Determining The Relevant Criteria For 3D Vocal Tract Characterisation

The original paper contains 30 sections, with 10 passages identified by our machine learning algorithms as central to this paper.

Paper Summary

SUMMARY PASSAGE 1

Introduction

Similarly, in studies on speech, Sulter et. al [29] used a single male subject to compare predicted resonances with measured values, and in ClÃ©ment et. al [30], one male speaker was used to compare vocal tract resonances obtained from recorded speech with those calculated from an area function of the 2 vocal tract acquired using MRI. Following on from the practices established in previous studies involving soprano singing and MRI methods, the principal aim of this study was to design and test a novel protocol to investigate the vocal tract characteristics that result in resonance tuning (rather than determining exactly how resonance tuning is affected by articulatory parameters). Measurements were taken from a single subject to test the practicalities and usefulness of this protocol, which combines direct measurements of vocal tract resonances with 3D MRI imaging, drawing on parameters identified in previous studies [22,24,25,26].

SUMMARY PASSAGE 2

Method

In this study a single professional singer was asked to phonate vowel sounds across her entire vocal range, both in an MRI machine, and in an anechoic chamber, where the MRI tasks were repeated and measurements of her vocal tract resonances were taken.

SUMMARY PASSAGE 3

(B).

An example of this is shown in Figure 5. For the same measurement as Figure 4, the 4th plane from the glottis slices through three separate areas (Figure 5(a)), however the 6th plane (Figure 5 Although the resonances of the vocal tract could be calculated directly from the area functions generated from MRI images, this would not take into account effects such as the radiation impedance at the subject's mouth, or the wall compliance within the vocal tract. Since the resonance measurements made in this experiment (using broad-band noise excitation) measure the resonances directly, they can be assumed to be taking these effects into account.

SUMMARY PASSAGE 4

Resonance Tuning Measurements

An example plot of P_{open}/P_{closed} against frequency is shown in Figure 6. As in previous work [1,9,13], these measurements were then cross-checked by another researcher. In some cases it was not possible to accurately identify the vocal tract resonances, especially for closed vowels or when the subject did not remain completely still whilst singing 1 , and these measurements were omitted from the results.

SUMMARY PASSAGE 5

2D Mri Measurements

All the MRI measurements, fundamental frequencies, and the measurements of the first and second resonances of the vocal tract (R_1 and R_2 respectively) while the singer was singing supine in the anechoic chamber, were imported into MATLAB [35], for statistical analysis. The linear correlations between all the MRI measurements and R_1 and R_2 were calculated, and a correlation matrix was generated (see Figure 7). The results that were not significant at the 5 % level were omitted from the matrix.

SUMMARY PASSAGE 6

Area Functions

The area function for the /A/ vowel is characterised by an approximately bell-shaped vocal tract: narrowing to approximately 1 cm^2 around 6-7 cm from the glottis (around the back of the tongue), then opening out around 13 cm, before narrowing at the mouth. Although the extent of mouth opening varied for different fundamental frequencies (between 4 and 12 cm^2), there did not appear to be any relationship between fundamental frequency and mouth opening.

SUMMARY PASSAGE 7

Difficulty

It is noted [41] that singers generally find the /A/ vowel the easiest and most natural to sing, as it does not require the extreme vocal tract adaptations required for the /i/ vowel (which is generally found difficult to sing, especially at high pitches), and this may be a reason for the lack of correlation between variables seen for the /A/ vowel.

SUMMARY PASSAGE 8

Jaw And Tongue

This suggests that there should be a correlation between fundamental frequency and jaw opening, however this was only seen for the /u/ vowel, and not for the other two vowels investigated. When asked if she was aware that she made changes to the shape of her vocal tract when singing high notes, she said that she also "brought her tongue forward and down as she sung higher". However no correlation between fundamental frequency and tongue dorsum was seen for any of the vowels.

SUMMARY PASSAGE 9

Convergence Of Area Functions At High Fundamental Frequencies

The area functions of the highest fundamental frequencies are similar for all three vowels, which agrees with the idea that singers make use of similar vocal tract positions across vowels at the top of their range [41].

SUMMARY PASSAGE 10

Non-Linear Effects

This study has only examined linear correlations between variables, and non-linear relationships may exist. Based on the acoustic properties of standing waves in tubes, it was expected that a simple linear relationship would be seen between the vocal tract resonances and factors that cause shortening/lengthening, or constriction/expansion of the vocal tract, such as the jaw opening, tongue height or larynx height. The larynx height, however, followed a similar pattern for all three vowels (see Figure 11); increasing at first with fundamental frequency, but then remaining approximately constant across the top half of the fundamental frequency range investigated.