

# INTONATION ANALYSIS OF A MULTI-CHANNEL CHOIR RECORDING

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## ABSTRACT

A multi-track recording of a 16-singer choir of many different choir pieces was done some years ago. In this investigation one piece is chosen and analysed singer by singer concerning intonation, synchronisation, and to what extent the singers of a voice section agree to each other. We try to find objective measures for getting closer to a definition of the so-called “chorus-effect”. The results show some expected effects of intonation dispersion and also an unexpected lining up of vibrato.

## 1. INTRODUCTION

Amateur choir singing has improved greatly in recent years, and many semiprofessional choirs almost reach a professional quality. Even so, there has not been much research in the field of choir acoustics, which could help to improve rehearsing methods. Earlier investigations dealt with F0-analysis, timbre and spectrum, SPL and formant frequencies. Some measurements were done with several singers singing within a choir, sometimes synthetic signals were used to simulate a choir, and some intonation analyses were done with ensembles. One of the particular properties of choral sound is the so-called “chorus effect”, that is, the combined sound of many sources that are similar but uncorrelated at the level of the waveform of the sound. To study the chorus effect, it is important to know what each choir singer is singing. Only a few recordings of a choir (as distinct from quartets, etc) have been studied, and we have found no detailed investigation with multi-channel recording of separated choir singer signals. With the advent of affordable multi-track equipment, such recordings are now easier to make than before. In his diploma thesis, author Jers (1998) used multi-track recordings to re-create “virtual choirs” in order to study the effect of singer directivity with singer placement and room acoustics taken into account. This resulted in a large material which also can be used for detailed studies of how the choir singers sing together: intonation, synchronisation, timbral matching etc. This paper reports on some attempts to assess choral intonation in detail, and presents a preliminary analysis of a complete choir recording concerning the degree of similarity between singers in intonation and vibrato.

## 2. MUSICIANS AND MUSIC

A multi-channel recording was done with the County Choir of North-Rhine Westfalia in Germany; an amateur choir with singers aged 20-32 years, recruited regionally. Some of them had soloist training, but the majority had learned by practising choir singing. The recording was made in their normal rehearsal room. The music should represent a real choir rehearsal situation, and therefore a 8-bar canon by Praetorius was chosen (fig. 1), and performed in unison, females and males one octave apart. The range of the piece is comfortable for every voice group, it has some melismatic and some syllabic parts, and some variety of different melodic intervals. The piece was rehearsed with the choir before and sung in German pronunciation of Latin.



Figure 1: Canon “Laudate Dominum” of Michael Praetorius

### 3. DATA ACQUISITION

A 16-channel recording system was used, with 16 miniature omnidirectional electret condenser microphones (Monacor MCE-100), a mixer (Target Q-Series 328+6), and two synchronised Tascam D-88 8-track PCM recorders. The microphones, purpose-built at the Institute of Technical Acoustics in Aachen, had flat frequency response up to 10 kHz. Each microphone was placed on the nose of a singer, close to the mouth, outside the voice airstream, and undisturbed by clothing etc. The error in frequency response incurred by this placement was later compensated for as described by Jers (1998). The 8-bar piece was sung twice: in normal tempo ( $\downarrow = 125$  bpm) and in a slower tempo ( $\downarrow = 80$  bpm). At this point the piece had already been rehearsed many times, so the training effect between these two takes should have been negligible. After recording the data was copied to a computer hard disc.

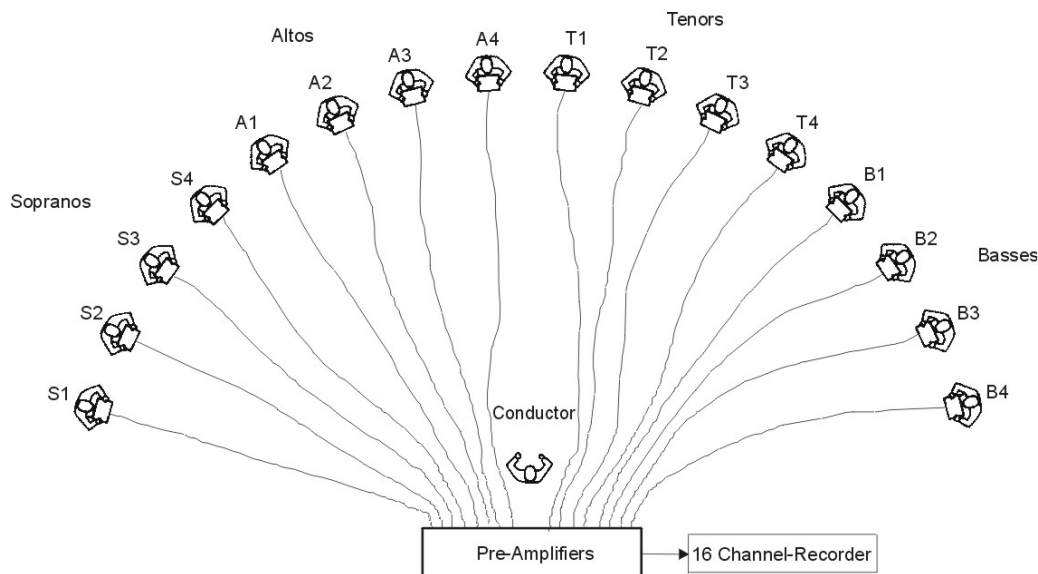


Figure 2: 16-channel recording of a choir

The choir consisted of 16 singers, four in each voice group (fig 2). The separation between the singers was 80-100 cm. The crosstalk between adjacent microphones was about 20 dB, which is enough for our analysis.

### 4. ANALYSIS AND RESULTS

The fundamental frequency (F0) contours were estimated using the correlogram utility of Soundswell [2], which uses auto-correlation and manual segmentation to produce F0 contours with a sampling rate of about 1 kHz and a resolution of better than 1 cent. These were converted into text files and read into Microsoft Excel for further analysis and display.

There are several types of dispersion in choral intonation. Each singer's F0 has microvariations over time, so to get an intonation value for one tone, we must compute the average F0 over the duration of the tone,  $MF0_N$ . This operation will also remove the vibrato, provided that there is a whole or large number of vibrato cycles in the tone. The standard deviation  $SF0_N$  over the tone is a measure of the singer's instability in F0, or, of the vibrato extent (RMS). It is also interesting to compute the average F0 of all singers or voices,  $MF0_V$ , reflecting the combined intonation of the ensemble; and the corresponding standard deviation  $SF0_V$ , reflecting the dispersion in F0 between singers. For readability, we first tabulate these symbols for the different F0 averages and standard deviations (table 1).

	Average	Standard deviation	Comment
Over time but within notes	$MF0_N$	$SF0_N$	One value per note per singer. $MF0_N$ measures the F0 of one note, $SF0_N$ measures the F0 stability of one singer
Over voices/singers	$MF0_V$	$SF0_V$	$MF0_V$ measures the average F0 of several singers, $SF0_V$ measures the scatter in F0 across singers.  Both change continuously with time
Over time-averaged notes and over singers	$MF0_{V,N}$	$SF0_{V,N}$	One value per note. Measures the mean $MF0_N$ and scatter in $MF0_N$ over singers

Table 1: Definition of symbols for different F0 averages and standard deviations

#### 4.1. Intonation

We will start by looking at the averages taken over the entire ensemble and then progress to lower levels of detail. Figure 3 is an analysis of the low-tempo version. It shows the  $MF0_V$  in cents relative to the root,  $N=16$  singers, and with  $SF0_V$  in a separate trace at the bottom.

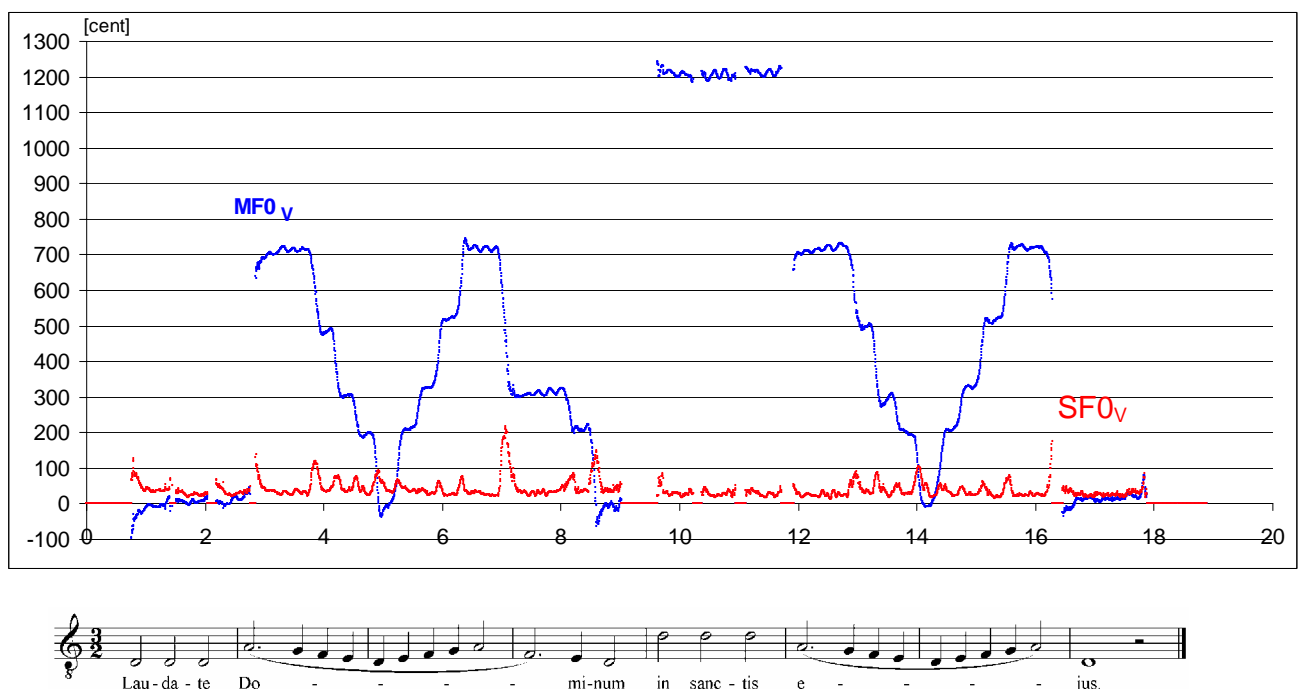


Figure 3: Average of the whole ensemble, Standard deviation across all 16 singers, slow tempo

It is easy to track the  $MF0_V$  curve with regard to the printed score, and the tone steps are clearly seen. One may note that the intonation on descending scales seems very accurate (in equal temperament), while on the

ascending scales there seems to be a tendency of pitching high, similar to an earlier investigation of coloratura passages of Sundberg (1989); in melodic intonation, the big intervals are enlarged, for example the fifths and the octaves. As might be expected, the standard deviation  $SF0_V$  at the transitions between the tones is high, caused both by some desynchronisation of the voices and by transient effects in arriving at the next pitch. After a transition, the  $SF0_V$  decreases to a baseline level after approximately 0.3 seconds. The overall time average of  $SF0_V$  was 39 cents. This value includes variations due to vibrato and flutter. Although  $MF0_V$  represents an average across all singers, there is still a clearly visible vibrato, increasing in extent to the end of a note.

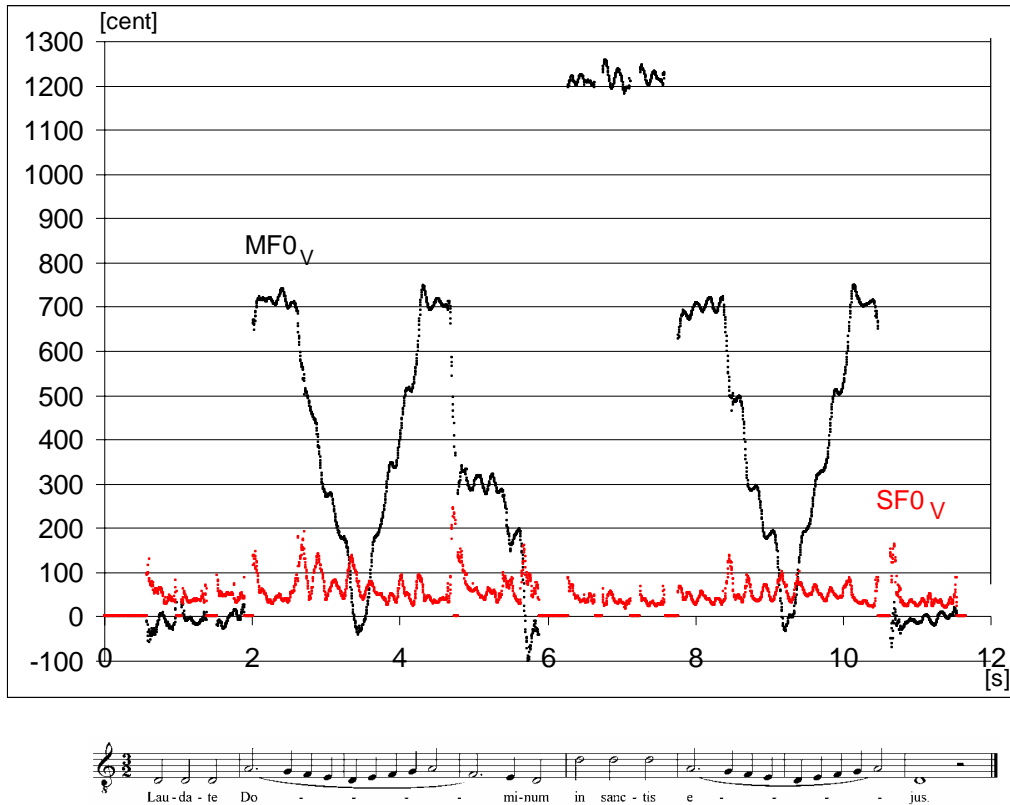


Figure 4:  $F0$  averaged over all 16 singers, with standard deviation, normal tempo

In the normal tempo version (Figure 4), similar tendencies may be observed: the big intervals are enlarged, steps upwards are sharpened and the vibrato is still visible, with an even larger extent than in the slow version. The main differences seem to be some over- or undershoots for the highest and the lowest tones, a slightly bigger increased standard deviation  $SF0_V$  at the tone transitions and a more glissando-like difference between tone steps. Probably the fast tempo gives less time to find the correct pitch of each note, thereby causing this greater imprecision. Greater imprecision was also found in the time average of  $SF0_V$ , which was 55 cents over the 8 bars, implying that the  $F0$  inaccuracies and/or instabilities increased a little in the higher tempo.

To compare with an earlier investigation of Ternström and Sundberg (1988), a statistical analysis of the long notes of this piece was done by calculating the  $SF0_{V,N}$ . This gives information about the degree of agreement in intonation among the singers.



Figure 5: Notes of the choir piece chosen for further intonation and vibrato analysis

For this purpose the  $MF0_N$  of the A4 of the female (A3 of the male voices) was calculated and the  $SF0_{V,N}$  for each voice group is shown in figure 6. Like the  $SF0_V$ , the  $SF0_{V,N}$  is lower in the slow version. There were no differences between the choir sections in this regard. Ternström and Sundberg (1988) found an average  $SF0_{V,N}$  of about 13 cents over six basses when the choir was singing to the conductor's satisfaction, which is similar to the slow version here.

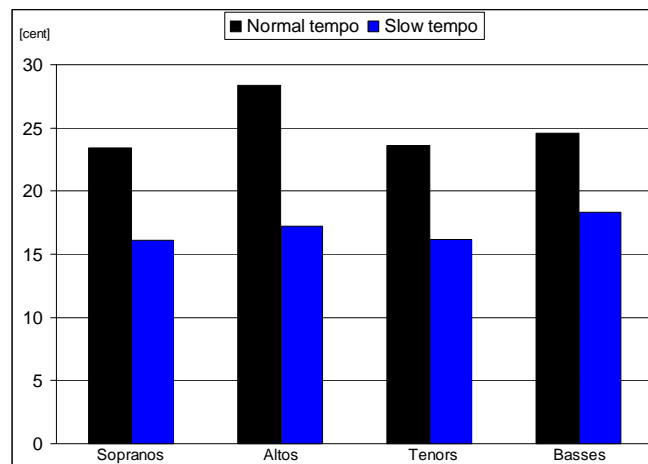


Figure 6:  $SF0_{V,N}$  over singers and note A4 for each voice group, normal and slow tempo

## 4.2. Vibrato

There are many investigations of soloist vibrato, but little has been looked at in choirs. Different choral traditions use different amounts of vibrato. In the choir studied here, some singers had vibrato and others did not. It can be argued that vibrato would be detrimental to choral intonation, since it would tend to blur the harmonies of the chords. From a perceptual and motor-control perspective, it seems very unlikely that singers would be able to consciously synchronise their vibratos, but if it were possible, then such a blurring might be less objectionable to the listener. Figures 7 and 8 shows the  $F0$  contours of the female singers on the first notes of bars two and six (slow version). Remarkably, most of the singers with vibrato did exhibit some degree of synchronisation. This is an interesting observation, but more experiments are needed to determine whether it is a common phenomenon. For the fast version, the picture was similar, except that vibrato was initiated immediately at the onset of the tones.

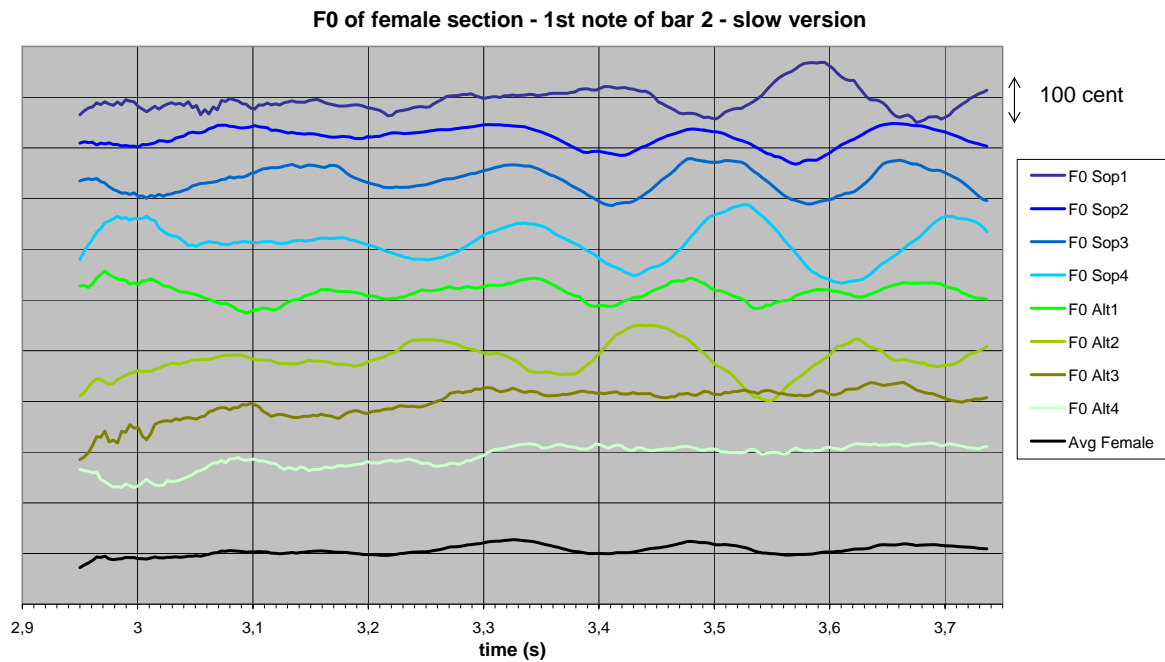


Figure 7: *Vibrato comparison of the female section – 1<sup>st</sup> note of bar 2 – slow version*

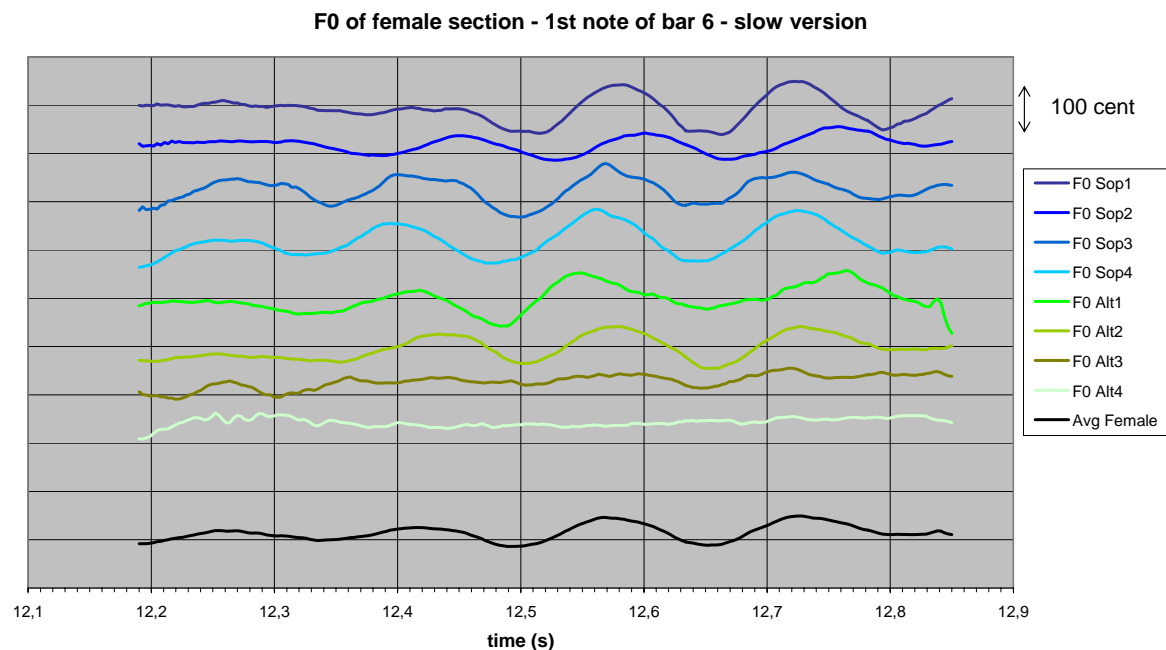


Figure 8: *Vibrato comparison of the female section – 1<sup>st</sup> note of bar 6 – slow version*

It can be argued that the vibrato oscillations will be the same if the note onsets act as synchronisation points, and we think that this is what is happening. For example, in going to a lower note from a higher note, singers typically perform a small F0 undershoot, which would act as the lower starting point for a vibrato cycle. In notes of longer duration than those measured here, it is possible that desynchronisation would set in.

## 5. CONCLUSION

The present investigation shows some details of intonation and vibrato behaviour of singers within a choir. Although it is not possible to draw general conclusions out of that, it seems to be possible to get closer to a definition of the “chorus-effect” with this material, as well as with further analysis. It has to be taken into account that the sound pressure level was not mentioned in this analysis, and we do not know how these findings are related to how the choral sound is perceived. Another 16-channel recording is planned for comparison and some listening tests will be done in the near future to get an idea of the phenomenons of choir acoustics.

## 6. ACKNOWLEDGEMENTS

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