Nasal loss before voiceless fricatives: a perceptually-based sound change

John J. Ohala & M. Grazia Busà

The environment of a following voiceless fricative tends to promote the loss of a nasal consonant (English *goose* < orig. *gans-*). On the other hand voiceless fricatives are also implicated in engendering "spontaneous" nasalization on vowels where there was no earlier nasal (Hindi /sāp/ < Sanskrit *sarpa* 'snake'). We argue that nasal loss is the inverse of spontaneous nasalization. In the latter, acoustic effects of the voiceless fricative produce an effect on adjacent vowels which mimic nasalization. Although normally discounted by listeners as a predictable contextual effect, these effects may be misinterpreted by some listeners as actual nasalization. In nasal loss, listeners misinterpret a pre-existing nasal next to a voiceless fricative as the kind of spurious nasal element they have come to expect in this environment and thus discount it. We report the results of a perceptual experiment which supports this scenario: given a vowel-nasal sequence of a certain duration, listeners are unable to detect the nasal when it appears before the voiceless fricatives [s] and [θ] but are able to detect it before the stop [t] (a following [z] produced an intermediate pattern).*

1. Introduction

What does it mean to give a phonetic account of a sound change?[1] Part of it must undoubtedly include showing that the target sound change is phonetically natural or expected, given what is known about the workings of the speech mechanism from present-day observations. This might be done by pointing out parallels between phonetic processes observed in the speech of contemporary speakers, perhaps using sensitive instrumentation, and the processes that led to the sound change. This would be the inductive approach. It could also involve connecting the diachronic facts with known physical constraints of the speaking mechanism. This would be the deductive approach. There are many examples of both types of account in the phonological literature: Key 1865, Passy 1890, Rousselot 1891, Grandgent 1896, Haden 1938, Zipf 1935, Grammont 1933, Durand 1955, von Essen 1964, Klingenheben 1928, Delattre 1946 as well as many recent works.[2] For example, Passy and Klingenheben and Chao 1936 all point to the inherent aerodynamic constraint which threatens the voicing of obstruents (see also Ohala 1983a, 1994a). Weymouth 1856 and Grandgent 1896 refer to the universal and timeless phonetic principles which lead to the development

Rivista di Linguistica, 7.1 (1995), pp. 125-144 *(ricevuto nell'ottobre 1994)*

of an epenthetic stop between nasals and adjacent oral obstruents (see also Ohala 1974, 1983a).

Yet simply to establish parallels between diachronic variation and synchronic variation (and/or its physical phonetic cause) is only part of the task. The reason is that *synchronic variation cannot be quite the same thing as sound change*. For example, the F0 differences on vowels following voiced and voiceless consonants in non-tone languages like English, Danish, Russian, and French parallel the development of tones in tone languages such as Chinese, Vietnamese, and Thai, but they nevertheless do not behave like sound changes (Hombert, Ohala, & Ewan 1979). The *synchronic* phonetic variation in F0 is mechanically linked to the voicing difference in the preceding consonant; it varies with the strength or temporal proximity of the conditioning environment and cannot occur independently of it (see Löfqvist et al 1989; Sawashima & Hirose 1983). The new tones that arose in Chinese and the other tone languages are no longer mechanically linked to the voicing of the preceding consonant; in fact, in most such cases the voicing in these consonants has been neutralized.[3] The difference, we maintain, lies in the fact that the synchronically co-varying phonetic events (between consonant voicing and following F0 differences) are linked or parsed together by present-day listeners. The sound change – change in the pronunciation norm – is initiated when listeners cease to parse together the phonetic cause and effect. In this paper we present an account of a common sound change precipitated by listeners' parsing errors.

The sound change targeted here consists of loss of a nasal consonant before voiceless fricatives. We will attempt to show (a) how this change is related to certain other sound changes, (b) that some of its aspects derive from physical phonetic factors and the way that listeners react to them (see also Kawasaki 1986, Beddor et al. 1986).

2. *Loss of nasal consonants before voiceless fricatives*

Sound changes involving loss of post-vocalic nasal consonants are rather common. This is one part of the origin of the distinctively nasal vowels in French (/dã/ < Latin *dens, dentis* 'tooth'; Hindi (/dãt/ < Sanskrit *danta* 'tooth'), and many other languages. In these cases the nasal consonant was lost and the preceding vowel nasalized. The phonetic quality of the segment following the nasal may promote its loss: voiceless obstruents in general have this effect. For example, in American English this environment has fostered the development of distinctively nasal vowels, e.g., [lɛ̃t] *lent* vs. [lɛt] *let* (Malécot 1960). In contrast, following

voiced stops may even have the effect of preserving the nasal or reintroducing it if it had been lost (see Greenlee & Ohala 1980; M. Ohala & J. Ohala 1991; J. Ohala & M. Ohala 1993a). However, there is ample evidence that in some cases *voiceless fricatives* are more effective in promoting loss of the nasal than are other segment types. This is the focus of the present paper.

Some examples are the following. In these examples a common pattern is evident: that in the process of losing the nasal consonant, the preceding vowel becomes nasalized. Sometimes the vowel nasalization has been lost, as in English, in (1), but there is reason to believe that here, too, the vowel was originally nasalized (Wyld 1927: 63).

(1) English (German forms are cited because they preserve the nasal consonant that was present in the parent language common to German and English). The last two forms show that following stops did not provide an environment for nasal loss.

	German	**English**
	Gans	goose
	fünf	five, fif(ty)
	unser	us
	Mund	mouth
But:		
	Hund	hound
	Wink	wink

(2) Western Ossetic (Digoron) (Henderson 1949). "A nasalized vowel followed by a fricative ["voiced" fricatives are usually devoiced finally] may occur as an alternative pronunciation to a sequence composed of vowel + nasal + fricative." E.g.:

insojnə	~	ĩsojnə
bat'unsun	~	bat'ũsun
qanẓ	~	qãẓ
iroŋχ	~	irõχ

(3) Eastern Ojibwa (Bloomfield 1956: 7). "The long vowels are strongly nasalized before the sequences of *n* plus *s*, *š*, *ʔ*, *y*; often before *s*, *š*, and always before *ʔ*, *y*, the closure of the *n* is then omitted and the *n*, accordingly, is represented only by the strong nasalization [...]".

(4) Dialectal Spanish. Delattre (1946) notes that many dialects of Spanish, especially in the New World, show a development of nasal vowels before nasals with subsequent loss of the nasal. This can occur before any non-initial nasal. However, the environment before voiceless fricatives often seems to promote this more than other environments. He quotes Navarro Tomás (1932: 112) on Iberian Spanish:

"En las sílabas *ins*, *cons*, y *trans* se pronuncia en general una *n* débil, breve y relajad, que a veces se reduce simplemente a una pequeña nasalización de la vocal precedente, y a veces se pierde por completo [...][1]".

(Navarro Tomás goes on to say that retention or loss of this *n* is a sociolinguistic variable.) Delattre cites Lenz (1940) as reporting that the nasalization of the vowel with accompanying loss of the nasal occurs only before fricatives in Chilean Spanish, e.g.,

Chilean Spanish	**Spanish elsewhere**	
ˈlõxa	ˈloŋxa	*market, exchange*
kõˈforme	konˈforme	*in agreement*
naˈrõxa	naˈraŋxa	*orange*
ũ xarˈðin	un xarˈðin	*a flower garden*
ˈgãso	ˈganso	*goose*

(5) Ila (Doke 1928). Homorganic nasals appear before stops and voiced fricatives but where such would be expected before voiceless fricatives, the preceding vowel becomes nasalized. (A nasalized vowel replacing a vowel plus a homorganic nasal may also occur as a variant pronunciation before voiced fricatives.) E.g., (transcription simplified):

Compare:

valam bala	*they go past me*
valan detela (< stem letela)	*they bring for me*
valan dirila (< stem ririla)	*they weep for me*
valaŋ kaka	*they refuse me*

But:

valã sempula (< stem sempula)	*they carry me*
valã ʃija (< stem ʃija)	*they leave me behind*

Variation:

waːɲʒanina	wãːʒanina	*he danced to me*

Dialectal variation:

Ila	**Lundwe**	
ĩːsa	iːnsa	*kidney*

(6) Old Irish (Thurneysen 1946: 128; transcription modified). "*n* before *s* and *ch* [IPA x] disappears, but lengthens a preceding short vowel." E.g.,

Old Irish				
géis	*swan*	cf.	OHG gans	*goose*
césaid	*suffers*	cf.	Lith. kenčiu	*I suffer*
mís	*month*	cf.	PIE *mēns -os	
drésacht	*creaking of wheels*	cf.	Lat. drensare	*to cry*

(7) Latin to Italian (Grandgent 1927). "When *n* was followed by a fricative (*f, j, s, v*),[5] it regularly fell early in Latin, and the preceding vowel was lengthened by compensation: *cēsor* [< *censor*, 'magistrate'], *cōjugi* [< *conjugi*, 'the married (couple)'], *cōventio* [< *conventio*, 'assembly'], *ī feri* [< *inferi*, 'the dead; lower world']. Before *f, j*, and *v*, however, the *n*, being always the final letter of a prefix, was usually restored by the analogy of the full forms in the prefixes in question *con-* and *in-*: *infantem* ['baby'] through *indignus* ['unworthy'], etc.; *conjungere* ['to connect'] through *conducere* ['to unite'], etc.; *convenire* ['to meet'] through *continere* ['to hold together'], etc. But before *s* the *n* was very often a part of the main word, and the fall was permanent, restoration occurring only at the end of a manifest prefix: *īsula*, *mēsis*, *spōsus* > It. *isola* [< Lat. *insūla* 'island'], *mese* [< Lat. *mensis* 'month'], *sposo* [< Lat. *sponsus* 'husband; bethrothed']; but *insignio* > It. *insegno* ['sign, mark']. Such a word as *pensare* ('to think') must be a new formation, the old *pensare* ('to weigh') having become *pesare*".[6]

Other examples (from Tuttle 1991 and personal observation of second author):

(Late) Latin	**Italian**	
institutus	istituto	*arrangement, institution*
ansa	(Milanese) asa	*handle, loop, occasion*
infer(n)u	(Sardinian) iffèrru	*below, the lower world*
absinthiu	(Nuorese) aθéθu	*artemisia, wormwood*
instans	istante	*moment*
transcribere	trascrivere	*to copy*

Sociolinguistically-determined variants:

Formal	**Informal**	
installare	istallare	*to install*
translitterare	traslitterare	*to transliterate*
translucido	traslucido	*translucent*

Nasal loss before voiceless fricatives (primarily [s]) is sporadic in Italian and occurs more often in core, "common", vocabulary than in learned vocabulary.

(8) Ciyao (Ngunga 1993) (Guthrie's P21). A nasal prefix that otherwise appears regularly in noun class 9/10 fails to appear before a stem beginning with /s/ (Armindo Ngunga, personal communication, December 1993).

	lu - ko^{ŋ}golo	*leg*	ŋ - go^{ŋ}golo	*legs*
	lu - pjó	*kidney*	m - bjó	*kidneys*
But:				
	lu - suló	*river*	suló	*rivers*
	lu - so^{m}be	*locust*	so^{m}be	*locusts*

(9) Prokosch (1939) shows that in the various Germanic dialects, although voiceless fricatives (or spirants) provide the principal environment for loss of a preceding nasal, it is often a different set of fricatives in each dialect.[7]
Germanic (Prokosch 1939: 86-87; transcription modified): "**n** (ŋ) before **x** disappears in Primitive Germanic; in Norse, the nasal also disappears before **s** and **f**, and in the Anglo-Frisian group (OE Fris OS) before **s f θ** [ð medially between voiced sounds]; a preceding short vowel is lengthened ('Compensatory Lengthening'); ɑ is always lengthened to **o:** in OE, sometimes in ON OFris. and OS". E.g.:

Germanic	**Gothic**	**Old Norse**	**Old English**	**Old Saxon**	**Old High German**	
fɑŋxɑnɑ	fɑ:xɑn	fɑ̄:	fo:n	fɑ:xɑn	fɑ:xɑn	*grasp,take*
θɑŋxta	θɑ:xtɑ	θɑ:ttɑ	θo:xte	θɑ:tɑ	dɑ:xtɑ	*thrive*
		gō:s	go:s	gɑ:s	gɑns	*goose*
	uns	o:s	u:s	u:s	uns	*us*
tumft		to:ft				*foundation*
	fimf		fi:f	fi:f		*five*
	kunθs		ku:θ	ku:θ	kund	*known*
	ɑnθɑr		o:θer	o:θɑr	ɑnθɑr	*other*

(10) Swahili (Tucker & Ashton 1942). A vowel is nasalized before a nasal; sometimes the nasalization is so strong that the nasal consonant is assimilated. The only examples of this involve a /z/ following the /n/. The voicing of /z/ is not very strong; it may be devoiced in an unstressed syllable before /i/:

tʃɛ̃:zɑ	~	tʃɛnzɑ	*orange*
gɑ̃:zi	~	gɑnzi	*numbness*

(11) Delaware (Voegelin 1946). "When the sequence ns or nš occurs medially before a vowel or finally, the spirant has a voiced timbre, but is by no means fully voiced; the preceding n is not actualized as a consonant but functions as an anusvara, nasalizing the preceding vowel which is always long."

There are differing opinions as whether it is voiceless fricatives which promote nasal loss, or fricatives in general, or continuants in general. Foley (1977: 58ff) claims that it is *continuants* which lead to nasal loss, not *fricatives*, per se, plus the relative *strength* of the segments and positions which determine nasal loss. In most cases it is not possible to say whether it is continuancy or frication (especially voiceless frication) that favors preceding nasal loss since fricatives are the only continuants in the language or the only continuants before which nasals appear. Tuttle (1991) argues that although voiceless sounds in general promote preceding nasal loss, fricatives provide a better environment for this process; hence the combination of voicelessness plus fricativeness is the optimal environment. He cites data from Nicolet (1929: 505ff) on the Val d'Antrona dialect (in Piedmont near the Swiss border) which shows nasal loss before both voiced and voiceless fricatives (but not before stops); see (13).

(12) Val d'Antrona dialect (Piedmont) (Nicolet 1929: 505ff; cited by Tuttle 1991; transcription modified).

brĩ:^{ɲ}ʃul	~	brĩ:ʃul	*juniper*		bantʃa	*bench*
tʃẽ:^{ɲ}ʃ	~	tʃẽ:ʃ	*prepared,neat*		tʃamp	*field*
fũ:^{ɲ}ʃ	~	fũ:ʃ	*mushroom(s)*		dʒamba	*leg*
mũ:^{ɲ}ʒa	~	mũ:ʒa	*to milk*		dʒanda	*acorn*
pi^{n}sa	~	pĩ:sa	*pliers*	But	lantʃa	*bog*
rã:^{m}f	~	rã:f	*crayfish*		ro:nda	*to render*
rã:^{ɲ}ʃ	~	rã:ʃ	*rancid*		runt/-da (m/f)	*round*
sũ:^{ɲ}ʒa	~	sũ:ʒa	*suet*		ʃampa	*paw*
vã:^{ɲ}ʃ	~	vã:ʃ	*cheek*		sant/-a (m/f)	*saint*

Without denying the possibility that continuancy of any sort may favor preceding nasal loss, in this paper we offer a phonetic explanation for nasal loss which applies to the environment of following voiceless fricatives. As for *strength* (or sonority), we are unable to evaluate its role since we don't know how to measure it in an objective way.

3. Voiceless fricatives also lead to spontaneous nasalization

An apparently puzzling thing about the above sound change is the occurrence of another sound change which is virtually its opposite (Bloch 1920, 1965; Turner 1921). Grierson (1922) gave the name *spontaneous nasalization* to cases in the Indo-Aryan languages where nasalization on a vowel or occasionally a nasal consonant itself appears in a word where historically there was no original nasal. Although this is far from being a regular sound change, one segment type that recurs in many of Bloch's, Turner's, and Grierson's examples is one having high airflow, e.g., any voiceless fricative, especially [h], aspirated stops and affricates (M. Ohala 1975, 1983). Examples are given in (13).

(13) Examples of spontaneous nasalization in Indo-Aryan (from Grierson 1922).

Sanskrit	**Prakrit**	**Old Hindi**	**Modern Hindi**	**Bengali**	
pakʃɑ	pɑkkʰɑ	pākh	[pə̃ŋkʰɑ]		*a side*
ɑkʃi	ɑkkʰi-		[ɑ̃kʰ]		*eye*
uččaka-	uččɑɑ-		[ũčɑ]	uɲčɑ	*high*
satyɑ-	saččɑ-	sɑ̃č-			*truth*
sɑrpɑ-	sɑppɑ-		[sɑ̃p]		*snake*

The same phenomenon exists in other languages; see J. Ohala (1975); Matisoff (1975); Tuttle (1991). The following passage from Jackson (1967: 174) is typical (here a VN orthographic sequence corresponds phonetically to a simple nasalized vowel; translations and explanation by us added in brackets).

(14) "It is remarkable that in French loanwords with "*cz*", and in others with Fr. *ss*, there is a certain tendency for the vowel to become nasalized, giving MB [Middle Breton] "*ncz*" or *ns(s)*, Mod. B. *ñs* in both cases. E.g., French *maçon* > Early Mod B *mañçzonner* 'mason', Mod B. *mañsoner*; French *rosse* (with plural suffix, *-ed*) > MB *roncet* or *ronceet* 'horses' > Early Mod. B. *rounçet, rounçeet*; French *vis* ['screw'] > MB *vicc* > Early Mod. B. *viçz, binçz* or *biñs* > Mod. B. *biñs*".

As noted by J. Ohala & M. Ohala (1991), there is a plausible, if phonetically complex argument to explain the association between high airflow segments and perceived nasalization:

(a) High airflow segments like voiceless fricatives and aspirated stops require for their production a greater-than-normal glottal opening (vis-a-vis comparable voiceless segments like voiceless unaspirated stops).

(b) This greater-than-normal glottal opening may spread via assimilation to the margins of adjacent vowels, even though these vowels may remain completely voiced.

(c) This slightly open glottis creates acoustic effects due to some coupling between the oral and the sub-glottal cavities that mimic the

effects of coupling of the oral and nasal cavities, i.e., lowered amplitude and increased bandwidth of formant one.

(d) Vowels that sound nasal to listeners, even though they are not physiologically nasal, can be reinterpreted and produced as nasal, thus precipitating a sound change.

Points (a-c) are well documented in the phonetic literature (for point (a) and (b): Klatt, Stevens, & Mead 1968; Sawashima 1969; Löfqvist & McGowan 1991; for point (c): Fujimura & Lindqvist 1971). Ohala & Amador (1981, summarized in J. Ohala 1983b), using vowels from both American English and Mexican Spanish, demonstrated the validity of point (d). They demonstrated that vowel stimuli made by iterating single periods from the portions of vowels immediately adjacent to voiceless fricatives [s, θ, x, f] were judged by listeners to be about as nasalized as comparable periods made from vowel margins near nasal consonants. Such pseudo-nasalization is liable to be misinterpreted by listeners as actual nasalization and reproduced by them as such thus leading to the sound changes mentioned above. Ohala & Amador's study was also substantially replicated by J. Ohala & M. Ohala (1993b) using Hindi material.

Probably related to spontaneous nasalization is the sound change commonly known as "s-aspiration", e.g., in various dialects of Spanish (Widdison 1991 and this volume; Ohala 1993; Romero, this volume). In particular Spanish dialects post-vocalic [s] became a kind of [h]-like offglide to the vowel, e.g., *los equipos* [loʰ ekipoʰ]. The change [s] > [h] is not uncommon in other languages' histories as well, although not always in post-vocalic position. Since this was characteristic of Classical Greek (IE **septm* 'seven' > Cl. Gk hɛpta) but not Latin, English has many doublets (cognates) borrowed from these two ancient sources which show an [s] (Latin) ~ [h] (Greek) alternation: *super- ~ hyper-*, *sex- ~ hex-* ('six'), *semi- ~ hemi-* ('half'). Widdison showed that the slightly open glottis on the margins of vowels near [s] sound like the [h]-like termination characteristic of those Spanish dialects exhibiting s-aspiration. That is, simply by removing the [s] in a word like [pasta] (as spoken by a speaker of Mexican Spanish, a dialect that does not have s-aspiration), he was able to produce a token that sounded like the [paʰta] of a dialect with s-aspiration (and which contrasted with [pata]). (Separate arguments are offered as to why the [s] might have been short and liable to loss in this environment.) Again, the sound change is explained by positing that listeners reinterpreted the special glottal state on vowel margins near [s] (the only voiceless fricative to appear in this context in Spanish) as an intended event.

Spontaneous nasalization and s-aspiration, then, we hypothesize to be related in that both involve listeners' reinterpretation of the special glottal state found on vowel margins adjacent to voiceless fricatives; in one case it is reinterpreted as nasalization and in the other as a kind of [h]-like offglide.

4. The relevance of spontaneous nasalization to nasal effacement

To reconcile spontaneous nasalization with its seeming opposite, nasal effacement, we present briefly an account of sound change as listeners' parsing errors (see also Ohala 1989, 1992, 1993, 1994a).

Consider a speaker attempting to convey to a listener a string of phonetic units, A B C D. In Fig. 1a,b we represent what might happen between the speaker and listener; the units intended by the speaker and interpreted by the listener are represented by capital letters A, B1, etc., and the resulting articulatory and acoustic events generated by the speaker are represented by lower case letters a1, b2, etc. As shown in the figure, a particular unit, **A**, may give rise to phonetic events which are distributed in the time and frequency domains and overlapped with the events associated with other units. For example, cues for the voicing of

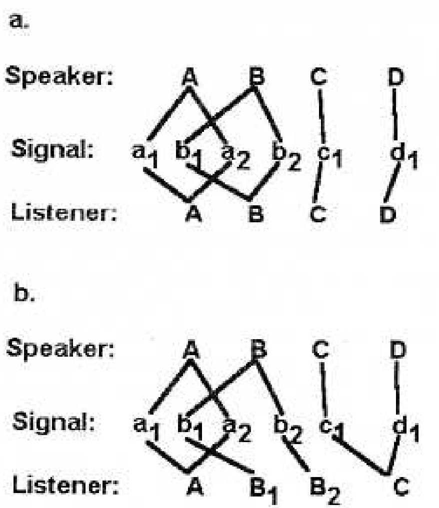

Figure 1. Schematic representation of stages involved in transmitting a pronunciation from speaker to listener; (a) listener correctly parses the phonetic string produced by the speaker; (b) the listener misparses the phonetic string thus precipitating a potential sound change. See text for further details.

a medial stop might include the duration of the preceding vowel and an F_0 perturbation on the following vowel; those vowels themselves present cues for the vowels' identity as well as for the consonants flanking them. The listener must be able to parse together the events associated with the units underlying the speaker's production. In the vast majority of cases the listener parses the signal correctly and infers the speaker's intended string of units; see Fig. 1a. But sometimes the listener may misparse the signal. See Fig. 1b. The signal would be misapprehended if two events associated with one unit, $\mathbf{b_1}$, $\mathbf{b_2}$, were parsed separately as $\mathbf{B_1}$, $\mathbf{B_2}$. For example, as mentioned above, it is thought that this is how certain new tones originated in the daughter dialects of Middle Chinese and certain Southeast Asian languages: the naturally-occurring F_0 perturbation accompanying obstruents of different voicing were taken as independent aspects of the signal and, in the process, exaggerated into distinct lexical tones (Hombert, Ohala & Ewan 1979). Such an error can be called a 'dissociation' parsing error:[8] two events that should have been associated were not. This, we posit, underlies spontaneous nasalization and s-aspiration (as well as tonal development and the vast majority of phonetically-conditioned sound changes).

But there is another way the signal could be misapprehended by the listener: events stemming from two *separate* speech units, say **B** and **C**, could be erroneously parsed *together* by the listener. In Fig. 1a the listener was correct to parse $\mathbf{a_1}$ and $\mathbf{a_2}$ together but in Fig. 2 errs in parsing **b** and **c** together. Errors of this sort, which can be referred to as false association,[9] can easily occur in cases where the events **b** and **c** resemble those that in other instances *should* be parsed together. For example, in many dialects of North American English the [j] which is part of the vowel nucleus of [ju] is lost after apical consonants, e.g., *tune* is [tun], whereas this [j] is retained when non-apical consonants appear before it, e.g., *beauty* [bjuti], *cute* [kjut]. Presumably the [j] was lost because listeners thought it was a predictable feature of the apical consonant which, like the [j], would have a sharply falling F2 before [u]; in contrast, labials and velars would not have F2 transitions in this environment which would be confused with the [j] itself.

False association parsing errors give rise to those sound changes labeled dissimilations. We hypothesize that this same error underlies nasal effacement before voiceless fricatives. We have reviewed evidence above which shows that the margins of vowels near voiceless fricatives may have an acoustic effect which mimics nasalization. Normally listeners should be aware of this and correctly parse the nasal cue with the fricative – thus no sound change occurs. Spontaneous nasalization occurs when listeners fail to make this parsing and take the apparent nasalization as actual (independent) nasalization. But equally, if there is a distinctive nasal segment present in the signal before a voiceless fricative, listeners could make a false association parsing error and *parse the nasal element with the fricative*, i.e., regard it as the illusory nasalization they are used to and thus discount.

To test this we evaluated the hypothesis: if listeners are asked to judge whether they hear a syllable ending either with /-VC/ or /-VNC/, the number of /-VNC/ responses should be less if the C is a voiceless fricative as opposed to control consonants such as a voiceless stop or a voiced fricative.

5. An experiment

5.1. Stimuli

We recorded a male native speaker of American English (JJO) pronouncing the sequences /gen/, /as/, /aθ/, /az/ and /at/. The /n/ in the /gen/ syllable was end-truncated to 70 msec, amplitude ramped over 10 msec at the end, and then incrementally truncated further (from right to left) in seven 10-msec chunks, thus making an 8 point continuum where the nasal ranged from 70 msec at one end to no nasal at the other. The vowel [ɛ] was heavily nasalized, as is normal with American English. Extracted /s/, /θ/, /z/, or burst of the /t/ (plus the preceding silence) was spliced onto all items of the continuum thus making a total of 32 stimuli (8-pt continuum x 4 final consonants).

5.2. Procedure

Fourteen American English speakers and fourteen Italian speakers were recruited as listeners. They were first trained in differentiating /-VNC/ from /-VC/ by presenting them with the identified endpoints of the 4 continua and then requiring them to identify them correctly in a second presentation. Ten subjects from each language passed the training session with perfect scores and were then administered the main test. The test session consisted of all 32 stimuli presented twice in randomized order (interstimulus interval = 4 sec). Subjects heard the stimuli played over an analog tape recorder via earphones. They indicated their response to a given stimulus by circling the appropriate answer (of two possibilities) on an answer sheet, e.g., 'genth geth'. All subjects were instructed that these were nonsense words and the Italian subjects were instructed that some of the "words" would have sounds or sequences not common to Italian.

5.3. Results

We report here the test session results of ten subjects for each language who passed the training session. Fig. 2 presents the results in terms of number of response categories as a function of the conditions. In spite of passing the training session, three subjects in each of the two language groups mis-identified one or more of the end point stimuli in one or more conditions. As it turns out, the main effects are statistically significant whether these are included in the sample or excluded, so we give here results for all 20 subjects. As the figure shows, there were fewer 'nasal' responses (i.e., /-VN-/) for the stimuli ending in /s/ and /θ/ than for those ending in /t/. Somewhat unexpectedly, in the case of the Italian subjects, /z/ behaved not like /t/ but had an effect more or less in between that of /s θ/ and /t/. (But the sound /z/ in this context is not typical of Italian.) A 2-way ANOVA, with variables being listeners' language and the consonantal environment, showed, however, that this difference between the two language groups was not significant, nor was the

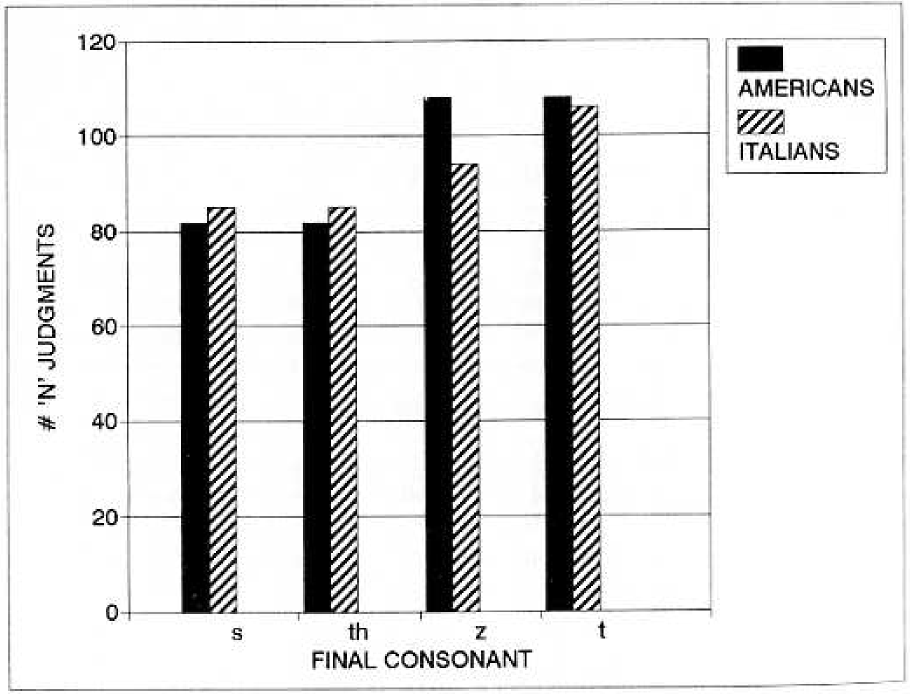

Figure 2. Results of the listening experiment. Y-axis: number of 'nasal consonant detected' judgments in the specified environment, x-axis. Solid bars: American English listeners; cross-hatched bars: Italian listeners.

interaction between language and consonantal environment. There was, however, a significant effect between words ($F(3,54) = 9.011$, $p < .001$). A post-hoc test (Sheffé) showed that there was a significant difference between the mean judgments before [s] and [θ] on the one hand and [t] on the other ($p < .05$); there was no significant difference between those before [z] and the others. Fig. 3 shows the responses for the 4 different conditions as a function of the degree of truncation of the nasal. When the stimuli had a nasal consonant about 30 msec long a majority of the listeners failed to detect the [n] whereas when the same [gɛn-] stimulus was before a [z] or [t] they did detect it.

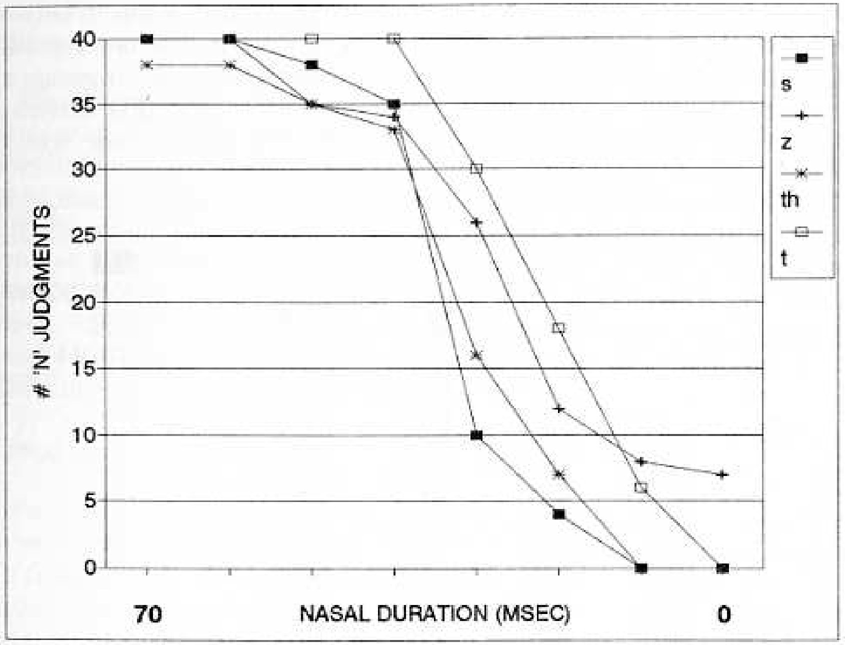

Figure 3. Results of the listening experiment. Y-axis: number of 'nasal consonant detected' judgments as a function of the duration of the nasal, x-axis, for four different environments.

6. *Conclusions*

Our interpretation of these results is that they demonstrate that nasal effacement can be understood by reference to the perceptual domain. Could the results of the listening experiment be explained by an auditory effect that would apply to any auditory stimuli, not just speech,

i.e., a sequence of nasal-like buzz followed by noise? If so, this would be a form of backward masking, i.e., where a given sound impairs the listener's ability to detect properties (or the presence) of an immediately preceding sound. But we are unaware of any backward masking effect with properties that could explain our results. Typically, backward masking requires that the masking sound be very much louder than the masked sound; this was not the case with our stimuli and, in fact, the intensity of the noise component of the two consonants that showed the greatest effect, [s, θ] have very different intensities of noise, i.e., high intensity (above 4 kHz) for [s] and low intensity for [θ]. Moreover, it is typically the case that it is frequencies higher than the masking frequency which are more effectively masked (Warren 1982: 64ff); this was also not true of our stimuli where the vowel amplitude is greatest below 4 kHz. In the absence of any plausible auditory effect to explain our results, we believe our 'phonetic' explanation deserves allegiance.

As discussed above, opinion varies as to whether it is fricatives, per se, or continuants (which include fricatives), or just voiceless fricatives which provide the optimal environment for preceding nasal loss. The fact that, among the Italian subjects, the [z] environment seemed to obscure the preceding nasal less than the [s] and [θ] environment but more than the [t] environment, may conform to Tuttle's implied hierarchy of environments for nasal loss (from more to less likely to promote nasal loss): voiceless fricatives, voiced fricatives, voiceless stops, voiced stops. If so, we have not identified the phonetic properties of [z] which would account for this. There is some evidence that the state of the vocal cords is different for voiced fricatives than voiced stops (Sawashima & Hirose 1983) but not to the extent of creating a slightly open glottis as in the case of voiceless fricatives. If other segment types besides voiceless fricatives do promote nasal loss, they may have other, different, as yet unidentified phonetic properties which effect this. It is also possible that all such segments, including voiceless fricatives, have varying magnitude of some unidentified property which leads to nasal loss. Only further research can reveal this.

Our results are also broadly consistent with (but do not directly support) our hypothesis that nasal loss occurs due to listeners inappropriately implementing a normalizing process: "removing" or discounting phonetic events thought to be predictable consequences of other purposeful sounds. That is, that nasal loss is in a sense the "inverse" of spontaneous nasalization. We are aware that these two phonological processes may not be exact inverses of each other. Our basic claim is that spontaneous nasalization results in nasalization being introduced (next to certain segments) where it had not existed before, whereas in nasal loss, a pre-existing nasal *consonant* is lost in much the same environment. The environment common to both processes is provided by voiceless fricatives. But whereas spontaneous nasalization is also observed near affricates and aspirated stops (i.e., whose production requires high airflow), such segments have not been found to promote nasal loss. Furthermore, the most common form of spontaneous nasalization involves introduction of nasalization on a vowel flanking the conditioning segment (e.g. Breton [bĩs] < Fr *vis)*; in a minority of cases an actual nasal consonant is introduced (e.g., Spanish *bonanza* [bonansa] < *bonaça* < Lat. *bon-* 'good'). In contrast, nasal loss most commonly involves loss of a nasal consonant, often leaving nasalization on the preceding vowel (e.g., Western Ossetic iroŋχ ~ irõχ). In at least some of the cases where just the nasal is lost and no nasalization remains on the preceding vowel, it is possible to reconstruct a stage where the vowel nasalization was present (e.g., English *goose* < **gans-*, where the vowel length suggests the distinctive nasalization). No doubt there is still much to learn about both spontaneous nasalization and nasal loss that would remove these "rough edges" on the conceptual framework we provide linking these two otherwise remarkably inverse sound changes. These issues can only be resolved by uniting the study of sound change with experimental phonetic research, much as Rousselot did more than a century ago.

Addresses of the authors:

John J. Ohala: Dept. of Linguistics, University of California, Berkeley, CA, 94720, USA

M. Grazia Busà: Dip. Lingue e Letterature Straniere Moderne, Università di Bologna, via Cartoleria, 5, 40100 Bologna

Notes

* We thank Terry Nearey and Terry Baxter of the Department of Linguistics, University of Alberta, where the stimuli were prepared and Margaret Tiso and Bonnie Ponthier at the University of California Study Center in Padova where the listening tests were run and Giulio Vidotto at the Department of Psychology, University of Padova, for his help with the statistics. In addition, we are grateful to Arianna Uguzzoni for helpful comments and bibliographic leads and to Carol Fowler for her helpful comments on an earlier draft. Finally, we thank all of our subjects.

1 This paper is an extensively revised version of portions of Ohala, Busà & Harrison (1992), "Phonological and psychological evidence that listeners normalize the speech signal", *Proceedings, International Conference on Spoken Language Processing, Banff, 12-16 Oct 1992*, Edmonton, University of Alberta:1303-1306.

2 See Ohala & Jaeger 1986 (especially the chapters by Lindblom, Wright, Kawasaki, Maddieson, Janson); Huffman & Krakow 1993; Demolin & Dominicy, forthcoming.

3 In some cases the voicing of the consonants remain, e.g., in Yabem (Capell 1949).

4 "In the syllables *ins*, *cons*, and *trans* there is generally pronounced a weak, short and lax *n*, which at times is reduced simply to a trace of nasalization on the preceding vowel, and at times is lost completely".

5 Allen (1978:37-42) disputes that *j* was ever a fricative. He also indicates that the evidence points to the *v* [w] as having a fricative pronunciation only by the 1st century A.D.

6 See also Kent (1932:171) and Allen (1978:28-30) who give further examples; Kent documents the loss of the entire -ns- sequence in specific environments.

7 For further examples and a discussion of how nasal loss might interact with so-called compensatory vowel lengthening, see de Chene and Anderson (1979).

8 In other papers this has been called 'hypo-correction' or 'under-correction' (Ohala 1981, 1989).

9 In other papers this has been called 'hyper-correction' or 'over-correction'; see previous note.

References

Allen W.S. (1978), *Vox Latina. The pronunciation of Classical Latin*, 2nd ed., Cambridge, Cambridge University Press.

Beddor P.S., R.A. Krakow & L.M. Goldstein (1986), "Perceptual constraints and phonological change: A study of nasal vowel height", *Phonology Yearbook* 3:197-217.

Bloch J. (1920), *La formation de la langue marathe*, Paris, E. Champion.

Bloch J. (1965), *Indo-Aryan. From the Vedas to modern times*, Paris, Librairie d'Amerique et d'Orient Adrien-Maisonneuve.

Bloomfield L. (1956), *Eastern Ojibwa; grammatical sketch, texts, and word list*, Ann Arbor, University of Michigan Press.

Capell A. (1949), "Two tonal languages of New Guinea", *Bulletin of the School of Oriental and African Studies* 8:184-192.

Chao Y.-R. (1936), "Types of plosives in Chinese", *Proceedings of the 2nd International Congress of Phonetic Sciences*, Cambridge, Cambridge University Press:106-110.

De Chene B. & S.R. Anderson (1979), "Compensatory lengthening", *Language* 55:505-535.

Delattre P. (1946), "Stages of Old French phonetic changes observed in Modern Spanish", *Publications of the Modern Language Association* 61:7-41.

Demolin D. & M. Dominicy (eds.) (forthcoming), *Sound change and experimental phonetics*, Amsterdam, Benjamins.

Doke C.M. (1928), "An outline of Ila phonetics", *Bantu Studies* 3:127-153.

Durand M. (1955), "Du rôle de l'auditeur dans la formation des sons du language", *Journal de Psychologie Normale et Pathologique* 52:347-355.

von Essen O. (1964), "An acoustic explanation of the sound shift [ɫ] > [u] and [l]

> [i]", in D. Abercrombie et al. (eds.), *In honour of Daniel Jones*, London, Longmans:53-58.

Foley J. (1977), *Foundations of phonology*, Cambridge, Cambridge University Press.

Fujimura O. & J. Lindqvist (1971), "Sweep-tone measurements of vocal-tract characteristics", *J. Acoust. Soc. Am.* 49:541-558.

Grammont M. (1933), *Traité de phonétique*, Paris, Librairie Delagrave.

Grandgent Ch.H. (1896), "Warmpth", *Publications of the Mod. Lang. Assoc.* 11 (New Series 4):63-75.

Grandgent Ch.H. (1927), *From Latin to Italian. An historical outline of the phonology and morphology of the Italian language*, Cambridge, Harvard University Press.

Greenlee M. & J.J. Ohala (1980), "Phonetically motivated parallels between child phonology and historical sound change", *Language Sciences* 2:283-308.

Grierson G. (1922), "Spontaneous Nasalization in the Indo-Aryan languages", *Journal of the Royal Asiatic Society of Great Britain*, July:381-388.

Haden E.F. (1938), *The physiology of French consonant changes: a study in experimental phonetics*, [*Language Dissertations*, No. 26] Baltimore, Linguistic Society of America.

Henderson E.J.A. (1949), "A phonetic study of western Ossetic (Digoron)", *Bulletin of the School of Oriental and African Studies* 13:36-79.

Hombert J.-M., J.J. Ohala & W.G. Ewan (1979), "Phonetic explanations for the development of tones", *Language* 55:37-58.

Huffman M.K. & R.A. Krakow (eds.), *Nasals, nasalization, and the velum*, [Phonetics and Phonology Series, Vol. 5] San Diego, CA, Academic Press.

Jackson K.H. (1967), *A historical phonology of Breton*, The Dublin Institute for Advanced Studies.

Kawasaki H. (1986), "Phonetic explanation for phonological universals: The case of distinctive vowel nasalization", in J.J. Ohala & J.J. Jeri (eds.), *Experimental Phonology*, Orlando, FL, Academic Press:81-103.

Kent R. (1932), *The sounds of Latin. A descriptive and historical approach*, [Language Monographs No. 12], Baltimore, Waverly Press.

Key T.H. (1855), "On vowel-assimilations, especially in relation to Professor Willis's experiment on vowel-sounds", *Transactions of the Philological Society* 5:192-204.

Klatt D.H., K.N. Stevens & J. Mead (1968), "Studies of articulatory activity and airflow during speech", in A. Bouhuys (ed.), *Sound production in man. Annals of the New York Academy of Sciences* 155:42-54.

Klingenheben A. (1928), "Stimmtonverlust bei Geminaten", *Festschrift Meinhof*, Hamburg, Kommissionsverlag von L. Friederichsen & Co.:134-145.

Lenz R. (1940), *El español en Chile*, [Facultad de filosofía y letras de la Universidad de Buenos Aires. Instituto de filología], *Biblioteca de dialectología hispanoamericana*. vol. 6.

Löfqvist A., T. Baer, N.S. McGarr & R.S. Story (1989), "The cricothyroid muscle in voicing control", *Journal of the Acoustical Society of America* 85:1314-1321.

Löfqvist A. & R.S. McGowan (1991), "Voice source variations in running speech", in J. Gauffin & B. Hammarberg (eds.), *Vocal fold physiology. Acoustic, perceptual, and physiological aspects of voice mechanisms*, San Diego, CA, Singular Publishing Group:113-120.

Malécot A. (1960), "Vowel nasality as a distinctive feature in American English", *Language* 36:222-229.

Matisoff J.A. (1975), "Rhinoglottophilia: the mysterious connection between nasality and glottality", in Ch.A. Ferguson, L.M. Hyman & J.J. Ohala (eds.), *Nasálfest: Papers from a symposium on nasals and nasalization*, Stanford, Language Universals Project:265-287.

Navarro Tomás, T. (1932), *Manual de pronunciación española*, 4th ed., Madrid, Hernando.

Nicolet N. (1929), *Der Dialekt des Antronatales ...*, [Beiheft. Z. f. Romanische Philologie, 79], Halle, Niemeyer.

Ngunga A.S.A. (1993), *Observations on vowel length in Ciyao*, Ms. Berkeley.

Ohala J.J. (1974), "Experimental historical phonology", in J.M. Anderson & C. Jones (eds.), *Historical linguistics II. Theory and description in phonology*, Amsterdam, North Holland:353-389.

Ohala J.J. (1975), "Phonetic explanations for nasal sound patterns", Ch.A. Ferguson, L.M. Hyman & J.J. Ohala (eds.), *Nasálfest: Papers from a symposium on nasals and nasalization*, Stanford, Language Universals Project:289-316.

Ohala J.J. (1981), "The listener as a source of sound change", in C.S. Masek, R.A. Hendrick, M.F. Miller (eds.), *Papers from the Parasession on Language & Behavior*, Chicago, Chi. Ling. Soc.:178-203.

Ohala J.J. (1983a), "The origin of sound patterns in vocal tract constraints", in P.F. MacNeilage (ed.), *The production of speech*, New York, Springer-Verlag:189-216.

Ohala J.J. (1983b), "The phonological end justifies any means", in S. Hattori & K. Inoue (eds.), *Proc. of the XIIIth Int. Cong. of Linguists, Tokyo, 29 Aug.-4 Sept. 1982*, Tokyo:232-243.

Ohala J.J. (1989), "Sound change is drawn from a pool of synchronic variation", in L.E. Breivik & E.H. Jahr (eds.), *Language Change: Contributions to the study of its causes*, Berlin, Mouton de Gruyter:173-198.

Ohala J.J. (1992), "What's cognitive, what's not, in sound change", in G. Kellermann & M.D. Morrissey (eds.), *Diachrony within synchrony: Language history and cognition*, Frankfurt/M, Peter Lang Verlag:309-355.

Ohala J.J. (1993), "Sound change as nature's speech perception experiment", *Speech Communication* 13:155-161.

Ohala J.J. (1994a), "Speech aerodynamics", in R.E. Asher & J.M.Y. Simpson (eds), *The Encyclopedia of Language and Linguistics*, Oxford, Pergamon:4144-4148

Ohala J.J. (1994b), "Hierarchies of environments for sound variation; plus implications for 'neutral' vowels in vowel harmony", *Acta Linguistica Hafniensia* 13:371-382.

Ohala J.J. & M. Amador (1981), "Spontaneous nasalization", *J. Acoust. Soc. Am.* 68:S54-S55.

Ohala J.J. & J.J. Jaeger (eds.) (1986), *Experimental phonology*, Orlando, FL, Academic Press.

Ohala J.J. & M. Ohala (1993a), "The phonetics of nasal phonology: theorems and data", in M.K. Huffman & R.A. Krakow (eds.), *Nasals, nasalization, and the* *velum*, [Phonetics and Phonology Series, Vol. 5], San Diego, CA, Academic Press:225-249.

OHALA J.J. & M. OHALA (1993b), "Nasals and nasalization in Hindi", *Proceedings of the 3rd International Symposium on Language and Linguistics: Pan-Asiatic Linguistics*, Chulalongkorn University, Bangkok, Thailand, 8-10 Jan 92, vol. 3.

OHALA M. (1975), "Nasals and nasalization in Hindi", in CH.A. FERGUSON, L.M. HYMAN, & J.J. OHALA (eds.), *Nasálfest. Papers from a symposium on nasals and nasalization*, Stanford Language Universals Project:317-332.

OHALA M. (1983), *Aspects of Hindi phonology*, Delhi, Motilal Banarsidass.

OHALA M. & J.J. OHALA (1991), "Nasal epenthesis in Hindi", *Phonetica* 48:207-220.

PASSY P. (1890), *Étude sur les changements phonétiques*, (Paris, Librairie Firmin-Didot).

PROKOSCH E. (1939), *A comparative Germanic grammar*, Baltimore, Linguistic Society of America.

ROUSSELOT P.-J. (1891), *Les modifications phonétiques du langages, etudiées dans le patois d'une famille de Cellefrouin (Charente)*, Paris, H. Welter.

SAWASHIMA M. (1969), "Devoiced syllables in Japanese", *Annual Bulletin, Research Institute of Logopedics and Phoniatrics* [University of Tokyo] 3:35-41.

SAWASHIMA M. & H. HIROSE (1983), "Laryngeal gestures in speech production", in P.F. MACNEILAGE (ed.), *The production of speech*, New York, Springer--Verlag:11-38.

THURNEYSEN R. (1946), *A grammar of Old Irish*, [rev. & enlarged ed.; translated from the German by D.A. Binchy & O. Bergin], Dublin, Dublin Institute for Advanced Studies.

TUCKER A.N. & E.O. ASHTON (1942), "Swahili phonetics". *African Studies* 1:77-103; 161-182.

TURNER R.L. (1921), "Gujarati phonology", *Journal of the Royal Asiatic Society*, pts. 3-4.

TUTTLE E.F. (1991), "Nasalization in Northern Italy: syllabic constraints and strength scales as developmental parameters", *Rivista di Linguistica* 3:23-92.

VOEGELIN CH.F. (1946), "Delaware, an Eastern Algonquian language", in H. HOIJER (ed.), *Linguistic structures of Native America*, [Viking Fund Publications in Anthropology No. 6], New York, Viking Fund:130-157.

WARREN R.M. (1982), *Auditory perception. A new synthesis*, New York, Pergamon.

WEYMOUTH R.F. (1856), "On the liquids, especially in relation to certain mutes", *Transactions of the Philological Society*, [London]:18-32.

WIDDISON K.A. (1991), *The phonetic basis for s-aspiration in Spanish*, Unpub. Doc. diss., University of California, Berkeley.

WYLD H.C. (1927), *A short history of English*, 3rd ed., London, John Murray.

ZIPF G.K. (1935), *The psycho-biology of language*, Boston, Houghton Mifflin Co.