root node or an autosegment is controversial. For instance, there are many cases which seem to show that this feature behaves phonologically as an autosegment in Spanish Spirantisation (Harris 1984, Mascaró 1984, Padgett 1991), Hungarian Fricative Affrication (Vago 1980, Hume 1992), Polish Nasal Gliding (Rubach 1994), etc. In addition, as for the fricative part of affricates, Steriade (1993: 404–405) assumes that 'after projection of hierarchical segment structure (including *A* positions), all plosives project a release which, in the unmarked case, is of the approximant variety', and that the 'choice between affricated and plain release is universally available to only a limited class of features and feature combinations'. On the assumption that 'the fricative release of affricates is not a distinctive property', the fricative part of affricates is projected in phonological derivations. In Steriade's model, then, affricates, which are underlyingly stops, are predicted to pattern after release projection as fricatives, not as plosives, with respect to segments on their righthand sides. Thus, in derivation, affricates are expected to show edge effects after release projection, because they are assumed to be contour segments. However, the stop analysis of affricates predicts that affricates will never show edge effects, and will pattern with fricatives only by virtue of the feature [strident].[12]

So far it has been shown that strident affricates pattern with plosives by virtue of the feature [−continuant] and with strident fricatives by virtue of [+strident], not [+continuant].

3 The context of phonological plosive assibilation

In this section, two asymmetries are identified in the process of high vocoid-conditioned phonological plosive assibilation, whether lexical or postlexical: (a) only high vocoids constitute assibilation triggers and (b) only following high vocoids, not preceding ones, constitute assibilation triggers.

As shown in Axininca Campa and Finnish in (1) and (2), lexical assibilation usually occurs before the high front vowel /i/ across certain

[12] This prediction appears to be correct. There are further facts that support the stop analysis of affricates. See Kim (1997) and Clements (1999).

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morpheme boundaries, but not before a non-high vowel. Another example that shows such asymmetries in lexical assibilation comes from Korean. As shown in (10), the stem-final plosives /t tʰ/ are affricated when followed by derivational suffixes or inflectional suffixes which begin with /(h)i/.[13,14]

(10) *Affrication in Modern Korean*

a. *before derivational suffixes*

i. *before the nominative suffix* /i/

/mat + i/	→ [ma.dᶻi]	'first child'
/pʰi put^{h} + i/	→ [pʰi.pu.tˢʰi]	'one's own child'

ii. *before the adverbial suffix* /u/

/kat^{h} + i/	→ [ka.tˢʰi]	'together'
/kut + i/	→ [ku.dᶻi]	'firmly'

iii. *before the causative suffixes* /i/ *and* /hi/

/put^{h} + i + ta/	→ [pu.tˢʰi.da]	'to be attached'
/mut + hi + ta/	→ [mu.tˢʰi.da]	'to be buried'

b. *before inflectional suffixes*

i. *before the copula* /i/

/sot^{h} + i + ta/	→ [so.tˢʰi.da]	'(it) is a kettle'

ii. *before the subject case marker* /i/

/k'it^{h} + i/	→ [k'i.tˢʰi]	'end' + SUBJ
/mit^{h} + i/	→ [mi.tˢʰi]	'bottom' + SUBJ

iii. *before the conjunction case marker* /ilaŋ/ 'and'

/pat^{h} + ilaŋ/	→ [pa.tˢʰi.raŋ]	'field and'
/sot^{h} + ilaŋ/	→ [so.tˢʰi.raŋ]	'kettle and'

But as shown in (11), affrication does not occur when the same stem-final plosive /t/ is followed by any vocoids other than /i/.

(11) *No affrication before vocoids other than* /i/ *in Korean*

/tot + a/	→ [to.da]	*[to.dᶻa]	'to rise' + IND
/put^{h} + ə/	→ [pu.tʰə]	*[pu.tˢʰə]	'to attach' + IND
/put^{h} + ɨmjən/	→ [pu.tʰi.mjən]	*[pu.tˢʰi.mjən]	'to attach' + 'if'
/pat^{h} + esə/	→ [pɑ.tʰesə]	*[pa.tˢʰe.sə]	'in a field'
/kat^{h} + ɛ/	→ [kɑ.tʰɛ]	*[ka.tˢʰɛ]	'to be the same' + IND
/kat^{h} + u/	→ [ka.tʰu]	*[ka.tˢʰu]	'to be the same' + QUES

Nor does it occur in /ti/ sequences within morphemes, as in /mati/ 'knot' → [madi], *[madᶻi], /puti/ 'without fail, please' → [pudi], *[pudᶻi].

[13] In this paper, Korean affricates are transcribed as alveolars /tˢ tˢʰ tˢ'/, not post-alveolars, on the basis of phonological and experimental evidence summarised in Kim (1997, 1999).

[14] Korean plain consonants, except /s/, are voiced in intervocalic position. Thus the voiceless plain affricate /tˢ/ is changed into [dᶻ] intervocalically.

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In addition, we can find phonological plosive assibilation before other high vocoids, such as /w u j y ɥ/. For instance, the phonological process of affrication found in Lomongo, a Bantu language (Hulstaert 1957, 1961, Kenstowicz & Kisseberth 1977) is triggered by the high vocoids /w/ and /y/.[15] As shown in (12a), non-coronal consonants remain unchanged when followed by the two glides /w y/. Whether underlyingly or derived from vowels, however, the consonants [t d l] are replaced by affricates in the same context, as in (12b).

(12)

		passive	*causative*	
a.	-bák-a	-bák-w-a	-bák-y-a	'fasten'
	-kámb-a	-kámb-w-a	-kámb-y-a	'suffer'
	-sɛŋg-a	-sɛŋg-w-a	-sɛŋg-y-a	'sculpt'
b.	-mat-a	-mat^{s}-w-a	-mat^{s}-a[16]	'tread'
	-kund-a	-kund^{z}-w-a	-kund^{z}-a	'bury'
	-ul-a	-ud^{z}-w-a	-ud^{z}-a	'be imprisoned'

A high vocoid can trigger the affrication of a plosive, not only in lexical assibilation, but also in postlexical assibilation.[17] In Japanese, which has no affricates in underlying representations (e.g. Vance 1987, Shibatani 1990), the underlying plosive /t/ is affricated to [t^{s}] before the vowel /u/, and to [t^{ʃ}] before the vowel /i/, regardless of morpheme boundaries. Therefore, as shown in (13a), /t/ is affricated before /u/ and /i/ across a morpheme boundary, and in loanwords when the plosive /t/ of the source language is followed by the epenthetic vowel /u/, it is also affricated into [t^{s}], as in /katuretu/ 'cutlet' → [kat^{s}uret^{s}u] (Shibatani 1990).[18] Before the other vowels, /a e o/, the consonant /t/ surfaces as [t], as shown in (13b) for /tat-/ 'to stand'.

(13)

a.	/tat + u/	[tat^{s}u]	'to stand' + PRES
	/tat + i + mas + u/	[tat^{ʃ}imasu]	'to stand' + POLITE + PRES

[15] We replace Kenstowicz & Kisseberth (1977)'s /j/ with the IPA symbol /d^{z}/, but we keep /y/ for IPA /j/, as it is widely used in the Bantu literature.

[16] Kenstowicz & Kisseberth (1977) propose that the glide /y/ is deleted after the derived affricates [t^{s} d^{z}] by a separate process.

[17] The terms 'lexical' and 'postlexical' phonological processes are used in contrast to gradient phonetic processes discussed by Keating (1988), Cohn (1990), etc., in which categorical ones are phonological, whereas gradient ones are phonetic.

[18] One reviewer pointed out that in some loanwords /t/ before /i/ does not affricate for some speakers (e.g. [pa:ti] 'party'), even though /t/ before /u/ generally does. According to Tsujimura (1996), we can also find some loanwords where the affricates [t^{s} t^{ʃ}] occur before non-high vowels in Japanese.

(i) [kant^{s}o:ne] 'canzone'
[t^{ʃ}esu] 'chess'
[t^{ʃ}okore:to] 'chocolate'

We can attribute the lack of affrication in [pa:ti] and affricates before non-high vowels in the above three examples to an attempt by Japanese speakers to pronounce the loanwords as close to the originals as possible.

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b.	/tat + e/	[tate]	'to stand' + IMP
	/tat + a + nai/	[tatanai]	'to stand' + NEG
	/tat + oo/	[tatoo]	'to stand' + COHORT

Hence, Japanese Affrication of the plosive /t/ before the vowels /i u/ in (13a) is allophonic but categorical, as a case of postlexical assibilation.

Similarly, there is a sound change from Proto-Bantu to Mvumbo which also shows plosive assibilation before the high vowels /i/ and /u/. As shown in (14a), the plosives /b d t g k/ in Proto-Bantu were affricated in Mvumbo, to /$d^{ʒ}$ $t^{ʃ}$/ before /i/ or to /$b^{ʋ}$ p^{f}/ before /u/. But plosives before non-high vocoids in Proto-Bantu were not affricated in Mvumbo, as in (14b) (from Ohala 1983, after Guthrie 1967–71).

(14)

	Proto-Bantu	*Mvumbo*	
a.	*-buma	$b^{ʋ}$umo	'fruit'
	*-dib-	$d^{ʒ}$iwo	'shut'
	*-dut	-$b^{ʋ}$ure	'pull'
	*-tiitʊ	$t^{ʃ}$ir	'animal'
	*-tud-	-p^{f}ule	'forge'
	*-gida	ma-$t^{ʃ}$ie	'blood'
	*-gubʊ	m-$b^{ʋ}$uu	'hippopotamus'
	*-kiŋgo	$t^{ʃ}$iuŋ	'neck, nape'
	*-kuba	p^{f}uwo	'chicken'
b.	*-bod	-buo	'become rotten'
	*-dɪ	-di	'eat'
	*-toog	-tuog	'boil up'
	*-gada	-kala	'mat'
	*-konde	-kwande	'banana'

In contrast, the underlying plosives /t d/ in Quebec French are usually affricated into [t^{s} d^{z}] only before high front vocoids. As shown in (15), the consonants /t d/ are affricated before the high front vowel /i/, the high front rounded vowel /y/, the palatal glide /j/ or the high front rounded glide /ɥ/ within a morpheme (Charbonneau & Jacques 1972, Cedergren *et al*. 1991, Ostiguy & Tousignant 1993, Papen 1998).

(15)

Standard French	*Quebec French*	
pe[ti]t	pe[t^{s}i]t	'little'
[ti]pe	[t^{s}i]pe	'type'
[tj]ens	[t^{s}j]ens	'(I) hold'
[ty]rc	[t^{s}y]rc	'Turk'
[tɥ]er	[t^{s}ɥ]er	'to kill'
[di]x	[d^{z}i]x	'ten'
[di:]re	[d^{z}i:]re	'to say'
[dj]eu	[d^{z}j]eu	'God'
[dy:]rer	[d^{z}y:]rer	'to continue'
[ty] viens le matin	[t^{s}y] viens le matin	'you come in the morning'
il est plain[ti]f	il est plain[t^{s}i]f	'he is plaintive'

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However, the same plosive consonants are not affricated before the other vowels in Quebec French, as shown in (16) (Ostiguy & Tousignant 1993).

(16) [t]ante 'aunt' [d]é 'dice'
[t]outou 'puppy' [d]ernier 'last'
[t]onne 'ton' [d]ouceur 'softness'
[t]ôt 'early'

According to Ostiguy & Tousignant (1993), Quebec French affrication is obligatory within lexical items, as in (15), whereas it occurs optionally across word boundaries. As shown below, when the high front rounded vowel /y/ in *universitaires* 'university professors' follows the word *huit* 'eight', the word-final plosive /t/ in the latter either remains unchanged or is affricated to [tˢ], as in (17a). This is also true of the voiced counterpart /d/ when followed by the word *idée* 'idea', as in (17b).

(17) Les huit universitaires ont eu une drôle d'idée.
'The eight university professors have had a strange idea.'
a. [ty]/[tˢy] b. [di]/[dᶻi]

According to Papen (1998: 166), Quebec French assibilation is 'now so categorical that it is unnoticed by the general population'. Given that affricates are not phonemes in Quebec French or in standard French (e.g. Leclerc 1989, Battye & Hintze 1992, Ostiguy & Tousignant 1993), and that the occurrence of stridency on the surface is salient enough to distinguish the strident affricates from the non-strident plosive consonants [t d], Quebec French Affrication can be considered as an allophonic process occurring in postlexical phonology, like Japanese Affrication.

On the other hand, plosive assibilation after a high vocoid seems to be rare cross-linguistically. For instance, in Bhat (1978), Kirchner (1998) and Lavoie (2000), few linguistic data are reported on plosive assibilation in the context.

To sum up, the linguistic data presented in this subsection has shown that the context of phonological plosive assibilation is asymmetrical in two respects: (a) the process is triggered by high vocoids such as /i j y ɥ u w/, and not by non-high vocoids; (b) it typically occurs before a high vocoid, instead of after it.

4 A phonetic account

On the basis of the discussion and linguistic data in the above two sections, a phonetic account will now be provided for the two asymmetries in phonological plosive assibilation. First, it is argued that the first asymmetry – the process is normally triggered only by high vocoids – has an articulatory explanation. On the basis of phonetic data (Charbonneau & Jacques 1972, Cedergren *et al.* 1991, 1995), it is noted that stridency is generated when the tongue moves from the oral closure of a coronal plosive consonant toward a high vocoid. Second, the other asymmetry –

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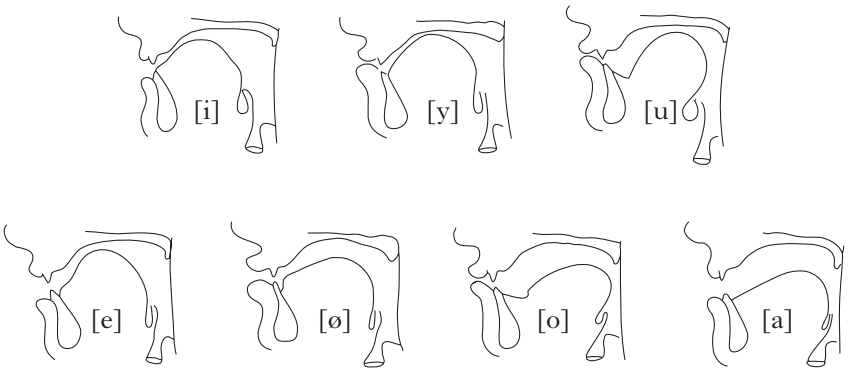


Figure 1
X-ray data of the Standard French high vowels [i y u] and non-high vowels [e ø o a] (from Bothorel *et al*. 1986)

the occurrence of phonological plosive assibilation before a high vocoid, not after it – is argued to have an acoustic and aerodynamic explanation. Experiments on the Korean consonant /t/ were carried out to find out whether transient frication is present after a high vocoid or before a non-high vocoid as well as before high vocoids, and the aerodynamics of egressive plosive formation is considered.

4.1 The effect of vowel height on turbulence

The comparison of X-ray data of high vocoids to that of non-high ones can help understand why the asymmetry that assibilation is only triggered by high vocoids such as /i j y ɥ u w/ can occur.

Figure 1 presents X-ray data of standard Modern French vocoids from Bothorel *et al*. (1986). In the tracings of the French high vocoids [i y u], a narrow constriction in the oral cavity can be noted. The tongue rises close to the palate for [i] and [y], and close to the velum for [u]. On the other hand, in the articulation of the French non-high vowels [e ø o a], the tongue does not rise as close to the palate or to the velum as it does in the high vowels [i y u]. Instead of a narrow oral constriction, the French non-high vowels have a relatively lower tongue body.

From the X-ray data in Fig. 1, the asymmetry – that assibilation is triggered only by high vocoids – can be attributed to the fact that only high vocoids have a narrow enough constriction to set up the conditions required to produce turbulence. Since the tongue lowers more in a non-high vocoid than in a high vocoid, as shown in Fig. 1, a plosive consonant before a non-high vocoid would have relatively briefer frication due to the lack of a narrow oral constriction for air turbulence.[19]

[19] §4.2 provides acoustic data showing that the frication duration after the /t/ release is much longer before the high vowels /i u/ than before the non-high ones /e a/ in Korean.

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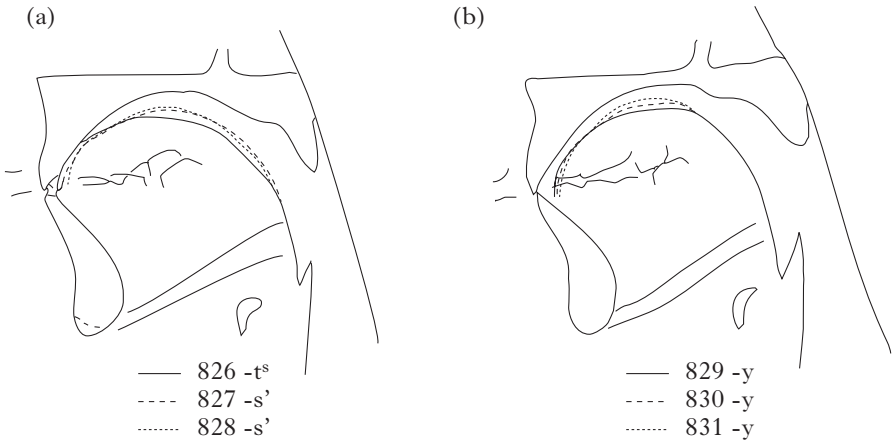


Figure 2
X-ray data of *tu* [t^{s}y] in *Tu viens le matin* 'You come in the morning' (from Charbonneau & Jacques 1972)

In support of this claim, we can refer to phonetic data on Quebec French Assibilation discussed by Charbonneau & Jacques (1972) and Cedergren *et al*. (1991, 1995). These studies report that when a plosive is followed by a high front vocoid in Quebec French, the generation of stridency results from the articulatory movement of the tongue toward a high vocoid.

According to the X-ray study of Charbonneau & Jacques (1972), the plosive consonant /t/ before the high front rounded vowel /y/ in *tu viens le matin* 'you come in the morning' shows the articulatory characteristics of affricates. In Fig. 2a, the occlusion of the plosive /t/ (826) is released with a very narrow constriction (827, 828) when the tongue moves from the alveolar ridge toward the palate for the following high front rounded vowel /y/.[20] The sequence of the oral closure of the plosive /t/ followed by the release into a very narrow constriction from behind the upper teeth to the alveolar ridge produces turbulence, resulting in the affricate [t^s].

The generation of stridency is made possible by the presence of a narrow oral constriction in the high front rounded vowel [y]. As shown in Fig. 2b, a continuous narrow oral constriction is maintained, even when the blade of the tongue moves away from the alveolar ridge and the front of the tongue moves toward the hard palate. Therefore, Fig. 2 shows that stridency is articulatorily correlated with the narrow oral constriction which arises when the tongue moves from the oral closure of the plosive toward the high front vocoid.

The generation of stridency in Quebec French is also observed when the plosive /t/ is followed by the high front vowel /i/ in an experiment

[20] The numbers in Fig. 2 refer to continuous frames related to the articulation of the sequence /ty/ in X-ray tracings of Charbonneau & Jacques (1972). According to the authors, the time interval between frames is 2·8 cs.

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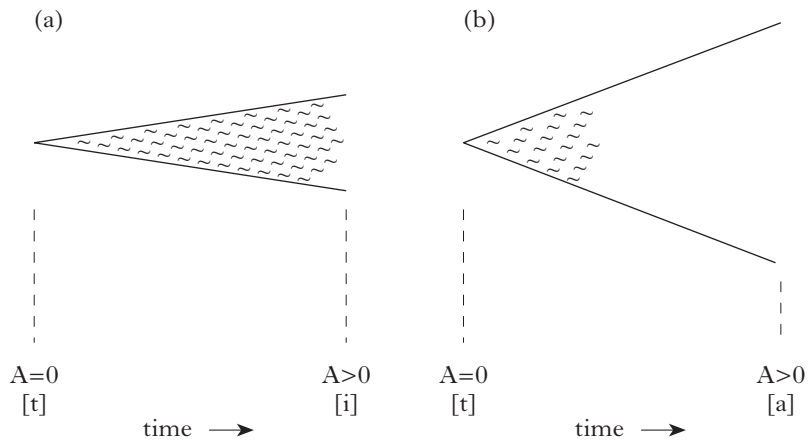


Figure 3
The generation of stridency after [t] release: (a) [t] release into a high vowel; (b) [t] release into a non-high vowel.
A: value of a cross-section area; ~~: turbulent airflow.

involving speech synthesis. Cedergren *et al*. (1991) describe an articulatory synthesis system in which information on the motor-sensory targets of a segment is integrated into a physiological module. The experiment shows that the fricative component of a surface affricate [t^{s}] is generated at the transition from the apico-alveolar plosive /t/ to the following high front vocoid. During the transition, the onset of vocal cord vibration for the vowel /i/ is delayed longer than when the plosive precedes the non-high vowels /e a/. In Fig. 3, the two different transitions are illustrated schematically.

Figure 3a represents Quebec French Assibilation as modelled by Cedergren *et al*. (1991, 1995). Air turbulence arises when the tongue blade moves along the path from /t/ to /i/. Here, the complete oral closure of the plosive /t/ is indicated as a zero-valued cross-section of the oral cavity. When the tongue blade moves toward the following vowel /i/, the cross-sectional area between the plosive /t/ and the vowel /i/ becomes wider only gradually, yielding air turbulence in between. In contrast, when the plosive /t/ is followed by a non-high vowel such as /e a/, the constriction opens more abruptly and the duration of the turbulent airflow is relatively shorter.[21] This is because the much wider oral cross-section area of the

[21] According to Catford (1977: 45), 'the discharge of the standard quantity of air through the narrow opening takes measurably longer than it does through a wider opening. In other words, the volume discharged per unit time (the volume-velocity) of the flow is higher through the wider channel'. Thus 'the ''closer'' vowels such as [i] (as in English *see*), or [u] (as in English *two*) have longer exhalation times (that is, lower volume-velocities) than more ''open'' vowels such as [ɛ] (as in English *bed*)

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non-high vowel [a] is not narrow enough to maintain turbulent airflow, as shown in Fig. 3b.

Note that in Japanese (13) and the sound change of Proto-Bantu to Mvumbo (14), assibilation also occurs when a plosive consonant is followed by the high back vowel /u/. Plosive assibilation in the context can be given the same account as in Fig. 3a. Because the vowel /u/ has a narrow articulatory channel like /i/, we can also expect that air turbulence arises when the tongue blade moves from /t/ to the vowel /u/.[22]

Consequently, the asymmetry that only high vocoids constitute assibilation triggers has an articulatory explanation: only high vocoids provide an oral constriction narrow enough to sustain stridency when the tongue moves from a plosive consonant toward a high vocoid.

4.2 The effect of the transition from plosive to vocoid on turbulence

The second asymmetry, that assibilation usually occurs before a high vocoid, not after it, provides another clue to the phonetic bases of phonological plosive assibilation. We shall argue that the conditions that create transient frication in the vicinity of plosives are not present anywhere but at the transition from a plosive consonant to a high vocoid. For this argument, acoustic experiments on the Korean plosive consonant /t/ were made and the aerodynamics of egressive plosive formation were considered.

Six Korean native speakers in their twenties (three males and three females) participated in two acoustic experiments. In the first experiment, the duration of frication at the release of the plosive consonant /t/ was examined in the monomorphemic sequences /mati/ 'knot', /mita/ 'to get torn', /mate/ (nonsense word), /mata/ 'every' and in the heteromorphemic sequence /mat+i/ 'first child' (it will be recalled from the earlier discussion of Korean that /t/ is not phonologically affricated to [tˢ] before /i/ in the same morpheme, whereas it is affricated before /i/ across a morpheme boundary, as in (10)). The five test words together with other words were embedded in the frame sentence /neka __ palimhapnita/ 'I pronounce __'. Unaware of the purpose of the experiment, the subjects read the randomly ordered frame sentences including the test words and others four times at normal speed, with two filler sentences added at the top and the bottom of the sheet of paper. Thus each test word was read a total of 24 times by six speakers (4 tokens × 6 speakers). Given the asymmetry effects, we expected that the tautomorphemic plosive consonant /t/ should show a longer period of phonetic frication at the release

or [æ] (as in English *bad*). The inference again is that [i] or [u] have narrower articulatory channels than [ɛ] and [æ].'

[22] This is supported by acoustic experiments in §4.2. The acoustic study of the Korean consonant /t/ shows that the duration of frication noise after the /t/ release before /u/ is as long as that before /i/, and longer than that before non-high vowels such as /e a/.

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in /a __ i/ than in the contexts /a __ e/, /a __ a/ and /i __ a/, and that the period of phonetic frication of /t/ in /mati/ should be shorter than that of the lexically derived affricate in /mat+i/.

Figure 4 shows wide-band spectrograms of the five test words – /mat+i/, /mati/, /mate/, /mata/ and /mita/ – in the third repetition spoken by one male subject (M1). The frication duration after /t/ release in a monomorphemic sequence /ti/ is not the same as that in /t+i/ sequences across a morpheme boundary wherein /t/ is phonologically affricated in Korean, as in /mat+i/ 'first child'. As shown in Fig. 4, the frication duration after /t/ release in /mat+i/ 'first child' (a) is 55·09 ms, almost twice as long as that in /mati/ 'knot' (b), which is 32·15 ms.[23] On the other hand, frication duration after /t/ release is 13·35 ms in /mita/ (c), 14·98 ms in /mate/ (d) and 8·72 ms in /mata/ (e).

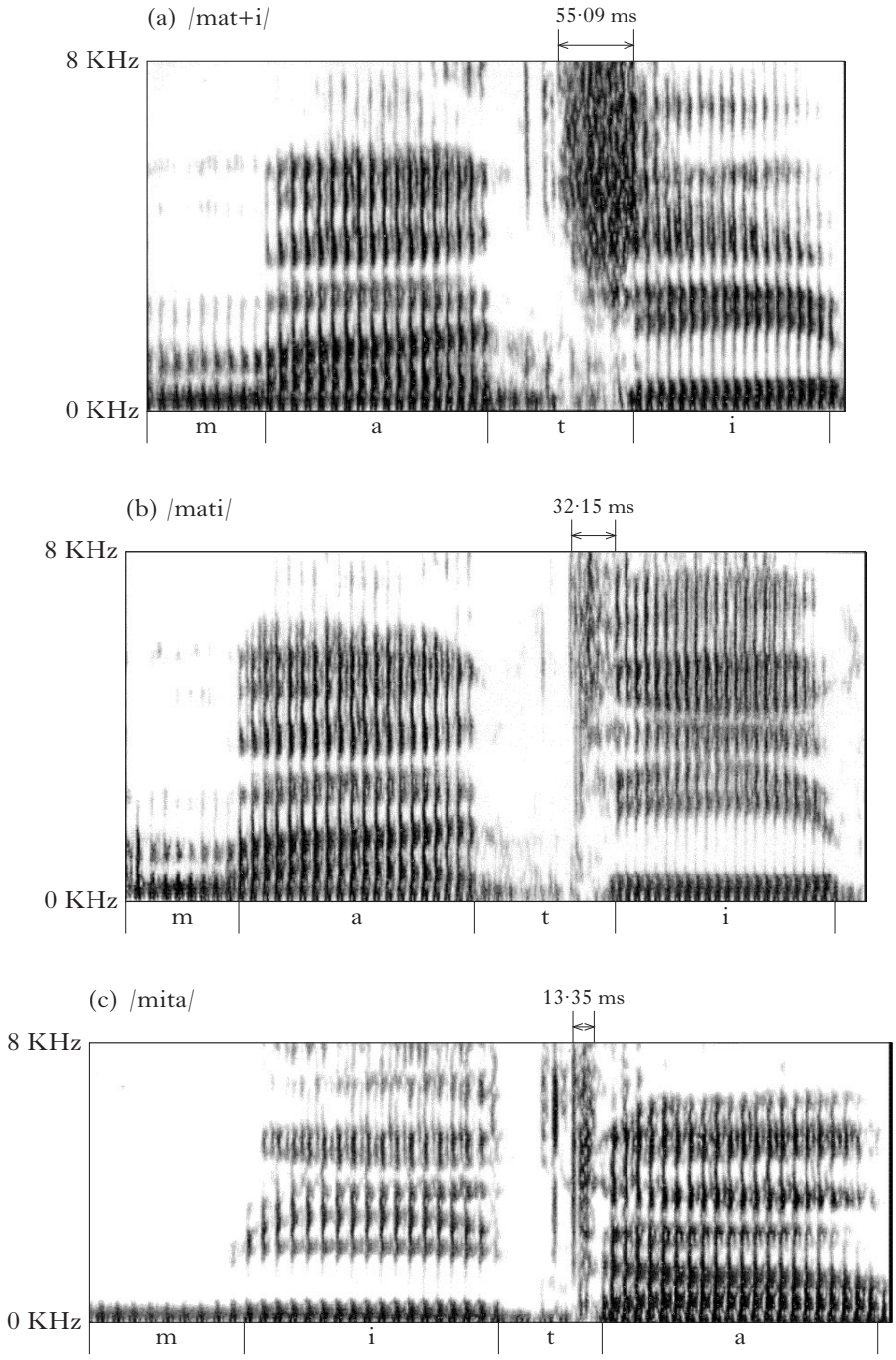
Table I shows the average duration of frication after /t/ release in the four repetitions of the five test words and total mean values and standard deviation of frication duration over thirty tokens by six speakers for each test word. The average duration of /t/ frication before the high vowel /i/ in /mat+i/ is 69·3 ms, more than twice as long as before the same vowel in /mati/ across the six subjects. The frication duration after the release of the plosive /t/ in the test words /mati/ and /mat+i/ was statistically significant ($t(23) = 10{\cdot}7$, $p < 0{\cdot}0001$) in a pairwise two-tailed *t*-test. Hence phonetic assibilation, when present, is still shorter in duration than phonological assibilation.

As for phonetic assibilation in the contexts /a __ i/, /a __ e/, /i __ a/ and /a __ a/, the average duration of tautomorphemic /t/ frication before the high vowel /i/ across the six subjects is 30·7 ms, more than twice as long as before the non-high vowels /e a/ in the contexts /a __ e/ and /i __ a/ and three times the duration of average frication noise following /t/ in the context /a __ a/. A two-way repeated measures ANOVA revealed a main effect for phonetic environment ($F(3, 24) = 112{\cdot}8$, $p < 0{\cdot}0001$) and no interaction with speakers ($F(5, 24) = 0{\cdot}6$, $p < 0{\cdot}9363$). A Scheffe's post hoc comparison showed that frication duration after /t/ release in /mati/ is statistically longer than that in /mate, mata, mita/: $F(1, 24) = 36{\cdot}7$ for /mati/ *vs.* /mate/, $F(1, 24) = 48{\cdot}4$ for /mati/ *vs.* /mata/ and $F(1, 24) = 29{\cdot}3$ for /mati/ *vs.* /mita/. No other pair was found to be significantly different.

A separate experiment was conducted to see whether frication noise after /t/ release before /u/ is phonetically longer than before /e a/ or after /u/ and also whether it is as long as that before /i/. In this experiment the two test words /matu/ 'horse head' and /muta/ (nonsense word) were added to the test words used in the above experiment and embedded in the same frame sentence. The test words were read at normal speed four times by the same subjects.

[23] Frication duration was measured from the beginning of the high-frequency frication after the /t/ release to the end of it. The end of the high-frequency frication corresponded to the onset of a following vowel, or ended a little earlier the vowel began, depending on the speaker.

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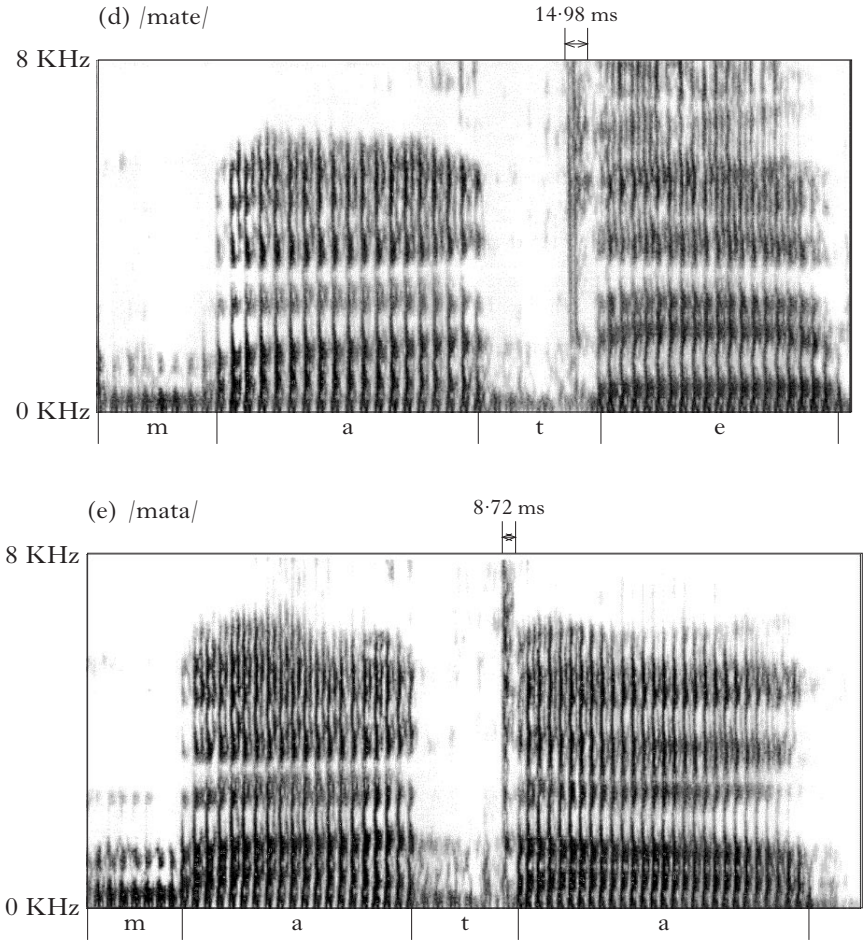


Figure 4
Wide-band spectrograms of the Korean plosive /t/ in (a) /mat+i/ 'first child', (b) /mati/ 'knot', (c) /mita/ 'to get torn', (d) /mate/ (nonsense word), (e) /mata/ 'every'.

In this second experiment, across the six subjects, the average duration of /t/ frication before the high back vowel /u/ in /matu/ was 19·3 ms, while that before the vowel /i/ in /mati/ was 20·5 ms. A pairwise two-tailed *t*-test showed that the frication duration after the release of the plosive /t/ in /matu/ is not statistically different from that in /mati/ ($t(23) = -0{\cdot}8$, $p < 0{\cdot}4358$). On the other hand, the average duration of /t/ frication after the high back vowel /u/ in /muta/ is 7·7 ms, and a pairwise two-tailed *t*-test showed that the frication noise after /t/ release is statistically longer before /u/ in the test word /matu/ than after /u/ in /muta/ ($t(23) = 11{\cdot}2$, $p < 0{\cdot}0001$).

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	a__+i	a__i	i__a	a__e	a__a
M1	56·9	26·2	15·5	9·6	6·0
M2	89·5	51·6	15·8	15·2	10·4
M3	67·4	38·0	14·4	11·3	8·9
W1	51·3	17·5	9·6	8·3	7·0
W2	65·4	24·4	11·5	10·6	8·0
W3	85·5	26·6	12·3	11·4	9·4
mean	69·3	30·7	13·2	11·1	8·3
standard deviation	18·4	12·7	3·3	3·6	2·0

Table I

The average duration of frication after /t/ release over the four tokens of the test words spoken by each speaker, total mean values and standard deviation of frication duration across six speakers (M = male; W = female).

In short, across the six subjects, phonetic frication duration after /t/ release before /i u/ is statistically longer than before the non-high vocoids /e a/ or after the high vocoids /i u/, though phonetic assibilation in /mati/ is still shorter in duration than phonological assibilation in /mat+i/. Given the articulatory account in the above subsection, the results of this acoustic study support the view that the conditions that create transient frication in the vicinity of plosives are present in plosive consonant+high vocoid sequences, but not before non-high vocoids or after high vocoids.

The aerodynamics of egressive plosive formation also support this view. An egressive pulmonic airstream creates different aerodynamic conditions before and after the arrest phases of a plosive. In experimental studies of airflow traces (e.g. Subtelny *et al*. 1966, Catford 1977, Stevens 1998), airflow at release is much greater than before the arrest of a plosive consonant. Catford (1977) and Stevens (1998), among others, argue that two conditions are conducive to producing frication noise: cross-sectional area of the arrest and volume velocity of airflow (amount of air that passes through the channel per unit of time), which is partly a function of glottal opening and partly of air pressure, as discussed in the next paragraph. According to Stevens (1998: 388), 'the ratio of constriction area to glottal area that maximizes the amplitude of the noise at the constriction is calculated to be … about 45 percent'. That is, the ideal glottal opening is about twice as large as the area of the constriction.

As for airflow before the arrest of a plosive, very little intraoral pressure is built up near the instant of arrest and hence the airflow is not very great, as shown in Fig. 5. According to Stevens (1998: 326–328), 'prior to 3 to 10 ms preceding the implosion (depending on the rate of closure), the supraglottal movements have no major influence on the glottal vibration pattern and cause essentially no increase in intraoral pressure'. However,

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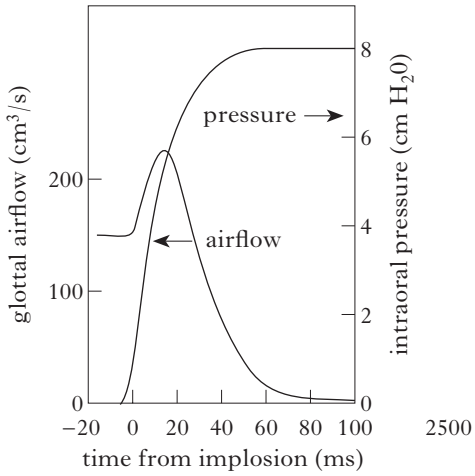


Figure 5

Calculations of intraoral pressure and glottal airflow immediately following closure for a plosive consonant following a vowel (from Stevens 1998).

'immediately following closure there is a buildup of pressure behind the constriction', because 'the increased glottal opening could cause the pressure to increase somewhat ... rapidly'. 'If the duration of the closure extends beyond 50 ms, the intraoral pressure reaches a steady value equal to the subglottal pressure, and the glottal airflow decreases essentially to zero', as in Fig. 5. At the release, there is already large intraoral pressure, because 'the principal influences on intraoral pressure and on glottal activity occur after the instant of closure', and this causes much greater airflow at the release. Consequently, before the arrest of a plosive, where there is little airflow and very little intraoral pressure, the threshold conditions for producing frication noise could never be attained. In contrast, a greater airflow at the release facilitates the threshold conditions for producing frication noise.

To sum up, this section has provided a phonetic account of phonological plosive assibilation. It was argued in §4.1 that the asymmetric occurrence of assibilation before a high vocoid but not before a non-high vocoid or after a high vocoid has an articulatory explanation: a narrow enough channel to create long-duration turbulence is created only at the transition from a plosive to a high vocoid. It was then shown in §4.2 that acoustic experiments on the Korean consonant /t/ and a consideration of the aerodynamics of egressive plosive formation confirm the view that the conditions that create long-duration transient frication in the vicinity of plosives are present only in plosive + high vocoid sequences, and not before non-high vocoids or after high vocoids, at least in the data considered here.

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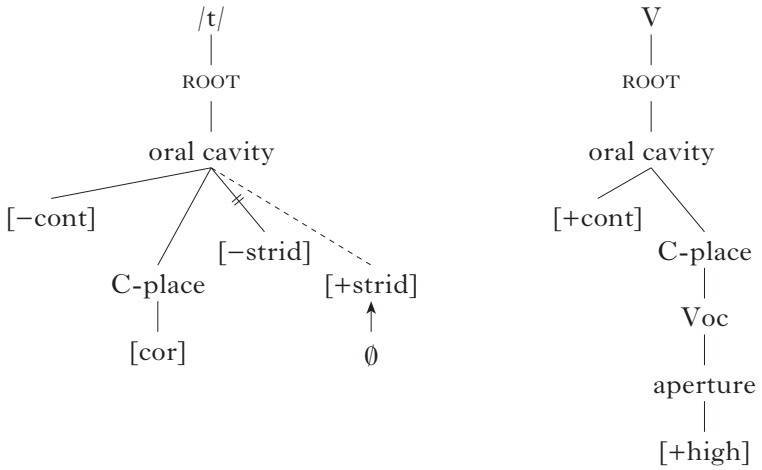
5 The phonological representation of assibilation

This section has two goals: (a) to offer a phonological analysis of pre-high-vocoid assibilation, including both the affrication and frication cases, and (b) to defend it against other analyses.

5.1 A phonological analysis of assibilation

First, it is proposed that the generation of air turbulence in the context of phonological assibilation is phonologically interpreted as the insertion of the feature [+strident] into the feature complex characterising the plosive in a plosive+high vocoid sequence, with the deletion of the previous feature [−strident], if present. This analysis is shown in (18).

(18) *Affrication of the plosive consonant* /t/



On the other hand, regarding the creation of sibilant fricatives, it is proposed that sibilant frication before high vowels arises in one of two ways: first, by a context-free process which replaces sibilant affricates by the corresponding fricatives across the board; or second, by a context-sensitive process which creates sibilant fricatives directly from plosives before high vowels. In the following discussion, the first process is illustrated by Finnish and French data and the second by Korean data.

In Finnish, where affricates are not allowed (Sauvageot 1946, Harms 1964), sibilant fricatives are created from intermediate strident affricates by a structure-preserving, context-free constraint ruling out affricates. Sound change in the history of French offers a further case of context-free shift of strident affricates to fricatives. Plosive consonants in Classical Latin were first palatalised before the palatal glide /j/ in Late Latin, being later changed into affricates in Old/Gallo-Roman French and subsequently changed into fricatives in Modern French, as shown in (19) (Leclerc 1989, Jacobs 1991).

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(19) a. CL *ratione* > MdFr *raison* [rɛzɔ̃] 'reason'
*ratjone > *ratʲjone > *ratˢjone > *radᶻone > *rajzɔn > rɛzɔ̃

b. CL *fortia* > MdFr *force* [fɔrs] 'force'
*fɔrtja > *fɔrtʲja > *fɔrtˢja > *fɔrsə > fɔrs

c. CL *hordiu* > MdFr *orge* [ɔrʒ] 'barley'
*ɔrdju > *ɔrdʲju > *ɔrdʒju > *ɔrdʒə > ɔrʒ

d. CL *centu* > MdFr *cent* [sɑ̃] 'hundred'
*kjentu > *kʲjentu > *tjentu > *tˢɑ̃nt > sɑ̃

e. CL *argilla* > MdFr *argile* [arʒil] 'clay'
*argjilla > *argʲilə > *ardʲilə > *ardʒilə > arʒil

f. CL *carru* > MdFr *char* [ʃar] 'cart'
*kjarru > *kʲjarru > *tjarru > *tʃar > ʃar

g. CL *gamba* > MdFr *jambe* [ʒɑ̃b] 'leg'
*gjamba > *gʲjamba > *djamba > *dʒambə > *dʒɑ̃mbə > ʒɑ̃b

h. CL *tibia* > MdFr *tige* [tiʒ] 'stalk'
*tibjia > *tibʲia > *tidʒə > *tiʒə > tiʒ

i. CL *sapia* > MdFr *sache* [saʃ] 'he knows (SUBJ)'
*sapjia > *sapʲia > *satʃə > *saʃə > saʃ

j. CL *cavea* > MdFr *cage* [kaʒ] 'cage'
*kavjea > *kavʲea > *kadʒə > *kaʒə > kaʒ

Thus the sibilant fricatives in Modern French in (19) derive from affricates, and the affricates result in turn from the palatalised obstruents /pʲ bʲ tʲ dʲ kʲ gʲ/ before the palatal glide in Late Latin. The affricates /tˢ dᶻ tʃ dʒ/, which were phonemes in Old French (e.g. Bruneau 1966, Harris 1997), began to reduce to fricatives in the twelfth century, not only before the high vowels /i y u/, as in (19e), but also before the non-high vowels /e a ɔ ə/, as in (19a–d, f–j) (Pope 1952, Leclerc 1989).

The data in (19) indicate that, in the history of French, sibilant frication occurred context-freely outside the affrication context, and was not restricted to apply under the same conditions as affrication itself, that is, before high vocoids.[24] In such cases, frication must be represented as the context-free loss of the feature [−continuant], regardless of which vowel follows the consonant.

Modern Korean provides an example of the second frication, i.e. context-sensitive frication which creates sibilant fricatives directly from plosives before high vowels. As shown in (20), the noun-stem final plosive

[24] According to Calabrese (1993), a direct change from a stop into a fricative is possible, although rare, in a palatalisation context. For example, such a change is observed in (i.b) in the Northern Italian dialect of Sologno:

(i)

	Latin	*Sologno*
a. /tj/ → /ttʃ/	puteu	puttʃ
	matea	matʃ (*but also* maʃʃ)
b. /kj/ → /ʃʃ/	bracchiu	braʃʃ
	facio	faʃʃ (*but also* faʃ)

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/t^h/ usually surfaces as its counterpart affricate [t^{sh}] in formal speech when it is followed by inflectional suffixes such as the subject case marker /i/ (a), the copula /i/ (b) and the conjunction case marker /ilaŋ/ 'and' (c). However, in the same contexts, the plosive consonant can optionally surface as the fricative [s] in informal speech.[25]

(20) a. *before the subject case marker* /i/

/p^hat^h+i/ → [$p^ha.t^{sh}i$]	~	[$p^ha.si$]	'red bean'+SUBJ
/sot^h+i/ → [$so.t^{sh}i$]	~	[so.si]	'kettle'+SUBJ
/mit^h+i/ → [$mi.t^{sh}i$]	~	[mi.si]	'bottom'+SUBJ

b. *before the copula* /i/

/p^hat^h+i+ta/ → [$p^ha.t^{sh}i.da$]	~	[$p^ha.si.da$]	'(it) is red bean'
/sot^h+i+ta/ → [$so.t^{sh}i.da$]	~	[so.si.da]	'(it) is a kettle'

c. *before the conjunction case marker* /ilaŋ/ 'and'

/pat^h+ilaŋ/ → [$pa.t^{sh}i.raŋ$]	~	[pa.si.raŋ]	'field and'
/sot^h+ilaŋ/ → [$so.t^{sh}i.raŋ$]	~	[so.si.raŋ]	'kettle and'

However, before non-high vowels, the stem-final stop consonant /t^h/ remains unchanged, as in (21).

(21)

/pat^h+esə/ → [$pa.t^he.sə$]	*[pa.se.sə]	'in the field'
/mat^h+a/ → [$ma.t^ha$]	*[ma.sa]	'(I, you) undertake, smell'
/put^h+ə/ → [$pu.t^hə$]	*[pu.sə]	'(it) sticks'
/kat^h+ɛ/ → [$ka.t^hɛ$]	*[ka.sɛ]	'(it) is the same'

So far it has been argued that the phonetic origin of the frication noise, which occurs at the release of a plosive into a high vocoid in assibilation, is interpreted in phonology as the insertion of the feature [+strident] into the phonological representation of a plosive. In the case of assibilation to an affricate, the feature [+strident] is added to the feature complex characterising the plosive in a plosive+high vocoid sequence. Furthermore, in the case of assibilation to a fricative, the feature [−continuant] is deleted, either across the board or in the assibilation context, according to the language.

5.2 Alternatives

The account of phonological assibilation as the insertion of the feature [+strident] in (18) might at first sight seem less natural than one involving feature spreading, i.e. assimilation, since natural sound changes often result from assimilation to or dissimilation from a neighbouring sound. However, we cannot assume that [+strident] spreads from following vocoids, since they are vocalic sounds which do not have an oral constriction narrow enough for stridency to be produced and which thus do not bear the feature [+strident].

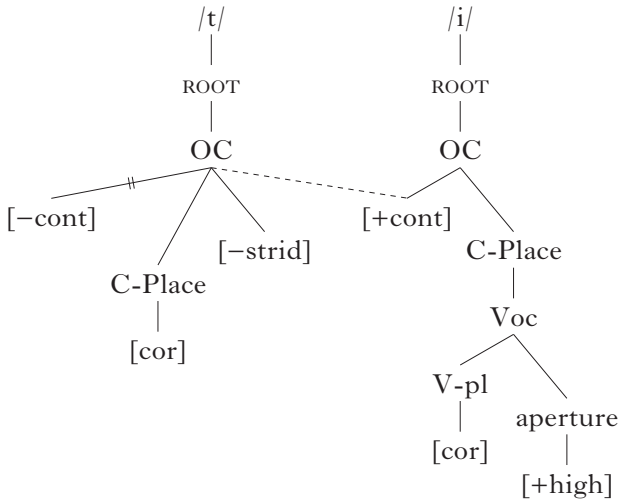
As an alternative, one might consider an analysis spreading the feature

[25] There are few nouns ending in /t/ in Korean. Noun-final consonants /t/ were replaced by /s/ in Middle Korean, from the beginning (e.g. Lee 1972, 1978) or middle of the sixteenth century (e.g. Huh 1985).

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[+continuant] from a following high front vocoid to a stop, as shown in (22). Since the resulting contour '[−continuant][+continuant]' is ill-formed (as shown in §2), the spread of [+continuant] automatically triggers the deletion of [−continuant], giving rise to a non-strident fricative.

(22)



This alternative is inadequate for several reasons. First, it fails to derive strident affricates, which are [−continuant, +strident] sounds, as shown in §2. Instead, it incorrectly produces [+continuant, −strident] sounds, that is non-strident fricatives, which occur rarely, if at all, as a result of a pre-high-vocoid affrication.

Second, it fails to relate assibilation to the phonetic condition underlying this process, as proposed in the paper. The [+continuant] spreading analysis fails to account for the observation that phonological assibilation is phonetically based on the presence of turbulent noise at the plosive release before a high vocoid. Thus the two asymmetries in phonological assibilation discussed in §3 cannot be accounted for.

Third, in this alternative, a default process inserting [+strident] into fricatives unspecified for this feature would have to be assumed in order for the non-strident fricatives derived from the [+continuant] spreading to be replaced with their less marked strident fricative counterparts. But the default process, if it is context-free, as default processes are standardly assumed to be, will fail to restrict the insertion of the feature [+strident] just before high vocoids as is required. And this analysis still fails to produce affricates.

In short, the continuant-spreading analysis, however natural we might think it to be, simply fails to describe the facts correctly, and can be dismissed on that basis.

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6 Conclusion

In this paper, a phonetic account of phonological plosive assibilation has been proposed as a case of a phonetically based phonological process. Based on the phonological representation of sibilants first proposed by Jakobson *et al*. (1951), and discussions of the two asymmetries observed in cross-linguistic phonological assibilation, the following two results have been proposed. One, the high vocoid-conditioned phonological plosive assibilation is phonetically based on the brief period of turbulence that sometimes occurs at the release of a plosive into a high vocoid. Second, the turbulence is interpreted in the phonology as the insertion of the feature [+strident] into the phonological representation of a plosive, with the loss of the feature [−continuant] in the case of frication.

We can raise the question of what, in our account, rules out a language with an assibilation process inserting [+strident] before non-high vowels or after high vowels. Given the above account, the phonetic conditioning giving rise to prolonged turbulence should rarely, if ever, arise outside the contexts discussed here, or others where similar aerodynamic conditions are present.

Consequently, not only does the proposed phonological interpretation do justice to the phonetic origin of assibilation, it also correctly reflects the cross-linguistic conditions on high vocoid-conditioned phonological plosive assibilation.

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