

# Empirically Evaluating Vocal Intonation

Johanna Devaney  
School of Music  
The Ohio State University

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speculative approaches to tuning  
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# Introduction

## Prior Work on Solo Intonation

## Extracting Intonation Data

## Empirical Evaluation of Solo and Ensemble Singing

## Conclusions

# Introduction

- This talk focuses on my work on intonation in trained singers in the Western tradition
- It will describe three experiments and relates their findings to earlier research
  - Solo singing
  - 2-part singing (with one voice pre-recorded)
  - 3- and 4-part singing (whole ensembles)

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# Prior Work on Intonation

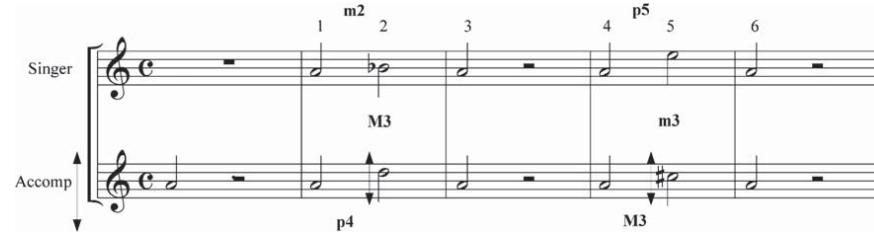
- Schoen (1922) studied 5 accompanied professional singers
  - sharper than equal temperament
  - less sharp when descending than when ascending
- Prame (1997) studied 10 accompanied professional singers
  - intonation deviated substantially, but not consistently, from equal temperament

# Prior Work on Intonation

- Vurma and Ross (2006) studied 13 *a cappella* professional singers
  - ascending/descending semitones smaller than EQT
  - ascending/descending tritones and fifths larger than than EQT



- Vurma (2010) studied 15 accompanied professional singers
  - singers' intonation did not change significantly when the synthesized voice was detuned 20 or 40 cents narrower



# Introduction

Prior Work on Solo Intonation

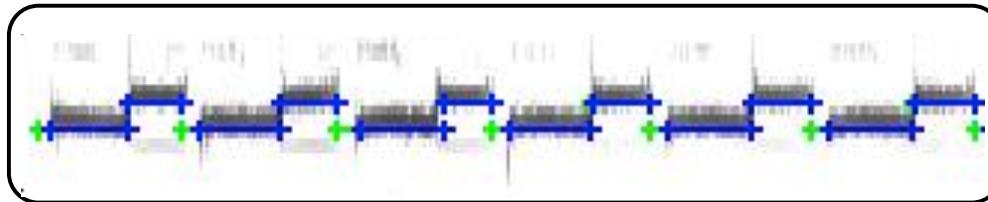
## Extracting Intonation Data

Empirical Evaluation of Solo and Ensemble Singing

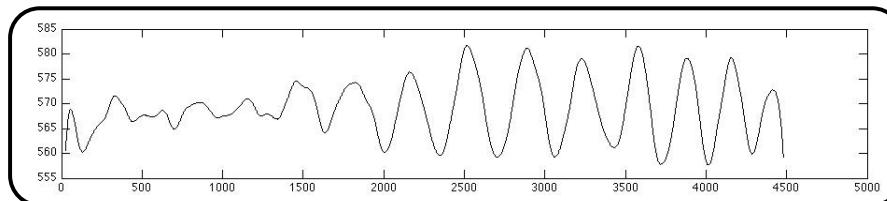
Conclusions

# Extracting Performance Data

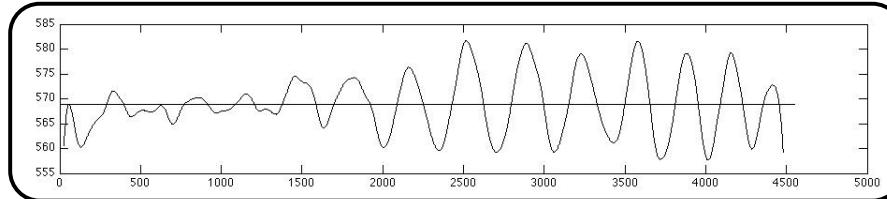
Identify Note Onsets and Offsets



Fundamental Frequency (Fo) Estimation

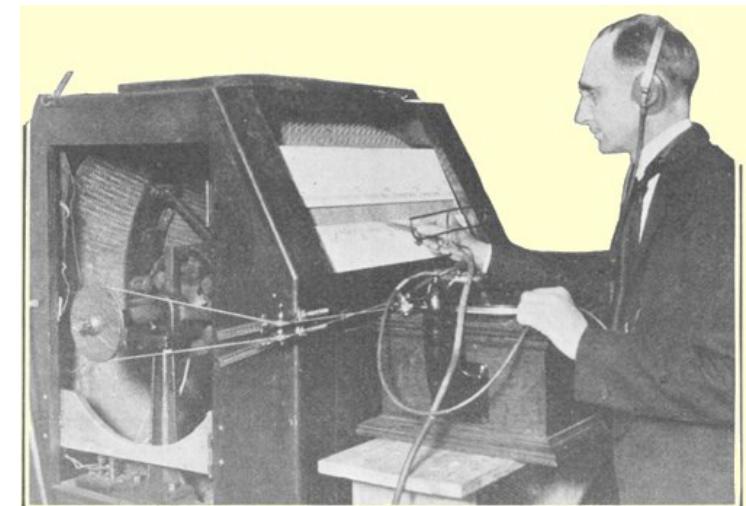


Perceived Pitch



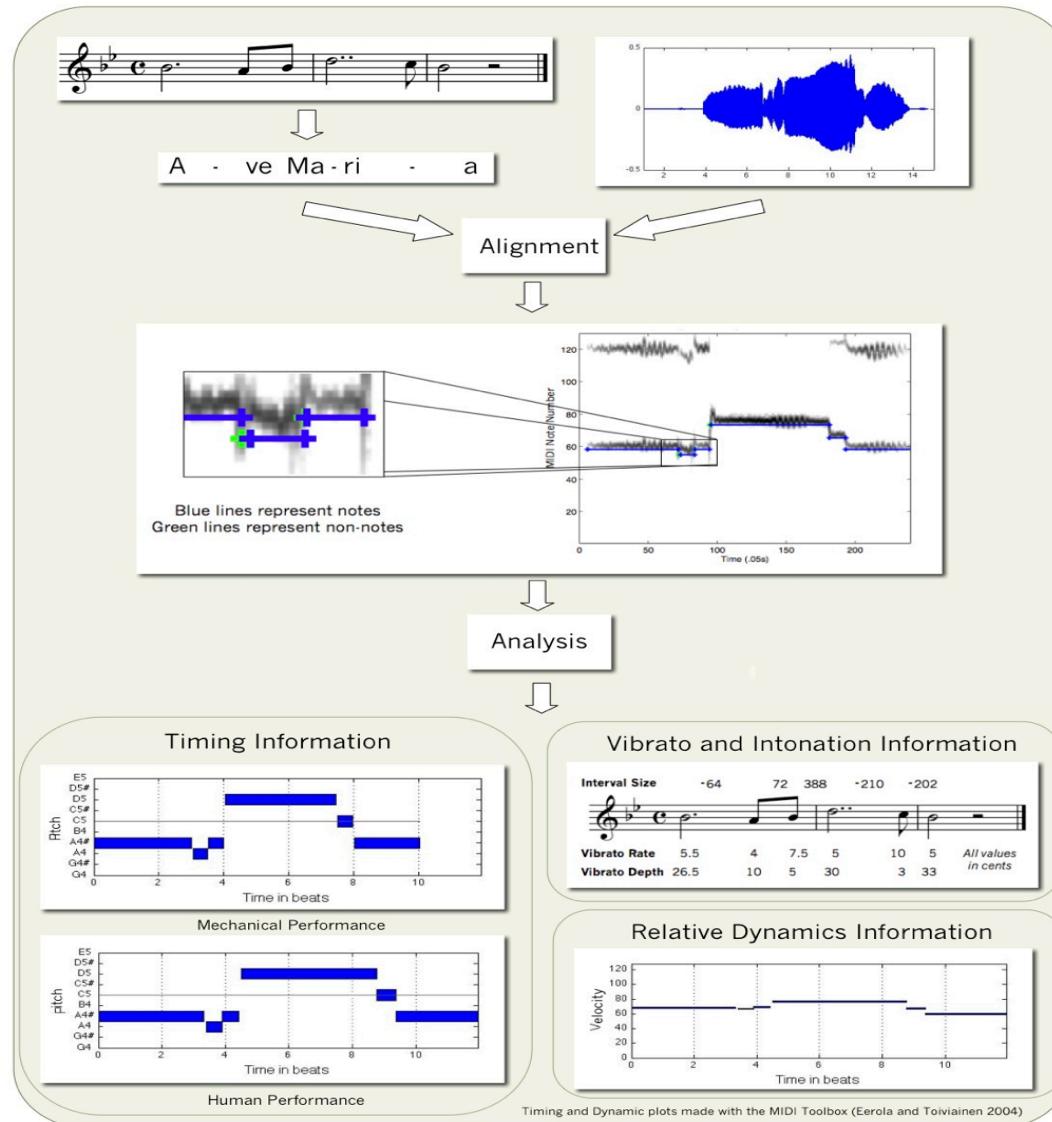
# Older Approaches

- Annotation of note onsets and offsets done manually
- Manual pitch extraction
  - phono-photographic apparatus
  - computer-generated spectrographic representations of the audio
- Automatic fundamental frequency estimation
  - PRAAT (Boersma 1993; 2001)
  - YIN (Kawahara and de Chevigné 2002)



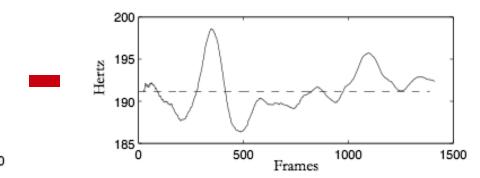
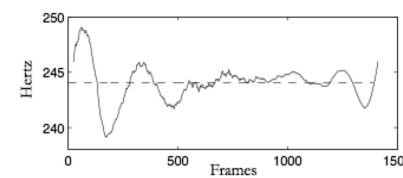
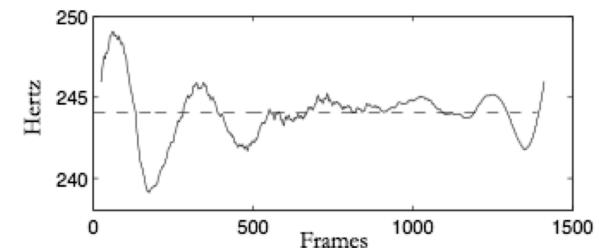
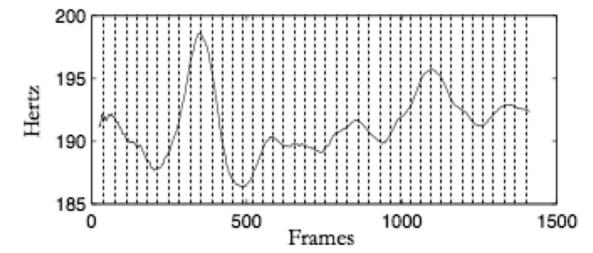
The tonoscope for analyzing the pitch of the tones on a disk phonograph record

# Automatic Music Performance Analysis and Comparison Toolkit (AMPACT)



# $F_o$ and Interval Size Calculations

- The YIN algorithm used for  $F_o$  estimation (de Cheveigné and Kawahara 2002)
- Perceived pitch was calculated by taking a weighted mean based on the  $F_o$ '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



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# Solo Singing

- Subjects
  - 6 undergraduate singers
  - 6 professional singers
- Experimental Material
  - Schubert's "Ave Maria"
    - 3x *a cappella* & 3x accompanied
- Factors Considered
  - adherence to fixed systems (EQT/JI/Pythagorean)
  - *a cappella* vs. accompaniment
  - ascending vs. descending
  - effect of leading tone function
  - effect of training

# Solo Singing: Schubert's Ave Maria

The musical score consists of five staves of music for voice and piano. The vocal part is highlighted with various markings: dashed circles around ascending intervals (A-Bb), solid circles around descending intervals (Bb-A), and boxes around other intervals. The piano part is shown in a separate staff. The vocal line includes lyrics such as "Ave Maria", "Gloria", "Alleluia", "Dominus", "Benedictus", and "Ave Maris". Specific markings include "LT" (leading tone) and "3" indicating a three-note cluster or chord.

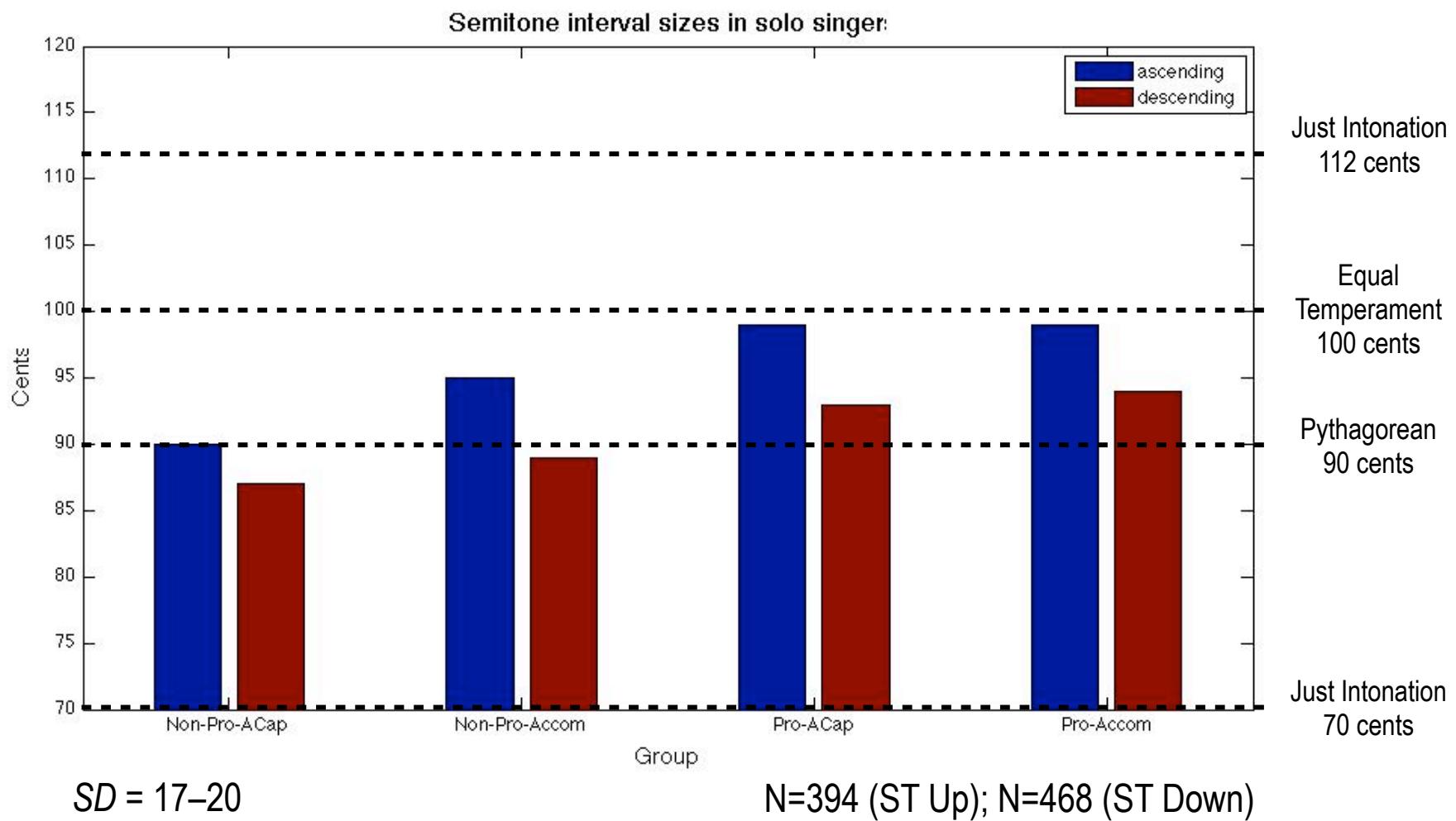
A-Bb ascending interval  
*LT indicates a leading tone*

Bb-A descending interval

Other ascending semitones

Other descending semitones

# Solo Singing: Semitones



# Solo Singing: Schubert's Ave Maria

The musical score consists of six staves of music for a solo voice. The vocal line is continuous, with various intonation markings placed above the notes. These markings include circles and squares of different sizes and dashed or solid outlines, some containing the number '3'. The lyrics are written below the staff. The markings are distributed across the entire vocal range, indicating specific pitch targets or intonation patterns for the singer.

A - ve Ma - ri - a, Gra - ti - a ple na Ma - ri - a gra ti - a

ple - na, Ma - ri - a gra - ti - a ple - na A - ve A - ve Do - mi -

nus, Do - mi - nus te - cum Be - ne - dic - ta tu in mu - li - e - ri - bus et

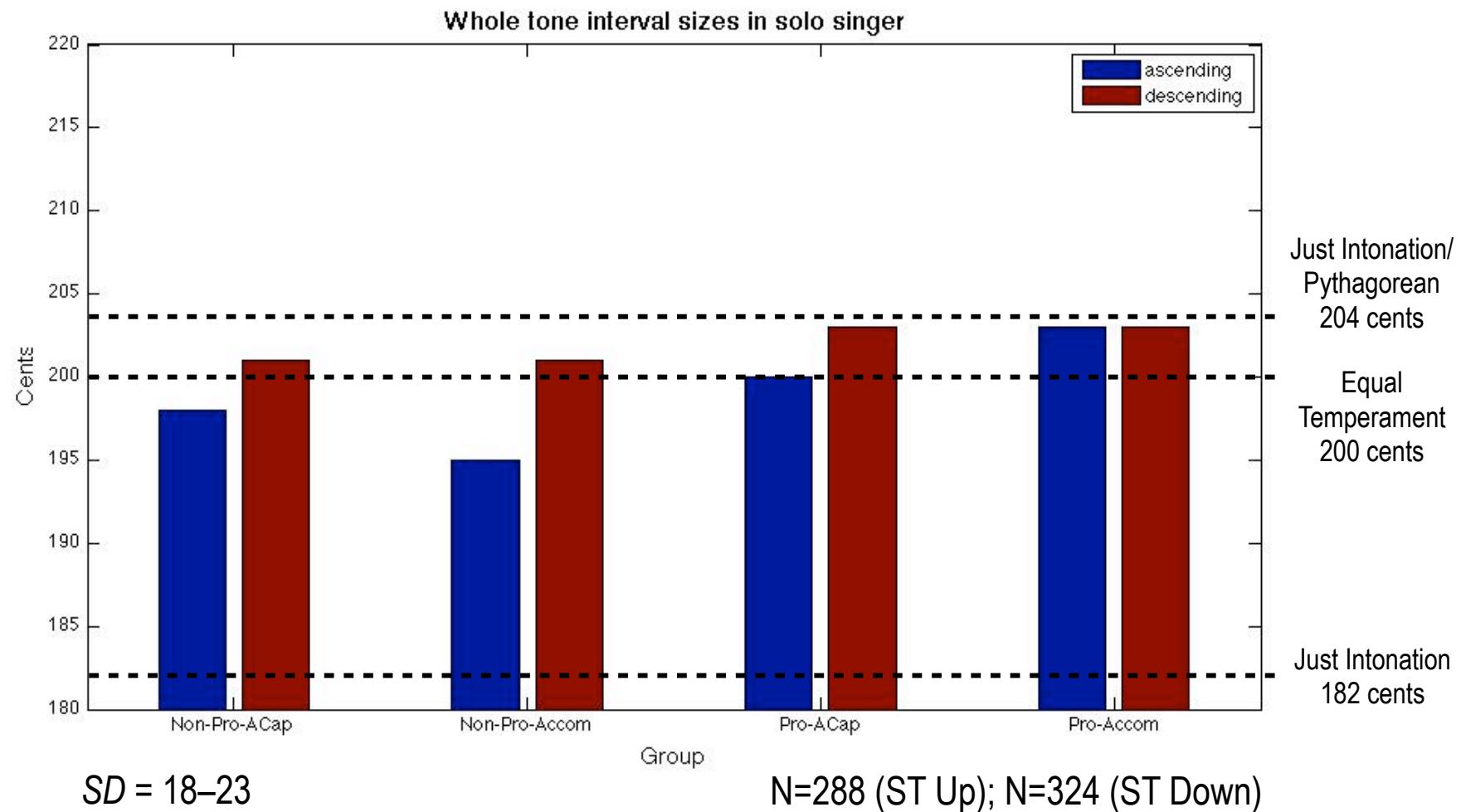
be - ne - di - c - tus, et be - ne - dic - tus fru - c - tus ven - tris, ven - tris

tu - i Je - sus. A - ve - Ma - ri - a!

- Ascending chord tone to non-chord tone whole tone
- Ascending non-chord to chord tone whole tone
- Ascending chord tone to chord tone whole tone

- Descending chord tone to non-chord tone whole tone
- Descending non-chord to chord tone whole tone
- Descending chord tone to chord tone whole tone

# Solo Singing: Whole tones



# Solo Singing: Results

- ACCOMPANIMENT: Non-pro singers' accompanied semitones were 3 cents larger than *a cappella* ones
- DIRECTION: Ascending semitones were 7–8 cents larger on average than descending ones
- LEADING TONES: Non-pro singers tended to compress leading tones, pro singers did not
- EFFECT OF TRAINING
  - Pro singers were more consistent with one another in their intonation than non-professionals
  - Pro singers' semitones were 6 cents larger on average than non-pro singers' semitones

# Two-Part Singing (Pilot)

- Subjects
  - 3 non-professional: amateur singers
  - 3 professionals: possess at least one graduate-level degree in voice performance
- Experimental Material
  - subjects were asked to sing a simple semitone pattern against a recorded version of the lower-line that was detuned in various ways at two pitch heights



# Two-Part Singing (Pilot)

- Factors Considered
  - adherence to fixed systems (EQT/JI/Pythagorean)
  - ascending vs. descending
  - effect of training
  - pitch height
  - tuning of accompaniment
  - vertical interval context

# Two-Part Singing: Exercises

A musical staff with a treble clef and a bass clef. It consists of four measures divided by vertical bar lines. The top line has four notes: a quarter note, a eighth note, a eighth note, and a quarter note. The bottom line has four notes: a eighth note, a eighth note, a eighth note, and a quarter note. Red text labels are placed below each measure: 'm3' for the first, 'm6' for the second, 'P5' for the third, and 'm6' for the fourth.

A musical staff with a treble clef and a bass clef. It consists of four measures divided by vertical bar lines. The top line has four notes: a quarter note, a eighth note, a eighth note, and a quarter note. The bottom line has four notes: a eighth note, a eighth note, a eighth note, and a quarter note. Red text labels are placed below each measure: 'm3' for the first, 'm3' for the second, 'P5' for the third, and 'm3' for the fourth.

A musical staff with a treble clef and a bass clef. It consists of four measures divided by vertical bar lines. The top line has four notes: a quarter note, a eighth note, a eighth note, and a quarter note. The bottom line has four notes: a eighth note, a eighth note, a eighth note, and a quarter note. Red text labels are placed below each measure: 'm3' for the first, 'P5' for the second, 'm3' for the third, and 'P8' for the fourth.

A musical staff with a treble clef and a bass clef. It consists of three measures divided by vertical bar lines. The top line has three notes: a quarter note, a eighth note, and a eighth note. The bottom line has three notes: a eighth note, a eighth note, and a eighth note. Red text labels are placed below each measure: 'm3' for the first, 'TT' for the second, and 'P5' for the third.

# Two-Part Singing: Retunings

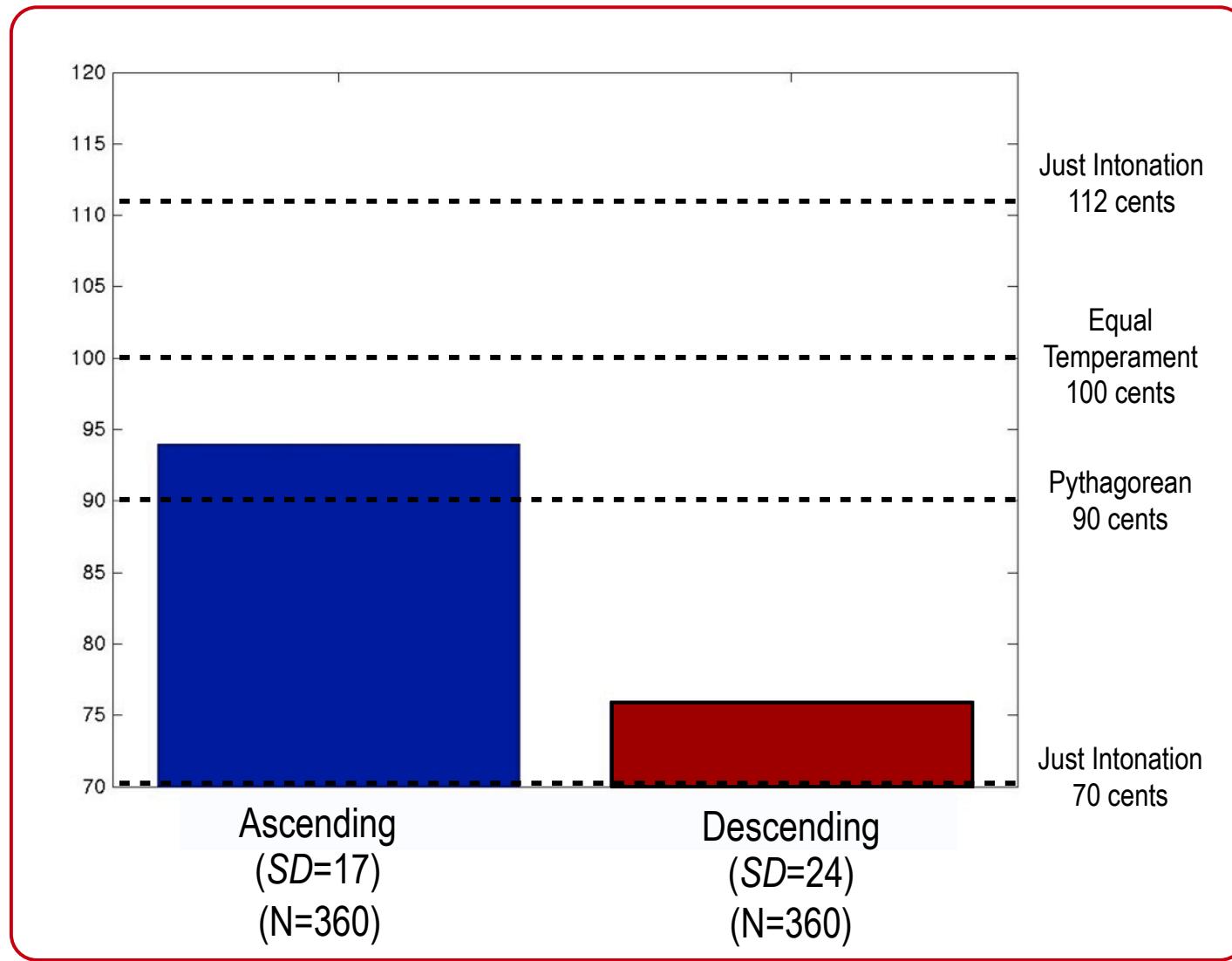
**Just Intonation**

	D	G	D		
1	-2	-4	-2		
2	D	D	F		
	-2	-2	14		
3	D	Bb	F		
	-2	12	14		
4	F	D	A		
	14	-2	0		
5	F	G	A		
	14	18	0		
6	F	G	D		
	14	18	20		
7	F	Eb	F		
	-8	-12	-8		
8	A	G	F		
	0	-4	-8		
9	A	D	F		
	0	-2	-8		
10	F	Eb	D	C	F
	14	10	-2	16	14
11	F	G	C	D	
	-8	-4	-6	-2	
12	F	Bb	F		
	-8	-10	-8		
13	D	G	A	A	
	20	18	22	22	
14	G	F	E	F	
	-4	-8	2	-8	
15	G	F	Eb	F	
	-4	-8	-12	-8	

**Modified Just Intonation**

	D	G	D		
	-2	18	20		
	D	D	F		
	-2	-25	-8		
	D	Bb	F		
	-2	-10	-8		
	F	D	A		
	14	20	22		
	F	G	A		
	-8	-4	-23		
	F	G	D		
	-8	-27	-25		
	F	Eb	F		
	14	33	14		
	A	G	F		
	0	18	37		
	A	D	F		
	22	20	14		
	F	Eb	D	C	F
	-8	-12	-2	-6	-8
	F	G	C	D	
	14	18	16	20	
	F	Bb	F		
	14	12	14		
	D	G	A	A	
		-27	-23	-23	
	G	F	E	F	
	18	14	2	14	
	G	F	Eb	F	
	18	14	10	14	

# Two-Part Singing: Semitones



# Two-Part Singing: Results

- DIRECTION: Ascending semitones were on average 21 cents larger on average than descending semitones
- EFFECT OF TRAINING: Non-pros' semitones were on average 17 cents on average smaller than pros' semitones
- PITCH HEIGHT: Semitones in exercises starting on G were 6 cents larger on average than the semitones than exercises starting on Bb
- TUNING: *not significant*
- VERTICAL INTERVAL CONTEXT: Semitones sung a perfect octave above the lower voice were 7 cents larger on average than those sung above other intervals
  - *there were no significant differences for other intervals*

# Three- and Four-Part Singing

- 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"

# Three- and Four-Part Singing

- Factors Considered
  - Melodic Intervals
    - adherence to fixed systems (EQT/JI/Pythagorean)
    - ascending vs. descending
    - semitone spelling
    - vertical interval context
  - Vertical Intervals
    - adherence to fixed systems (EQT/JI/Pythagorean)

# Semitone Exercises (Wild)

Soprano (S) 1 2 3 4 5 6

Alto (A)

Tenor (T)

Bass (B)

Soprano (S) 7 8 9 10 11 12

Alto (A)

Tenor (T)

Bass (B)

Soprano (S) 13 14 15 16 17 18

Alto (A)

Tenor (T)

Bass (B)

Soprano (S) 19 20 21 22 23

Alto (A)

Tenor (T)

Bass (B)

Soprano (S) 24 25 26 27

Alto (A)

Tenor (T)

Bass (B)

	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)

S 1 2 3 4 5 6

A

T

B

S 7 8 9 10 11 12

A

T

B

S 13 14 15 16 17 18

A

T

B

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

# Benedetti Progression



# Praetorius - Semitones/Whole Tones

Soprano (S), Alto (A), Tenor (T), Bass (B) vocal parts.

Measure 1: Soprano has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines. The final note is circled with a solid line and labeled "LT".

Measure 2: Alto has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines.

Measure 3: Tenor has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines.

Measure 4: Bass has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines.

Measure 7: Soprano has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines. The final note is circled with a solid line and labeled "LT".

Measure 13: Soprano has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines. The final note is circled with a solid line and labeled "LT".

Alto, Tenor, and Bass parts are mostly blank in these measures.

Soprano (S), Alto (A), Tenor (T), Bass (B) vocal parts.

Measure 1: Soprano has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines.

Measure 2: Alto has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines.

Measure 3: Tenor has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines.

Measure 4: Bass has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines.

Measure 7: Soprano has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines.

Measure 8: Alto has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines.

Measure 9: Tenor has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines.

Measure 10: Bass has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines.

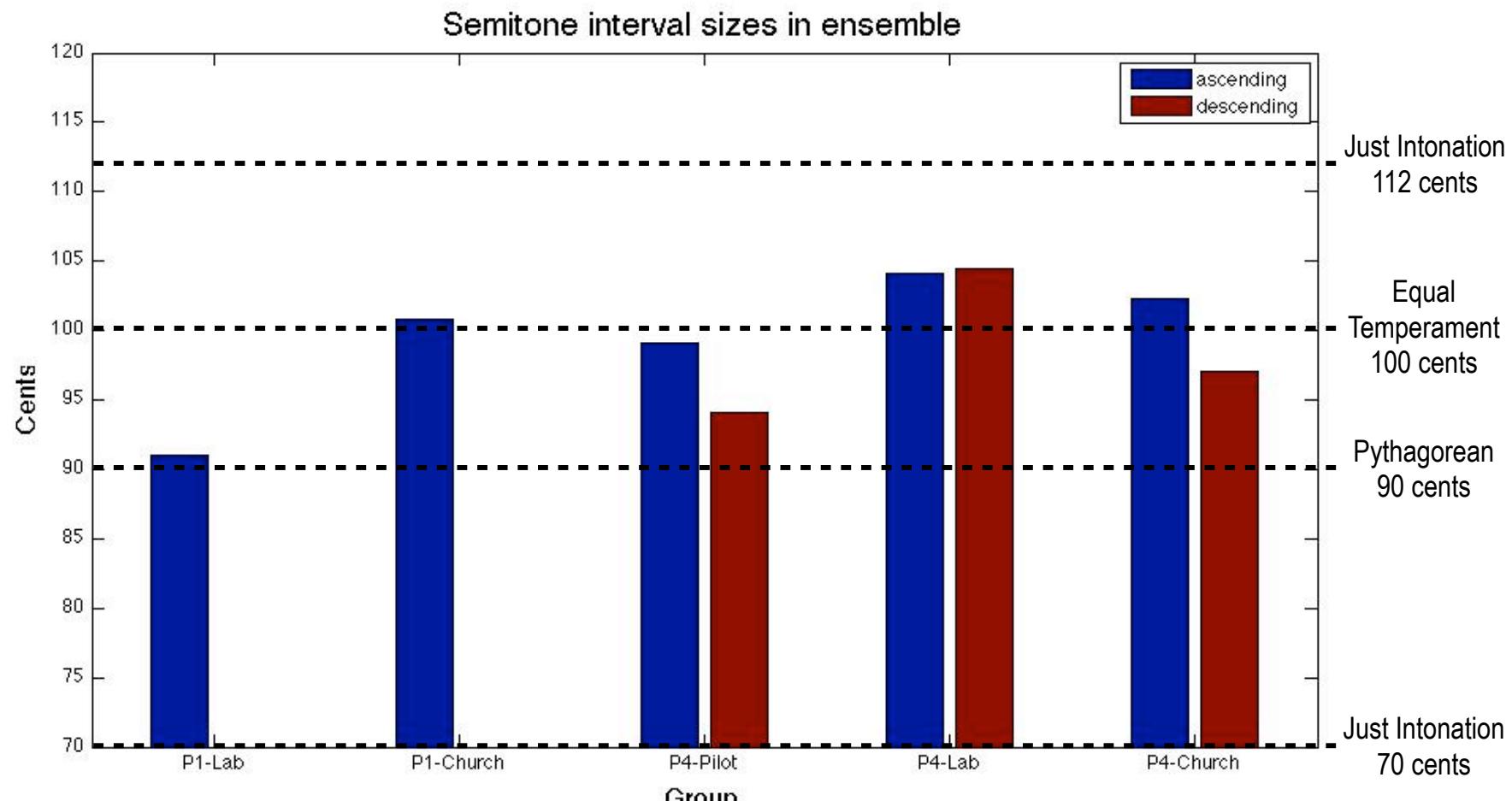
Measure 13: Soprano has a dotted eighth note followed by a sixteenth note. The next two notes are circled with dashed lines.

Alto, Tenor, and Bass parts are mostly blank in these measures.

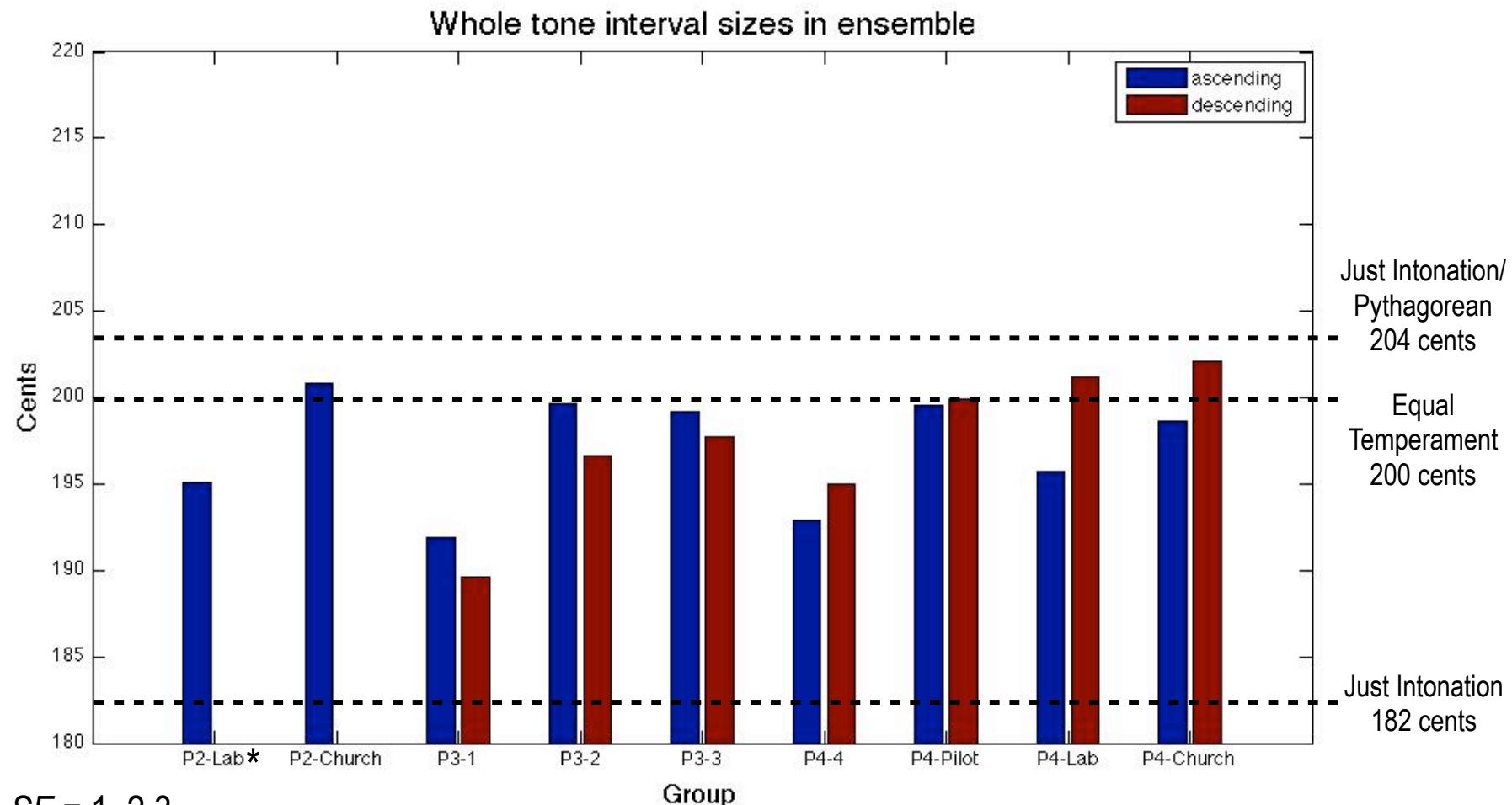
# Praetorius - Vertical Intervals

The image displays three staves of musical notation for four voices: Soprano (S), Alto (A), Tenor (T), and Bass (B). The music is in common time, with a key signature of one flat. The notation is divided into measures by vertical bar lines. Horizontal dashed boxes highlight specific vertical intervals between voices at measure 7, measure 13, and measure 18. These intervals are labeled with Roman numerals: V vi and V I. The voices are represented as follows: Soprano (S) in soprano clef, Alto (A) in alto clef, Tenor (T) in tenor clef, and Bass (B) in bass clef.

# Three- and Four-Part: Semitones



# Three- and Four-Part: Whole Tones



# Three- and Four-Part: Results

- MELODIC INTERVALS
  - DIRECTION: Where there was a significant effect that the ascending intervals were larger than the descending intervals, mirroring the solo experiment
  - SEMITONE SPELLING: There was a significant difference in the Lab ensemble between diatonic/chromatic
  - VERTICAL CONTEXT: No significant effects
- VERTICAL INTERVALS
  - Closer to Just Intonation tuning in cadential contexts

# Summary

	Semitones			Whole Tones		
	Solo	2-part	3/4 part	Solo	2-part	3/4-part
sharper than EQT (Schoen 1922)	✗	✗	✗	✗	N/A	✗
larger ascending intervals (Schoen 1922)	✓	✓	✓	✗	N/A	-
semitones smaller than EQT (Vurma and Ross 2006)	✓	✓	✓	N/A	N/A	N/A
no impact of accompaniment detuning (Vurma 2010)	✓ pros	✓	N/A	N/A	N/A	N/A
effect of training	✓	✓	N/A	✗	N/A	N/A
harmonic or vertical context	✓ non-pros	✓ octaves	✗	✗	N/A	✗

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# Conclusions

- This paper has presented the results for three empirical studies of vocal intonation (solo, 2-part, and 3-/4-part)
- A number of the findings from earlier studies have been upheld
  - including the observation that singers do not conform to an idealized system
- The context in which intervals occur may systematically effect their tuning
  - but this requires more investigation
- It is still an open question as to the best way to analyze vertical intonation tendencies

# Acknowledgements



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# Thank you!

Slides available at [www.devaney.ca](http://www.devaney.ca)

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