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PHONETIC EXPLANATIONS FOR NASAL SOUND PATTERNS

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I. Introduction

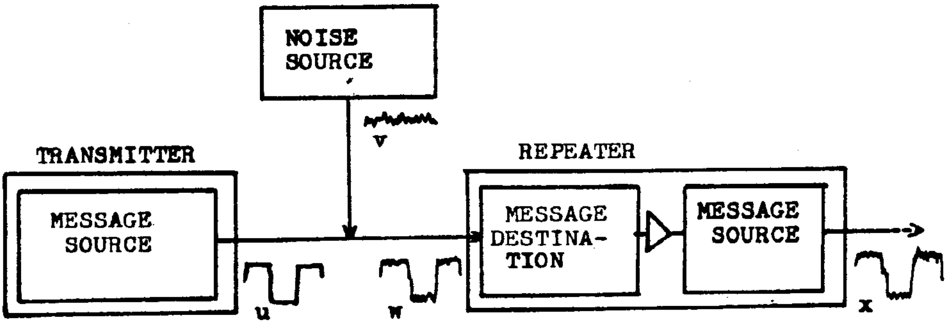
Universal sound patterns must arise due to the universal constraints or tendencies of the human physiological mechanisms involved in speech production and perception. The way the physical constraints of the speech mechanism leave their imprint on speech, particularly via sound change, can best be understood by likening speech communication to a transmission line with relay stations or "repeaters", as in Figure 1 (page 290). A transmitter sends out a signal, u, to which noise, v, is added, yielding the distorted signal, w = u + v, which is picked up by the receiver, part of the repeater unit. It is this distorted signal, w, which is retransmitted as the signal, x, sent to the next repeater.

In the case of human speech, important sources of "noise" are the constraints of the transmitting and receiving systems, that is, limitations of the vocal tract and of the auditory mechanisms. This is represented schematically in Figure 2 (page 290). The speaker, although intending to produce a certain pronunciation may, due to vocal tract constraints, actually produce something slightly different. For example, the sequence [m] + [θ] is frequently rendered as [mpe], e.g., warmth is pronounced [wɔrmpθ], i.e., with an epenthetic stop. This is due to the fact that the soft palate and vocal cords prematurely adopt the position required *for* the following [θ] even while the labial closure of the [m] is held; in other words, due to anticipatory assimilation, the [m] becomes partially denasalized. (See further discussion below.) Since the listener does not have independent access to the mind of the speaker, he may take [wɔrmpθ] to be the intended pronunciation and so, when he in turn speaks, may intentionally render the word with the epenthetic [p].

Auditory constraints affect pronunciation somewhat differently. Words containing speech signals which are auditorily ambiguous, i.e., those which, as far as the listener is able to tell, may have been produced by any one of two or more distinct articulations, may be articulatorily reinterpreted by the listener when he repeats the given word. (See also: Durand 1956, Ohala 1974a).

It seems self-evident, then, that in order to gain some understanding of the shape or of the patterning of speech sounds, including the direction of their change over the years, one must examine how the human articulatory and perceptual systems operate. I find it difficult to give serious consideration to phonological works which purport to explain the naturalness,

Figure 1.



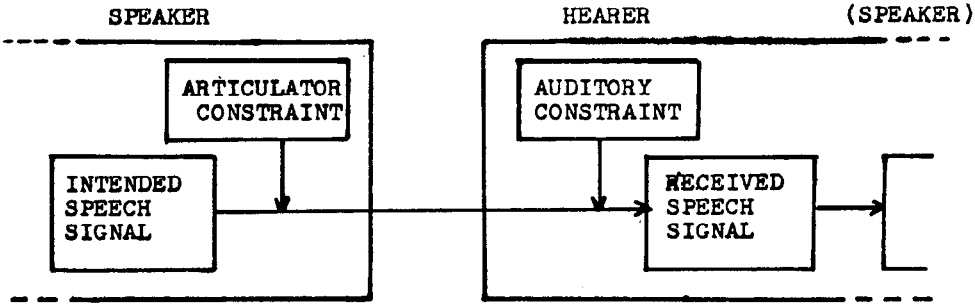


Figure 2.

expectedness, or unmarked character of sound patterns while ignoring or explicitly denying the relevance of anatomical, physiological, or acoustic-auditory aspects of speech to their task.

In this paper I will briefly review some of the known articulatory, acoustic, and auditory facts concerning nasals and nasalization and then by reference to these facts offer predictions or explanations for nasal sound patterns. Needless to say the phonetic data on nasals and nasalizations will be incomplete--either because certain points are unknown to me or are unknown in general. The validity of these predictions and explanations, then, must be tested. Nevertheless, I think this is a useful undertaking since whether the predictions are upheld or not, this will encourage us to refine and make more precise our claims and guide us in the collection of data, both phonetic and phonological.

In some cases the instrumental studies can only verify that the phonetic variation which gave rise to sound changes long ago are still present today. In this way they can show that the changes are due to universal phonetic factors even though we may not know the precise nature of these factors. Some of these may seem obvious and trivial, but this is due in part to the fact that certain details of the physics and physiology of nasals are well known. When other details are known, then, hopefully, the rest of these explanations will appear obvious, too. That is the nature of explanation: to make a relation or pattern or set of facts appear self-evident by reference to previously known or previously accepted facts.

II. Review of the phonetics of nasals and nasalization

Nasal anatomy and physiology. The most important anatomical structures for nasals are, of course, the velum and the nasal cavity. As is well known, the velum (LATIN for "veil") is a relatively thick flap of tissue that serves as a valve for directing air through the nasal cavity, if lowered, or through the oral cavity only, if raised. There are some half-dozen muscles inserting into the velum which actively control both its elevation and lowering (Fritzell 1969). Since the lowest position of the velum during speech is still higher than its position during rest (breathing through the nose) it would appear that every position of the velum during speech requires some muscular activity (Moll and Shriner 1967).

It is often suggested that the velum is a very sluggish articulator (in order to explain assimilation of velic position) but what little evidence we have suggests it is no slower than the lips or vocal cords, and probably is less slow in its movements than the tongue body (Hudgins and Stetson 1937, Scully 1974).

The nasal cavity has a fixed volume--c. 50 cm^3 (Fant 1960)--and a fixed shape, so there is no possibility of creating constrictions at various points within it as there is in the case of the oral cavity. The nasal cavity has a relatively large surface area for its volume and most of the surface is soft and acoustically absorbent.

Nasal consonants are implemented by a simultaneous oral closure (at some point from the lips to the back edge of the velum) and velopharyngeal opening (from 1 to 6 cm^2) (House 1957, Bzock 1968). Nasal vowels, glides, and "liquids" combine an oral opening with a velopharyngeal opening.

The nasal cavity itself and its termination, the nostrils, offer little resistance to air flow (c. 2.0 cm H_20/liter/sec--Warren, Duany, and Fischer 1969). The velopharyngeal port offers high resistance when it is closed and variable resistance when the opening varies. The air flow during nasal consonants is directed through the nose and during nasalized vowels through the nose and the mouth. However, the actual direction of DC airflow matters only for plosives, fricatives, and trills, where the passage of air through a small aperture creates turbulence and thus audible noise. In the case of "voiceless nasals" it is the high air flow through the nostrils that creates audible turbulence. For all other sounds what matters is how the valvular action of the velum couples or uncouples the nasal resonating cavity to the oral resonating cavity.

Nasal acoustics. Nasals and nasalized vowels are rather complex acoustically. Nasal consonants' spectra are characterized by both resonances of the combined pharyngeal and nasal tract and one antiresonance of the oral side cavity. The resonances are relatively stable no matter what the consonantal point of articulation, but the frequency of the antiresonance varies inversely with the length of the oral side cavity (House 1957, Fant 1960, Fujimura 1962, Kacprowski and Mikiel 1965-66). (See Figure 3, page 293). The anti-resonance for the velar nasal is generally so high in frequency that it is perceptually less evident (since high frequencies are severely attenuated in nasal consonants). The formant transitions in adjoining vowels also serve to differentiate nasal consonants although there is evidence that these are less effective cues for differentiating place of articulation of nasals than are the formant transitions of oral obstruents (Malécot 1956, 1960a). Due to the large surface area of the nasal cavity there is considerable damping of the sound in nasals resulting in large bandwidths for nasal formants and anti-formants and a general decrease in the overall amplitude of the sounds vis-à-vis vowels (Sacia and Beck 1926). The transitions between a vowel and a nasal thus involve a step-function change in both amplitude and spectrum (House 1957).

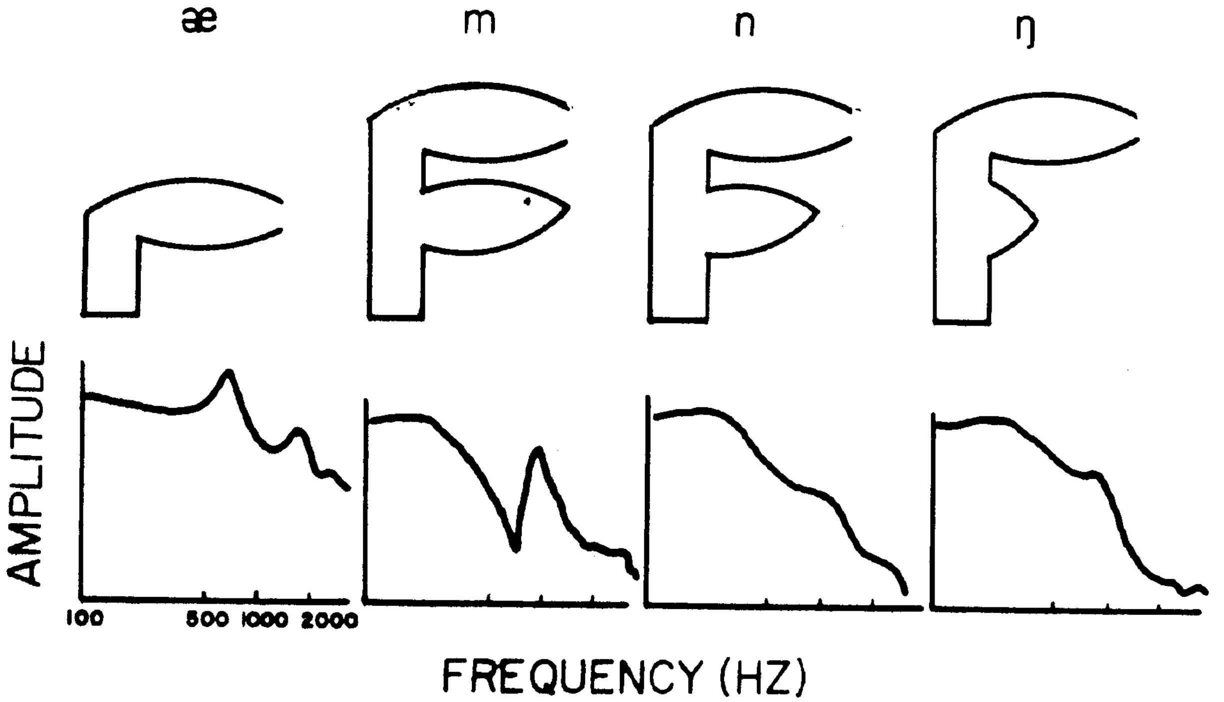


Figure 3. Top: schematic representation of resonating cavities for [æ], [m], [n], and [ŋ]. The essential articulatory difference between the various nasals consists in the length of the side (oral) cavity branching off from the main (pharyngeal-nasal) resonating cavity (after Fujimura 1962). Bottom: spectra of sounds characteristic of resonating cavities at top (from House 1957).

Nasalized vowels have an even more complicated spectrum consisting of several oral and nasal formants mixed in with anti-formants from both cavities, the exact frequencies of which depend upon (a) the vowel configuration and (b) the amount of velopharyngeal coupling of the two cavities. Compared to oral vowels, nasalized vowels will have, in theory, an upward-shifted F1 (of the oral cavity), lowered amplitude, and increased bandwidth of all formants. Additional nasal resonances may be found around 250-300 Hz and sporadically elsewhere (House and Stevens 1956, Fant 1960). House (1957), correcting the previously-reported results of House and Stevens (1956) predicted a lowering of F1 for the low vowels [æ] and [a], but still predicted a raising of F1 for non-low vowels. It is the region of the first formant, then, where the most significant acoustic changes take place in the nasalization of a vowel. The numerically first formant in the nasalized vowel's spectrum may be an upward-shifted oral F1 or a nasal formant (Fujimura and Lindqvist 1971).

Actual measurements of the spectra of nasalized vowels do reveal the predicted F1 amplitude decrease and bandwidth increase, but do not show any obvious or consistent frequency change (Dickson 1962, Smith 1951, Dave 1967, Coleman 1963, Bloomer and Peterson 1955, Björk, Nylen, Møller, and Fant 1961).

Perception of nasals and nasalized vowels. Perceptually, nasal consonants as a class are highly distinct from other consonants (except, perhaps, [l]) but are very much confused among themselves (Miller and Nicely 1955, Wang and Fillmore 1961, Singh and Black 1966, Mohr and Wang 1968, Shockey and Reddy 1974). Only the velar nasal may be confused with a nasalized vowel a significant amount (House 1957). Among nasal consonants, [ŋ] is often confused with [m] and [n], and the sequence [mi] is frequently confused with [ni] (House 1957, Malécot 1956). (It should be kept in mind, however, that most of the perceptual studies of nasals and nasalized vowels have been done using ENGLISH speakers as the listeners. Many of the results, then, may be due to facts of ENGLISH, and not due to human universal factors.)

Nasalized vowels are perceptually less distinct from each other than are oral vowels, but again, the contrast between oral/nasal in vowels is relatively high (Mohr and Wang 1968).

III. Explaining nasal sound patterns

By referring to the above empirically-determined facts, and additional phonetic facts about speech, predictions and explanations of nasal sound patterns can be attempted.

1. There can be no pharyngeal or glottal nasal consonants, assuming

these terms for place and manner of articulation are used as they are in "bilabial nasal". A complete closure in the vocal tract further back than the velopharyngeal port would make coupling or non-coupling of the oral and nasal cavities irrelevant. (This is one of the "obvious" predictions that can be made by reference to known physiological and acoustic facts. However, even this fact cannot be readily accounted for if the only representation of speech sounds one uses is a distinctive feature representation of the sort popular in the current phonological literature. What is self-evident, for example, about the incompatibility of the feature [+nasal] and $\begin{bmatrix} +\text{consonantal} \\ -\text{continuant} \\ +\text{low} \\ +\text{back} \end{bmatrix}$ or [+glottal closure] in the Chomsky and Halle 1968 feature system?)

2. Nasal consonants do not block tonal assimilation and they are not famous for causing tonal splits or for ushering tone into a language. Nasal consonants are usually voiced and they do not actively inhibit voicing. These points follow from the fact that the nasal cavity offers relatively little resistance to air flow and thus does not cause or allow any appreciable build-up of oral pressure and concomitant decrease in the pressure drop across the glottis (a decrease in the pressure drop, if it did occur, would tend to perturb pitch and, if great enough, would inhibit voicing as well). Related to this is the apparent difference in the origin of voiceless nasals versus voiceless stops. Whereas voiceless stops frequently derive from former voiced stops (since an oral stop does tend to inhibit voicing), voiceless nasals, in those cases where the history is known, seem to be derived instead from sequences of voiceless fricative + nasal, e.g., there is evidence, presented in Table 1, that BURMESE /n̥/, (actually [n̥n]), < /hn-/ < /sn-/. Children have also been reported to substitute [n̥n] for /sN/ clusters in ENGLISH (James Lorentz, personal communication).

TABLE 1. (From Graham Thurgood, personal communication).

Written TIBETAN	Written BURMESE	MODERN BURMESE	Translation
sna	hna	/n̥a/	"nose"
smin-po	hmań'	/m̥ɛ̃'/	"ripe"
snye-ma	hnam	/n̥ã/	"green"

3. Voiceless nasals are typically partially voiced, e.g., BURMESE /n̥-/ is actually [n̥n-] (Ladefoged 1971). This may be due partly to their development from fricative + nasal clusters, as mentioned above in (2), but it may also be required by acoustic-auditory facts. Acoustically the noise from all voicless nasals, no matter what their oral point of articulation, comes from the audible turbulence in the air flow at the nostrils. This noise is diffuse and low in intensity, since the nostrils cannot be constricted very much and since there are no resonance cavities in front of the nostrils. There will also be no appreciable shaping of the noise spectrum by any of the resonating cavities behind the nostrils, either. In particular there will be no significant effect due to the anti-resonances of the oral side cavity, variations in the dimensions of which are the only articulatory differences between /m̥/, /n̥/, etc. Thus the noise spectra of all voiceless nasals will be alike and will be perceptually undifferentiable. The voiced portions of the voiceless nasals may be necessary to maintain an audible difference between them. Of course, some information on the point of articulation of even a totally voiceless nasal will be provided by the formant transitions in adjacent vowels.

Like other low intensity fricatives, the voiceless nasals are indistinct and should be prone to deletion (cf. the probable development of the initial cluster in ENGLISH <u>knight</u> [kn]>[n̥n]>[n] (Jespersen 1961: 352; cf. also Grammont 1965: 95).

4. <u>Nasal-stop</u> clusters tend to be homorganic. This undoubtedly follows in part from the acoustic similarity of the various nasal consonants, i.e., as they are auditorily ambiguous as to place of articulation they may be articulatorily re-interpreted.

5. Other things being equal the nasality of a consonant is a diachronically stable feature (Chen 1973). This follows from the perceptual distinctness of nasals vs. other consonants. (The notion "perceptual distinctness" among consonants remains intuitive for the present; for a definition of distinctness in vowels, see Liljencrantz and Lindblom 1972.) Possibly related to this is the apparent fact that nasal consonants rarely present any difficulty for children learning language (Carrell 1937, Robinson 1947, Morley 1959).

6. [n] and [l] alternate. This would follow from their very similar perceptual cues: both have transitions next to vowels which involve sudden spectral and amplitude discontinuities, both maintain voicing and pitch unperturbed, and both have spectra containing anti-resonances.

7. [mi] and [ni] alternate (Chen 1973). As mentioned above, [mi] and [ni] are confused in perceptual tests (House 1957, Malécot 1956). This is probably due to the nasal murmurs and the formant transitions in the

following vowel being very similar in this particular vocalic environment (Fujimura 1962, Fant 1960). This pattern is related to that in SLAVIC where [p^j] → [t] (Andersen 1972). In general, the change [labial] → [dental] / _____ [palatal] is not uncommon.

8. The alternation [ŋ] ~ Ṽ should be more common than the alternation of other nasals with Ṽ. Perceptual experiments, cited above, reveal this pattern. House (1957) explains this by noting that the velar nasal has primarily just a single resonating cavity with a small, perhaps negligible side-cavity, unlike other nasals, and thus negligible anti-resonances with large bandwidths and is more like that of a nasalized vowel than are those of any other nasal.

9. Related to (8) is the prediction that of all the nasal consonants one would expect [ŋ] to be most prone to change or deletion. Insofar as the zero of [ŋ] is situated in the more attenuated higher frequencies, it is less perceptible than the zeroes of other nasals and thus make [ŋ] just that much less of a nasal.

10. Languages may have more contrasts in point of articulation among nasals in word final position than in word initial position. This would follow from the finding that velic opening is greater for word-final nasals than word initial nasals (Ohala 1971; see Figure 4 page 298) although we do not yet know why this is true, and from the fact that the distinctness of the spectra for the various nasal consonants is proportional to the amount of oral-nasal coupling. (Cf. also Stevens 1946 who found nasals to be better perceived post- rather than pre-vocalically.) Of course, another factor which would contribute to this pattern would be the apparent tendency of many medial or final nasals to develop from former homorganic nasal + stop clusters, the stop of which is subsequently lost (consonant deletion is more common in final position, especially in consonant clusters).

ENGLISH, of course, provides an example of a language which contrasts /m, n, ŋ/ in final position, but only /m, n/ in initial position.

This generalization, if true, goes against the usual tendency in languages to have more contrasts in syllable-initial position than in syllable-final position. However, this latter tendency probably arises due to many phonetic factors which affect obstruents (typically the majority of the sounds in languages' consonant inventories) but which do not affect nasals, e.g., final obstruents but not nasals are subject to devoicing, thus neutralizing the voicing contrast in that position (but less frequently in initial position), also obstruents but not nasals frequently contrast via differences in release (aspirated vs. unaspirated, affricated vs. plain) which cannot be reliably effected on final consonants, which are frequently unreleased.

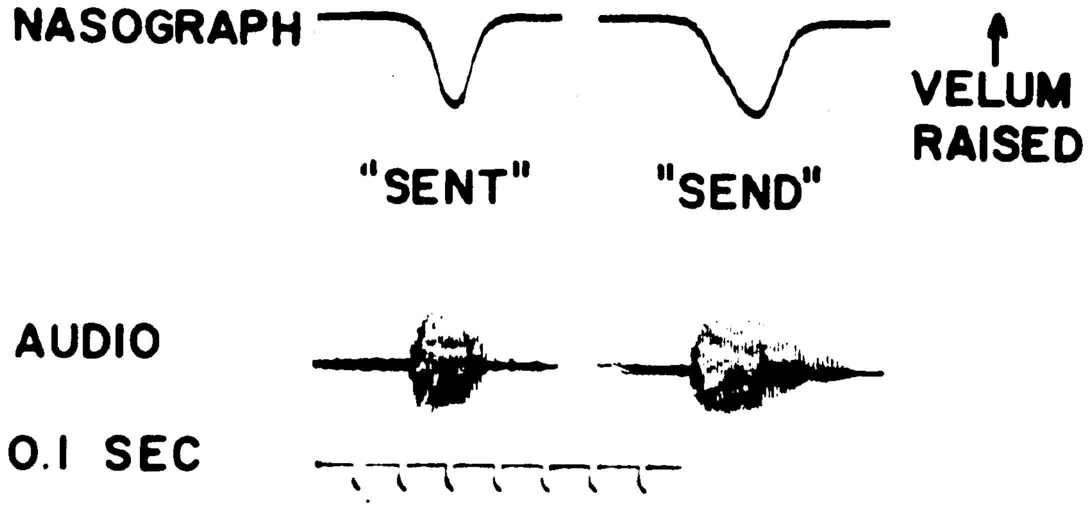


Figure 4. From top: nasograph signal, audio (voice) signal, 0.1 sec time standard. Left: the utterance "sent"; right: "send" as spoken by an adult male speaker of Midwestern American English. The amplitude of velopharyngeal opening is approximately the same for both words, however the duration of the nasal consonant is about 30 ms in "sent", 100 ms in "send".

11. Chen (1973) provides evidence from CHINESE and other languages that the order in which vowels become distinctively nasalized is low to high. Whatever may be the cause of this pattern (see discussion below), it is clear from many phonetic studies that the "seeds" of this pattern are present today in many languages not considered to have distinctive vowel nasality, since it has been widely observed that soft palate elevation for "oral" vowels varies directly with the tongue "height" of the vowel (Czermak 1857, Schuh 1858, Weeks 1893, Eijkman 1914, Nusbaum, Foley, Wells, and Judson 1935, Harrington 1944, Bloomer 1953, Croatto and Croatto-Martinolli 1959, Moll 1962, Bzock 1968, Moller, Martin, and Christiansen 1971, Ohala 1971, Benson 1972, Clumeck 1975). Also, the lower an "oral" vowel is, the more it may be perceived as nasal by trained listeners (Lintz and Sherman 1961).

An early theory attributed this to some mechanical connection between the tongue body and the soft palate--perhaps the palatoglossus muscle (Harrington 1946, Moll 1962). This theory suggested that the lower position of the soft palate during low vowels was due to some passive pull by the tongue. However recent electromyographic studies show that the muscles which control the elevation of the velum actively control the variations in velic elevation for the various vowels (Böhme, Šram, and Kalvodova 1966, Lubker 1968, Fritzell 1969, Bell-Berti 1973). As Lubker suggests, this is probably due to the fact that high vowels can least tolerate the distortions a small amount of velopharyngeal opening would induce in their spectra, whereas low vowels, for the same amount of velopharyngeal opening, would suffer less spectral change (see 12, below; also: House and Stevens 1956, Fant 1960). This, however, not only doesn't explain why low vowels become nasalized before high vowels do, it even tends to predict the opposite would happen: if nasalization crept in it would be more noticeable on the high vowels.

It may be possible to resolve this paradox. If one supposed that a lowered soft palate was tolerated on low vowels then one might guess there would be considerable variation in velic elevation on low vowels in oral environments. The fact is, though, that there is electromyographic and nasographic data showing that for many AMERICAN ENGLISH speakers the velum is actively and consistently pulled down during low supposedly "oral" vowels in oral environment, e.g., in "bad", "bod", and "bawd" (Bell-Berti 1973, Clumeck 1975). It would seem that a little bit of nasalization is not just tolerated on these vowels, it is required. This parallels tonal development from consonantally-induced perturbations in pitch: initially the pitch perturbations after stops were "accidental" but tolerated--later they became a necessary part of the contrast (Ohala 1974b, Hombert forthcoming).

Chen also claims that front vowels become nasalized sooner than back vowels of comparable height. If true, this may have an explanation similar to that for the low to high pattern mentioned above. This explanation is developed more fully in (12).

12. The extent to which oral sounds may become nasalized via assimilation depends upon their acoustic and articulatory requirements.

Nasalization would be least compatible with oral obstruents, especially stops, since the noise of fricatives and affricates and the burst at the release of stops requires a build up of air pressure in the oral cavity. This would require that no air leak out of the oral cavity into the nasal cavity. This pattern is generally well attested in the phonological literature (Schourup 1972) and in phonetic studies, too (Bloomer 1953, Hagerty, Hill, Petitit and Kane 1958, Matsuya, Miyazaki, and Yamaoka 1974, Moller, Martin , and Christiansen 1971). Predictably, cleft palate speakers have great difficulty producing adequate oral obstruents (Moore and Sommers 1973).

There are reliable reports, however, of voiced stops allowing some velic leakage at the very beginning of the stop closure, attaining a completely air-tight oral cavity only immediately before the stop release (Yanagihara and Hyde 1966), and of some voiceless fricatives having a small velic opening during part or all of their duration (Björk 1961).

Although it may be possible to produce an adequate [s], (and other voiceless fricatives), with some small velic leakage, it is extremely doubtful that voiced fricatives could be produced with a detectable amount of nasalization. Sound symbolized [ṽ], [ð̃] are claimed to exist (Anderson 1975), but it is unlikely these are fricatives (and thus obstruents) in the same sense as [v], [ð] are. They might best be considered nasalized frictionless continuants similar to [w̃] and [j̃]. In general, voiced fricatives are far less noisy than voiceless fricatives because the necessity of maintaining voicing requires that the oral pressure be less than the subglottal pressure and thus lower than the oral pressure for voiceless fricatives (which is substantially equal to subglottal pressure). If there were velic opening the oral air pressure build-up would be even less and it is doubtful that the air could be forced through the oral constriction with sufficient velocity to create detectable amounts of friction. What IPA symbols to use in transcribing these sounds may be a problem (although for [ṽ] IPA does recognize [ɱ]) but that shouldn't prevent our being able to figure out their correct physical implementation.

Glottal and pharyngeal obstruents may be nasalized for two reasons: an open velopharyngeal port would not prevent the build-up of air pressure behind the glottal or pharyngeal constrictions since it is in front of those constrictions, and the noise produced by voiceless glottal and pharyngeal obstruents is so diffuse, so low in intensity, and with higher frequencies dominating in the spectrum that oral-nasal coupling would have little acoustic effect on it (Schourup 1972, Ohala 1974b; cf. also Bloomer 1953). (See below for an additional reason why [h] and nasalization may correlate.)

As the main effect of nasalization in sonorants is in the region of the first formant, we could take as a rule of thumb: the lower is the Fl of a segment, the less will it tolerate nasalization (assuming there is reason to maintain the acoustic image of the segment); if two segments have the same Fl, the one with the lower F2 will be less tolerant of invading nasalization. Table 2 gives the frequencies of the first two formants for a number of segments (data from Lehiste 1964). Consonants and vowels are listed separately in the predicted order of least to most tolerant of nasalization.

This rule and the data on formant frequencies correctly predicts that low vowels will acquire nasalization first and that for vowels of comparable height (Fl), the fronter vowels would admit nasalization first, both of which patterns have been noted by Chen (1973). That [w, j] resist nasalization more than [l] is compatible with some of my unpublished nasograph data.

13. Given that the addition of nasalization to a vowel changes its spectrum (see above), it is likely that it will change the perceived quality of the vowel, too, even without there necessarily being any change in tongue configuration. Passy (1891), Straka (1955), Delattre (1970), and Chen (1973) cite historical evidence that nasalization tends to lower vowel quality. Some synchronic descriptions of languages report the same pattern (Beach 1938, Lowman 1932, Hyman 1975:88). Ruhlen (1974) and Rochet (1974), however, argue that the evidence is not conclusive on the point and Bhat (1975) has marshalled evidence that nasalization will tend to raise the quality of a vowel. From the predictions of House and Stevens (1956), House (1957), Fant (1960), Hecker (1962), and Fujimura and Lindqvist

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TABLE 2. (Data from Lehiste 1964)

	w	j	l	r	u	i	ɛ	ɔ	æ	a
Fl	300	250-300	400	400	310	315	535	565	600	635
F2	600	2000	900	1000-1600	785	2000	1585	915	1700	1085

(1971) (see above) concerning the shifting of the first oral formant during nasalization, one would expect that non-low vowels would appear to be auditorily lowered and low vowels raised. Complicating the picture, however, are the introduction of nasal formants, especially the first nasal formant, which in some cases might be lower in frequency than the original unshifted first oral formant (Fujimura and Lindqvist 1971). If these nasal formants are auditorily prominent then one might expect that nasalization could raise a vowel--depending on the degree of oral-nasal coupling. As mentioned above, though, acoustic studies of nasalized vowels in natural speech have not yielded any consistent findings on this point. Nevertheless, Wright (1975) in a preliminary perceptual study, obtained auditory judgments from listeners that the quality of non low vowels is lowered when nasalized, whereas that of low vowels is raised. These results parallel exactly the predictions of House and Stevens, etc.

14. The assimilation by a vowel or consonant of the position of the soft palate in an adjacent segment is widely attested. This includes both assimilatory nasalization and denasalization. (I would be unwilling to join Schacter 1969 in calling assimilatory denasalization 'unnatural'.)

Some amount of assimilation of velic position may be necessary since the soft palate cannot move from a closed to open position or vice-versa instantaneously. It might take about 50 ms. to move from a closed to an open position large enough to create noticeable nasalization. This much, then, may be physiologically necessary; any systematic anticipatory or preseveratory assimilation beyond this is best considered a language-specific development.

Assimilation of velic position, like most assimilation, is anticipatory, although perseveratory assimilation is not rare and some of it is quite striking in that it spreads through entire words (Robins 1957, Bendor-Samuel 1966). ENGLISH exhibits both anticipatory and perseveratory nasalization of vowels and anticipatory denasalization of nasal consonants (Ohala 1971a, 1971b, 1972a, 1974b).[1] In the case of ENGLISH vowels, there is greater assimilatory nasalization if the nasal consonant follows rather than precedes the vowel (see Figure 4, page 298) (Kelly 1934).

Malécot (1960) has shown that nasalization is distinctive in ENGLISH on vowels before voiceless stops, e.g., *camp* vs. *cap* [k^hæ̃p], [k^hæp]. (Nevertheless, Chomsky 1964: 96, along with many other phonologists,

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[1] Anticipatory denasalization is responsible for the so-called 'epenthetic' stops between nasals and following obstruents, e.g., the [p] in *warmth* [wɔrmpθ]. Cf. also Grandgent 1896, Millardet 1911, van Dantzig 1931, Kroeker 1972, Rousselot 1891.

seems unwilling to admit that there is distinctive vowel nasalization in ENGLISH.)

Nasalization apparently develops in this environment since the voiceless stop so shortens the preceding nasal consonant that it is no longer detectable, causing the nasalization on the vowel before it to become perceptually more salient. There is, in fact, a quite compelling impression that the vowel in "sent" is more nasalized than that in "send", but nasograph data, such as that in Figure 5 (page 304) reveal that both vowels have an equal amount of velic opening. This pattern may also underlie the HINDI morpheme structure constraint that says long nasalized vowels can be followed only by a voiceless stop or by a homorganic nasal + voiced stop, but not by a homorganic nasal plus a voiceless stop nor simply by a voiced stop without the homorganic nasal (M. Ohala 1972, 1975).

15. There are intriguing reports in the literature on sound change about vowels being more susceptible to become nasalized in the environment of certain obstruents as opposed to others, even when no nasal consonant is adjacent to it. Hetzron (1969), Ohala (1972b), Matisoff (1975) and M. Ohala (1975) cite evidence that [s], glottal and pharyngeal consonants seem to neighbor vowels that become nasalized "spontaneously". A partial explanation for the involvement of glottal and pharyngeal consonants has been given above (12). In addition, [h] may produce an effect on vowels that "mocks" that of nasalization. Because of the open glottis during phonation accompanying an [h] (or breathy-voice), the spectrum of the vowel will be changed in the following ways: there will be upward shifting of the formants, especially F1 (Ohala 1974a), increased bandwidth of the formants, presence of anti-resonances in the spectrum and an overall lowering of the amplitude of the vowel (cf. also Fant 1973: 8, Fujimura and Lindqvist 1971). This is identical to the effect of nasalization on vowels. Articulatory re-interpretation of the signal may occur, i.e., actual nasalization may be produced on the vowel.

Although I know of no reason why [s] should induce nasalization on neighboring vowels, it is interesting to note that Lintz and Sherman (1961) found that trained listeners judged vowels in the environment of continuants to be more "nasal" (perceptually) than vowels in the environment of noncontinuants.

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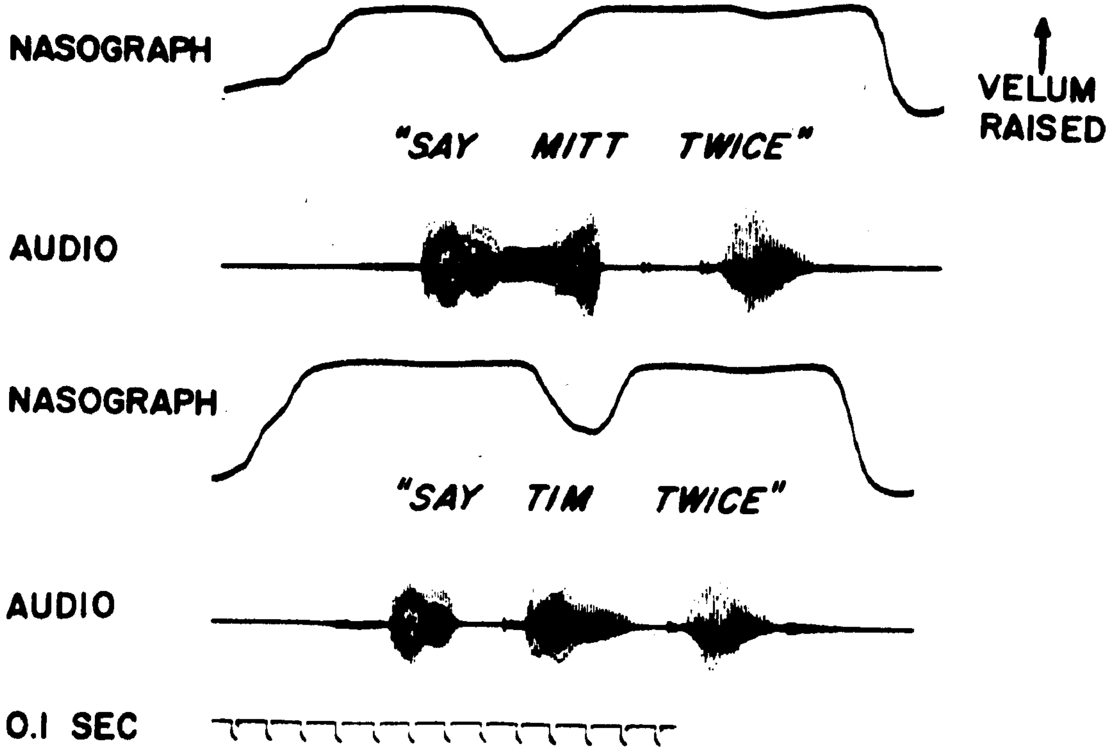

Figure 5. Parameters as in Figure 4. Velopharyngeal opening is typically greater for syllable-final nasals than for syllable-initial nasals.

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Note: These references include more works than were cited in the text. This list is offered as the beginning of a comprehensive bibliography of nasals and nasalization.

List of Abbreviations

ANPE	Archives Néerlandaises de Phonétique Experimentale
CPJ	Cleft Palate Journal
FPh	Folia Phoniatrica
ICPS	International Congress of Phonetic Sciences
IJAL	International Journal of American Linguistics
IRAL	International Review of Applied Linguistics
JASA	Journal of the Acoustical Society of America
JSD	Journal of Speech Disorders
JSHD	Journal of Speech and Hearing Disorders
JSHR	Journal of Speech and Hearing Research
Lg	Language
L & Sp	Language and Speech
PIL	Papers in Linguistics
POLA	Project on Linguistic Analysis Reports (Berkeley)
STL-QPSR	Speech Transmission Laboratory, Quarterly Progress and Status Reports (Stockholm)
SpM	Speech Monographs

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