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Verner's Law*

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1 Introduction

Verner's Law (Verner 1875) is generally recognized as one of the supreme achievements of nineteenth century linguistics. The Law, as is well known, accounts for the unexpected appearance in Germanic of voicing in fricatives. In his paper, Verner showed that the unexpected voicing was correlated with the position of the word accent in the Indo-European proto-language and attempted to provide a phonetic explanation for this fact. He suggested that fricatives had a tendency to become voiced "word internally in voiced surroundings" <"inlautend bei toenender Nachbarschaft"> (p. 114), but that this spontaneous voicing was counteracted and overcome by "the stronger airflow <that> is a property which the expiratory accent has in common with voiceless consonants" (p. 116).

Verner's explanation has two weak points: 1) It does not explain why the hypothesized natural tendency of fricatives to "become voiced in voiced surroundings" is restricted to word-internal position. Since in ordinary speech there are no pauses between words, the same phonetic conditions prevail across word boundaries, yet there is no voicing of fricatives in word-initial position. 2) Since Indo-European had a pitch accent rather than an expiratory accent, Verner also hypothesized that at an early point in history Germanic had supplemented the original Indo-European pitch accent with an expiratory accent. There is, however, no other evidence for such a development. Yet this hypothesis is crucial for Verner's account; absent the expiratory accent there is no source for the stronger airflow that, according to Verner, suppressed

* For an earlier discussion of these issues, see Noyer 1991 and Calabrese and Halle 1998. Translations here and below are mine. Thanks to Sylvain Bromberger and Andrew Nevins for helpful criticisms.

the spontaneous voicing of fricatives in voiced surroundings.

The alternative account offered in this paper makes do without either of these assumptions. It is proposed below that Verner's Law is an instance of sound change due to the addition of a phonological rule, and phonological rules, unless specifically marked, do not apply across word boundaries. The paper also shows that in the light of recent advances in the understanding of the phonetics of voicing and pitch, there is no need to posit an early development in Germanic of an expiratory accent for which there is no (other) supporting evidence. As shown in Halle and Stevens 1971, the voicing contrasts in obstruents and the pitch (F_0) contrasts of vowels are produced by the same articulatory mechanism — i.e., vocal fold stiffening. In particular, vocal fold stiffening produces voicelessness in obstruents and high pitch in vowels, whereas vocal fold slackening results in voicing of obstruents and in low pitch in vowels. Since stressed vowels have high pitch, they are produced with stiff vocal folds; unaccented vowels, by contrast, have low pitch and are produced with slackened vocal folds. The voicing of fricatives in position after unaccented (low pitch) vowels is then seen as an assimilatory process, where a particular feature ([−stiff vocal folds]) is spread from a vowel to the following fricative in the word, see (11) below.

2 On Grimm's Law, the Composite Character of Phonemes, and the Mechanism of Sound Change

One of the earliest results of linguistic research of the nineteenth century was the discovery that in words where the other IE languages have /ptk/ — i.e., a voiceless stops — the corresponding word in Germanic has /fθx/ — i.e., a voiceless fricative. Typical examples of these correspondences are the word initial consonants in (1).

(1)	Latin	Greek	Baltic	Sanskrit	Germanic	(Eng)
	ped	pod	ped	pad	fUt	(foot)
	tre:	tri	tri	tray	θri:	(three)
	kent-	he-kat	—	—	hʌndred	(hundred)

The generally accepted account of these facts is that at some point in history the speech of some speakers of the Indo-European proto-language changed.

These speakers — the forebears of speakers of the modern Germanic languages — replaced the voiceless stops /ptk/ with the fricatives /fθx/[1]. This change is commonly referred to as (Part One of) Grimm's Law.

It is to be observed that while the Germanic examples in (1) differ from the rest, the phonetic differences between the words in Germanic and their reflexes in the other IE languages are of a very restricted kind. Specifically, where other IE languages have stops — i.e., sounds produced with complete blockage of the air flow — Germanic has continuants — i.e., sounds produced with some air flowing out into the ambient atmosphere. In all other respects the Germanic /fθx/ are identical with IE /ptk/ found elsewhere: the closure in both sets is produced with the same articulator (thus, both /p/ and /f/ are produced with the lips, /t/ and /θ/ with tongue blade or coronal articulator, and /k/ and /x/ with the tongue body or dorsal articulator); moreover, in both sets, the phonemes are produced without vocal fold vibration (i.e., without voicing), and without lowering the velum (i.e., without nasalization), etc.

These regularities reflect the composite character of speech sounds; i.e., the fact that phonemes are not further unanalyzable atoms, but are rather complexes of features of the kind illustrated in (2).

(2)	p	b	f	v	m	t	d	θ	ð	s	z	n	k	g	x	ɣ	ŋ	
	−	−	−	−	+	−	−	−	−	−	−	+	−	−	−	−	+	Nasal
	−	−	+	+	(−)	−	−	+	+	+	+	(−)	−	−	+	+	(−)	Continuant
	−	+	−	+	(+)	−	+	−	+	−	+	(+)	−	+	−	+	(+)	Voiced
	L	L	L	L	L	C	C	C	C	C	C	C	D	D	D	D	D	Articulator

where the capital letters in the last row designate the different articulators of the consonant: L stands for Labial or lips, C for Coronal or tongue blade, and D for Dorsal or tongue body. (For more discussion see Halle 1995 and Halle, Vaux and Wolfe 2000.)

Though phonetic features have been familiar to scholars for generations, the idea that features rather than speech sounds are the primitive entities of phonetics in terms of which all regularities must be stated was not generally

[1] The /h/ in (1) found in English and other modern languages is the result of a subsequent change, which turned /x/ into /h/.

accepted.[2] It was assumed rather that the primitives of phonetics were the sounds (phonemes) and that the features were classificatory properties in terms of which relations between sounds are expressed. The important conceptual advance made by Jakobson and Trubetzkoy at the end of the 1920's was to shift focus and treat the features as the ultimate constituents of language. On this view, which is illustrated in the table (2), each sound is a composite entity made up of features.

It is a well-known fact that speech sounds are subject to special rules of pronunciation which differ from language to language. A simple example of this fact is that in English the voiceless stops /ptk/ are pronounced with a marked aspiration (h-sound) in the words pill, till, kill, but not in the words spill, still, skill. This is a peculiarity of English, which is not shared by French or Russian. The standard way of characterizing the English facts is to posit a special rule that states that voiceless stops are aspirated if they begin a syllable that bears stress, but are pronounced without aspiration elsewhere.

The rule mechanism provides a plausible account for the emergence of the differences between Germanic and other IE languages illustrated in (1). In particular, it is assumed here that at some point in history, a subgroup of speakers of the IE proto-language began to pronounce the voiceless stops /ptk/ as voiceless fricatives /fθx/, and that the formal reflex of this change was the addition of rule (3). (For some discussion of rule addition, see Halle 1962 and Chomsky and Halle 1968.)

(3) $[-\text{continuant}] \rightarrow [+\text{continuant}]$ in env. $\begin{bmatrix} \_\_\_\_\_ \\ -\text{voiced} \end{bmatrix}$

i.e., a noncontinuant (stop) is changed to continuant (fricative) if it is voiceless. (The actual rule was subject to the further restriction that it did not

[2] An important exception to the prevailing views was the phonetic alphabet of A. M. Bell's 1867 *Visible Speech*, where the graphic elements composing each letter stood for phonetic features i.e., specific actions of particular articulators. (See Halle 1978.) Bell's important conception of speech sounds as entities composed of more elementary features was lost when the International Phonetic Association replaced Bell's alphabet with the familiar Roman alphabet supplemented with diacritics. It is significant that in the 1920's Bell's alphabet was unknown to Jakobson and Trubetzkoy, to the point where even his name is not mentioned in the extensive correspondence between these two scholars (see Jakobson 1975).

apply after obstruents; this restriction is omitted in (3).)

The assumption here is that at least in the initial stages, the forebears of speakers of Germanic made use of rule (3), much like speakers of modern English make use of the rule of aspiration. Ultimately, the rule was dropped and its effects were directly reflected in the representation of the words and morphemes. At that point, words like those in (1) were memorized by speakers as beginning with /fθx/ rather than with /ptk/, and rule (3) was dropped from the language.

3 Verner's Law

By the middle of the nineteenth century Grimm's Law — i.e., rule (3) — was generally recognized as an essential step in the evolution of the Germanic languages from the IE proto-language, and much scholarly research was devoted to documenting its effects in the different Germanic languages. This research discovered that many of the fricatives that arose as a result of rule (3) were — unexpectedly — voiced rather than voiceless. This was a serious embarrassment to the linguistics of the 1860's and 1870's, for as Karl Verner, the scholar who actually discovered the explanation for these unexpected facts, wrote:

(4) Indeed, comparative linguistics cannot exclude accidents altogether; but it cannot admit accidents en masse like those here, where the irregular changes are almost as frequent as the regular ones. In such cases there must exist — as it were — a rule for the irregularity; it is necessary only to discover it. (101)

The regurality that Verner discovered was stated by him as in (5)[3]:

(5) IE *k,t,p* first changed everywhere into *h,þ,f*; the voiceless fricatives that arose in this manner plus the voiceless fricative *s* that was directly inherited from IE, then became themselves voiced word-internally in voiced surroundings <inlautend bei tönender Nachbarschaft>, but remained voiceless after <im Nachlaute> accented syllables. (114)

[3] Verner's statement (5) does not have the form of a rule (cf. (3)), but describes rather the effects of adding rules to the language.

For his contemporaries, the most striking aspect of Verner's account of the evolution of the IE obstruents in Germanic was his discovery that the puzzling appearance of voicing in fricatives depended on the position of the word accent. This dependence on accent was especially surprising, because the accent that Verner invoked was not the one found in the modern Germanic languages. It was rather the mobile accent of IE as found in Sanskrit, Lithuanian and some modern Slavic languages. In these languages, accent can strike any syllable of the word. This mobility of the accent still survives in the reflexes of the words in the modern languages, in examples such as those in (6), where in (6a) cognate words have stem accent (barytone), while in (6b) cognate word have suffixal accent (oxytone).

(6)		Skt	Slav	Lith	
	a.	b^hrátar	brát-a	bról-is	'brother'
		–	ív-a	íev-a	'willow'
	b.	ni:d-ám	gne:zd-ó	lizd-áms	'nest'
		ras-á:	ras-á	ras-à	'dew'

Accent mobility of the kind exemplified in (6) is completely foreign to Germanic, where word stress is known to have resided on the initial stem syllable for over 2000 years.

It was known even before Verner that the unexpected voicing never occurred in word initial position. In (5) Verner dealt with this exception by stipulating that fricatives became voiced only word-internally ("inlautend"). As shown by the examples in (1), there is indeed no voicing in word-initial position; and as shown in (7), the unexpected voicing occurs only word-internally where the preceding vowel is unstressed in the other IE languages.

(7)	Eng.	hundred	Lith. šimt-è (SgInstr)	Skt.	śat-á
		seven	Lith. septyn-ì	Vedic Skt.	sapt-á
		ear	Lith. aus-ìs	Attic Gk.	o:t-ós

In his paper Verner collected many additional examples of the same kind as those in (7) and thus established the fact that the unexpected voicing process was directly tied to the location of the IE word accent. Since in the Germanic languages words were known to have been accented on the initial syllable at a very early point in time, he concluded that the voicing process must have taken place at an even earlier time, before the mobile accent of the Indo-European

proto-language had been replaced by fixed initial stress in the languages of the Germanic branch.

As illustrated by the last example in (7) the voicing process affected not only the Germanic fricatives /fθx/, which derive from the cognate IE stops /ptk/; it also affected the fricative /s/, which the Germanic languages had inherited unchanged from the proto-language.[4] As pointed out by Verner (p. 113-f)., if the change (see (11) for a formal statement) affected all fricatives of the language, the voicing of /s/ would follow automatically. This observation allows us to draw yet a further inference about the early history of the Germanic languages. Since the fricatives other than /s/ arose in Germanic as a result of Grimm's Law (rule (3)), Verner's Law must have come into the language after Grimm's Law, but, as noted above, before the replacement of the IE mobile accent with fixed initial stress. Verner had thus reconstructed details of a state of affairs that was centuries older than that of any recorded form of Germanic. The great interest of these conclusions readily explains the general acclaim with which Verner's discovery was greeted.[5]

While most attention has been paid to this historical aspect of Verner's discovery, this was not the only issue treated in his paper. He also provided reasons for this change. As the wording of (5) shows, Verner conceived of the change as one in which fricatives became — spontaneously — voiced in voiced surroundings, with two special exceptions: in position after accented syllables and word-initially. Verner believed that "<t>he fact that voiceless fricatives in accented syllables resisted the general tendency to become voiced is readily explained physiologically" (115). He remarked that stressed vowels and voiceless obstruents are alike phonetically in that both are produced with greater, more forceful airflow, whereas in unstressed vowels and voiced obstruents the airflow is less forceful. It is this shared phonetic property of more forceful airflow that, according to Verner, explains the lack of voicing in obstruents in position after stressed vowels.

[4] The voiced counterpart of /s/ subsequently changed to /r/.

[5] It may be worth remarking in this connection that in terms familiar to phonologists of the beginning of the twenty-first century, Verner's achievement consisted in accounting for phonological regularities of great opacity (in the sense of Kiparsky 1971 and elsewhere), where the correspondences between different items are no longer "so easy to recognize that they are likely to strike immediately <even> the layman and that one need not be a linguist to appreciate their validity." (Meillet 1954, p. 4)

Purely phonetic considerations such as those adduced just above, however, cannot provide a complete explanation for Verner's Law, because the phonetic conditions are true of all languages, but only the Germanic languages were subject to Verner's Law. This objection does not arise if it is assumed, as proposed above with respect to Grimm's Law (cf. (3)) and to the aspiration of voiceless stops in English, that the change is the result of the addition of a phonological rule to the language.

On purely phonetic grounds, spontaneous voicing should have extended to word-initial fricatives where preceded by an unaccented syllable, at least in those many cases where word boundaries are not phonetically marked by pauses or otherwise.[6] As will be recalled Verner dealt with this fact by stipulating in (5) that spontaneous voicing applied only word-internally. This stipulation, however, goes beyond pure phonetics since, as just noted, word boundaries are usually not phonetically marked.

Moreover, Verner's stipulation also fails to explain the fact that there is no spontaneous voicing word-internally after unaccented prefixes such as Germanic bi-, as in English befall, or participial ga-, as in German gefallen.

None of these objections arises if, as suggested just above, sound change is assumed to be due to the addition of a rule to the phonology of the language, for in the unmarked case phonological rules do not apply across boundaries separating one word from the next or a proclitic (prefix) from the word following it.

4 On the Phonetics of Voicing

One of the first examples presented to students in elementary phonetics classes the world over is the contrast between voiced and voiceless obstruents of the kind illustrated in (8).

(8)	ice	seal	rite	time	grief	feel	rip	pea	leak	call
	eyes	zeal	ride	dime	grieve	veal	rib	bee	league	gall

Beginning students are told that the examples in the top row contrast with those in the bottom row by the absence vs. presence of periodic vocal fold vibrations in corresponding obstruents. It is usually explained that the

[6] For a review of criticisms of Verner's explanation, see Rooth 1974.

presence vs. absence of vocal fold vibration is controlled by appropriate positioning of the folds. For example, Ladefoged and Maddieson's 1996 summa of 20th century phonetic research *The Sounds of the World's Languages* states (p. 50) that "the same position <of the vocal folds – MH> as occurs in ordinary voiced vowels and in ... nasals is normally maintained in stops that are phonologically voiced." It is the relative position of the vocal folds that, according to Ladefoged and Maddieson, distinguishes this class of speech sounds from voiceless stops and continuants, "in which the vocal folds are not vibrating because they are separated by too wide an aperture." (p. 52)[7]

This traditional view of voicing goes counter to the evidence in important respects. As noted by Ladefoged and Maddieson 1996 (see pp. 66-70 and pp. 82-90), spread vocal folds do not always suppress vocal fold vibration: both voiced and voiceless aspirated stops are produced with vocal folds that are wide apart. In view of this, it was proposed in Halle and Stevens 1971 (following here Kim 1970) that vocal fold spreading is the primary mechanisms not of voicelessness, but of aspiration. Halle and Stevens 1971 went on to propose that the articulatory mechanism underlying the voicing contrast is stiffening of the folds: in obstruents stiff vocal folds prevent vibration, whereas slack or nonstiff vocal folds are required in order for the folds to vibrate.

In normal speech the direction of the air flow is outward from the lungs to the lips. This direction of the air flow is due to the fact that air pressure in the lungs is always larger than that in the ambient atmosphere. The air flows first from the lungs into the wind-pipe or trachea. It passes next through the glottis, which is a special narrowing formed by the vocal folds at the top of trachea. The air then passes through the oral (mouth) cavity and the lips out into the atmosphere.

There is an important difference between the air flow in obstruents — i.e., stops and fricatives — on the one hand, and in all other classes of speech sounds, on the other. In obstruents the air flow in the oral cavity is impeded or totally stopped by a constriction formed by the tongue or lips. In sonorants — i.e., in vowels, glides liquids or nasals — no such impediment is

[7] This was also Verner's view, who quoted Brücke's 1857 *Grundzüge der Physiologie*, that "for the voiceless (consonants) the vocal folds are wide open ... for the voiced consonants by contrast the vocal folds are narrowed almost to the point of touching ..." (116)

present, and the air is allowed to flow freely out into the ambient atmosphere.

Since in the production of obstruents air is trapped in the oral cavity, there is a pressure build-up in the cavity. Of necessity, this pressure is of a magnitude intermediate between that in the lungs and atmospheric pressure (cf. (9a)). By contrast, as indicated in (9b) in sonorants, where no air is trapped inside the mouth, the oral air pressure is the same as that of the surrounding atmosphere. As a consequence, the pressure drop across the vocal folds is smaller in the case of obstruents and larger in the case of sonorants. I have indicated this at the right side of (9).

(9) a. Obstruents: $P_{lungs} >> P_{oral} >> P_{atmospheric}$: $P_{lungs} - P_{oral}$ small
b. Sonorants: $P_{lungs} >> [P_{oral} = P_{atmospheric}]$: $P_{lungs} - P_{oral}$ large

This difference in pressure drop is of importance for matters under discussion here since it is the pressure drop across the vocal folds that constitutes the force causing the vocal folds to vibrate. The vocal folds can be prevented from vibrating by stiffening them, but this effect can be produced only when the pressure drop across the folds is small. In particular, as shown in yet unpublished work by Stevens and Halle, given a small pressure drop across the vocal folds (of 3 cm H_2O or less) an increase in the stiffness of about 30% suppresses vocal fold vibration.

This fact brings up the obvious question as to what effect the same difference in vocal fold stiffness has in sonorants, where the pressure drop across the folds is large, say 6 cm of H_2O or more. Given a drop of this magnitude, a 30% increase in vocal fold stiffness is no longer sufficient to stop the folds from vibrating. Instead, the increased stiffness results in more rapid vibrations of the folds. Acoustic theory allows us to calculate that the 30% increase in stiffness that suppresses vocal fold vibration in obstruents would result in a vowel in an increase in the rate of vocal fold vibration of about 15%, e.g., about 15Hz at a fundamental frequency of 100Hz.[8]

Differences in the fundamental frequency F_0 of this magnitude have been found to distinguish the initial portions of English vowels following voiced and voiceless obstruents. Among the earliest documentations of such

[8] The frequency of vibration varies as the square root of the stiffness. Thus an increase in stiffness of 30% will increase the frequency by a factor of the square root of 1.3 = 1.15; which amounts to an increase from 100 to 115 Hz.

differences in F_0 of vowels in these two contexts were the measurements of House and Fairbanks 1953, and their results have since been replicated in numerous further studies.

These effects on the F_0 of vowels are immediately explained by the assumption that both voicing and voicelessness in obstruents and vowel pitch are implemented by varying the stiffness of the vocal folds. This is an important improvement on the more traditional glottal aperture view of voicing discussed at the beginning of this section, for on that view the connection between the voicing of obstruents and the pitch perturbations in the following vowel needs separate explanation. Thus, in a paper devoted to this question, Kingston and Diehl (1994, 434-f.) write:

(10) The invariant lowering of F_0 implies that some laryngeal articulation in English [+voiced] stops is the same across initial and intervocalic contexts. What is this articulation and could it depress F_0 automatically in adjacent vowels? At first blush, the most likely candidate is glottal closure, but the available data ... show that glottal closure alone is sufficient neither to produce voice nor to lower F_0, and that F_0 lowering may instead come from the deliberate slackening of the vocal folds. The most troublesome fact is that a small glottal aperture does not always lower F_0, nor is F_0 always lower next to a stop with a smaller glottal aperture than next to one with a larger aperture.

Kingston and Diehl are correct that the lowering of F_0 in the vowel is due to the extension of some laryngeal articulation from the consonant to the following vowel. But, as they note, their candidate — "glottal closure" — fails to account for the data. They go so far as to propose that F_0 lowering in the vowel is due "to deliberate slackening of the vocal folds", and thus come close to the answer in Halle and Stevens 1971, but they fail to consider this proposal, even though it had been in the literature for almost a quarter century at the time Kingston and Diehl wrote their paper.[9]

To sum up, the articulatory action of vocal fold stiffening results in two distinct auditory effects: in obstruents differences in stiffening produce voicing contrasts, whereas in vowels differences in vocal fold stiffening result in F_0

[9] The Halle-Stevens 1971 paper is not listed in the bibliography of either Kingston and Diehl 1994 or Ladefoged and Maddieson 1996.

(pitch) contrasts. Vocal fold stiffening also accounts naturally for the House-Fairbanks effects, which are now seen as by-products of the speech production process, where an articulatory gesture in an obstruent is extended beyond the domain of the obstruent to the immediately following vowel.[10]

5 The Assimilation of [stiff vf]

The elimination of the feature [voice] and its replacement with the feature [+/−stiff vocal folds] changes both the form and our understanding of the nature of Verner's Law. As already noted, in many languages — arguably including the Indo-European proto-language — the difference between accented and unaccented vowels is phonetically implemented by pitch differences: accented vowels have High pitch, unaccented vowels, Low pitch. In light of the discussion in the preceding section, this means that accented vowels are [+stiff vf] and unaccented vowels are [−stiff vf], while voiceless obstruents are [+stiff vf] and voiced obstruents are [−stiff vf]. When reformulated in these terms, the change described by Verner's Law turns out to be a typical instance of feature assimilation, where the feature [−stiff vf] is spread from an (unaccented low pitch) vowel to the following fricative. We express this by the rule (11), where the feature [−stiff vf] is spread from a vowel to the following fricative.

(11) [+son] [−son]
[−cons] [+cont]
[−stiff vf]

The assimilation process in rule (11) differs from the process described by Verner in (5). As noted above, according to Verner, the change was due to fricatives becoming (spontaneously) voiced word-internally in voiced surroundings, but remaining voiceless after accented syllables, where greater airflow prevented the process from occurring. In this formulation by Verner,

[10] Kingston and Diehl report that in Tamil "F_0 differences are not always observed next to stops that differ in whether there is voicing during the closure," (436) and suggest that this difference between English and Tamil is due to differences in the phonology of the two languages. A discussion of this observation must be deferred to another occasion.

there is no phonetic relationship between the environment and the effects of the change.

In rule (11), by contrast, the change is directly related to the environment in which it occurs. But the formal expression of this fact in rule (11) is possible only because the single feature [stiff vf] has been shown to underlie both obstruent voicing and vowel pitch. The improved understanding of the nature of Verner's Law reflected in (11) is the direct result of a better understanding of obstruent voicing and its connection to the fundamental pitch of vowels discussed in sec. 4.

Feature assimilation or the spreading of a feature to an adjacent phoneme is a common occurrence in phonology and is readily explained as an instance of articulatory inertia. There are numerous examples in the literature where vowels assimilate nasality from an adjacent nasal consonant, or where a consonant assimilates backness from a following vowel (consonant palatalization in Slavic), etc. All such processes are reflexes of assimilatory rules similar to (11).

Instances where the feature [+stiff vf] is spread from one obstruent to another are well-known. For example, the exponent of the English past tense is the [+stiff vf] /t/ after stems ending with a [+stiff vf] obstruent (as in place-[t], cough-[t], bake-[t]), but the [−stiff vf] [d] elsewhere (as in play-[d], raise-[d], call-[d]). In (11), on the other hand, the feature [−stiff vf] is spread from a vowel to an obstruent. Such assimilatory processes are not uncommon. Poser 1981 discusses an example of this kind from Jabem, a Melanesian language of New Guinea, and Halle and Stevens 1971 showed that "tonogenesis" in the languages of South East Asia is the result of the spread of both [+stiff vf] and [−stiff vf] from an obstruent to the following vowel.

In summary, the replacement of the two features [voice] and [high pitch] by the single feature [stiff vf] has several desirable consequences. It allows us to view Verner's Law as an assimilatory process, a process that is both natural and widely attested in the languages of the world. The fact that the feature [−stiff vf] is spread from a vowel to a following obstruent immediately explains why the Germanic fricatives became voiced — rather than voiceless — and why this change took place in position after unstressed vowels, and not after stressed vowels. As noted above, Verner believed that pitch accents — as opposed to expiratory accents — could not affect the voicing of obstruents, and was therefore led to hypothesize that the IE pitch accent had been

supplemented by an expiratory accent before Verner's Law went into effect, a hypothesis for which there is no other evidence. This ad hoc hypothesis becomes unnecessary once it is understood that vowel pitches both affect and are affected by the voicing of obstruents. By introducing the feature [stiff vf] we have thus improved the formulation of Verner's Law, while fully preserving the force of his discovery.

6 On the Articulatory Basis of the Features

While the increase in explanatory adequacy just noted, in and of itself, justifies the replacement of the features [voice] and [high pitch] with [stiff vf], it may now be possible to "seek a level of explanation deeper than explanatory adequacy: asking not only what the properties of language are, but why they are that way." (Chomsky 2001) In seeking such a deeper explanation, it is worth noting that the two features [voice] and [high pitch] are traditionally regarded as auditory/acoustic in nature. The proposal to replace these two features by [stiff vf] therefore amounts to replacing two features that are auditory/acoustic in character by a single articulatory feature.

The replacement of auditory/acoustic features by features that are articulatory is not without precedent. In Chomsky and Halle 1968 (SPE) (see pp. 304-308) the articulatory features [back], [high] and [low] were introduced to replace the features [grave], [acute] and [sharp] that were part of the feature system of Jakobson, Fant and Halle 1951, which was explicitly acoustic, rather than articulatory in nature. As I recall it, the primary motivation for the change in SPE was a series of arguments urged on us by the late James McCawley (pc). The one that was most compelling for me was his observation concerning the rule governing consonant palatalization in Slavic.

As is well known, the Slavic palatalized consonants — i.e., consonants in which a raising of the front of the tongue to a position similar to [i] is superimposed on the primary consonantal configuration (see Ladefoged and Maddieson 1996, 363-ff.) — evolved in position before front vowels. This fact is naturally expressed as an instance where a consonant assimilates the [−back] articulation of the following vowel. This straightforward account is not available in the acoustic feature system of Jakobson, Fant and Halle 1951, because in this system front vowels are characterized as [−grave] and share this feature with the coronal consonants [t] and [č], whereas palatalized

consonant are [+sharp]. As McCawley pointed out to us, the Slavic process of palatalization would therefore have to be stated as in (12a), that is by means of a rule where there is no connection between the change and the context in which the change occurs. Once the acoustic features [sharp] and [grave] are replaced by the articulatory feature [back], the facts can be described by the simpler and more natural assimilatory rule in (12b). It is worth noting that rule (12b) bears a formal resemblance to Verner's Law as stated in (11), for in both a feature of a vowel is spread to an adjacent consonant.

(12) a. Consonants become [+sharp] in position before [−grave] vowels

b. +cons −cons

−back

We thus have two instances where the replacement of auditory/acoustic features by features based on the articulation improves the explanatory adequacy of the account of the facts. From this we might draw the further — more radical — inference that the universal system of features is composed of articulatory features exclusively and does not admit features based on auditory/acoustic properties. This implies further that all auditory/acoustic features must be eliminated from the universal feature set and replaced by features based on the articulation. A proposal to this effect was made in Halle and Stevens 1992, and additional supporting evidence is given in Halle 1995, Halle, Vaux, Wolfe 2000, and Halle 2002.

The proposal that speech perception is grounded in the articulation is a basic tenet of the motor theory of speech of the late Alvin Liberman and his colleagues at Haskins Laboratories (see Liberman 1996, Liberman and Mattingly 1985, Liberman and Whalen 2000). There is, however, a crucial difference between the motor theory and the one advocated here in that the motor theory is specifically concerned with speech production and perception, whereas the theory advanced here is not so limited.

The difference between the two theories stands out most clearly when we compare the primitive units of the two theories. In the motor theory, the primitive units are *gestures*, which are conceived as actual articulatory actions in real time. In the alternative theory advocated here the primitives are *features*, which serve a dual function. On the one hand, features are the elements in terms of which words and morphemes are represented in

speakers's memories: words and morphemes are represented in speakers' memories in the form of feature columns such as those in (2). The other function of features is to serve as instructions for the articulatory actions by means of which the words and morphemes are realized phonetically as acoustic events. Thus, each feature is also an instruction for a specific articulatory action; e.g., [+stiff vf] is interpreted as the instruction to increase the stiffness of the vocal folds; [−back] is the instruction to move the tongue body forward away from the spinal column, etc.

The instruction for articulatory action that defines a feature need not always be executed, for a speaker can think of a sequence of morphemes without pronouncing anything. Moreover, when executed in different contexts a given feature may result in strikingly different acoustic events; e.g., as explained above, in vowels the feature [+stiff vf] is manifested by vocal cord vibration with a specific frequency F_0, whereas in obstruents, the same feature results in the total absence of vocal fold vibration. But — and this is most important — features are not exclusively articulatory or perceptual entities; they are rather elements of speakers' knowledge of their language. It is only when interpreted <and executed> as instructions for articulatory actions that features give rise to specific articulatory and auditory/acoustic events. In this respect the features differ fundamentally from the gestures of the motor theory.

On the important issue of speech perception, the two theories are considerably more alike. Both theories assume that the acoustic speech signal is directly transduced by the human auditory system into the primitive entities of the respective theories; i.e., gestures or features. On this view, the acoustic signal is only one of several factors that determine the perception of speech. Liberman 1996 contains extensive evidence supporting this view.

This evidence dovetails interestingly with the evidence from recent neurophysiological research showing that humans, as well as other primates, exhibit excitations in motor areas not only when executing a particular action, but also when observing the same action being executed by another individual. According to Fadiga et al 2001, the same motor centers in the brain are activated both in the active production of speech as well as in speech perception where the perceiver engages in no overt motor activity. According to Fadiga et al. these findings imply that "speech perception and speech production processes use a common repertoire of motor primitives that during speech production are at the basis of articulatory gesture generation,

while during speech perception are activated in the listener as the result of an acoustically evoked motor 'resonance'."[11] Production and perception may therefore have a great deal more in common than has generally been supposed.

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[11] Calvert et al. 1997 report that the same areas in auditory cortex are activated both when subjects hear speech and when they see someone speaking without hearing it. "The common repertoire of motor primitives" is thus activated also by visual cues of speech.

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