Sopranos with a singer's formant? Historical, Physiological, and Acoustical Aspects of Castrato Singing

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Abstract

Starting in the sixteenth century castrato singing was a wide spread phenomenon, mainly cultivated in the Italian opera tradition for more than 250 years. Prepubertal castration is likely to imply that a boyish larynx is combined with an enlarged thorax and with a vocal tract of dimensions likely to approach or match those of an adult male. Current interest in Baroque opera and in the history of musical performance raises the question as to the characteristics of the castrato singers vocal art.

In the present study we attempt to combine the information embedded in historical sources, and the knowledge of the development of the human vocal organs, the aim being to explore hypotheses regarding the acoustical properties. Our basic assumption is that the castrato voice combined the male adult vocal tract with the prepubertal voice source. A well trained boy soprano's rendering of Franz Schubert's Ave Maria on the vowel /a/ was inverse filtered and the voice source thus obtained was processed by a vocal tract filter with formant frequencies adjusted in such a way that a singer's formant with a centre frequency corresponding to an operatic tenor, baritone and bass voice was obtained. The syntheses can be listened to at http://www.speech.kth.se/~jsu/castrato_examples.

Introduction

The ancient concept castrato, defined by Jean Jacques Rousseau (1778) as "a musician [singer] who, in infancy, has been deprived of his genital organs in order to preserve his high voice", is today particularly connected with singers. In Europe, pre-pubertal castration aiming at preserving the boy's voice was performed at least from the end of the 16th century, and during the 17th and 18th centuries the vocal castrati dominated in particular the opera seria.

Morphological effects of pre-pubertal castration offer some information relevant to attempts to imagine how a typical castrato voice sounded. From a medical point of view, a castrato is a male who has been deprived of his testicles and is thereby sterile, but not necessarily impotent. The medical aspects of castration concern the practical execution of the operation. Our historical knowledge in this area is very limited, since contemporary witnesses to, or descriptions of the detailed operational, medical procedure are missing to a great extent. This is not surprising, as the operation was illegal and those who performed it subject to threat of punishment.

The main consequence of the castration, however, was a deficiency of the male sex hormone testosterone, which is primarily developed in the testes. The hormonal level of testosterone is normally quite low in childhood and increases dramatically during puberty. Testosterone is involved in different physiological processes in the normal male body. It boosts the maturing of the testicles and thereby induces the production of sperm. Also, the primary and secondary male sex characteristics develop under the influence of testosterone. This hormone also contributes to the closing of the

epiphyseal cartilage and therefore prevents excessive body growth. Furthermore, the influence of testosterone brings about a rapid growth of the vocal folds, almost doubling their membranous parts, lowering the fundamental frequency of the boy's speaking voice about one octave.

If the castration was performed before the beginning of puberty, that is, for example, before the age of 10, the testosterone deficiency caused the larynx to remain infantile in size while the extremities and the chest grew excessively. Numerous descriptions of the appearance of the castrati as well as pictorial evidence exist, illustrating or exaggerating their specific bodily characteristics (Figure 1). The described effects on physiology had various manifestations. The large lung volume would have consequences for the breathing. The short, prepubertal vocal folds would be significant to the voice source, and the large head and short, thick neck would produce special vocal tract resonance characteristics.

The castrati were carefully educated in vocal art and music. After the operation they were sent either to a conservatory or to a private teacher for training. Most of them made their debut between sixteen and eighteen years of age, usually in a female role. The majority of the castrati were, seen from our point of view, mezzo sopranos.

The curriculum comprised two stages: (1) voice training, i.e., building the instrument, and (2) ornamentation. Vocal training focused on messa di voce, breath control, registration, intonation and intervallic progression. At the second stage, they were taught all the stylistic variations needed to cope with the requirements of opera seria and the church music of their time.

Contemporary sources reveal diverging views of the castrato voice. Often it was compared to a woman's voice in pitch, a boy's voice in timbre and a man's voice in power. The fact that some women could, at least temporarily, assume the roles as castrati seems to speak in favour of the first statement, and Handel apparently had no problem exchanging the castrato voice for a female soprano to save money. The title role in Handel's opera Rinaldo was sung by the castrati Nicolini and Bernacchi and by the female sopranos Barbier and Vico (Barbier, 1989). Some female sopranos, like Signora Passerini, gladly exchanged the hoop skirt for male attire if they were given the chance to sing a typical castrato role such as Arbaces in Thomas Arne's opera Artaxerxes. (Walsh, 1973).

According to Raguenet (Haböck 1927) "a castrato voice passes with a light and sweet sound through the accompaniment, rises delightfully over all the instruments in a way that cannot be described, it must be heard. Those are pure voices and tones of nightingales." De Brosse (1888) reports that the timbre was that of a boy soprano but that the voice was brilliant, light, with a great range. Ancillon (1718) describes it as "a squealing, languishing voice" but in connection with the singer Jeronimo as: "so soft and ravishingly mellow, that nothing

Figure 1. Caricatures of castrato singers Farinelli and Valeriano Pellegrino (left and right).

can better represent it than the flute-stops of some organs". There were also those who thought that the castrato voice was neither like a boy's nor a woman's voice (Smollett, 1988).

Thus, some sources describe the vocal sound of the castrato as sweet, soft, and ingratiating, others as hard, brilliant, and penetrating. On the other hand, descriptions of sounds are evidently unreliable as a source of acoustical interpretation.

The voice of the last castrato, Alessandro Moreschi, can be listened to in gramophone recordings from the first years on the 20th century. However, the sound quality does not allow any conclusions as to how the voice of a castrato may have sounded in reality.

A spectacular attempt to synthesize a castrato was made some years ago for the movie Farinelli (Depalle et al., 1994). The main strategy was to combine the voices of a counter tenor and a soprano. Figure 2 shows the long-term-average spectrum (LTAS) of the result taken from the CD (Auvidis, 1994) published with the movie. In the same graph, mean LTAS curves for commercial recordings of four sopranos and four baritones are shown for comparison. Expectably, the baritones´ voices show a clear peak centered at 2800 Hz, approximately. The sopranos and also the Farinelli synthesis obviously lack a singer's formant.

Even though the method used for this synthesis of a castrato voice was quite productive, also other synthesis strategies are possible. The castrati combined a boy's vocal folds with the vocal tract of an adult male. The length of the vocal folds increase as well as the structure of the vocal folds change during puberty. Such changes can be assumed to influence the acoustic properties of the voice source, i.e. the transglottal airflow produced when the vibrating vocal folds chop the air stream from the lungs. For example, it can be postulated that long vocal folds will produce a greater amplitude of the transglottal airflow pulses produced at a given fundamental frequency with a given lung pressure than shorter vocal folds. This will generate a typical difference in the relative amplitude of the voice source fundamental (Gauffin & Sundberg, 1989; Fant, 2005). Hence it is reasonable to assume that puberty causes typical changes of the voice source.

Moreover, the voices of our male operatic singers are characterized by the singer's formant, a group of salient strong partials between 2.5 and 3 kHz present in all voiced sounds (Sundberg, 2001). It seems to be a resonatory effect that can be achieved with an adult male vocal tract. Hence, it seems possible that the castrato voice possessed a singer's formant. As female opera singers do not produce a singer's formant, the combination of a soprano pitch range and a singer's formant would have been quite unique for castrato voices. The aim of the present investigation was to explore the possibility that a castrato had a boy's voice source combined with the vocal tract of an adult containing a singer's formant. The overall strategy was to filter out the effects on the sound

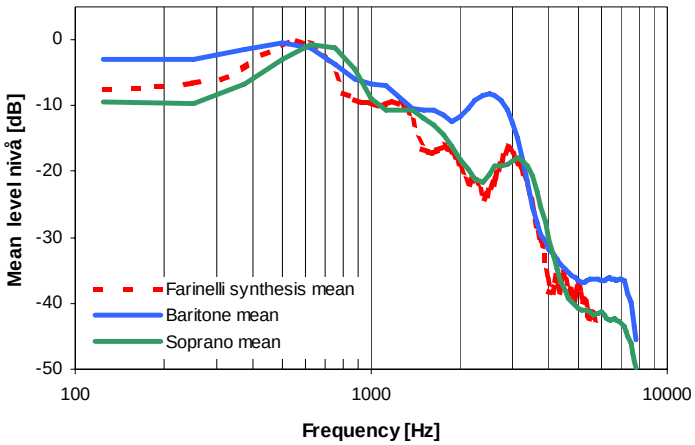

Figure 2. Mean long-term-average spectra of four classically trained operatic baritone and soprano singers (solid blue and green curves, respectively) and of four arias from the synthesis of Farinelli's voice used in the movie (dashed red curve). All sections analyzed contained also an orchestral accompaniment.

of the formants in a recording of a boy soprano and then to filter his voice source with an adult male vocal tract.

Method

A highly experienced boy soprano, frequently performing vocal solo parts in concerts, volunteered as research subject. In a sound treated booth he sang Franz Schubert's song *Ave Maria* in Bb major (F0 range 350-700 Hz without piano accompaniment, and replacing the text with the vowel /a/ (sound example 1). The recording was made on a Sony DAT machine with a head-mounted AV-JEFE TCM 110 tiepin electret microphone.

The inverse filtering of the recording was carried out by means of the custom made Decap program written by Svante Granqvist. It processes the input signal by a set of inverse filters, the frequencies and bandwidths of which are set manually. The program displays the spectrum and waveform before and after the filtering. A ripple-free closed phase and a smooth source spectrum envelope of the flow signal are normally used as criteria for tuning the filters.

However, the formant frequencies varied somewhat during the song. This implied that a given combination of inverse filter frequencies and bandwidths failed to produce a ripple-free closed phase throughout the entire piece. Therefore, this criterion had to be abandoned. Instead, an LTAS analysis was carried out of the entire song. As can be seen in Figure 3, the LTAS showed marked peaks at 660 Hz, 1220 Hz, 3660 Hz and 4220 Hz. These frequencies were assumed to represent the mean values of formants 1, 2, 3 and 4. Hence, the song was inverse filtered using these frequencies. The resulting signal, the spectrum of which is shown in the same Figure 3, was assumed to be a fair representation of the boy's voice source.

This signal was then fed to a formant synthesizer, the custom made FormTize computer program by Svante Granqvist. After specification of formant frequencies and bandwidths it processes the input signal with a transfer function of a resonator possessing the specified formant frequencies and bandwidths. The two lowest formant frequencies were set to 600 and 1050 Hz, values typical of an adult male /a/ vowel. As the centre frequency of the singer's formant tends to vary with voice classification (Sundberg, 2001), three sets of formant frequencies were used for the synthesis, one with a low, one with a medium and one with a high centre frequency of the singer's formant, see Table 1. These formant frequencies typically yield the timbre of operatic bass, baritone and tenor voices, respectively (Berndtsson & Sundberg, 1995).

Table 1. Formant frequencies used for the syntheses, which can be listened to in the sound examples.

	Synthesis number		
Formant	1	2	3
1	600	600	600
2	1050	1050	1050
3	2300	2500	2700
4	2500	2700	2900
5	2700	2900	3200

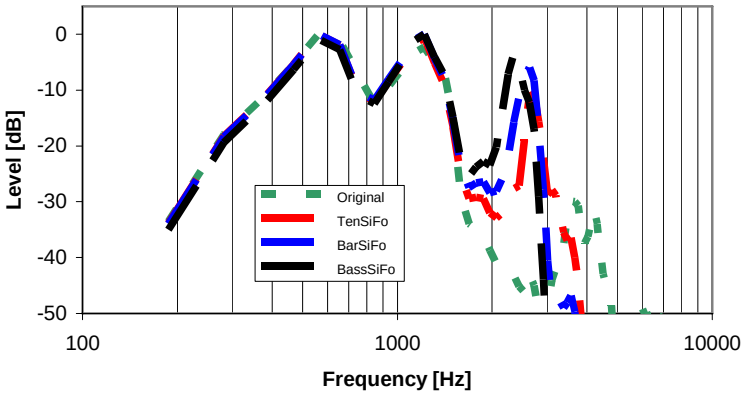

Figure 3. Blue dotted curve: LTAS of the boy soprano's rendering of F. Schubert's song Ave Maria on the vowel /a/. Black, blue and red curves: LTAS of the synthesized versions of the same song with the center frequency of the singer's formant tuned to a low, a middle and a high frequency, see Table 1.

Results

The LTAS of the syntheses thus obtained (sound examples 2, 3, 4) are shown in Figure 3. It can be seen that the syntheses depart considerably from the original. The boy soprano's LTAS peaks at 3.6 kHz and 4.2 kHz were replaced by high peaks near 2.35 kHz, 2.63 kHz, and 2.72 kHz, in the three syntheses, respectively. As expected, the timbre was affected by these changes, particularly at lower pitches.

Discussion and Conclusions

The main point is if our syntheses sound as the real castrati did. Unfortunately – or perhaps fortunately – there is no way that we can find the answer to that question. On the other hand, it is tempting to speculate.

One can assume that different castrati had different personal voice qualities, which would explain the divergence in the descriptions of the castrato voice. For example, a penetrating voice quality would hardly be perceived as a flute like timbre, since flutes are characterised by spectra with a strongly dominating fundamental, whilst a penetrating quality would rather be compatible with a voice possessing strong high overtones. One could also suspect that contemporary descriptions referred to particular singers rather than to common denominators, which would have been difficult to deduce in the absence of today's travel facilities and sound reproducing systems.

In our time, female opera-singers' voices do not have a singer's formant (Sundberg, 2001). One plausible reason would be that the female pharynx is too short and narrow compared to the typical male vocal tract. It seems perfectly possible that this limitation did not apply to castrati. Another reason may be that it would counteract timbral equalisation. The singer's formant is created by a clustering of formants three, four, and five. This implies that the formant cluster enhances partials that fall within a rather narrow frequency range. At high pitches, the frequency distance between partials is wide. Consequently, only some of the tones in the soprano range would have a partial falling within the singer's formant range, while other tones would not. Thus, some tones would sound quite brilliant and others would sound rather dull. In our synthesis, we have explored this case and some lack of timbral equalisation can be noted by careful listening. On the other hand, the brilliance that occurs in some tones adds a quality that could perhaps be useful for expressive purposes.

If the result of the castration was nothing but a perfectly typical female voice timbre, there would be no voice quality gain from the castration. If so, the fascination with the castrati in the Baroque era would originate from nothing but extra-musical factors. On the other hand, the combination of a singer's formant and female vocal range explored in the present study would make the voice of the castrato quite unique.

Acknowledgements

The musical cooperation of the boy soprano and his teacher Christoffer Holgersson of the Adolf Fredrik Music School in Stockholm is gratefully acknowledged. Previous versions of the castrato synthesis could be listened to at the exhibition on castrati arranged by co-author MT at the Drottningholm Theatre Museum, Stockholm.

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Sound examples

1. original boy's voice.
   http:\\www.speech.kth.se\~jsu\castrato_examples\1original.wav
2. synthesis with a singers formant typical of a tenor's voice.
   http:\\www.speech.kth.se\~jsu\castrato_examples\2tenorsifo.wav
3. synthesis with a singer's formant typical of a baritone's voice.
   http:\\www.speech.kth.se\~jsu\castrato_examples\3barsifo.wav
4. synthesis with a singer's formant typical of a bass' voice.
   http:\\www.speech.kth.se\~jsu\castrato_examples\4basssifo.wav