Sound change is drawn from a pool of synchronic variation

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> "... [As for the stars] it is inconceivable that we should ever be able to study by any means whatsoever their chemical composition or mineralogical structure ..."
> Auguste Comte 1974: 74 [1830–1842].

1. Introduction

The Bible's story of the tower of Babel and similar myths in other cultures show that people have long puzzled over the causes of linguistic diversity. In addition to direct intervention by the gods, language change was also an early candidate answer to this question (see Plato's *Kratylos*) and, as is well known, is the principal cause of diversity entertained by modern researchers. I do not propose to review and evaluate the extensive literature which has accumulated over the past two millennia on the causes of language change but the title of the symposium at which this paper was given, "The causes of language change: Do we know them yet?", testifies to the fact that there has not yet been any consensus on what the causes are. In this paper I propose to give what I think is a currently acceptable answer to the question, focussing only on sound change. To give some nod to previous work on this question, I should admit that most of what I present here has been said before but perhaps not all as part of the same argument, perhaps not with the same evidential support, and perhaps coupled to other claims that I would dispute.

To give a direct answer to the question posed by this symposium: with qualifications, yes, we can identify some of the causes of sound change or at least locate the domain in which they lie. The ultimate proof of this is being able to duplicate sound change in the laboratory. Being able to study sound change in the lab is a breakthrough for historical linguistics comparable to that introduced in astronomy by Fraunhofer and Kirchhoff when they found that an analysis of light from stars could reveal their constituents in the same way that terrestrial substances could be analysed in the laboratory by their emitted or absorbed light (hence confounding Comte's prediction, the epigram offered in irony at the start of this paper). In my own work I impose a (for me) useful restriction: I study those sound changes attested in similar form in diverse languages. This helps to guarantee that they will owe something to universal and timeless physical or physiological factors – i. e., the things easily brought into the lab – and not to language- or culture-specific factors. This limitation tends to eliminate changes due to paradigm levelling, spelling pronunciations, and the like. I hasten to add, however, that there is no principled reason why these latter factors could not be studied in a controlled way – it just happens that, in general, they have not been (however, see Thumb and Marbe 1901; Bybee and Pardo 1981).

A further qualification is that we can identify only some of the causes of sound change and, perhaps, make improved speculation on some of the others. As we know from centuries of philosophical discussion, causation is a complicated matter. Consider, for example, a heart attack. Leaving aside the low-level mechanistic causes of the event (diminished oxygen supply to the heart muscles caused by a blockage of the flow of blood in the artery serving those muscles, etc.), one commonly attributes heart attacks to immediate causes or triggers such as a shock, physical exertion, and so on. But one can also identify pre-conditions which contributed to the event, e. g., the behaviour of the victim: his diet, whether he smoked, took exercise, lived a stressful life, etc. A public health official interested in improving the lot of the population as a whole would focus on the pre-condition causes since the other causes, sudden shocks, etc., are uncontrollable and can be expected to happen by chance no matter what measures might be taken. I propose to treat sound change the way public health workers treat heart attacks. By this I do not mean that I intend to try to prevent sound change – indeed, I do not think it is harmful at all and, in any case, there is little we could do to control it – but rather that I will try to identify those causes which are the preconditions for sound change. As for the immediate triggers of sound change in a particular language at a particular time, I will have little to say about them except to suggest that these things are bound to happen and that it is not so interesting to try to identify them. Opposed to this view, there are those who believe that unless a complete, nomological account can be given of the causes of sound change – that is, including why a particular sound change happened in a specific language at a specific time —, the whole enterprise is bankrupt (Dinnsen 1980; Lass 1980). I have answered these critics (Ohala 1987) by pointing out that completely nomological (exceptionless, lawful) accounts of natural phenomena do not exist in any scientific domain; all sciences resort ultimately to probabilistic explanations. That is, those causes they have under their control they deal with; those they do not, they handle in a probabilistic way. Like the public health worker, we may not be able to predict (or post-dict) everything, e. g., who will suffer a heart attack, but we can make probabilistic predictions useful enough for the larger population to make it worth the effort.

I will also have little to say beyond speculation about the spread or transmission of sound change, i. e., either how a changed pronunciation spreads through the lexicon, the segment inventory, or to other speakers of the language. I will try to show how a change in the pronunciation norm of a given word occurs in at least one speaker; what happens to this changed norm after that will involve different mechanisms and ones not properly part of the cause of change.

With these preliminaries out of the way, I now give in abbreviated form my conception of the mechanism of sound change.

2. The pre-condition cause of sound change: synchronic variation

There exists in any speech community at any point in time a great deal of hidden variation in the pronunciation of words. I say "hidden" variation because I am not referring to the obvious variation of the sort found in English *give me* vs. *gimme* or French *je ne sais pas* vs. [ʃepɑ]; such variation, in my view, is the consequence of sound changes that have already happened. Were I to include them in my account I would be, as it were, begging the question: assuming what I was required to demonstrate. By "hidden" I mean rather that speakers exhibit variations in their pronunciation which they and listeners usually do not recognize as variation. When pronunciation is transmitted, however, the existence of this variation can create ambiguity and lead to the listener's misapprehension of the intended pronunciation norm. A misapprehended pronunciation is a changed pronunciation, i. e., sound change. Analogues of the mechanism I have in mind may be found in scribal errors made by medieval manuscript copyists, in transcription errors between DNA and RNA, in the transmission errors of signals over telephone lines. In all of these cases as well as in normal speech transmission there is sufficient redundancy in the message to allow most such errors to be corrected, but the error correction is not perfect and so occasionally the signal is changed between the source and the destination.

3. Where does the variation come from?

3.1 One source of variation is the speaker

One of the most important discoveries of modern instrumental phonetics is the incredible amount of variation that exists in pronunciation, not only between speakers but also in the speech of a single speaker. This is what plagues those who are trying to accomplish automatic speech recognition. In fact, if synchronic variation is the stuff out of which sound change emerges, as I claim, the surprising thing is that sounds do not change more often. I have an answer for that, too, which I will give later but first I will give a taxonomy and examples of the sources of variation that can be traced to speech production. What is remarkable about synchronic variation in speech is the striking parallelism it exhibits with sound change manifested in dialect variation, morphophonemic alternation, and in cross-language tendencies in segment inventories, and phonotactics.

The vocal tract is a physical entity subject to physical constraints: anatomical, elasto-inertial, neuro-muscular, aerodynamic, acoustic. Whatever the intention of the speaker may be, the speech that emerges from the vocal tract is the product of that intention plus the effect of physical constraints. Though the speaker's intention may be the same from one utterance to another, the speech signal will vary if the effect of the physical constraints vary – as they will with rate and loudness of speech, etc. Some simple examples will illustrate this.

3.1.1 Aerodynamic constraints

Consider first some well-known aerodynamic constraints on voicing (Passy 1890; Chao 1936; Chomsky and Halle 1968: 301). Voicing requires a) the proper positioning of the vocal cords and b) air flow through the glottis. The rate of flow itself depends in part on there being greater air pressure below than above the glottis. During a voiced stop the air flowing through the glottis accumulates in the oral cavity and causes the oral pressure to rise. Normally within about 65 msec the oral pressure just about equals subglottal pressure, the air flow decreases, and voicing is extinguished (Ohala and Riordan 1979; Ohala 1983a). Voicing can be extended beyond this interval but only if some active measures are taken to accommodate the glottal air flow, e.g., by actively expanding the vocal tract as in done in implosives (which is apparently the option taken by Sindhi; see Ohala 1983a). The longer the stop closure or the further back the oral stop closure is made – such that there is less room for vocal tract expansion – the more likely devoicing of stops becomes.

These constraints on voicing have clearly shaped sound change in a number of languages. First, there is the purely statistical tendency that if languages have no voicing distinction in obstruents the series they do have is invariably voiceless. Second, there is the well-documented fact that if languages use the voicing contrast in stops but have gaps at certain places of articulation in the voiced series, including voiced implosives, these gaps are invariably in the back places of articulation (Chao 1936, Greenberg 1970, Gamkrelidze 1975, Sherman 1975, Pinkerton 1986, Maddieson 1984). Dutch, Thai, Czech, and many dialects of Modern Arabic show this. Third, Nubian shows morphophonemic variation that attests both to the tendency of long stop closures to devoice and for this to occur especially to back-articulated stops (Bell 1971, Ohala and Riordan 1979); see (1).

(1) Morphophonemic variation in Nubian

Noun Stem	Stem + 'and'	
/fab/	/fab:ɔn/	'father'
/sɛgɛd/	/sɛgɛt:ɔn/	'scorpion'
/kadʒ/	/katʃ:ɔn/	'donkey'
/mɷg/	/mɷk:ɔn/	'dog'

Another example of an aerodynamic constraint is that governing the generation of turbulence or frication in air flow. Briefly, frication increases

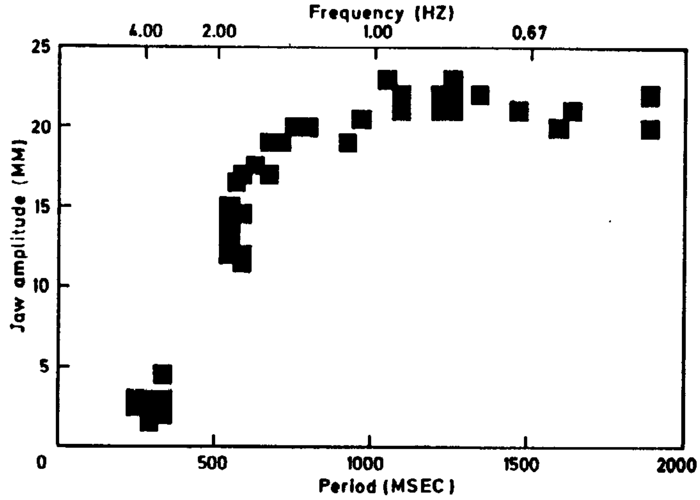

Figure 1. Amplitude (ordinate) vs. frequency (abscissa) of jaw movement during production of the sequence [sɑsɑsɑsɑ ...] spoken at a gradually increasing rate by the author. Jaw movement transduced photoelectrically.

in intensity as a function of, first, the shape of the channel through which the air flows and, second, the velocity of the air. For a given quantity of air flow (volume velocity), the velocity increases as it is forced through a channel with a smaller diameter. This is the basis for the more fricated release of stops, especially apical stops, before high vowels and glides vis-à-vis their release before low vowels. Thus, a /t/ is more likely to have a noisy release before /j/ or /i/ than before /a/ and, as is well known, gives rise to (a) the English dialectal variants /tjun/ and /tʃun/, 'tune', (b) the morphophonemic alternation act ~ actual ([ækt], [æktʃuəl]), and similar cases of spirantization in many other languages. To illustrate this phonetic effect figure 1 presents spectrographic and waveform displays of the syllables /ti/, /te/, /tɑ/ and reveals greater amplitude and duration of noise upon the release of the /t/ before /i/, less before /e/ and least before the low open vowel /ɑ/.

Other probable aerodynamic constraints which influence sound change have been reviewed in Ohala (1983 a).

Before going on to other types of constraints, let us consider the significance of the two just presented. What I am claiming is that the devoicing of voiced stops and the frication of stop releases can happen inadvertently or unintentionally. It is not so much that the spirit is willing but the flesh is weak but that the spirit is not constrained by aerodynamics but the flesh is. As a result, the speech heard by the listener contains "noise" – some extra details, some missing details, some distortions – which were not the intention of the speaker. Listeners, then, have the task of figuring out what aspects of the signal they hear is intended and what is noise. In general, they do fairly well at this but occasionally they mistake noise for signal and incorporate that into their lexical representations of words.

3.1.2 Elasto-inertial constraints

Figure 2 shows how the amplitude of jaw opening decreases when the frequency or rate of the gestures increases, i. e., when less time is allotted to it (data from a study done with Valerie Mamini; see Ohala 1981 a). The amplitude begins to show clear frequency-dependent attenuation at about 1.5 Hz ('frequency' here roughly corresponds to syllabic rate) and is subject to an absolute limit at about 4 Hz. Although more mobile articulators may be capable of faster movements, they, too, have their limits. This no doubt reflects elastic, inertial, and neuromuscular constraints (see also Nelson, Perkell, and Westbury 1984). In any case, it appears that if the rate of speaking is increased, as it is during unstressed syllables, or when a gesture has a target quite opposite from those of the segments before and after it, articulatory positions may not be achieved as well as when more time is devoted to the gesture. This is the well-known principle of "undershoot" (Lindblom 1963). I think this accounts for the frequently observed change of stops to fricatives in intervocalic position, as in Spanish, see (2a). This change, spirantization, typically affects voiced stops intervocalically more than voiceless stops, and this is true of Spanish, too; see (2b). I think this stems from the fact that voiceless stops are generally longer than voiced stops (Westbury 1979) which in turn is due in part to the aerodynamic constraint discussed earlier: voiced stops are kept short in order to avoid the constraint which imperils voicing. A further indication that it is the short time devoted to the gesture which leads to undershoot is the fact that in Spanish (and many other languages) this spirantization of voiced stops does not occur when preceded by homorganic nasals, as in (2c). In this case the stop gesture (if not all other articulatory gestures associated with the stop) is quite long: it is the duration of the closure for the nasal plus that for the

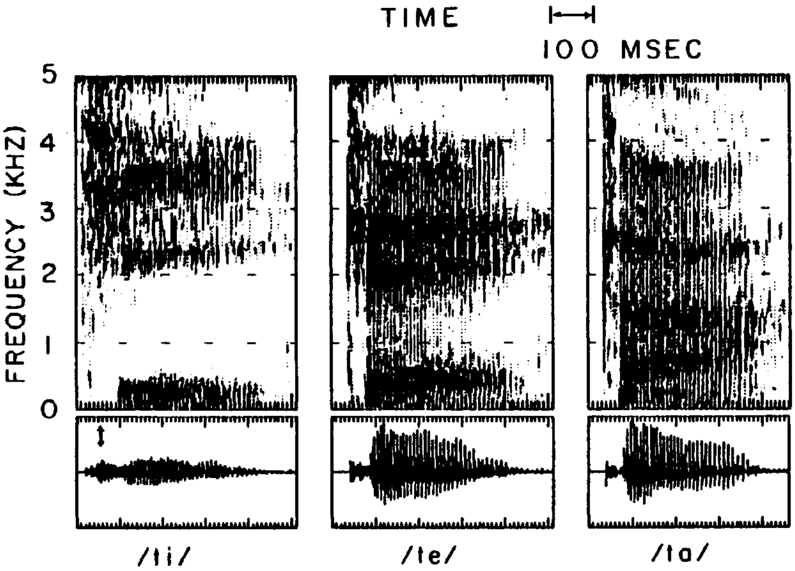

Figure 2. Spectrograms (top) and waveforms (bottom) of the syllables /ti/, /te/, and /ta/ spoken by the author. Arrows point to the greater-than-average noise at the release of the /t/ before the high close vowel /i/.

stop; as a consequence significant undershoot does not occur and the stop closure is realized as such.

(2a) /goma/ [goma] 'gum' but /mago/ [maɣo] 'magician'
/beso/ [beso] 'kiss' but /saber/ [saβeɾ] 'to know'
b) /raton/ [raton] 'mouse'
/tako/ [tako] 'wad'
c) /mango/ [maŋgo] 'handle'
/sombra/ [sombɾa] 'shadow'

Another case which probably involves elastic constraints is the perturbation of pitch (F0) after voiced and voiceless obstruents, specifically, the higher F0 found after voiceless segments as opposed to voiced. See figure 3 which shows the F0 curves on the vowels in the syllables /sɑ/ (solid line) and /zɑ/ (dashed line). This effect has been found in diverse languages (Ohala 1978 a). Its cause is not precisely known but there is good reason to suspect that like the other effects reviewed it has a physical cause – one hypothesis is that in implementing the voiced-voiceless

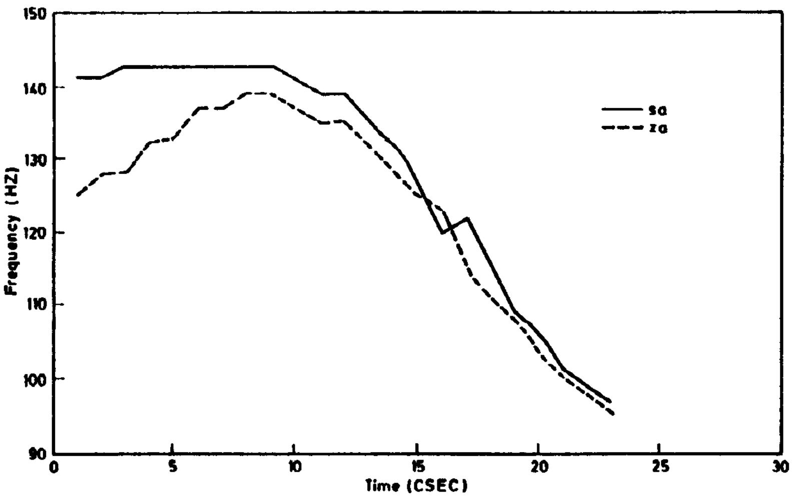

Figure 3. Fundamental frequency contours on the vowels in the syllables /sɑ/ (solid line) and /zɑ/ (dashed line), spoken by the author in the frame sentence 'Say ______'.

distinction some of the laryngeal tissues are tensed differentially in a way that affects F0 (Hombert, Ohala, and Ewan 1979, Ohala 1978 a). Quite plausibly this effect is behind the common pattern of distinctive tone developing on vowels that followed consonants that once manifested a voicing contrast (Edkins 1864: 54 ff.; Maspéro 1912: 112–114; Hombert et al. 1979; Ohala 1982); see (3, data from Svantesson 1983: 69).

(3)	*Southern Kammu*	*Northern Kammu*	
	klɑɑŋ	klɑ́ɑŋ	'eagle'
	glɑɑŋ	klɑ̀ɑŋ	'stone'

Many more examples could be offered of sources of variation that can be traced to the various physical and physiological constraints applying during speech production (Ohala 1975, 1978 b, 1980, 1983 a, b) but perhaps the ones just reviewed are sufficient to document my claim of the pervasiveness of synchronic, inadvertent variation in pronunciation.

I now turn to variation due to action of the listener.

3.2 Another source of variation is the listener

3.2.1 Confusion of similar sounds

The mapping between vocal tract shape and the output sound is a many-to-one mapping, i. e., the same or similar sound may result from two or more different vocal-tract configurations. When listeners repeat what they have heard they may use an articulation different from the original. Henry Sweet (1874: 15–16, 1900: 21–22) was among those who recognized this mechanism for sound change, exemplifying it with the variant forms of English 'through' as [θɹu] and [fɹu]. Modern acoustic analysis has revealed a great many other acoustic similarities between distinct articulations. These have been supplemented by confusion studies where listeners occasionally report they have heard a sound different from the one they were presented with. Crucially, those sounds shown to be similar by the acoustic analysis and/or the perceptual data are those which figure often in sound changes (Durand 1955; Winitz, Scheib, and Reeds 1972; Ohala and Lorentz 1977; Ohala 1975, 1978c, 1979, 1983c, 1985).

A literally classic example is the sound change of Indo-European labiovelar stops to labial stops (in certain vocalic environments) in Classical Greek, as in (4a, Meillet 1967). Other languages have similar sound changes as shown in (4b, Guthrie 1967–1970, Suarez 1973).

(4a)	*Proto-Indo-European*	*Classical Greek*	
	*ekwos	hippos	'horse'
	*gwiwos	bios	'life'
b)	*Proto-Bantu*	*West Teke*	
	*-kumu	pfumu	'chief'
	Proto-Zapotec	*Matatlan Zapotec*	*Isthmus Zapotec*
	*kkʷa-	kwan	pa 'interrogative indefinite'

This impressed many linguists as a rather dramatic change, difficult to account for in articulatory terms, and so they attempted to construct some rather fantastic intermediate stages, including labial-velar stops [k͡p, g͡b] (Whatmough 1937). They were correct that it does not lend itself to an articulatory explanation but they might have saved themselves the trouble of inventing the implausible intermediate stages. Acoustic analysis reveals that these sounds are very close. Moreover, perceptual experiments show that they (or sounds similar to them) are often confused by listeners

(Winitz et al. 1972; Ohala and Lorentz 1977; Kawasaki 1982). (Moreover, in this case acoustic theory can derive or predict the similarity from first principles; Fant 1960.)

A similar case is that of palatalized labials and palatalized velars which change to apicals, as exemplified in several languages in (5, Bělič 1966, Li 1977, Malkiel 1963, Jaberg and Jud 1928–1940, Guthrie 1967–1970).

(5)	*Standard Czech*	*East Bohemian*		
	mʲɛstɔ	nɛstɔ	'town'	
	pʲɛt	tɛt	'five'	
	Lungchow	*T'ien-chow*		
	pjaa	tʃaa	'fish'	
	Latin	*Old Spanish*	*Spanish*	
	amplu >	ampju	> antʃo	'large, spacious'
	Roman Italian	*Genoese Italian*		
	pjeno	tʃena	'full'	
	bjaŋko	dʒaŋku	'white'	
	Proto-Bantu	*Zulu*		
	pia	> -tʃha 'new'		

Again, spectrograms reveal the closeness of, e.g., palatalized labials. Figures 4a and 4b demonstrate this. (Although since these are utterances produced by a native speaker of English, instead of a distinctively palatalized labial, we will have to content ourselves with the non-distinctive palatalization of labials that occurs before the palatal vowel /i/.) Figure 4a shows that /b/ and /d/ exhibit formant 2 and 3 patterns that are quite different before the vowel /ɑ/ – in fact formant 2 is rising in the former but falling in the latter –, whereas in Figure 4b, where the /b/ is phonetically palatalized, the two sounds have very similar patterns, showing only a slightly lower formant 2 and 3 in the case of /b/. What looks similar to the eye in these displays will sound similar to the ear and thus be subject to confusion.

These results are reinforced by listening tests: listeners are presented with spoken syllables or words (usually nonsense, i.e., eliminating higher-order redundancies) and are required to identify what they think they heard. The typical tabulation of the results, a confusion matrix, see Table 1 (from Winitz et al. 1972; spoken input sounds listed vertically, responses or output listed horizontally), reveals mistakes, at least some of which occur due to the auditory closeness of the target and the reported sounds. We see from this that the consonant in the syllable /pi/ is misheard

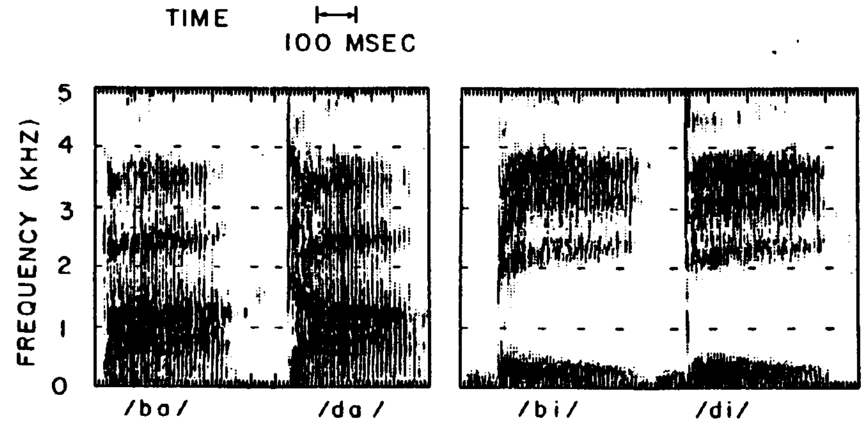

Figure 4. *a.* Spectrograms of the syllables /bɑ/, /dɑ/ spoken by the author. The transitions of formants 2 and 3 are quite different for the two stops. *b.* Spectrograms of the syllables /bi/, /di/ spoken by the author. Here the transitions of formants 2 and 3 are rather similar for the two stops.

as /t/ large percentage of time (38%), thus mirroring the sound change discussed earlier, where palatalized labials change to apicals. /k/ and /p/ also show a high degree of confusion before the vowel /u/, thus duplicating the sound change in (4). (This confusion matrix also shows an even higher percentage of confusions between /k/ and /t/ before the vowel /ɪ/, which helps to explain the very common change of "velar softening", e.g., English [tʃɪkən] 'chicken' from earlier *cicen* ([kiken]), cognate with 'cock'.)

When listeners confuse these sounds in listening tests they are, in effect, duplicating sound change in the laboratory. If they had spoken their responses out loud instead of marking them on paper, the parallel would be even more striking; this could easily be implemented by a trivial redesign of the typical confusion study.

3.2.2 Hypo-correction

Earlier I suggested that if there is so much variation in speech we should expect far more sound change than we actually find. Of course, part of the answer to this is that the listener who has to learn the pronunciation of words by hearing them from others has multiple sources of information concerning the pronunciation norm: other speakers' pronunciation, other listeners' reactions to his attempts at pronunciation, and, in certain literate

Table 1. Confusion matrix from Winitz et al. (1972). Spoken syllables consisted of stop bursts plus 100 msec of following transition and vowel; high-fidelity listening conditions.

	Heard:	/p/	/t/	/k/
Spoken:	/pi/	.46	.38	.17
	/pa/	.83	.07	.11
	/pu/	.68	.10	.23
	/ti/	.03	.88	.09
	/ta/	.15	.63	.22
	/tu/	.10	.80	.11
	/ki/	.15	.47	.38
	/ka/	.11	.20	.70
	/ku/	.24	.18	.58

cultures, the spelling. But there is another source of error correction: the listener's experience with speech. Confronted with a potential distortion, the listener can acquire sufficient experience to be able to factor it out. He knows that a slightly affricated release to a stop before a high front vowel or glide is to be expected and that it is not part of the speaker's intention. (I believe this phenomenon is related to that usually considered in psychology under perceptual constancy, e. g., the fact that when viewing objects illuminated by the setting sun we usually factor out the reddish tint imparted to all coloured objects by the sun's light and thereby achieve some colour constancy.)

We could represent this error correction using traditional phonological shorthand: the existence of the physical processes which give rise to spurious phonetic events, e. g., affrication of stops, may be represented as in (6).

(6) t – – –→ tʃ / ____ i (physical phonetic process)

Such a process, I claim, gives rise in the mind of the listener to a rule (7) which undoes the process.

(7) tʃ – – –→ t / ____ i (corrective rule counteracting (6))

Crucial to the implementation of rule (7) is the presence of the environment. If the environment were missing, however, that is, if the listener for some reason failed to detect it, the corrective rule would not be applied. Of course, the rule would also not be applied if the listener failed to construct the rule in the first place – as might be the case with an inexperienced listener. In either case, the physical phonetic process (6) would not be undone and would be taken by the listener at "face value" as the intended pronunciation. This is transparently the scenario of many familiar sound changes, as reviewed above, i.e., they constitute what Jakobson called phonologization of what were previously contextually conditioned phonetic events. What was "noise" in the signal gets incorporated in the signal. It is important to note that (6) is not a rule of grammar; it is a rule of physics, of the vocal tract. The listener has no access to the input of the rule, i.e., the intention of the speaker; he hears and copies at face value only the output.

Some implications of this conception of these sound changes should be emphasized. The change represented in (6) is a constant one and can be expected to occur, given the proper physical conditions, in the speech of every speaker of any language at any time. A sound change – a mini-sound change, if one prefers – occurs when a listener at some point in time takes the output of the rule as the pronunciation norm. We cannot predict when this misapprehension will occur but the probability of its occurrence must be relatively high.

From this we can conclude that when the development of distinctive vowel nasalization in French is described in the typical way as in (8),

(8) bon – – → bõ

it is coded in a misleading way since it collapses two distinct processes. As given in (9) there is first a synchronic physical process of vowels being

(9) bon – – → bõn
bõn – – → bõ

nasalized before a nasal consonant, and second, there was the failure to detect the nasal consonant which therefore resulted in its omission. The first process is implemented by the speaker as an on-going condition. The second is implemented by the listener at a specific point in time. Again, neither constitutes a rule of grammar when the sound change first occurs. (It is, of course, possible that some other speakers/listeners, noticing alternate pronunciations of the same word, /bon/ ~ /bõ/, may formulate a rule in their grammars similar to (8), but such a rule or alternation, properly considered, is not part of the initiation of the sound change. It is, rather, part of the propagation of the already-initiated change.)

It is undoubtedly the case that when the vowel nasalization was taken to be distinctive by the listener it would have an exaggerated quality in his speech vis-à-vis the speech of the original speaker. Nevertheless, there is evidence that at its very inception the same degree of nasalization appears different to the listener depending on the interpretation given to it: Kawasaki (1986) showed that listeners judge the nasalization on the vowel in syllables like /mĩm/ to be greater when flanking nasal consonants have been spliced away than when they are retained.

Vowel nasalization also induces apparent changes in the quality of vowels, especially vowel height (Wright 1986). Beddor, Krakow, and Goldstein (1986) have shown that when syllables like [bẽnd] are produced, where the nasal consonant is preserved, this quality change is not noticed by listeners – presumably because they have implemented a corrective rule. But when the nasal – the segment which conditions the vowel nasalization – is deleted, the vowel quality change towards [æ] becomes readily apparent because in this case listeners cannot implement the correction.

This is a common and easily-demonstrated phenomenon using an interactive speech workstation that permits one to listen to selected parts of the speech signal: a speech sound "sounds" different depending on how much of the flanking sounds one includes. Without the flanking sounds, the stressed vowel in *welcome*, supposedly [ɛ], sounds more like [ɷ]; with the flanking sounds, the [ɛ] is readily heard. Such modified percepts mirror many common historical processes: the simultaneous change in the quality of a segment along with the loss of the environment which conditioned the change.

There are, of course, sound changes which have the character of being the phonologizations of phonetically motivated details in which the conditioning environment is not lost, e. g., vowel harmony (for its phonetic basis, see Öhman 1966). Either the corrective rules were not applied or were not created by some listeners. There is anecdotal evidence in support of the latter possibility: I interpret the vowel in *drink* as the same as that in *drip* /dɹɪp/ whereas other speakers equate it to the vowel in *dream* /dɹim/. (Similar disagreements exist about other vowels before /ŋ/ and also before /ɹ/.) Phonetically it is true that the vowel in *drink* is not identical with that in *drip* because – as I interpret it – the velar nasal has a long transition which could be taken as "tensing" the vowel. I apparently factor out this effect, attributing it to the consonant but other listeners attribute it to the vowel itself. (If the [ŋk] is spliced off, then I also hear this vowel as closer to that in *dream*.)

3.2.3 Hyper-correction

The existence of listeners' corrective rules sets the stage for another kind of variation leading to sound change: the inappropriate application of these corrective rules. The failure to implement the corrective rules was labelled 'hypo-correction'; implementing the rules when they are not called for, then, is 'hyper-correction'. This is familiar enough in other areas of grammar (e.g., the supposed Cockney [tʃɪkɪŋ] 'chicken', where the socially marked rule ɪŋ ---→ ɪn which yields [stɛpɪn] instead of [stɛpɪŋ] 'stepping', is corrected; see, however, Sivertsen 1960: 129) and it may occur as well when listeners interpret the speech they hear. A few examples:

Darden (1970) describes a case in Slavic where the front vowel [a] becomes the back vowel [ɑ] in the environment of palatal or palatalized consonants; see (10).

(10) mẽguk + ājisiji > mẽgučājsij > mẽgučɑ̄jšiji 'softest'
stoj + ā- > stojɑ̄ 'stand'

This is, on the face of it, a rather unusual development since we expect back vowels to become front in the environment of front or palatalized segments. Well, apparently so did some of the listeners of this language. Accordingly, they applied their corrective rules and factored out what they thought was the overlaid frontness and reconstructed the back vowel [ɑ].

Shona, according to Mkanganwi (1972) shows a diachronic development where the labial velar glide [w] becomes the velar [ɣ] after labial consonants, as in (11).

(11)	*Proto-Bantu*		*Pre-Shona*		*Shona*	
	*-bua	>	*-bwa	>	-bɣa	'dog'
	*-mu-	>	kumwa	>	kumɣa	'to drink'

I interpret this as some listeners taking the labial part of the labial velar glide as a predictable offglide from the preceding labial consonant and therefore factoring it out, leaving just the velar component.

These are examples of dissimilation, of course, and constitute what may be characterized as auditory camouflage, i. e., the perceiver erroneously attributing a given detail to the surroundings rather than to the object it is actually a property of, e. g., attributing the whiteness of an arctic hare to the surrounding white snow and thus not recognizing it. I believe that the account just given for cases like these, so-called contact dissimilation, also applies to the better known dissimilation at a distance, e. g., Grassmann's Law in Sanskrit and Greek. (12) gives examples of Grassmann's Law and a few other cases. (Data from Grassmann 1863, Boyd-Bowman 1954, Karlgren 1923, Campbell 1973, Orr and Longacre 1968.)

(12) Examples of dissimilation at a distance.

Languages involved			Example			
Indo-European	>	Sanskrit	*$b^h end^h$	>	$band^h$-	'bind'
Pre-Classical Greek	>	Classical Greek	*$t^h rik^h os$	>	$trik^h os$	'hair'
Latin	>	Italian	quīnque	>	cinque	'five'
Ancient Chinese	>	Cantonese	*pjam	>	pin	'diminish'
Proto-Quichean	>	Tzutujil	*k'aq	>	$k'^j aq$	'flea'
Proto-Quechumaran	>	Quechua	*t'ant'a	>	t'anta	'bread'

As before, I claim that in these cases, given the same feature playing a distinctive role in two sites in a word, the listener interpreted its presence on one site as a predictable – and therefore detachable – spillover from the other site. Consistent with this – in fact predicted by it – is that dissimilation only involves features which phonetic studies have shown to be ones whose cues spread in time, e. g., aspiration, glottalization, retroflexion, labialization, palatalization, pharyngealization, etc., but should not involve features whose cues do not span long intervals, e. g., stop, affricate. For those features whose acoustic cues are well known through phonetic studies, this prediction is borne out (Ohala 1981 b, 1986).

There is additional evidence supporting this conception of dissimilation: As I discussed earlier, sound changes that come about due to hypocorrection, which is to say those where physically caused distortions get copied or phonologized, often involve loss of the conditioning environment along with the phonetically changed segment. In contrast, in cases of dissimilation, my account predicts that the conditioning environment may not be lost at the same time as the affected segment changes. That is, to consider a possible alternative version of Grassmann's Law in Sanskrit and the dissimilation of labialization in Latin, exemplified above, the kinds of sound changes in (13) should not happen.

(13)	$\text{b}^{\text{h}}\text{end}^{\text{h}}$ > ben	(where loss of the dissimilator is only found
	$\text{k}^{\text{w}}\text{iŋk}^{\text{w}}\text{e}$ > kine	where it had caused dissimilation)

The conditioning environment may not be lost because it has to be there for the listener to assign the blame to for what he imagines to be the spread of one of its features elsewhere in the word. As far as I have been able to determine, this prediction is borne out – which amazes me since it could so easily have been falsified.

Furthermore, as pointed out to me by Paul Kiparsky, this account also explains what up to now remained a puzzle: sound changes due to hypo-correction often create new segments, e.g., the case mentioned above of the development of distinctive nasalization on vowels in French; but sound change due to dissimilation invariably results in segments already attested in the language's segment inventory, e.g., in Grassmann's Law the deaspiration of the voiced aspirates resulted in segments, the simple voiced stops, which were well established in the Sanskrit segment inventory. This would follow from the view of dissimilation as a normalizing or corrective process (even if inappropriately applied); the output of corrective rules must be a known entity.

Finally, there is experimental evidence. Beddor et al., cited above, have shown that their listeners who would compensate for the distorting effects of nasalization on vowel quality occasionally overcompensated and reacted as if the vowel they heard had a height in the direction opposite that caused by nasalization.

4. Discussion

I have given a relatively abbreviated account of what I believe to be some of the causes – the pre-conditions – of common sound changes attested in many unrelated languages. Although, as mentioned earlier, much of what I have presented has been said before by others, it is the combination of several points which differentiates this account from previous ones. Of these points, I would emphasize two.

4.1 Eschewing teleology

First, this account of sound change is entirely non-teleological. I have not said that sounds change in order to be easier to pronounce, to be easier to hear, to make phonological systems more symmetrical, to be easier to learn, or to achieve any other goal, however desirable it may seem, a priori, to linguists. In fact, I do not think sound change creates any significant improvement or defect in language. There is sufficient redundancy in language that the message which speech encodes gets through as well (or no worse) before and after sound change. The only teleology I need in my account – a very innocent one which does not contaminate its mechanistic purity – is that listeners do their best to imitate the pronunciations they hear (or think they hear) in others' speech and thus adhere to the pronunciation norm.

I exclude teleology not because it is impossible or even implausible that speakers choose, even unconsciously, to deviate from the established pronunciation norm, but rather because it is a sound research strategy. It is too easy to invoke teleology – purpose – without any real justification. Similarly, in explanations for phenomena in the physical world we eschew explanations of the sort "God wants it that way" etc., not because we are certain that God cannot influence things – in fact we cannot be sure of this – but rather because it is an extravagant assumption, too easily invoked, which deflects us from seeking more immediate causes.

In any case, there is a certain messiness connected with many teleological accounts of language change. For example, Lightner (1970) claims that distinctive vowel nasalization arises as in (8), above, in order to prevent merger and homophony between a form /bon/ which has lost its final /n/ and coexisting form /bo/. If so, one may legitimately ask why the lexical distinction is preserved so consistently with vowel nasalization and not some other feature which would serve as well, e.g., tone or creaky voice? Also, some homophony does result from such sound changes: in the history of French, *fin* 'end' > [fɛ̃]; *faim* 'hunger' > [fɛ̃]. Finally, if speakers had such control over their speech forms as to be able to compensate for the loss of the final nasal, one wonders why they deleted the final nasal in the first place. How can speakers be masters of pronunciation change in one area but helpless victims in other cases?

Teleology has occasionally been invoked for phenomena that, if properly investigated, might be amenable to a mechanistic account. Prague school phonologists and those influenced by them emphasize the role of overall phonological structure in determining sound change, e. g., the filling of a "hole" in the sound inventory of a language in order to make it more symmetrical or in the equilibrium (Jakobson 1978 [1931]; Martinet 1952). Symmetry undoubtedly pleases the aesthetic sense of the linguist but it is not clear what its value is for the native speaker for whom the sole function of the sound inventory is its capacity to carry signals, not to serve as an object of beauty. All human languages manifest asymmetry or disequilibrium in some part of their phonology but seem, nevertheless, to function adequately for communication. Still, "hole filling" sound changes and the fact that some sound changes seem to affect whole classes of sounds, e. g., Grimm's Law, suggest that somehow the phonological system of a language does play a role. I would speculate, though, that when, to pick an example discussed above, one vowel or a subset of vowels in a language becomes distinctively nasal, as happened to the French low vowels in the tenth century (Pope 1934: 169) listeners, by definition, learn to detect the acoustic differences between an oral and a nasal vowel. To the extent that the same acoustic cues would differentiate other oral/nasal vowel pairs[1], the listeners would be predisposed – auditorily sensitive, so to speak – to the presence of nasalization on other vowels, assuming these vowels were subject to the same conditions which led to the phonologization of the vowel nasalization in the first place. That is, the scenario for becoming distinctively nasalized would be essentially the same for all vowels as schematized in (9), but its initial occurrence on one vowel would set the stage for its occurrence on other vowels. There is no need to appeal to ill-defined notions such as "system pressure", "pattern symmetry", "equilibrium", and the like, nor to maintain that the language is any better or any more "fit" as a result of these sound changes. Indeed, after French took four centuries to create nasal counterparts for all of its vowels – achieving, one might imagine, a more nearly symmetrical vowel system, a series of mergers took place among the nasal vowels such that today only certain low vowels are distinctively nasal (Pope 1934: 169 ff.). It seems languages are never satisfied! More to the point, it seems that languages are not seeking the satisfaction of some "ideal" configuration.

It is somewhat ironic that whereas in generative phonology sound changes are taken as evidence that speakers have altered their grammars (King 1969), in the picture I present here it is the *lack of sound change* (in the face of the extensive phonetic variation in speech) which prompts the hypothesis that speakers create rules – corrective rules – in their grammars; sound change itself, in its initiation, is taken to be non-mentalistic.

4.2 Studying sound change in the laboratory

Second, and this is the most important aspect, I have tried to show how most details of this account can be studied in the laboratory. I can, in fact, give recipes for eliciting in the lab sound changes caused by the different mechanisms discussed: confusion of similar sounds, hypo-correction, and hyper-correction:

1. As discussed above, to duplicate in the laboratory sound changes due to the similarity of sounds one only needs to conduct a simple listening test in which one notes instances of listeners identifying one sound as another.
2. To demonstrate hypo-correction: record speech exhibiting the kind of physical phonetic effects discussed earlier, and then let subjects listen to these samples with the conditioning environment deleted or masked. Under these conditions, listeners are unable to engage the kind of error-correcting strategies discussed above and will tend to identify the sounds in their distorted form – more so than when they hear them with the conditioning environment intact.
3. To demonstrate hyper-correction: let listeners hear speech samples having a segment bearing a particular distinctive feature juxtaposed to a segment which might have contributed that feature spuriously. Listeners will report less of that feature than is objectively present by virtue of having factored it out. The experiments by Kawasaki (1986) and Beddor et al. (1986) cited above, as well as those by Mann and Repp (1980) and Ohala and Feder (1987), illustrate this.

Bringing the study of sound change into the laboratory obviously does not by itself immediately answer all the questions one might have about the details of its mechanisms but it does permit systematic work to be started on these questions. To cite one example: it seems that a great many sound changes are asymmetrical in their direction. An important example is velar softening, k – – –→ tʃ /i, mentioned above. Significantly, this asymmetry is manifested in the confusion studies, too; Table 1 shows that /k/ was confused with /t/ before /i/ 47% of the time but /t/ with /k/ in the same environment only 9%. It is possible to offer phonetically-based hypotheses for this phenomenon (Ohala 1983 b, c, 1985) which can ultimately be subjected to laboratory evaluation.

What is important about "laboratory evaluation" is the possibility of conducting controlled observations on sound change in order to carefully evaluate competing hypotheses concerning its mechanisms. In this sense "laboratory" should not be interpreted literally as "a space equipped with an elaborate array of instruments" but rather as a set of techniques or an arsenal of methods which can be used anywhere. Having recourse to such methods is the only way the study of sound change is going to progress beyond the Kiplingesque *Just-So* stories offered in the past.

Note

1. This is largely true. Vis-à-vis their oral counterparts, nasal vowels have greater bandwidth of formants, a lower ratio of the intensity of formant 1 to that of the higher formants, and, possibly, an extra nasal formant in the region around 500 Hz (see Ohala 1975 and references therein).

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