A Study of Intonation in SATB Ensembles

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Canada

Introduction

Prior Work on Intonation

Tools for Automatically Extracting Performance Parameters

Intonation Experiment

Conclusions/Future Work

Introduction

- Study of the influence of musical context on SATB ensembles intonation
- Background in Music Technology
  - Automatic extraction of intonation-related data
- Background in Music Theory
  - Use of specially designed exercises designed for this experiment and music theoretical analysis of existing music

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Prior Work on Intonation

- Schoen (1922) studied 5 performances of Gounod's "Ave Maria"
  - accompanied singers were sharper than equal temperament
    - intervals tended to be flatter when descending and sharper when ascending
- Prame (1997) studied 10 performances of Schubert's "Ave Maria"
  - accompanied singers deviated from equal temperament
    - range of the average deviation was -12 to +20 cents
- Jers and Terström (2005) examined intonation in 1 fast and 1 slow performance by a 16 voice a cappella ensemble
  - a greater amount of intonation dispersion at the faster tempo
    - descending intervals were closer to equal temperament while ascending intervals were sharper

Prior Work on Intonation

- Vurma and Ross (2006) studied 13 professional singers performing a melodic intonation in a short exercises
  - ascending and descending semitones were smaller than EQT
  - ascending and descending fifths were larger than than EQT
- Howard (2007) studied 2 *a cappella* SATB quartets
  - the ensembles used non-equal temperament with a tendency toward, though not full compliance with, Just-Intonation
- Vurma (2010) studied 15 professional singers' intonation in 2-part 6-note exercises with a synthesized lower voice
  - singers' intonation did not change significantly when the synthesized voice was detuned

Our Work on Solo Intonation

- Subjects
  - 6 undergraduate vocal majors
  - 6 professional singers
- Experimental Material: Schubert's "Ave Maria" performed
  - 3 times a cappella
  - 3 times with accompaniment
- Data Analysis
  - *a cappella* vs. accompanied
  - ascending vs. descending
  - various semitone and whole tone intervallic conditions
  - singer and group identity

Our Work on Solo Intonation

- Findings (Devaney, Wild, and Fujinaga 2011)
  - Ascending semitones and whole tones tended to be larger than descending ones
  - Non-professional singers tended to compress ascending semitones with a leading tone function
  - Professional singers' intonation was more consistent between *a cappella* and accompanied performances than non-professionals
  - Professional singers' intonation was more consistent with one another than non-professionals

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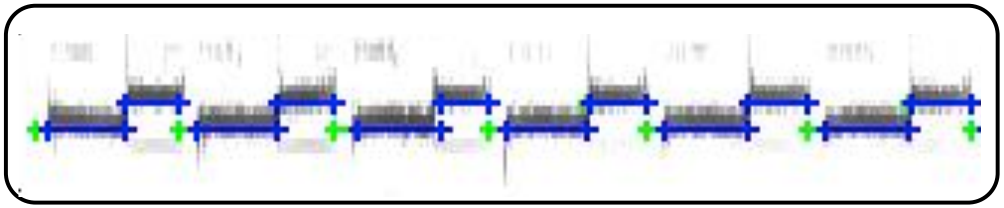
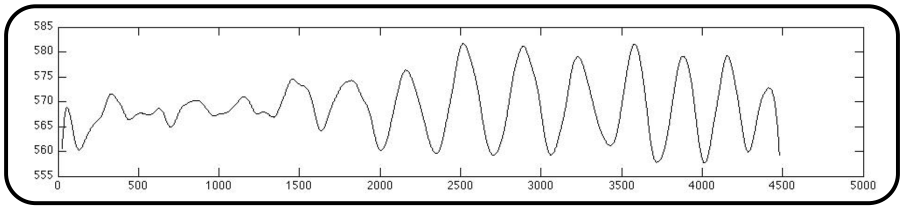
Extracting Performance Parameters

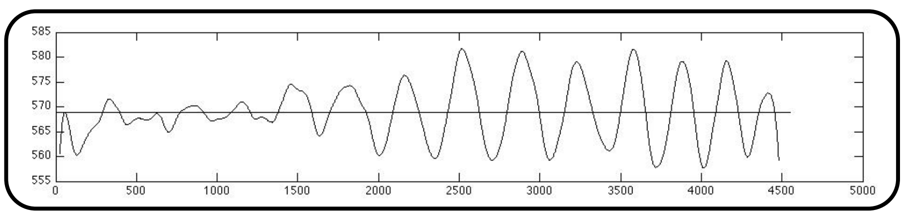
Identify Note Onsets and Offsets



Fundamental Frequency (F0) Estimation

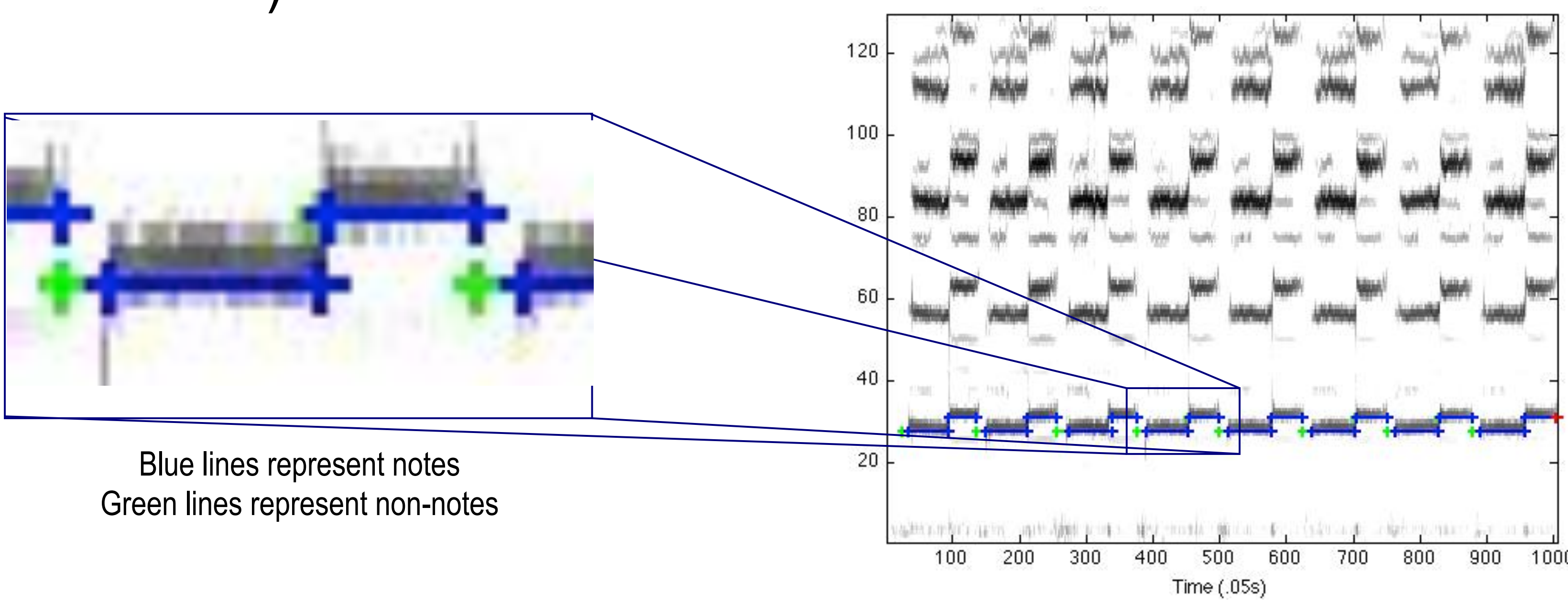


Perceived Pitch



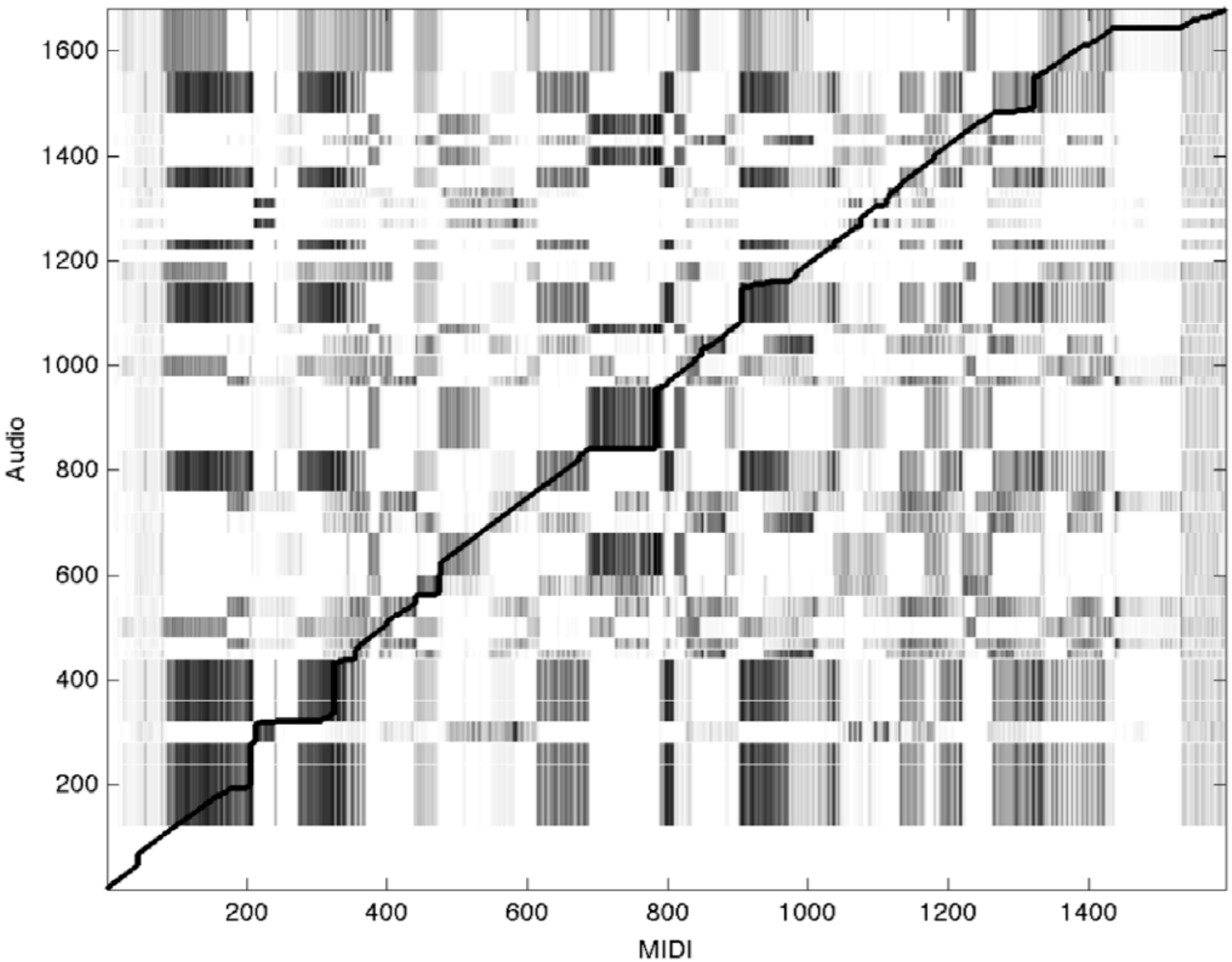
Identifying Note Onset and Offset

- Note onsets and offsets in the recordings were identified through MIDI-audio alignment
  - The method used in this dissertation is a two-step dynamic time warping (Orio and Schwarz)/hidden Markov model alignment algorithm optimized for the singing voice (Devaney, Mandel, & Ellis 2009)

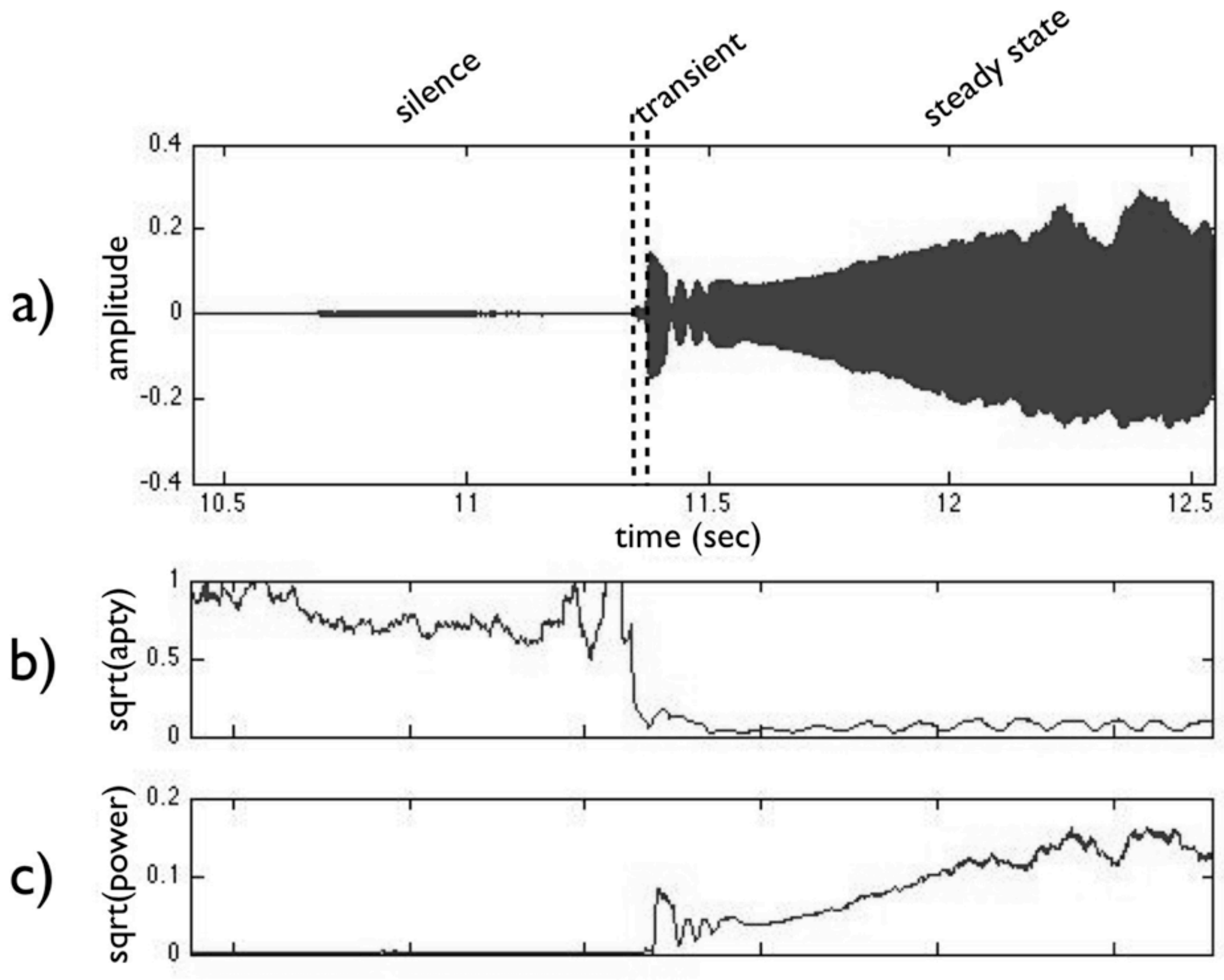


Blue lines represent notes
Green lines represent non-notes

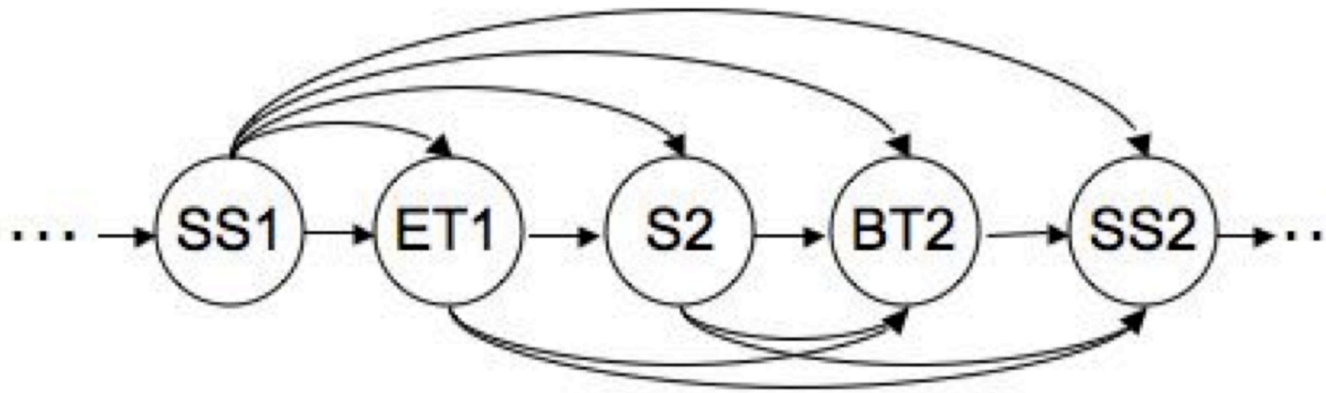
Dynamic Time Warping Matrix

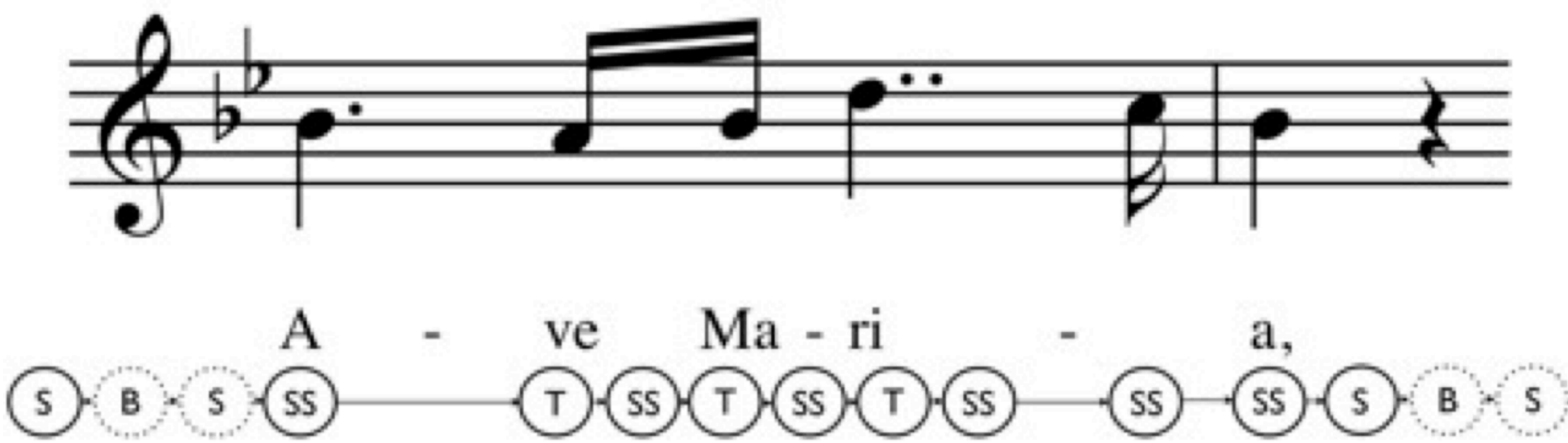


Acoustic Properties of the Singing Voice

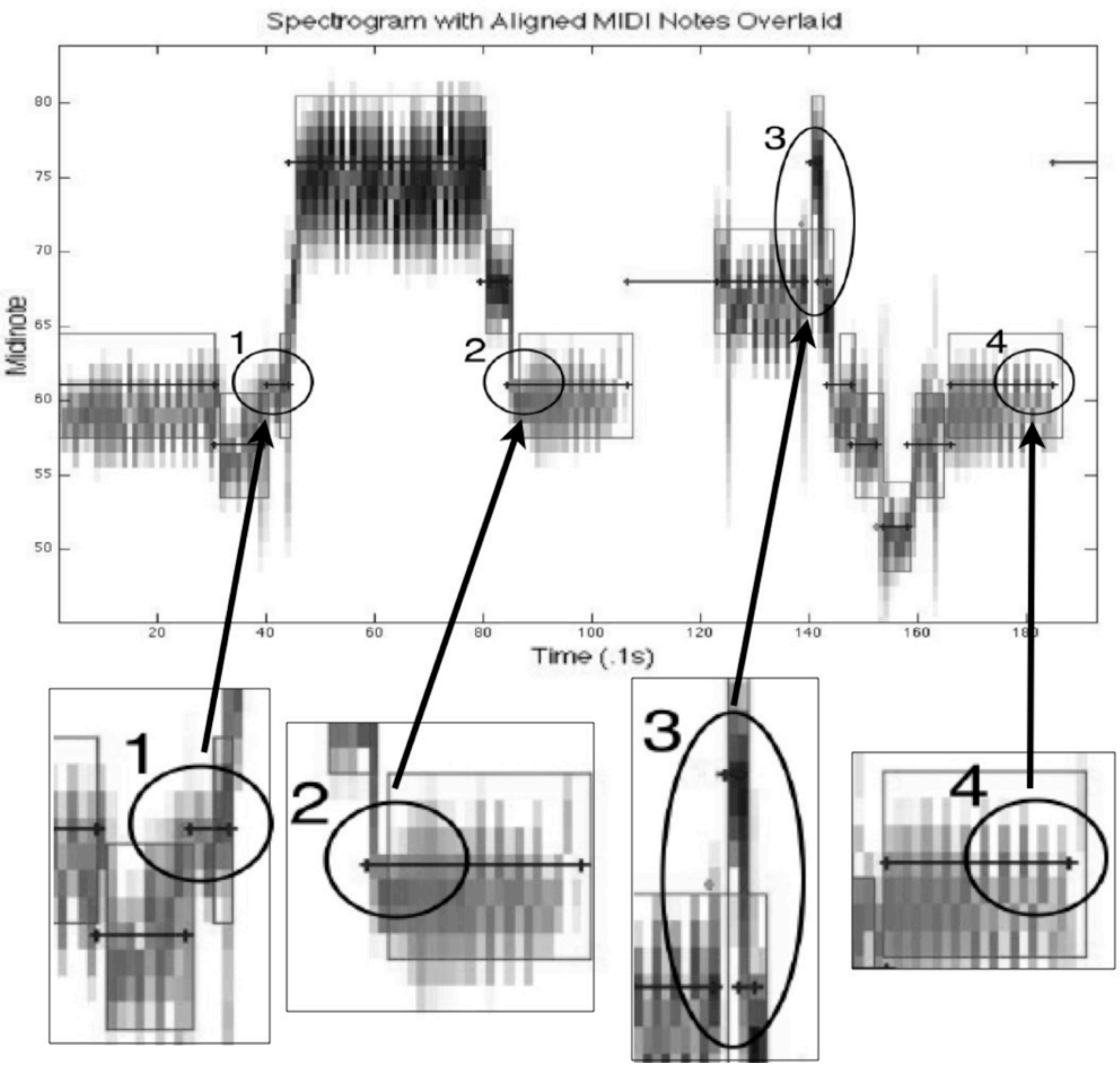


HMM States



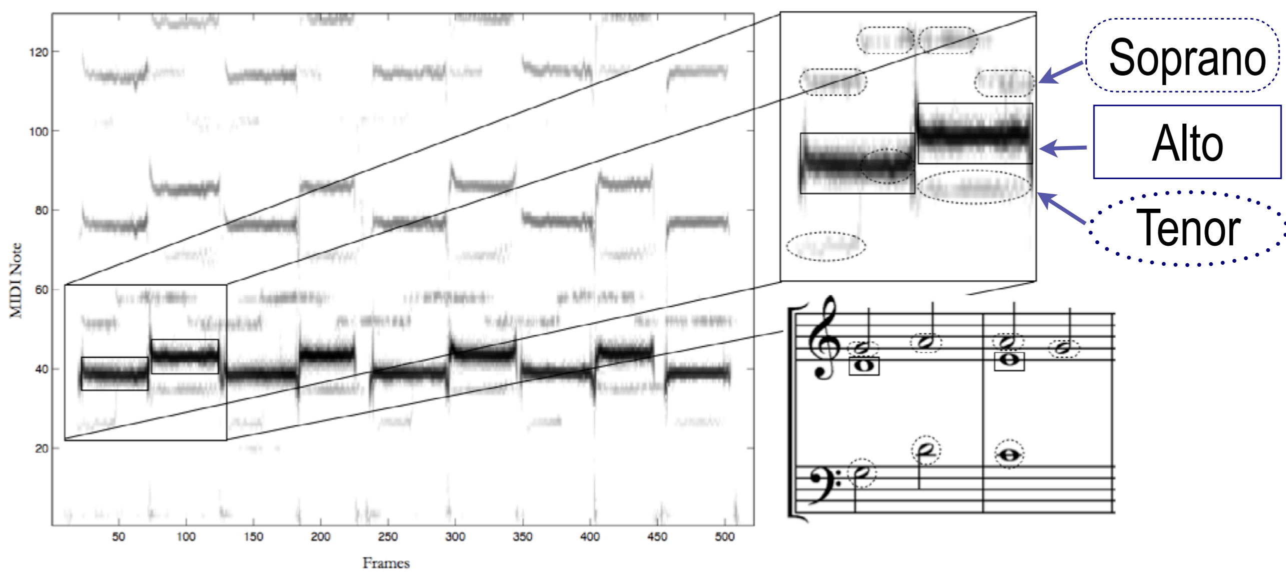


Alignment Improvements



Fundamental Frequency (F_0) Estimation

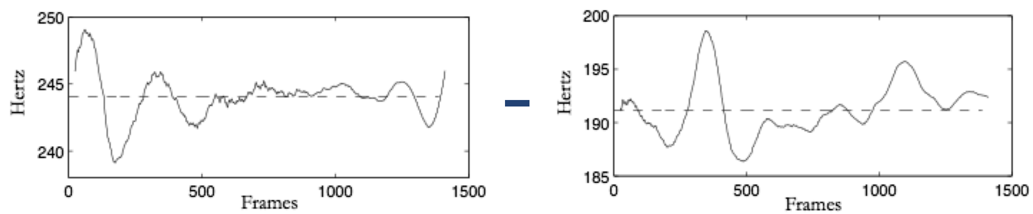
- The YIN algorithm was used for F_0 estimation (de Cheveigné and Kawahara 2002)
  - A single F_0 estimate is calculated for each frame of audio
  - YIN was designed for monophonic F_0 estimation
  - The ability to specify the minimum and maximum expected F_0 allows YIN to work more robustly for quasi-polyphonic signals



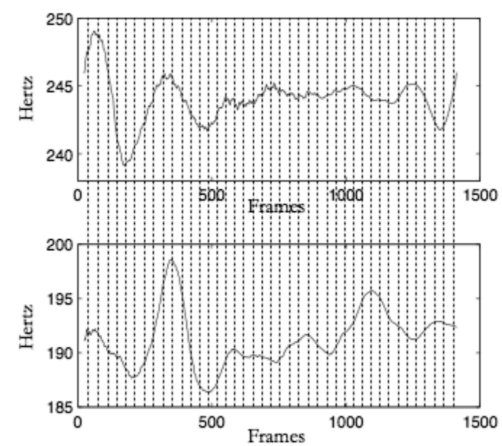
Calculating Interval Size

- Perceived pitch was calculated by taking a weighted mean based on the F_0's rate of change, with higher weightings for frames that had a slower rate of change (Gockel et al. 2001)

- Horizontal interval size was calculated as the difference between two perceived pitch calculations



- Vertical interval size was calculated by taking the mean across the difference in F_0 estimates for each frame



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Intonation Experiment

- Subjects
  - 1 semi-professional quartet (pilot)
  - 2 professional quartets (lab and church)
- Experimental Material
  - Exercises composed by Jonathan Wild and Peter Schubert, where semitones and whole tones occur in different contexts
  - Chord progression by Giambattista Benedetti
  - Michael Praetorius' "Lo how a rose e'er blooming"

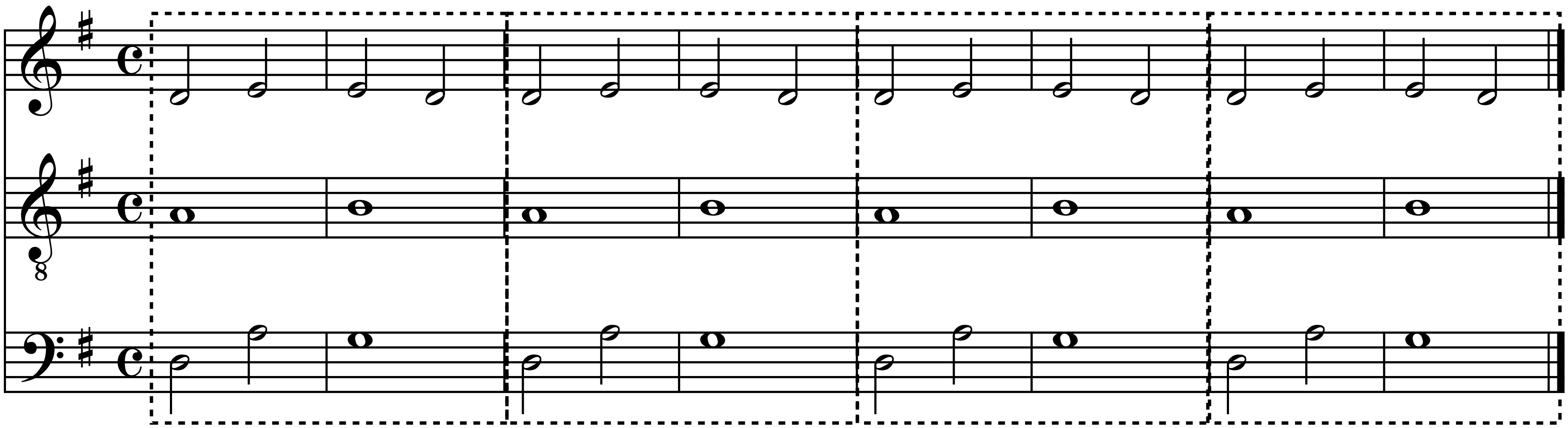
Semitone Exercises (Wild)

	Chromatic semitones	$\hat{7}-\hat{8}$	$\hat{2}-\hat{3}$	$\hat{3}-\hat{4}$	$\hat{5}-\hat{6}$
Soprano	1–5	6	7	8	9
Alto	10–14	15	16	17	18
Tenor	19–23	24	25	26	27

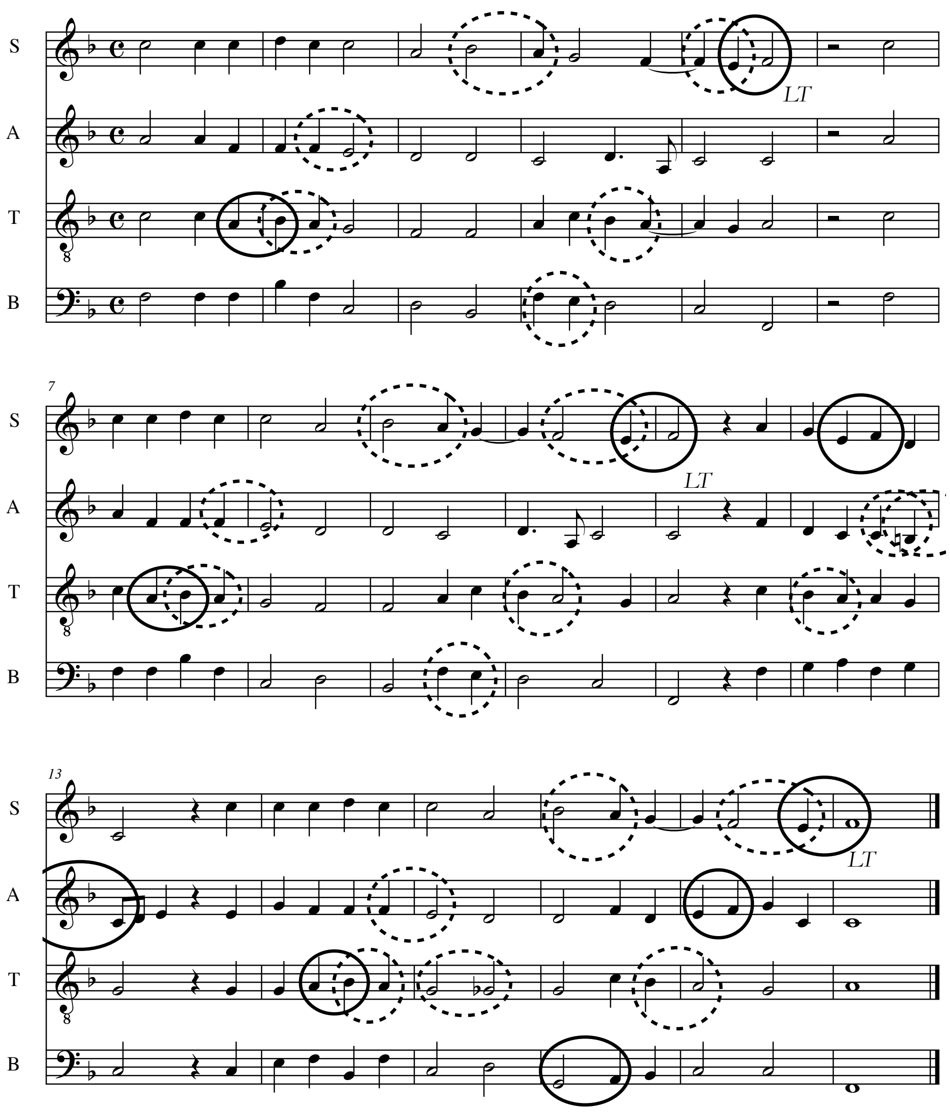
Whole tone Exercises (Schubert)

	$\hat{2}-\hat{3}$	$\hat{5}-\hat{6}$	$\hat{4}-\hat{5}$	$\hat{3}-\hat{4}$	$\hat{1}-\hat{2}$	$\hat{6}-\hat{7}$
Soprano	1	2	3	4	5	6
Alto	7	8	9	10	11	12
Tenor	13	14	15	16	17	18

Benedetti Progression



Praetorius - Semitones/Whole Tones



Praetorius - Vertical Intervals

Experimental Method

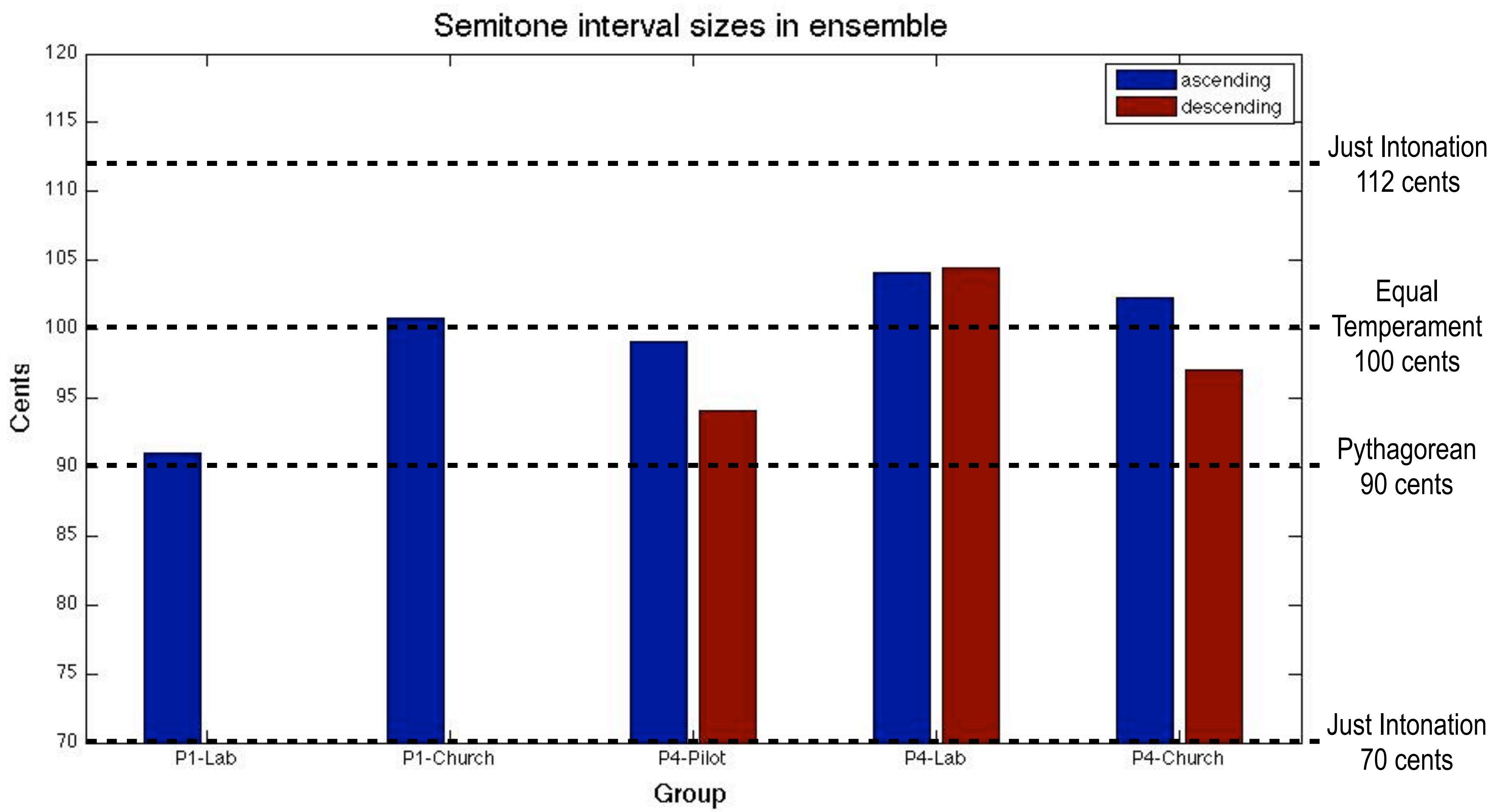

- Recording set-up (Lab Ensemble)
  - Room – Critical Listening Lab in CIRMMT
  - The whole ensemble was recorded with a pair of cardioid microphone
  - Each ensemble singer was also miked with a cardioid headband mic
  - Recording was done a Mac Pro

- Recording set-up (Church Ensemble)
  - Room – St Mathias Church, Westmount
  - Same mics as the lab recordings
  - Recording was done on a portable 16-track recorder

Regression Analysis

- Linear regression analysis used to determine effects (including size and direction)
    - ascending vs. descending
    - semitone intervallic conditions (part one and four)
    - whole tone intervallic conditions (part two)
    - singer and group identity

Melodic Interval Size: *Semitones*



SE = 1–2.3

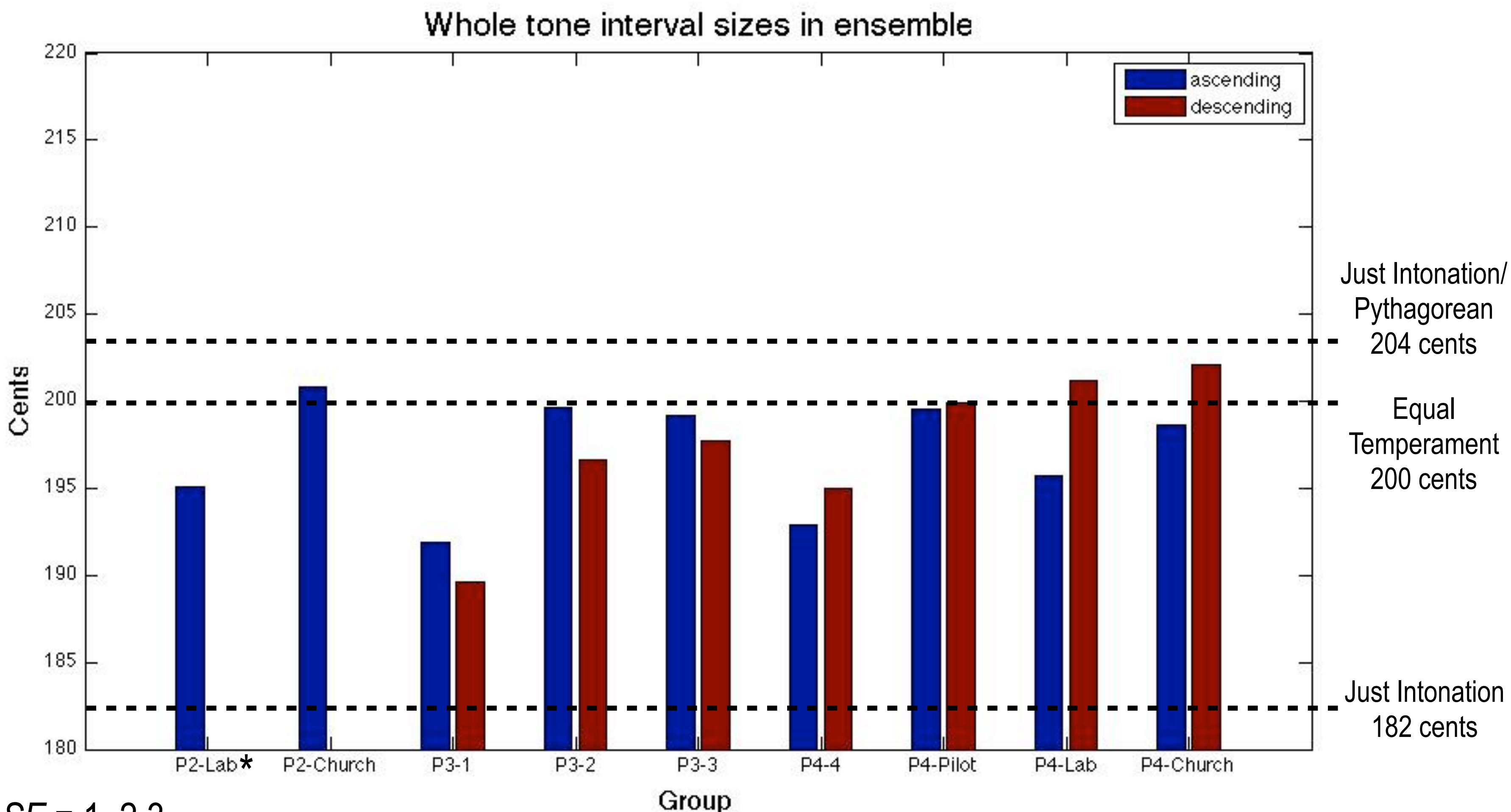
Melodic Interval Size: *Semitones*

- Only one semitone category for each of the Lab and Church ensembles showed a significant effect
- The Church ensemble's ascending semitones were on average 8 cents larger than their descending semitones

Melodic Interval Size: *Semitones*

	Pilot	Lab	Church
Overall size (all)	closest to equal temperament (except for P4 descending)	closest to equal temperament (except for P1 ascending)	closest to equal temperament
Direction (P4)	*P4 - Not Significant*	*P4 - Not Significant*	P4 - ascending semitones 8 cents larger on average
Intervalic Conditions (P1, P4)	*N/A*	P1 - diatonic vs chromatic was significantly different P1 - 1 condition significantly different from leading tone *P4 - Not Significant*	*P1 - diatonic vs chromatic not significant* P1 - 1 condition significantly different from leading tone *P4 - Not Significant*
Singer Identity (P1, P3, P4)	*Not Significant*	*P1 - Not Significant* P4 - Bass	P1 - Tenor, Alto P4 - Tenor, Alto, Bass

Melodic Interval Size: *Whole Tones*



SE = 1–2.3

Except * where *SE* = 5.5

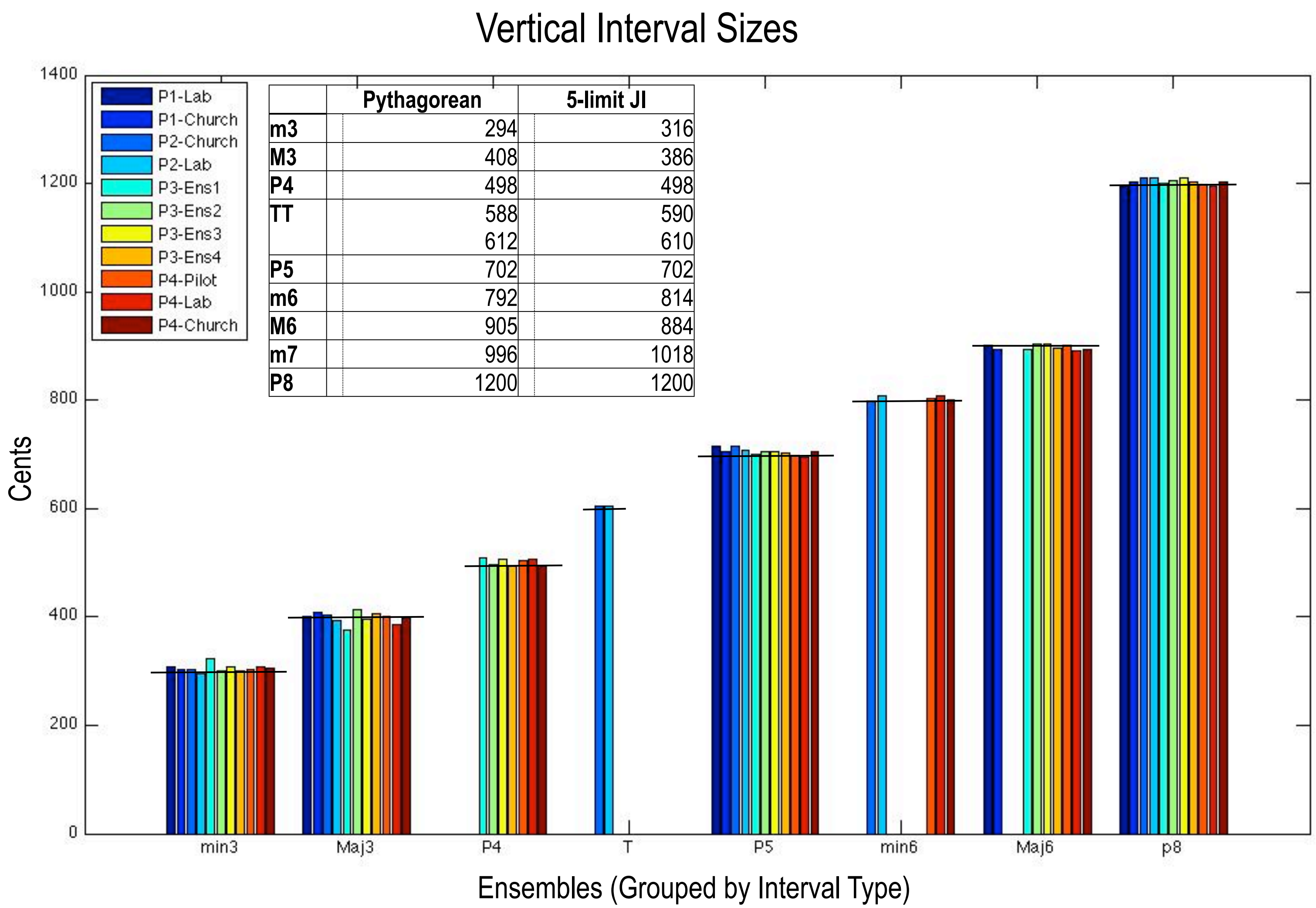
Melodic Interval Size: *Whole Tones*

- Only one whole tone category for the Lab ensemble showed a significant effect
- The Lab ensemble's ascending whole tones were 4 cents smaller on average than their descending whole tones
- The Church ensemble's ascending whole tones were 5 cents smaller on average than their descending whole tones

Melodic Interval Size: *Whole Tones*

	Pilot	Lab	Church
Overall size (all)	closest to equal temperament	closest to equal temperament	closest to equal temperament
Direction (P4)	*P3 - Not Significant* *P4 - Not Significant*	*P3 - Not Significant* P4 - ascending 5 cents smaller	*P3 - Not Significant* P4 - ascending 5 cents smaller
Intervalic Conditions (P2)	*N/A*	P2 - effect for 1 condition	P2 - *Not Significant*
Singer Identity (P2, P3, P4)	P3 - Middle *P4 - Not Significant*	P2 - Tenor, Alto P3 - Middle *P4 - Not Significant*	P2 - Alto *P3 - Not Significant* P4 - Alto

Vertical Interval Size



	Pythagorean	5-limit JI
m3	294	316
M3	408	386
P4	498	498
TT	588 612	590 610
P5	702	702
m6	792	814
M6	905	884
m7	996	1018
P8	1200	1200

Vertical Interval Size

- Question: Do singers tend towards Just Intonation when tuning vertical intervals?

- If the coincidence of partials encourages Just Intonation tuning, one would expect that Major Thirds would be tuned more justly than intervals with fewer partials in common
  - For most of the ensembles, the Major Thirds were closer to equal temperament (400 cents) than Just Intonation (386 cents)

Vertical Interval Size

	m3	M3	P4	TT	P5	m6	M6	m7	P8
Equal Temperament	300	400	500	600	700	800	900	1000	1200
5-limit Just Intonation	316	386	498	590 610	702	814	884	1018	1200
Pythagorean	294	408	498	588 612	702	792	905	996	1200

- When cadential context was taken into account in the Praetorius, a *t*-test ($p = 0.05$) revealed that the tuning was closer to Just Intonation in cadential contexts than non-cadential contexts

	Pilot	Lab	Church
Cadence	14.356	14.108	14.261
Non-Cadence	**17.027**	**16.631**	**17.254**

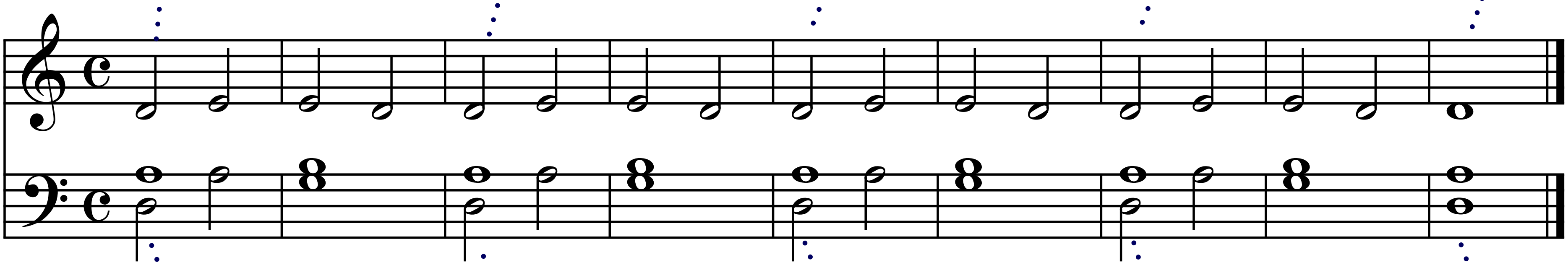
Mean deviation in cents from idealized Just Intonation tunings

Pitch Drift

Theoretical intonation calculations for the Benedetti chord progression

Tuned to bass note

D	E	E	D	D	E	E	D	D	E	E	D	D	E	E	D	D
0	4	18	0	0	4	18	0	0	4	4	0	0	4	4	0	0
A		B		A		B		A		B		A		B		A
2		16		2		16		2		16		2		16		2
D	A	G		D	A	G		D	A	G		D	A	G		D
0	2	-2		0	2	-2		0	2	-2		0	2	-2		0



Tuned to sustained note

D	E	E	D	D	E	E	D	D	E	E	D	D	E	E	D	D
0	4	4	22	22	26	26	44	44	48	48	66	66	70	70	88	88
A		B		A		B		A		B		A		B		A
2		6		24		28		46		50		68		72		90
D	A	G		D	A	G		D	A	G		D	A	G		D
0	2	20		22	24	42		44	46	64		66	68	86		88

VOCALOID New Singing Synthesis Technology

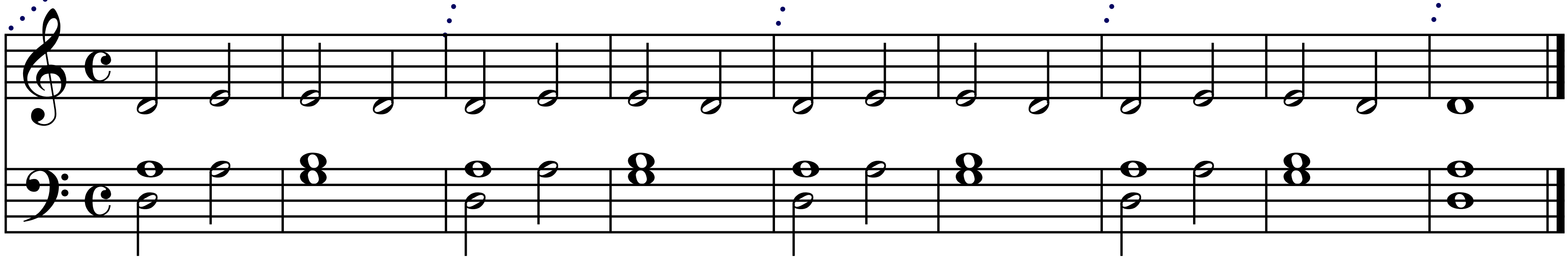
Pocaloid

Many thanks to Gabriel Vigliensoni for creating the Vocaloid versions

Pitch Drift

Example of an actual performance

D	E	E	D	D	E	E	D	D	E	E	D	D	E	E	D	D
-7	-20	-23	-501	-9	-17	1	20	1	-16	-20	8	5	-9	-13	19	6
A		B		A		B		A		B		A		B		A
15		24		15		20		8		20		-1		15		11
D	A	G		D	A	G		D	A	G		D	A	G		D
0	-18	-6		3	-14	-13		-2	-13	4		13	-15	-1		8

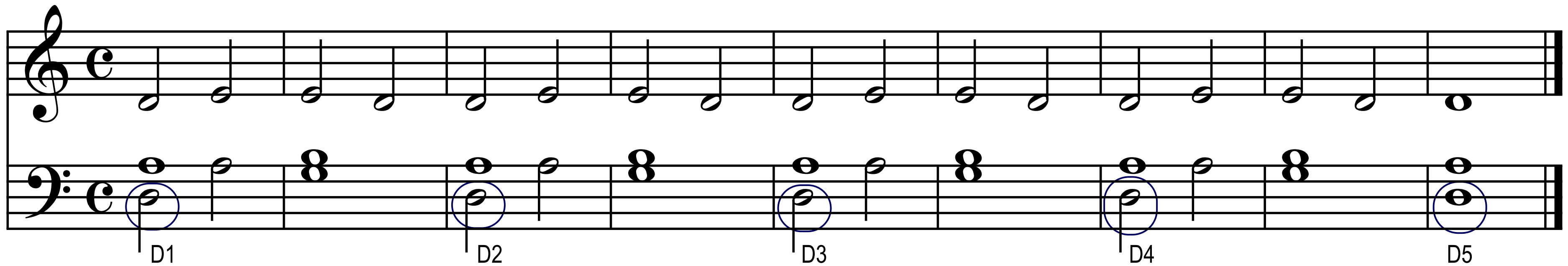


Pitch Drift

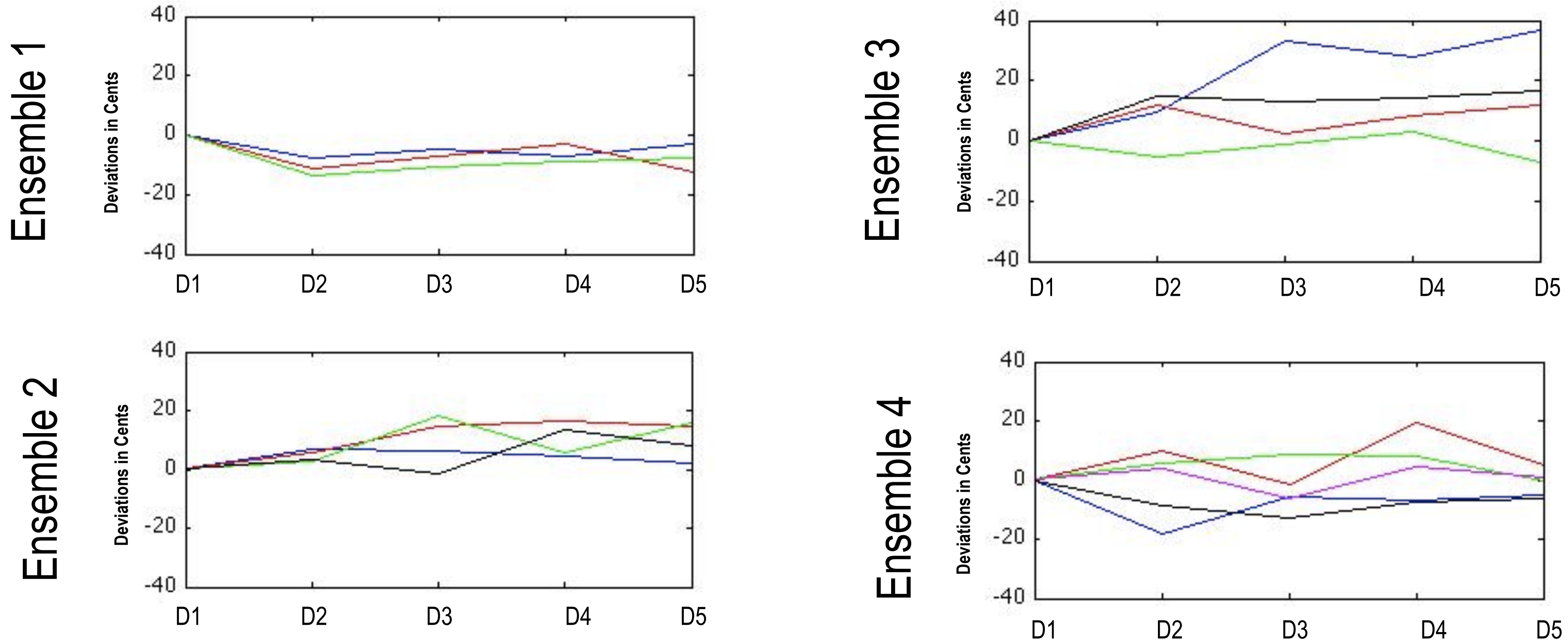
- Ensemble 1 – Semi-professional singers* (ATB, lab)
- Ensemble 2 – Professional singers** (ATB, lab)
- Ensemble 3 – Professional singers** (SAT, church)
- Ensemble 4 – Professional singers** (ATB, church)

**no conductor* ***conducted by Peter Schubert*

Pitch Drift



D1
D2
D3
D4
D5



Ensemble 1
Ensemble 3
Ensemble 2
Ensemble 4
Deviations in Cents
40
20
0
-20
-40
D1
D2
D3
D4
D5

Impact of Syllable on Intonation

Benedetti

Ensemble	# takes on 'mi'	# takes on 'ma'
2	2	2
3	2	2
4	3	3

	Melodic ("mi")	Melodic ("ma")	Vertical ("mi")	Vertical ("ma")
Ensemble 2	1.7	-0.1	4.3	8.6
Ensemble 3	2.3	-0.3	**5.3**	1.0
Ensemble 4	-1.8	0.2	-0.02	**4.8**

Bolding indicates significant difference

Praetorius

Ensemble	# takes in German	# takes on 'mi'
Lab	4	3
Church	4	4

	Melodic (German)	Melodic ("mi")	Vertical (German)	Vertical ("mi")
Lab	**3.180**	0.128	**0.4284**	-4.385
Church	**1.971**	-1.702	-0.205	1.089

Bolding indicates significant difference

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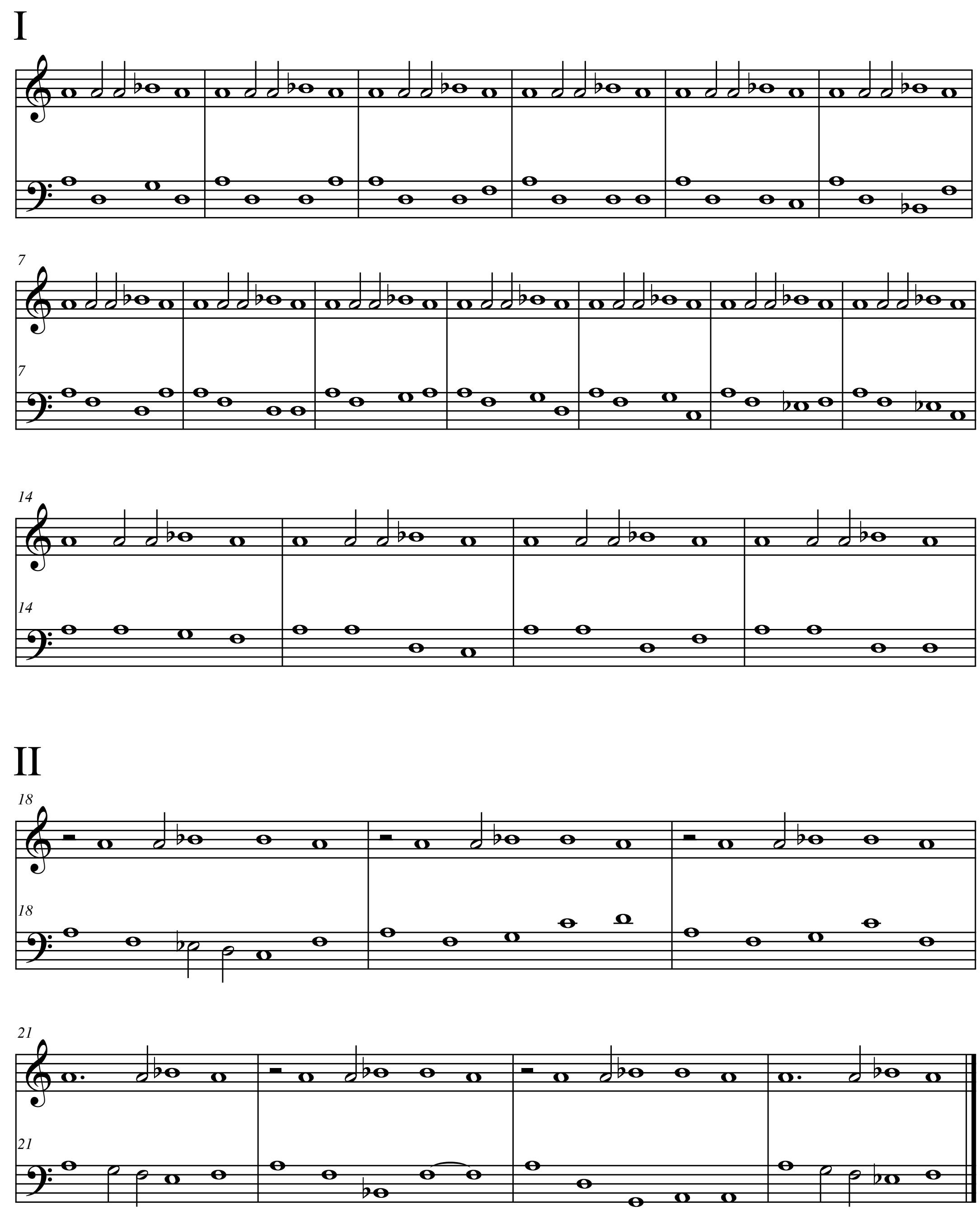
Conclusions

- Neither horizontal or vertical interval conformed to a fixed system
  - Significant differences between ascending/descending semitones and whole tones
  - Significant difference for Lab ensemble between diatonic/chromatic
  - Vertical intervals were closer to Just Intonation tuning in cadential contexts in all ensembles
- Variable amounts of drift were observed in the ensembles
  - None of the ensembles exhibited sharpening predicted by Benedetti
- There were some significant effects for syllable
  - When the Praetorius was sung with the original german text both horizontal and vertical intervals were larger than when sung on “mi”

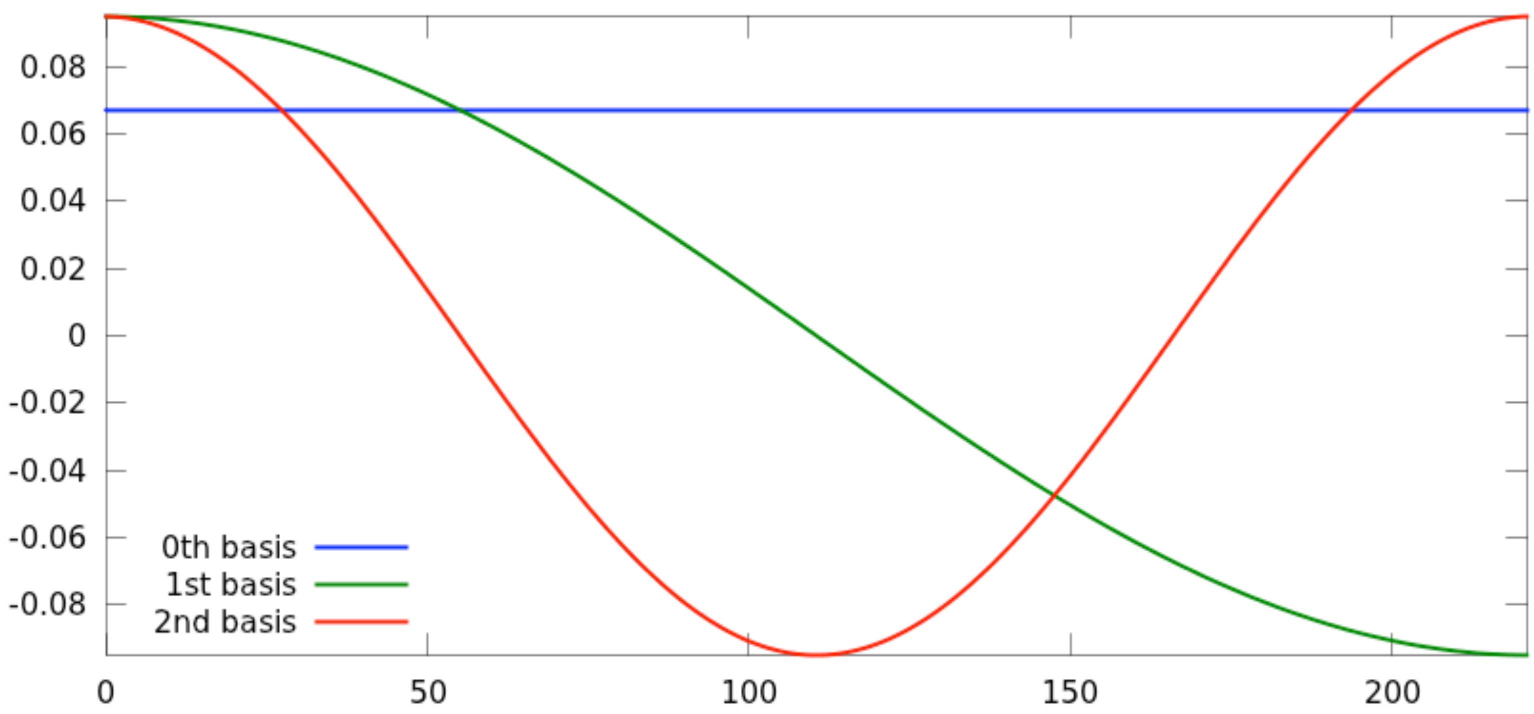
Future Work

- A more controlled experiment
- Same pattern in the upper voice over randomized lower voice



Future Work

- Modeling slope and curvature in fundamental frequencies with the first two coefficients of the Discrete Cosine Transform (Devaney, Mandel and Fujinaga 2011)



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Thank you!

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