Resonance Tuning in Three Girl Choristers

Rebecca R. Vos, Helena Daffern, and David M. Howard, *Heslington, York, United Kingdom*

Summary: Objective. The phenomenon of resonance tuning, whereby a singer modifies the shape of their vocal tract to increase the acoustic power output, is commonly exploited across large pitch ranges by professional sopranos and has been observed to a lesser degree in nonexpert adult singers.

This study considers the employment of two common resonance tuning techniques in experienced child singers; tuning the first vocal tract resonance to the fundamental (R_1: f_o) and tuning the second resonance to the second harmonic (R_2:2 f_o).

Methods. Wide-band excitation at the subject's mouth during singing was used to measure the vocal tract resonances of three girl choristers, and vowel formant values in speech were extracted from samples of spoken text.

Measured resonance values were cross-referenced with first and second harmonics for sung vowels across the subjects' ranges to identify the resonance tuning techniques employed, and these results were compared with those previously observed by others in professional adult classical singers.

Results and Conclusions. There was clear evidence that the subjects employed resonance tuning techniques comparable with the strategies used by adult singers. The protocol and results presented here pave the way for further studies exploring the development of resonance tuning techniques in young soprano voices, with the potential to impact on approaches to classical singing training in the future.

Key Words: Formant–Resonance–Tuning–Chorister–Singing.

INTRODUCTION

Voiced sounds are produced when the harmonic signal produced by the larynx is passed through the vocal tract. The resonances of the vocal tract (R_i) give rise to broad peaks in the spectrum of the acoustic output of the voice, which are generally known as "formants" (F_i). For adult soprano singers, the first and second formants in speech typically lie between 310 and 860 Hz and 920 and 2790 Hz (D#4 and A5, and A#5 and F7), respectively.[1] At the upper end of the soprano range, therefore, where the fundamental frequency can exceed 1000 Hz, it is not only possible but highly likely that the fundamental frequency will fall above the first and possibly the second formant.

If all the harmonics of the voice source fall above the resonances of the vocal tract, there will be little or no acoustic energy in the frequency range of the resonances. This implies that not only will the production of sound be much less efficient, as some resonances of the vocal tract are not being utilized to their full potential, but it is likely that the vowel will be harder to identify,[2] as there is little or no spectral energy at the resonant frequencies.

Both male and female children have similar vocal ranges to adult females[3]; therefore, it could be assumed that similar difficulties in both the production and the perception of singing at high fundamental frequencies will be observed in children's singing as in that of adult sopranos.

Resonance tuning is a technique known to be used by adult sopranos,[4–7] whereby singers modify the shape of their vocal tracts to change its resonant frequencies[8]; "tuning" a vocal tract resonance to just above a harmonic enhances the amplitude of that harmonic, allowing the singer to produce more acoustic power without requiring an increased airflow, thus improving the acoustic efficiency of the voice.[9] Since children have shorter vocal tracts than adult females, their vocal tract resonances are higher by approximately 20%[10,11]; however, because children are also generally able to sing at a higher range of pitches, they can be expected to encounter similar effects as adult female singers as there will be a part of their range when the fundamental frequencies become higher than the first (and possibly also second) resonance.

Evidence of R_1:f_o and R_2:2f_o tuning has been observed in the upper part of the adult soprano range, as shown in Figure 1.[4,5] These tuning techniques were found to be employed extensively by professional singers, and also by advanced amateur singers, and to some extent by nonexpert singers (one had trained but had not sung for 7 years, the other three had experience in choirs and two of them had received some singing lessons).

The detection of resonance tuning in nonexpert singers, who all employed R_1:f_o tuning over some part of their range, raises the question of whether resonance tuning is a technique unique to adult singers and learned with singing training and experience, or one which is also employed by young singers.

Previous work on developmental changes in children's voices has identified changes in the long-term average spectra of children's singing voices with age; Sergeant and Welch[12] found that children developed more acoustic energy in their voices below 5.75 kHz with age. They also found that the pitch range of children increases as they grew older. Howard and Graham[13] found that the relationship between the closed quotient of the vocal folds and the fundamental frequency changed as female choristers developed their singing, and there was a small increase in amplitude and dynamic range.

This experiment investigates how the use of resonance tuning manifests in young singers, by measuring the vocal tract resonances of highly experienced female choristers, and how their practices compare with those of adult singers.

Accepted for publication January 27, 2016.

From the York Centre for Singing Science and Department of Electronics, University of York, Heslington, York, United Kingdom.

Address correspondence and reprint requests to Rebecca R. Vos, York Centre for Singing Science and Department of Electronics, University of York, Heslington, York YO10 5DD, United Kingdom. E-mail: rebecca.vos@york.ac.uk

Journal of Voice, Vol. 31, No. 1, pp. 122.e1–122.e7

0892-1997

http://dx.doi.org/10.1016/j.jvoice.2016.01.013

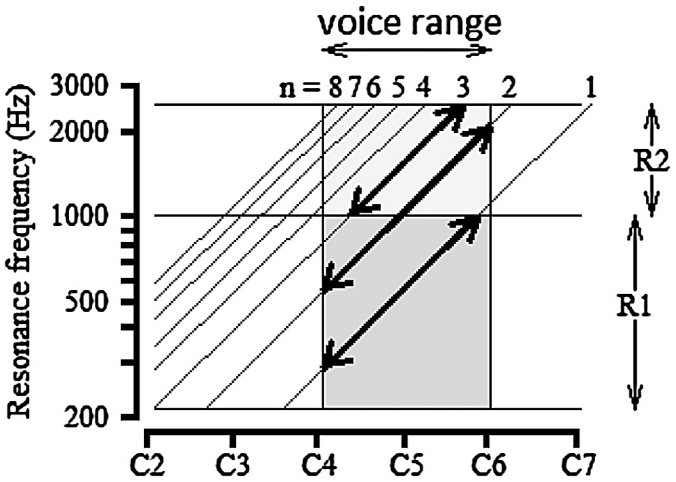

FIGURE 1. The possible resonance tuning strategies for soprano voice ranges on a log-log plot. Typical ranges of the vocal tract resonances R_1 and R_2 are shown in *dark* and *light grey*, respectively, and the *narrow diagonal lines* indicate when a resonance frequency coincides with the nth harmonic (nf_o) of the sung pitch (f_o), for the first eight harmonics, as identified at the top of the figure. The vertical lines indicate the typical soprano singing range. The *thick double-headed diagonal arrows* indicate possible tuning strategies, including those that have been measured or proposed (after[5]).

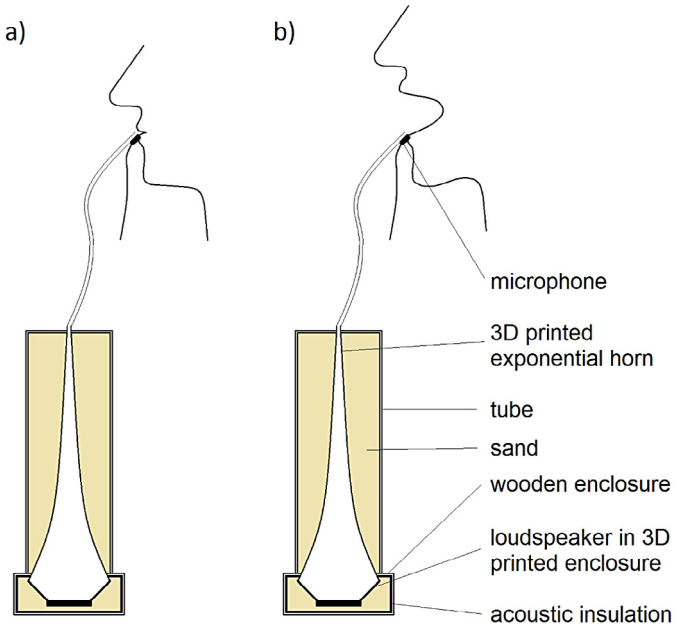

FIGURE 2. The equipment used to simultaneously play and record a signal at the subject's mouth using a 3D-printed impedance-matching horn and a microphone. The impedance-matching horn is enclosed in a wooden enclosure filled with sand. The flexible tubing allows the subject to position the acoustic source and microphone on their bottom lip.

METHOD

Subjects

The subjects chosen were two choristers from York Minster and one chorister from a well-respected local church choir. All three have singing lessons and perform regularly; the Minster choristers, 6 days per week; the Church chorister, at least twice per week. Details of the choristers are summarized in Table 1. Older choristers were chosen (York Minster choristers are aged 7–13 years) so that the effects of experience and training were most likely to be observed, based on the current understanding of increased resonance tuning with singing experience in adults.[4] Female subjects were chosen so that any resonance strategies employed could be compared with those of their adult counterparts. The subjects chosen all had ranges up to around A5.

Resonance detection

The method used to determine the resonances of the vocal tract, initially developed by Epps et al,[14] and used by others including Garnier et al,[4] Henrich et al,[5] and Joliveau et al,[6] involved exciting the vocal tract at the mouth with a synthesized broadband signal, and recording the response with a lavalier microphone also placed at the subject's mouth (see Figure 2). The experimental setup for this study is shown in Figure 2.

The excitation signal used here consisted of harmonics spaced 5.38 Hz apart, from 250 Hz to 3500 Hz, and phases adjusted to improve the signal-to-noise ratio.[15] The device was held by the subject, touching their bottom lip.

Using software developed by Henrich et al,[5] a calibration procedure was first carried out, which involved measuring the pressure response at the mouth with the subject's mouth closed (P_{closed}), and adjusting the amplitudes of the frequency components so that the signal strength of the microphone at the subject's mouth was independent of frequency. (The amplitudes of each frequency component in the input signal were adjusted so that

TABLE 1.
Details of the Choristers' Ages and Singing Experience

Chorister	Age (Years)	Choir	Years as Chorister	Singing Lessons (Years)	ABRSM Exams*
1	14	York Minster	6	3.5	Grade 5 Singing
2	15	St Olave's Church, York	9	3	Grade 5 Singing, Grade 5 Clarinet, Grade 5 Piano
3	13	York Minster	5	1.5	Grade 4 Singing, Grade 3 Clarinet, Grade 2 Piano

* The Associated Board of the Royal Schools of Music (ABRSM) is an examinations board and registered charity based in London, UK, which provides examinations in music at centers around the world. According to the UK Qualifications and Credit Framework, grades 4 and 5 are equivalent to a General Certificate of Secondary Education (GCSE), whereas grades 6–8 are equivalent to an advanced level (A level). (http://gb.abrsm.org/en/home).