

# Empirically Evaluating Vocal Intonation

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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 the results from 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 Solo Intonation

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# Prior Work on Intonation

- Schoen (1922) studied 5 accompanied professional singers
  - larger than equal temperament
  - larger ascending intervals than descending intervals
- 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

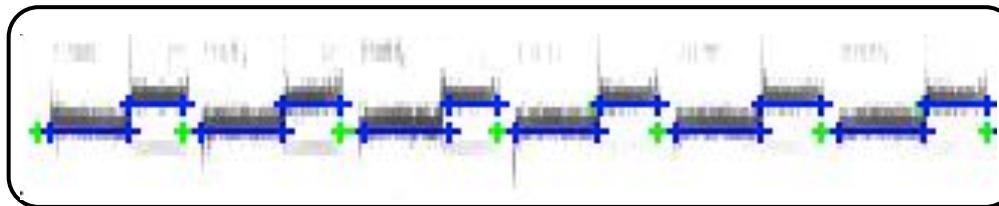
## Extracting Intonation Data

Empirical Evaluation of Solo and Ensemble Singing

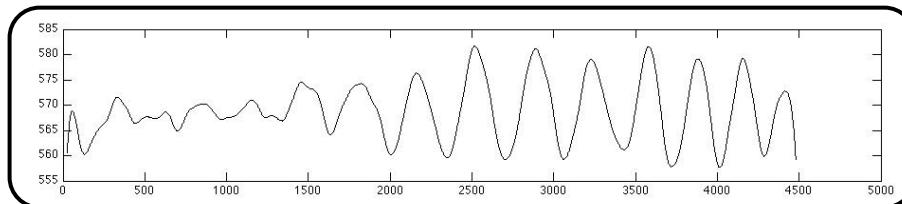
Conclusions

# Extracting Performance Data

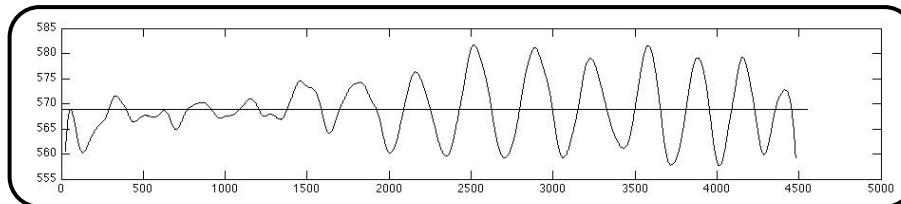
Identify Note Onsets and Offsets



Fundamental Frequency (Fo) Estimation



Perceived Pitch



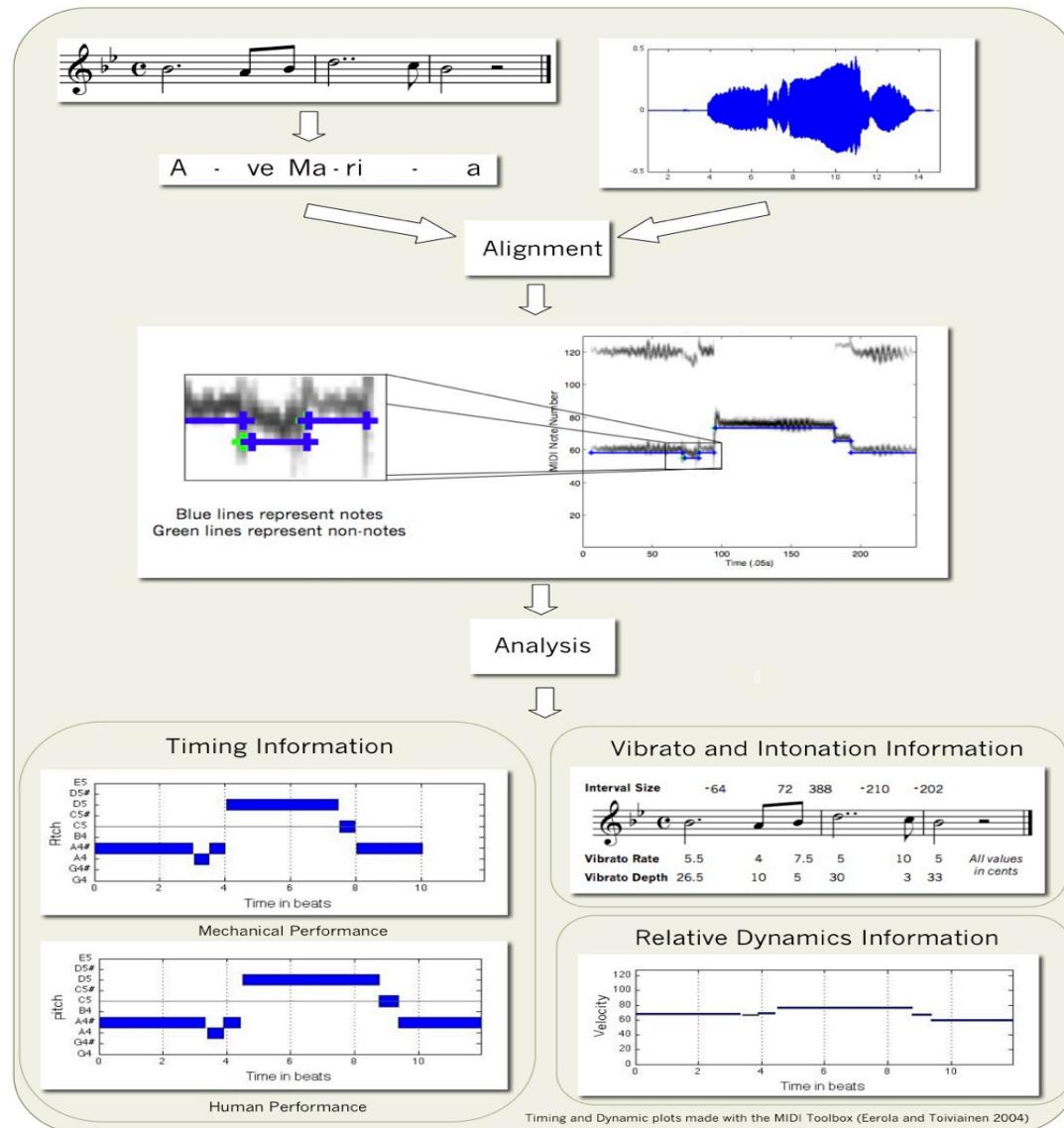
# Older Approaches

- 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.org)



MIDI-Audio Alignment  
(Devaney, Mandel and Ellis 2009)

F<sub>0</sub> estimation  
(de Cheveigné and Kawahara 2002)

Perceived Pitch estimation  
(Gockel et al. 2001)

Loudness estimation  
(Glasberg and Moore 2002)

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# Solo Singing

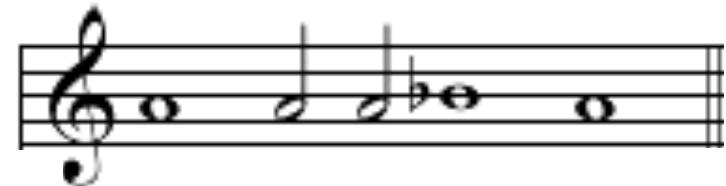
- Subjects
  - 6 undergraduate singers
  - 6 professional singers
- Experimental Material
  - Schubert's "Ave Maria"
  - 3x *a cappella* & 3x accompanied

# Solo Singing: Factors

- TUNING SYSTEMS: No strict adherence, on average smaller than equal temperament (more so for semitones than whole tones)
- 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
    - Equal-temperament
    - Just Intonation
    - Just Intonation + Syntonic Comma



# Two-Part Singing: Exercises

A musical staff with two parts. The top part (soprano) has notes: A, G, F, E. The bottom part (bass) has notes: D, C, B, A. The staff is divided into four measures by vertical bar lines. Red text labels are placed below each measure: m3, m6, P5, m6.

A musical staff with two parts. The top part (soprano) has notes: A, G, F, E. The bottom part (bass) has notes: D, C, B, A. The staff is divided into four measures by vertical bar lines. Red text labels are placed below each measure: m3, m3, P5, m3.

A musical staff with two parts. The top part (soprano) has notes: A, G, F, E. The bottom part (bass) has notes: D, C, B, A. The staff is divided into four measures by vertical bar lines. Red text labels are placed below each measure: m3, P5, m3, P8.

A musical staff with two parts. The top part (soprano) has notes: A, G, F, E. The bottom part (bass) has notes: D, C, B, A. The staff is divided into three measures by vertical bar lines. Red text labels are placed below each measure: m3, TT, P5.

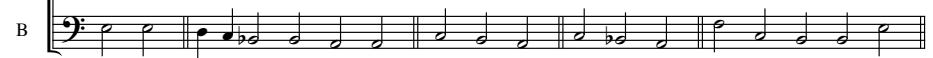
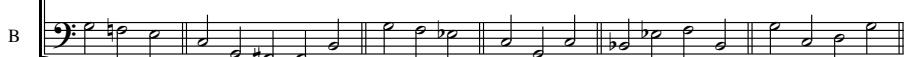
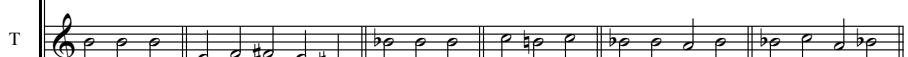
# Two-Part Singing: Factors

- TUNINGS SYSTEM: No strict adherence, on average smaller than equal temperament
- 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 in 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"

# 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)

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



# Three- and Four-Part: Factors

- MELODIC INTERVALS
  - TUNINGS SYSTEM: No strict adherence, on average smaller than equal temperament
  - 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
  - On average, closest to equal temperament
  - Closer to Just Intonation tuning in cadential contexts

# Summary

	Semitones			Whole Tones		
	Solo	2-part	3/4 part	Solo	2-part	3/4-part
larger 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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- 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



C I R  
M M T   Centre for Interdisciplinary Research  
in Music Media and Technology



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sciences humaines du Canada

Canada

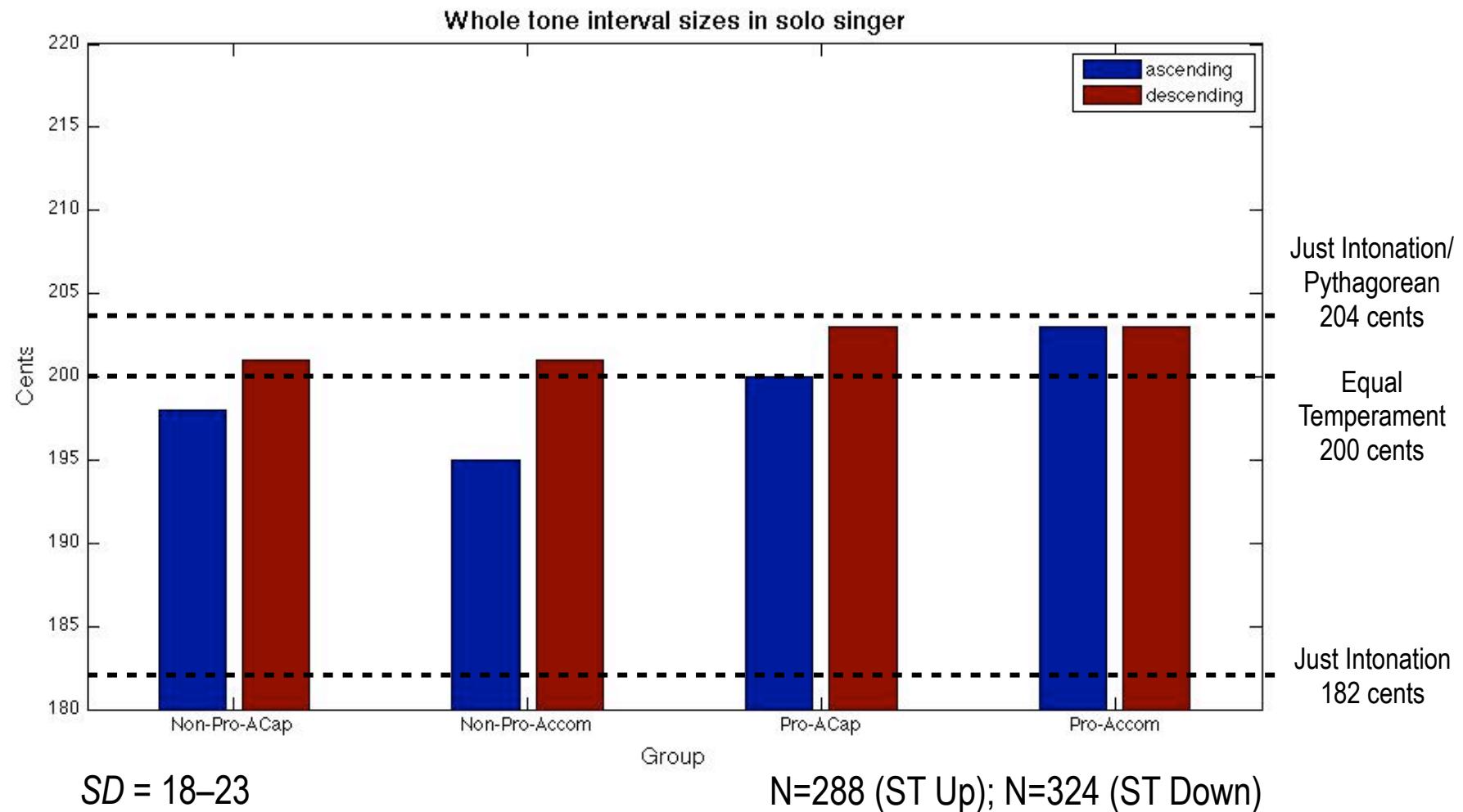
# Thank you!

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

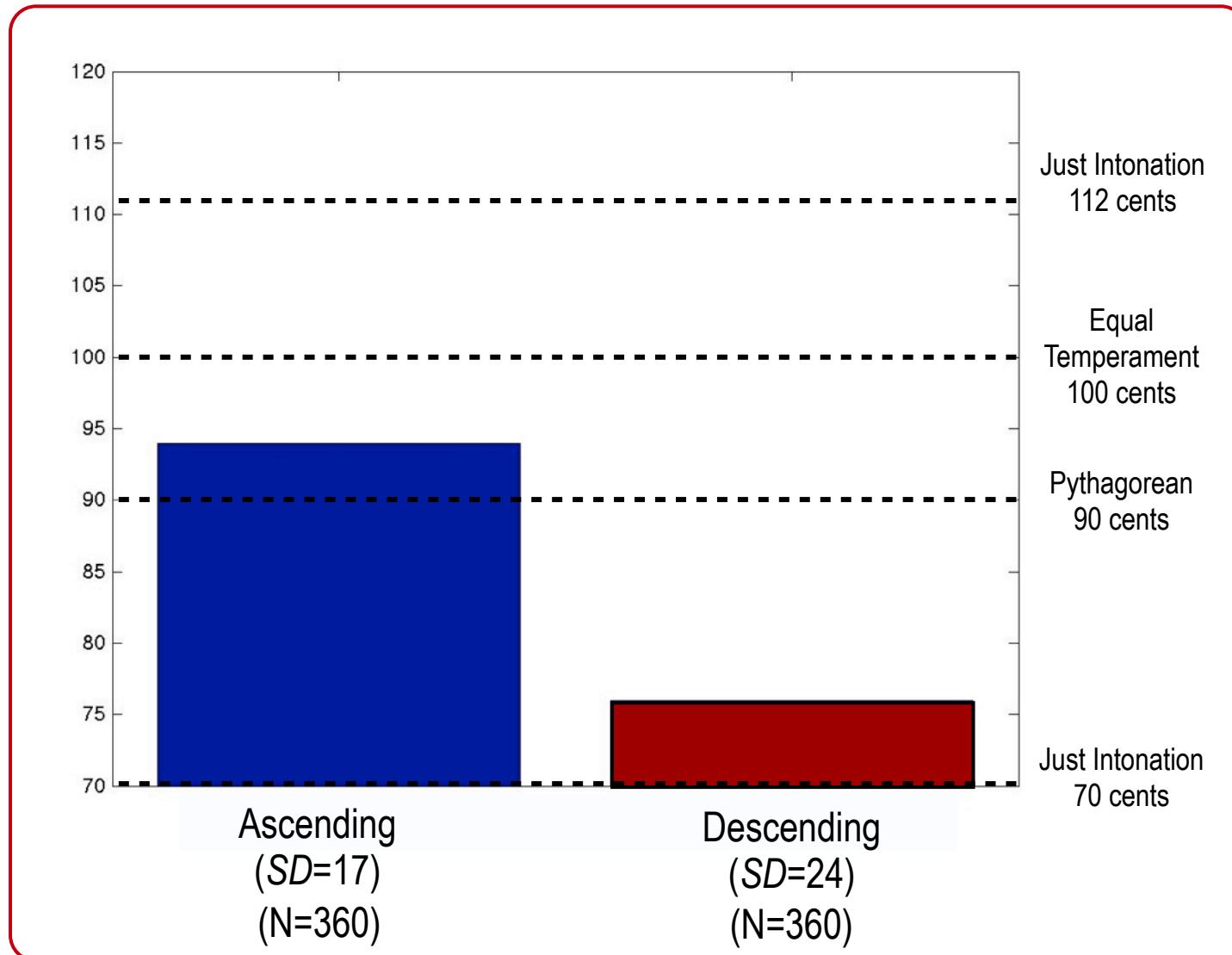
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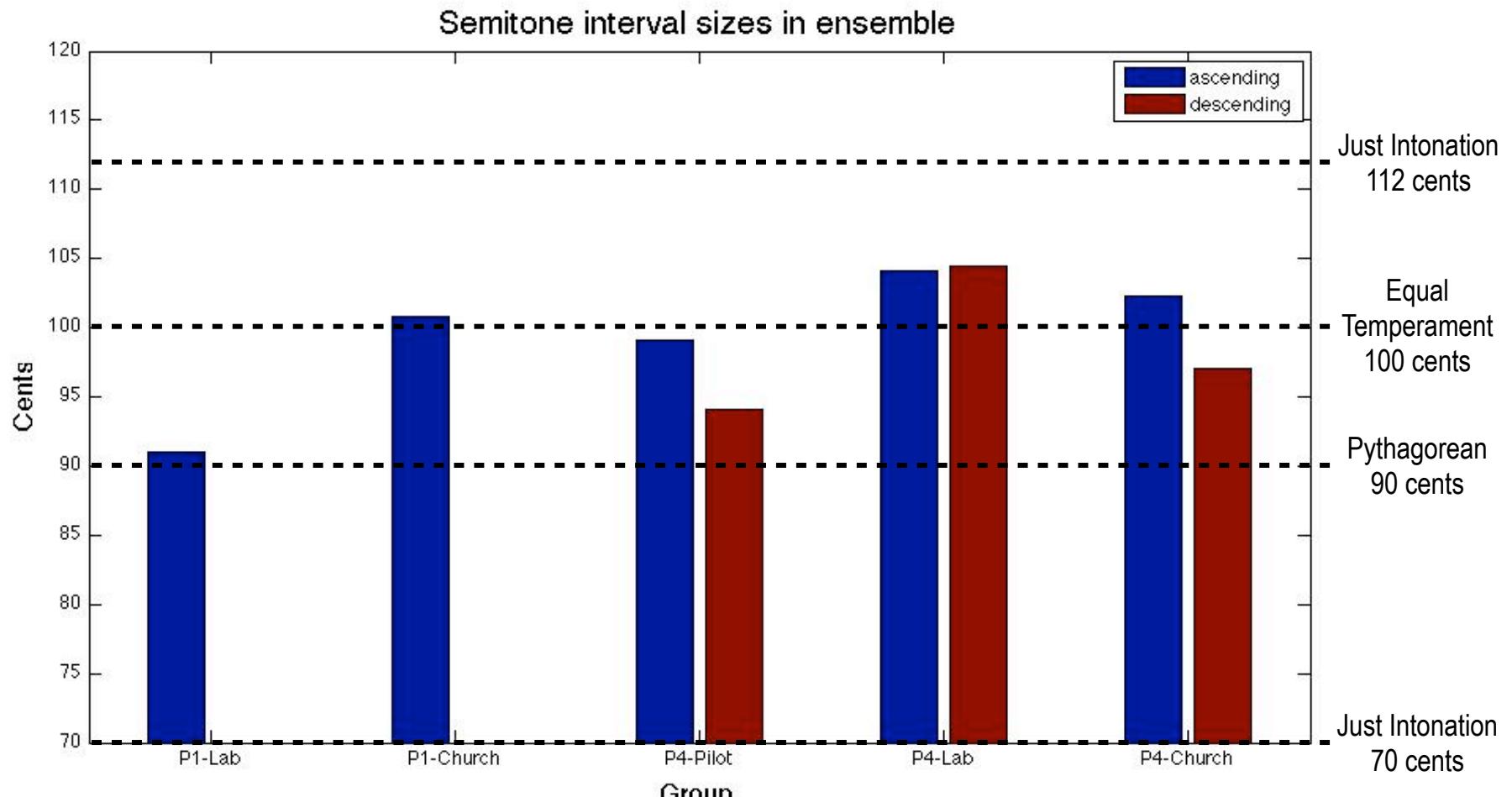
# Solo Singing: Whole tones



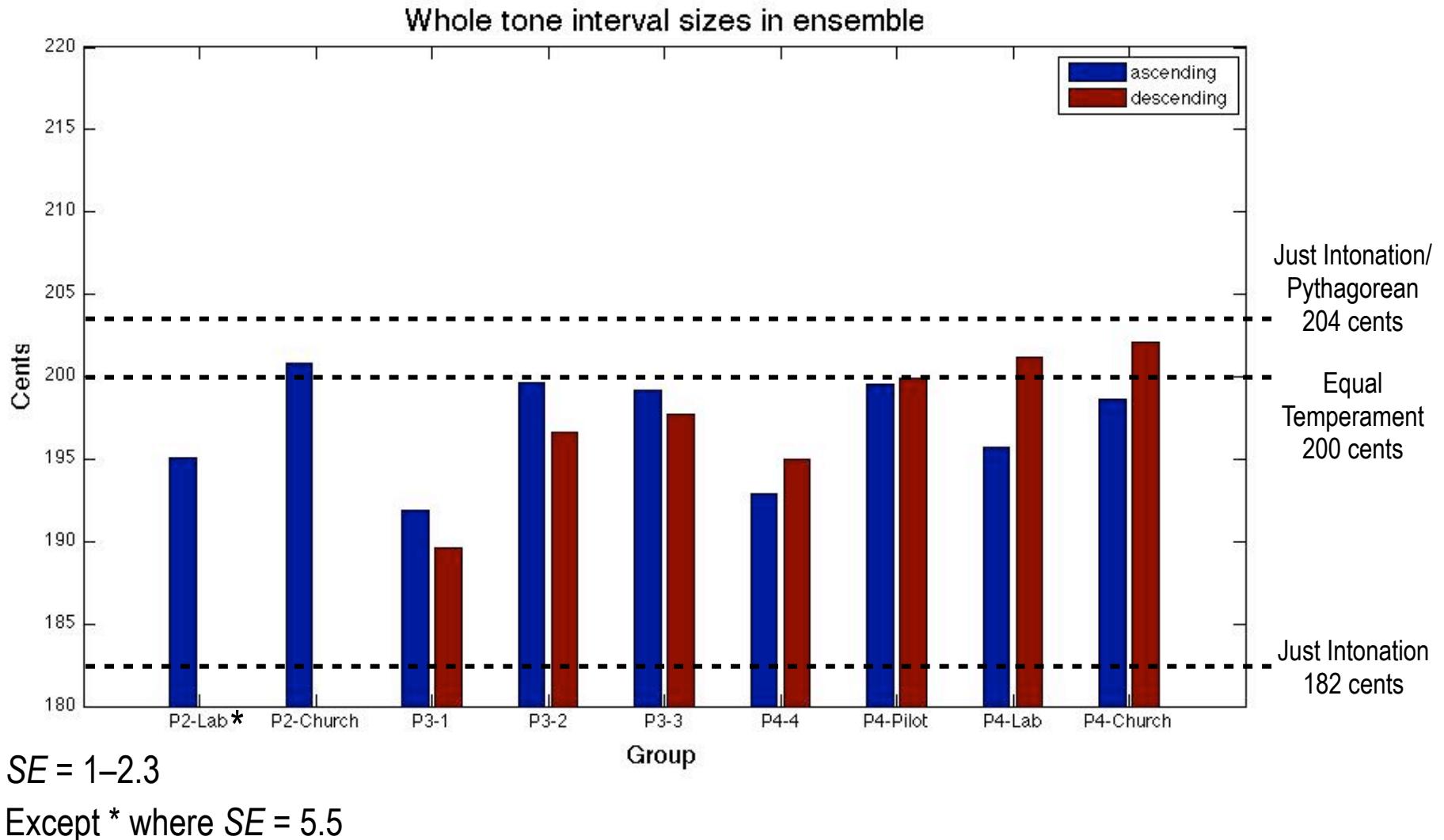
# Two-Part Singing: Semitones



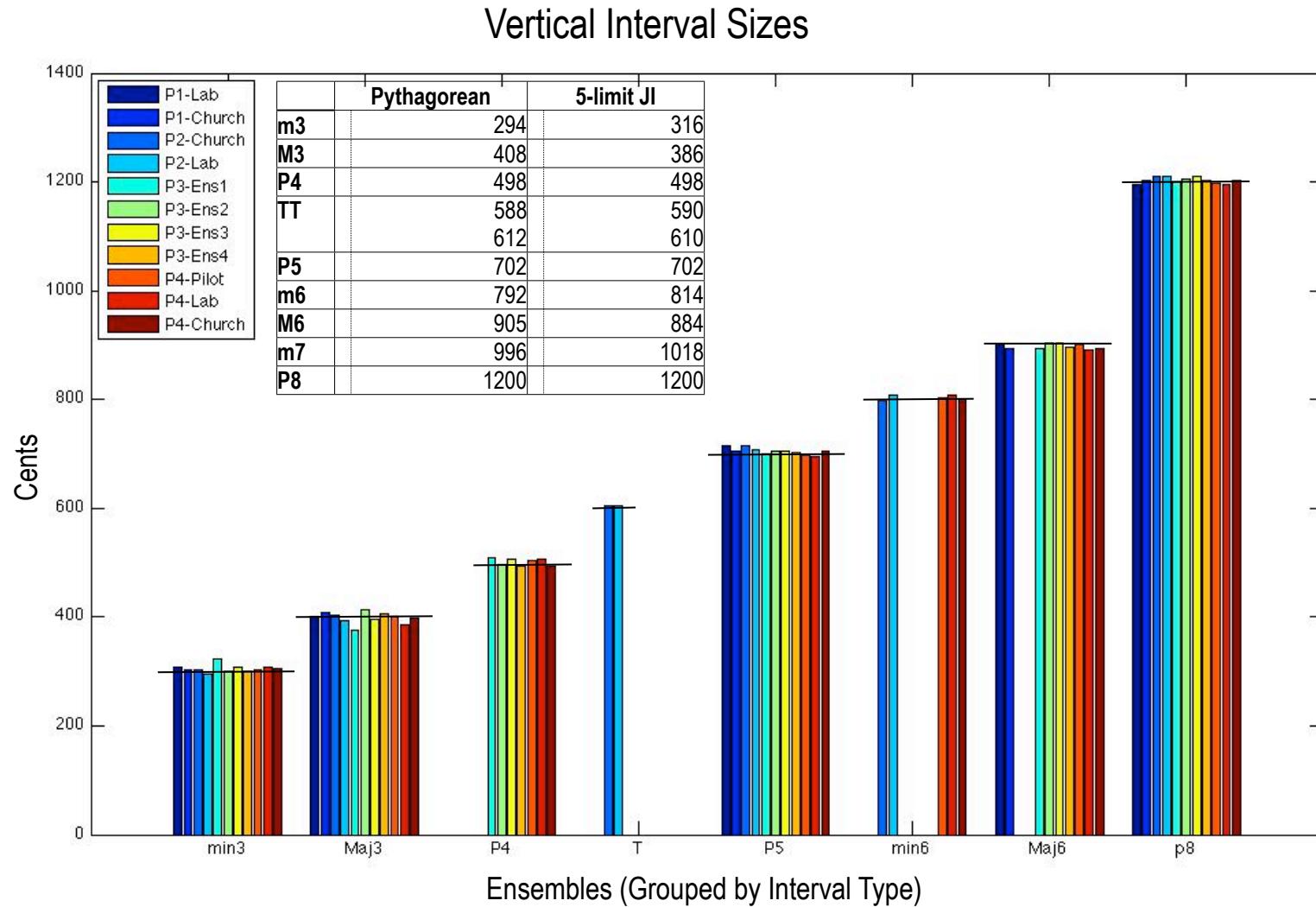
# Three- and Four-Part: Semitones



# Three- and Four-Part: Whole Tones



# Vertical Interval Size



# Solo Singing: Schubert's Ave Maria

The musical score consists of six staves of music in G clef, common time, and A major. The lyrics are written below each staff. Annotations include dashed circles around specific notes, solid circles around other notes, and boxes around groups of notes. Some annotations contain the letter 'LT' (Leading Tone) or the number '3'. The lyrics are:

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 - - - etus, et be - ne - dic - tus fru - ctus ven - tris, ven - tris  
tu - i Je - sus, A - ve Ma - ri - - - a!

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

Bb-A descending interval

Other ascending semitones

Other descending semitones

# Solo Singing: Schubert's Ave Maria

The musical score consists of six staves of music for soprano voice and piano. Annotations are used to analyze the intonation patterns:

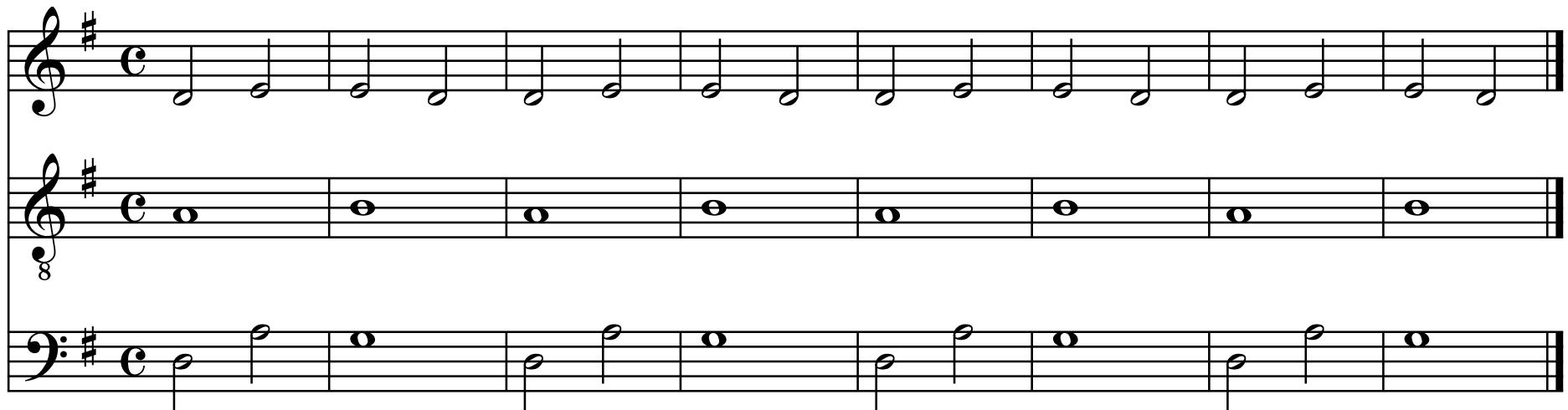
- O**: Ascending chord tone to non-chord tone whole tone
- : Ascending non-chord to chord tone whole tone
- : Ascending chord tone to chord tone whole tone
- : Descending chord tone to non-chord tone whole tone
- : Descending non-chord to chord tone whole tone
- : Descending chord tone to chord tone whole tone

Annotations are placed above the vocal line, corresponding to specific notes and chords. For example, in measure 1, there are three annotations: one circle (O) over a note, one square (□) over a note, and one circle (O) over a note. In measure 4, there are two circles (O) over notes. In measure 6, there is a circle (O) over a note and a square (□) over a note. In measure 8, there is a circle (O) over a note and a square (□) over a note. In measure 10, there is a circle (O) over a note and a square (□) over a note.

- O**: 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

# Benedetti Progression



# Praetorius - Semitones/Whole Tones

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

Measure 1: Circles highlight notes at the beginning of the measure. Dashed circles highlight notes in the first two measures. A circled 'LT' is at the end of the first measure.

Measure 7: Circles highlight notes in the first two measures. Dashed circles highlight notes in the first three measures. A circled 'LT' is at the end of the first measure.

Measure 13: Circles highlight notes in the first two measures. Dashed circles highlight notes in the first three measures. Circles highlight notes in the first four measures. A circled 'LT' is at the end of the first measure.

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

Measure 1: Boxed groups highlight notes in the first two measures. Dashed boxes highlight notes in the first three measures.

Measure 7: Boxed groups highlight notes in the first two measures. Dashed boxes highlight notes in the first three measures.

Measure 13: Boxed groups highlight notes in the first two measures. Dashed boxes highlight notes in the first three measures.

# Praetorius - Vertical Intervals

Musical score for Praetorius' Vertical Intervals, showing three systems of music for four voices (Soprano, Alto, Tenor, Bass). The score is in common time and includes measure numbers 7, 13, and 18.

The vocal parts are:

- Soprano (S)
- Alto (A)
- Tenor (T)
- Bass (B)

Harmonic analysis labels are placed below the bass staff:

- Measure 7: V vi
- Measure 13: V vi
- Measure 18: V I
- Measure 19: V I