An Experimental Study of Absolute Pitch in a Professional Soprano

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ABSTRACT

This experiment was aimed at modifying the proprioceptive references of a professional soprano endowed with absolute pitch. To do so, an osteopathic doctor changed the height of her larynx by altering the tension between the hyoid bone and the occipital bone. A cephalometric analysis of X-rays taken before and after the manipulations indicated that the position of the phonatory organs had indeed been affected. The results of an acoustic analysis, and perception tests on the tones produced before and after manipulation provided irrefutable evidence of the influence of the laryngeal manipulations on the tonal accuracy of the emission. This study demonstrates the critical role that this soprano's kinesthetic-pallesthetic memory plays in pitch recognition, and suggests the existence of different types of absolute pitch.

1. INTRODUCTION

Most opera singers who possess absolute pitch — that is, the ability to recognize or produce a tone of a given frequency without an external reference — utilize a strategy which suggests that their proprioceptive memory acts as an internal tuning fork. This hypothesis was tested here in an experiment aimed at modifying the proprioceptive references of a professional singer endowed with absolute pitch. For this reason, we chose a soprano who uses a vocal technique that involves a slight downward shift of the larynx for singing in the lower register and a slight upward shift for singing in the upper register, a characteristic of high, vocalizing voices. Given that opera singers possess an extremely precise kinesthetic memory of the positions of their phonatory organs when singing each tone in their tessitura, modifying the position of one of these organs necessarily disrupts their proprioceptive control of tonal accuracy [1]. In this experiment, an osteopathic doctor performed a series of manipulations on this singer in order to modify the height of her larynx in such a way that she lost her proprioceptive references.

2. EXPERIMENT

2.1 Experimental Setup

Profile X-rays of the head and neck in left/plate position (distance: 3 meters, duration of exposure: 0.15 sec, voltage: 120 kv, current: 100 mAS) were taken before and after manipulation. The subject was standing and was allowed to assume a natural position without any constraints (such as the use of a cephalostat, or positioning in the Frankfort Plane by the radiologist). In order to be able to analyze the soprano's comments and perform the acoustic study of her voice quality before and after manipulation, the entire session was recorded on a professional Nagra III tape recorder equipped with a omnidirectional Sennheiser ME40 microphone. So as not to influence her analysis of what she was feeling, she was not informed of the true reason for the manipulations she would undergo.

2.2 Experimental Procedure

To obtain reference X-rays and recordings before the osteopathic doctor performed the manipulation, the soprano was asked to sing her entire tessitura from the lower to the upper register, and then to sing the vowel [a] in the lower register on $B\flat_3$ (233 Hz) and in the upper register on $B\flat_5$ (932 Hz). A profile X-ray was taken for each of these two tones, with simultaneous recording of the sound. Next, the practitioner had the subject lie down. He controlled the position of the temporal occipital bone with one hand, and of the hyoid bone with the other. The first part of the preparation phase required balancing the tensions. To do this, he began by holding the occipital bone in a fixed position and slightly drawing the hyoid bone forward; then he held the hyoid bone in a fixed position and slightly pushed the occipital bone backward. The second part required finding a point of equilibrium between these two extremes, which relaxes the tissues and enables the proper arrival of blood, lymph, and interstitial tissues. Only at this point can the manipulation be performed. Two approaches are possible: the practitioner can either change the hyoid bone tension relative to the occipital bone, or change the occipital bone tension relative to the hyoid bone. The second solution was chosen because it is closer to physiological reality. In this case,

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the doctor acts upon the occipital bone, either by moving the hyoid bone downward and thereby preventing the larynx from rising, which corresponds to the laryngeal position used by this soprano to sing in the lower register, or by moving it upward and thereby preventing the larynx from lowering, which corresponds to the laryngeal position she uses to sing in the upper register.

Then the *first manipulation* was performed to set the singer's larynx in the lower-register position via the anteriorization of her occipital bone. This was achieved by sliding the occipital condyle along the glenoid cavity of the atlas in such a way that the posterior surface of the odontoid apophysis of the axis touched the posterior part of the foramen magnum. This occipital bone position causes the anteriorization of the styloid apophysis of the temporal bone, which releases stylohyoid muscle tension and lowers the hyoid bone and the larynx. The experiment must be completed within the next ten minutes, after which the phonatory organs return to their initial position. In this low-larynx position, the soprano was asked to sing the vowel [a] in her upper register (on B♭5) as a profile X-ray was being taken and her voice was being recorded. Then she was asked to sing across her tessitura from the lower register to the upper register, and to state her impressions.

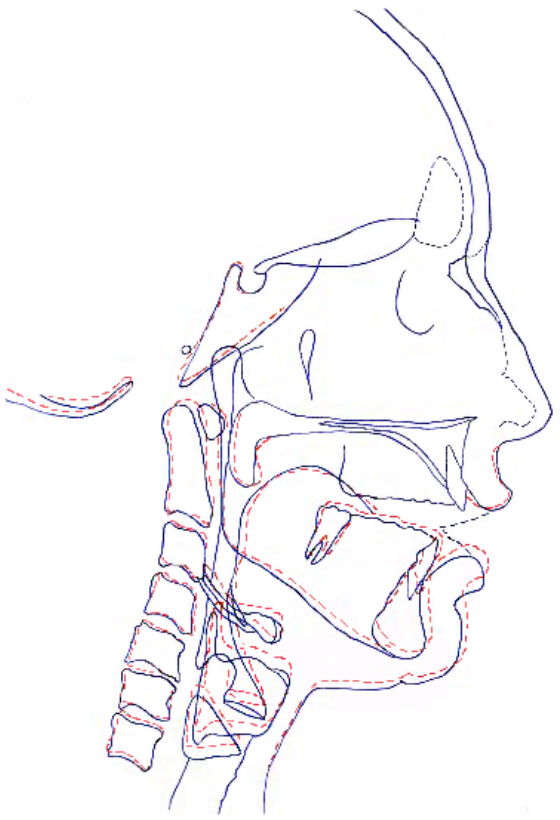

Figure 1. Radiographic tracing showing the phonatory positions for singing in the lower register, before manipulation (solid lines) and after manipulation (dotted lines)

The same process was used for the *second manipulation*, which set the subject's larynx in the upper-register position. This time, the manipulation consisted in posteriorizing the occipital bone relative to the atlas, in order to trigger a superior-posterior shift of the styloid apophysis and thereby increase the tension of the stylohyoid muscle, causing the hyoid bone to pivot upward and backward and the laryngeal box to rise.

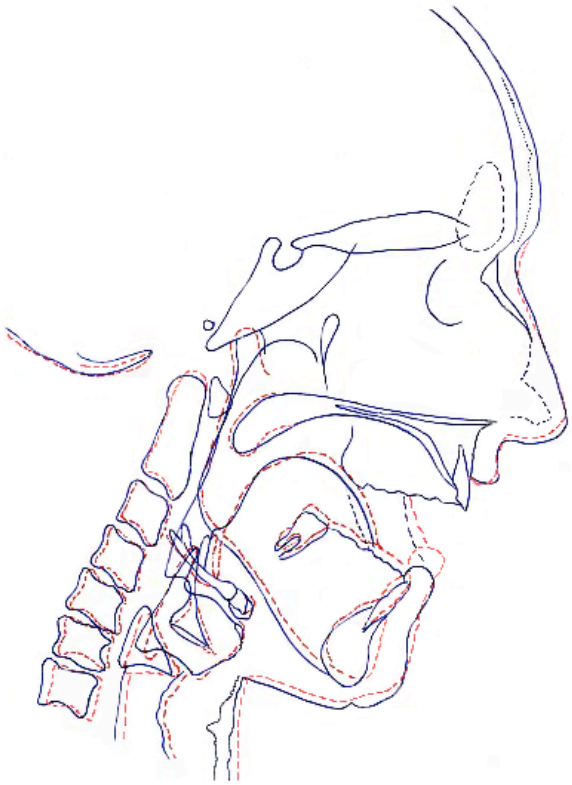

Figure 2. Radiographic tracing showing the phonatory positions for singing in the upper register, before manipulation (solid lines) and after manipulation (dotted lines)

3. CEPHALOMETRIC ANALYSIS

The four X-rays of the vowel [a], i.e., in the lower register on B♭3 and in the upper register on B♭5, before and after manipulation, were analyzed using a method derived from cephalometry [2] and adapted to the radiological study of phonation [3]. For this analysis, 31 parameters were measured: head position, anterior-posterior movements of the cervical spine, craniocervical angle, buccal opening, labial opening, lip projection or retraction (upper and lower), lip thickness (upper and lower), lip height (upper and lower), tongue mass orientation, aperture, region of articulation, velar tension, degree of pharyngouvular nasalization and dorsouvular buccalization, vertical and anterior-posterior movements of the hyoid bone and its tilt, thyrohyoidian space, vertical and anterior-posterior movements of the thyroid cartilage and its tilt, vertical and anterior-posterior movements of the cricoid cartilage and its tilt, pharyngeal cavity dimensions at its maximal constriction points (rhinopharyngeal, buccopharyngeal, and hypopharyngeal), and vocal tract length.

4. PHYSIOLOGICAL & ACOUSTIC ANALYSIS

For each manipulation, the anamnesis is given and then followed by the results of the acoustical and physiological analyses.

4.1 First Manipulation

After the first manipulation aimed at setting the larynx in the lower-register position, the subject said that she felt "pulled downward" and was experiencing difficulty singing in the upper register. Moreover, the acoustic analysis confirmed these statements by revealing the poor quality of the high-pitched tones produced. A comparison of the radiographic tracings of the vowel [a] sung in the upper register (on Bb5) before and after manipulation pointed out:

Phonatory positions specific to lower-register emission
* anteriorization of the cervical spine (Δ = + 3.6 mm)
* lowering (Δ = - 2.7) and anteriorization of the laryngeal box (Δ = + 7.7 mm)
* less pronounced hyoid tilt (Δ = - 4°)
* less pronounced thyrocricoidian shift (Δ = - 7°)

Phonatory positions specific to upper-register emission
* identical tongue position
* identical velum position
* nearly identical thyrohyoidian space

Compensating phonatory positions
* smaller labial opening (Δ = - 9 mm)
* smaller buccal opening (Δ = - 2.9 mm)
* slight tilt of the head (Δ = - 2°)

4.2 Interpretation

The lowering of the laryngeal box caused by the manipulation resulted in a vocal-tract volume increase that required the subject to make an acoustic adjustment in order to sing in the upper register [4]. She achieved this by reducing the mandibular opening in order to decrease the volume of the buccal resonator and compensate for the upper-lip spreading brought about by the considerable rise in the cheeks, one of this soprano's characteristic facial expressions for upper-register singing. The head tilt angle with respect to the Frankfort Plane was 2° after the manipulation. The singer tried to counteract the resulting occipital anteriorization by lowering her head. Thus raised and posteriorized her occipital bone and its styloid apophysis, which moved the hyoid bone upward and backward and thereby facilitate the thyrocricoidian shift required in the upper register [5]. Without this compensatory maneuver, which enabled her to raise the "place" of her voice[1], the soprano said she would have been unable to produce this high-pitched tone. The Bb5 after manipulation was a comma lower than the one sung beforehand. It was also not in “as high a place” and “less in the head”.

4.3 Second Manipulation

After the second manipulation aimed at setting the larynx in the upper-register position, the singer said that the high-pitched tones were easier to produce, although she experienced no additional difficulty with lower-register ones. The acoustic analysis confirmed an excellent vocal quality across the lower- to upper-register range. The comparison between the radiographic tracings of the vowel [a] sung in the lower register on Bb3 before and after manipulation pointed out:

Phonatory positions specific to upper-register emission
* slight posteriorization of the cervical spine (Δ = - 1 mm)
* posteriorization (Δ = - 0.7 mm), elevation (Δ = + 1.6 mm), and verticalization of the hyoid bone (Δ = + 4°)
* rise of the laryngeal box (Δ = + 2 mm)
* decrease in the thyrohyoidian space (Δ = - 0,2 mm)
* greater thyrocricoidian shift (Δ = + 3°)
* larger mandibular opening (Δ = + 3.6 mm)
* slightly less labialization (Δ = - 1 mm)
* shortening of the vocal tract (Δ = - 5 mm)

Phonatory positions specific to lower-register emission
* nearly identical tongue position
* nearly identical velum position
* identical thyrocricoidian shift

Compensating phonatory positions
* smaller labial opening (Δ = - 3.8 mm)

4.4 Interpretation

Bec Because lower-register emission does not require mobilization of the phonatory organs as much as upper-register emission, the soprano did not have any major problems singing in the lower register with her larynx positioned for the upper register. This accounts for why her compensating phonatory positions were limited to an attempt to correct the vowel's timbre by reducing the labial opening. Indeed, the smaller vocal-tract volume resulting from the second manipulation required an acoustic adjustment aimed at darkening the timbre in the lower register. To do this, the vocal tract could be lengthened by substantial labial projection and its volume could be decreased by reducing the buccal opening. But the extent of labial projection was almost identical here to that used before the manipulation, most likely because this position is the singer's physiological limit. The buccal opening was similar to that in the upper-register, and for this reason, it was greater after the manipulation. The soprano attempted to compensate for the insufficient labialization and overly wide buccal opening by reducing her labial opening. The Bb3 sung after the manipulation was a quarter tone higher than beforehand. Moreover, it sounded less like a *chest tone*[2] and thus possessed a much lighter timbre than a low-pitched tone produced by this soprano under normal conditions.

[1] The *"place"* of the voice or a tone corresponds to the location of the singer's internal voice sensitivities (of pallesthetic origin) aroused by a vibration. Vibrations are sensed in the craniofacial region during upper-register emission, giving singers the impression that their voice is "resonating" in the head (hence the expressions *head voice* and *head resonance*), and in the thoracic region during lower-register emission, giving them the impression that their voice is "resonating" in the chest (hence the expressions *chest voice* and *chest resonance*).

[2] A *chest tone* is produced with the larynx in a low position, which provokes strong pallesthetic sensitivities in the thoracic region.

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5. PERCEPTION TESTS

5.1 Listeners

A perceptual study of the Bb3 and Bb5 sung before and after manipulation was conducted on 10 musicians (Group 1) who rated only accuracy, and on 5 singing teachers and 5 professional singers (Group 2) who rated accuracy as well as voice placement. The soprano who had undergone the manipulations eight months earlier was also asked to rate her own productions, although without being told what experiment was at stake (Group 3).

5.2 Testing

The listeners were presented with two pairs of tones: [lower register before manipulation vs. lower register after manipulation], and [upper register before manipulation vs. upper register after manipulation]. The instructions were to compare the second tone to the first one in each pair. The stimuli were assembled on tape in loops containing ten randomly ordered repetitions. All 20 listeners who judged tonal accuracy responded unanimously (i.e., all on-key tones were unanimously judged to be on-key and all off-key tones were judged to have the same tonal deviation relative to the target tone). The ten listeners in Group 2 and the listener in Group 3 also responded unanimously regarding voice placement, except for a few minor differences in wording. The listeners also performed a frequency-tuning test consisting of using a frequency generator to equate the different tones assembled on tape. This enabled them to more precisely quantify the tonal inaccuracies they had noted during the first part of the test.

5.3 Additional Test

The soprano who had served as the subject was given an additional test consisting in evaluating her own productions by ear (by naming the tone heard). The tones to be judged were assembled on tape in random order and interspersed with ten tones from the reference recording made before the manipulations. There were no repetitions and the subject was tested once. The soprano said that the tones she had produced after the manipulation were "horribly off key". She estimated the high-pitched tone to be one comma too low and the low-pitched tone, a quarter tone too high, which is exactly what the acoustic analysis of both tones indicated.

6. CONCLUSION

This study showed, firstly, that vocal technique is the result of powerful reflex conditioning, insofar as the height of the laryngeal box automatically determines the singer's phonatory positions. This means, for example, that when the larynx is positioned for singing in the lower register, the organs take on the phonatory positions specific to that register, even during the emission of high-pitched tones. The same holds true for the upper register. This study also pointed out the important role that proprioceptive memory plays in pitch recognition for the subject studied here, and thus suggested the existence of different types of absolute pitch. This soprano is endowed with a form of absolute pitch which, unlike that of most instrumentalists, does not call upon auditory memory. Instead, she relies on kinesthetic memory (memory of muscle contractions), which is generally highly developed in opera singers, and thus on pallesthetic memory (memory of vibratory sensations) since differences in the position of the larynx induce different pallesthetic sensations. It is her kinesthetic-pallesthetic memory that enables this singer — via the mental positioning of her phonatory organs — to find the exact pitch of the tones she must recognize or sing. If for any reason the position of these organs is disrupted, she loses her ability to correctly assess pitch and can no longer control the tonal accuracy of the notes she produces.

ACKNOWLEDGMENTS

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IN MEMORIAM

In memory of my cousin Félix Fabre (1913-2001) who, by opening my eyes as a child to the wonders of the world and the mysteries of life, aroused in me the curiosity of the mind, the driving need to learn, to understand, and to explain, which led me to my vocation as a researcher.

REFERENCES

[1] Scotto Di Carlo, N. "Internal Voice Sensitivities in Opera Singers". Basel: Folia Phoniatrica et Logopaedica, 1994, 46, 2, pp. 79-85.

[2] Muller, L. Céphalométrie et Orthodontie, Paris: S.P.M.D, 1973.

[3] Scotto Di Carlo, N. Application des méthodes céphalométriques à l'étude radiologique de la voix chantée. Aix: P.U.P., 1976.

[4] Scotto Di Carlo, N. "La voix chantée". Paris: La Recherche, 1991, 22, 235, pp. 1016-1025.

[5] Scotto Di Carlo, N. "X-ray study of a professional soprano's postural strategy for increasing laryngeal mobility". Folia Phoniatrica et Logopaedica, 2002, 54, 4, pp. 65-170.