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What's Cognitive, What's Not in Sound Change

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What's cognitive, what's not, in sound change

John J. Ohala

1. Introduction

I have three general goals in this paper. First, I will pursue a familiar theme in the literature on sound change: the present as a key to the past (Delattre 1946; Haden 1938; Labov 1974). A better way of stating this, actually, would be 'the universal as a key to the past or present' since I believe that in order to understand both diachronic and synchronic variation in speech we must have recourse to constant and timeless principles which are not entirely unique to speech. Second, I will also attempt to give an update on efforts to study sound change in the laboratory, a tradition that has a notable history but which has been somewhat neglected in recent decades (e.g., Rousselot 1891, Roudet 1910; Verner 1913; Stetson 1928; Grammont 1933; Haden 1938). Third, given the theme of the conference for which this paper was prepared, I propose to assess the cognitive element in sound change.

More specific goals include confronting the issue of teleology in sound change, addressing the question of whether sound change is abrupt or gradual, explaining differences between changes with opposite vectors or directionality, i.e., those broadly classified as assimilatory and dissimilatory, delineating the contributions of the speaker and hearer in sound change, and proposing an experimental paradigm for the phonetic study of sound change.

The plan of exposition, in brief, is first to discuss how sound change is prevented in the face of abundant variation in speech. This is "correction". I then characterize sound change as the result of two different types of breakdown of correction, namely "hypo-correction" and "hyper-correction".

2. The limits of this exposition

Most of what I present here will not be totally new. Virtually everything has been said before by other writers on sound change (but I will not present a review of this literature nor make extensive reference to it).

Perhaps the novel aspect will be in the particular combination of claims and the marshalling of supporting evidence, especially lab-based evidence, for them.

An important limitation is that I will focus only on sound changes that occur in similar form in languages distant from each other in time, geography, family membership, and typology. This tends to insure that they will be sound changes determined by language universal factors (phonetic or cognitive) and not by language- or culture-specific factors. This eliminates pronunciation changes due to the influence of spelling, paradigm regularization, linguistic taboos and other similar socio-cultural factors.

A further limitation is that I will be concerned only with the initiation of sound changes, not their transmission. I am interested in the initial 'mutation' that leads to change in pronunciation, not how this change propagates from one speaker to another, from one word to another, from one style of speaking to another, say, informal to formal. Such propagation presumably involves psychological and sociological factors that can differ in unpredictable ways from one speaker, one language, and one culture to another. Furthermore, such propagation is presumably the way all the elements of language propagate even when 'change' is not involved. This limitation of scope is similar to that in evolutionary biology: what needs to be explained is how changes in the genome originated in the first place. The way that change gets transmitted to the next generation is by ordinary means of reproduction.

3. Sound change parallels synchronic variation

Virtually all writers accept that sound change is happening at all times including the present. Where they disagree is whether or not sound change can be detected as it happens. I claim that although sound change may not be easily detected 'on the hoof',it and its phonetic pre-conditions can be observed in the lab. The basis for this claim is very simple: a detailed examination of speech phenomena, both in production and perception, reveals extensive variation ("change") that parallels sound change. The points of similarity are so close, I maintain, that one must conclude that somehow one is dealing with the same thing. There are differences between synchronic variation and sound change but these can be accounted for without denying the essential link between the two.

Many examples exist of the parallels between diachronic and synchronic variation: tonal development, affrication of stops before high vowels and glides, stop epenthesis, spontaneous nasalization (Hombert, Ohala, and Ewan 1979; Ohala 1974, 1981a, 1983, 1989a). I will discuss here just a few instructive examples.

3.1. Variation in speech production

3.1.1. Consonants 'color' adjacent vowels

Michailovsky (1975) documents the sound changes from Written Tibetan (c. 8th century) to modern Lhasa Tibetan as shown in (1) (transcription simplified). In general, initial clusters were simplified and final consonants were dropped. When the final consonants were anything other than apical, the preceding vowel quality was retained; where the final consonant was an apical and the vowel had been a back rounded vowel, the vowel changed to front rounded.

(1)	Written Tibetan	Lhasa Tibetan	Translation
	gop	qhõ:	"price"
	nub	nu:	"west"
	But:		
	lus	ly:	"body"
	bod	phø:	"Tibet"
	ston	tø̃-	"autumn"

Similar sound changes are evident in Lisu, another Tibeto-Burman language (Thurgood and Javkin 1975), and allophonically in Tigre (Palmer 1962) and Burera (Glasgow & Glasgow 1967). So, in many languages we find that apical consonants condition the fronting of back vowels.

Parallel to this are the findings of several acoustic studies on the influence of surrounding consonants on vowel quality. Lindblom 1963 is one of the earliest such studies and perhaps still the most extensive. He recorded a Swedish speaker uttering CVC Swedish syllables (some of them nonsense) where C1 = C2 was any of the three voiced stops /b,d,g/

and the vowel (V) was any of the 8 short Swedish vowels /ɪ ɛ ʏ ɵ a ɔ o ʊ/. These were embedded in sentence frames so that each syllable was uttered with varying durations ranging from 80 to 300 msec. When the syllable was shorter, the formant frequencies of the vowel (measured in the middle of vowel) shifted towards those characteristic of the boundary between the consonant and the vowel. (It wouldn't be quite appropriate to speak of *the* formant frequencies of the consonant since these vary significantly as a function of the adjacent vowel, very much so for velars, less so for apicals.) Lindblom posited equations which accounted well for the data. Fig. 1 shows the results of applying his equations to six of the vowels he studied,/ɪ ɛ ɵ a ɔ ʊ/. The plots, which have logarithmic scales, show Formant 1 (F1) vs Formant 2 (F2) on the x and y axes, respectively. (Note that the origin has not been rotated to the upper right corner as is sometimes done to make the plots more closely resemble the traditional vowel space.) Data points closest to the periphery of the vowel space give the 320 msec-long value for the vowel -- approximately its value if uttered in isolation. Lines connect the values for the vowels at decrements of 60 msec down to an extreme of 80 msec total duration (which, strictly speaking, is an extrapolation since most vowels were never less than 100 msec long). Keeping in mind the rules of thumb that vowel height correlates inversely with F1 and vowel frontness with F2, the figure shows that the apical environment, d_d, had the greatest fronting influence on back vowels.

The conspicuous effect that apicals have on back vowels has been documented for other languages as well: English (Stevens, House, and Paul 1966), French (Chollet 1976),Japanese (Kuwahara & Sakai 1972). Kuwahara and Sakai showed that when spliced out of the consonant context, a fronted "back" vowel will be identified by listeners as a front vowel. I have demonstrated this effect myself: vowels made by iterating single periods from the transitions between, say /o/ and /d/, will sound like the front rounded vowel [ ]. However, even though acoustically and perceptually these back vowels are fronted, it is important to note that this does not mean that they are necessarily *articulated* as front vowels. This may seem paradoxical but it nevertheless derives from the following two points: First, the mapping between vocal tract shapes and the output sounds is of the type known as 'many-to-one' (Maeda 1990), so that a vowel that is acoustically and perceptually front rounded may be produced by more than one vocal tract shape, one of which, to be sure, is articulated as a front round vowel but others of which may not be. Second, a cine-x-ray study of MacNeilage and DeClerk (1969) and a distance-sensing palatographic study by Chuang and Wang (1975)

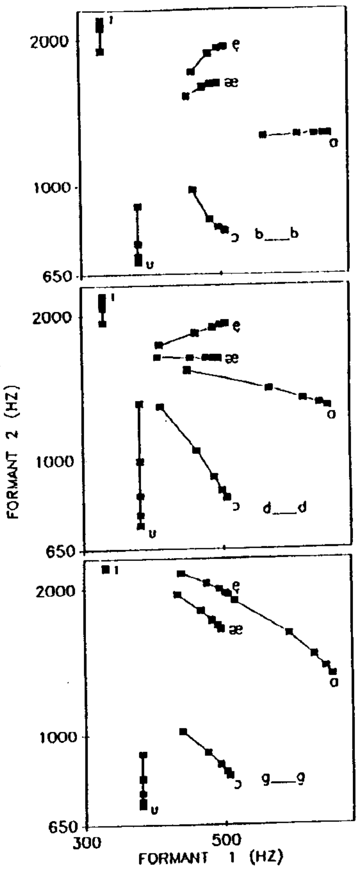

Fig. 1: Trajectories showing perturbation of the quality of 6 short Swedish vowels as a function of (a) the consonantal environment, from top: b_b, d_d, g_g, and (b) duration: 320 msec (points next to vowel symbols) and with 60 msec decrements, down to 80 msec. Formant scales are logarithmic. Based on Lindblom's (1963) equations summarizing acoustic measurements from speech of a Swedish speaker.

suggest that what happens to a vowel like /u/ in an apical environment is not that the tongue body constriction moves forward but that the apical constriction is more or less superimposed on the vowel -- presumably more so as the vowel gets shorter and coarticulation with the adjacent consonant(s) increases. In other words, it is this partial apical constriction superimposed on an otherwise perfectly good /u/ which causes F2 to rise and thus to create a vowel which mimics a front rounded vowel both acoustically and perceptually. (See also Ohala 1974b, 1981b.)

Although there are some complexities in this case, the overall parallelism between the diachronic and synchronic data is clear. Of the various places of articulation, it is those that permit simultaneous (coarticulated) apical constrictions which lead to fronting of back vowels.

I have focused here only on the interaction between apical consonants and back vowels but there are well documented and generally well understood interactions, synchronically and diachronically, between various vowels and labials (especially labial velars), pharyngeals, laterals, and nasals, among others (Lehiste 1964; Broad and Fertig 1970).

3.1.2. Stop gaps

If languages utilize a voicing contrast on stops, they typically show voiced vs voiceless stops at all places of articulation. There are exceptions, however.

Sherman (1975) surveyed 87 languages exhibiting gaps in their voiced vs. voiceless stop inventory and reported the gap frequencies by place and voicing as shown in Table 1. Insofar as ejectives are inherently voiceless and most implosives voiced, the same pattern obtains for glottalized obstruents as well, i.e., back-articulated stops disfavored for voicing and front-articulated stops for voicelessness (Chao 1936, Greenberg 1970, Gamkrelidze 1975; Javkin 1977; Ohala 1983a, Pinkerton 1986, Maddieson 1984: 35ff., 105ff).

Table 1. Incidence of stop gaps according to place of articulation and voicing in 87 languages. (Sum exceeds 87 since some languages had more than one gap.) Data from Sherman 1975.

	Labial	Apical	Velar
Voiceless	34	0	0
Voiced	2	21	40

Some representative stop inventories are given in (2).

(2) Thai / Efik

Thai			Efik			
p	t	k	t	k	kʷ	k͡p
pʰ	tʰ	kʰ	b	d		
b	d					

In some cases the history of the language is known and it can be ascertained that the gaps were once filled. Dutch is one such example; there the /g/ became devoiced and unstopped and is now usually a [ ]. One can also speculate that some of the 'gaps' in the voiced series developed because they were never filled, while voiced stops at other places of articulation emerged as the phonologized allophone of originalvoiceless stops or nasals.

Although apparently somewhat rare, there is at least one case where a morphophonemic pattern shows the same asymmetrical disfavoring of voicing and place of articulation. In one dialect of Nubian the alternations shown in (3) demonstrate that when geminated, a voiced labial stop remains voiced but any stop articulated further back is devoiced (Bell 1971, Ohala 1983a).

(3) Morphophonemic variation in Nubian.

Noun Stem	Stem + "and"	Translation
/fab/	/fab:ɔn/	"father"
/sɛgɛd/	/sɛgɛt:ɔn/	"scorpion"
/kadʒ/	/katʃ:ɔn/	"donkey"
/mɔg/	/mɔk:ɔn/	"dog"

Gamkrelidze showed that even languages that possess fully symmetrical stop inventories, i.e., voiced and voiceless stops at all places of articulation, the disfavored segment types occur less frequently in running speech. This is true for English as is evident from Wang and Crawford's (1960) survey of several studies of the text frequencies of English consonants. All showed g < b and p < k (where '<' means 'less frequent').

One reason why voiceless labials are subject to loss is that they are harder to detect than other stops. They have no resonating cavity downstream to amplify their burst -- and the burst is one of the most important perceptual cues for stops, especially voiceless stops (Zue 1976: 63-64; 67-68; Edwards 1981; Lisker 1986). Any stop articulated further back, even dentals, have some resonating cavity which serves to enhance the burst intensity as well as to give distinctive spectral shaping to the noise burst so that it differs from ambient noise (Fant 1960: 192ff). Additionally, the shape of the channel through which the high air flow passes during the burst of a labial may not be optimal for the sake of creating highly turbulent, noisy, air flow (Stevens 1971; Shadle 1990). (But this latter characteristicmay be shared by other stops, too, e.g., velars).

The reason why voiced velars are disfavored is quite different. It is not that they are hard to detect but that for aerodynamic reasons they are hard to produce, i.e., to maintain the co-occurrence of (a) velar place, (b) the stop quality, and (c) voicing. Such sounds often change one or more of these three features. The basic physical principles involved are well known and have been alluded to by Passy (1890: 161-162) and Chao (1936) among others. Voicing (vibration of the vocal cords) requires air flow through the vocal cords. During the stop closure the exit of air from the supraglottal cavity is blocked so that the air accumulates, thus causing oral pressure to rise. When the difference in pressures between the oral and subglottal cavities gets too small or actually becomes zero, air flow will fall below the level needed to maintain vocal cord vibration. In fact, if there is no change in the volume of the oral cavity, this pressure equalization and consequent extinguishing of voicing would take place within 10 or 15 msec (Ohala 1976, 1983). As it happens there usually is expansion of the oral cavity either passively or actively. Active expansion would involve, for example, lowering the larynx or lowering the jaw. Passive expansion occurs simply when greater pressure impinges on the soft tissue of the oral cavity -- it "gives" in much the same way as the walls of a balloon does when it is blown up (although obviously over a much smaller range). This can be seen especially on some labial stops where a brief (and slight) puffing up of the cheeks may be observed. The amount of compliant tissue on which the stop-created pressure can impinge differs depending on the place of articulation of the stop: more compliant tissue is exposed in labial stops than in apicals and more in apicals than in velars. (There doesn't have to be very much oral cavity expansion in order to maintain voicing: as a rough approximation, for each 1 cubic centimeter expansion voicing could be prolonged an additional 10 msec.)

Ohala and Riordan (1979) conducted an experiment in which a speaker produced prolonged voiced stops while the air built up behind the constriction was artificially vented through a nasal-pharyngeal catheter. At unpredictable moments this vent was suddenly blocked. Of interest was how long after thisblockage the voicing could be maintained where, it was hypothesized, only passive expansion of the oral cavity walls could occur. They found that the median duration of voicing for labials, alveolars, and velars was 82, 63, 52 msec., respectively. Such magnitudes of stop closure durations correlate roughly with those reported in the phonetic literature (Lehiste 1970: 28). To be sure, voiced stops, especially geminate stops can have much greater duration than this but in such cases active expansion of the oral cavity presumably also takes place.[1]

What emerges from this data is parallelism between the diachronic and synchronic data as regards the favoring or disfavoring of stops at different places of articulation depending on their voicing.

3.2. *Variation in speech perception*

It was mentioned above that some of the mappings between vocal tract shapes and the sounds that result are many-to-one mappings. That is, although there is a physically determined mapping from any given vocal tract configuration to the sound produced, the mapping in the reverse direction is not determinate -- often more than one tract shape could have produced a given sound. This has far-reaching consequences for speech perception both synchronically and diachronically. Simply put: the speech signal is in many instances ambiguous as to the vocal tract configuration that generated it. Listeners, therefore, may select a different articulatory configuration from that used by the speaker(s) from whom they learned a given spoken form.

Even though the ambiguity of the acoustic speech signal is well-founded theoretically (Maeda 1990), more needs to be said regarding the relevance of this for normal speech perception and sound change. It might legitimately be objected that this ambiguity was established primarily for static and redundancy-free conditions and that real speech is instead dynamic and highly redundant. This is true but there are additional reasons why the speech signal can be ambiguous on occasion. Under noisy conditions or when the listener is inattentive or inexperienced in interpreting the signal, even acoustically similar (not necessarily identical) signals can be confused. There is ample evidence from the phoneticliterature and even from everyday experience that speech sounds are confused.[2]

Bredsdorff (1821 [1982]), Sweet (1874: 8), Durand (1955), Andersen (1973, 1989) among others, recognized the ambiguity of the speech signal as one cause of sound change. Sweet's example was the confusion of English [θ] and [f], as in [fɹu] for [θɹu] "through". (Incidentally, the [θ]/[f] confusion is evident in the study of Miller and Nicely (1955), even under minimal band-pass filtering and the best signal-to-noise ratio.) The non-unique mapping between sound and tract shape is reflected in the Jakobsonian distinctive features (Jakobson, Fant, and Halle 1952). For example, positing one acoustic feature [+flat] for articulations as diverse as labialization, retroflexion, velarization and pharyngealization implies that all these different tract shapes can give rise to the same acoustic effect, namely a lowering of the higher resonances. The phonetic literature provides many other examples (Jonasson 1971; Beddor & Krakow & Goldstein 1986; Ohala 1974b, 1983b, 1985a; Ohala and Lorentz 1977, in press); a few will be presented here in some detail.

(It should be mentioned that an ambiguous acoustic signal will not always be misjudged. Rather, listeners may do so with a certain probability, always less than 1.0. Faced with an unclear signal, they guess the speaker's intention; sometimes they guess right and there is no deviation from what was spoken but sometimes they get it wrong and only then is there an error in perception.)

3.2.1. Labialized velars > labials

As is well known Indo-European labialized velars become labials in Classical Greek in certain environments; see Table 2a. Similar changes

Table 2: Instances of labialized velars changing to labials

a.	Indo-European >	Classical Greek	
	*ekwōs	hippos	"horse"
	*g^{w}iwos	bios	"life"
	*yek^{w}r̥	hepatos	"liver"
b.	Proto-Bantu >	West Teke	
	*-kumu	pfuma	"chief"
	Proto-Yuman >	Yuma	
	*$imalik^{w}i$	$mal^{y}pu$	"navel"
	Proto-Muskogean >	Choctaw	
	*k^{w}ihi	bihi	"mulberry"
	*uNk^{w}i	umbi	"pawpaw
	Songkhla (free variants)		
	\khwai	\fai	"fire"
	/khon	/fon	"rain"
	Proto-Zapotec >	Isthmus Zapotec	
	*kk^{w}a-	pa	"where"

took place in other languages, whether the velars are labialized inherently or via coarticulation from an adjacent rounded glide or vowel; see Table 2b (for sources of data, see Ohala & Lorentz 1977).

3.2.2. Palatalized labials > apicals

Changes of palatalized labials to apicals in Bohemian Czech are documented in the writings of Belic (1966) and Andersen (1973); see Table 3a. The same type of change is found in many other languages, too; see Table 3b (for sources of these data see Ohala 1978).

Such changes exhibit abrupt shifts in articulation but resist interpretation in purely articulatory terms.[3]

3.2.3. Velar softening

The familiar change of velar stops to apical or palatoalveolar stops or affricates near front glides or vowels, e.g, English *chin* [tʃɪ̀n] < OE *cinn* ult. < IE *genu*, if examined in detail, shows similar problems for a strictly articulatory interpretation (Ohala 1986b). This change seems superficially to be explicable as a case of articulatory assimilation, but is also better accounted for as an articulatorily abrupt change mediated by the acoustic similarity of the two sounds. There are two reasons for this claim. First, many of these palatalizations result in a place of articulation that is actually further forward than the narrowest constriction for [j] or [i] and certainly for that of any mid or lower front vowel. Segments exhibiting place of articulation assimilations often undershoot what they assimilate but they do not overshoot, e.g., before the vowel /ɔ/ which has its narrowest constriction in the pharynx, a /k/ is at most uvular, not pharyngeal. Second, the "active" articulator is different 'before' and 'after' these changes: the tongue body in a "fronted" velar but the tongue apex or blade in the resulting apical stops or affricates. These articulators are too different for the change to be due to articulatory assimilation. On the other hand, a very plausible case can be made for the confusion of all these articulatorily quite distinct sounds due to their acoustic-perceptual similarity.

Table 3: Instances of palatalized labials changing to apicals

a.	Standard Czech	East Bohemian	
	[mʲɛstɔ]	[nɛstɔ]	"town"
	[pʲɛt]	[tɛt]	"five"
b.	Lungchow	T'ien-chow	
	pjaa	čaa	"fish"
	pjau	čau	"empty"
	Roman Italian	Genoese Italian	
	[pjeno]	[tʃena]	"full"
	[pjanta]	[tʃanta]	"to plant"
	[bjaŋko]	[dʒaŋku]	"white"
	Proto-Bantu >	Xhosa, Zulu	
	*pia	-tʃha	"new"
	Pre-Classical Greek >	Classical Greek	
	*gʷam-yo	baino	"I come"
	*thaph-yo	thapto	"bury"

Gwari Dialects

Kuta	Ganagana	Nupe	
bye	dywe	dzo	"sow"
opya	epʃa	etswa	"moon"

3.3. Phonetic parallels

There is considerable overlap in the F2 onsets of [g] and [b] for the back rounded vowels [u o], that is, where both would be phonetically labialized. All three stops' F2 onsets also overlap before the high front unrounded vowels [i I e], that is, where they would be phonetically palatalized (Fant 1973). This doesn't mean, of course, that the CV sequences [gu] and [bu] or [bi] [di] [gi] cannot be differentiated; of course, they can. Other cues serve to differentiate them: F3 transitions and especially the stop bursts. (However, see Ohala 1985b on the similarity of velar and apical stop bursts before [i].) But if the listener misses these other cues for whatever reasons then these groups of sounds are likely to be confused. This would be true of any pair of sounds or sound sequences subject to confusion.

Data from one of the few published confusion studies which varied both the consonant ([p t k]) and the vowel ([i a u]) in CV stimuli, Winitz, Scheib, and Reeds (1972), show that in one condition in which listeners heard the stop burst and 100 msec of the signal following it, the three most probable confusions were as follows (where '>' means 'was misidentified as' and the number in parentheses are the probabilities of such misidentification): ki > ti (.47), pi > ti (.38), ku > pu (.24). Additional evidence of the confusion of palatalized labials with apicals comes from a study of VC transitions by Lyublinskaya (1966). Another "earmark" of most of these confusions is that they are asymmetrical, that is confusions in the reverse direction show a much lower probability: ti > ki (.09) and ti > pi (.03). (For speculations on the cause of such asymmetries see Ohala 1983b, 1985b, in press a.)

It cannot be a coincidence that such variation showing specific asymmetries and conditioning factors should be manifested in sound change and in synchronic acoustic and perceptual phonetic data.

4. Implications of the diachronic / synchronic parallels

I have presented a few examples of parallels between diachronic variation (sound changes) and synchronic variation, the latter in both listeners' and speakers' behaviors. Does the similarity between these kinds of variation mean that they are in fact the same thing? Does listener variation constitute sound change? Does speaker variation? Let's take these questions one at a time.

4.1. Listener variation = "Mini" sound change

I would answer that with suitable qualifications, listener variation does constitute potential sound change. The essential element here is that a listener forms a different pronunciation norm (= lexical underlying form) from that of a speaker. All that keeps such listener confusions from taking their place in *A historical phonology of X* is the spread of these new norms to other speakers (via normal first- or second-language learning) and, perhaps, its spread to other similar lexical items. Such spread, of course, is mediated primarily by psychological and social factors and lies outside the domain I consider here. Working against such spread is the inhibition of innovations which comes from the fact that language norms, including pronunciation norms, are redundantly represented in and maintained by all the speakers of a language. A listener usually has more than one opportunity to learn the pronunciation of words and thus to correct the results of misperception.

Although most listener misperceptions are eventually corrected and thus do not lead to sound changes that affect large numbers of speakers, we should not underestimate the incidence of such potential or 'mini' sound changes (as I have called them -- Ohala 1974a). The phenomenon of "phoneme restoration" discovered by Warren (1970) indicates that some fraction of what we perceive in speech actually comes from the expectations we generate of what should be in the signal, based on phonological, lexical, syntactic, semantic, and pragmatic redundancies. Phonetic events that we would be likely to misperceive or to perceive differently if presented in a redundancy-free context we normalize when heard in a redundant context (Ohala and Feder 1987). Sound changes, then, can originate from that very small fraction of listener misperceptions that are not corrected or normalized and which then spread to other speakers and, possibly, other words.

4.2. Speaker variation ≠ Sound change

In answer to the question of whether variation in speech production constitutes sound change the answer must be 'no'. The reason is that the kind of phonetically-predictable variation described above does not constitute the creation of a new pronunciation norm.[4] From the point of the view of the speaker, no "change" has occurred. There is evidence that listeners can compensate for such variation and it is reasonable to assume that speakers know this (being listeners themselves) and so allow variation in their speech only to the extent that it can be "undone" by listeners (see also Lindblom 1990).

Evidence that listeners compensate for predictable contextual variation in speech comes from a variety of studies. Mann and Repp (1980) showed that listeners shift the boundary between [s] and [ʃ] as a function of the rounding of the following vowel. A fricative with a lower center frequency is accepted as [s] before the rounded vowel [u] presumably because listeners know that due to coarticulation the fricative would be rounded before rounded vowels (lip rounding acts as a low-pass filter to lower the center frequency). Beddor, Krakow & Goldstein (1986) showed that adding nasalization to vowel stimuli that would be identified primarily as [ɛ] when oral, caused an increase in the number of [æ] identifications. However, when such vowels appeared before a nasal consonant they were again primarily identified as [ɛ]'s, i.e., as they would be if oral. Presumably this happened because in the latter condition listeners were able to factor out the effect of nasalization when it could so obviously be predicted by the presence of a nasal consonant. Ohala, Riordan, and Kawasaki (1978), reported in Ohala (1981b), demonstrated that when presented with a continuum of vowels between [i] and [u], listeners accept a more front vowel as [u] when it is surrounded by alveolar consonants than when flanked by labial consonants; presumably listeners know that alveolars tend to induce fronting of back vowels (as discussed above in connection with the Lindblom 1963 study), and so factor out the distorting effect of the consonant. Other research testifying to listeners' ability to compensate for predictable modifications of speech sounds come from research by Pickett and Decker (1963), Ladefoged and Broadbent (1957), Ohala and Feder (1987). For that matter, the ability of the listener to compensate for distortionscaused by the channel over which they hear the speech (e.g., telephone, room acoustics, persistent background noise), is a manifestation of the same adaptive capacity.

If the variation in speech production is not sound change, then how does it happen that it parallels diachronic variation so closely? The resolution of this seeming paradox makes an interesting story.

4.3. How synchronic variation in speech production can lead to sound change: Hypo-correction

4.3.1. Hypo-correction

What keeps speaker variation from constituting sound change is the ability of the listener, discussed above, to compensate for or correct for predictable distortions in the speech signal. However, if, for any reason, the listener fails to do this correction, then the speech signal will be taken at face value, that is, with the phonetic distortion misconstrued as part of the signal intended by the speaker. Such a misapprehension of the speech signal on the part of the listener would constitute a potential sound change, that is, a "mini" sound change. I call this "hypo-correction".

Hypo-correction may occur if the listener is inexperienced with the language or dialect. For example, a speaker unfamiliar with the voicing contrast may not know how this contrast affects the pitch of adjacent vowels, namely that at the junction of the consonant and vowel the pitch is slightly higher for the voiceless than the voiced consonant. Where the experienced listener would "discount" or factor out this pitch difference as a purely predictable phonetic perturbation, the inexperienced listener may not. Hypo-correction may also occur if the listener fails to hear that part of the speech signal which would enable a correction. For example, if a listener failed to hear the final consonant in a syllable -- perhaps because it was unreleased -- then they would be less likely to factor out the consonantally caused perturbation in the quality of the preceding vowel (unlike the listeners in the experiments cited above (Ohala 1981b, Ohala and Feder 1987). Kawasaki (1986) showed that listeners hear more nasalization on vowels in words like /nʌn/ and /mɪm/ if the flanking nasals are attenuated or eliminated altogether than if the nasals are present. In essence this is what the study by Beddor et al. also demonstrated: with a nasal consonant appended to a nasal vowel, listeners could discount the perturbation in vowel quality; without the nasal consonants to blame for the perturbations, they heard the perturbed vowel quality as it was.

Many visual illusions are based on similar principles: two parallel horizontal lines equally long, one aligned above the other, are superimposed both on a blank page and on a photograph of railroad tracks receding into the distance. In the first case one sees the lines as equal, in the second case, the top line seems longer since the viewer "normalizes" its length as dictated by the perspective in the photograph.

4.3.2. Distinctive features of hypo-correction

There are two important characteristics to sound changes that come about due to hypo-correction. First (perhaps to restate the obvious), these are changes whose *direction is predicted by an understanding of physical phonetics*, that is, *speech production*. Most -- but not all -- of these sound changes would be characterized as assimilative. Physical phonetic considerations dictate that since the velar valve cannot open and close instantaneously, then either the segments adjacent to a nasal will have to be somewhat nasal (as the valve opening encroaches on the duration of the nasal consonant) or the nasal itself will have to be denasalized for some of its duration. Both assimilative patterns occur, e.g., Sanskrit dant > Hindi /dɑ̃t/ "tooth" (where nasality invades the preceding vowel); *Thom's son* > /tampsən/ "Thompson" (where "orality" of the fricative intrudes onto the initial part of the following nasal, carving out an oral stop [p] from it); see Ohala 1974a, 1975, 1981c. In the Tibetan example given above the vowels are shifted in a direction that one would expect from superimposing an apical constriction onto back vowels.

Second, it often happens (but certainly not always) that in sound changes due to hypo-correction *the conditioning environment is lost at the same time as the conditioned change occurs*. In the Tibetan example, the apical consonants were lost in addition to the fronting of the back vowels. In the development of nasal vowels in Hindi, the nasal consonant disappeared in addition to the nasalization of the preceding vowels. In cases of tonal development from consonants' voicing distinction, the consonants merge to voicelessness at the same time as the tonal distinction develops. Many more examples could be given that fit this same mold.[5] This strongly suggests that the typical scenario of sound changes due to hypo-correction in which the conditioning environment is lost is not well represented by the usual characterizations given in (4) and (5).

(4) VN > Ṽ

(5) V > Ṽ / __N

N > Ø / Ṽ__

(4) is adequate as a simple description of 'before' and 'after' but doesn't motivate or show the link between the two phonetic changes, the nasalization of the vowel and the loss of the nasal. (5) posits a two stage process which in most cases cannot be justified on historical evidence and seems to be motivated because of self-imposed difficulties in representing two or more simultaneous changes using the conventional rewrite formalism.

But there is a very plausible alternative which I give in (6) (where the slashes and square brackets denote forms that are lexical and intended vs those that are physical phonetic, respectively.).

(6)		Time 1	Time 2
	a.	/VN/ > [ṼN]	a. /VN/ > [Ṽ]
	b.	[ṼN] > /VN/	b. [Ṽ] > /Ṽ/

Time 1 represents the situation before any sound change takes place, i.e., part (a) states that vowels are predictably nasalized before nasal consonants and part (b) that listeners reconstruct the functionally non-nasal character of the vowels. These two processes, though stated in conventionalrule formalism, are not to be interpreted as typical rules of grammar. The first part, (a), is a constant, physically-caused process; it is not a rule of grammar but a constraint of the vocal tract. Part (b) is a cognitive act on the part of the listener. I would be willing to call this a rule of grammar although of a type not acknowledged by most phonologists. The only important difference between the processes at Time 1 and Time 2 is the loss, in (a), of the final nasal. This process, too, is presumed to take place in the physical domain. Perhaps the final nasal was intended by the speaker but was weakly articulated or simply that it wasn't detected by the listener due to inattention or noise. Part (a) is also not a rule of grammar. Part (b) is a cognitive process whereby the nasalization on the vowel is interpreted at face value (since the lack of detectable nasal consonant nearby leaves the listener no other option).

Thus, rather than stating that the vowel *became* nasalized and subsequently the nasal was lost, this new characterization states that *the vowel was always nasalized* (but that listeners could discount the nasalization when the nasal was still present). Then when the nasal was dropped or not detected the nasalization was simply interpreted at face value. Thus the loss of the nasal and the distinctiveness of nasalization on the vowel are directly linked; the change was, in essence, a single process.

4.3.3. Advantages of the preceding account of sound change via hypo-correction

The discussion of how distinctive vowel nasalization arises is used just as one example among many that could be given for sound changes occurring due hypo-correction. However, even as regards the particular case of nasal vowels, there are some distinct advantages to the scenario in (6) vis-a-vis others that have been offered.

Lightner's 'Why and how does vowel nasalization take place?'

Consider, first, the account given by Lightner (1970) who concludes in essence that distinctive vowel nasalization occurs after loss of a final nasal in order to avoid losing information (aboutlexical distinctions). As discussed by Ohala (1971a) this is an unsatisfactory explanation. Loss of information does occur when final consonants, including nasals, are lost, e.g., French [pwa] < both *poids* "weight" and *pois* "peas", [blɑ̃] < both *blond* "blond" and *blanc* "white", [ʁɑ̃] < both *rang* "rank" and *rond* "round". Second, if the only reason for nasalizing the vowel is to prevent the loss of information, then why don't we find other phonetic means being used to do this, e.g., why don't some languages replace the lost nasal with a tonal distinction, with diphthongization, or even by modifying and adding another consonant at the beginning of the syllable? Finally, one has to ask of this and all teleological accounts of sound change: if speakers had such presence of mind as to compensate for the loss of information resulting from the dropping of the nasal, then why did they allow the final nasal to be lost in the first place? Why didn't they just keep things as they were? Why are speakers helpless in the face of changes at first but capable of reacting to them at the next step? These logical difficulties are avoided by the scenario offered here.

It is not teleological and it accounts for why vowel nasalization (but not tone, etc.) results from loss of adjacent nasal consonants.

Two-stage models

An embarrassment to the two-stage model in (5) is that one ought to be able to find instances or periods in the development of languages where the first rule, the creation of distinctive nasalization before nasal consonants, had occurred but the second rule, the loss of the nasal, had not. In fact, as Kawasaki (1986) noted in her survey of scores of languages possessing distinctive nasal vowels, such vowels are quite rare next to nasal consonants. They are virtually non-existent before final nasal consonants and are rare or unstable after nasal consonants.[6] Treating the distinctive vowel nasalization and nasal consonant loss as linked in one step avoids this embarrassment.

Finally, the characterization of such changes as hypo-correction has the advantage that various aspects of it are supported by perceptual studies (Kawasaki 1986).

4.3.4. Beyond hypo-correction

Although it is difficult to tabulate sound changes and types of sound changes, and do statistics on them, I think it is safe to say that the vast majority of common cross-language sound changes are of the types just discussed, those due to confusion and hypo-correction, that is, the listener taking the speech signal -- possibly a degraded one -- as he hears it, at face value. These would include some cases of loss and addition of segments and syllables. But there is another remarkable, though smaller, class of sound changes which doesn't fall under those discussed so far, namely, dissimilation.

4.4. Dissimilation

4.4.1. Is dissimilation "unnatural"?

Some phonologists have been reluctant to admit dissimilation as a full-fledged member of the society of common sound changes. Along with metathesis, it has been characterized as a minor class of change, "unnatural", "sporadic", or regular only under special circumstances, etc. (Bloomfield 1933: 390; Schane 1972; Miranda 1974; Hock 1986, ch. 6). I think this caution is based on a lack of understanding of the basis of dissimilation. I have offered a theory which, I hope, makes it understandable (Ohala 1981b, 1985b, 1986b, 1989a). It is a logical extension of the account of sound change just presented.

4.4.2. Some examples of dissimilation

In spite of dissimilation occasionally being judged as sporadic, there are numerous cases of it in the diachronic record, some of them showing about as much regularity as one finds with any sound change.

A full taxonomy of dissimilation would include , first, *dissimilation at distance*, where the segment dissimilated is separated from the conditioning segment by one or more intervening segments; some examples are given in Table 4a, which includes perhaps the most famous case, Grassmann's Law. Then there would also be *contact dissimilation*, where the conditioned and conditioning segments are immediately adjacent to each other, as, for example, in Shona /bwa/ > [ɓɣɑ] "dog" (where the initial labial stop dissimilated the labial component of the following labio-velar glide) (Mkanganwi 1972). Another example of contact dissimilation from Slavic is given in Table 4b. Cross cutting these two categories are dissimilation as a diachronic process, i.e., where an actual change can be documented (e.g., all the cases in Table 4a), and *preventative dissimilation* where an expected or potential change or sequences of sounds seems to have been prevented from occurring due to dissimilation; an example from Sanskrit from Allen (1951) is given in Table 4c. In this latter category should be placed common phonotactic constraints, a sample of which are also given in Table 4d (see also Ohala, in press c). (For sources of these data, see Ohala 1981b.)

Many more examples could be provided for all of these types. Taken together, they constitute a substantial corpus.

4.4.3. Dissimilation is hyper-correction

The first things we should notice about dissimilation is that the direction of the change (or prevention of change) is the reverse of what we would expect given "natural" articulatory phonetic tendencies. This is presumably why some phonologists were reluctant to include dissimilation in their taxonomies of "natural" sound changes. For example, the Cantonese and Yao constraint against initial labial consonants and following rounded vowels is counter to what we would expect given normal coarticulation where rounding from one segment often intrudes onto adjacent ones (as in Old English u-umlaut). Likewise the backing of the low front vowel in the environment of palatal or palatalized consonants in Slavic is the reverse effect expected from palatal(ized) segments. But we have already examined a process which reverses or "undoes" predictable phonetic perturbations: the corrective or normalizing action of the listener. What the vocal tract does to perturb speech sounds, the listener undoes. Is it possible to invoke the listener as the cause of these "backwards" sound changes? I claim that it is. Dissimilation, I maintain, is hyper-correction -- the listener inappropriately correcting or "cleaning up" the signal.

As reviewed above, normal speech perception requires that the listener factor out the coloring of speech sounds by neighboring sounds. When this is done for a phonetically front vowel in the environment of palatal consonants an intended back vowel may be successfully recovered by the listener. But what if the vowel was intended to be front while flanked by palatal consonants? Then this corrective process would erroneously yield a back vowel, i.e., a vowel other than that intended by the speaker. This seems to be the origin of the dissimilatory front vowel backing exemplified in Table 4b and the dissimilation of the labial element of labial velar approximants after labials in Shona. Where two nearby segments share a distinctive feature that exhibits long time span assimilation there is a potential for dissimilation. (I must add that my conception of 'distinctive feature' is much broader than that usually found in current phonology. It is more nearly equivalent to the notion of 'relevant perceptual cue.' Even so-called 'minimal pairs', e.g., English /bæg/ vs. /bæŋ/, could (and do) have several differentiating cues. For

Table 4: Instances of dissimilation

a. Proto-Indo-European > Sanskrit

*b̤end̤	band̤	"bind"

Proto-Quichean > Tzutujil

*k'aq	k'ʲaq	"flea"

Ancient Chinese > Cantonese

*pjam	pin	"diminish"

Proto-Quechumaran > Quechua

*t'ant'a	t'anta	"bread"

b. Slavic

stoj + ā > stojā "stand"

c. Sanskrit

sarsrāṇa (for expected *sarṣrāṇa)

d. Yao

*C V C
[lab]

English

*#C [lab] w- ; *#C [stop] [apical] l-

Arabic

*C [phar] V C [phar]

most phonologists 'distinctive' is opposed to 'redundant' but not for me.)

Dissimilation, then, is largely the (inappropriate) undoing of expected effects of assimilation but we must allow that patterns of assimilation vary from one language to another. It is well recognized, for example, that the pattern of assimilation of nasalization by vowels before nasal consonants is different in American English and, say, Swedish. In the case of Grassmann's Law it may be difficult to imagine that the vowels (and sonorant consonants) which intervened between the aspirated consonants were themselves aspirated through assimilation.[7] For example, Hindi, a daughter language of Sanskrit, also has voiced aspirated (breathy voiced) stops but this type of anticipatory assimilation of aspiration does not occur (Ohala, M. 1979). Nevertheless, it must have occurred in other Indo-Aryan languages; consider, e.g., Gujarati /lạb/ < Sanskrit /laḇ/ "benefit" ('̤' = breathy voice) (Dave 1970).

Grassmann's Law has often been regarded as somehow "odd" or remarkable(more so than other dissimilations); see note 10. In fact, sound changes that are virtually identical to or at least highly reminiscent of Grassmann's Laws are found in several other languages, e.g. Sukuma (a Bantu language) (Bennett 1967), Ofo (a Siouan language) (de Reuse 1981), and especially various modern Indo-Aryan languages such as Sindhi (Turner 1923-25), Marathi (Grammont 1933: 316), Maithili (Jha 1958: 142), and Harauti (Allen 1957). (In some of these languages the sibilant [s] also acts as a dissimilator of aspiration. Interestingly, there is evidence that voiceless fricatives, especially sibilants like [s], also pattern together with aspirated stops in other phonological phenomena (M. Ohala 1983: 10; Ohala 1983b).) Thus, Grassmann's Law is not odd and attempts by some phonologists (Kiparsky 1965, Iverson 1985) to deny its independent origin in Greek and Sanskrit and to construct a scenario whereby it had a common origin in these two languages are uncalled for.

4.4.4. Supporting evidence that dissimilation is hyper-correction

There is circumstantial evidence which supports the above account of dissimilation.

What dissimilates

If, as claimed, dissimilation arises from the listener (inappropriately) factoring out expected non-distinctive perturbations in speech, then the only phonetic events subject to dissimilation should be those which could arise due to such perturbations. In general, this prediction is borne out.

For example, although features like aspiration, glottalization, retroflexion, palatalization, etc., are known to stretch over fairly long time spans (60 msec or more), features like stop and affricate do not. Accordingly, cases of dissimilation involving the former set are common, the latter, rare or non-existent. (See Ohala 1981b, 1986b for further details.)

It is important to emphasize that what matters here is the existence and perceptual importance of long duration *cues* for these phonemes and that most phonemes have multiple cues. For the most part laterals are cued by specific amplitude and spectral discontinuities (vis-a-vis flanking vowels) and these are relatively abrupt (occurring within c. 40 msec or less). These acoustic discontinuities correspond, of course, to an articulatory discontinuity: the abrupt formation or release of apical contact with the palate while one or both sides of the tongue are lowered. They would not therefore be expected to be subject to dissimilation. However, in many languages laterals also have distinctive onglides or offglides stretching over 60 msec or more (Lehiste 1964: ch. 2; Javkin 1979: ch. 3). (It is well known, for example, that in many dialects of English the post-vocalic velarized lateral has essentially been replaced by the long onglide which resembles an [o] or [w] glide (Sivertsen 1960: 131ff). In other languages, notably the Romance languages, palatal /l/'s have a more [j]-like offglides (and have on occasion been replaced by [j]'s). The so-called vocalization of [l], either to front or back glide or vowel is well attested (Roudet, 1910: 304-5; de Kolovrat 1923). Thus, although laterality as a phonetic feature cannot spill over onto adjacent segments, one of its perceptual cues can and it is therefore subject to dissimilation, as in the text-book examples: Late Latin (LL) *calamellum* > Old Provencal *caramel* "cornstalk, reed" (Grandgent 1905: 83). The similarity and thus interaction between one [l] offglide and [j] is demonstrated perhaps in a case cited by Meyer-Lübke (1890, 1: 346). In Portuguese and some dialects of Spanish one finds a change of /pl/ > /pj/ (and ultimately > /j/ or /ʃ/) , e.g., LL *plumbo* "lead" > Portuguese *chumbo* [8], LL *planu*, Spanish *llano* [jano], "flat". But such a change did not happen to the word *playa* "beach" <

LL *plagia*, presumably due to preventative dissimilation by the medial palatal segment.

Place of articulation cues can extend over 60 msec or more, especially velars and especially post-vocalic onglides (Lehiste & Peterson 1961), and thus is susceptible to dissimilation as the Chinese and Tzutujil cases demonstrate above (Table 4).

Features that dissimilate are perceptually nonrobust features

Stevens (1980) has suggested that phonological features can be differentiated into those that are fast and therefore robust perceptually, i.e., manifesting themselves in 30 msec or less, and those that are slow and consequently less robust. Languages construct their segment inventories using the robust features first; these include, according to Stevens, [voice], [nasal], [continuant], [grave], [compact]. (See Stevens and Keyser 1989 for a revision of this set of basic features.) Languages with small segment inventories may use few or no features beyond these. Languages with large segment inventories create added contrasts by augmenting (but not replacing) the robust features with less robust ones such as [flat], [sharp], etc. Although the details need further research, this dichotomy in features corresponds roughly[9] to those that aren't and those that are susceptible to dissimilation. Stevens' differentiation of features (or cues) according to their temporal properties seems to be valid and to have important implications for diverse phonological phenomena.

Loss vs. retention of the conditioning environment in sound change

As noted above, it often happens in the sound changes called hypo-corrections that the conditioning environment disappears at the same time as the conditioned change takes place. These aspects are probably causally linked: if a listener does not detect the conditioning environment, he will not be able to "blame" the conditioned change on it and therefore will not be able to factor it out. In contrast, given the above account of dissimilation or sound changes due to hyper-correction, the conditioning environment *cannot* be lost at the same time as the conditioned change occurs. This is because the conditioning environment must be detected in order for a listener to blame it for what he erroneously regards as a conditioned change. For example, we should not find sound changes like that in (7), a different version of Grassmann's Law in Sanskrit, i.e., where the deaspiration of the initial stop occurred only where a following aspirated stop had been lost.

(7) bhandh > ban

As far as I am aware this restriction on the form of dissimilatory changes (vis-a-vis assimilatory changes) is borne out.

The result of dissimilatory sound changes

Although sound changes due to hypo-correction may lead to the creation of new phonological contrasts, e.g., the Tibetan case in (1) where front rounded vowels were introduced into the language, most (all?) sound changes due to hyper-correction do not introduce novel contrasts to the language (Grammont 1895: 16; Kiparsky 1986). This asymmetry follows from hyper-correction being in essence a normalizing action, i.e., a reconstruction of something normal from something that was regarded as a perturbation of the normal.

The direction of dissimilation

Dissimilation is largely anticipatory, i.e., of two phonetically similar sounds, it is the first that usually undergoes change (Grammont 1895). This can be traced back to *assimilation* being more commonly anticipatory than perseveratory (Grammont 1895: 184-185; Javkin 1979: 75-76) and to dissimilation being largely the undoing of (presumed) assimilatory effects. There are some isolated cases characterized as anticipatory assimilation where the directionality can be explained phonetically (but these have no relevance to dissimilation; Ohala, in press b) but for the most part we do not yet have any explanatory account of assimilation or its direction.

4.4.5. Other accounts of dissimilation

Many theories have been offered as explanations for dissimilation and it is not feasible here to give an extensive review of them. However, it may be useful to compare a few of these with that presented here.

Grammont; Carnoy

Grammont (1895, 1933) proposes a number of "laws" to account for the direction of dissimilation. These are initially purely inductive generalizations, e.g., "explosive appuyée, combinée ou non, dissimile explosive intervocalique"[40], "de deux phonèmes intervocaliques c'est le premier qui est dissimilé" [79]. He proposes the general principle called 'la loi du plus fort' to cover the majority of all such cases, i.e., that the stronger of two phonemes dissimilates the weaker. However, it is not clear how one knows which of two sounds is stronger except by consulting his long list of inductive laws. He accounts for the largely anticipatory character of such changes by noting (p. 184-185) "... la parole va moins vite que la pensée; l'attention est en avance sur les organes vocaux. ... il en resulte une négligence dans la prononciation de la première partie des mots et par suite une faiblesse inhérente aux phonèmes que s'y trouvent." Kent (1936) offers the same explanation for the direction of assimilation. My comments on Kent's explanation apply as well to Grammont's (Ohala, in press b):

> ... [the] basic notion is not implausible: speech errors do exhibit anticipation of sounds, e.g., *teep a cape* < *keep a tape*; but the character of such speech errors does not resemble in detail what one finds in [assimilations like LL *octo* > Italian *otto*]. In speech errors, the anticipated sound can itself be replaced by the sound it supplants and, moreover, the anticipated sound almost invariably is one occupying a similar position in another syllable, i.e., in onset, nucleus, or coda position [whereas dissimilation can involve segments in the initial and final position in the same syllable]. Also, it is universally accepted that all articulations (all voluntary movement, in fact) must be preceded by the 'thoughts' that control them, but how, exactly, does 'thought' get transduced into movement? It is not true that by just thinking or intending to say an utterance we actually say it. So Kent's account is not a sufficient explanation for anticipatory assimilation.

Carnoy (1918) gives what is essentially a variant of Grammont's account, characterizing dissimilation as a "mild case" of haplology[10]: "... when two sounds or two syllables coincide and have to be visualized together and articulated after one another. In that case the image of one of them easily crowds out the image of the other, and both speakers and hearers hardly realize that one of the repeated members has been omitted (haplology)..."

Both of these accounts cannot explain why only certain features are subject to dissimilation.

Ladefoged

Ladefoged (1984) claims that one contributory cause to the dissimilation in Grassmann's Law is 'economy of effort': "Aspirated consonants are ... costly in that they use considerable respiratory energy. A word with two such sounds is very costly, and an obvious candidate for pruning in any attempt to reduce the overall effort required for an utterance."[11] It is easy to appeal to ease of articulation as a cause of sound change and it often has been but it is difficult to come up with a convincing way to measure the physiological energy required to speak different speech sounds (however, see Lindblom and Lubker 1985). In any case one would expect, *a priori*, that since energy expenditure is cumulative as one progresses from beginning to end of a word or phrase, the need to prune energy-costly sounds would be greater on the second of the two aspirates, not the first. Also, if energy expenditure played a significant role in dissimilation, it shouldn't matter that the initial conditions for it be two phonetically *similar* sounds, even dissimilar sounds should dissimilate, say, an aspirated stop and a nearby implosive or a click. (I am not willing to say what sounds require excessive articulatory energy but I pick the latter two as not implausible candidates). But this is not what we find.

Autosegmental Phonology

In the notation known as autosegmental phonology, dissimilation is accommodated by a constraint, the "obligatory contour principle" (OCP) that limits the permissible linking between features (autosegments) and the segmental placeholders in the 'CV' skeleton or tier. The OCP prohibits the specification of adjacent identical segments in phonological representations (Leben 1973; McCarthy 1979, 1989). When, for example, a sequence of two labial segments is disallowed in a language there would be underlying independent links between the [labial] feature and the CV skeleton, as in (8a). The OCP would then be invoked to eliminate it. If two labial segments *are* allowed in a language, then the feature [labial] would have multiple links to the relevant elements in the CV tier as in (8b).

(8) a. * C | [lab] C | [lab] b. C \ [lab] / C

This is just a notation; it can represent dissimilation but it cannot explain it. It provides no "first principles" from which to predict which features are likely to dissimilate and which not.

4.4.6. Experimental Evidence for Dissimilation as Hyper-Correction

The basic mechanism of the preceding account of dissimilation is listener's correction. Experimental evidence for this has already been cited. Excessive correction has been found by Beddor, Krakow, & Goldstein (see above). When the stimuli in their [ɛ] - [æ̃] vowel continuum were only slightly nasalized but followed by a nasal consonant listeners showed a tendency to "over-correct" in that they heard more [ɛ]'s than they would have had the continuum been oral.

4.4.7. Listeners' Expectations are Responsible for Other Sound Changes

Any phonetic event which listeners come to expect to be present in speech unintentionally is potentially subject to removal by them when they form their own lexical forms. Not all such spurious events need to be those produced by assimilation. An example is the epenthetic vowel that appears between obstruents and following tapped or trilled 'r''s. Given that a tap or trill is just one or more brief interruptions of flanking vowels, a brief vowel-like entity may break up clusters of an obstruent and following tap or trill. Normally, listeners learn to disregard this. Sometimes, however, hypo-correction creates a sound change where this automatic vowel becomes a full one, e.g., Menendez-Pidal (1926: 217-218) notes the existence in Spanish, sometimes sporadically, of a 'vocal relajada' breaking up clusters of the sort Cl and Cr, e.g., *Ingalaterra, coronica, eg*^{e}*lesia, p*^{e}*redicto*. Evidence that listeners can reverse this pattern can be found in a study by Millardet (1910): "[l]a voyelle protonique initiale a ... une tendance a disparaitre entre occlusive initiale et [r] + voyelle" [90-91] and provides the examples *crante* < *quarranta*, *priggle* < *periculu*. The implication of his observation is that both the unstressed environment as well as the special character of [r] (which often has brief vowel segments surrounding it) are factors in this vowel loss.

5. The Cognitive Component of Sound Change

As discussed above, when a listener attends to speech -- and the signal is less than perfect -- there can be four outcomes:

a. correction (or resolution of the ambiguities)
b. confusion of acoustically similar sounds
c. hypo-correction
d. hyper-correction

It may be useful to collapse (b) and (c). The distinction between these two hinged on whether the listener lacked disambiguating cuesinherent in (i.e., simultaneous with) a speech sound or sound sequence, as in [pj] vs. [t], or lacked such cues from the immediate environment, as in [ẽ] vs. /e(n)/. With these categories collapsed, one is left with the simpler taxonomy of perceptual scenarios below:

A. Correction
B. Hypo-correction
C. Hyper-correction

(A) results in no sound change and represents the outcome in the overwhelming majority of speaker-listener interactions. (B) and (C) result in sound changes and, of these, (B) is much more common.

In order to assess, even speculatively, the cognitive activity in these three scenarios, it seems reasonable to represent the act of perceiving speech schematically as in Fig. 2. There is cognitive activity involved in all three perceptual scenarios, especially (A) and (C) since in addition to the minimal cognitive activity of segmentation, comparison, and categorization they involve at least one pass through the feedback loop constituting the correction procedure. Hypo-correction, (B), would involve just the basic categorization and comparison. In contrast to typical teleological accounts of sound change, then, I maintain that the vast majority of sound changes occur as a result of *less* cognitive effort than in normal, successful, speech perception.

Granted, this is vastly oversimplified but if it is accepted in its broad outline, what emerges is that most cognitive activity is involved in *preventing* sound change, i.e., in attempting to maintain congruence between the speaker's and the listener's pronunciation norms. This cognitive activity is bound to be highly complex and highly interesting given its great flexibility in dealing with a wide variety of possible distortions and perturbations in speech. But this essential part of every native speaker's linguistic competence (and therefore part of the "grammar") has been almost totally neglected by phonologists who profess interest in speakers' competence. (Of course, it has not been neglected by phoneticians, psychologists, speech pathologists, and communication engineers.)

Finally, it is important to emphasize that although sound change does occur anyway, we are not able to identify any component of this system that has the purpose of changing pronunciation norms. The whole system is geared toward maintaining norms. Sound change occurs due to a break-down, as it were, of the system. Thus although we must say that cognitive activity occurs in the transmission of pronunciation norms from one speaker to another, from generation to the next, *there is no cognitive action whose purpose is to cause the change*. Keeping in mind all the restrictions in the domain of sound change laid out at the beginning of this paper (focusing only on common sound changes, widely attested across languages), I claim that sound change is not teleological. This contrasts sharply with a long tradition of theorizing about sound change that maintains that it occurs to improve or simplify speech: to make it easier to pronounce, easier to detect, easier to process (in the sense of making the grammar simpler) (Müller (1864: 176ff; Whitney 1867: 69ff; King 1969; ch. 4). We must carefully differentiate between explicitly teleological views of sound change and those that embody a kind of 'natural selection' mechanism, like the Darwinian view of change and development of species, i.e. that the variations in pronunciation (or grammar) that make speech communication easier or more effective survive at the expense of those more difficult and less effective. This is the view of Lindblom (1989). Like Darwin's theory these are also inherently non-teleological since there is no mind directing the change, no choices made to take one path over another. I am skeptical of such theories, too, since it is not clear to me that sound change results in any improvement in speech

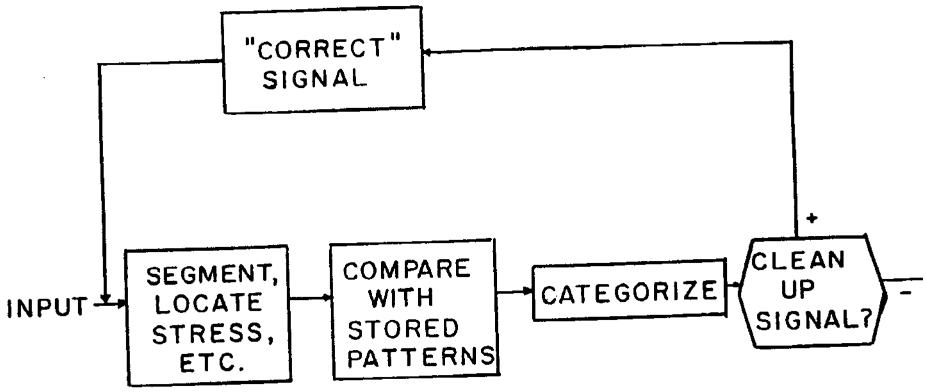

Fig. 2. Simplified schema of speech perception (see text for discussion).

communication (Ohala 1989b). However, this issue is beyond the scope of this paper.

The diachronic change in pronunciation norms, then, I would liken to the changes that have occurred in other areas, for example, scribal errors in copying manuscripts or errors in DNA replication. Another example: My own handwriting is pretty bad and it has happened more than once that my handwritten version of the name 'Fant' has been misinterpreted as 'Faut' by my students. One can *describe* the change using rule formalism as *n* > *u*, but presumably no one would ascribe this rule to the intention or "grammar" of either the writer or the reader. Any such change that occurs between my intended writing and the students' interpretation of it, like most sound changes, is not purposeful. I know my handwriting is not very clear but I assume, as speakers must about their listeners, that my intention can be reconstructed. Sometimes this assumption is wrong and change occurs.

6. A General Recipe for the Study of Sound Change in the Laboratory

The way to study the perceptual processes that lead to sound change has been exemplified in the citations to the experimental literature above. To be specific, it would involve the following:

First, one should ideally have some basis for hypothesizing that a certain change, A > B / (C)[12], is motivated by physical phonetic factors. This could come deductively from phonetic theory or inductively from a survey of sound patterns in the languages of the world or from an examination of instrumental records of speech (where the variation is noticed but the underlying cause is unknown).

To demonstrate the "mini" sound change of A > B / C due to hypo-correction one should present to listeners sequences of the sort AC where the suspected conditioning environment is somehow attenuated or eliminated. The hypothesis would be supported by a finding that there was an increase in the probability of some of the original A's being identified as B's. Kawasaki's (1986) study, cited above, exemplifies this. Attenuation of the nasal consonants flanking a nasalized vowel increased the degree of perceived nasalization.

To demonstrate the change of B > A / C due to hyper-correction one should present to listeners sequences of the sort B+C where the B would be identified as B in isolation or in some neutral or other control context and it is spliced or artificially juxtaposed to C (an environment, it is recalled, that is known to perturb A > B). The hypothesis would be supported if there was an increased probability of B being identified as A. The study by Mann and Repp (1980) matches this formula. One of the stimuli on their [s] - [ʃ] continuum would be identified primarily as [ʃ] when it appeared before the vowel [ɑ] (which can be taken as a kind of neutral environment) but the same stimulus had an increased probability of being identified as [s] when it appeared before the vowel [u], a context known to make intended [s]'s more [ʃ]-like.

The experiment by Beddor, Krakow, & Goldstein is one of the few that exemplifies for a single type of variation (change of vowel quality with superimposed nasalization) the perceptual results of both hypo-correction and hyper-correction. Furthermore, they demonstrated that the given phonetic distortion in vowel quality can be explained to a large extent by physical phonetic theory.

7. Conclusions

This paper had three main goals. First it was a demonstration (once again) of how a study of the present can illuminate the past or, more specifically, to show that present-day variation in speech behavior -- both in the production and perception domains -- is the stuff out of which sound changes are made. Variation in perception constitutes potential sound change; variation in production can lead to sound change if it confuses the listener. In addition, sound change can come about when the listener "second-guesses" the speech signal. Second, it was a demonstration of how sound change can be studied in the laboratory. This is not sound change "on the hoof" but it bears the same relationship to it as *in vitro* studies do to *in situ* studies in biology: retaining enough of the relevant features to be able to offer useful predictions and explanations. Third, it proposed to assess the cognitive component of sound change. Sound change is viewed as a break-down of normal speech perception which necessarily involves some "clean-up" or correction of the received signal. Failure to implement this correction (hypo-correction) or inappropriate correction (hyper-correction) are the basic phonetic causes of sound change. However, there is no cognitive element in all this whose *purpose* is to create a change of pronunciation norms. In this respect, I contest teleological accounts of sound change, i.e., that sounds change in order to ease production, make speech easier to hear, or to make it easier to learn or process.

There is no denying that teleology (choice, intention) can underlie the spread of a phonetically natural sound change. What I resist is the idea that the initiation or creation of a phonetically-motivated variant pronunciation comes about in this way. The reader can either accept or reject the arguments and supporting laboratory evidence I offer on this point but there is an additional strategic reason for eschewing teleology here: it is too easily invoked, almost impossible to prove, and serves to stifle further empirical studies into possible mechanistic or non-teleological causes of change. I avoid explanations of the sort "... the speaker chose a different pronunciation in order to optimize [something]" for the same reason that modern science rejects explanations like "... the earth's climate is getting warmer because the gods are angry with us". Not that such explanations may not, in the end, be the right ones, but it is part of the tradition of modern science to seek the less extravagant explanation before embracing the extravagant ones. This is, after all, the nature of explanation: reducing the unknown to the known -- not to further unknown, uncertain, or unprovable entities.

The account given here proposes answers to other classic questions in diachronic phonology. Sound change is claimed to be abrupt, not gradual, that is, when initiated, a pronunciation norm shifts discretely from one shape to another. Variation in speech production is indisputably continuous but such variation does not constitute sound change until it is interpreted -- or rather misinterpreted -- by a listener. These interpretations are necessarily drawn from a smaller, discontinuous, set. Although it is the speaker's behavior -- the variation in speech production -- which sets the stage for sound change, it is the listener who is actually the initiator. (Here it must be re-emphasized that the discussion concerns only phonetically "natural" sound changes attested in many different languages.) Important supporting evidence for this point comes from the finding that listeners are able to compensate perceptually for a great deal of variation in speaking.

The long-standing puzzle of sound changes that "go in opposite directions", e.g., assimilation and dissimilation, (certain cases of) syncope and epenthesis, is resolved by attributing those that proceed in the direction predicted by physical phonetic theory (e.g., assimilation) to the listener failing tonormalize the speech signal and instead taking it at face value. This is 'hypo-correction'. Sound changes that go in the unexpected direction (e.g., dissimilation) are attributed to the listener "normalizing" a signal that didn't need normalizing. This is 'hyper-correction'.

This does not mean that "anything goes": that when A > B one simply labels it hypo-correction and when B > A one calls it hyper-correction. "Anything" does not go; I have attempted to put some constraints on the two types of mechanisms: what features or phonetic events can be involved in both types, differences in whether or not the conditioning environment can be dropped at the same time as the conditioned change, differences in the likelihood that one type of change or other will result in new phonological contrasts for the language in question, etc. And, finally, the ultimate constraint is that these changes should be duplicated in the laboratory under appropriate conditions. It is true that only a small fraction of well-attested sound changes have been investigated in the laboratory and that as Twaddell (1935: 33) remarked "... promissory notes of the laboratory ... are liable to a heavy discount." Nevertheless, in this case I am optimistic that the program of experimental study of the phonetic factors contributing to sound change is well underway, indeed, many traditional experimental phonetic studies not done explicitly under the "phonology" banner are still relevant to its issues.

Phonetic explanations for sound patterns in language have occasionally been criticized or discounted in essence for not being able to explain everything about sound change: they cannot explain why a given sound change took place in a given language at a given time, etc. (Lass 1980; Dinnsen 1980). I have answered these criticisms elsewhere (Ohala 1987, 1989a). Briefly: no scientific discipline has perfect knowledge of the universe such that it can explain everything in its domain. All scientific explanations are just approximations, have only probabilistic validity, and (as history of science teaches us) are subject to revision or rejection as new discoveries are made or new theories proposed. Yet I don't think anyone would thereby declare that physics, chemistry, and biology are failures because they share these limitations. Phonetic explanations of sound change do not differ qualitatively from those offered in other scientific disciplines, though given the newness and complexity of our field, the explanations may be quantitatively inferior to those of the mature disciplines. Probabilistic models are used to good advantage in speech perception (Nearey & Hogan 1986) and as far as I know no one has declared this inappropriate. We cannot explain why a specific individual identified a specific token of [θ] as [f] under high-fidelity conditions in the Miller and Nicely (1955) study. We can, however, begin to explain why in this study 25% of all identifications of [θ] were [f] (based on quantifiable points of similarity) and thus why across languages we can expect to find a certain level of similar substitutions in sound change. If probabilistic accounts are acceptable in the domain of perceptual phonetics then they should be acceptable in the domain of sound change because these are overlapping domains.

Finally, if the integration of phonetics and sound change offered here has any merit, it demonstrates the potential usefulness of historical phonology for speech technology, especially automatic speech recognition. Sound change provides us clues to how humans perceive speech and that is what we need to know in order to design machines which do the same.

Notes

1. Sometimes measurements of natural speech show the influence of place of articulation on voicing during stops (Smith 1978) and sometimes such evidence is less clear (Lisker & Abramson 1964; Westbury 1979).
2. See, however, Fowler (1986) who promotes the 'direct realist' view that the acoustic speech signal contains all the information necessary to the listener to ascertain the articulation used by the speaker.
3. Not that this hasn't been attempted; see, e.g., Whatmough (1937).
4. It is important here not to confuse phonologized variation, i.e., sound changes that have already taken place, with phonetically-caused variation. Sound change created the new pronunciation norm /dɪdʒə/ from /dɪd ju/ "did you". Now both of these norms co-exist and a speaker may select either one depending on speaking style, etc. But if /dɪdʒə/ is selected now it is not a modification of the norm /dɪd ju/, it is a norm by itself.
5. In order not to neglect the cases where sound changes involving hypo-correction do *not* entail loss of the conditioning environment, I should mention one: vowel harmony. Assimilation of some of the features of one vowel by another is a phonetically natural process since it has been detected phonetically in languages lacking phonological vowel harmony (Ohman 1966). The vowel which conditions the change does not itself disappear.
6. This syllable-initial vs. -final assymetry by itself is presumably due to the fact that syllable-initial nasal consonants exhibit less velic opening than syllabic-final nasals and thus induce less nasalization on adjacent vowels; see Ohala (1971b). Why initial vs. final nasal consonants have this difference is not known.
7. Thus Sturtevant (1935) remarked a propos of Grassmann's Law: "It is scarcely possible that first the intervening vowel was ... endowed with aspiration and that the prior consonant was then affected by the vowel."
8. This is another example of the sound change discussed above in 3.2.2.
9. I think traditional phonological features are excessively abstract entities that don't lend themselves to characterization in simple physical terms such as the number of msec it takes to realize them. Any given

phonological or lexical contrast is signaled by multiple acoustic cues. It is these cues that are fast or slow, robust or weak. Also rather than a strict dichotomy, there is a fast-slow continuum.

10. So does Zipf (1935: 84-86) although the motivation for dissimilation and haplology is given as a tendency to reduce the coplexity of sounds in close proximity.
11. Such an explanation for Grassmann's Law has been around for some time; cf. Max Müller on its manifestation in Greek: "An aspirate requires great effort ... beginning from the abdominal muscles and ending in the muscles that open the glottis to its widest extent. It was in order to economize this muscular energy that the tenuis was substituted for the aspirate..."(1864: 179-180).
12. A null C, i.e., the absence of an apparent conditioning environment, would hold when two acoustically similar sounds are confused.

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