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Velum Behavior in Professional Classic Operatic Singing

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Summary: The velopharyngeal opening (VPO) is analyzed in 17 professional operatic singers, 3 high sopranos, 3 sopranos, 2 mezzo-sopranos, 3 tenors, 2 baritones, 2 bass-baritones, and 2 basses singing the vowels [a, i, u] at middle degree of vocal loudness at different pitches throughout their pitch range. Three methods were used for detection of a VPO. One was nasofiberscopy, which revealed VPO of various shapes in several singers. Another method was recording nasal and oral airflow by means of a divided flow mask. These measurements showed a nasal DC airflow at least at some pitches in a majority of the singers. A third method was a comparison of the level of the fundamental in the nasal and oral airflow signals; this level difference was less than 15 dB in cases where a nasal DC airflow was observed. Values less than 15 dB were observed in some cases, thus suggesting the presence of a VPO. The tokens produced by the singers were assessed by an expert panel with respect to nasal quality of the vowel timbre; no correlation was found between rated nasal quality and the presence of a VPO.
Key Words: Operatic singing—Velopharyngeal opening—Nasalization.

INTRODUCTION

In vocal training and therapy, exercises involving the velopharyngeal opening (henceforth VPO) have a long tradition.[1–4] A classical exercise is to phonate on a nasal murmur or to initiate vowel phonation by such a murmur, e.g., [ma, mu, mi]. This seemingly suggests that a VPO is beneficial in singing. Determining whether or not there is a VPO in singers is not trivial. There are two indisputable signs of a VPO, however. One is visual evidence, e.g., x-ray or nasofiberscope documentation, or illumination combined with photodetector documentation. Another is airflow evidence in terms of a nasal DC airflow. Yet, while both of these types of criteria are sufficient, neither of them represents a necessary condition. For example, a VPO may be difficult to see by nasofiberscopy, and a nasal DC airflow may be difficult to observe due to measurement problems.

A third type of criterion is used in some commercially available devices such as the nasometer. One measures the sound level difference between the radiated nasal and oral sounds, usually expressed as a ratio or percentage. The recorded oral and nasal energies are passed through filters that emphasize sound energy in the frequency range of the first for-

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mant for most vowels. This sound level criterion seems somewhat problematic when applied to singers, as resonance in the nasal and/or oral cavities may affect sound levels considerably, particularly at high fundamental frequencies.

A better method is to measure the amplitude difference between the nasal and oral sounds only in the fundamental frequency component (M. Rothenberg, personal communication, 2001). The underlying theory is that a narrow VPO can be regarded as a slit, the acoustic impedance of which increases with frequency. Hence, the lowest spectrum partial, i.e., the fundamental is likely to squeeze through even a narrow VPO, such that its amplitude in the nasal sound is increased. By using only the fundamental, the reading is also made less dependent on vowel articulation. By using AC instead of DC energy, the readings are less sensitive to airflow components caused by jaw movements in continuous speech or in singing.

Signs of a VPO have been found in classical singers by different methods, such as x-ray imaging,[5] flow and nasometer measurements, and nasofiberscopy.[6–8] On the other hand, Austin,[9] using a photodetector, found small or no VPO in singers. The purpose of the present investigation was to find out to what extent professional opera singers use a VPO during singing and if such an opening is necessarily associated with a nasal quality of the voice timbre.

METHOD

Seventeen professional operatic singers of different classifications, all premiere opera soloists working in Denmark, and some singing frequently in the prestigious international opera houses, volunteered as subjects, see Table 1. All were educated in Denmark, either privately or at the Royal Academies of Music in Copenhagen or Aarhus, except one who received her education in Norway. Their task was to repeatedly sing the word [panta] in mezzoforte, piano, and forte on each tone in an ascending A major triad extending over their entire pitch range. The starting and ending pitches were adapted to the singer's individual pitch range. This yielded a set of seven pitches for most of the subjects, see Table 1. Thereafter, the same protocol was repeated for the words [puntu] and [pinti]. The duration of each syllable was about 1 s, although most singers sang the second syllable longer than the first. The singers sang this entire material twice, first for recording oral and nasal airflow and then for recording the VP port by means of a nasofiberscope. Thus the entire mezzoforte material from 15 of the singers consisted of 42 tokens (7 pitches $\times$ 3 vowels $\times$ 2 experimental settings), of 48 tokens (8 pitches $\times$ 3 vowels $\times$ 2 experimental settings) from baritone 1, and of 36 tokens (6 pitches $\times$ 3 vowels $\times$ 2 experimental settings) from bass-baritone 1.

TABLE 1. *Recorded Pitch Ranges of the Various Singers*

Classification	F_0
High soprano 1	A3 – A5
High soprano 2	A3 – A5
High soprano 3	A3 – A5
Soprano 1	A3 – A5
Soprano 2	A3 – A5
Soprano 3	A3 – A5
Mezzo-soprano 1	A3 – A5
Mezzo-soprano 2	A3 – A5
Tenor 1	A2 – A4
Tenor 2	A2 – A4
Tenor 3	A2 – A4
Baritone 1	E2 – A4
Baritone 2	A2 – A4
Bass-baritone 1	A2 – E4
Bass-baritone 2	E2 – E4
Bass 1	E2 – E4
Bass 2	E2 – E4

The experimental setup for the flow measurements is shown in Figure 1. Oral and nasal airflow were separated by means of a divider plate mounted in a flow mask (Glottal Enterprises, Syracuse, NY, model MS 100-R2) that the singers held tightly to their faces. The singers found the mask moderately disturbing to their vocal production. One reason would be that the mask disturbed the normal auditory feedback. Also, some singers found that the mask prevented them from using jaw openings as wide as they desired. These flow signals were recorded together with an audio signal on separate tracks of a multichannel data recorder (TEAC RD-200T PCM, Tokyo, Japan). Calibration signals were recorded on the same tape.

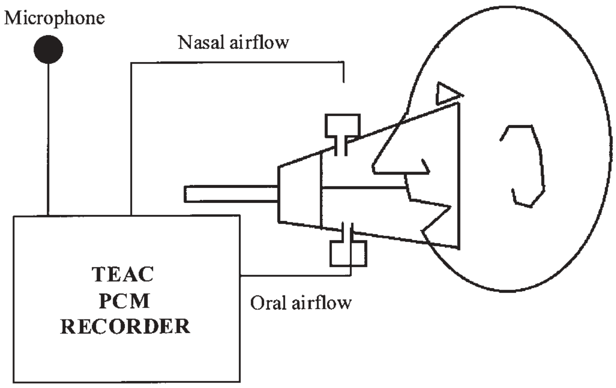

FIGURE 1. Block scheme of the experimental setup for the recordings of nasal and oral DC airflow.

For visual documentation of VPO, a flexible naso-pharyngoscope (Olympus, Tokyo, Japan, ENF P3) was used. The fiberscope was introduced after topical anesthesia was applied to the nasal cavity. The signal was recorded on a video recorder (Panasonic super VHS), together with an audio signal. None of the singers found that the fiberscope disturbed their vocal production appreciably, although the experimental conditions obviously deviated from a typical performance situation. All recordings were made at the Department of Phoniatrics, Bispebjerg Hospital, Copenhagen.

The audio signal and the two flow signals were digitized on separate tracks, using the Swell signal analysis workstation.[10] The DC components of the oral and nasal airflow were measured by means of the histogram subroutine as the average airflow during each word on each pitch. Henceforth this mean airflow will be referred to as the oral and the nasal DC airflow. Zero flow was determined from the occlusions from the consonant [p]. Mostly, it varied less than ±10 mL/s within a triad series, probably due to the effect of exhaled and inhaled air on the acoustic resistance of the mesh. As the singers sustained the second vowel longer than the first, the second vowel was selected for analysis.

Quantitative estimates of VPO were obtained from four phoniatricians. Their task was to rate, along 100-mm-long visual analogue scales (VAS), the degree of VPO seen on the videotape of the second vowel in the word [panta]. The VAS extremes were marked “completely closed” and “completely open.” Only the series sung in mezzoforte was included in the tape, which presented the entire triad pattern by each singer in one sequence. The sound was low-pass filtered at 500 Hz to prevent the use of auditory criteria. Each phoniatrician received a personal copy of the tape. No replicated stimuli were included in the tape, since the phoniatricians were free to play the various stimuli as many times as they wanted.

An overall assessment of the degree of “nasal quality” was collected from a listening test on the audio signal recorded during the naso-fiberscope session. Six singing teachers of the Royal Academy of Music, Copenhagen, served as the expert panel. Each mezzoforte production of the word [panta] at each pitch occurred in randomized order on the test tape. The stimuli were separated by a 8.5-s-long pauses. Each stimulus appeared twice on the tape. The tape, total duration 23 min, was presented in an ordinary room over loudspeakers to the entire panel in one session with a short break after the first half of the tape. The task of the panel was to rate on a 100-mm-long VAS to what extent they found that resonance in the nasopharynx contributed to the timbre. The extremes of the scale were labeled “not at all” and “extremely,” and the center “partially.”

RESULTS

Airflow data

For high soprano 1 and for soprano 3 no flow values were obtained, presumably because of mask leakage. For the remaining subjects, the oral flow varied between vowels and with pitch. The maximum flow tended to vary systematically with classification. Thus, voices with higher pitch ranges showed lower flow values than voices with lower pitch ranges, presumably reflecting different vocal fold length. The variation with pitch varied between the singers. In some singers oral flow decreased with increasing pitch, in some it remained rather constant, while in some it showed no systematic variation. In most cases the flow was reasonably similar in the three vowels.

Nasal DC airflow during the second vowel in the test word [puntu] was observed in nine of the singers, at least at some pitches: high soprano 3, all 3 tenors, both baritones, bass-baritone 2, and both basses, Figure 2. The occurrence of the nasal flow varied between pitches and occurred for the vowels [a] and [u], while nasal flow was observed for the vowel [i] only in tenor 2. These results indicate that these singers sang with a VPO. Interestingly, tenors 1 and 3 showed a small nasal DC flow for the pitches C#4 and E4, and tenor 2 in-

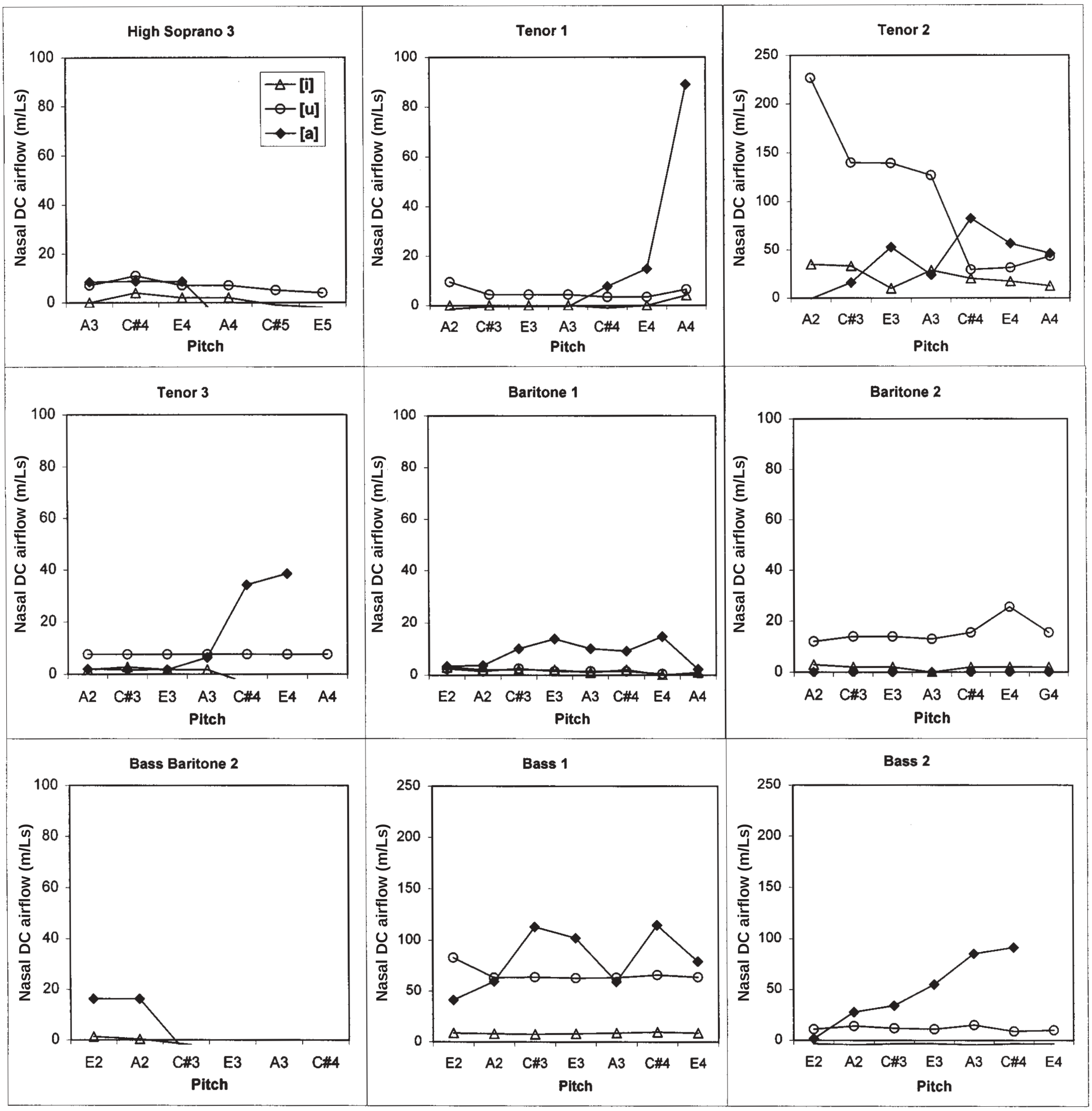

FIGURE 2. Nasal DC airflow recorded during the second vowel in the test words [panta], [puntu], and [pinti] sung at middle degree of vocal loudness. The graphs show the results only for those singers who exhibited a nonzero nasal DC airflow at least on some pitches.

creased his nasal DC flow considerably at these same pitches.

As mentioned, a VPO might exist even in the absence of a recorded nasal DC airflow. For example, incomplete contact between the mask and the face may reduce the amplitude of the recorded nasal DC airflow considerably. In such cases, the level of the fundamental in the nasal airflow, $L0_n$, offers an alternative. In case of a VPO, $L0_n$ should be stronger than about 15 dB below the level of the fundamental in the concomitant oral airflow, $L0_o$. Therefore narrow band spectrum analysis was carried out on the nasal and oral AC signals for all productions of the vowel [a], and the difference $L0_n$ - $L0_o$ was determined. Figure 3 shows the relationship between the nasal DC airflow and $L0_n$ - $L0_o$. The data show that the $L0_n$ - $L0_o$ difference was less than 15 dB in cases when the nasal DC flow was greater than zero, but also show many cases where a zero nasal DC flow was associated with an $L0_n$ - $L0_o$ difference less than 15 dB. Four of the singers from whom no nasal DC flow was recorded showed an $L0_n$ - $L0_o$ difference smaller than 15 dB, at least at one pitch, see Figure 4. Thus, also these singers probably sang with a VPO.

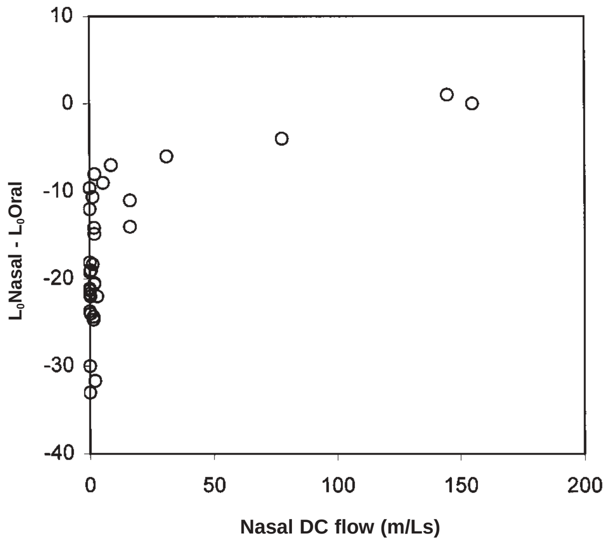

FIGURE 3. Relationship between nasal DC airflow and $L0_n$ - $L0_O$, i.e., the level difference between the fundamental in the nasal AC airflow signal ($L0_n$) and the fundamental in the oral AC airflow signal ($L0_O$).

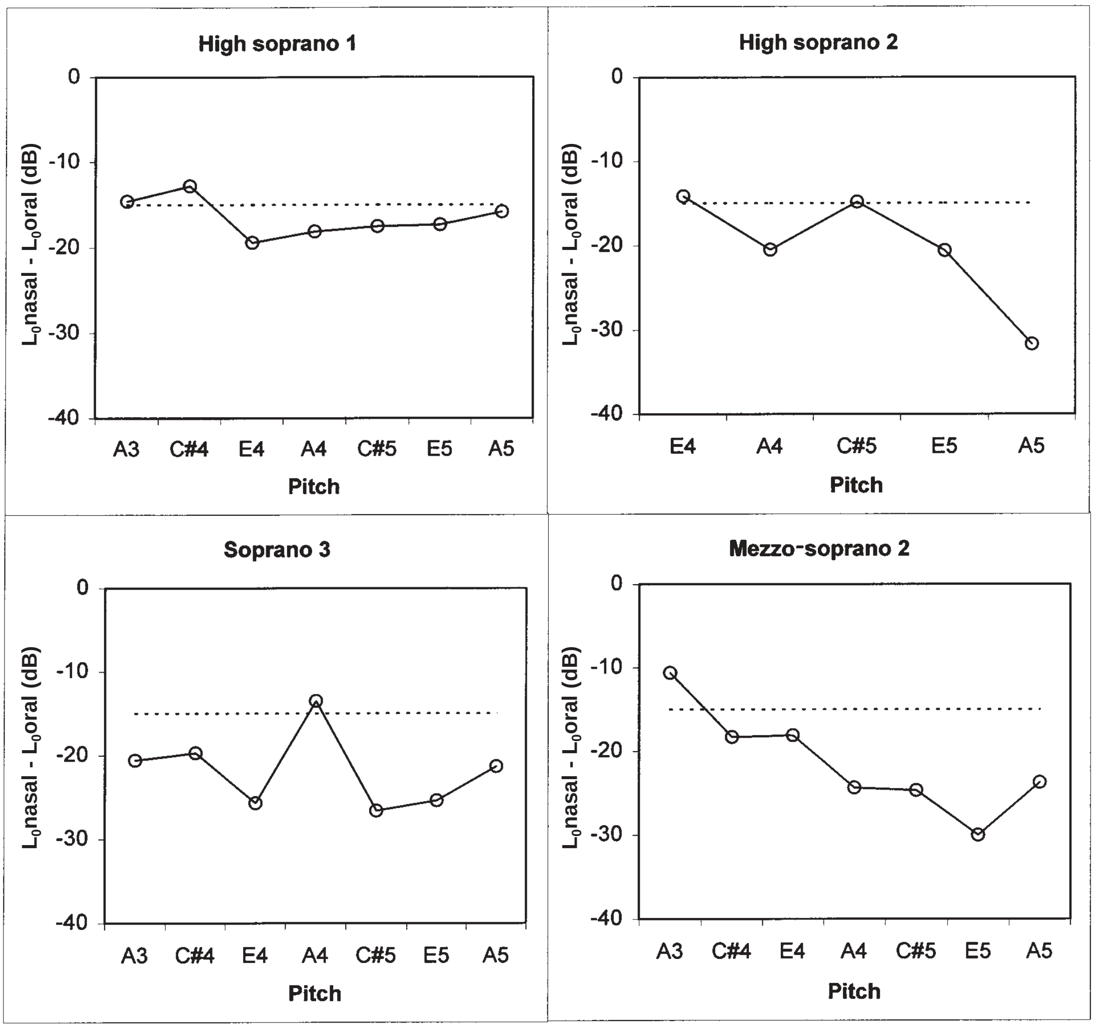

FIGURE 4. $L0_n$ - $L0_o$ for the singers for whom no nasal DC airflow was observed and who showed an $L0_n$ - $L0_O$ greater than –15 dB, at least at some pitches.

Nasofiberscope data

The video recordings revealed several examples of a VPO. The openings could be grouped into three different types, as illustrated by the schematical examples shown in Figure 5: (1) one extending along the *coronal* direction with retracted sidewalls and with the distance between the velum and pharyngeal wall being small or nil; (2) one extending along the *sagittal* direction with advanced sidewalls and greater distance between the velum and pharyngeal wall; and (3) a *constricted type*, with advanced sidewalls and a narrow distance between the velum and posterior pharyngeal wall showing Passavant's ridge. The coronal opening was associated with different vertical positions of the velum.

As mentioned, four phoniatricians rated the degree of VPO in the [panta] series along a 100-mm-long VAS. The ratings ranged over 72, 73, 82, and 92 mm for the four raters. The Cronbach's coefficient alfa averaged across pitches was 0.822. Figure 6 compares the mean ratings with the corresponding nasal DC airflow data for the nine singers in whom all phoniatricians observed a VPO. In the figures the nasal DC airflow is also included for the singers. To increase comparability between the ratings and the flow values, the latter are expressed as percentages of the simultaneous oral flow rather than in flow units. Thus, a value of 100 for the rating corresponds to a fully opened velopharyngeal passage according to the phoniatricians' mean ratings and a value of 100 for the nasal DC airflow indicates that the nasal and oral airflows were equal.

As illustrated in Figure 6, the phoniatricians observed a VPO systematically increasing with pitch in

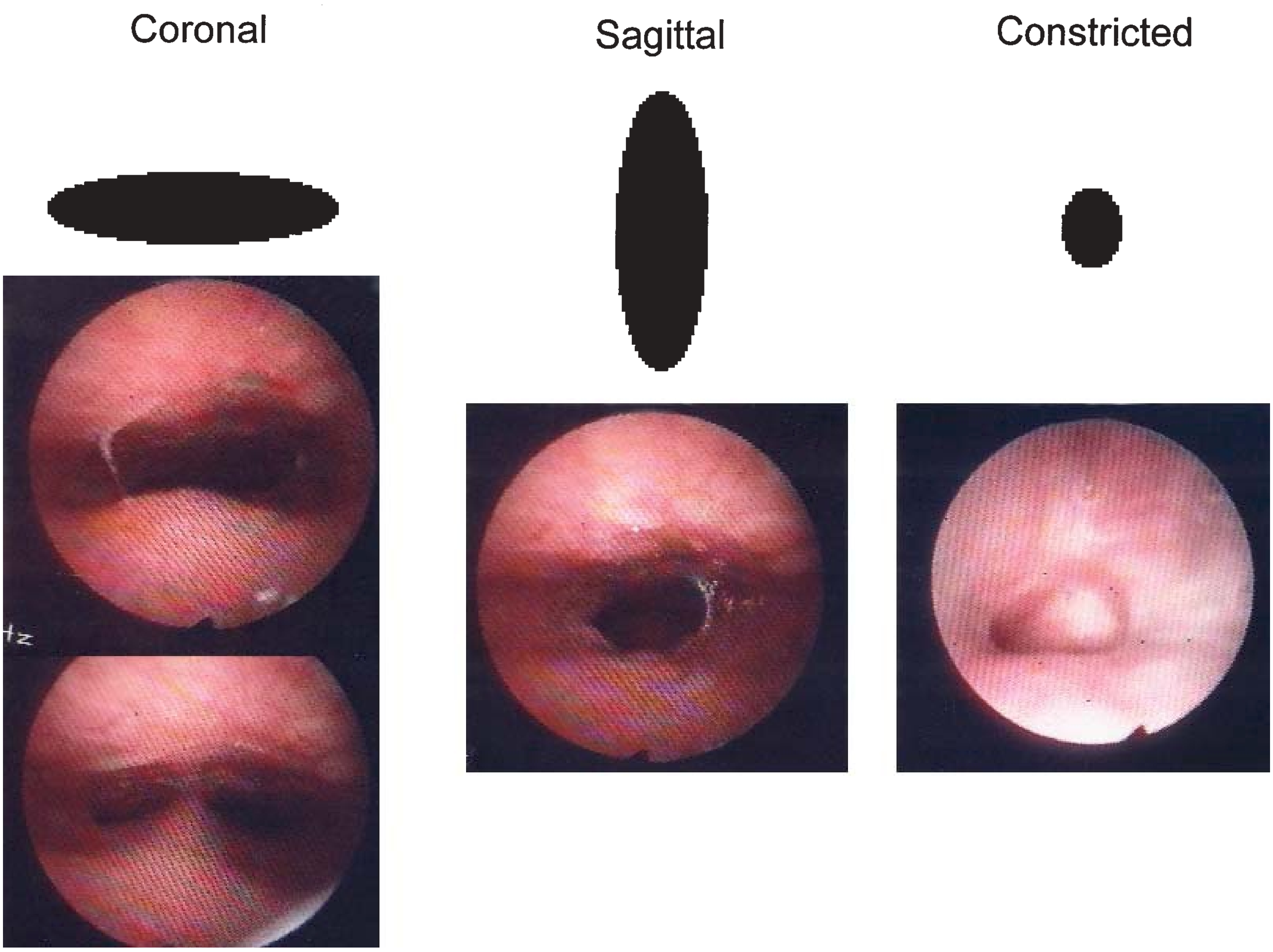

FIGURE 5. Schematical examples from the nasofiberscopy documentation of the three main shapes of VPO observed in the singers.

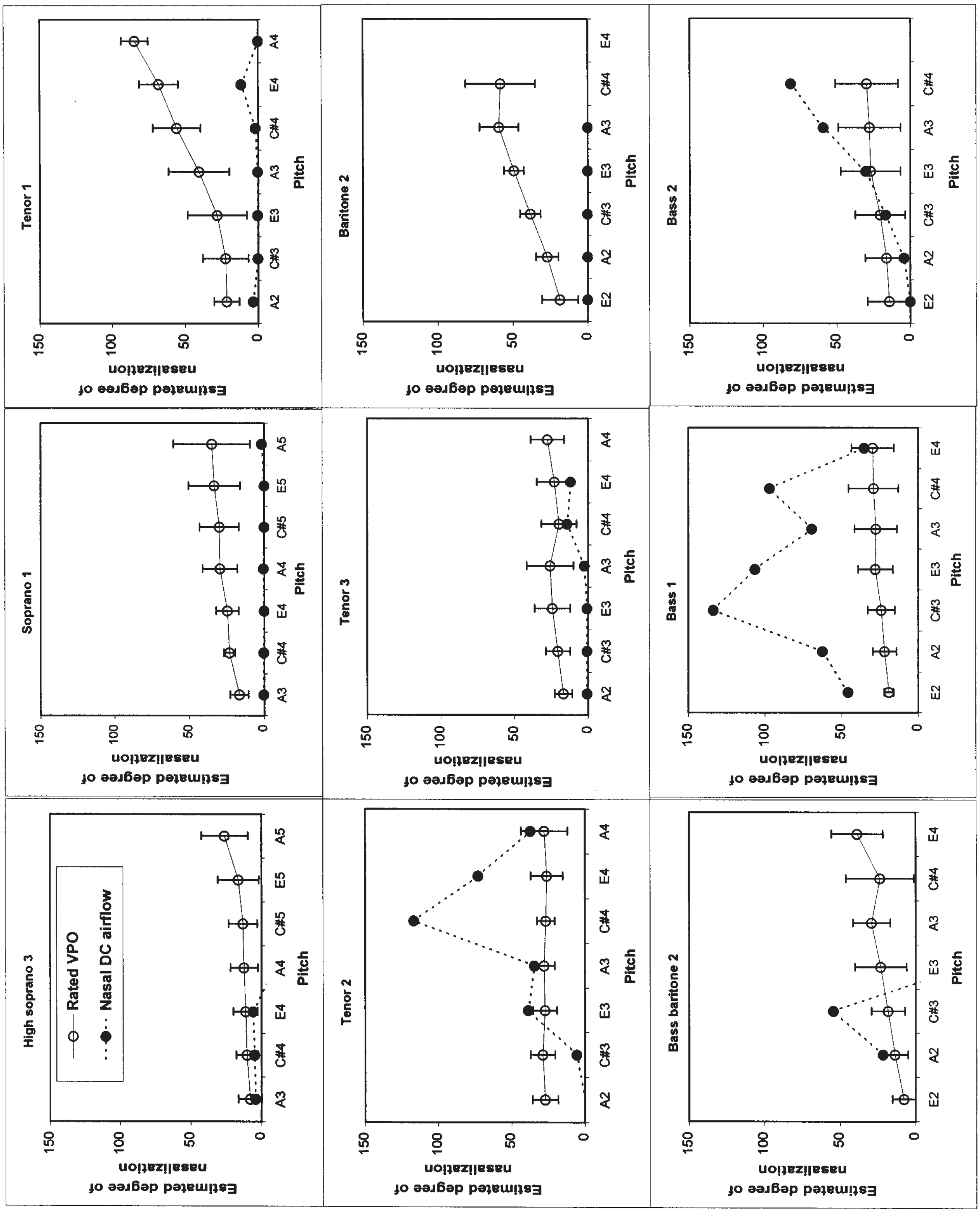

FIGURE 6. Comparison between the means of the phoniatricians' ratings of the size of the VPO and the nasal DC airflow data for the 9 singers who showed such an airflow. For the sake of comparison, the flow values are expressed as percentages of the simultaneous oral flow rather than in flow units.

singers high soprano 3, soprano 1, tenor 1, baritone 2 and bass-baritone 2. Mostly the airflow data showed little correspondence with the VPO ratings, and for many pitches the ratings indicated the presence of a VPO, while no nasal DC airflow was measured. These discrepancies may reflect a different singing behavior in the flow mask experiment and in the nasofiberscope experiment.

Perceptual evaluation

The rating of the degree of perceived nasal quality turned out to be difficult, as demonstrated by the low intrarater reliability, see Table 2. The Cronbach's coefficient alfa amounted to 0.69. The mean ratings for the different singers are shown in Figure 7. Only

TABLE 2.
Intrarater Reliability in Terms of Pearson's Correlation Coefficients for the Repeated Stimuli for the 6 Singing Teachers who Estimated the Degree of Nasal Quality

Listener	*r*
1	0.470
2	0.531
3	0.706
4	0.470
5	0.560
6	0.473

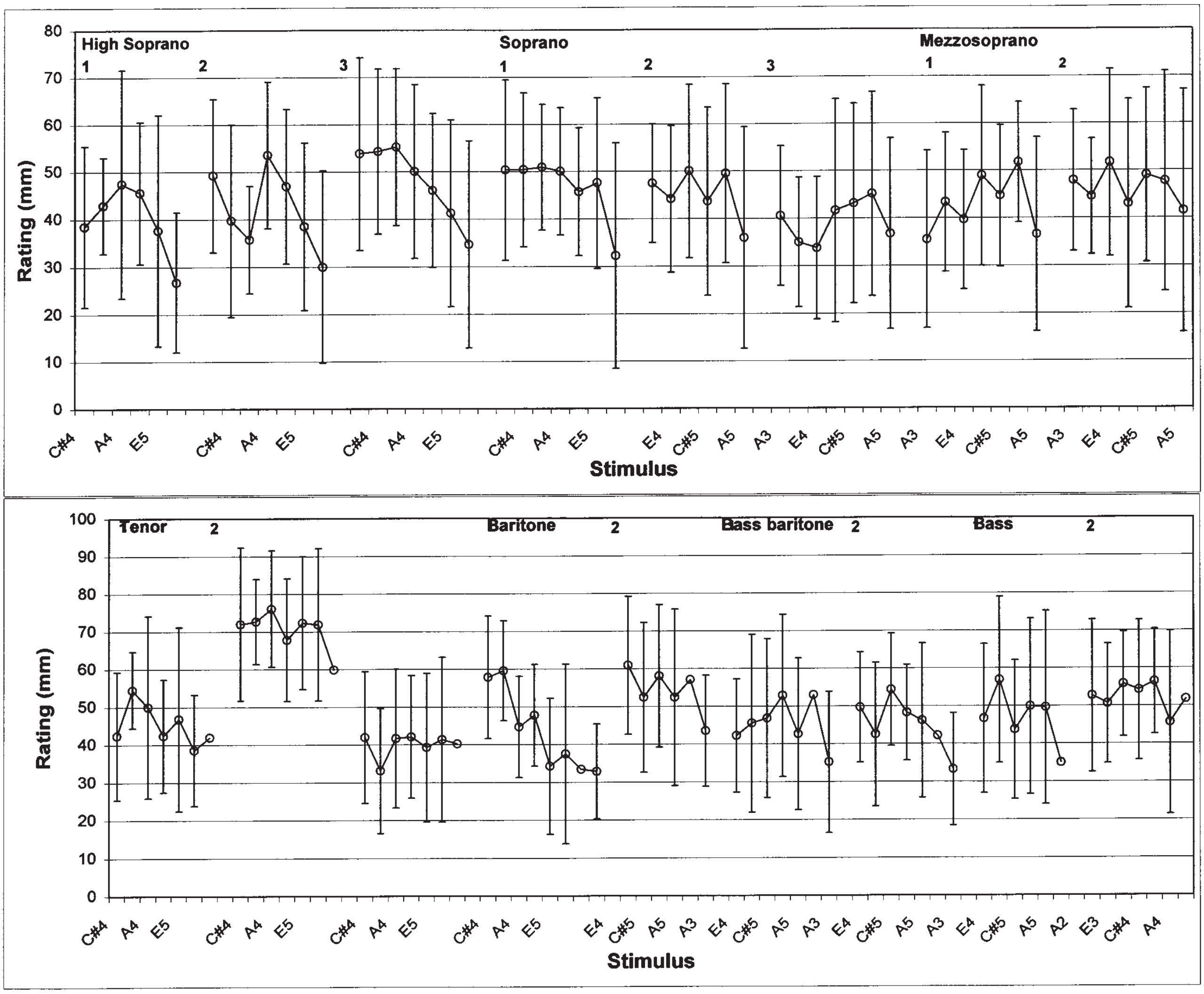

FIGURE 7. Mean ratings of the degree of perceived nasal quality for the indicated singers. The bars represent ±1 standard deviation.

tenor 2, who also showed a considerable nasal DC flow, scored clearly higher than all other subjects. Given these results, no correlation is to be expected between perceived nasal quality and nasal DC airflow, see Figure 8. The lack of correlation is apparent. This suggests that the degree of perceived nasal quality is not related to the existence of a VPO in the vowel [a].

The discrepancy between the airflow data and the ratings of perceived nasal quality may, at least in part, be due to the fact that the airflow data and the audio material used in the listening test were not recorded in the same session. A more strict comparison would be to examine the relation between rated VPO and perceived nasal quality. However, this comparison also failed to show any relationship, as illustrated in Figure 9. A clear nasal quality was perceived only in tenor 2 while only a minor VPO was observed from his video recording. Also, a rather wide VPO was observed in some singers without causing a particularly high degree of nasal quality. This confirms that the degree of nasal quality is not related to the VPO size. In other words, singers seem capable of using even a wide VPO without adding a nasal quality to their vowel timbre.

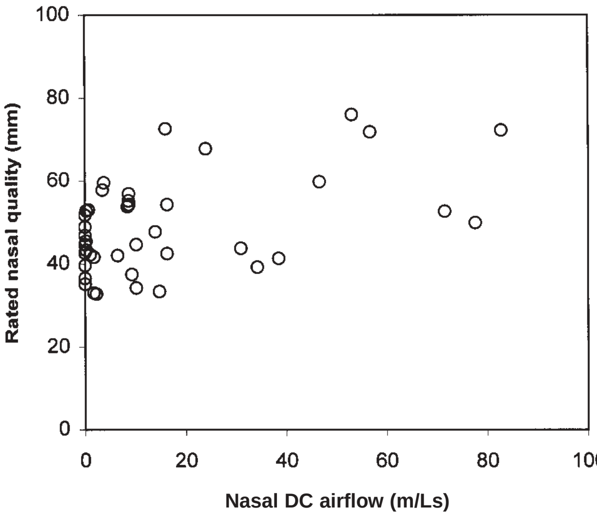

FIGURE 8. Relationship between measured nasal DC airflow and corresponding mean ratings of nasal quality.

DISCUSSION

Our investigation has certain limitations. First, nasal DC airflow could not be measured simultaneously with the nasofiberscopy. A second limitation is that the DC flow data are dependent on a tight seal between the mask and the face. Third, the mask deprived the singers of their normal auditory feedback and also limited their possibilities to sing with a wide jaw opening. For these reasons our conclusions are conservative. Thus, neither a zero nasal DC airflow, nor the absence of a clearly visible VPO in the nasofiberscope recordings, can be interpreted as evidence of the absence of a VPO. Only the presence of such airflow and/or a clearly visible VPO can be

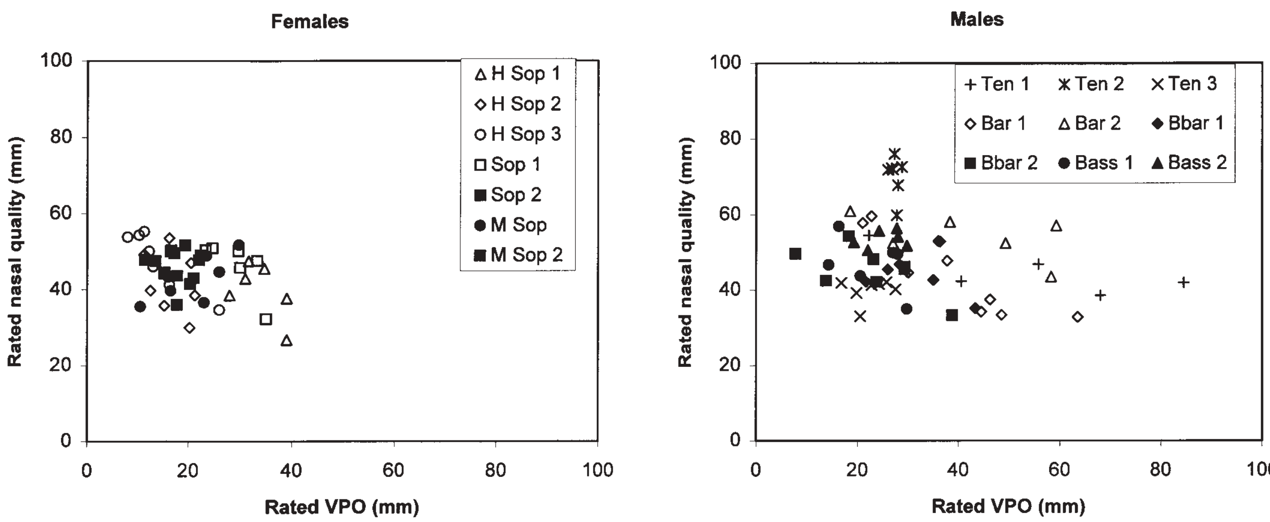

FIGURE 9. Relationship between mean ratings of VPO and corresponding mean ratings of perceived nasal quality.

regarded as proof of a VPO. Such proof was found in 9 of the singers. In 6 other singers, the $L0_n$ - $L0_o$ difference was less than 15 dB, thus suggesting a VPO also in these cases. Thus, it is likely that 15 of the 17 singers sang with a VPO, at least under some conditions.

Our study has demonstrated great difficulties in detecting a VPO, suggesting that many commercially available devices will provide unreliable data when used on singers. Moreover, the use of transillumination would be problematic, given the varying shape of the VPO, particularly the position of Passavant's ridge. The airflow data show that some professional operatic singers undoubtedly sing with a VPO on the vowels [a] and [u]. This is in accordance with earlier investigations by Millet and Dejonckere[8] and by Gramming and associates.[6] Interestingly, both our bass singers showed a clear VPO and in the latter investigation a large VPO was observed in a bass singer. Millet and Dejonckere found VPO shapes similar to those documented in our study. On the other hand, our results do not agree with observations made by McIver and Miller[8] and do not support the view of Miller[11] and Austin[9,12] that the VPO should be closed in classical singing.

What is the benefit of a VPO? First, a VPO may not necessarily be a goal in itself. There are strong neural relations between the velar and the laryngeal regions, suggesting that velar adjustment may be associated with effects on phonation.[13] Second, it seems clear that a VPO does not necessarily cause a nasal quality. Also, the differing shapes of the VPO in different subjects appear to suggest that singers carefully tune the degree of opening, perhaps in order to color the timbre. As demonstrated by Fant[14] a VPO tends to reduce the amplitude of the first formant of the vowel [a] and may decrease the level difference between the first and third formants in the vowels [a] and [e]. Thus, singers may gain a relatively greater prominence of the singer's formant by allowing an appropriately tuned VPO. Also, it is interesting that all three tenors showed signs of a VPO at the passagio pitches C#4 and E4; a VPO may facilitate a seamless timbral transition in this pitch range. We plan to investigate these aspects in the future.

CONCLUSIONS

In this investigation we have attempted to find out to what extent classically trained professional opera singers use a VPO when singing the vowels [a, i, u]. The presence of a VPO was investigated by nasofiberscopy as well as by measuring nasal DC airflow as captured by means of a divided flow mask. The presence of a VPO is difficult to determine by both these methods, since airflow data may fail to reveal a VPO in cases of mask leakage, and a VPO may not be visible by nasofiberscopy. Therefore, the level difference of the fundamental in the oral and nasal flow signals was also measured. In cases of a nasal DC airflow, this level difference was found to be less than 15 dB.

Given the difficulties in determining the presence of a VPO, our conclusions need to be conservative. Yet, clear evidence of a VPO was found for all singer classifications, at least under some conditions. The VPO was observed for the vowels [a] and [u] and one of the tenors also showed a VPO on the vowel [i]. Three main shapes of VPOs were observed by nasofiberscopy, a constricted opening or an opening extending in a coronal or a sagittal direction. These varying VPO shapes suggest that singers may use a VPO to fine-tune vocal timbre. All tenors showed that a VPO was near their passaggio. A listening test revealed that the observed VPO showed no correlation with perceived nasal quality for the vowel [a]. The benefit of a well-controlled VPO for vocal timbre and its relevance to vocal pedagogy remain unclear, requiring future investigation.

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