

Head-Corrected Ultrasound During the Second Passaggio Acoustic Transition of Sopranos

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Background: Singing voice pedagogy maintains that sopranos have an acoustic transition for f_0 between 587 Hz (D5 \sharp) and 700 Hz (F5 \sharp). Known as the *second passaggio*, it requires a change in vocal tract articulation to alter the resonance frequencies of the vowel to maximize the first harmonic's intensity. Specifically, on a sung /a/ vowel, the transition consists of a change from second resonance (R_2) tracking of the second harmonic to first resonance (R_1) tracking of the first harmonic, or fundamental [3]. One aim of this experiment was to quantify this transition on a sung /a/ vowel using the acoustic measure L_1 - L_2 , the radiated level difference between the first two harmonics. Another goal was to explore articulatory correlates that might produce the acoustic change. Previous researchers noted increased lip and jaw openings [1, 2, 4], and a small increase in tongue dorsum height, with some sopranos [1]. Our research sought more detailed information using head-corrected ultrasound of the tongue with optical tracking [5].

Methods: 17 females (ages 19-31) were accepted into the study: 9 judged by the first author as “techniqued” because of the ability to make the acoustic change, and 8 deemed “un-techniqued” because of the inability to make the change (confirmed by perceptual experiment). Participants sang chromatic scales and glissandi on /a/ from C5 \sharp (523 Hz) to G5 \sharp (784 Hz) at three sound levels (Normal, Soft, Loud) with three repetitions of each. Voices were recorded in a sound-attenuating booth with the microphone a consistent 30 cm from the lips. L_1 - L_2 was measured as the mean level difference across the note duration. The articulatory element of the study repeated the acoustic experiment protocol with ultrasound (Ultrasonix) and optical tracking (NDI Optotrak). Tongue contours were obtained (GetContours) and then translated and rotated into head space relative to the probe position.

Results and discussion: When the L_1 - L_2 measure is plotted by musical note for the 3 most techniqued and the 3 least techniqued participants, we observe that the most techniqued sopranos made the change from negative to positive values of L_1 - L_2 as early as D5 \sharp , and they reach L_1 - L_2 values of 15 to 18 dB SPL by G5 \sharp . In contrast, the 3 least techniqued singers exhibit

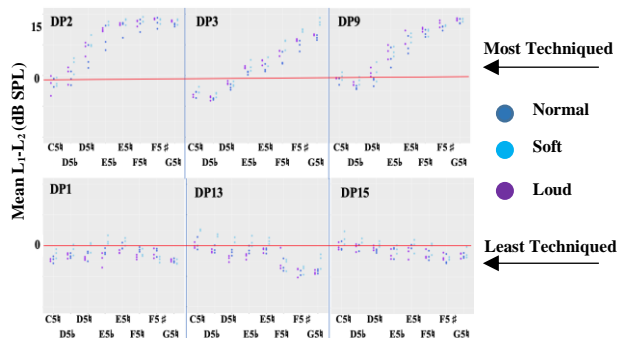


Figure 1: Mean L_1 - L_2 values by musical note for chromatic scales of the most and least techniqued singers.

negative values of L_1 - L_2 up to G5 \sharp (Fig. 1). Articulatory results show larger lip aperture, lower jaw position, and lower anterior tongue position in the most techniqued sopranos. Interestingly, the most techniqued singers made only small changes from C5 \sharp to G5 \sharp because they were already very close to the articulatory position necessary for G5 \sharp when they started the scale (Fig. 2). Further, the most critical articulatory factor was found to be the size of a triangular area between two points on the hard palate and the most anterior point of the tongue (Fig. 3).

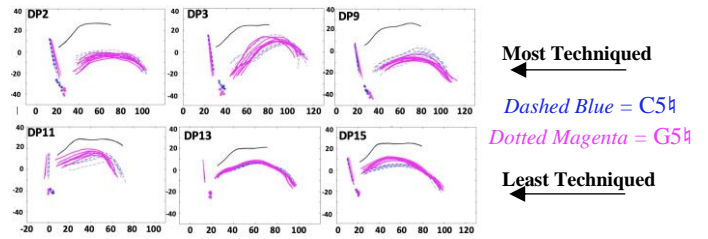


Figure 2: Tongue contours with palate traces, lip aperture, and jaw position for the most and least techniqued singers. Anterior is left. Dashed Blue = articulatory positions at C5 \sharp ; Dotted Magenta = G5 \sharp .

When mean L_1 - L_2 for each participant is graphed against anterior oral cavity triangle area, we observe that 7 of the 8 designated techniqued singers exhibit anterior oral cavities that are 2 to 3 times larger than those of the untechniqued singers (Fig. 4). The larger anterior oral cavity appears to accommodate a lower frequency of R_2 , presumably lowering L_2 and thus increasing L_1 - L_2 . [Supported by NIH grant DC-002717.]

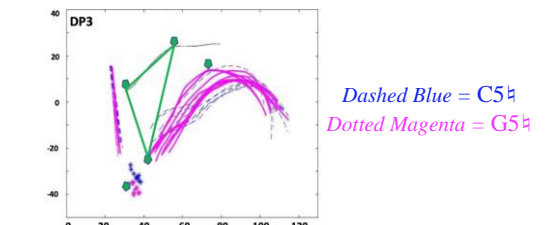


Figure 3: Illustration of anterior oral cavity triangle area in sq. mm.

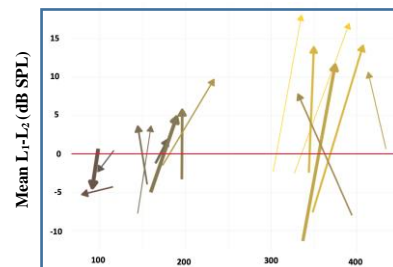


Figure 4: Mean L_1 - L_2 plotted against anterior oral cavity triangle area in sq. mm. Each arrow represents a single participant; direction is C5 \sharp to G5 \sharp . The color changes from light gold to dark brown as mean L_1 - L_2 goes from high positive to negative values.

References

- [1] Echternach, M., Sundberg, J., Arndt, S., Markl, M., Schumacher, M., & Richter, B. (2010). Vocal tract in female registers - a dynamic real-time MRI study. *J. Voice*, 24(2), 133-139.
- [2] Garnier, M., Henrich, N., Smith, J., & Wolfe, J. (2010). Vocal tract adjustments in the high soprano range. *JASA*, 127(6), 3771-3780.
- [3] Miller, D. G. (2000). Registers in singing. Empirical and systematic studies in the theory of the singing voice. University of Groningen, pp. 52-53.
- [4] Sundberg, J., & Skoog, J. (1997). Dependence of jaw opening on pitch and vowel in singers. *J. Voice*, 11(3), 301-306.
- [5] Whalen, D. H., Iskarous, K., Tiede, M. K., Ostry, D. J., Lehnert-LeHouillier, H., Vatikiotis-Bateson, E., & Hailey, D. S. (2005). The Haskins optically corrected ultrasound system (HOCUS). *JSLHR*, 48(3), 543-553.

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