A Case Study on the Efficacy of Ultrasound Biofeedback in Voice Pedagogy

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ABSTRACT

This paper presents a case study on the use of ultrasound as visual biofeedback in a short master class lesson for two young, tenor singers-in-training. Even in such a short period of time, the singers both exhibit subjectively improved changes in production techniques such as the movement and position of the tongue and the Low Mandible Maneuver (LMM – the downward relaxation of the singer's posterior mandible); a technique used to increase the space in the oropharynx used as a resonance cavity which is found in most world-class opera singers. The former specifically showed expedited kinesiological and biomechanical improvements and understanding (e.g. coordination, direction and point of articulation) through the visual information of the ultrasound; an important but difficult aspect especially at the beginning of voice training. Observed measures of formant values suggest that the young singers are able to maintain recognizable vowel production while modifying their articulation technique.

Keywords: singing, pedagogy, ultrasound, phonetics

1. INTRODUCTION

The classical singer inhabits a phonetic world far removed from speech norms. Because of the demands of the style, a massive retraining of neuromuscular phonetic activity is required and involves mastery in three key areas:

1. ***Power*****:** the classical singer has to fill large venues and often sings over the accompaniment of full orchestra *without* the aid of electrical amplification;
2. ***Tone*****:** the classical performing tradition demands a tonal richness that is simply not found in the norms of everyday speech. To satisfy this additional demand, singers must maximize the resonance (internal space) available to their voices during every note, loud or soft, high or low, all while clearly enunciating the phonetic sounds of a variety of languages); and
3. ***Range*****:** the pitch range in the classical style is extreme by most other stylistic standards and the power/tone combination has to be maintained from the very lowest to the very highest notes that the singer's anatomy and physiology can provide.

Combined, these demands can seem almost superhuman yet classical singers must accomplish this routinely without overstressing or injuring their vocal folds or attendant musculature.

Aside from the genetic endowment of the singer, many of the trainable technical advances in the singer's technique arise from enhancing the volume of the resonance areas of the voice in the oral cavity and the pharynx. Nair and Nair [5] have found that the Low Mandible Maneuver (LMM) – the habituation of the downward relaxation of the singer's posterior mandible, a maneuver based on the first 10% of the yawn sequence in which the entire mandible platform drops – is one such fundamental technique that has significant ramifications for resonance production by enabling a concomitantly lowered larynx and increased resonant space in the pharyngeal and oral cavities**.** Its use also has a rather significant effect on the tongue shapes required for all sung phonemes. Hence, classical singers have to use the tongue in a far more active way than they do in speech (the cause for the mantra many students hear ad nauseam – "the jaw is not an elevator for a lazy tongue!"). The ultrasound images in Figure 1 show a comparison of the sung and spoken example of the back vowel [ɑ]. Although the differences may appear minimal, mere millimeter changes in tongue shape and position can have a considerable effect on the sound radiating from the singer´s mouth.

It is possible to view the LMM as an articulatory setting (see [3, 4]). In this view, part of voice pedagogy can be construed as modifying a student's articulatory setting. According to Timmermans et al. [6], voice training is applied when "voice optimization is necessary". Some aspects of the articulatory setting for singing such as the LMM are, however, quite extreme from a speech point of view. However, the linguistic part of a given song – the lyrics – is still expected to be relatively comprehensible. In the case of the LMM, the tongue must be retrained to achieve (relatively) natural

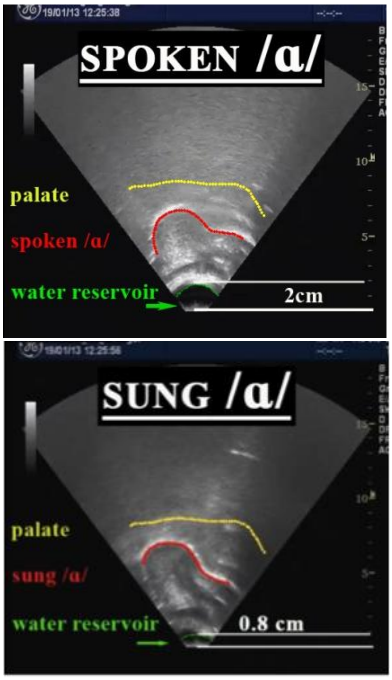

Figure 1: Ultrasound images of the midsagittal tongue surface during production of a spoken /ɑ/ vowel (top) and performance of a LMM /ɑ/ vowel (bottom). Notice the size and shape of the fluid reservoir at the bottom of the wedge which indicates that the mandible has dropped approximately 1 cm. (Images from [5])

sounding language while maintaining a maximal jaw opening which is not generally found in speech.

Traditional approaches to vocal pedagogy rely almost exclusively on kinesthetically-based descriptions and auditory modeling with the teacher relying on his/her (well-trained) ears to discern whether the student has achieved the goal. Singers rarely get any direct visual biofeedback on their production. Modern technology is changing this. Ultrasound provides a tool whereby singers can easily see the action of their tongues while they are actually singing. Ultrasound has been successfully used as biofeedback in both clinical settings [1] and in the language classroom [2]. Voice pedagogy already uses eye-body biofeedback in the form of virtual real-time spectrography. It was thus a short leap to the use of ultrasound as biofeedback in the voice studio. The present paper presents a case study on the use of ultrasound as a biofeedback training tool in the context of classical voice pedagogy.

2. PROCEDURES

Two male opera students, both tenors, each underwent a short (~10 minute) training session as part of a master class with one of the authors, a world-class singer and teacher who regularly uses ultrasound as a teaching tool. A portable Logiq E ultrasound and 3S-RS transducer were used throughout the session. The sessions were also audio recorded on a Zoom H4n recorder with X/Y stereo condenser microphones at 16bit/44.1kHz. For the data analyses the ultrasound contours were traced using ImageJ and the formants were extracted using a praat script.

2.1. Subject A

Figure 2 shows Subject A's spoken [i] at the beginning of the session.

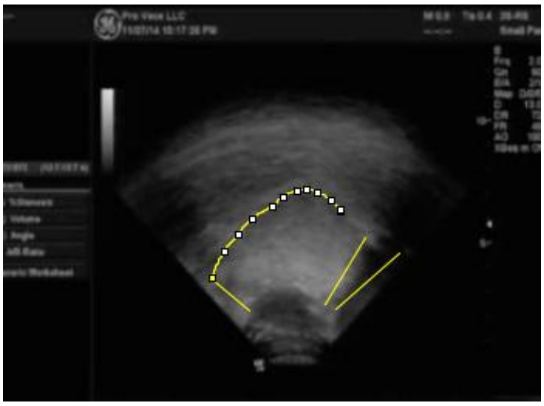

Figure 2: Subject A, spoken [i] (0:46)

Figure 3 shows his sung production of [i] as the teacher starts explaining how to read the ultrasound as well as instructing the singer to focus on expanding the resonance space in the oropharynx. Already he is starting to elongate his tongue while watching the ultrasound. Subjectively there is also an increase of audible resonance. As expected, the [i] shifts a bit to [ɪ] in response to jaw lowering, which is very common at the beginning of ultrasound training before a "fine tuning" can be done.

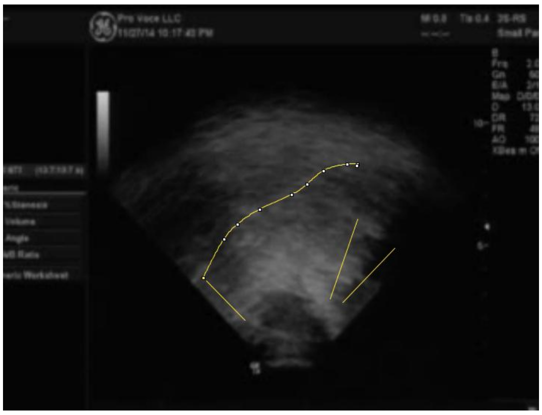

Figure 3: Subject A singing [i] using ultrasound to guide tongue placement (1:06)

In Figure 4 the instructions were that the singer prepare the vowel [ɑ] while singing the consonant [m] by watching his tongue on the screen. Both the [m] and the vowel have improved impressionistically in audible resonance. In addition, the singer utilized a less spread [m] hence, he cleanly shifted to the vowel [ɑ]. The subject is also correcting his pharyngeal resonance space on his own while watching the screen.

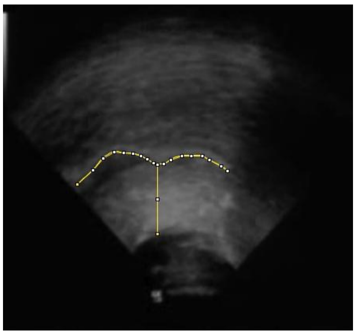

Figure 4: Subject A singing [mɑ] (6:55)

By the time at which Figure 5 is taken the singer was guided through the ultrasound to find the Point of Articulation (PoA) for [k] while dealing with the necessary increase of intraoral pressure without the help of pharyngeal musculature; however, the shift from the articulator set to the vowel [ɑ] is faster and cleaner as well as the resonance space in the pharynx is consistently more open than when the lesson started.

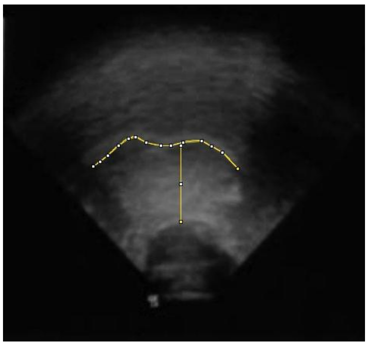

Figure 5: Subject A singing [kɑ] (9:03)

2.2. Subject B

Figure 6 shows Subject B's sung [ɑ] at the beginning of the session.

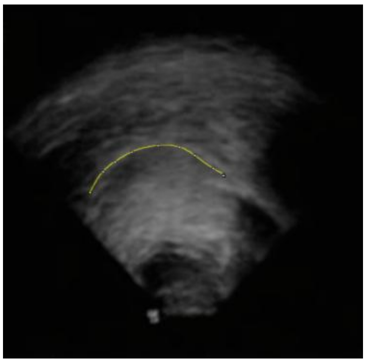

Figure 6: Subject B, sung [ɑ] (0:40)

Figure 7 comes from just after brief instructions on pharyngeal resonance space and what to look for in the ultrasound. Already there is considerable improvement in [ɑ] (note the more advanced tongue root, indicating an increase in pharyngeal volume).

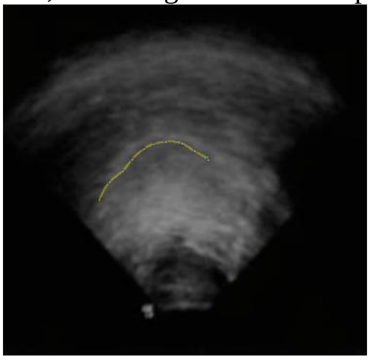

Figure 7: Subject B singing [ɑ] (1:06)

Figure 8 comes from work on preparing the vowel while the bilabial nasal [m] is being sung. The subject was told to specifically look for the shape of the [ɑ] vowel and then prepare it behind the [m]. As a result, the vowel is showing great improvement and a clean shift.

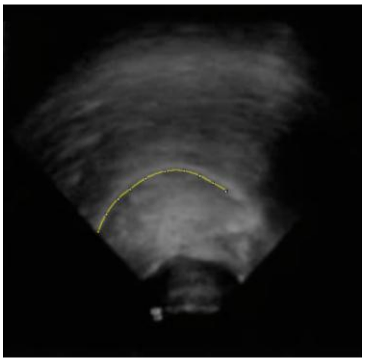

Figure 8: Subject B singing [mɑ] (3:02)

Figure 9 comes from later in the session when the singer was working on the role of extrinsic neck muscles in singing and how to control the movement of the tongue without concomitant unwanted facial spreading. A step-by-step guided exercise of the tongue movement was performed by watching the ultrasound while mimicking both [ɑ] and [i] vowels without singing. Once the singer was able to benchmark the desired tongue positions he was asked to repeat it while singing. There is a very great impressionistic improvement in both vowels. Figure 9 shows his [i] vowel.

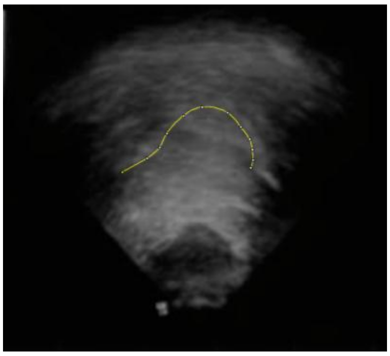

Figure 9: Subject B singing [i] (8:20)

2.3. Acoustic Measures

As singers need to maintain intelligibility while they sing, measurements of the first four formants for the first and last sung instances of [i] and [ɑ] were taken at the midpoint of the vowel by using PRAAT. These are given in Table 1. As there are only 2 subjects and only one token for each vowel statistical analysis would be inappropriate but the results are included to give an indication of the consistency of the singers' vowel production. The ultrasound video suggests that the singers are actively changing their production of the vowels by the end of the session but the formant measures suggest that they have maintained the vowel quality while changing the articulation.

One of the characteristics of resonance that could potentially increase with an improved tongue positioning is intensity. Intensity measures were taken for the first and last sung instances of [i] and [ɑ] and are given in Table 2. Neither subject shows much of an increase (although Subject A is louder by about 1 dB at the end of his session for both vowels). Nevertheless, a clear improvement can be heard impressionistically in the audible resonance of these vowels.

Formants (Hz)						
singer	vowel	token	f1	f2	f3	f4
A	[ɑ]	first	622.4	1020.9	2626.1	2961.2
A	[ɑ]	last	721.4	1123.4	2658.5	3117.4
A	[i]	first	388.6	2157.0	2406.5	3148.6
A	[i]	last	372.7	2108.3	2486.1	3210.3
B	[ɑ]	first	726.3	2149.5	2699.6	3341.6
B	[ɑ]	last	710.6	2149.4	2821.1	3323.0
B	[i]	first	235.1	1911.5	2192.5	3097.5
B	[i]	last	361.2	2097.3	2779.1	3054.4

Table 1: Formant values for the first and last sung instances of [i] and [ɑ]

Intensity (dB SPL)					
singer	vowel	token	mean	max	min
A	[ɑ]	first	66.5	62.4	62.4
A	[ɑ]	last	67.7	74.9	61.0
A	[i]	first	66.0	74.4	54.7
A	[i]	last	67.9	75.4	57.0
B	[ɑ]	first	70.6	74.4	67.0
B	[ɑ]	last	70.8	75.3	65.0
B	[i]	first	68.3	75.3	58.3
B	[i]	last	67.8	74.4	55.0

Table 2: Intensity values for the first and last sung instances of [i] and [ɑ]

3. DISCUSSION

Singing in itself, but especially the use of language in singing, is a complex motor behaviour that requires a highly specific positioning of physical structures (including those for inhalation, LMM, tongue posture, abdominals, etc.). Thus, overcoming the problem of phoneme rehabituation while concentrating on resonance creation and good tone production is a behavioural modification that cannot be accomplished in a single 10-minute session.

However, the ease and rapidity with which both singers in this case study modified their vowel production towards the technique used by the world's top opera singers supports the view that ultrasound is a tool which has much promise in the voice studio.

To test this approach further, the authors are engaging in a larger, long-term study to examine the changes in singing students who use ultrasound biofeedback on a regular basis so we can observe long-term phoneme rehabituation and acoustical gains. The case study presented here offers a strong suggestion that regular use of ultrasound as visual biofeedback in the singing studio will enable singers-in-training to progress quickly as they retrain their articulators to the new articulatory setting they need to be successful.

The use of ultrasound with singers outlined here also draws attention to the fact that the production of "speech" sounds for singing is not the same as the production of equivalent sounds for speech. It behoves phoneticians who work with singers to look closely at what the top singers do for a particular style of singing and learn what adaptations are necessary.

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