Exposé

Analysis of the development of the singing voice in regard to directivity during consecutive years of training at the tertiary level

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Introduction

The human voice is fascinating and also unique. At first to communicate with other humans, but even more – and also a form of communicating – it is used as an instrument by singers.

On the one hand the singing of notes (of course this also true for speaking) follows a discrete model which depends on adequate respiration, glottal movement which modulates the air stream and to articulate the modulated air stream within the resonance space the articulators like the tongue, palate and lips are used to provoke a certain temporal and spectral composition. Further, the proper use of the resonance space and the mouth opening allows the singer to control the directivity of the sound which is most important when accompanied by a big orchestra and performing in front of large audiences.

On the other hand countless other aspects like posture, muscular training and awareness of the content of the interpreted Lieder or Arias need to be considered to achieve extraordinary proficiency.

The singer's characteristics can be summed up to vocal range and texture of the voice which define the voice type (e.g. soprano vs. alto). The vocal timbre is defined by the fundamental frequency and the strength of its harmonics. The larger amount of energy in the high frequency range (i.e. resonant frequencies), which can vary from singer to singer, is called the singer's formant and is highly directive. The vocal weight defines a more technical term which is referred still to the tonality of the voice but defines the vocal agility (coloratura vs. dramatic) [1].

To accomplish great musical expressivity different dynamic indications, differing qualities in timbre, phrasing and articulation are necessary. The main focus throughout classes and lessons at the tertiary level is to strengthen the ability to control the aforementioned.

The training of the singing voice is a long way run that takes years of practising with right amount of technical lessons, interpretation in rehearsal and performing live on stage in front of an audience (with fellow musicians).

Especially at tertiary level the development of the singing technique sometimes lies in very small changes and therefore often in slightly perceived quality differences by the students during lessons. Nevertheless, this training builds the foundation for the singer to maintain a healthy voice.

Investigation of the singing voice

The aim of this PHD thesis is the investigation of the singing voice in terms of its characteristics and the improvement of the qualities of a singing voice over time in a non-invasive way. Especially the directivity of individual singers should be on the scale. In classical training the singer's formant is a recognizable characteristic. The challenging task is to find global parameters/features that define performance characteristics of the singing voice and are useful and robust enough to show a significant improvement of the singing technique of an individual singer over a period of time. The robustness of such features also defines their generality. Therefore, another challenging task is to prove that these features not only hold for one singer but even for a larger group of singers.

One of the hypotheses is that temporal, spectral and directive features are expected to show a higher variability for untrained voices than for trained voices. Further, the overall variability is expected to be lower or at least the same as for individual subjects.

Another hypothesis is that vocal fatigue can be detected with spectral features and should occur earlier for untrained students. Also the change of directivity patterns when the singer gets exhausted is an interesting subject to study.

This thesis should comprise the following tasks:

PRESTUDY

- Organizing a collaboration with Institute 7 Voice, Lied and Oratorio and select suitable singing exercises ("messa di voce", projection, focusing, emphasis on formants, repetitions, vowels, fricatives, dynamics – pp to ff)
- Collaboration with Institute 9 Drama (elocution teachers)
- Acquiring a pilot group of six singers (university/conservatory)
- The setup of a measurement procedure to record individual singers in an anechoic chamber within a large scale microphone array
- Concept study for measuring the directivity of a singer (w/o normalizing patterns)
- Concept study for measuring the directivity of singers during slight movements (Tracking System, Video Analysis – mouth opening/posture, Video Cues – animated conductor gives timings for exercises)
- Concept study for measuring the directivity of singers during different room acoustical scenarios ("Spatial Decomposition Method", Frank, Zotter [2])
- Investigation on fundamental descriptors of the singing voice (study of audio descriptors for speech and musical signals)
- Investigation of vibrato as a natural cyclic representation of reproduction
- Investigation of vocal fatigue ("singer's exhaustion") in relation to training time

MAIN STUDY

- Expand the pilot group of singers to 3 singers for each voice specialization (baritone, tenor, alto, mezzosoprano, soprano)
- Recordings at least once a semester over time period of 2 $^{1}/_{2}$ years
- Feedback with teachers and students
- Diary of how much time the singers invested in practicing the exercises
- Improvement and further investigation on fundamental descriptors for the singing voice
- Listening tests – teachers and expert listening panel
- Statistical evaluation of the measurements – interpretation of the results in regards to performance improvement in relation to directivity of pronounced formants and the overall directivity. Exploring the relationship of room acoustics (e.g. application of the "double SDM" approach proposed by Frank, Zotter in [2]), vocal fatigue and the amount of time invested in training.
- Reduction of the used measurement setup to a portable setup – robust descriptors (spectral shape, vibrato extent) for the everyday use which in best case allows to make assumptions about the singers directivity pattern

Recent Research

The directivity patterns of singers have been investigated by Monson and Hunter (2011-2012), Cabrera, Davis and Connolly (2011), Malte Kob and H. Jers (1999), Marshall and Meyer (1985), Brian Katz and Christophe d'Allesandro (2007).

Monson and Hunter [3] investigated the radiation of low and high frequency energy in the horizontal plane but with little insight on the proficiency of the singers. Cabrera, Davis and Connolly [4] measured long-term horizontal directivity patterns of eight professional opera singers in different acoustic environments. Kob and Jers [5] studied the directivity pattern of a singer by using a turntable for their measurements and compared the data with measurements of a dummy head. Marshall and Meyer [6] investigated 3 singers (baritone, alto and soprano) in an anechoic chamber and an evaluation of the auditory impression of choir and solo singers in a hemi-anechoic environment. A more detailed measurement analysis of directivity patterns of a professional singer is reported by Katz and d'Allesandro [7] which shows interesting results about the changes in the directivity patterns of sung vowels for different intensities (fortissimo, forte, mezzoforte and piano). Also focusing and projection were investigated for one singer (counter tenor) and did show some increase in energy for the high frequency range. A promising long-term study

of the development of the singing voice has been done by Ferguson, Kenny, Mitchell, Ryan, and Cabrera [8], but an detailed signal analysis scheme nor measured directivity patterns of the participating singers are missing.

Claim

Therefore, no study so far included a large group of singers and investigated the directivity patterns of the singing voice and used short time signal analysis with a time averaging scheme over the natural vibrato cycles in relation with perceived quality over several consecutive years. The proposed averaging method would align temporal and spectral data in regard to natural vibrato cycles comparing singers in the same recording environment for different synthetic sound fields. The existing microphone setup at the Institute of Electronic Music and Acoustics which should be used is also unique as it comprises 64 measurement microphones positioned on a sphere. Therefore, the subjects, all of whom in the best case are students of the University of Music and Performing Arts Graz, can be captured spatially for each recording at once. That means the data does not to be clustered from several measurements and the subjects are less stressed.

The sound field reproduction scheme will be used (SDM technique as proposed by Frank and Zotter in [2]) which uses the audio signals captured by the microphone array (cf. Figure 1) and feeds it back to the singer via headphones or loudspeakers with a scalable amount of reverb.

Figure 1 Large scale microphone array with 64 NTI measurement microphones. The singers are supposed to stand inside the array while getting cues from a screen and via talkback. A tracking system should measure the head movements and a video camera will be used to study the relationships with mouth opening and posture.

The studies of Zora Schärer Kalkandjiev [9] already showed that the room acoustics clearly take influence in the characteristic of the performance of an instrumentalist. One hypothesis is that an influence in singing in regard to the amount of reverberation takes place and can be shown within the feature set.

The idea for the main study is to investigate a large group of singers (as large as possible) in different stages of their singing education to build a large enough data set for proving the assumptions. The subjects should be tested regularly over a longer period to see how and if they improve. At first the singing and behaviour in the measurement room of a pilot group with a size of six singers (different registers, different education levels) should be examined to set up the best possible measurement procedure. The reproducibility of several singing exercises should be studied and improved (in discussion with singing teachers, elocution teachers) and trimmed for the larger group tested over at least 2 years (each semester half a day of recording time for each participant). A first concept of such a singing exercise is depicted in Figure 2. The classical *messa di voce* exercise can be adapted to investigate three states of singing. The steadier the short term energy and the lower the vibrato extent (spectral analysis via Fourier Transform) should indicate the quality of the singing technique.

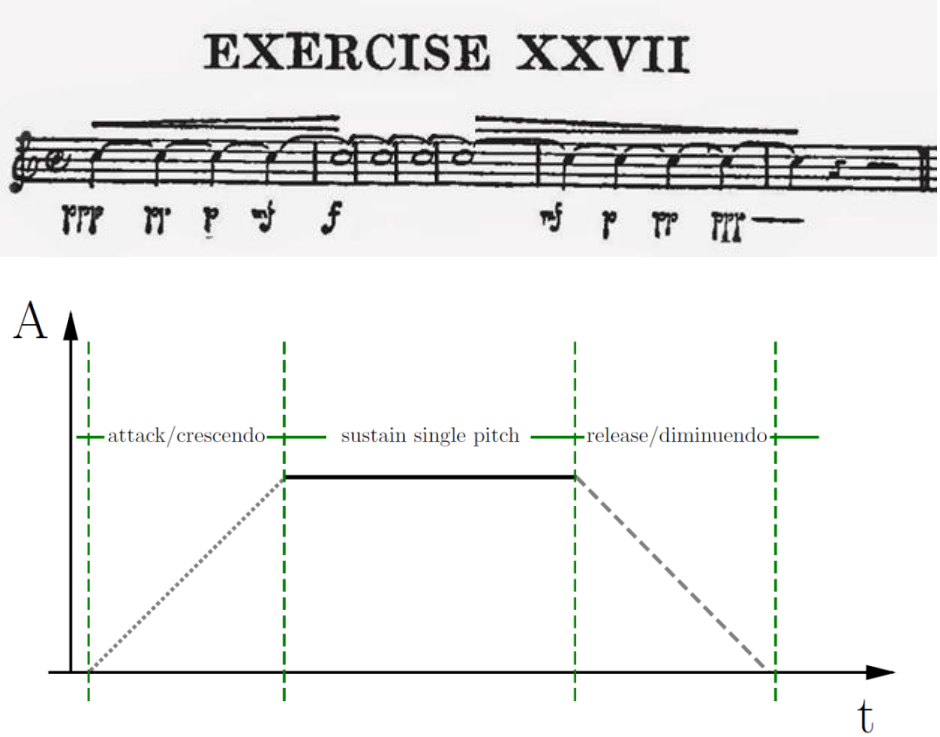

Figure 2 Adaptation of the *messa di voce* exercise. The adapted exercise should comprise of the typical crescendo and diminuendo parts (or in terms of signal analysis attack and release sections) but also of an extended sustain part. The main principle of the exercise is sustaining the pitch while gradually increasing and decreasing the volume.

The features for the investigation should be temporal, spectral features with an emphasis on short time energy signal analysis. The natural vibrato cycles should be used as timings for an averaging scheme to provide comparability (cf. Figure 3). The directivity of the singers should be investigated, whereas the directional features should compare the amount of energy the singer produces on axis (to the front/audience) and the amount of energy in off-center directions. Also under investigation is the ability to control the formants frequency region and how it influences directivity. Throughout the training the singer's fatigue should be reduced, which should be shown with a steadier performance and displayed within the mentioned feature set.

The results should lead to a better understanding of a singer's voice and radiation patterns in different room acoustical scenarios. They also should give insight on the variations in terms of aesthetic qualities in a singing voice and provide knowledge and tools and help improving the effectiveness of the training of novice students at the tertiary level. Further, the results can provide further knowledge on proper microphone positioning for recordings and provide data for improving the quality of artificial dummy heads.

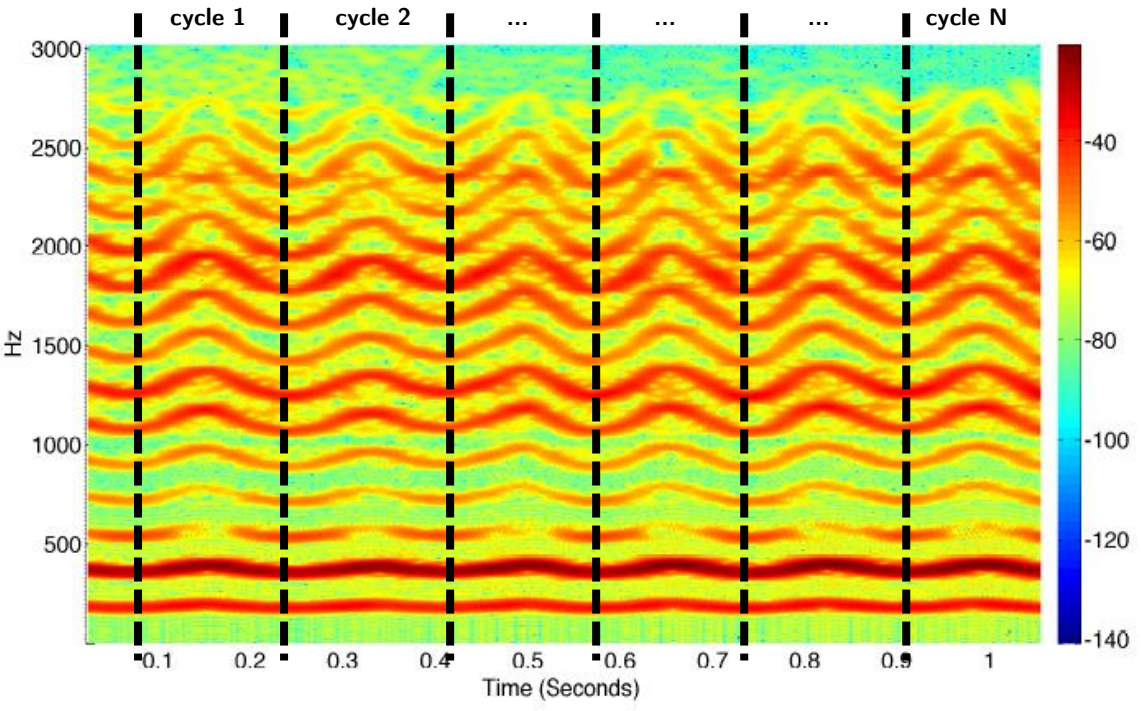

Figure 3 Spectrogram of a short segment of vibrato. The spectrogram (i.e. frequency modulation of ca. 4-8 Hz) shows continuous repetitions of the vibrato on the time axis (i.e. vibrato cycles), which could be used as time alignment for an accurate averaging scheme [10].

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[3] "Horizontal directivity of low- and high-frequency energy in speech and singing", Brian Monson, Eric Hunter and Brad Story, The Journal of the Acoustical Society of America, vol.132 (1), July 2012

[4] "Long-term horizontal vocal directivity of opera singers: Effects of singing projection and acoustic environment", Journal of Voice 2011, vol.25 (6), e291-303

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