DIVERSE RESONANCE TUNING STRATEGIES FOR WOMEN SINGERS

John Smith
Physics, University of New South Wales, Sydney
john.smith@unsw.edu.au

Joe Wolfe
Physics, University of New South Wales, Sydney
j.wolfe@unsw.edu.au

Nathalie Henrich
CNRS GIPSA Lab, Grenoble, France
Nathalie.Henrich@gipsa-lab.grenoble-inp.fr

Maëva Garnier
CNRS GIPSA Lab, Grenoble, France
maeva.garnier@gipsa-lab.grenoble-inp.fr

ABSTRACT

Over a range from 200 to 2000 Hz, the fundamental frequency f_0 of women's singing voices covers the range of the first two resonances ($R1$ and $R2$) of the vocal tract. This allows diverse techniques of resonance tuning. Resonances were measured using broadband excitation at their lips. A commonly noted strategy, used by sopranos, and some altos, is to tune $R1$ close to the fundamental frequency f_0 ($R1$: f_0 tuning) once f_0 approached the value of $R1$ of that vowel in speech. At extremely high pitch, sopranos could no longer increase $R1$ sufficiently and switched from $R1$: f_0 to $R2$: f_0 tuning. At lower pitch many singers of various singing styles found it advantageous to use $R1$:2 f_0 tuning Additionally, many sopranos employed $R2$:2 f_0 tuning over some of their range, often simultaneously with $R1$: f_0 tuning.

1. INTRODUCTION

Introductions to phonetic acoustics typically explain how some of the high harmonics of the voice are provided with an acoustic boost by the first two acoustic resonances of the vocal tract, with frequencies $R1$ and $R2$. The resultant formants or maxima in the envelope of the spectrum of the voice have roles in characterizing vowels and some consonants [1]. In singing text, these resonances have important additional functions: because they act as impedance matchers between the glottis and the external radiation field, they enhance the level of sound produced by the voice.

Women's singing voices of different types typically have a fundamental frequency f_0 in the range 160 to 2000 Hz. Singing in the higher part of this range obviously complicates the phonetic role of the tract resonances. However, singers can use either or both of these resonances in strategies to provide high output sound levels with relatively little effort, and perhaps also to assist sound production. This paper looks at some of these strategies.

In normal speech the vibrating vocal folds produce a signal with fundamental frequency f_0, which is usually unrelated to the particular phoneme being produced. Different phonemes are associated with different resonance frequencies of the tract. When a harmonic of the voice (an integral multiple of f_0) lies sufficiently close to any one of the Ri, that harmonic is radiated strongly.

Resonance tuning (also known as formant tuning), is the adjustment of the frequency of one or more resonances to match that of one or more harmonics of the voice. Resonance tuning offers singers a technique that can increase loudness with little extra vocal effort [2,3,4]. Furthermore, it has been suggested that the vibration and stability of the vocal folds may be enhanced if they experience an inertive load; i.e. if the resonance frequency is slightly above f_0 [5].

At the low pitch used by most men singers, it is likely that harmonics of f_0 will be reasonably close to $R1$ and/or $R2$, and consequently no widespread resonance tuning strategy is necessary. At the higher pitches used by women, a range of tuning strategies involving both $R1$ and $R2$ become important. These are the subject of the present paper.

2. MATERIALS AND METHODS

2.1 Measuring tract resonances

The measurements were conducted at UNSW in a room treated to reduce reverberation and to reduce external noise. The room has more than 30 dB insulation from the surrounding lab, where sound levels are already low. The average reverberation time over the range used is about 12 ms.

Vocal tract resonances were measured at the lips during singing using broadband excitation at the lips [6,7] – see Figure 1.

At high frequencies, this technique provides much more accurate measurements than those that use the output sound alone; e.g. linear prediction or inverse-filtering. The technique is also less perturbing than approaches that involve external mechanical vibration or that employ various non-periodic phonations. It is also avoids the problem of calculating acoustics from geometry that arises if MRI measurements are used.

The technique does, however, have some disadvantages. One is that the vocal gesture needs to be held for a second or so to get good signal to noise ratio (luckily singers are very good at this). It also has the disadvantage that the tract is measured in parallel with the external radiation field – this means that weak resonances might not be detected.

It is worth mentioning the potential effect of sub-glottal resonances. These are potentially important to the vibration of the vocal folds, because they contribute to the acoustic load on the fold's regeneration mechanism. Could they also affect measurements of the supra-glottal resonances via excitation at the lips? The answer is yes, in the case of respiration, when the vocal folds are widely separated and a new technique [8] allows us to discern them as separate resonances when measuring at the lips. For vocalisation, however, the supra- and sub-glottal tracts are acoustically separated by the inertance of the air between the folds. Its reactance is proportional to frequency, so simple calculations show that, at the frequencies of interest, the glottis impedance effectively seals the tract, which then behaves, to a good approximation, as a closed duct.

There is also a potential slight disadvantage of requiring singers to perform with a device positioned at the lower lip. The flexible mount allows normal jaw movement, but large movements of the body and head are not possible. To date, none of the subjects have reported difficulties.

2.2 The subjects

The data set examined herein is from measurements on 31 volunteer singers; 4 altos and 27 sopranos. Their experience varied from nationally recognized to amateur. Details of the singers are available elsewhere [9,10,11]. Each singer usually sang a sequence of sustained notes in an ascending diatonic scale that ranged from their lowest to highest comfortable pitch.

3. RESULTS AND DISCUSSION

3.1 $R1$:f_0 tuning at high pitch

Sopranos are obvious candidates to benefit from resonance tuning, because $R1$ covers almost all of the standard soprano range (C4-C6; 260-1050 Hz). Thus as f_0 increases and approaches the value of $R1$ for that vowel in speech, a soprano can advantageously increase $R1$ to match f_0 as shown in Figure 2 – the classic tuning of Sundberg [3,4]. This $R1$:f_0 tuning (also known as F1:H1 tuning) was used by almost all the sopranos in our studies once f_0 increased above 400 to 500 Hz. Indeed in the range 500 to 1000 Hz (approx. C5 to C6) this $R1$:f_0 tuning provides the only possible tuning for $R1$. This has an interesting consequence; at high pitch the variation in the values of $R1$ for different singers is greatly reduced in comparison with the values at low pitch – see Figure 2 in [11].

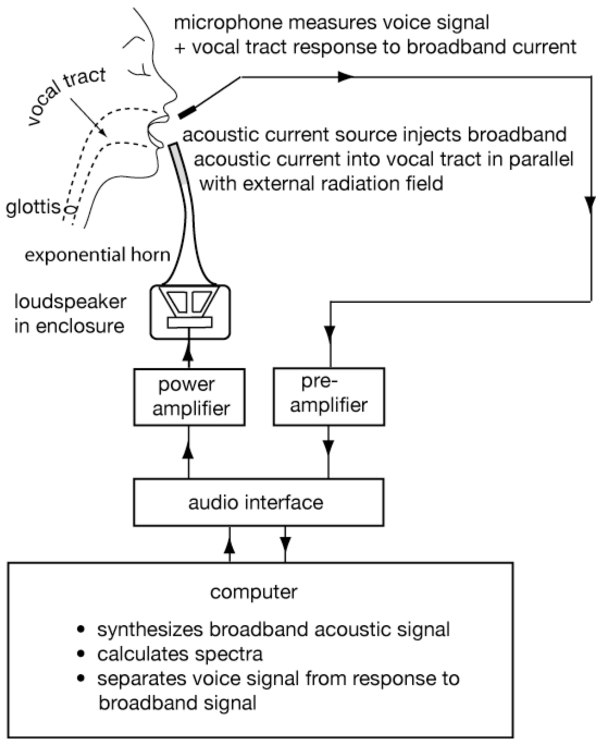

Figure 1. Schematic diagram (not to scale) showing the technique used for real-time measurement of vocal tract resonances. The microphone is normally mounted alongside, and parallel with, the end of the acoustic current source; in this diagram they have been separated for clarity.

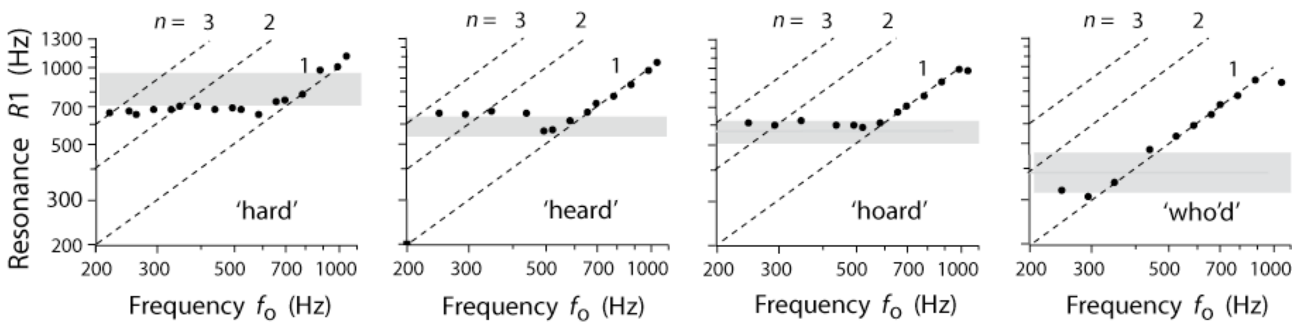

Figure 2. Example of a soprano starting to use $R1$:f_0 tuning when f_0 approaches the value of $R1$ for that vowel in speech. The dashed diagonal lines indicate the relationships $R1 = nf_0$. Shaded areas indicate the mean ± standard deviation for that vowel in speech measured for sopranos. Data from singer S9 in [9].

3.2 $R2:f_0$ tuning at extremely high pitch

The maximum value of $R1$ in normal speech is typically around 1000 Hz. Some sopranos have learnt to extend this upper limit considerably; Figure 3A shows an extreme example where a soprano has tuned $R1$ to nearly 1500 Hz (around F#6). However, most singers cannot maintain $R1:f_0$ tuning much above 1000 Hz [12]. However because the ranges of $R1$ and $R2$ overlap, it is then possible for a soprano to switch to $R2:f_0$ tuning, and to maintain this for f_0 as high as the upper limit of R2 (approx. 2500 Hz or around Eb7) – see Figure 3B.

The use of resonance tuning in the range above 1 kHz may have an importance beyond that of impedance matching the glottis to the radiation field. This is the range of the whistle voice or flageolet register. The mechanism of voice production in this range is not completely understood. Nevertheless, it is possible that a tuned acoustic load could play an important role in determining or stabilising the pitch in this register [11]. It is further possible that learning $R2:f_0$ tuning could be one of the most important steps for a soprano aiming to extend her range to include this register.

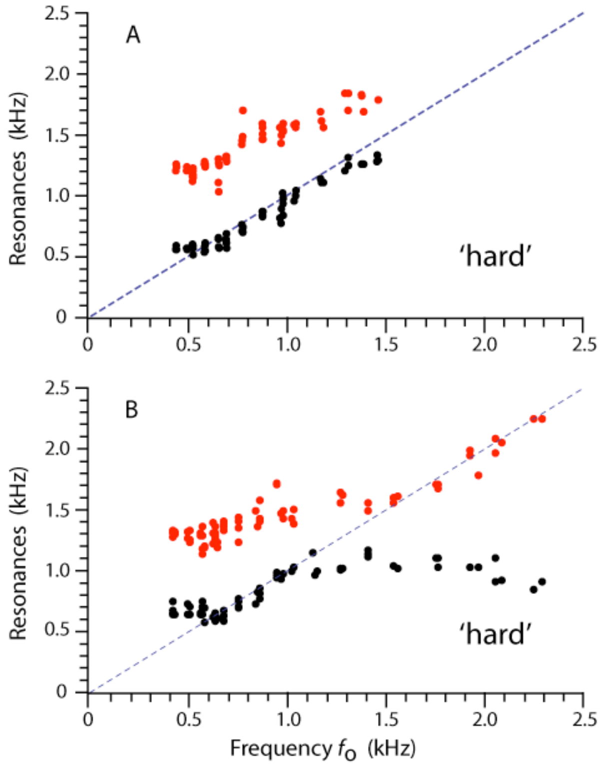

Figure 3. Two examples of a soprano singing the vowel in 'hard' at very high pitch above C6. Figure A (top) shows that singer AD4 [11] could maintain $R1:f_0$ tuning as high as 1500 Hz. Figure B (lower) shows that singer NE1 [11] switched from $R1:f_0$ to $R2:f_0$ tuning once $R1$ could no longer be increased. The dashed diagonal line indicates the relationship $Ri = nf_0$. The measured frequencies of $R1$ and $R2$ are indicated by black and red dots respectively.

3.3 $R1:f_0$ tuning by altos

Altos have a lower value of maximum pitch and so have a smaller range over which $R1:f_0$ tuning would be helpful, particularly for open and mid vowels – see Figure 4. For these vowels it would be possible for sopranos and altos to decrease $R1$ and start $R1:f_0$ tuning at lower values of f_0, but it appears that singers are generally reluctant to decrease $R1$. Perhaps this is because a decrease in $R1$ would often be achieved by reducing the jaw height, with a consequent decrease in radiation efficiency and hence sound level.

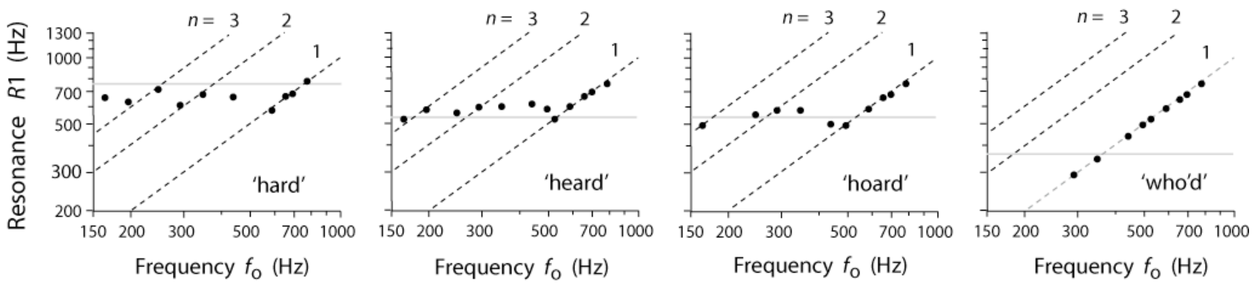

Figure 4. Examples of an alto starting to use $R1:f_0$ tuning when f_0 approaches the value of $R1$ for that vowel in speech. The dashed diagonal lines indicate the relationships $R1 = nf_0$. The horizontal grey lines indicate the value of $R1$ measured for this singer and vowel in speech. Data from alto A1 in [10].

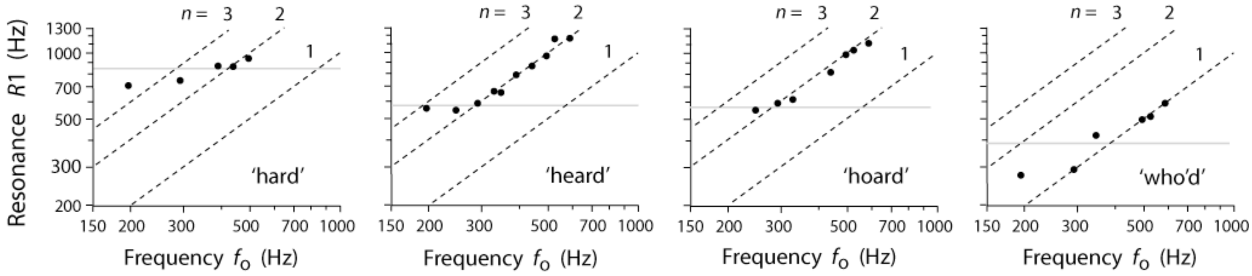

Figure 5. Example of an alto using $R1{:}2f_0$ tuning for the open and mid vowels once $2f_0$ approaches the value of $R1$ for that vowel in speech. She uses $R1{:}f_0$ tuning for the closed vowel in 'who'd' where $R1$ in speech is lower. The dashed diagonal lines indicate the relationships $R1 = nf_0$. The horizontal grey lines indicate the value of $R1$ measured for this singer and vowel in speech. Data from alto A2 in [10].

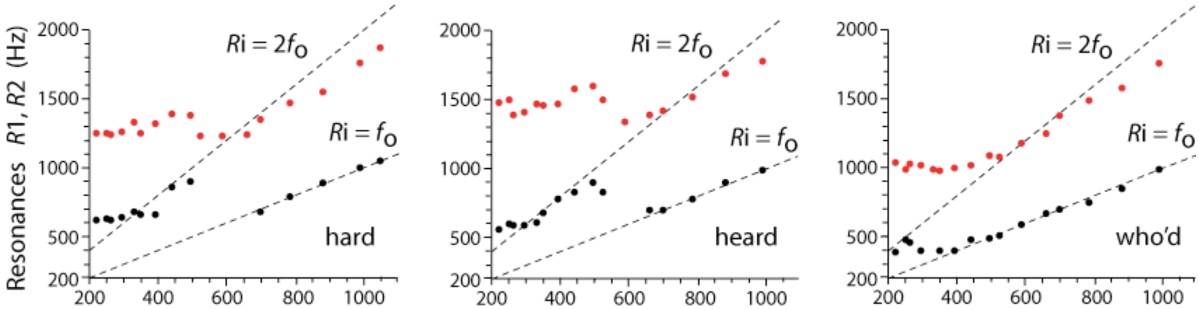

Figure 6. Example of a soprano using $R1{:}2f_0$ tuning at relatively low pitch. She then switches to simultaneous $R1{:}f_0$ and $R2{:}2f_0$ tuning. The dashed diagonal lines indicate the relationships $Ri = nf_0$. The measured frequencies of $R1$ and $R2$ are indicated by black and red dots respectively. Data from singer S7 in [10].

3.4 $R1{:}2f_0$ tuning by altos and sopranos

An alternative to decreasing $R1$ in order to start using $R1{:}f_0$ tuning at lower pitches is to use $R1{:}2f_0$ tuning instead – see Figure 5. This strategy can allow resonance tuning to be employed over a wider range than if only $R1{:}f_0$ tuning were used.

This $R1{:}2f_0$ tuning by altos is widely used in the folk music of some cultures. In this frequency range the ear is more sensitive to the second harmonic ($2f_0$) than the fundamental f_0. Consequently this tuning can produce a very loud sound with an unusual timbre. Both of these features can be heard in a style of Bulgarian women's singing [13] in which $R1{:}2f_0$ tuning by altos is used. $R1{:}2f_0$ tuning can also be used in 'belting', a loud theatrical singing style [14].

3.5 $R2{:}2f_0$ tuning

Figure 6 shows an example where a soprano uses $R1{:}2f_0$ tuning at low pitch. However once f_0 approaches the value of $R1$ for that vowel in speech she switches to $R1{:}f_0$ tuning with simultaneous $R2{:}2f_0$ tuning once f_0 has increased sufficiently.

It was found that many singers exhibited $R2{:}2f_0$ tuning over at least a part of their range, and this often occurred simultaneously with $R1{:}f_0$ tuning. This is possible because an increase in $R1$ produced by mouth opening will usually produce an increase in $R2$. A relatively small adjustment could then allow this double tuning.

4. CONCLUSIONS

Diverse strategies of resonance tuning are quite widely used by women singers. Although $R1{:}f_0$ tuning is the most common, $R2{:}f_0$ tuning and $R1{:}2f_0$ tuning can be employed in the upper and lower regions of the singing range. Some singers also use $R2{:}2f_0$ tuning, often simultaneously with $R1{:}f_0$ tuning.

Acknowledgments
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