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DOES THE NOSE RESONATE DURING SINGING?

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ABSTRACT

The role of the nasal resonances in singing is unclear. Teachers of singing often advise singers to place their voice "in the mask", which may mean that the singers are supposed to project or focus their attention to vibrations of the skull and forehead. Such vibrations are produced in the bony structures of the cranium by the sound pressure in the vocal tract. According to the testimony of many singers sensations in the "mask" provide a useful feedback and even evoke the impression that the sound is emitted from these parts of the head while, in reality, the primary sound radiator is the mouth opening, except for some nasalized sounds. Provided the velar port is slightly open so as to permit some nasal colouring, the nasal cavities may contribute to the colouring of a singer's voice. The behavior of the velum during various vocal exercises is inspected from above by means of a fibroscope introduced into the nose of some professional singers. Also the oral and nasal flow signals are analysed. The results suggest differing velar strategies. An attempt is made to assess their acoustic implications by means of a model of the vocal tract.

INTRODUCTION

Nasal resonance is commonly regarded as an important factor among singers and voice teachers. Most singers strive for "placing the tone in the mask" and find that sensations in the "mask" provide a useful feedback during singing. This supports the hypothesis that they open the velar port, thus allowing the nasal structures to vibrate and function as an aggregate resonator.

However, the corroboration of this hypothesis is still missing. Vennard (1964), partly replicating a clearly invasive experiment by Wooldridge (quoted ibid.), compared male singers' low-pitched vowels produced under normal conditions with vowels produced with the nasal passages and nasopharynx filled with cotton gauze. In addition he filled the maxillary sinuses with water. No significant differences between spectra of the vowels produced under these two conditions were found, and expert listeners were unable to distinguish the conditions.

Yanagisawa & al. (1990) used simultaneous velar and laryngeal videendoscopy to observe the behavior of the soft palate in singers of both sexes. They found the velum constantly closed, even for an /i/ as sung in "twang" qualities. Pershall & Boone (1987) also used videendoscopy below and above the velum for studying supraglottal participation in professional singers of both sexes. They found that velum was closed throughout the entire pitch range in all subjects.

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Yanagisawa & al. (1991), using the simultaneous velar and laryngeal videoendoscopy, examined the positioning of the soft palate in singers of both sexes during production of the nasal consonant /ŋ/. They found that the soft palate was lifted and the velopharyngeal port narrowed considerably at higher than at lower fundamental frequencies. They observed that the velar port assumed different shapes: a wide opening, a limited opening with a medial contact between the soft palate and the posterior pharyngeal wall leaving lateral openings or a complete velopharyngeal closure.

Passavant (quoted in Vennard, 1967) inserted tubes in the nose which enforced a velopharyngeal opening of different dimensions. He found that an opening of 12 mm² in cross-section had no effect upon vowel quality, while an opening of 28 mm² resulted in distinct nasality.

Summarising, there is, on the one hand, a heavy experiential evidence of nasal resonance involvement during singing. On the other hand, the results of experimental investigations on singers have shown that the velum is invariably closed during singing of vowels. This discrepancy suggests that there might have been some important limitations in the collection of data. For instance, it may be relevant that the velar port can assume many different shapes, as observed by Yanigasawa & al. (1991). Also, a prominent Passavant cushion may hide a velar opening to a nasofiberscope observation. It should also be recalled that the acoustic effect even of a minor velar coupling may be quite significant at least in some vowels. Furthermore, some of the experimental techniques used in the past may have been overly invasive; a fiberscope passing through the velar port may not leave the function of this port completely unaffected. Finally, even within the realm of Western operatic singing there may be differences between traditions.

The purpose of the present investigation was to re-examine the issue of the use of the velopharyngeal port in singing. We applied three different analysis techniques: (1) flexible nasofiberscope; (2) recordings of oral and nasal flow; (3) experiments on a vocal tract model.

METHOD

Four professional singers were investigated, two sopranos (F1 and F2), one bass (M1), and one baritone (M2). Of these, F1 was an internationally renowned opera singer, F2 an advanced student, also with considerable experience of solo singing, M1 an experienced professional opera singer, and M2 a highly experienced singing teacher. The protocol consisted of a number of speaking and singing tasks which included stops, nasals, and vowels: speech samples involving velar activity [pVnta], singing tasks such as ascending/descending fifth-wide scales, duodecime-wide ascending/descending triads, octaves and nasalized vowels.

In a first recording session, oral and nasal flow were captured by means of a double flow mask (Glottal Enterprises) so as to assess the relative amount of nasal flow. These signals were recorded on a DAT multichannel tape recorder together with the audio signal. Then, in a subsequent second part of the experiment, the subjects repeated the entire protocol while the velopharyngeal port was observed by means of a flexible fiberscope inserted through a nostril after topical anaesthesia. The fiberscope was
attached to a video camera and tape recorder. Finally, while the nose was illuminated from inside by the nasofiberscope, the subjects sang some exercises on the vowel [a] while the mouth opening was being photographed by a second video camera; the idea was that an open velopharyngeal orifice would allow the light from the nose cavity to pass down and hence illuminate the posterior pharynx wall. It turned out that this method worked only under certain conditions that were rarely fulfilled by some subjects; often the back pharynx wall remained hidden because the tongue was bunched upwards in the mouth cavity.

ANALYSIS

Assuming that the impedance of a velopharyngeal channel is reactive, it is considerably lower at low frequencies than at phonatory frequencies. Hence, a DC leakage through the nasal passage should be a safe indication of an incomplete velopharyngeal closure. The DC component of the nasal airflow was analysed by an oscillograph after LP filtering at 10 Hz. Calibration of the flow signal was made after the recordings.

To evaluate the acoustic significance of a velopharyngeal leakage, model experiments were performed using a software program, TRACTTALK (Lin, 1990). The model was fed with area function data of the Swedish sung vowels /a, i, u/, derived by Sundberg (1970) from x-ray profiles of a professional baritone singer (subject RL). The model also included a nasal tract (Båvegård et al., 1993). Different degrees of nasal coupling were tried by assigning a diameter of the first nasal cylinder of 0, 10, 100, and 200 mm², length 10 mm. Results were obtained in terms of transfer functions and sound stimuli. Typical male and female settings were used for the voice source parameters.

RESULTS

Flow data analysis

Under certain conditions two of the subjects exhibited clearly velopharyngeal openings when they sang sustained vowels, as can be seen in Figure 1. Soprano F1 showed no evidence of a velar opening during the production of scales and triads in the lower part of her range; a nasal flow was evident only in nasal consonants and in nasalized vowels. Soprano F2, on the other hand, showed a nasal DC flow for all tasks in the experiment thus indicating a constantly open velopharyngeal port. The bass singer M1 also revealed a nasal leakage in most of the tasks. However, the leakage was frequently greater on the first syllable than on the second syllable in the word [pVnta]. Interestingly, the velar port remained slightly open even during the burst intervals of the plosives [p] and [t] thus causing short term peaks in the nasal DC flow. The lesser nasalization of the second syllable may be a coarticulation effect of the plosive consonant [t] which preceded the final vowel. Baritone M2, finally, showed no evidence of a nasal DC flow for any of the tasks.

Videoendoscopy

The fiberscope recordings were sometimes difficult to interpret. The position and angle of the fiberscope tip was crucial, but when it visualised the proper portion of the
In the case of soprano F1, the fiberscope imaging complemented the nasal flow data in an interesting manner. The flow data which were recorded only in the lower part of this subject’s range, showed no velar leakage. However, the nasofiberscope revealed that the subject sang the tones in the top part of her range with a slight velar orifice. For the remaining subjects, the fiberscope recordings showed velar behaviours which were in good accordance with flow data. Thus, the velar port of soprano F2 mostly remained slightly open in most tasks; on one occasion she even was blowing a saliva bubble in her velar port. Bass M1 also showed a slightly open velar orifice. Baritone M2 showed no evidence of a velar leakage.

The vertical positioning of the velum was found to change with pitch in most subjects. For subjects F1, F2, and M1 the velum was lowered for the highest pitches and raised for the lower pitches, regardless of whether or not there was a velar opening. Subject M2, by contrast, exhibited the opposite behaviour, raising the velum for his highest pitches. This suggests that the velum plays the role of an articulator in singing.
Figure 2. Upper four panels: Photographs of the velopharyngeal aperture in singer subjects F1 and F2 (left) and M2 and M1 (right) as observed from above by means of a naso-videofiberscope; note the saliva bubble in the picture of subject F2. Lower picture: frontal view of bass singer M1 revealing a nasal opening in terms of illumination of the back pharynx wall from a nasofiberscope.
Oral video recording
The oral video recordings often had to be discarded, as the tongue hump hid the back pharynx wall. The method was useful only in two cases, soprano F2 and bass M1, where the pharynx could occasionally be seen to be clearly illuminated. The findings confirmed the conclusions above.

Acoustic modelling
The model experiments yielded convincing results for the vowels [a] and [u] while for [i] they seemed unrealistic, presumably because of errors in the area function. Figure 3 shows the effects of different sizes of a velar orifice applied to area functions. For the [u] with a velar passage of than 10 mm² an interesting formant cluster appeared at 2.5 kHz. No such effect could be observed in the vowel [a]. On the contrary, the effect of minor nasal couplings was almost nil; a clear effect appeared on the second formant only when the velar passage was 40 mm².

![Diagram showing area functions and transfer functions for vowels [a] and [u]](image)

Figure 3. Effects of a velar orifice, cross sectional area 10 mm², length 10 mm, applied to area functions for the vowels [a:] and [u:] derived from lateral X-ray photos of a professional baritone singer. The left panels show the area functions and the right panels the transfer functions with and without the orifice (dotted and solid curves).
These dramatically vowel dependent results are not surprising. The effect of introducing a small hole in a tube is entirely dependent on the positions of the nodes and the antinodes of the standing waves (Fant 1960; Fant & Pauli, 1974). A nasalized vowel can be regarded as a tube provided with an opening to a side branch. For such a configuration the acoustic effect of such an opening is determined by the area ratio at the point of coupling between the main tube and the side branch opening. This area ratio is quite different between the vowels discussed.

DISCUSSION AND CONCLUSIONS
Above we tentatively accepted a nasal DC flow and a velar opening visible by nasofiberscopy as sufficient criteria for the existence of a velopharyngeal leakage. The first mentioned criterion seems quite uncontroversial: if there is a DC flow, there is certainly a velar opening. However, if the opening is very narrow its impedance is resistive and independent of frequency. In this case the resistance may be high enough to arrest a DC flow. The second criterion also seems uncontroversial even though orifices invisible by nasofiberscopy may exist. For instance, in certain nasopharyngeal configurations an anterior bulging of the posterior nasopharyngeal wall may obliterate a narrow velopharyngeal orifice. This means that all our subjects may, in fact, have sung with a velopharyngeal opening, which, however, was very narrow in two of the subjects.

The interindividual variability in the use of the velopharyngeal port is thought provoking and quite unlike many other findings regarding the characteristics of singing. For instance, in spite of the great variability in vocal timbre between different singers, all male singers and altos have been found to possess a singer's formant and the voice source characteristics seem similar. Here, we have found individual variability possibly contributing to individual voice timbre differences.

Soprano F1 was the teacher of soprano F2. Still, they displayed divergent velar behaviours. This may of course be due to an imperfect vocal technique of the less experienced subject. Another possibility is that the individual variability in their vocal and nasal tract morphologies entails the necessity of different velar techniques.

Remarkably, our results clearly disagree with all previous findings reported on singers. We believe that this is due to differences between singing styles. It would be worthwhile to compare singers with different techniques in the future.

The complementation of nasofiberscopy by nasal flow measurement seems promising. More experimentation with vocal tract modelling may also be rewarding. For instance, it would be interesting to explore the effects of different nasal area functions on the spectrum.

Another interesting area is the articulatory significance of the singers' pitch dependent changes of the velum position. This observation suggests that the singers used the velum to shape the vocal tract so as to arrive at a target constellation of formant frequencies. Comparisons of formant frequencies before and after velar surgery, a routine operation to relieve snoring problems, might provide valuable insights into this phenomenon.
REFERENCES


