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WAGNER'S MUSIC IS EVEN BETTER THAN IT SOUNDS:

IMPLICATIONS OF VOWEL-PITCH MATCHING FOR INTELLIGIBILITY AND EASE OF SINGING

John Smith and Joe Wolfe

School of Physics, University of New South Wales

ABSTRACT

The vowels of European languages are primarily distinguished by the two lowest resonance frequencies ($R1$ and $R2$) of the vocal tract. Once the pitch frequency f_0 exceeds the value of $R1$ in normal speech, sopranos can deliberately tune $R1$ to match f_0. This can increase the loudness, uniformity of timbre and ease of singing, but with a reduction in intelligibility once R1 is varied from its value in normal speech. The amount of resonance tuning required would be reduced if the pitch of the note written for a vowel corresponded with its usual range of $R1$. Analysis of soprano rôles in operas by different composers indicates that Wagner aided the acoustics of the soprano voice at high pitch when setting text to music.

1. INTRODUCTION

In normal speech, the vibrating vocal folds generate a harmonically rich signal with pitch frequency f_0, which interacts with resonances of frequency Ri in the vocal tract to produce sound with a spectral envelope that exhibits broad peaks, called formants, with frequency Fi. We follow the original definitions of Fant [6] and reserve the term 'formant' for broad peaks in the spectral envelope and 'resonance' for the acoustic resonances of the vocal tract that produce them – see Wolfe, Garnier and Smith [20] for further discussion.

These resonances have bandwidths of 100 Hz or so, and can be controlled independently of f_0 by varying the position and shape of the tongue, jaw, lips and larynx [11]. Vowels in European languages are largely identified by the frequencies of the first two formants ($F1$,$F2$) and thus of the resonances ($R1$, $R2$) that produce them. In adult conversational speech, f_0 is typically in the range 100 to 300 Hz, whereas the resonances $R1$ and $R2$ lie in the approximate ranges of 300–800 Hz and 800–2000 Hz respectively. Consequently, f_0 and/or some of its harmonics (i.e. $2f_0$, $3f_0$, etc) usually fall close enough to each resonance to receive a useful power boost and to produce identifiable formants. The situation is similar for most singing ranges when f_0 is less than about 500 Hz (near the 'high C' of tenors). However, f_0 for sopranos can range from 250 Hz to 1000 Hz or even higher.

Four problems can arise when f_0 exceeds significantly the normal range of $R1$ for a vowel. First, the acoustic load of the air in vocal tract upon the vocal folds and glottis changes from inertive ('mass-like') when $f_0<R1$ to compliant ('spring-like') when $f_0>R1$. It has been suggested that vocal fold vibration might then become less efficient and less stable [17-19].

Second, the sound level is usually reduced, as little acoustic energy will be radiated at frequency f_0. Third, a strong variation in the amplitudes of the fundamental and/or second harmonic may occur as the pitch changes, producing possibly undesirable discontinuities in timbre. Finally, the effective absence of $F1$ means that vowels with a similar value of $F2$ become indistinguishable. Indeed, as f_0 increases, the spacing of harmonics can become so large that even $F2$ may also effectively disappear.

For a soprano, a solution to all but the last of these problems is to tune $R1$ close to, but slightly above, f_0 [9,10,15,16,19] This should increase power, increase the ease of singing and help maintain timbral homogeneity. Once suitable measurements were made, it was found that sopranos do indeed 'modify' their vowels when singing at high pitch [3,4].

This solution, called resonance tuning, has no disadvantages when singing *vocalise* because there is no textual information. However, when singing text, $F1$ will consequently be similar to $R1$ and no longer have an appropriate value for many phoneme-pitch combinations. One would then expect an increased probability that vowels are confused as the difference between f_0 and the value of $R1$ in normal speech increases [8,12,13]. In an earlier study [5], we found that correct recognition in speech decreases exponentially with displacement on the ($R1$,$R2$) plane. Thus, with resonance tuning, a vowel would be likely to be confused with another of higher $R1$ once f_0 exceeded its normal $R1$ by about 100–200 Hz.

This confusion could be minimised if a composer took advantage of vowel-pitch matching; i.e. if each vowel were sung with a fundamental frequency f_0 that was consistent with its usual range of $R1$. Further, the singer would no longer need to tune the resonance significantly [2]: the libretto would partially do it for her, making it easier to sing with a high ratio of output power to input effort, and perhaps provide greater stability.

Berlioz mentions the problem of reduced intelligibility of sopranos in his classic *Treatise on modern instrumentation and orchestration* [1]. However, no-one seems to have investigated whether composers and/or librettists used vowel-pitch matching (either consciously or unconsciously) to improve the intelligibility and/or to make the music easier to sing. In collaborations in which words were set to music, the task of resonance tuning would fall to the composer; if the 'music came first' it would be the librettist's task. A composer who was also the librettist would be in an ideal position to implement resonance tuning

If resonance tuning were present, the vowel distribution would vary systematically with pitch: vowels associated with a low $R1$ would be sung less often at high pitch and *vice versa*. If not, we should expect the distribution of vowels to be independent of pitch, simply reflecting that of the libretto. This paper reports a study that examines the distribution of vowels with pitch for soprano rôles in several operas by different composers.

2. METHODS

The phoneme and fundamental (pitch) frequency f_0 were recorded for each note sung by the chosen soprano in each opera studied using published scores. This was performed manually using each score in conjunction with pencil and paper. Any obvious ornamentation, grace notes, trills, and mordants were not included as they carry no textual information – see also [14]. (Because resonances and formants are broad, high precision in fundamental frequency is not required, so A4 = 440 Hz was assumed throughout.)

3. RESULTS

Figure 1 shows the results of the analysis for the rôle of Brünnhilde in *Götterdämmerung* by Wagner. To simplify presentation, the 12 vowels of German were grouped into the four standard categories according to their jaw height in the vocoid or Cardinal Vowel space. The ranges of $R1$ we associated with each category were: *closed* 250–400 Hz, *close–mid* (or *half-close*) 400–550 Hz, *open–mid* (or *half-open*) 550–750 Hz, and *open* 750–1000 Hz. Of course the values of $R1$ will vary with language, dialect, accent, etc. It is also possible that listeners may learn to use a different formant 'map' for sopranos (i.e. a different categorisation of the vowel plane), in much the same way that we use different maps for men, women and children. Ultimately, we can only make an informed guess at the vowel sound imagined by the composer-librettist. Although there might be uncertainty about the range of resonance frequencies in each category, the important feature for this study is that their order with increasing frequency is known.

Figure 1 shows the distribution of vowels grouped into the four categories for jaw height and thus $R1$. It is immediately apparent that the vowel distribution does vary with frequency, and in a fashion that helps match $R1$ to f_0. Thus the closed and close-mid vowels with low $R1$ become less common as f_0 rises above 500–600 Hz. Conversely, the fraction of open-mid and open vowels increases significantly above 600 Hz. The open vowels are, of course, preferred at high pitch, whereas other vowels would be seriously distorted by resonance tuning. However, open vowels are also used across the whole pitch range. The unmodified $R1$ for these vowels is sufficiently high that, for almost the whole of the soprano range, the vocal tract load at the glottis is inertive, which might help stability. Further, for notes in the low soprano range, $R1$ may be excited by a second or even third harmonic. So the open vowels are least likely to be distorted by resonance tuning.

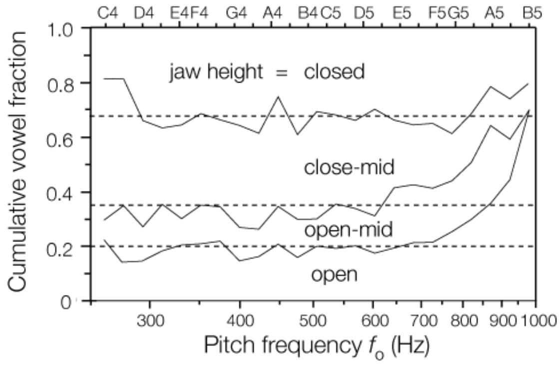

Figure 1: A semi-logarithmic plot of the cumulative vowel fraction as a function of written pitch frequency for the rôle of Brünnhilde in *Götterdämmerung* by Wagner. The open vowels lie between the axis and the lowest continuous line, open-mid between the two lowest continuous lines, etc. The dashed lines show the null hypothesis: equal distribution of vowels across pitch. (2665 notes)

Evidence for a favourable distribution of vowels with pitch for sopranos was also found in the other Wagner operas we studied [14]. These rôles were Brünnhilde in *Die Walküre* and *Siegfried*, and Isolde in *Tristan und Isolde*. However the effect was greatest in *Götterdämmerung*.

Does this degree of favourable vowel-pitch matching exist in operas by other composers? Figure 2 shows the results for the soprano rôle of Sophie in *Der Rosenkavalier* by Richard Strauss. Although Richard Strauss was an experienced operatic composer with a long-term collaboration with the librettist of this opera, Hugo von Hoffmannsthal, there is no evidence of a favourable distribution of vowels at high pitch, However, the closed vowels are more common at low pitch.

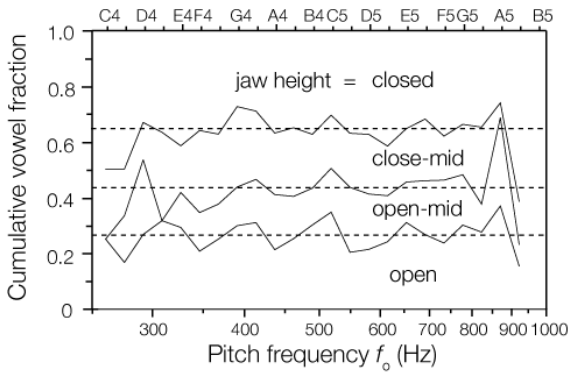

Figure 2: A semi-logarithmic plot of the cumulative vowel fraction as a function of written pitch frequency for the soprano rôle of Sophie in *Der Rosenkavalier* by Richard Strauss. (2140 notes).

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Figure 3 shows the analysis of the opera *Lulu* by Alban Berg. This opera involves several aspects of serial composition, with separate tone rows for each character. This formulaic method of composition used by Berg should relax some of the melodic constraints that might influence vowel-pitch matching. There is no evidence of a favourable vowel distribution with pitch. Indeed the closed vowels occur more often at high pitch.

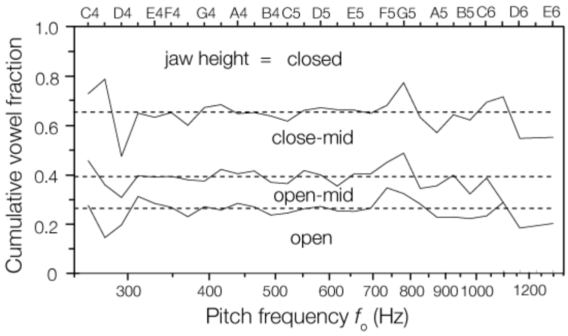

Figure 3: A semi-logarithmic plot of the cumulative vowel fraction as a function of written pitch frequency for the soprano rôle of Lulu in *Lulu* by Alban Berg. (4525 notes)

Does the occurrence of favourable vowel-pitch matching depend upon the language? Figures 4 and 5 shows results for an Italian and a Russian opera respectively. The vowels were grouped into three standard categories according to their jaw height in the vocoid or Cardinal Vowel space. The soprano rôle of Fiordiligi in *Così fan tutte*, an opera buffa by Mozart, shows no significant variation of vowels with pitch, except surprisingly at low notes where the closed vowels are less likely than at the highest notes; this could reduce intelligibility. Again the soprano rôle of Katerina in *Lady McBeth of Mtsensk District* by Shostakovich (who shares the credit for the libretto) showed no systematic variation of vowel distribution with pitch.

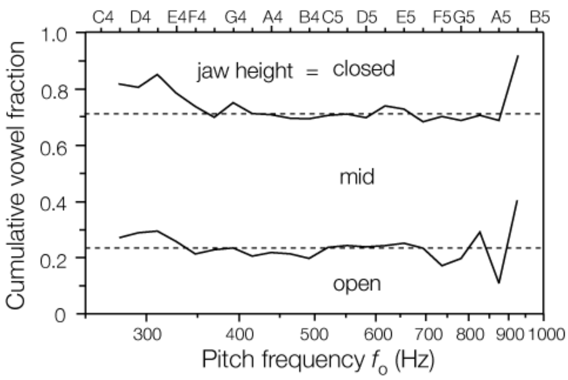

Figure 4: A semi-logarithmic plot of the cumulative vowel fraction as a function of written pitch frequency for the soprano rôle of Fiordiligi in *Così fan tutte* by Mozart. (6831 notes)

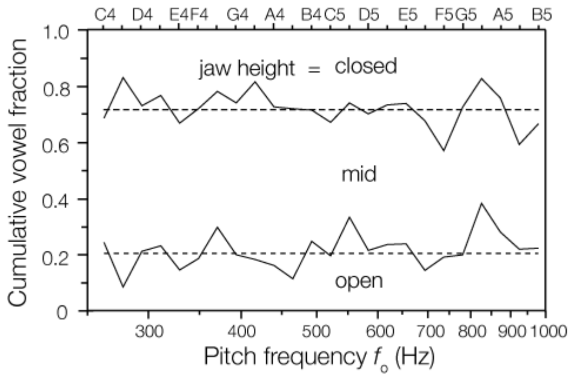

Figure 5: A semi-logarithmic plot of the cumulative vowel fraction as a function of written pitch frequency for the soprano rôle of Katerina in *Lady McBeth of Mtsensk District* by Shostakovich. (2392 notes)

The vowel distributions shown in Figures 1-5 are quite 'noisy', partially because the distribution of notes with pitch is not uniform [14]. The exception is *Lulu*, where the formulaic method of composition necessarily helps produce a relatively flat distribution. The 'noise' (partially due to the scatter in samples) increases at the extremes of the soprano range, presumably because very high notes are physically demanding and dramatically effective if used sparingly, and because sopranos' low notes often have reduced dynamic range.

4. DISCUSSION

At this point it is interesting to speculate why Wagner might have used favourable vowel-pitch matching when setting text to music in his operas. There are several possible reasons including:

- Wagner always wrote his own librettos
- Wagner was proud of these librettos and they were often published separately before the opera was written.
- Wagner's idea of opera was a continuous music drama. Earlier operas often linked separate arias and choruses with explanatory recitative and thus had less need for intelligibility at high pitch. Furthermore, the high pitch writing for soprano in earlier operas is often aimed at technical display, rather than conveying text.
- The singers in Wagner's later operas often have to communicate lengthy, subtle aspects of plot via text alone, without any stage action to help the audience. Intelligibility could thus be very important. (In many other operas one could probably remove the text and still get the gist of the opera through the stage action alone).
- Wagner's operas placed unprecedented demands on the singers, who are required to sing very long sections of text accompanied by a very large orchestra. Consequently

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anything that helped the singers would be a distinct advantage.

- Wagner had the time to polish each opera until he was completely satisfied. •

5. CONCLUSIONS

The authors are unaware of any written evidence about the composers' intentions nor of whether they were advised on this issue by sopranos, with whom they sometimes had quite close relations. However, it appears that Wagner, either consciously or unconsciously, did take the acoustics of the soprano voice at high pitch into account when setting text to music. This is consistent with the increased importance of textual information in his operas, the increasing size of his orchestras, and the more complex vocal parts.

6. ACKNOWLEDGEMENTS

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