The Oro-pharyngeal articulation of nasal vowels: Problems and perspectives

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Abstract

This paper outlines the prospectus for an instrumentally-based approach to the articulation of nasal vowels. Complexity in the acoustics of nasal vowels has long been acknowledged but complexity in their articulation has received less attention. A growing body of research suggests that velopharyngeal opening (VPO) is complemented by other articulatory gestures which may enhance or counteract the acoustic outcomes of VPO. In this paper, some of the fundamental considerations of this research are clarified and challenges for future work are described.

Index Terms: nasalization, nasal vowels, motor equivalence, articulation

1. Foundations

1.1. Motor equivalence in speech and in nasalization

The planning and implementation of movement has long been a puzzle for students of motor control. It is well known that similar movement outcomes can be attained using a variety of muscle cominbations; moreover, muscles may vary their functional roles from movement to movement [1]. These observations come under the umbrella of *motor equivalence* [2], which suggests that "a family of equivalent. . . postures are used" to reach the same goal, even under identical task conditions [3, p. 320]. Motor equivalence is implicated in speech-related movements, as well. For speech, it has been shown that the configuration of the vocal tract can change, under the influence of some obstruction, in order to achieve an intended vocalization [4, 5]. Motor equivalence may even be a necessary characteristic of speech because speakers are routinely called upon to produce what is apparently the same speech sound in multiple contexts; more generally, the speaker must reach some goal from multiple starting points. In speech research, however, it remains unsettled whether the intended goal is articulatory or acoustic [6, 7].

A potentially fruitful, albeit complex, example of motor equivalence in speech is the nasal (or nasalized) vowel.[1] Long recognized as one of the most complex objects of phonetic analysis—and one of the last to yield its secrets—nasal vowels are produced by increasing the size of velopharyngeal opening (VPO) to some critical level while also maintaining an oral outlet during phonation.

Some acoustic consequences of VPO (like F1 modulation) mimic acoustic effects that can be achieved through other articulatory means (like movements of the tongue). This leaves open the possibility that instead of modulating VPO, some other articulator may be used to achieve the acoustic consequences of VPO, either in the absence of adequate nasality or as a reinforcement of the same. For example, speakers with smaller nasal cavities, for whom the acoustic consequences of VPO alone may be somewhat weak, show a pattern of lingual and labial articulation that can be said to enhance nasality [10]. This supports the hypothesis that the acoustic characteristics of nasalization can be attained by a family of speech gestures that include, but are not limited to, the opening of the velopharyngeal port. Recent research explores this family of gestures in a variety of languages including French [11] and Hindi [12]. This paper discusses the challenges and possibilities for research on the oro-pharyngeal articulation of nasal and nasalized vowels.

1.2. Minimal difference and derivation

In any phonological inventory, nasal vowels often have oral congeners, i.e., counterparts that, at least by convention, are regarded as identical to their partners in every respect except degree of VPO. I will call this the assumption of minimal difference.

The consequences of velopharyngeal opening are often considered a series of 'changes' to the spectrum of

[1] It is standard to describe any vowel produced with an open velopharyngeal port as *nasalized* (only consonants are considered *nasal*) [8]. However, because *nasalize* carries a causative / resultative meaning, in at least some cases it seems misleading to refer to phonologically underived vowels with velopharyngeal opening as *nasalized*, particularly in cases where the provenance of these vowels is poorly understood. The term *nasal* is used less often to to refer to phonologically underived vowels that manifest velopharyngeal opening [9]. Unfortunately, we lack a convenient term, uncolored by the presence or absence of phonological process, for referring to vowels with an open velopharyngeal port. (We also lack a convenient term for designating vowels nasalized diachronically, for which the conditioning phonological environment has since disappeared.) I use *nasalized* only for vowels whose velopharyngeal opening is conditioned by synchronic phonological context; the rest, including those unspecified for phonological derivation, are *nasal*.

a nasal vowel's oral counterpart. While complex in outcome, these acoustic differences are believed to originate merely in the coupling of the oro-pharyngeal tube with the nasal cavity (including its sinuses). It is generally taken for granted that the spectrum of a nasal vowel can be derived from the spectrum of an oral vowel plus the spectrum of a nasal tube (or conjoined set of tubes), with a specified VPO. This notion is tied to the premise that nasal and oral vowels of the same quality share some strong synchronic or diachronic relationship. I will call this the assumption of derivation.

The assumption of minimal difference between oral and nasal vowel pairs /Ṽ/ and /V/, along with the assumption that /Ṽ/ is derived from /V/, lie at the heart of several claims related to the phonetics and typological distribution of nasal vowels. For example, these assumptions help account for the generalization that nasal vowels are centralized in terms of height. Made explicit, the claim goes something like this: Acoustic differences between /Ṽ/ and /V/ result from the fact that VPO has caused /V/ to become /Ṽ/. Both the assumption of derivation and the assumption of minimal difference deserve scrutiny; in this paper, the assumption of minimal difference will be considered.

Until recently, the assumption of minimal difference between oral–nasal vowel pairs has been difficult to validate instrumentally.[2] The difficulty with minimal difference stems from the limited utility of acoustic data when it comes to positing an articulatory configuration. As has long been recognized, there is a many-to-one relation between articulation and acoustics. A further complication is that VPO affects the low frequencies of vocal tract output. Consequently, classical methods of acoustic-to-articulatory mapping for oral sounds lose much of their power for nasal sounds. In the absence of VPO, for example, a rising F1 may indicate the presence of a pharyngeal constriction [13]. In the presence of VPO, on the other hand, F1 may depend as much on pharyngealization as on VPO itself. Without additional articulatory signals, these two potential causes become inextricable.

In effect, to argue that VPO raises F1 is to argue that it raises F1 *with respect to some other vowel*, just as Perturbation Theory predicts that F1 or F2 change with respect to the unconstricted vocal tract associated with [ə] [13]. This is a useful argument when a synchronic or diachronic process of nasalization is under consideration, e.g. /VN/ → [ṼN], where both the identity of /V/ and the source of nasality (here, a nasal consonant, N) are known. However, even when the assumption of derivation is supported by diachronic and / or synchronic phonological evidence, the assumption of minimal difference between nasal–oral vowel pairs may still be unfounded. For example, /Ṽ/ may differ in any number of respects (tongue height, lip rounding, pharyngeal constriction, etc.) from /V/. With respect to phonological processes like the one sketched above, the oro-pharyngeal configurations of /V/ and /Ṽ/ may differ, suggesting $/V_1/ \rightarrow [\tilde{V}_2]$, where the resulting phonetic form not only manifests VPO but a different oro-pharyngeal configuration, as well. A synchronic phenomenon along these lines has been demonstrated in American English nasalized vowels [14, 15]. Such differences can be used to explain the development and distribution (dispersion) of vowels in (phonological) nasal–oral vowel inventories [16] as well as the role of motor equivalence in the production of phonemic nasal vowels. The latter has particular implications for the remediation of speech characterized by velopharyngeal dysfunction [17].

[2] By contrast, the assumption of derivation is dependent on what is known or can be inferred about the synchronic and diachronic phonology of the language under investigation.

2. Problems

It may be helpful to outline some relevant practical challenges to this line of research, in order to lay out some goals and considerations for future work.

2.1. The acoustics of nasal vowels

Nasalization in vowels is characterized by more than one acoustic feature, including changes in the position of spectral peaks, the addition of spectral zeros, and the widening of peak bandwidths. While a number of perceptually-motivated measures have been proposed for characterizing the degree of nasality in vowels (e.g., the differential prominence of low-frequency harmonics), there is much less consensus on how the height and backness of nasal vowels should be measured. Because algorithms like linear predictive coding (LPC) are not designed to detect zeros, LPC-based automatic formant detection in nasal vowels is prone to a high error rate [12] and generally requires human intervention [18]. It seems desirable to use acoustic methods and measures that are common to oral and nasal vowels, in order to preserve our intuition that oral and nasal vowels occupy the same vowel space. In other words, it would be helpful to characterize the height and backness of nasal vowels in such a way that their relation to oral vowels can still be investigated.

2.2. The perception of oro-pharyngeal differences

So far, oro-pharyngeal differences have been posited in nasal–oral vowel pairs in French and Hindi. These articulatory differences should be used as inputs of articulatory-to-acoustic synthesis in order to determine whether the output yields a perceptible difference in vowel quality. For example, does the acoustic output of the oro-pharyngeal configuration associated with /ũ/ sound more like /o/ than /u/? The answer to this question could provide more evidence that the object of speech perception is fundamentally acoustic rather than motoric, since demonstrably different gestures are being employed to attain acoustic consequences associated with VPO. In other words, results from work on the articulation of nasal vowels could help show that speakers try to achieve an acoustic goal by whatever articulatory means are available, instead of trying to achieve a gestural goal.

2.3. The interpretation of oro-pharyngeal differences

In the case of nasalized vowels, it should be possible to extend studies like [15] to any number of languages in which coarticulatory nasalization is reported. In phonological systems with a large number of vowel qualities (like English), it may be more common to find evidence of compensatory articulatory gestures in the presence of VPO. Presumably, these gestures would serve to limit acoustic ambiguity among vowel phonemes by counteracting the acoustic effects of VPO, as posited by [15].

In the case of phonemic nasal vowels, it is not clear whether observed oro-pharyngeal differences are implicated in reinforcing the perception of nasality or simply in constructing a phonological vowel space with minimal overlap between constituents. So far, there is no evidence that phonemic nasal vowels are produced under circumstances where a novel oro-pharyngeal gesture is substituted for VPO. Because oro-pharyngeal modifications of nasal vowels seem to accompany VPO rather than replace it, one hypothesis is that additional gestures serve to enhance nasality. In this case, one might expect to find stable patterns of articulatory complementation for nasal vowels across languages, e.g., a universal like: All high nasal vowels manifest a lower tongue position than their oral congeners. If this proves true in a range of tests across different languages, a reasonable conclusion could follow along these lines: Because VPO results in acoustic centralization of nasal vowels, producing nasal vowels with less peripheral articulatory postures reinforces this acoustic tendency. In turn, such a conclusion would have implications for both auditory and proprioceptive feedback mechanisms in speech.

However, it may not be necessary to invoke an acoustic target associated with nasality to explain the presence of such articulatory behaviors. Instead, the acoustic goal may be to differentiate vowel qualities by any convenient means. By this reasoning, oro-pharyngeal differences between oral–nasal vowel pairs may be intended simply to create unique vowels instead of vowels that are somehow ‘more nasal’. Evidence of clockwise movement in the articulation of nasal vowels in both Quebecois French [11] and Hindi [12] could support, at least partially, nasal enhancement as a cross-linguistic tendency.

2.4. The effects of other resonant cavities

The acoustic effects of VPO can be mimicked by coupling the vocal tract to other resonant cavities. This can yield resonant effects similar to those of the nasal cavity and its sinuses. Through the operation of a relatively open glottis [19] the sub-glottal airway (including the trachea, bronchi, and lungs) can serve as an additional resonator [20]. In Indo-Aryan, for example, nasal vowels may have developed near voiceless consonants because anticipation of these consonants increased glottal width during the vowel. This increase in glottal width should couple the sub- and supraglottal airways to a greater extent than is observed during typical phonation [21]. Electroglottography could be used to track quantities like the glottal open quotient during nasal vowels, to determine whether greater glottal opening, and therefore greater subglottal coupling, routinely accompanies VPO.

The piriform sinuses, acoustic sidebranches that open to the hypopharynx, contribute a zero to the vocal tract transfer function and have been shown to lower F1–F4 [22]. For this reason, piriform sinus opening can be argued to have acoustic consequences comparable to those of VPO. It is as yet unknown whether piriform sinus opening cooccurs with, and perhaps complements, VPO. Advances in magnetic resonance technology have made this a tractable problem [23]. Because the contribution of other resonant cavities to the percept of nasality is potentially great, these effects should be dealt with systematically in future work.

3. Implications

3.1. Motor equivalence

The research contemplated here may result in the broad, cross-linguistic finding that speakers articulate nasal vowels using gestures that can be argued to enhance nasality. If this is so, it would amount to further evidence of motor equivalence in speech. In other words, it would suggest that a nasal acoustic signal can be achieved through a variety of articulatory means.

3.2. Typological claims

Nasal vowel inventories differ in a variety of systematic ways from oral vowel inventories. For example, languages often have fewer nasal vowels than oral vowels and no language has more nasal than oral vowels. In addition, nasal vowels are distinguished by fewer degrees of height than oral vowels. In virtually all languages that include nasal vowels, each nasal vowel appears to have an oral counterpart which, at least according to transcription, is regarded as sharing the same oro-pharyngeal quality [24].

Articulatory measures of vowel nasality may shed more light on these typological generalizations. For example, the assumption of minimal difference described earlier is fundamental to the notion that nasal vowels have oral counterparts. If minimal difference can be disproven, then it would suggest that nasal vowels do not have oral counterparts at all, potentially altering views on the complexity of vowel inventories. The contraction of height distinctions among nasal vowels is well-motivated by acoustic and perceptual studies showing the importance of F1 for the perception of nasality [25, 26, 27]. It has been argued that this loss of discriminability favors “the development of additional enhancing properties” [25, p. 1574] which must be documented using articulatory measures.

3.3. Nasal harmony

Nasal harmony is a phonological process by which one nasal sound triggers the nasalization of adjacent, erstwhile oral, sounds. In languages with nasal harmony, like Guarani, it is tempting to speculate that the spectral consequences of VPO may be minimized through articulatory strategies intended to achieve a relatively constant percept of vowel quality (height / backness). Articulatory differences between nasal vowels and nasalized vowels in nasal harmony languages could be especially revealing in this regard.

4. Conclusions

While there are considerable challenges for research on the oro-pharyngeal articulation of nasal vowels, the implications are extensive and range across several fields. The results of this work will help us understand the ways speech articulators can be employed to compensate for or enhance the acoustic consequences of using other articulators. Advanced methods in bioimaging will allow us to approach the problem with an unprecedented focus on fine articulatory detail. It is hoped that, across many experiments, a clear understanding will emerge about how the acoustically complex nasal signal is achieved and how its effects may be counteracted.

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6. References

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