A NASOENDOSCOPIC STUDY OF 'HEAD RESONANCE' AND 'IMPOSTO' IN CLASSICAL SINGING

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ABSTRACT

Background: Classical singing pedagogy uses many concepts which lack precise definition and whose acoustic and physiologic correlates are unclear. This study focuses on the concepts 'head resonance' and 'imposto'.

In singing guidebooks, head resonance has been described as causing vibratory sensations on the face and head, auditively it has been described as a bright colour especially predominating in the higher pitch range.

'Imposto' has been related to the sensation of 'air flow' or 'sympathetic resonance vibrations' on or over the upper bridge of nose, and it also has been pursued using a 'closing mechanism of the upper respiratory track' (activation of nasalis muscle).

Study Design: Experimental cross-sectional study.

Method: Five subjects (3 classical singers, 1 amateur singer and a non-singer) were investigated with nasofiberoscopy during phonation. The singers were instructed to sing [i:] on one comfortable self-chosen pitch in three ways: 1) without head resonance, 2) with head resonance, and 3) using imposto (exploiting the nasalis muscle). The non-singer was investigated without phonation, while just holding his breath after inhalation first normally and then while producing imposto. The following measurements were made on the fiberoscopic images: 1) height of soft palate, 2) area of the hypopharynx, 3) area of the epilaryngeal tube inlet.

Results: The singers raised the soft palate and narrowed the epilaryngeal inlet during head resonance and even more during imposto. The pharynx to epilarynx ratio increased. Similar narrowing of the epilaryngeal tube inlet was observed in the non-singer when constricting the nasalis,

Conclusions: The results suggest that both the head resonance and imposto are related to control of the pharyngeal space and epilaryngeal tube, and that the nasal muscles may be used as an aid in regulating the epilaryngeal tube width, which in turn, improves the voice-source -tract interaction.

Key Words: vocal pedagogy, nasal muscles, epilaryngeal tube, voice source- tract interaction

1. INTRODUCTION

Singing pedagogy operates not only with instructions based on the anatomy and physiology of the vocal organ but largely also on descriptions based on bodily sensations or imagination. On one hand, bodily sensations are important guides in voice production and improved sensitivity to sensations is essential in the voice training process. On the other hand, the use of concepts that base on more or less subjective sensations often causes confusion and misunderstandings that may even lead to vocal misuse. There are many pedagogical concepts that lack precise definition and whose descriptions even seem to be controversial. Their acoustic and physiologic correlates are more or less unclear. One of the widely used pedagogical concepts in singing training is ‘head resonance’.

1.1 Descriptions and explanations of ‘head resonance’

‘Head resonance’ has been described as vibratory sensations in the head-, and forehead and between the eyes [1,2,3,4]. Often a difference is made between head resonance and nose/mask resonance, although not necessarily consistently. ‘Head resonance’ has been used to mean softer singing [1,2,5,6] and nose/mask resonance has been related to a bright and edgy voice color that gives clarity and projection to the tone [3,6]. On the other hand, nasal resonance has been seen as a kind of prerequisite for full brilliance, which in turn is obtainable through head resonance [3]. Furthermore, head resonance has been defined as ‘vibration of a soundwave’ around the structures of the head, such as the nasal cavities, sinuses and mouth. In turn, mask resonance, has been defined as vibrations in the area around and including the eyes, which creates head resonance [1]. H~~h~~ead resonance has also been described as causing vibrations behind the eyes, placing the voice in the mask [4]. Head resonance has been associated with higher and lighter notes [1] and described as the quality of tone produced in the high range with normal volume [7]. On the other hand, it has been used for soft singing throughout the range [6] and for the most brilliant voice quality throughout the range [3]. Eventhough Bunch [8] does not use expressions like ‘head resonance’ or ‘nose/mask resonance’ recognizing that some experimental results [e.g. Vennard 9] have suggested that the nose cavity and the sinuses of the face have little value for the sound quality, she regards ‘vertical focus’ as fundamental to vocal efficiency and hygiene. When she describes ‘high vertical focus’, writing “the tone seems to float in the head as though it were disconnected from the throat’, one may wonder, whether this is actually what some would call head resonance. Similarly as some [3,6] state that the head resonance can (and should) be produced throughout the pitch range, the vertical focus is pitch independent [8].

Those who relate ‘head resonance’ to a high pitch range (and soft volume) may use the expression synonymously with ‘head register’, while for others these expressions are different things that should not be confused [2,6]. Those who make a distinction between head resonance and mask/nose resonance may or may not use different exercises to develop these qualities. For instance, [2] recommends yawning to find head resonance and an inner smile and phonation on 'ng' to achieve nasal resonance, while Manen [3] suggests humming on nasals to achieve both qualities. According to Manen [3], the difference is that the airflow should be directed up to frontal sinuses for head resonance. Koistinen [4] recommends high pitched humming on 'ng' to get an idea of head resonance and singing in the mask. Although nasal consonants are often used as exercises, whether to find head resonance or nose/mask resonance, the aim is not the 'nasality' of the sound, i.e. the nasality as used in nasalized French vowels [3,10].

Many pedagogues do not make a distinction between different 'resonances' but state, for example that the voice should vibrate in the face and head – or in the face as high up as possible [11]. Likewise, Allen [12] writes that "nasal resonators, maxillary bones and cavities located in the cheekbones and the frontal resonators in the forehead just beneath and above the eyebrows form the powerful resonator, 'the mask'. These cavities add ring, edge, focus and volume to the voice".

Some singing pedagogues [3,12,13] assume that the head or nose/mask resonance is truly the result of (acoustic) resonances in the nose and sinuses. On the other hand, according to the experiments by Vennard [9] damping these acoustic resonances by filling up the sinuses with liquid did not alter the voice quality of the singer. This seems to suggest that vibratory sensations in the 'head resonance' – or 'nose/mask resonance' as appropriate - can be explained as sympathetic vibrations of the tissue originating from the acoustic resonances elsewhere in the vocal tract [14]. In voice science, head (and mask) resonance has been related to the singer's formant [15]. As Sundberg [16] puts it, "some singing teachers refer to this - a singer's formant - phenomenon as 'head resonance' or 'placement in the mask'". According to Schutte and Miller [17], 'placement', focus, and ring are pedagogical terms related to the singer's formant. A synthesis study by Ekholm [18] confirmed that listeners related 'ring' to samples with a singer's formant. Are head resonance and ring related to the same acoustic phenomenon? As far as we know, no systematic studies have been carried out to explore the acoustic origin of the perception of head resonance and mask resonance in the classical singing of males and females. Titze [19] uses the concept of 'resonant voice' to refer to a voice that feels easy to produce and causes vibratory sensations in the face and head. He defined 'resonant voice' as phonation where the energy transfer in the glottis occurs effectively and economically. The sound source and the vocal tract are then in sufficient interaction, and the phonation threshold is low. According to Titze [19], "when the energy conversion process at the glottis is efficient, the vibrations are distributed all over the head, neck, and thorax, but when the energy conversion process is poor, the vibrations are likely to remain more local." The vibrational energy will then be dissipated mainly in the vocal fold tissues.

It is possible to see 'resonant voice' as a general term for different types of 'resonances' (whether head resonance, nose/mask resonance etc.) that cause strong vibrations somewhere in and around the vocal organ accompanied with the sensations of ease of phonation, an increase ~~of~~ in sound volume, and improved voice quality.

As for the relation between 'head resonance' and 'head (voice) register', it must be noted that both expressions originate from vibrations sensed in the head. Head voice register has been used to refer to the upper pitch range [e.g. 8,16,20], at least in the classically trained singing voice. Although register terminology is still somewhat unclear, there is evidence supporting the view that head voice can be seen as equivalent to middle voice and mixed register, for example, a mixture between chest/modal register and falsetto. It has a spectral slope somewhere between chest voice and falsetto [21]. It implies an almost rectangular vertical glottal shape with nearly parallel vocal fold surfaces, which results in a low phonation threshold and keeps vocal fold collision moderate [22]. The amplitude of the vibration of the vocal folds, however, is close to that of the chest voice, and therefore it is possible to produce large sound power. It is also possible to sing over a large pitch range in this register [21]. Moreover, according to Titze [19,23] and Nix [24] semi-occlusions (like humming, lip trills, voiced fricatives) are a good way to adopt this head register posture and learn to adjust the vocal tract (epilarynx) to maximize the vibratory sensation and thus the acoustic-mechanic interaction in the vocal organ [23]. As it literally comes to 'head resonance', the resonances of the skull have been studied. Interestingly, it has been found that the skull resonates best at high frequencies, particularly at the range of the singer's formant [25].

1.2. Descriptions and explanations of 'Imposto'

Another song pedagogical concept in need of further clarification is 'imposto'. It is especially related to *Bel Canto* technique. Its relation to 'head resonance' is not clear. Manen [3] describes imposto mechanism as follows.

"An essential component of the Bel Canto technique is the exploitation of the upper respiratory tract, i.e. the nose and the nasopharynx, by switching the start of the note, the transient, from the larynx to the nasal passages behind the bridge of the nose."[p. 27.]

Imposto has further been used to refer to 'placement', which in turn means a place where sympathetic resonance is or should be felt during singing. Imposto has been located on the bridge of the nose [26], or above the bridge, between the eyes. It has been explained as 'air flowing and resonating in the frontal, ethmoidal, and maxillary sinuses of the head' [13]. Instructions to find 'imposto' include singing on 'hnn' and notizing a buzzing sensation in the forehead [13], and sniffing as though suddenly surprised by an usual smell, and then closing 'the sniffing route', as though protecting oneself from obnoxious fumes [27]. Mánén [3] described imposto to be achievable by using the closure mechanism of the entrance to the olfactory region', controllable by nasal muscle that compresses the cartilages at the nasal bridge. According to her, reflex closure of the entrance to the olfactory region is associated with simultaneous closing of the larynx. Manen and Hemsley [28,27] unite imposto and Hochgriff and consider it an important alternative control mechanism of the larynx for fine adjustments. According to Hemsley [27] when a singer makes the closure at the root of the nose, the glottis closes in sympathy. Starting the note from this region gives a clean attack. Further Hemsley suggests that, if the imposto grip is correctly activated, a singer can observe an immediate reaction also in the pelvis region. As many ideas of singing pedagogy, this hasn't been scientifically proven.

Aims of the present study

As far as the authors know, there are no systematic physiological studies on the vocal tract behavior related to singing with 'head resonance' and 'imposto'.

Therefore this study investigated 'head resonance' and 'imposto' using nasoendoscopy. The research questions were: (1) Do head resonance and imposto cause changes in the nasopharynx, hypopharynx and the epilarynx? (2) Do head resonance and imposto differ from each other in terms of these changes? Additionally, (3) do the same potential changes in nasopharynx, hypopharynx and epilarynx occur also in non-singers when they imitate 'imposto'?

1 METHODS

2.1 Participants and the tasks

Five volunteers with a healthy larynx participated in the nasoendoscopic study. Three of them (2 females, 1 male) were trained professional classical singers (a mezzo-soprano, a soprano and a tenor, age from 36 to 70) with at least 10 years of professional training and 10-40 years of experience in professional operatic singing and teaching of classical singing. The other two of the participants were non-singers (one 55 -year old female with some classical singing training in total for about 4 years, and one 38-year old male with no singing training at all).

At first both "head resonance" and "imposto" were described to the non-singers in the way they are described in song pedagogy (see Introduction). Imposto was described to feel like a saddle placed on the root of the nose [3, referring to Lilli Lehman] or a nose clipse, and then non-singers rehearsed the compression of nasalis muscle for a few minutes, guided by a professional classical singer. The participants were instructed to sing on one comfortable, self-chosen pitch in three

different ways: 1) without head resonance ('from the mouth'), 2) with "head resonance" ('from the head'), and 3) using 'imposto'. Pitches that the singers sang were E4 (amateur singer), G4 (professional soprano), E flat 4 (mezzo-soprano). The male singer sang E flat an octave lower (E flat 3).
The non-singer did not phonate but was instructed to inhale normally and hold breath, and thereafter to inhale normally and make imposto (constriction of nasalis muscle).

2.2 Nasofiberoscopy

Nasofiberoscopic registrations were made by an experienced ENT/phoniatrician using an endoscope (ORL Vision RS1, CCD supplied by Rehder & Partners). The subjects were scoped in a sitting position. The tasks were repeated, so that first the scope was in the nasopharynx, and then so that the scope was inserted in the pharynx. The position of the scope was carefully held the same by monitoring the view on a screen. No topical anesthesia was used. All participants tolerated the experiment well.

2.3 Analyses of nasofiberoscopic images

The following measurements (in pixels) were made from the nasofiberoscopic video: 1) height of soft palate, 2) area of the hypopharynx, and 3) area of the epilaryngeal tube inlet (Aditus laryngis), 4) Pharynx to epilarynx ratio was calculated, additionally 5) horizontal width and 6) antero-posterior (AP) width of the epilaryngeal tube inlet were measured.

The nasoendoscopic images were analyzed as follows. 1) The positioning of the velum (height of soft palate) was studied by measuring the distance from the highest part of the velum to the roof of the nasal cavity (see Figure 1a). 2) The areas of the pharyngeal inlet (Fig. 1b), and the epilaryngeal inlet (Aditus laryngis) were measured. The area of the epilaryngeal inlet is defined as the space surrounded by the epiglottis in the front, arytenoid cartilages in the back and the ary-epiglottic folds at the sides. Measurement of horizontal and AP width of the epilaryngeal tube inlet is also illustrated in Fig. 1 b. ImageJ software (Java8, 64 bits) was used in the measurements. The distances and areas were measured only qualitatively (in pixels), since no calibration was possible to obtain. All measurements were made three times to obtain estimates of intrarater reliability and to calculate measurement error for each participant and each measure separately. Furthermore, all measurements were made by two researchers to evaluate the interrater reliability of the measurements.

Please Figure 1 about here.

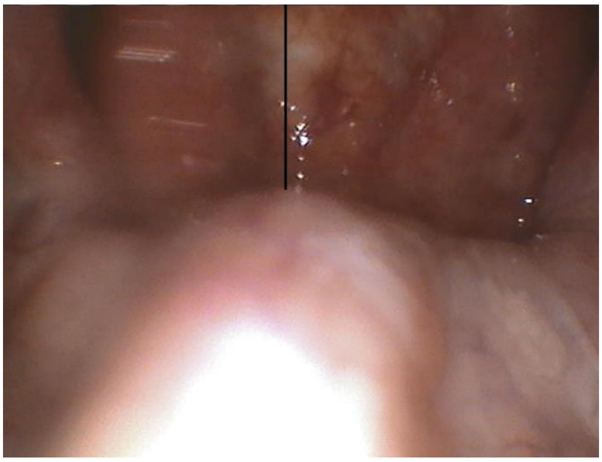


Fig. 1a. Distance from soft palate to roof of nasopharynx (Black line).

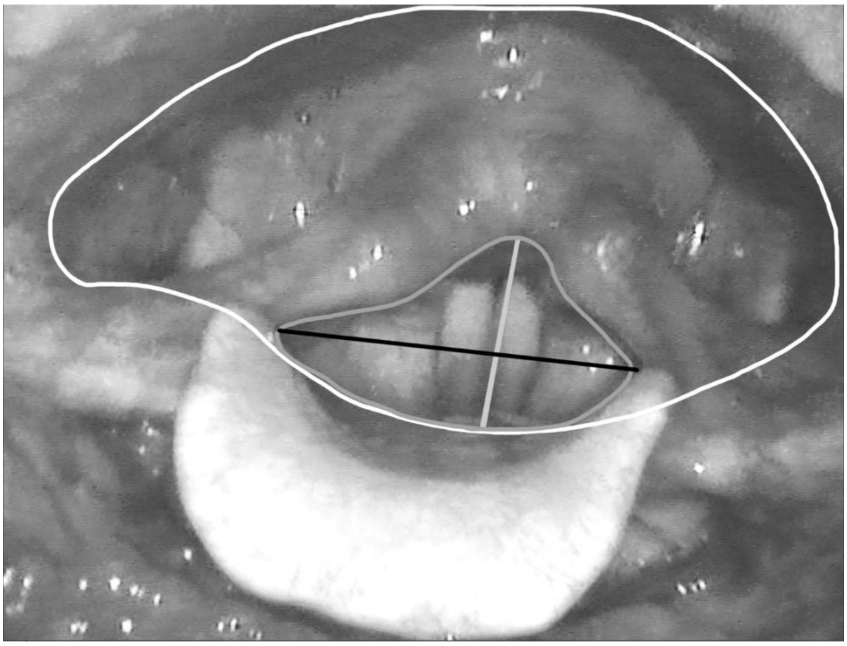


Fig.1b. Measurement of hypopharyngeal area (white line), area of the epilaryngeal inlet (Aditus larynges, dark grey line) and the width (black line) and antero-posterior depth (light grey line) of the epilaryngeal inlet.

3. RESULTS

There was a good correlation between the measurements of the two researchers (for velar height Spearman's rho: r = 0,87, p = 0,002; for hypopharyngeal area: rho = 0,80, p = 0,01 , and for epilaryngeal inlet: rho = 0,90, p = 0,037). Intrarater reliability between repeated measurements was also good: For velar height: rho = 0,997, p = 0,000; for hypopharyngeal area: rho = 0,85, p = 0,004, and for epilaryngeal outlet: rho = 0,97, p = 0,000. Therefore the measurement accuracy was regarded as satisfactory.

Table 1. Results for measurements of the nasopharynx (= height of velum), hypopharynx (area of the pharyngeal inlet), epilarynx (area of the epilaryngeal tube inlet), and horizontal and A-P width of the epilaryngeal tube inlet in pixels and changes (differences between 'without head resonance' and the other two voice qualities) in percentage. Error of measurement is difference in percentage between repeated measurements.

A mezzo-soprano	**Nasopharynx**	**Hypopharynx**	**Epilarynx**	**Aph/Ae**	**Epi width**	**Epi A-P**	**Epi width/A-P**
Without head resonance	1,60	7,76	1,21	6,42	1,72	1,16	1,49
With head resonance	1,40	7,96	1,13	7,01	1,95	1,15	1,70
Imposto	1,18	7,38	1,05	7,04	1,88	0,89	2,10
Changes in %	*12,50-26,25*	*2,58-4,9*	*6,61-13,22*	*9,19-9,66*	*9,30-13,37*	*0,86-23,27*	*14,09-40,94*
Error of measurement	*2,35-2,40*	*0,98-0,99*	*3,55-3,68*	*2,65-2,7*	*1,14*	*2,82*	
B soprano							
Without head resonance	1,96	7,34	1,20	6,11	2,23	1,15	1,90
With head resonance	1,62	6,82	0,92	7,43	1,83	0,91	2,00
Imposto	1,58	6,44	0,62	10,44	1,63	0,69	2,40
Changes in %	*17,35-19,39*	*7,08-12,26*	*23,33-48,33*	*21,60-70,87*	*17,94-26,90*	*20,87-40*	*5,26-26,31*
Error of measurement	*0,21*	*0,67*	*0,83*	*0,26*	*0,31*	*1,09*	
C tenor							
Without head resonance	3,99						
With head resonance	3,00						
Imposto	3,30						
Changes in %	*17,29-24,81*						
Error of measurement	*0,79*						
D female amateur							
Without head resonance	1,72	4,09	0,82	5,00	1,45	0,85	1,70
With head resonance	1,33	3,66	0,44	8,41	1,21	0,60	2,01
Imposto	1,09	3,53	0,41	8,70	1,28	0,60	2,13
Changes in %	22,67-36,63	*10,51-13,69*	46,34-50	*68,2-74*	*11,72-16,55*	*29,41*	*18,23-25,29*
Error of measurement	*0,68*	*9,12-10*	*1,50-1,53*	*10,4-11,6*	*3,67*	*0*	
Male Non-Singer							
breathing		5,32	1,22	4,36	1,59	0,77	2,08
imposto		5,28	0,46	11,52	1,47	0,52	2,82
Changes in %		*0,75*	*62,29*	*164,22*	*7,55*	*32,47*	*35,58*
Error of measurement		*6,75-7,24*	*4,39-4,59*	*2,4-2,47*	*4,09*	*6,76*	

All the singers raised the soft palate during head resonance, and most of them (both female singers and the female amateur singer) raised the velum even more with imposto (Table 1). Figures 2 a) and b) show an example of the changes found in the nasopharynx. In the male singer the laryngeal visibility was obscured by so strong a narrowing of the epilaryngeal inlet that measurements were not possible to make. Both female singers and the amateur singer narrowed the epilaryngeal inlet during head resonance and even more during imposto. Also, the ratio between the width and A-P depth of the epilaryngeal inlet increased, thus the A-P dimension narrowed more. The pharynx to epilarynx ratio increased in head resonance and even more in imposto (table 1). Figures 3 a) and b) illustrate the changes found in the low pharynx and epilaryngeal inlet. Similar narrowing of the epilaryngeal tube inlet was observed in the non-singer when constricting the nasalis (Figures 4a and b and Table 1).

It can be seen in table 1 that the differences between the voice qualities in various parameters clearly exceeded the error of measurement, except for the hypopharyngeal areas of the amateur singer and the non-singer.

Figure 2 shows an example of the changes in the nasopharynx, distance from soft palate to roof of nasopharynx, of subject B, the professional soprano.

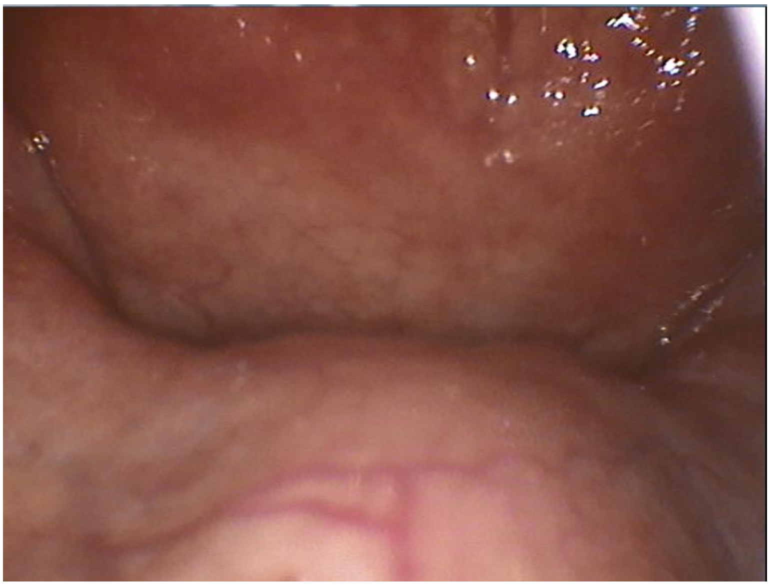


Fig. 2a. nasopharynx without head resonance or imposto.

Fig. 2b. Nasopharynx with head resonance.

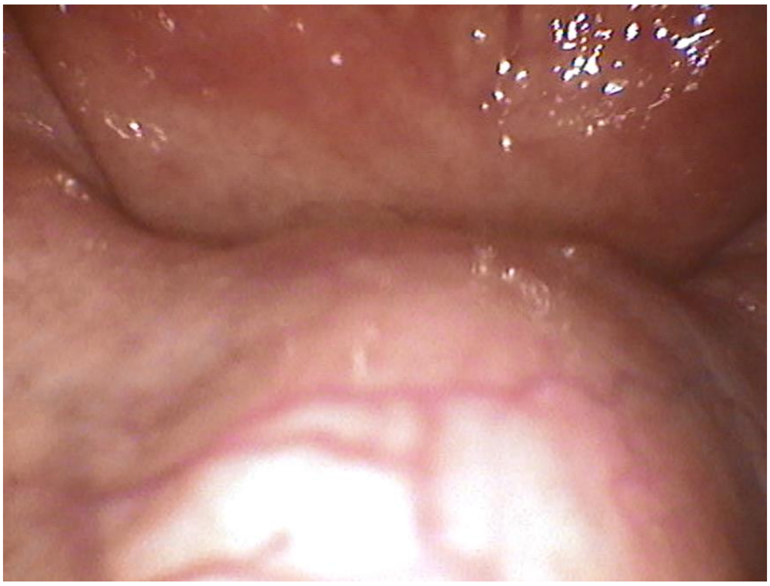
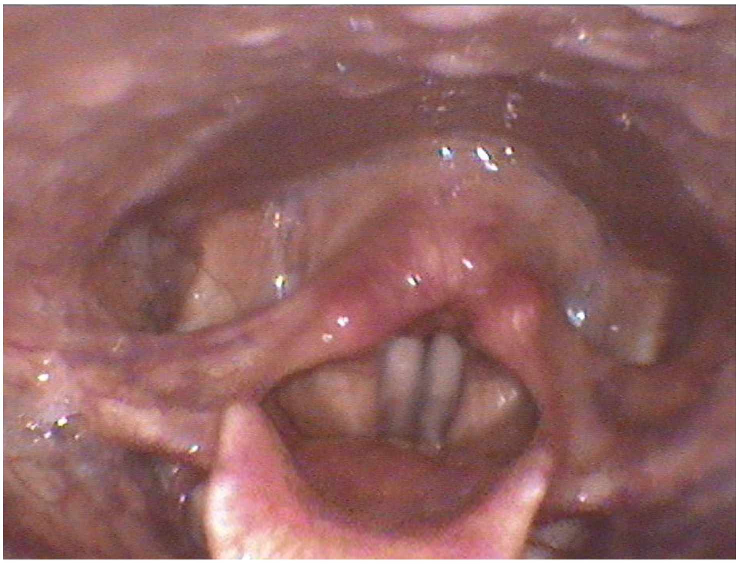


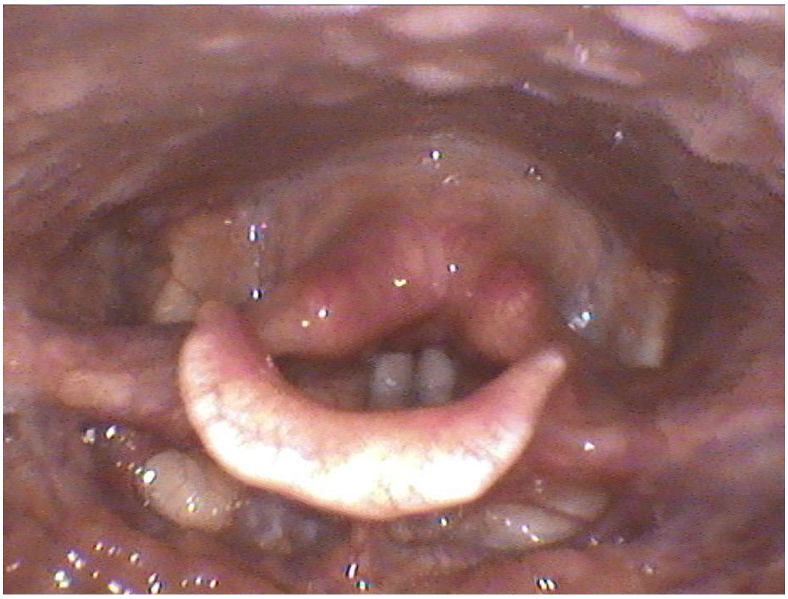
Fig. 2c. Nasopharynx with imposto.

Figures 3a-c show examples of the changes in the hypopharynx and epilaryngeal inlet of subject A, the professional mezzo-soprano.



3a. Hypopharynx and epilaryngeal inlet without head resonance or imposto.

3b. Hypopharynx and epilaryngeal inlet with head resonance.



3 c. Hypopharynx and epilaryngeal inlet with imposto.

Figures Fig. 4a-b show changes of the epilaryngeal inlet in the non-singer

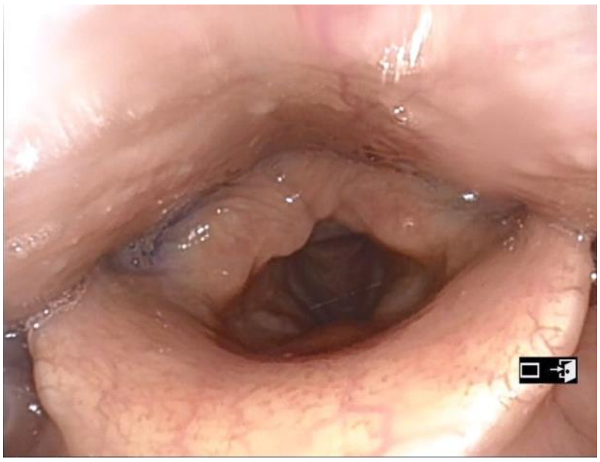


Fig. 4a Epilarynx in the male non-singer holding breath after inspiration without imposto.

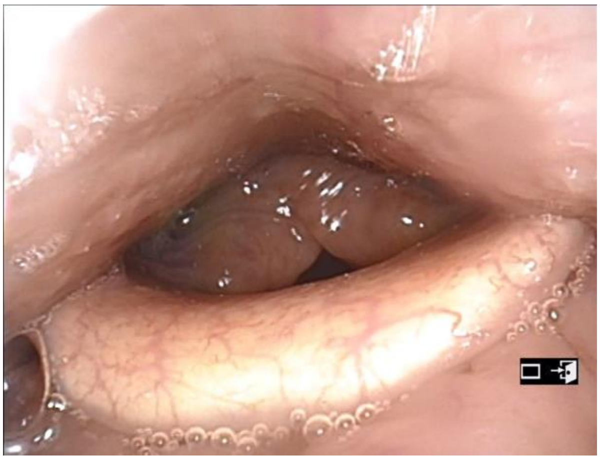


Fig. 4b. Epilarynx in the male non-singer holding breath after inspiration and making imposto (constriction of the nasalis muscle).

4. DISCUSSION

According to the results, head resonance and imposto did cause clearly visible changes in the nasopharynx, hypopharynx and larynx. Furthermore, imposto seemed to differ from head resonance by resulting in stronger changes. Finally, similar changes were observed in the amateur singer and in the non-singer.

The velum rose for head resonance and even more for imposto. The epilaryngeal inlet became narrower for head resonance, and the change was even more prominent for imposto. These results suggest that both head resonance and imposto are related to control of the pharyngeal width and epilaryngeal tube. Furthermore, it seems that the nasal muscles may be used as an aid in the epilaryngeal narrowing, as suggested by [3,27].

Raising the velum as in the beginning of yawning, would increase the pharyngeal space. A relatively wide pharynx and narrow epilarynx improve the voice-source-tract interaction. [29]. Widening of the pharynx (e.g. by lowering the larynx, relaxing the pharyngeal constrictors and to some extent by raising the velum) and narrowing of the epilarynx may be seen beneficial to establish the singer’s formant [29]. That makes the voice strong and ringing and helps especially male voices and the lowest pitch ranges of the female singers carry over the orchestra [30]. Although soprano singers do not seem to possess a particular singer's formant (a sound energy concentration within the same frequency range in the voice spectrum, regardless of vowel and pitch) at least in the higher pitch range [31,32,33] and their projection is related to the strengthening of the fundamental by tuning the first vocal tract resonance (F1) near the fundamental [31,34], the female singers do show epilaryngeal narrowing [35]. Epilaryngeal narrowing increases vocal tract reactance over a wide frequency range [29,36] and lowers phonation threshold, thus assisting vocal fold vibration [29]. It also lowers the impact stress related to vocal fold collision during phonation. Thus, it seems plausible to suggest that the increased vocal tract reactance due to epilaryngeal narrowing is highly beneficial also in female singers.

The fact that in the present study the area of the low pharynx seemed to decrease somewhat in head resonance and imposto is most likely related to the way the area was measured here: It comprised the area from the base of the epiglottis (tubercle) to the backwall of the pharynx. Therefore, narrowing of the pharynx seems to stem from tilting of the epiglottis backward in head resonance and imposto.

As to the relations between nasal muscles and the nasopharynx and hypopharynx, it is plausible that there are respiration related muscle connections along the nasal and vocal tract. Flaring of the nostrils is seen in patients who have difficulties in breathing, and it is also common as an associated gesture in patients with abductor spasmodic dysphonia [37]. A previous study by Aura et al. [38] found a widening of the pharynx and glottis to be related to the specific ‘singer's facial expression’ (taken before starting to sing) which seems to exploit *musculus nasalis* and *levator labii superioris alaeque nasi* and *musculus zygomaticus minor* muscles. In the present study, phonation with ‘head resonance’ and ‘imposto’, were observed to include narrowing of the epilaryngeal inlet. This narrowing was more prominent in imposto, which was seemingly obtained by a constriction of the nasal muscle. The fact that the results were similar also for non-singers support the suggestion that the singing related concepts studied here exploit respiration related in-born muscle connections.

It is possible to view the results in the framework of the general term ‘resonant voice’ [19] as the singer's way of applying source-filter interaction to achieve maximal output (both in terms of volume and genre-related quality) with minimal effort. Efficient energy conversion causes vibrations that can be felt in and around different parts of the voice organ, for example, somewhat depending on vowel, pitch and volume. The different ‘resonances’ (head/nose/mask etc.) may reflect the places where the maximal vibrations are sensed and potentially also differences in the way the interaction is achieved. The location of the maximal vibratory sensations may be related to the air pressure maxima of vocal tract resonances [see e.g.36]. The ways of controlling the interaction may include changes in the vocal tract setting (tongue and larynx position, opening or closing the nasal port) and changes in vocal fold adduction.

The two settings to control the interaction with least dependence on vowel and pitch are a narrowed epilaryngeal tube [29] and ‘head voice/mixed register’ phonation [22]. Exercises on various nasal consonants and other semi-occlusions (lip and tongue trills, raspberries etc) offer a way of achieving a head voice and producing the intense sensation of vibrations due to increased vocal tract air pressure. Aiming for similar vibratory sensations also with non-occluded vowels may result in the skill of controlling epilaryngeal tube width, for example, according to the needs of sound volume and projection.

The number of the participants was small but the results were fairly consistent and logical. Unfortunately the hypopharynx and epilarynx of the professional male singer could not be measured. Nasopharynx of the non-singer male was not scanned during head resonance and imposto. Further studies with a larger number of participants should focus on subglottic pressure and airflow during singing with and without head resonance and imposto. It would be of interest to study whether singing with head resonance and imposto would provide lower phonation threshold. Vocal fold contact should also be studied with electroglottography. The acoustic and perceptual effects of these three ways of singing should also be considered. As to the question of other possible differences in these postures setting, e.g. related to velopharyngeal opening, tongue position, laryngeal tilting and even in diaphragm descent, magnetic-resonance imaging is warranted.

5. CONCLUSION

This study investigated whether the head resonance and imposto cause changes in nasopharynx, hypopharynx and larynx. According to the results obtained from nasofiberoscopic analysis, ~~all~~ the ~~three~~ professional singers narrowed epilaryngeal inlet and raised the velum while producing head resonance and even more during imposto. The amateur singer acted in the same way, and also the non-singer narrowed the epilarynx during imposto. The imposto was related to constriction of the nasalis muscle.

The results suggest that head resonance and imposto are related to control of the epilaryngeal tube, and that the nasal muscles may be used as an aid in this maneuver, which in turn, improves the voice-source- vocal tract interaction. The increase in acoustic-mechanic interaction allows a lower phonation threshold pressure and a wider amplitude of the vocal fold vibration without excessive collision, and thus it would improve effective and economic vocal fold vibration.

Vocal fold vibration during imposto and head resonance should be studied with high-speed imaging in the future. As to the question of other possible differences between these postures e.g. related to velopharyngeal opening, tongue position, laryngeal tilting or the connection between nasal muscles and diaphragm activity etc., magnetic-resonance imaging is warranted.

6. ACKNOWLEDGEMENTS

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7. DISCLOSURE STATEMENT

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

8. REFERENCES

[1] Glossary of singing terms. https://www.successfulsinging.com/singing-guides/glossary-of-singing-terms/ (accessed 25 march 2020).

[2] E. Howard, Sing! The vocal power method. Alfred music publishing CA, USA, 2006.

[3] L. Mánén, The Art of singing, Faber Music LTD, 1974.

[4] M. Koistinen, Tunne kehosi-vapauta äänesi, Äänitimpurin käsikirja, [Feel your body – free your voice], in Finnish. Sulasol, Finland, 2004.

[5] What is Vocal Placement and How to Project Your Voice? https://www.becomesingers.com/techniques/vocal-placement (accessed 25 march 2020).

[6] https://en.wikipedia.org/wiki/Vocal_resonation (accessed 25 march 2020).

[7] Vocal vocabulary. https://kafm.net/vocab.html (accessed 25 march 2020).

[8] M. Bunch, Dynamics of the singing voice. Springer Verlag, Wien, 1982, p. 97-99.

[9] W. Vennard, An experiment to evaluate the importance of nasal resonance. Folia Phoniatrica, 16:1 (1964) 146-153. (DOI:10.1159/000262995).

[10] O. Brown, Discover your Voice, Singular publishing group, San Diego, ISBN 1-56593.704-X, 1996.

[11] K. Borg, Suomalainen laulajanaapinen, [Finnish abc for singers], in Finnish. Yhteiskirjapaino Oy, Helsinki, 1972.

[12] J. Allen, Secrets of singing. Female low & high voice. CPP/Belwin Inc. CA, USA, 1994. 0-7692-7805-1

[13] M. Nova, P. Collins, Singing Bel Canto Art & Science, Compton publishing, Oxford, UK, 2014.

[14] R. Gates, K. Obert, & A. Forrest, The Owner's Manual to the Voice : A Guide for Singers and Other Professional Voice Users, Oxford University Press, New York, 2013.

[15] G.L. Gibian, Synthesis of sung vowels. Quarterly Progress Report (MIT), 104, (1972), 243–247.

[16] J. Sundberg, Science of the singing voice 1987, p. 119.Northern Illinois University Press, Dekalb, Illinois

[17] H.K. Schutte, R. Miller, Resonance balance in register categories of the singing voice: a spectral analysis study, Folia phoniatrica 1984, 36(6):289-95.

[18] E. Ekholm, G. C.Papagiannis, F. P. Chagnon, Relating objective measurements to expert evaluation of voice quality in western classical singing: Critical perceptual parameters, Journal of Voice, 12, (1998) 2, p.182-196. https://doi.org/10.1016/S0892-1997(98)80038-6.

[19] I.R. Titze, Acoustic Interpretation of Resonant Voice. Journal of Voice, 15(4), (2001) 519–528. https://doi.org/10.1016/S0892-1997(01)00052-2.

[20] R. Miller, The Structure of singing – System and art in vocal technique, Shirmer,1996.

[21] I.R. Titze, Principles of voice production, Prentice-Hall, Inc. Englewood Cliffs, NJ, 1994.

[22] I.R. Titze, Bi-stable vocal fold adduction: A mechanism of modal-falsetto register shifts and mixed registration, The Journal of the Acoustical Society of America 2014, 135, 2091 (2014); https://doi.org/10.1121/1.4868355.

[23] I.R. Titze, Voice Training and Therapy With a Semi-Occluded Vocal Tract: Rationale and Scientific Underpinnings. Journal of Speech, Language, and Hearing Research 2006; 49:448–459.

[24] J. Nix and C. Blake Simpson, Semi-Occluded Vocal Tract Postures and Their Application in the Singing Voice Studio, Journal of Singing, January/February 2008, vol 64, No. 3, pp. 339–342.

[25] J. Horacek, J. Vesely, L. Pesek, M. Vohradnık, Fundamental dynamic characteristics of human skull. Part I – Experimental Modal Analysis and FE Modelling of Basic Vibration Properties, *Engineering MECHANICS 2004, 11(2), 139 – 158.*

[26] M. Hoch, A dictionary for a modern singer, Scarecrow Press, 2014.

[27] T. Hemsley, Singing and imagination, A human approach to a great musical tradition, Oxford university press, New York, 1998.

[28] L. Manen, Bel Canto, The teaching of the classical Italian song-schools, it's decline and restoration, Oxford University Press, 1987.

[29] I.R. Titze, B. Story, Acoustic interactions of the voice source with the lower vocal tract, The Journal of the Acoustical Society of America, 101(4):2234-43, 1997. https://doi-org.libproxy.tuni.fi/10.1121/1.418246

[30] J. Sundberg, Articulatory interpretation of the singing formant, Journal of the Acoustical Society of America 55 (1974) 838-844. https://doi-org.libproxy.tuni.fi/10.1121/1.1914609

[31] W. S. Brown, Singer's formant in sopranos: Fact or fiction? Journal of Voice - Official Journal of the Voice Foundation, 2001, 15(4), 457-468. doi:10.1016/S0892-1997(01)00046-7

[32] G. Bloothooft, R. Plomp, Spectral analysis of sung vowels. I. Variation due to differences between vowels, singers, and modes of singing. J Acoust Soc Am. 1984 75(4):1259-64. https://doi-org.libproxy.tuni.fi/10.1121/1.390732

[33] M. Rothenberg, Cosi' Fan Tutte and What it Means, or, Nonlinear Source-Tract Acoustic Interaction in the Soprano Voice and Some Implications for the Definition of Vocal Efficiency Vocal fold physiology: laryngeal function in phonation and respiration (1986) 254-263.

[34] J. Sundberg, Formant technique in a professional female singer. Acustica 1975, 3289-96.

[35] S. Cookman, K. deVore, Inside the Singing Voice, Laryngeal Teaching Series, vol. 4, Total Voice Inc., Chicago, 2006.

[36] Vampola T, Laukkanen A-M, Horácek J, Švec JG. Vocal tract changes caused by phonation into a tube: A case study using computer tomography and finite-element modeling. Journal of the Acoustical Society of America 129, 2011, (1): 310-315. DOI: 10.1121/1.3506347

[37] J.R. Menon, Flaring of ALA Nasi: A reliable diagnostic sign for Abductor Spasmodic Dysphonia. International Journal of Phonosurgery and laryngology 1 No 2 (2011) 41-43.

[38] M. Aura, A. Geneid, K. Bjørkøy, M. Rantanen & A-M. Laukkanen, The Nasal Musculature as a Control Panel for Singing-Why Classical Singers Use a Special Facial Expression? Journal of Voice, 2018, https://doi.org/10.1016/j.jvoice.2017.12.016