How do singers tune?

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Introduction

Prior Work on Intonation

Intonation Experiments

Conclusions

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Intonation Experiments

Conclusions

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- Research questions
  - How consistently do singers tune in performance
    - e.g., ascending vs. descending, *a cappella* vs. accompanied, replicating interval sizes across performances
  - How does their tuning relate to idealized tuning systems, such as Just Intonation, Pythagorean tuning, and equal temperament?

- Experiments
  - Solo: six non-professional and professional singers performed Schubert's "Ave Maria" both a cappella and with accompaniment
  - Ensemble: three different SATB quartets performed a set of exercises and Praetorius' "Lo how a rose e'er blooming"

- Interval size data was extracted automatically from the recordings for
  - Melodic intervals: semitone, whole tone
  - Vertical intervals: m3, M3, P4, TT, P5, m6, M6, m7, and P8

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- Sundberg, Prame, and Iwarsson (1995) studied professional singers' ability to replicate pitches when singing with accompaniment and found that the average difference between repeated notes was 8 cents
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- Howard (2007) studied two a cappella SATB quartets and found that the ensembles used non-equal temperament with a tendency toward, though not full compliance with Just-Intonation
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Intonation Experiments

- Solo Intonation Experiment
  - 6 undergraduate vocal majors and 6 professional singers
  - Franz Schubert's "Ave Maria"
    - sung *a cappella* and with accompaniment
- Ensemble Experiment
  - 1 semi-professional quartet (pilot) and 2 professional quartets (lab and church)
  - 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"

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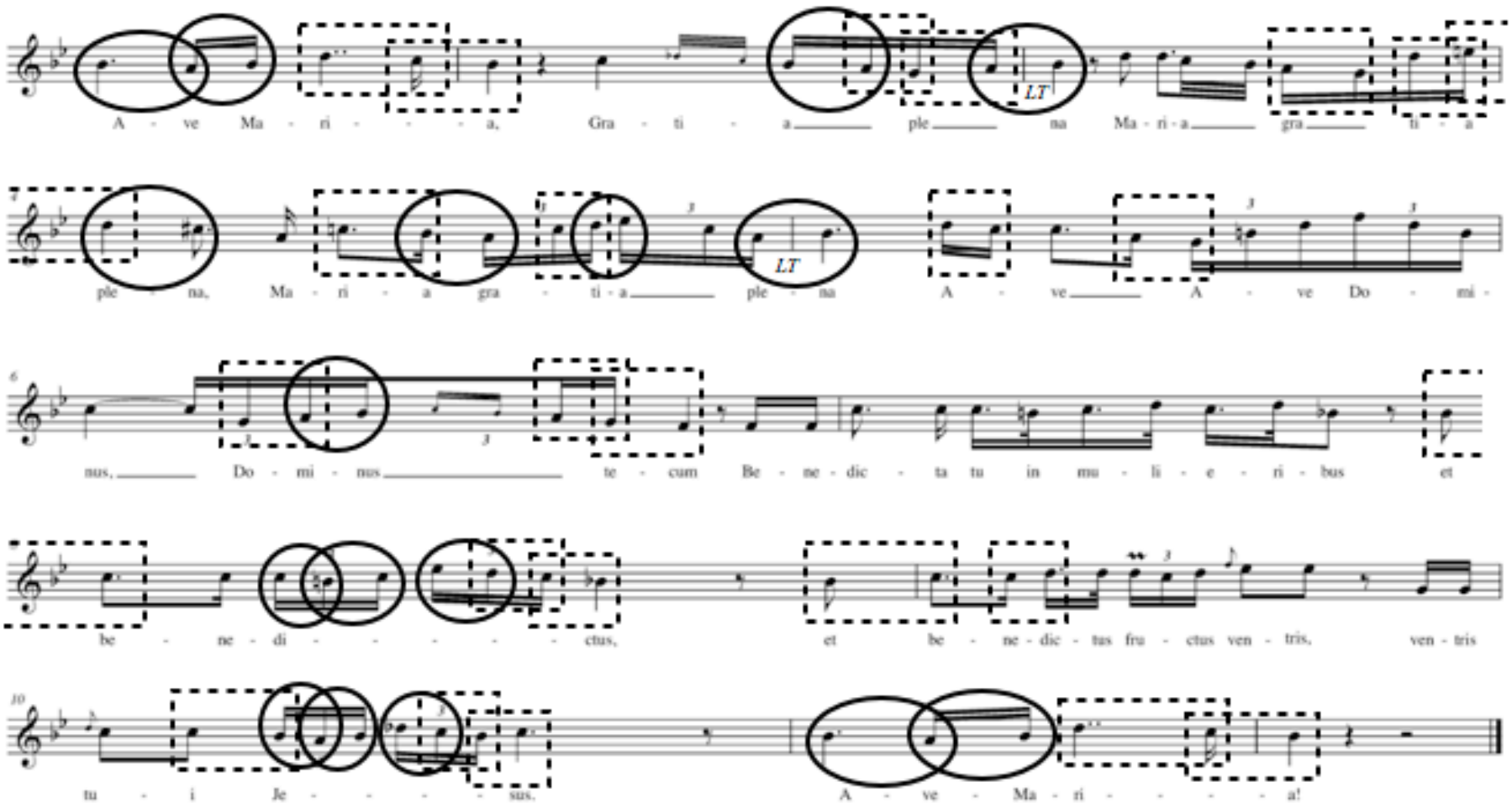

"Ave Maria" (Franz Schubert)

Semitones Analyzed Whole tones analyzed

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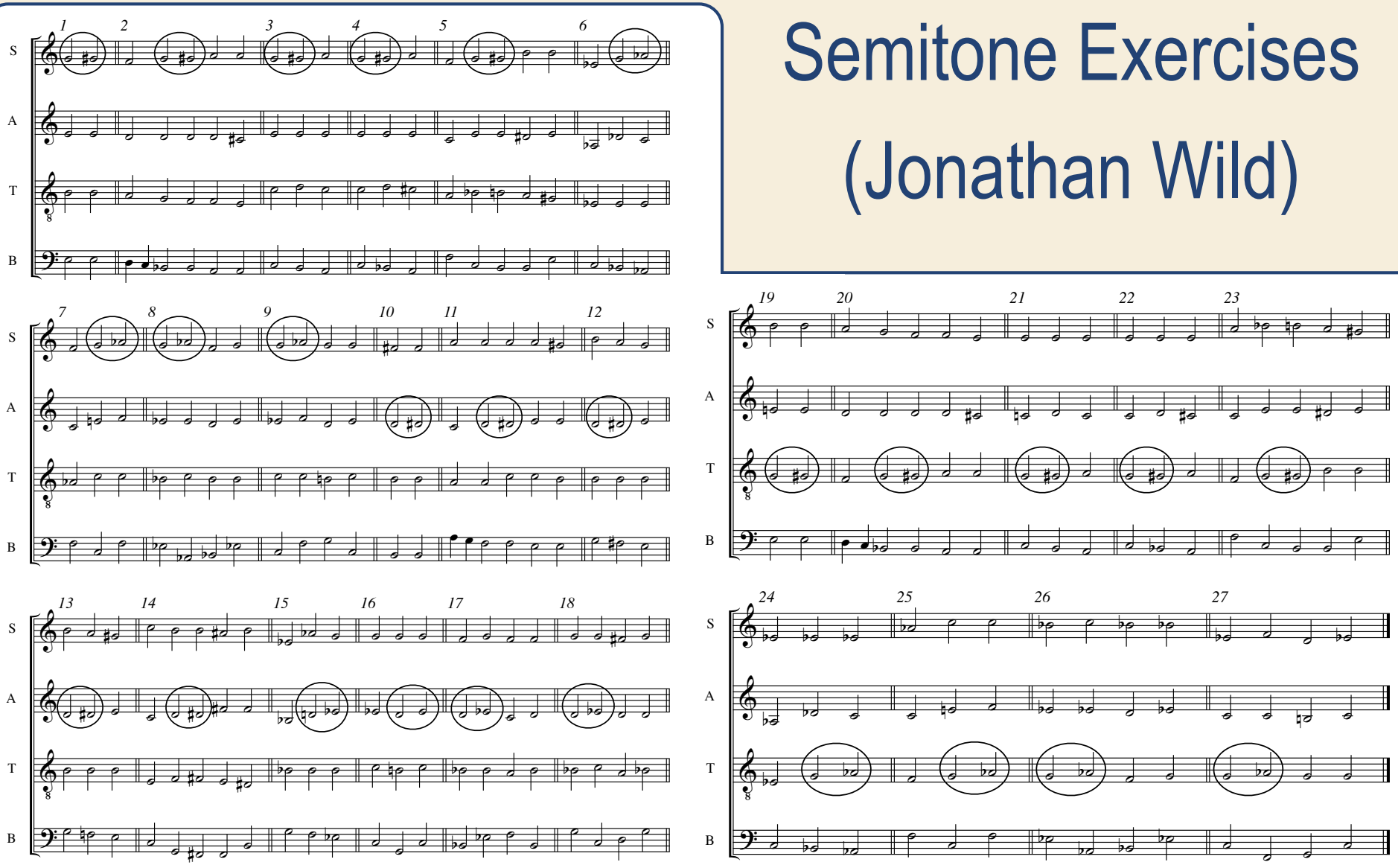
Intonation Experiments

Semitone Exercises (Jonathan Wild)



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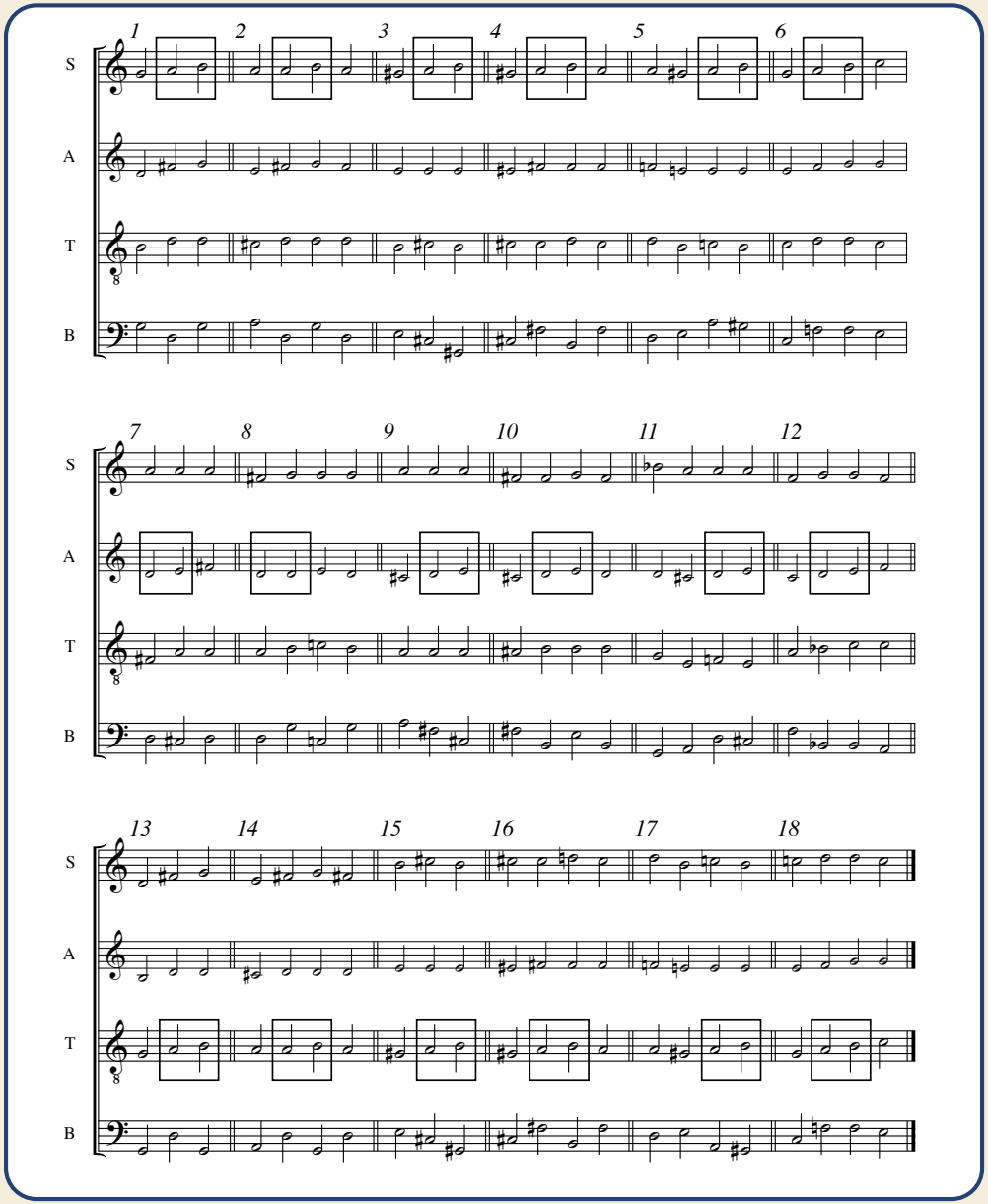

Whole Tone Exercises (Peter Schubert)

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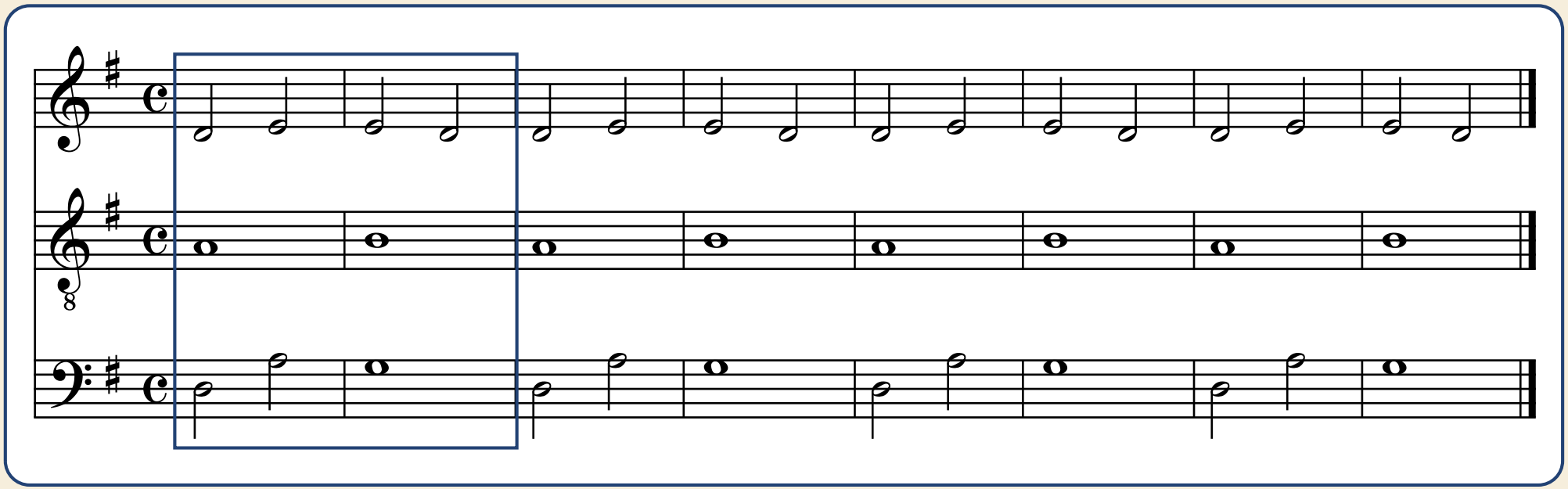

Repeated Progression

(Giambattista Benedetti)

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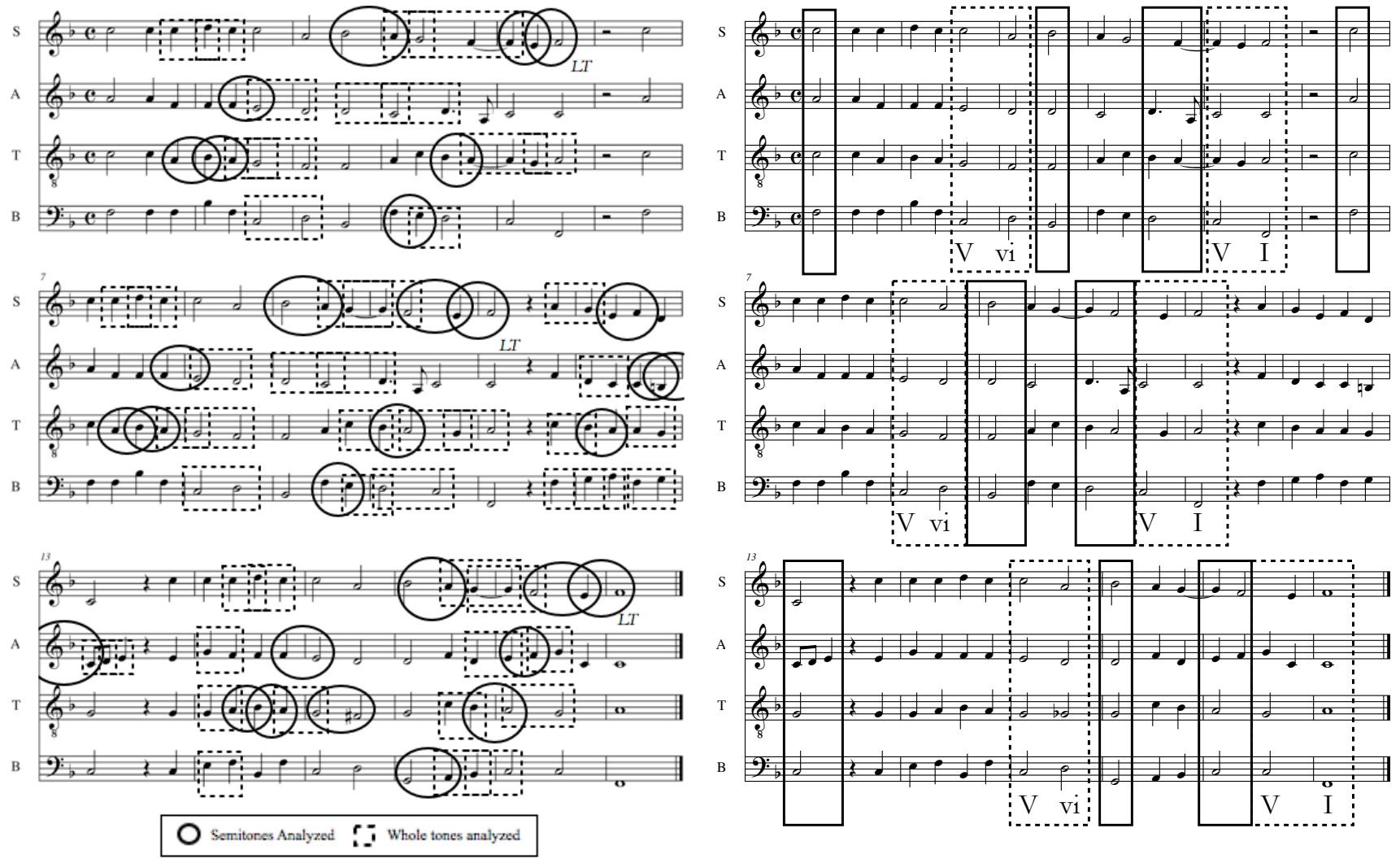
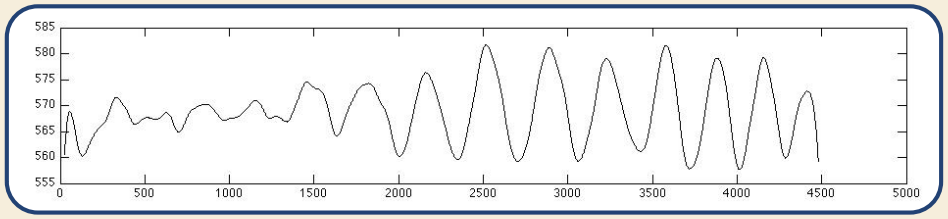


“Lo’ How a Rose e’er blooming” (Michael Praetorius)

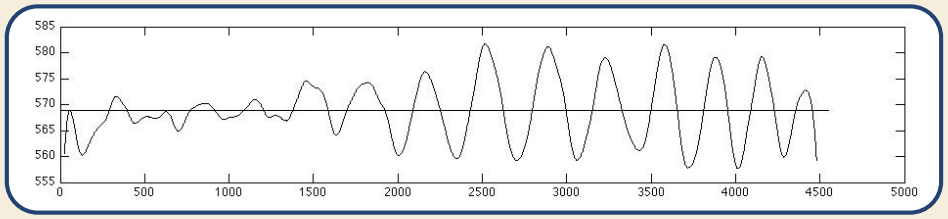
Intonation Experiments

Identify Note Onsets and Offsets

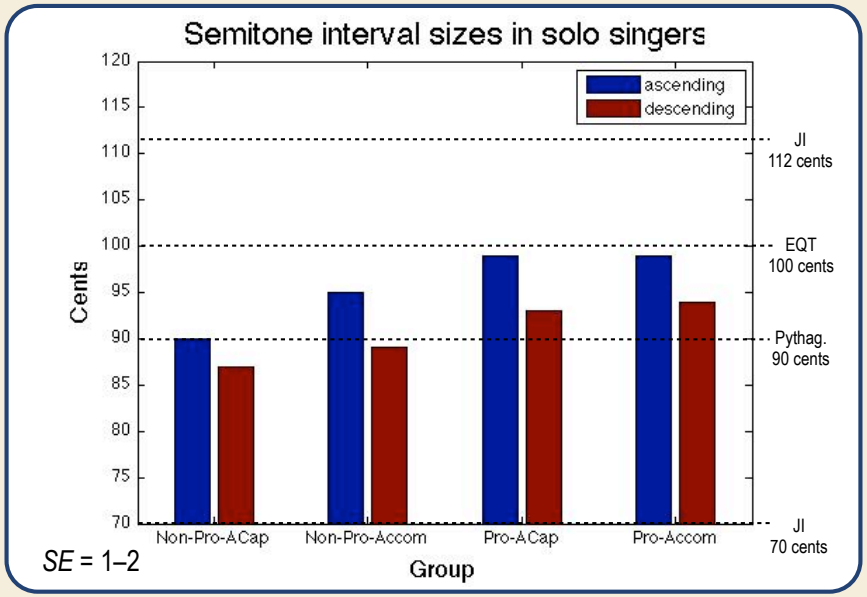
Fundamental Frequency (F0) Estimation

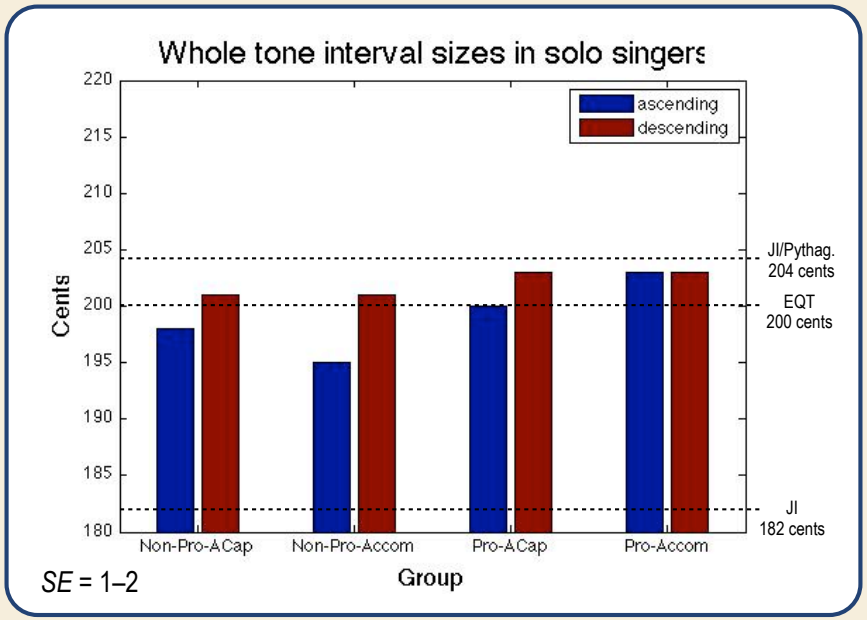


Perceived Pitch



Intonation Experiments - Solo





- Adherence to fixed systems
  - Semitones
    - mean of pros' ascending semitones closest to equal temperament
    - mean of non-pros' semitones (ascending and descending) and pros' descending semitones closest to Pythagorean
  - Whole tones
    - mean of pro's whole tones closest to Just Intonation/Pythagorean tuning (except for ascending *a cappella* whole tones)
    - mean of non-pro's whole tones (and pro's ascending *a cappella* whole tones) were closest to equal temperament

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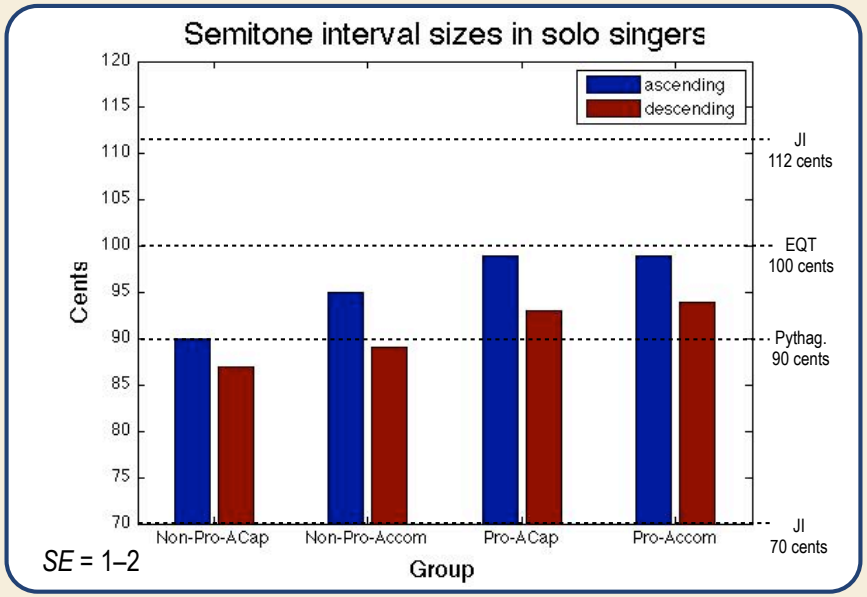

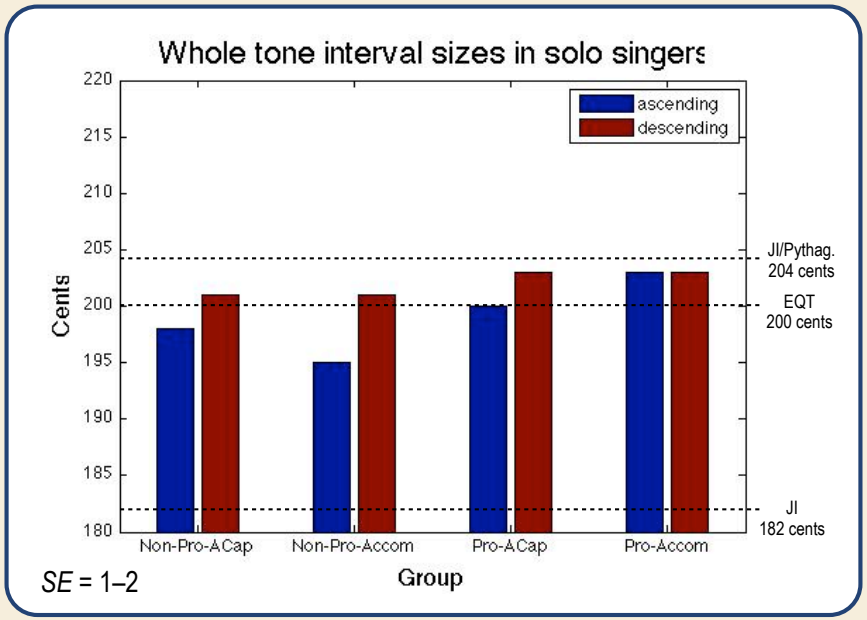

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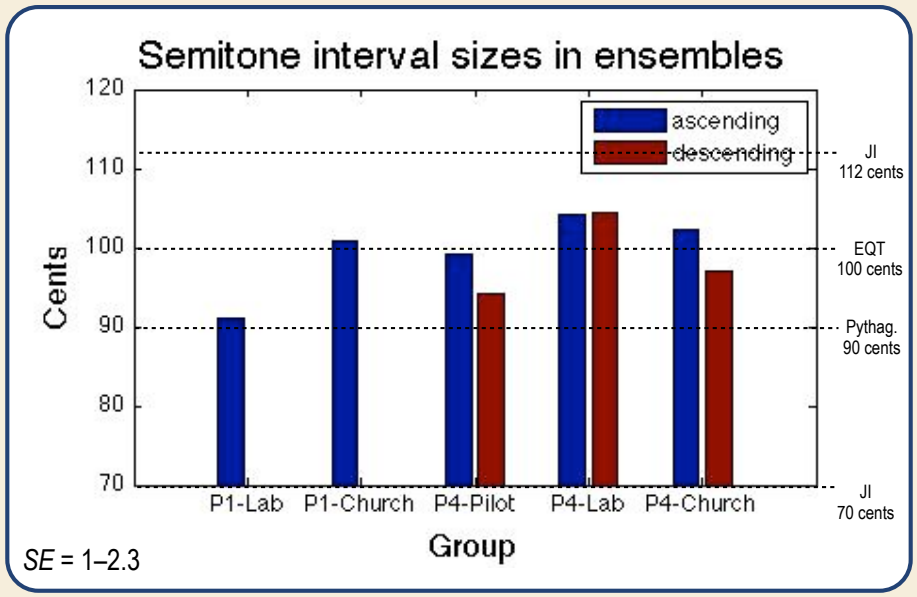

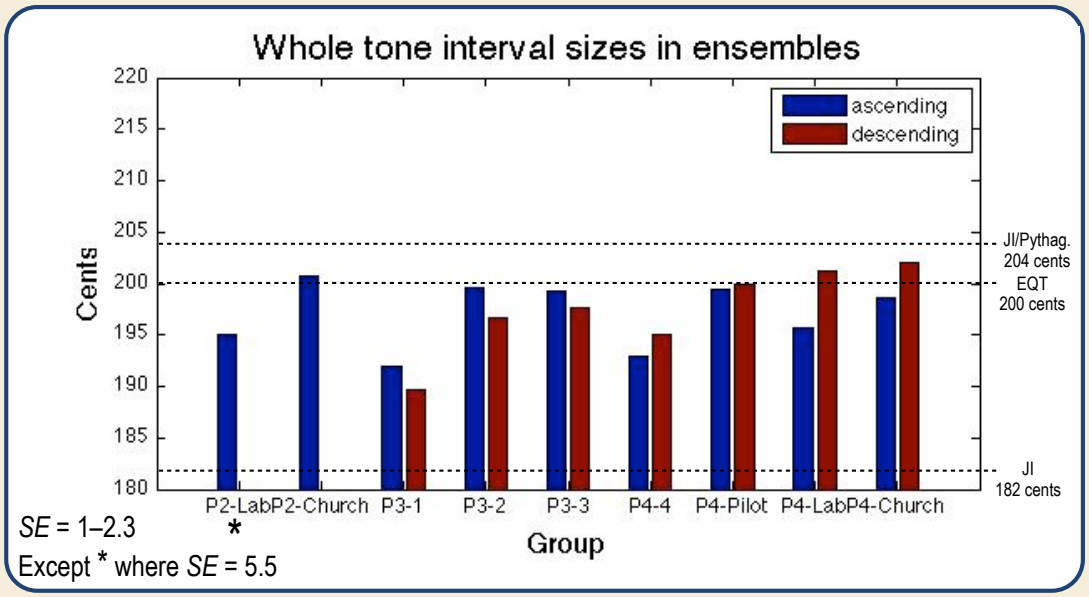

- Adherence to fixed systems
  - Semitones: means of most ascending and descending semitones were closest to equal temperament
    - Lab ensemble in part one was closest to Pythagorean
  - Whole tones: means of the majority of ascending and descending whole tones were closest to equal temperament
    - Ensemble 1's whole tones in Part Three were between 200 EQT and 182 JI tuning

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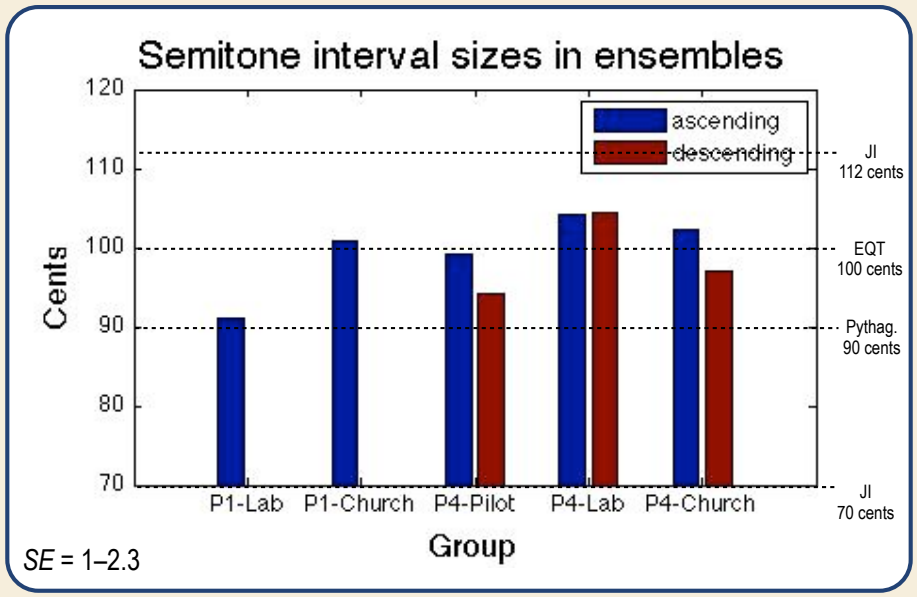

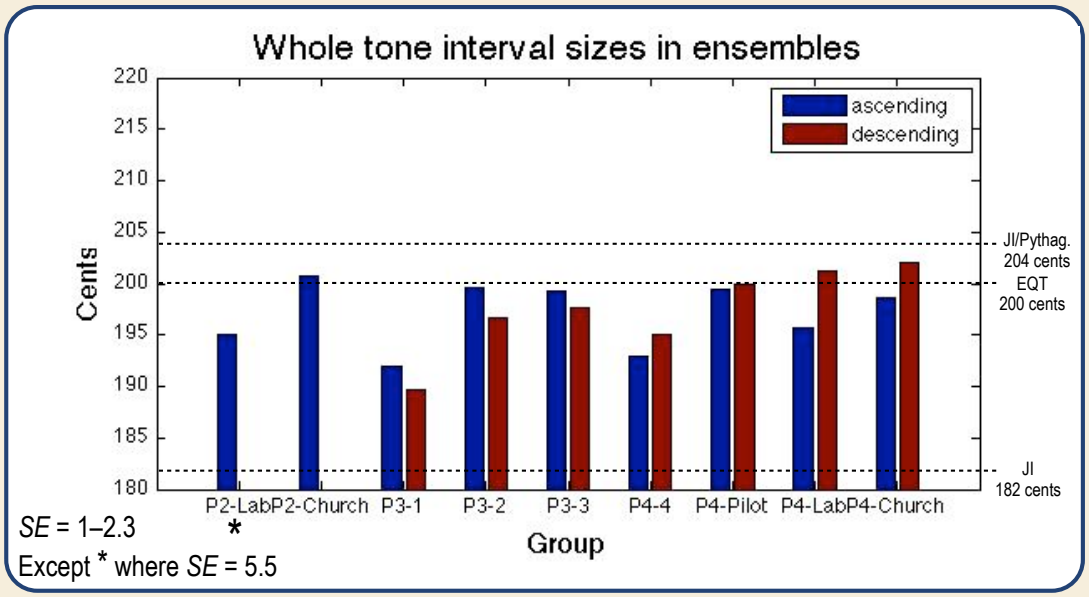

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  - most ensembles' means were closer to equal temperament (except for some ensembles' m6, M6, and m7)

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

- However, 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

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	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

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		Previous Findings	Current Findings
Adherence to a Fixed System	*Solo*	Schoen (1922): *sharper than EQT* Prame (1997): *deviation from EQT*	*closest to EQT* *(except non-pro semitones)*
	Ensemble	Howard (2007): *closest to JI*	*closest to EQT*

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Ascending vs Descending	*Solo*	Schoen (1922): *both descending and ascending intervals larger than EQT*	*descending semitones smaller** *descending whole tone larger**

** when the effect was significant ($p < 0.01$)*

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Accompanied vs. *a cappella*	*Solo*	Vurma (2010): *detuning of accompanying synthesized voices didn't significantly effect intonation*	*non-professionals showed an effect for semitone tuning but no effect for whole tone tuning*

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Just Noticeable Difference for Detecting Mistunings	Lynch et al. (1991): for melodic intervals: 10 cents (experienced musicians) Vurma (2010): for two-part intervals: 20–40 cents (experienced musicians)

Conclusions

- How consistently did the singers tune in performance?
  - In the solo experiment there were some significant effects for accompaniment and ascending vs. descending
  - In the ensemble experiment there were some significant effects for ascending vs. descending
- How did their tuning relate to idealized tuning systems?
  - Melodic intervals: the singers did not conform exactly to equal temperament but were closest to it than any other system
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