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The Listener as a Source of Sound Change

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In theories on the origins of sound change the speaker has usually been assigned the leading role: the speaker is claimed to have modified his pronunciation in order to reduce the energy expended in speaking, to have made his speech more distinct in order to make it more intelligible, to have simplified his grammar, etc. (Jespersen 1949:15ff; Martinet 1964:169ff; Halle 1962). Certainly it is true that the speaker plays an important role in sound change, although personally I do not think any of the above-mentioned activities are important aspects of this role (Ohala 1974a, 1975a; Hombert, Ohala, & Ewan 1979). Nevertheless, what about the listener? Does he play an essentially passive role--faithfully copying the pronunciations he hears, whether these have been altered by the speaker or not? In other words, is the listener just a pipeline for sound change? I suggest that the listener's role is far from passive and that a full understanding of the origins of sound change will require us to find out exactly what he's up to. In the process we may also understand speech perception better.

In this paper I am concerned only with sound changes which are attested in diverse, unrelated languages, i.e., those likely to have a phonetic origin. This excludes the language-specific and culture-specific sound changes such as might be precipitated by paradigm regularization, spelling pronunciations and the like.

Inherent Ambiguity in the Speech Signal

Although the listener has been neglected, he has not been completely ignored in discussions of the origins of sound change. From Sweet (1888) and Passy (1890) up to Durand (1956) it has been recognized that the many-to-one relationship between vocal tract shape and sound shape makes the acoustic speech signal inherently ambiguous with respect to how it was articulated. The listener is not always able to resolve this ambiguity and may, when he turns to speak, hit upon an articulation different from that used by other speakers. Thus we find sound changes such as those in (1), which

(1) English "with" realized dialectally as [wɪθ] ~ [wɪf]

Tibetan [sna] ~ Burmese [n̥na] "nose"

Proto-Indo-European *$g^{w}\bar{o}ws$ > Classical Greek bous "cow"

involve alternations of sounds which are quite different in articulation but very close auditorily.

This is an important class of sound changes not only because of their large number but also because their phonetic basis is well documented and, in some cases, such sound changes have been duplicated in the laboratory (Wright 1980; Ohala and Amador 1981).

How to Handle the Noise in Speech

Inherent ambiguity in the speech signal is not the only problem the listener faces. *Speech is extremely noisy.* By this I do not mean that ambient noise--from traffic, the wind, birds' cries, etc.--masks speech. Rather, I mean that if one imagines that there is only one or at least just a small number of accepted pronunciations for each word in the lexicon, it is nevertheless true that there are seemingly an unlimited number of measurably different phonetic variants of each word in actual speech--much to the dismay of those trying to do automatic speech recognition. Since the listener has to make an exact identification of the words in the speech signal, all this variability makes speech noisy from his point of view.

Speech is noisy in another sense, too. The listener has another task besides that of identifying the words in the signal. At some point he is expected to speak, too. When he turns to speak he has to use the acoustic/auditory information received from other speakers to figure out how to make the same sounds himself. This is a trickier task than might at first be apparent. There are a great many features of pronunciation that are not under the active control of the speaker; they are, instead, added by the physical constraints of the speech production anatomy or even neuro-anatomy.

For example, it is well documented that there are small, systematic perturbations of pitch on vowels following voiced and voiceless consonants: slightly higher pitch on vowels following voiceless consonants and slightly lower pitch on vowels following voiced consonants (Ohala 1973, 1974a, 1978; Hombert, Ohala, & Ewan 1979). These perturbations are large enough to be detected and, in fact, if other cues are absent, can be used to differentiate voiced and voiceless consonants (or aspirated and unaspirated) (Fujimura 1971). Nevertheless, the best information we have at present suggests that these perturbations are not actively controlled by the speaker, i.e., we do not find any systematic difference in the level of activity of the chief laryngeal muscle for controlling pitch (Hirose and Gay 1972). Somehow these pitch differences are just automatic, mechanical consequences of the gestures needed to make the voiced/voiceless distinction.

Another example comes from the acoustic consequences of the interaction between consonants and vowels. As shown in Figure 1, the vocal tract shape for the vowel [u] produces a sound with a low formant 1 (F1) and formant 2 (F2). A dental/alveolar constriction, however, gives rise to a sound with a low F1 and an F2 at about 1800 Hz. If these two sounds are coarticulated F2 is largely determined by the apical constriction. As shown in the right of the figure,

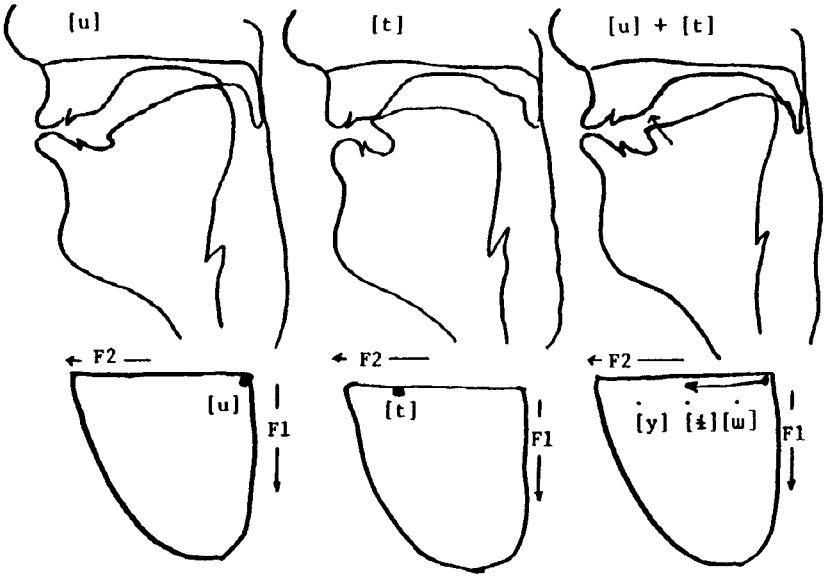


Figure 1. Vocal tract shape (top) and acoustic output (bottom) of [u], [t] and simultaneous coarticulation of [u] + [t].

this means that the vowel [u] or any back rounded vowel tends to be fronted on the acoustic/auditory vowel space when they appear in the environment of consonants like dentals which have a high F2. Depending on the degree of the dental constriction made simultaneously with the [u] configuration, the resulting vowel may sound like [ɯ], [ɨ], or [y]. Extensive phonetic data, both from the laboratory and the field, support this (Lindblom 1963; Stevens & House 1963; Glasgow & Glasgow 1967). (It must be emphasized that the lingual constriction for the back vowel is not necessarily fronted--see Ohala (1974b)--; the fronting of these vowels takes place in the acoustic/auditory domain, not the articulatory domain.)

Many other examples could be given of how vocal tract constraints distort the signal intended by the speaker, that is, the form of a word as specified in the lexicon, which, in the case of a word like *soot*, would include no mention of [ɯ], [ɨ], or [y]. The listener when he tries to repeat what he's heard must find out which of the many phonetic events in the acoustic signal he should actively control in his own articulation and which he should just "let happen" due to the mechanical properties of the vocal tract. In the examples given, he has to learn that the pitch differences after stops don't have to be controlled and that the vowel heard in the environment of dentals doesn't have to be an /ɯ/, /ɨ/, or /y/, but can be articulated as a target /u/. Evidently the listener does learn these

things, no doubt as the result of years of experience in speaking and listening to the sounds of his language. A speaker of a language that makes no use of a given phonetic feature, however, is likely to be unfamiliar with the types of distortion that may accompany that feature, e.g., American English speakers are unlikely to know about the special tense voice quality that accompanies the production of Arabic [ʕ].

What evidence is there that listeners have this ability to "undo" or to factor out the distortions in speech? First, I would just like to argue for the plausibility of the claim based on the existence of similar perceptual skills in a different sensory modality: vision. The way we view objects can greatly distort their appearance as this is registered on the retina. Things viewed from a distance seem smaller than the same thing seen close up. The circular rim of a cup seen at certain angles forms an ellipse on the retina. A white object viewed under green light will be tinted green. Nevertheless through experience our brains can exploit contextual cues and successfully correct these distortions and thereby achieve what psychologists call *size, shape,* and *color constancy*. (Gregory 1966). It is even possible for viewers to learn to "correct" the visual distortions created by their wearing special prismatic eyeglasses that invert the visual field, such that up is down and down is up (Kohler 1962). If the brain is capable of these reconstructions of a constant mental image from distorted sensory impressions, it does not stretch credibility that listeners can do the same kind of thing with speech.

Second, there is experimental evidence of this phenomenon. Ohala, Kawasaki, Riordan, and Caisse (forthcoming) looked for evidence of listeners' knowledge that the vowel /u/ would be fronted in dental environments. They synthesized short steady-state tokens of the the vowels [i] and [u] and six other vowels linearly interpolated between these two and the vowels [ɛ] and [ɔ] and eight vowels linearly interpolated between them. Each of these vowels were then placed between labial consonants, [f_p], and between dental/alveolar consonants, [s_t] and presented to American English listeners for a forced choice identification as /i/ or /u/ for the one series or as /ɛ/ or /ɔ/ in the other series. The answer sheets on which subjects marked their responses made clear the consonantal environment of each token. The results are shown graphically in Figure 2. Naturally there is a crossover point somewhere in the middle of these continua where listeners stop hearing front vowels and start hearing back vowels. But, as shown, this crossover point is further towards the front vowel end of the continua when the test vowels appeared in a dental/alveolar as opposed to a labial context. What this means is that listeners will accept as an /u/ or /ɔ/ a more fronted vowel if they can "blame" the phonetic context for this fronting. (See also Lindblom & Studdert-Kennedy 1967; Hiki, Sato, Igarashi, & Oizumi 1968; Fujisaki & Sekimoto 1975; Centmeyer 1975.)

In another experiment Kawasaki (1978) investigated listeners' judgements of the degree of perceived nasality of vowels as a func-

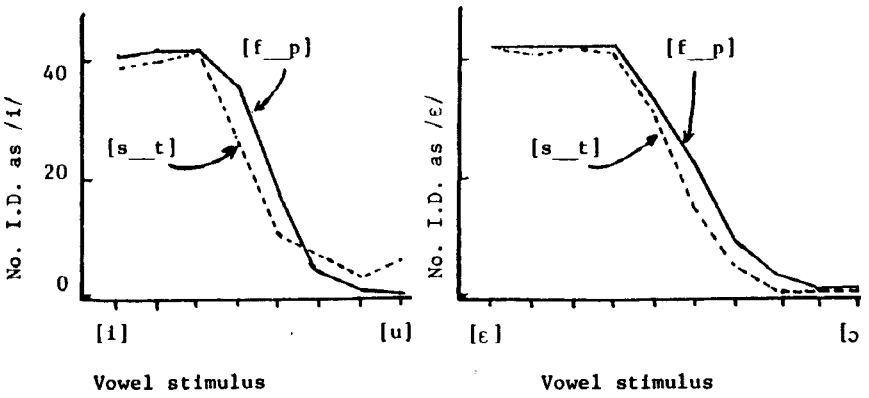


Figure 2. Identification of vowel quality as function of consonantal environment.

tion of the environment the vowels appear in. Starting with syllables like [mɪm] and [mɑm], she digitally processed them such that the nasal consonants had their amplitudes incrementally attenuated in 12 dB steps or were removed entirely. The vowels themselves were not modified in any way. American English listeners were asked to judge the degree of perceived nasalization on the vowels. She found an inverse correlation between perceived nasalization of the vowel and the extent of attenuation of the flanking nasal consonants. That is, the less evident perceptually the nasal consonants were, the more nasalized the vowels sounded and, conversely, the more evident the nasal consonants, the less was the perceived nasalization of the vowels. This is consistent with the notion that American English listeners consider vowel nasalization in such cases to be a distortion induced by the nasal consonants; upon detecting the source of the distortion, they can factor it out.

I will reiterate my claim in the form of a scenario, given in (2). A speaker intends to utter the sound sequence /ut/. (In this

(2) Scenario 1.

Speaker		Listener
/ʊt/		/ʊt/
↓		↑
distorted by vocal tract into		*reconstructed as*
↓		↑
[yt]	*heard as* ⟶	[yt]

and subsequent diagrams I use the slashes, '/.../', in their modern sense to represent lexical forms; square brackets, '[...]', to mark surface phonetic forms.) This utterance may be distorted if it is

subject to coarticulation into something like [yt]. This version is transmitted to the listener who applies his "reconstructive" rules, which, it will be recalled, crucially depend on his having correctly perceived the environment causing the distortion, in this case the [t]. The listener therefore reconstructs the intended signal /ut/.

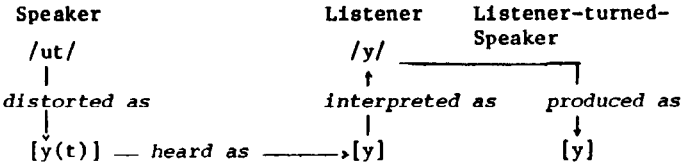
(By using the term 'rule' here I do not mean to put the listener's reconstructive process into the same category as the rules posited by traditional generative phonology and its offshoots. First, my reconstructive rules must operate on a highly variable input, i.e., features with continuous, not discrete, values and therefore not the same sort of features as those in the lexicon. Second, these rules do not function to take a more abstract representation and derive from it a less abstract representation; just the opposite. In this latter sense they may bear a superficial resemblance to the rules in "Upside-down phonology" (Leben 1979) except that reconstructive rules do not function to derive the allegedly common underlying form of different allomorphs, e.g., *profound, profundity,* but rather the common underlying forms of different allophones.

There is, however, an obvious similarity between these reconstructive rules and the Motor Theory of speech perception (Liberman, Cooper, Shankweiler, & Studdert-Kennedy 1967). That theory was also motivated by the problem of the extreme variability in the acoustic shape of words, although the solution proposed to that problem under the Motor Theory seems unnecessarily extravagent: that the listener internally synthesizes vocal tract shapes--or the commands that would produce them--which would give rise to sounds matching the incoming acoustic speech signal and then attempts to find a match between those vocal tract shapes and some stored articulatory template. Much simpler computations could underlie the listener's reconstructions, e.g., something like the equations proposed by Lindblom (1963) which predict degree of formant undershoot given the duration of the vowel.)

Sound Change from Failure to Apply Reconstructive Rules

Now we may ask what would happen if for some reason the listener failed to detect the environment that causes the distortion. We can go through another scenario, (3), to find out. Again, the speaker

(3) Scenario 2.



intends to say /ut/ which, as before, may become distorted such that the vowel is more like [y]. Now, however, the [t] may be weakly articulated or unreleased or simply become masked by ambient noise

such that the signal is received by the listener as [y]. In this case the listener's reconstructive rules are inapplicable since they crucially depend upon perceiving and knowing the source of the distortion. Lacking this, no reconstruction is done and the utterance is interpreted as it was received, /y/. When this listener turns speaker he will in his most careful, minimally coarticulated pronunciation say simply [y]. Thus, a sound change would have occurred--or, if one wishes, a mini-sound change, since it would so far only involve one speaker-hearer. However, if this person's speech is copied by other speakers this mini-sound change could become a regular sound change, i.e., characteristic of a well-defined speech community. (I assume without further argument that the initiation of such sound changes is accomplished by the phonetic mechanism just described; their spread, however, is done by social means, e.g., borrowing, imitation, etc.)

I do not believe Scenario 2 is purely hypothetical. It is precisely the way a very large class of sound changes came about. Consider the data in (4) which provides evidence of a sound change very similar to that in (3). Written Tibetan reflects the pronunciation of approximately the 8th century. From the first two words in (4)

(4)	*Written Tibetan*	*Lhasa Tibetan*	*English Gloss*
	gon	qhõ:	"price"
	nub	nu:	"west"
	BUT:		
	lus	ly:	"body"
	bod	phø:	"Tibet"
	ston	tɵ-	"autumn"

(Data from Michailovsky 1975; transcription simplified.)

it appears the back rounded vowels suffered no change in quality even though a following labial or velar consonant was lost. From the last three correspondences we see that dental consonants were also dropped in final position but in these cases the back rounded vowels were fronted. If these changes came about as schematized in Scenario 2, there are two ways to describe them: at the lexical level the word for "body" involved the change of /lus/ to /ly/, but at the phonetic level, assuming one starts with a maximally coarticulated form, [lys] changes to [ly]. Thus, at the lexical level the change was two-fold: the change in the quality of the vowel and the loss of the segment, /s/, which caused the quality change. However, at the physical phonetic level there was really only one change: the dropping of the final consonant. The change in the vowel quality was there all along.

A great many other sound changes can be fitted into this mold: those in which the conditioning environment is lost at the same time as the conditioned change, but where modern phonetic studies show

that such conditioning--distorting--is phonetically a synchronic fact of life.

For example, tonal development on vowels in a number of languages around the world, notably Chinese, was triggered by loss of the voicing contrast in pre-vocalic consonants (Hombert, et al. 1979). As has been noted above, even non-tonal langauges like English and French have phonetically different pitch contours on vowels following voiced and voiceless consonants. It was presumably this perturbation that formed the basis of the tonal developments in languages like Chinese.

Umlaut, e.g., /oki/ → /øk/, involves the simultaneous shift in the quality of a vowel and the loss of the palatal vowel that conditioned the shift. Modern phonetic studies show that in V_1CV_2 utterances, V_2 can influence the phonetic quality of V_1 (Öhman 1966).

Two points must be clarified. I do not claim that all those sound changes involving a shift in one segment conditioned by some *conditioning environment*, where phonetic studies can show a parallel but synchronic conditioned change, must necessarily show simultaneous loss of the *conditioning environment*. Vowel harmony results from sound changes that are very much akin to umlaut but in this case the conditioning environment is not lost. What I do claim in all these cases, whether the conditioning environment is lost or not, is that before the sound change occurs, the conditioning environment and the conditioned change are mechanically linked; the latter appears only if the former does and the listener knows this and can exploit this knowledge to undo the conditioned change. After the sound change the listener does not recognize the two as mechanically linked and the conditioned change exists independently of the conditioning environment. For ease of reference I will refer to these sound changes as the type involving "uncorrected distortion." Naturally, if the listener doesn't detect the conditioning environment, he won't be able to apply his knowledge of the link it has with other phonetic events. But there may be other reasons why listeners either fail to be aware of these links or if they are aware of them, fail to exploit them (Ohala, in press a).

I also do not claim that these uncorrected distortion-type of sound changes involve only the loss of the mechanical link between conditioned change and the conditioning environment. Some exaggeration and other qualitative changes in phonetic character of what was previously a distortion may also take place by mechanisms I have not discussed. For example, the tonal contrasts precipitated by loss of the voicing contrast in prevocalic consonants may be differentiated by larger pitch intervals than those previously caused by the physical phonetic constraints. Also, the [y] that our listener-turned-speaker in Scenario 2 utters is articulated with a single palatal constriction and thus differs from the vowel the speaker produced which just sounded like an [y] since it was made with a dental constriction superimposed on an [u].

There are some interesting implications which follow from Scenario 2. First, there is no need to invoke unwarranted teleological notions to explain sound changes which constitute uncorrected distortions. Lightner (1970) claimed that the reason why vowels became nasalized when a following nasal consonant was dropped was to preserve information about the lexical identity of the form. It is difficult to defend such claims even on logical grounds. If speakers have such control over the way their pronunciation changes, then why did they let the final nasal consonant drop in the first place? But now it is apparent that teleology isn't even needed for such cases: the nasalization of a vowel in the environment of a nasal is a phonetically natural distortion evident in languages like English. All that is needed to make the nasalization evident and independent of the nasal consonant is the dropping or attenuation of that nasal consonant, as shown by Kawasaki. The only teleology that needs to be invoked is to allow that the listener aims to pronounce words as nearly as possible in the way he has heard them from others.

Second, this scenario reduces the pressure to re-cast this type of sound change into two or more steps, as in (5), at least if all

(5) VN → ṼN → Ṽ

all the steps are said to represent the same level of description, typically the lexical level. One step (the broken line) will do.

Third, analyzed at the lexical level, these are phonologically abrupt sound changes. Of course, the notion that sound change is gradual is not very much in vogue these days (however, cf. Miranda 1974) due to the widespread belief--mistaken, in my opinion--that sound change is grammar change (i.e., modification of the rules in the grammar). The abruptness inherent in the sound changes represented by Scenario 2 do not involve any speaker changing the rules of his grammar.

Fourth, acceptance of Scenario 2 implies that we may investigate the mechanisms of sound change--or again, if one insists, *mini*-sound changes--right now, today, in the laboratory. The phonetic seeds of the sound change that led to tonal development in Chinese several centuries ago may be discovered and examined in the speech of contemporary English speakers. There have already been several laboratory-based studies of sound change which have been motivated by this view (Haden 1938; Ohala 1974a, 1975a, in press b; Ohala & Amador 1981; Kawasaki 1978; Javkin 1979; Wright 1980). Many of the standard phonetic literature may be re-examined for its relevance to sound change. The benefit, however, is not only in one direction: I believe that a study of sound change can also give us insight into the complex mechanisms of speech production and perception. Historical linguistics, in spite of its "dusty tome" image, has a great deal of practical applicability to work in speech recognition and speech pathology (Ohala 1975b, 1980, 1981, in press a; Greenlee & Ohala 1980).

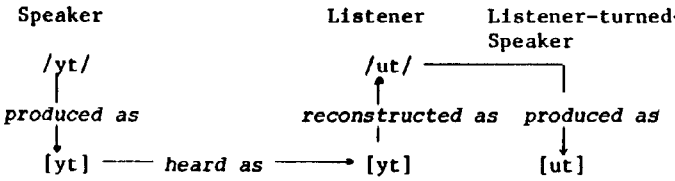
Scenario 2, like Scenario 1, has a visual analogue. Anyone who has taken a colored photograph of people or objects illuminated by the setting sun is often surprised at how red everything is in the finished photograph because "it didn't look like that when I took the picture." The reddish cast was there when the photograph was taken but wasn't noticed because the viewer's brain compensated for the color distortion. When viewing the photograph most of the cues needed to engage this compensatory color correction are absent or even contradicted by cues appropriate to other lighting conditions, thus the distorted color becomes perceptually evident. This "color change" is analogous to our "sound change."

In light of the discussion of Scenario 2 we can now see that what the listener was doing in Scenario 1 was using his knowledge to *prevent* sound change. He achieves constancy in recognized word shapes in spite of inconstancy in their transmitted acoustic form. In Scenario 2 inconstancy nevertheless gets perpetuated because the listener was prevented from applying his knowledge. Are there any instances where the listener introduces sound changes? I think there are, as detailed in the following sections.

Sound Change by the Listener

Consider Scenario 3, given in (6). Here the speaker intends to utter /yt/ and does so with acceptable fidelity such that the

(6) Scenario 3.



phonetic realization is [yt], which is also the form heard by the listener. Now, however, the listener draws upon his knowledge of how speech sounds interact and concludes, erroneously, that the vowel is distorted due to the presence of the dental consonant. He therefore "corrects" this imagined distortion and reconstructs the lexical form as /ut/. When he in turn speaks his most careful pronunciation, that is, with minimal coarticulation, will be [ut]. Thus, at the lexical level we would have a sound change /yt/→ /ut/ where a front vowel became backed in the environment of dentals, i.e., a consonant with a high F2--just the opposite of the sound change in Scenario 2.

This is not just a hypothetical scenario. (7) provides data from Slavic which gives evidence of the front vowel /a/ shifting to back /ɑ/ in the environment of palatal or palatalized consonants, i.e., consonants with high F2. Presumably the listeners took the [a] that they heard as a distorted /ɑ/ and so they hypercorrected

(7) mẽ̃guk + ājisiji > mẽ̃gučājsij > mẽ̃gučājšiji "softest"
stoj + ā- > stojā- "stand"

(Data from Darden 1970; transcription modified.)

it to /ɑ/. See Andersen (1978) for an analogous, if somewhat more complicated case.

Another relevant example is given in (8) which presents evidence of a sound change in Shona. Here a labial-velar glide /w/ changed to /ɣ/ after labial consonants. Presumably listeners felt

(8)	*Proto-Bantu*	*Pre-Shona*	*Shona*	*English Gloss*
	*-bua	> *-bwa	> -bɣa	"dog"
	*-mu-	> kumwa	> kumɣa	"to drink"

(Data from Guthrie 1967-70; Mkanganwi 1972.)

that the labial component of the /w/ was a predictable distortion introduced by the preceding labial consonant; they therefore factored it out. The velar component, however, could not be predicted by any contextual element and so it remained as /ɣ/.

These two cases, (7) and (8), are, of course, instances of dissimilation or more specifically, "contact" dissimilation or "immediate" dissimilation since the segment which was dissimilated was immediately adjacent to the segment responsible for the dissimilation. It is also known as "absorption." I believe it is possible to explain all cases of dissimilation proper, even so-called "distance dissimilation" (see below), as these two cases have been explained: as due to a misapplication of listeners' reconstructive rules.

Dissimilation proper consists of one of two speech sounds causing the other to lose one or more features which they share (Grammont 1965:269).[1] By adding the term 'proper' in this definition I mean to exclude cases said to exhibit dissimilation but which fail to meet the criteria suggested by Togeby (1964). For example, to count as a serious candidate for classification as dissimilation, the sound that changes in the environment of the same or similar sound should not change in the same way when a similar sound is absent in the immediate environment. Many cases of alleged dissimilation were quite properly dismissed by Togeby for this reason. Also, we should not count as dissimilation sound changes better explained in other ways. Thus, cases of so-called epenthetic stops such as that in (8a), rather than being explained as cases of dis-

(8a) *Earler Spanish* vendre < *Latin* ven(i)re "sell"

similation of two abutting sonorants, are better explained as cases of assimilatory denasalization of the latter portion of the nasal before a segment (the /r/) which, for articulatory or acoustic

reasons, must be non-nasal (Ohala 1975a, in press b).

This still leaves a great many interesting, indeed "classic" cases of dissimilation to deal with. I list some examples of dissimilation at a distance in (9).[2] (a) through (h) are cases of dissimilation as a process, i.e., where there has been a change in the phonetic form of words. Cases (i) through (k) are examples of "preventative" or "conservative" dissimilation where an expected sound change is blocked by dissimilation because had it proceeded it would have resulted in two similar sounds in the same word word or morpheme. Cases (l) and (m) are of unknown origin but presumably come from one of the other two types.

The first problem that needs to be addressed is that unlike the Slavic and Shona cases in (7) and (8) the two sounds participating in dissimilation in (9) are not adjacent to each other. A vowel and sometimes additional sounds intervene. If one of the sounds caused dissimilation in the other it seemingly did so through "action at a distance", a concept which many phonologists, just as Newton, were unwilling to accept. But it seems unavoidable since as Sturtevant (1935) remarked a propos of Grassmann's Law, (9a, b):

> It is scarcely possible that first the intervening vowel was...endowed with aspiration and that the prior consonant was then affected by the vowel.

The solution to this problem, I think, is to consider that what Sturtevant thought was 'scarcely possible' *is* possible and, in fact, is attested. The same is true for all of the other phonetic features which figure in dissimilation, whether "at a distance" or "in contact."

It is well known that some of the most important acoustic cues for primary place of articulation and certainly for secondary articulations are the formant transitions (of F2 and F3) which spread out from the point of onset or offset of the consonant into the preceding or following vowel, respectively. These formant transitions can be of varying durations from 30 msec on up to 60 msec or more (Lehiste & Peterson 1961). Thus, under certain conditions all of or a major fraction of vowel's total duration may be "colored" or distorted by these transitions (Lindblom 1963).

The acoustic cues for glottalized consonants have not been studied very extensively in the laboratory but there are reliable auditory analyses which suggest that a "tense" or "creaky" voice quality which appears on adjacent vowels is one of these cues. Keller (1959), in a description of Chontal, reports that vowels contiguous to glottalized consonants may be laryngealized and, significantly, that the laryngealization is greater between two such consonants than when just next to one.

In the case of voiced aspirated or breathy-voiced consonants, it is well known that an essential perceptual cue for them is the 40 to 50 msec of breathy-voiced phonation that spills out onto the following vowel. Furthermore, the fact, exemplified in (10), that

(9) Examples of Dissimilation at a Distance.

LANGUAGE	SOURCE	EXAMPLE
(a) IE > Sanskrit	Grassmann (1863)	*bend > band- "bind"
(b) IE > Cl, Greek	Grassmann (1863)	*t^hrik^{h}os > trik^{h}os "hair"
(c) Proto-Bantu > Sukuma	Guthrie (1967-70) Bennett (1967)	*takun- > -dak^{h}un "chew" (Note: Following Bennett I take this as a case of dissimilation of aspiration; the voicing change came later.)
(d) Latin > Italian	Grammont (1965)	quTnque > cinque "five"
(e) Anc. Chinese > Cantonese	Karlgren (1923)	*pjam > pin "diminish"
(f) Proto-Quichean > Tzutujil	Campbell (1977)	*k'aq > k'^{j}aq "flea" (Cf. also Salishan (Kinkade 1973).)
(g) Proto-Quechumaran > Quechua	Orr & Longacre (1968)	*t'ant'a > t'anta "bread" (Cf. also Lahu (Matisoff 1970).)
(h) Latin > Provencal	Togeby (1964)	meretrīce > meitritz
(i) Pre-Mam > Mam	J. Robertson (p.c.)	*k'iʃbisa > k^j'iʃbisa- "to puncture (with cactus needle)" (for expected *tʃ'iʃbisa-.)
(j) Sanskrit	Allen (1951)	sarsrāṇa (for expected *sarṣrāṇa.)
(k) IE > Latin	Meillet & Vendryes (1924)	dwēmo > dēmus "while, until" (for expected *bēmus.)
(l) Arabic	Lehn (1963)	*(C V C) [phar.] [phar.]
(m) Yao	Purnell (1965)	*(C^w V C) [lab]

Cf. also: Greenberg (1950) on Arabic; Cowan (1969) on Narragansett; Longacre (1962) on Proto-Popolucan-Mixtecan; Schachter & Fromkin (1968) on Fante; Holmer (1949) on Arawak; Mukarovsky (1962/3) on Limba; Allen (1962) on Hāṛautī; Hashimoto (1970) on Ancient Chinese.

many of the "murmured" (i.e., breathy-voiced) vowels in Gujarati originated from earlier sequences of *vowel + breathy-voiced consonant*, shows that the breathy-voice feature could also spill over onto preceding vowels as well.

(10) *Middle Indo-Aryan* l$a\underline{b}$ ▸ *Gujarati* lab "benefit"

(Data from Dave 1970.)

Punjabi replaced Middle Indo-Aryan breathy-voiced consonants by tone on adjacent vowels; some otherwise puzzling aspects of this tonal development can be readily explained by assuming that the breathy-voice feature spilled over onto preceding as well as following vowels (Ohala 1973).

Even voiceless aspirated consonants can leave their trace on adjacent vowels without necessarily making them voiceless. Vowels near these consonants may be produced with a wider-than-normal glottis, even though fully voiced, and this slight glottal opening has detectable acoustic-auditory impact on the spectrum of the vowel: the bandwidth of the resonances is increased and the relative amplitude of some of the resonances is changed (Fant 1973; Fujimura & Lindqvist 1971; Ohala & Amador 1981). The usefulness of these features as cues for aspirated consonants needs to be investigated but I think a plausible case for their relevance can be made.

Therefore action at a distance is not involved and the cases in (9) reduce more or less to cases like those discussed under "contact" dissimilation, (7) and (8). That is, the shared feature of the two sounds spread onto the intervening segments and the listener erroneously attributed it to one but not both of the sounds.[3] This is represented graphically in Figure 3.

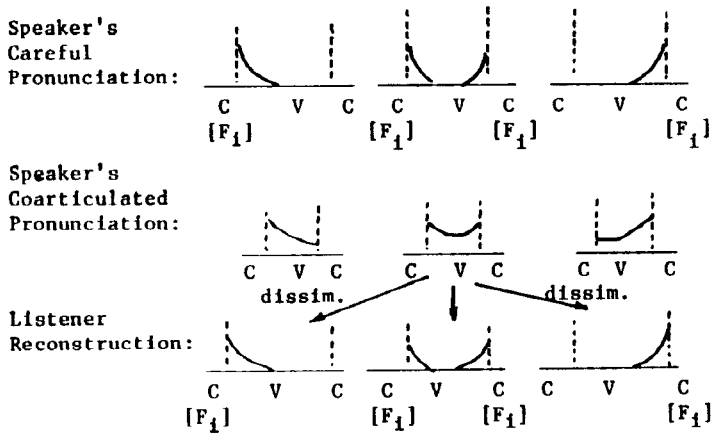


Figure 3. Parametric representation of how consonantal features spread over onto adjacent vowels.

So far I have just argued for the plausibility of the claim that the dissimilating feature could spread over onto intervening segments. What evidence is there that this *did* actually happen in the cases of dissimilation listed in (9). We should not expect it to be easy to get this type of evidence since the dissimilating feature belongs to the consonant and is present on the intervening segments only as a consonantly-induced distortion. As such, the feature is one which, as I have argued above, listeners should factor out of the vowel. It would not normally be expected to leave any trace of itself on these medial segments. Nevertheless, indirect evidence does exist to support my claim in some of the cases in (9).

In the case of Latin quīnque ‣ Italian cinque, (9d), we require evidence that the vowel intervening between the labio-velars /k^w...k^w/ was rounded by these consonants. Devine and Stephens (1977:37-42) provide this evidence, some of it direct testimony by Latin grammarians.

Yao, as indicated in (9m), repeated in (11a), has a morpheme structure constraint prohibiting morphemes having an initial labialized consonant and ending in a labial. However, it also has a constraint against morphemes with an initial labialized consonant followed by a rounded vowel, as indicated in (11b). The perturba-

(11) (a) *(C^w V C)
[lab]

(b) *(C^w V)
[round]

tion a labial or labial-velar would induce in a neighboring vowel would be a lowered F2 and/or F3. Rounded vowels also have lowered F2 and/or F3 (vis-a-vis other vowels). If we assume, as I have argued, that the dissimilation represented in (11a) came about due to the effects of the final labial consonant coloring the preceding vowel, then both (11a) and (11b) can be collapsed and expressed more generally as in (12) which simply says that an initial labialized consonant may not be followed by a vowel with a lowered F2/F3, whether this is an inherent feature or a perturbation induced by the following labial consonant. (A similar generalization may be

(12) *(C^w V)
[lowered F2/F3]

made for Cantonese (Hashimoto 1972) which not only prohibits labial final consonants in syllables beginning with labials or labial velars, but also prohibits certain rounded vowels from following those same initials.)

The Quichean dissimilation of back velars, noted in (9f), elaborated in (13), failed to occur if the intervening vowel was round. To understand this pattern we must recall that the way a back velar distorts a neighboring vowel is by lowering its F2 (like a labial, which is why both places of articulation are classified as [grave]

(13)	*Proto-Quichean*		*Tzutujil*	*English Gloss*
	keːx	▸	kʲeːx	"horse"
	kʼaq	▸	kʼʲaq	"flea"
	BUT:			
	koxl	▸	kox	"cougar"
	kʼox	▸	kʼoːx	"mask"

(Data from Campbell 1977.)

in the Jakobsonian feature system (Jakobson, Fant, & Halle 1963)) (Klatt & Stevens 1969). But a back velar cannot distort a vowel like [o] which has an F2 which is already as low as possible. One could say that the vowel [o] is "saturated" with low F2 and therefore a lowered F2, *as a property attributable to the consonant,* could not have spread onto the vowel. This limitation would not apply to the other vowels and so we may assume that the feature of lowered F2 *did* spread onto them.

There are also two interesting meta-patterns that cases of dissimilation exhibit which, as far as I know, have not been pointed out before, let alone accounted for, but which follow naturally from the hypothesis I have presented for the mechanism of dissimilation.

I have proposed that only those consonantal features should participate in dissimilation which have important perceptual cues spreading onto adjacent segments, especially vowels. Conversely, dissimilation should therefore *not* involve features of consonants which do not spill over onto adjacent segments. Taking into account the results of a wide variety of perceptual studies, I would offer the predictions stated in (14) regarding which features could be found in dissimilation, which could not, and two which I am uncertain how to classify. From personal familiarity of over 30 cases of dissimilation at a distance, I find that the vast majority involve features which I predict (post hoc, perhaps) could participate

(14)		
	Likely to dissimilate:	labialization uvularization pharyngealization palatalization retroflexion place of articulation glottalization aspiration
	Not likely to dissimilate:	fricative affricate stop voice
	???	nasal(ization) lateral

in dissimilation.

Nasal(ization) is in the "question mark" category because although nasal consonants do have perceptually relevant acoustic cues spreading onto adjacent vowels, i.e., nasalization, dissimilation should occur only if this is a perceptual cue that outweighs the perceptual cues provided by the nasal consonant itself (reduced amplitude, the nasal "murmur", etc.). This may happen in some languages. Laterals are in the same category because laterality *per se* cannot spill over onto adjacent segments. Laterals do, however, have prominent formant transitions on adjacent vowels (Lehiste 1964) but it is not clear what value these have as perceptual cues for these consonants. There are, nevertheless, well-known cases of dissimilation of laterals, one of which, from Latin, is given in (15

(15) liberalis **BUT** familiaris
mortalis popularis

It is obvious why, according to my hypothesis, we should not expect to find dissimilation of the features [fricative], [affricate and [stop]: none of them have major perceptual cues on adjacent segments. The feature [voice] is in this category, too, because although voicing obviously can be carried on vowels and other segments adjacent to voiced consonants, the voicing on the vowel does not serve as a perceptual cue to the voicing on the consonant.

Posner (1961) who surveyed instances--some critics would say "apparent instances" (Togeby 1964)--of dissimilation in Romance, concluded that the evidence for dissimilation of the features [stop] [fricative], [affricate], and [voice] is most equivocal.

There are at least two troublesome counterexamples to the predictions in (14), which I am aware of. One of these is Thurneysen's Law in Gothic (Jellinek 1926) in which the feature of [voice] on medial fricatives takes on a value opposite to that of the preceding consonant, as exemplified in (16). In Ohala (1979) I suggested that this case might be reanalyzed as the product of a prosodic phenomen which required that long and short syllables (with long and short constituent segments, respectively) alternate sequentially in the word. For aerodynamic reasons a long obstruent closure favors voicelessness, a short obstruent closure, voicing. This is, in fact, the probable phonetic basis for the variation in voicing of medial obstruents captured in Verner's Law. Flickinger (1981) has independently reached the same conclusion and has given an elegant marshalling of the philological data which support it. I am convinced by his arguments and therefore do not regard the Gothic case as a counterexample to my hypothesis.

(16) waldufni
riqiza
magaƀai

The other counterexample comes from sound changes described by Dyen (1972) from Proto-Austronesian to Ngaju-Dayak, exemplified in

(17), where two /s/'s in a form lead to the dissimilation of the first.

(17)	*Proto-Austronesian*		*Malay*	*Ngaju-Dayak*	*English Gloss*
	*sisik	>	sise?	tisik	"fish-scale"
	*susu	>	susu	tuso	"breast"

There are a number of possible resolutions of the conflict between my hypothesis and these (or any other) counterexamples:

1) discard my hypothesis,

2) reanalyze the counterexamples to show that they are not really counterexamples (such as was done for Thurneysen's Law in Gothic),

3) modify the hypothesis and the ancillary assumptions it is based on, e.g., by finding, perhaps, that fricatives do have important perceptual cues on adjacent vowels, and

4) allow that dissimilation may come about due to more than one mechanism.

Since there several as yet untried ways to rescue my hypothesis I do not feel any compulsion to discard it at present.

To digress, I would point out that the predictions in (14) have some possibly interesting implications for the reconstruction--or, one may say, the re-reconstruction of the Proto-Indo-European series of what are traditionally treated as voiced stops. As is well known, PIE roots exhibit a number of remarkable co-occurrence restrictions between initial and final consonants. Among these is the non-occurrence of two voiced stops in the same root (Meillet 1964). If this is an accurate account it constitutes yet another counterexample to my hypothesis. But Gamkrelidze and Ivanov (1973), Gamkrelidze (1975, 1979), and Hopper (1973) have questioned the identification of this series as consisting of voiced stops since, if they were, the series exhibits the typologically very odd behavior of having no */b/ (or at least a poorly represented */b/). Lack of a labial, however, is typologically common among voiceless, including voiceless glottalized series of obstruents, and thus these authors propose that this series was instead one of ejectives, i.e., /t', k'/. If these obstruents were ejectives or glottalized in some way, then the dissimilatory relationship between initial and final consonants would no longer be an exception to my hypothesis. Glottalization *is* one of the features predicted to participate in dissimilation; Quechua and Lahu, cited in (9g), constitute precedents.

The second meta-pattern shown by cases of dissimilation is one that contrasts with the patterns shown by sound changes which I have called cases of "uncorrected distortion". As schematized in Scenario 2 (3), some instances of this type of sound change involve the simultaneous conditioned change along with the loss of the conditioning environment. In cases of dissimilation, however, by the

very nature of the mechanism I propose for it, the conditioning environment could *not* be lost as part of the change--at least not at the same time. Thus, we should not find cases like those in (18), which are hypothetical remodelings of (9a) and (9d). This

(18) bend → ben (where the loss of the dissimilating segment is only found in cases where it had caused dissim.)
kʷinkʷe → kine

is so because I assume that dissimilation could only occur if the listener detected the segment which could be "blamed" for creating a distortion which would match the distinctive feature on the dissimilated segment. All the cases of dissimilation I know of adhere to this prediction, i.e., changes like those in (18) are not found.

Dissimilation also has a visual analogue. One class of probable examples are the many forms of visual illusions, one of which, a variant of the Hering figure, is given in Figure 4. Most viewers see the square which is superimposed on a background of concentric circles as having slightly inward-curving sides. In fact, the sides are straight. According to one theory (Gregory 1966) the circles lead the viewer to think he is looking at a projection of a spherical surface and that the square is projected on that surface. If this were really true the mid parts of the square's sides would indeed be curved as imagined. In other words, the viewer's brain misapplies visual constancy rules in the interpretation of the figure. Another less controversial example is ordinary camouflage. A white rabbit sitting in a snowdrift may be essentially invisible even though the viewer may be gazing directly at the patch of white contributed by the rabbit's fur. The viewer mistakenly attributes that patch of white to the background white of the snow. Likewise, to recall the Shona example in (8), the listener mistakenly attributed the labial component of the /w/ to the "background" labial consonant and thus failed to "hear" it (strictly speaking, he heard it but failed to recognize it as something distinct from the background). The labial glide was thus camouflaged by the labial consonant.

Why, it may be asked, should our brains maintain and use these reconstructive rules, both visual and phonological, if they sometimes give false information? The answer is that in the overwhelming majority of cases they give the right results: they do allow us to achieve perceptual constancy in spite of extreme stimulus variability. This may be the reason why dissimilation is far less common and less regular than other types of sound change. If they were a common source of listener and viewer error, then presumably they would not be used.

Conclusion

I have tried to marshal evidence that the listener plays an important role in sound change. First, the listener recognizes and thus factors out of the speech signal inherent phonetic variability

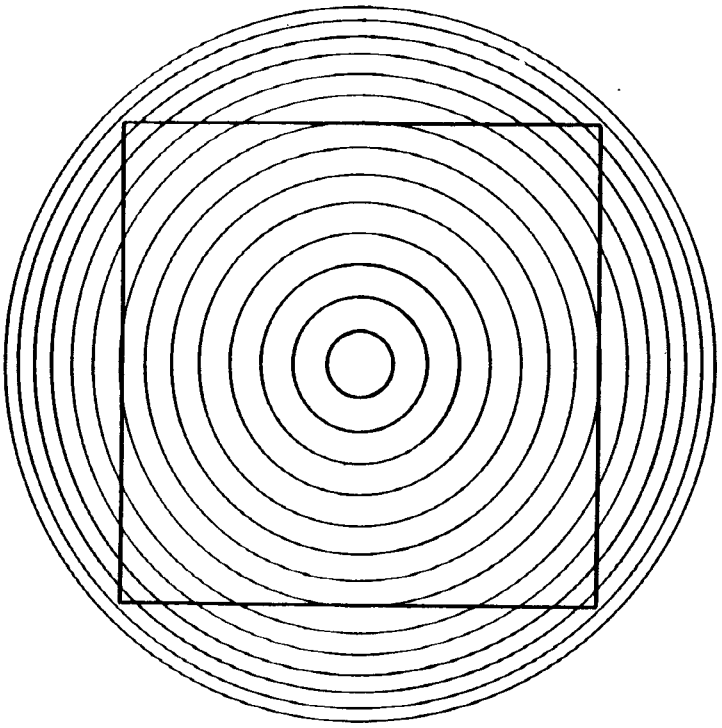


Figure 4. A variant of the Hering figure.

that would, except for his vigilance, have led to sound change. Second, the listener unknowingly participates in sound change by faithfully copying inherent phonetic variation. Third, in a few cases the listener triggers sound change by misapplying the reconstructive rules that serve to correct phonetic variability. In all these cases teleology has been reduced to a bare minimum: I assume only that speaker and hearer are interested in communicating and will pronounce words only as they have heard them (or think they have heard them) pronounced by others. Any teleological principles more powerful than that, e.g., that pronunciation is altered to make it easier, are premature and unnecessary.

My purpose in citing analogues from visual perception was not just expository. I believe that many of the principles of speech perception are similar to those used in visual perception. To the extent that we understand how perception works in one of these domains, we may well be on our way to understanding how it works in the other. Those who practice linguistics as an autonomous discipline, never straying from their dictionaries, texts, or even field notebooks,

make the task of finding out how language works a very difficult undertaking and also a much less exciting one.

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Footnotes

1 If two segments are similar in several features, dissimilati may lead to the complete elimination of one of the segments. This, I believe, is the reason for the frequent absence in languages of the world of phoneme sequences like /wu/, /ji/, and /dl-/.

2 Although I do not explicitly treat tonal dissimilation (e.g. in Hausa, cf. Hyman & Schuh 1974) and vowel dissimilation (in Finnish, Tswana, and Tamil), I think they can, in genera be accounted for by principles similar to those I invoke fo consonantal dissimilation.

3 The spread of such features onto adjacent segments, althoug motivated by physical constraints of the vocal tract, is *to some extent* controllable by the speaker. Thus, a phonetic study of pronunciation of words in Yoruba, a tone language, shows the same kind of consonantally-induced pitch perturba tions as have been found in English and French, non-tone languages, but they are shorter than those found in the lat two (Hombert et al. 1979).

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