

Intonation in solo vocal performance: A study of semitone and whole tone tuning in undergraduate and professional sopranos

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- Impact of training on tuning of melodic semitones and whole tones in solo singing
 - adherence to fixed systems
 - *a cappella* vs. accompaniment
 - ascending versus descending
 - harmonic context
- Schubert's “Ave Maria”
 - six undergraduate singers
 - six professional singers
- Automatic extraction of intonation-related information
 - notes onsets and offsets
 - fundamental frequency and perceived pitch

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Prior Work on Intonation

- Schoen (1922)
 - accompanied singers sharper than equal temperament
 - notes tended to be flatter when descending and sharper when ascending
- Sundberg, Prame, and Iwarsson (1995)
 - average difference between professional singers' repeated notes was 8 cents
- Prame (1997)
 - used same data as Sundberg, Prame, and Iwarsson
 - intonation deviated substantially, though not consistently, from equal temperament

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Experiment: *Method*

- Participants
 - 6 undergraduate soprano vocal majors from McGill University
 - completed an average of 2 years ($SD = 0.6$) of course work
 - mean age of 20.2 years ($SD = 2.1$)
 - average of 6 years ($SD = 2.9$) of private voice lessons
 - current daily practice time average of 1.1 hours ($SD = 0.7$)
 - 6 singers working professionally in the Montreal area
 - at least one graduate-level degree in voice performance
 - mean of 35.7 years ($SD = 11.5$), with a range from 28 to 58
 - average of 10.3 years ($SD = 6.0$) of private voice lessons
 - current daily practice time average of 1.5 hours ($SD = 0.5$)

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Experiment: *Method*

Ave Maria

Franz Schubert

The musical score for "Ave Maria" by Franz Schubert is shown in five staves of music. The vocal line is in soprano clef, mostly in A minor (two flats). The lyrics are written below the notes. Various intonation markings are highlighted:

- Circle with dashed line:** Used at the beginning of phrases like "Ave Maria" and "Ave maria".
- Circle:** Used to mark specific notes, such as the leading tone (LT) in measure 10.
- Dashed box:** Used to group notes together, often indicating ascending or descending intervals.
- Square:** Used to mark other ascending semitones.
- Boxed note:** Used to mark other descending semitones.

Specific markings include:
Measure 1: Circle with dashed line around the first two notes.
Measure 2: Circle with dashed line around the first two notes.
Measure 3: Circle with dashed line around the first two notes; circle around the LT.
Measure 4: Dashed box around the first two notes; square around the next two notes; circle with dashed line around the next two notes.
Measure 5: Circle with dashed line around the first two notes.
Measure 6: Circle with dashed line around the first two notes.
Measure 8: Dashed box around the first two notes; square around the next two notes.
Measure 10: Circle with dashed line around the first two notes; circle around the LT; circle with dashed line around the last two notes.

- | | | | |
|---|-----------------------------|---|----------------------------|
| ○ | A-Bb ascending interval | □ | Other ascending semitones |
| | LT indicates a leading tone | | |
| △ | Bb-A descending interval | ▣ | Other descending semitones |

Experiment: *Method*

Ave Maria

Franz Schubert

The musical score for "Ave Maria" by Franz Schubert is shown in five staves. The vocal line is in soprano C major. Intonation markings are indicated by various symbols placed over specific notes:

- Open circle (○):** Ascending chord tone to non-chord tone whole tone.
- Open square (□):** Ascending non-chord to chord tone whole tone.
- Open oval (○):** Ascending chord tone to chord tone whole tone.
- Dashed circle (○):** Descending chord tone to non-chord tone whole tone.
- Dashed square (□):** Descending non-chord to chord tone whole tone.
- Dashed oval (○):** Descending chord tone to chord tone whole tone.

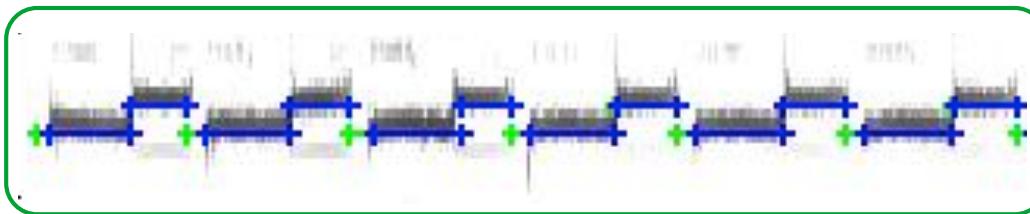
Annotations below the score correspond to the markings:

- Staff 1: A - ve Ma - ri - a, Gra - ti - a ple na Ma - ri - a gra - ti - a
- Staff 2: ple - na, Ma - ri - a gra - ti - a ple - na A - ve A - ve Do - mi -
- Staff 3: nus, Do - mi - nus te - cum Be - ne - dic - ta tu in mu - li - e - ri - bus et
- Staff 4: be - ne - di - ctus, et be - ne - dic - tus fru - ctus ven - tris, ven - tris
- Staff 5: tu - i Je - sus, A - ve - Ma - ri - a!

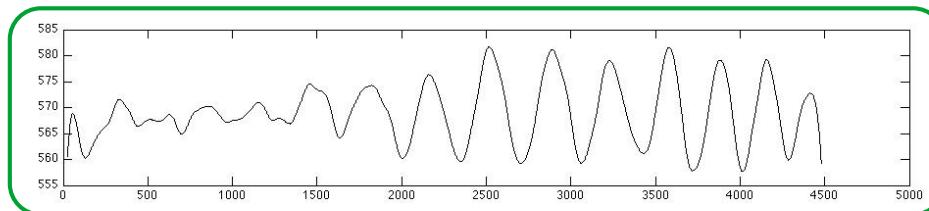
- | | |
|---|--|
| ○ | Ascending chord tone to non-chord tone whole tone |
| □ | Descending chord tone to non-chord tone whole tone |
| ○ | Ascending non-chord to chord tone whole tone |
| ○ | Descending chord tone to chord tone whole tone |
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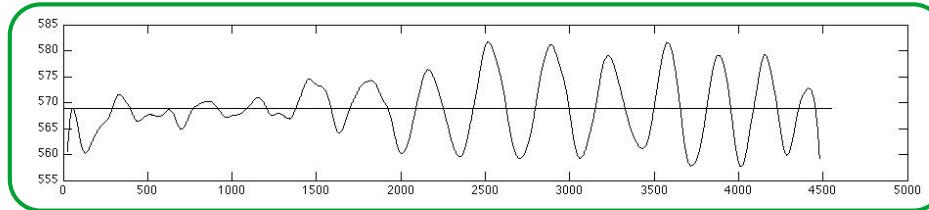
Identify Note Onsets and Offsets



Fundamental Frequency (Fo) Estimation

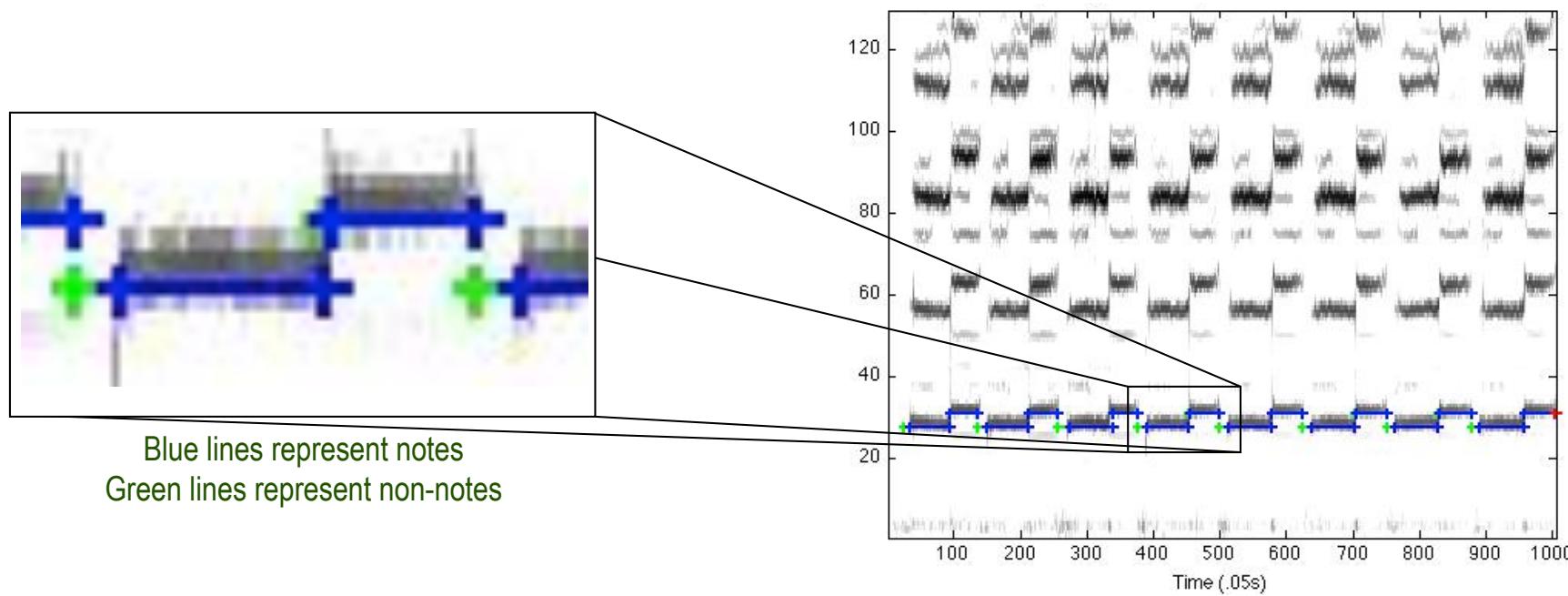


Perceived Pitch



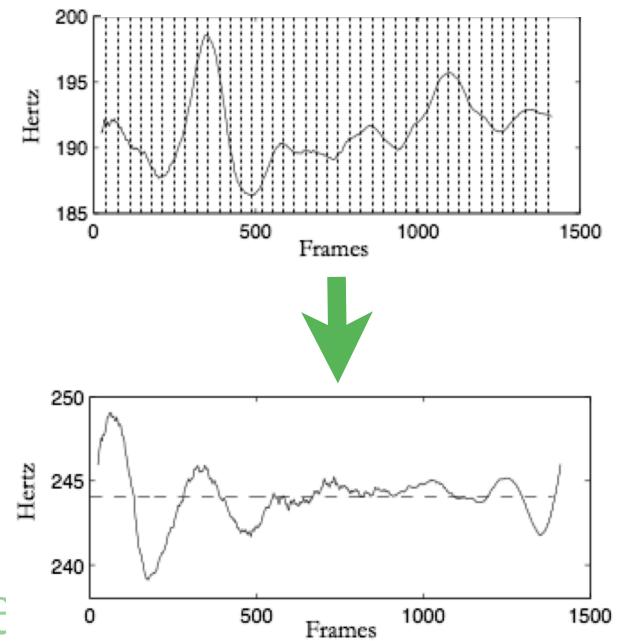
Identifying Note Onsets and Offsets

- Note onsets and offsets in the recordings were identified through MIDI-audio alignment
- Two-step dynamic time warping (DTW)/hidden Markov model (HMM) alignment algorithm optimized for the singing voice (Devaney, Mandel, & Ellis 2009)



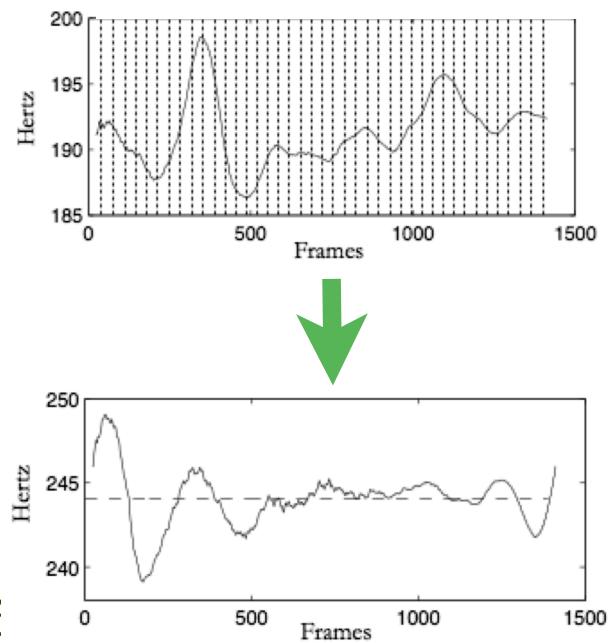
F_o and Interval Size Estimation

- The YIN algorithm was used for F_o estimation (de Cheveigné and Kawahara 2002)
 - A single F_o estimate was calculated for each frame of audio
- Perceived pitch calculated by taking a weighted mean based on the F_o 's rate of change (Gockel et al. 2001)
 - Frames with a slower rate of change given higher weightings
- Interval size calculated as the difference between two perceived pitch calculations



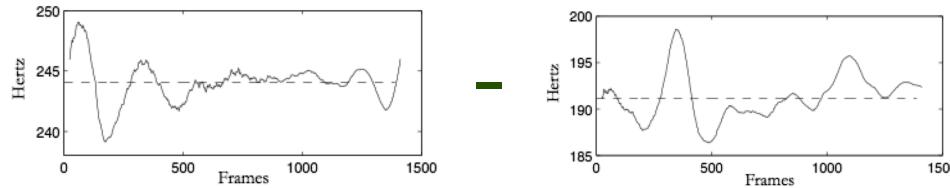
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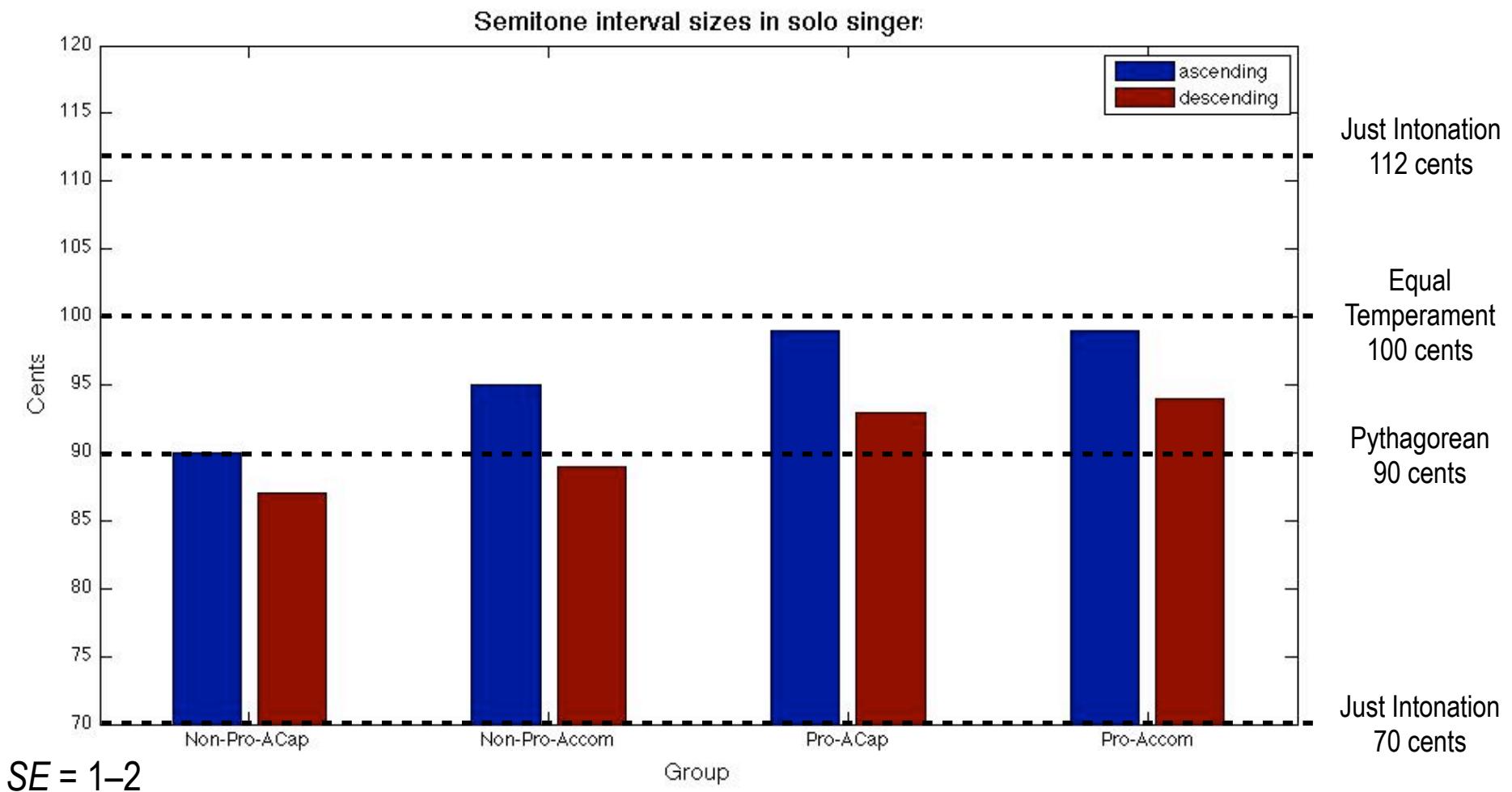


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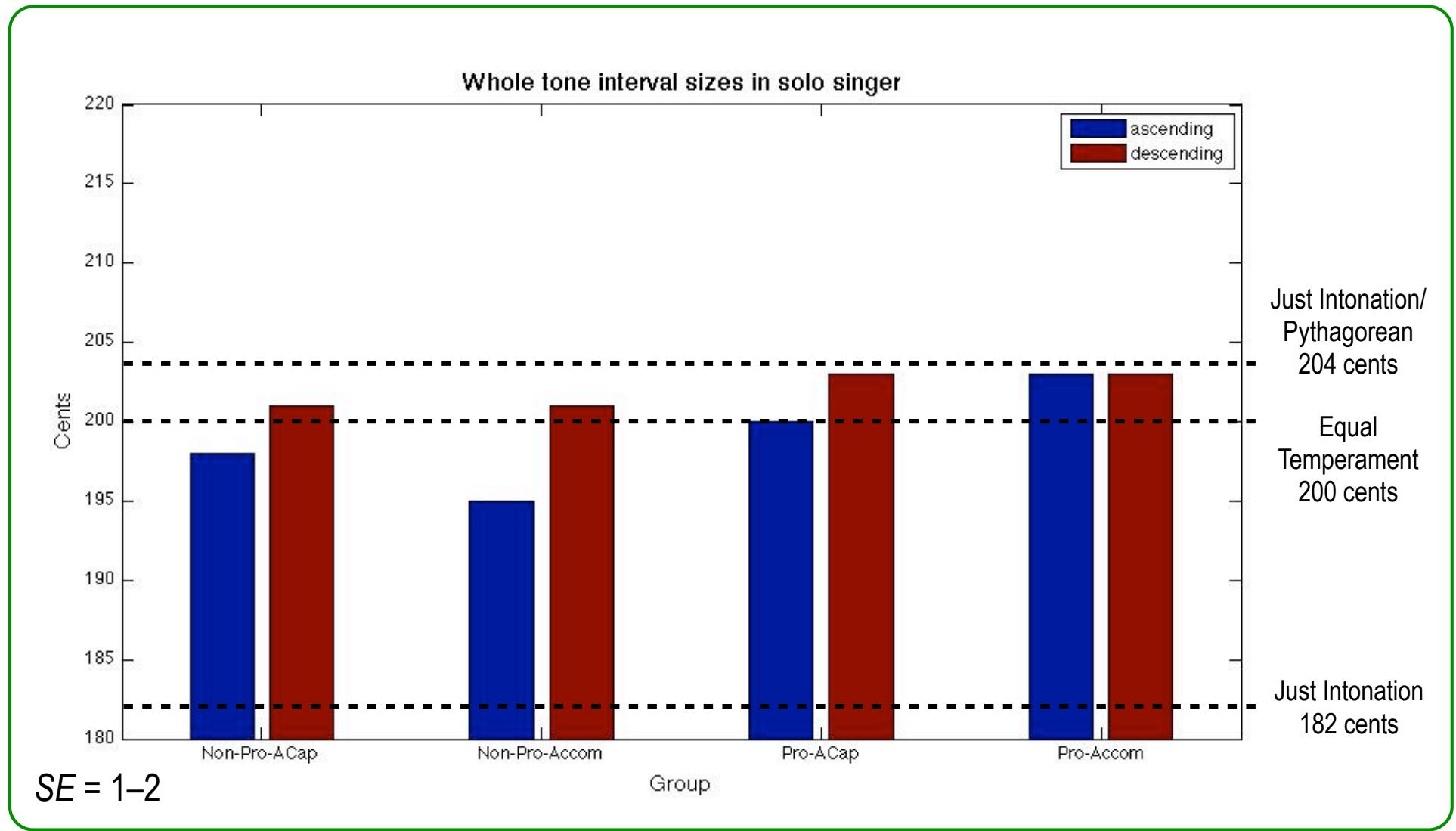
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Experiment: Results (Semitones)



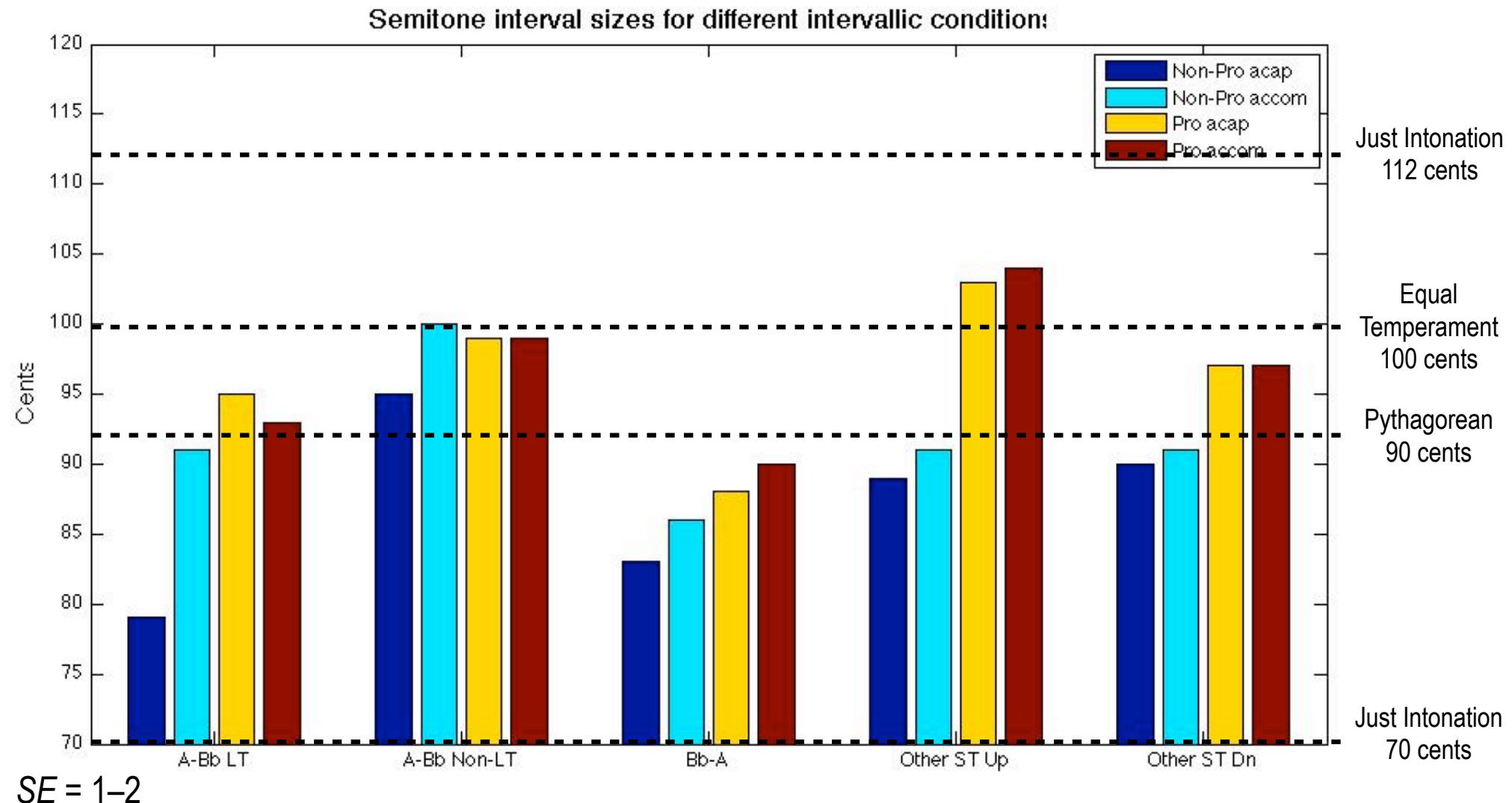
Experiment: Results (*Whole Tones*)



Experiment: *Results*

- Linear regression analysis ($p < 0.001$) showed some significant trends for
 - *a cappella* vs. accompanied
 - ascending vs. descending
 - various semitone and whole tone intervallic conditions
 - singer and group identity

Experiment: Results (Semitones)



Experiment: *Results (Semitones)*

Non-professionals

Professionals

Experiment: Results (*Semitones*)

| | Non-professionals | Professionals |
|----------------------|---|------------------------------|
| Accompaniment | accompanied intervals 3 cents larger on average | <i>No Significant Effect</i> |
| | | |

Experiment: Results (*Semitones*)

| | Non-professionals | Professionals |
|----------------------|---|---|
| Accompaniment | accompanied intervals 3 cents larger on average | <i>No Significant Effect</i> |
| Direction | ascending intervals 8 cents larger on average | ascending intervals 7 cents larger on average |

Experiment: Results (*Semitones*)

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| Accompaniment | accompanied intervals 3 cents larger on average | <i>No Significant Effect</i> |
| Direction | ascending intervals 8 cents larger on average | ascending intervals 7 cents larger on average |
| Intervalic Conditions | leadings tones 10 cents smaller on average | A-Bb/Bb-A semitones 7 cents smaller on average |

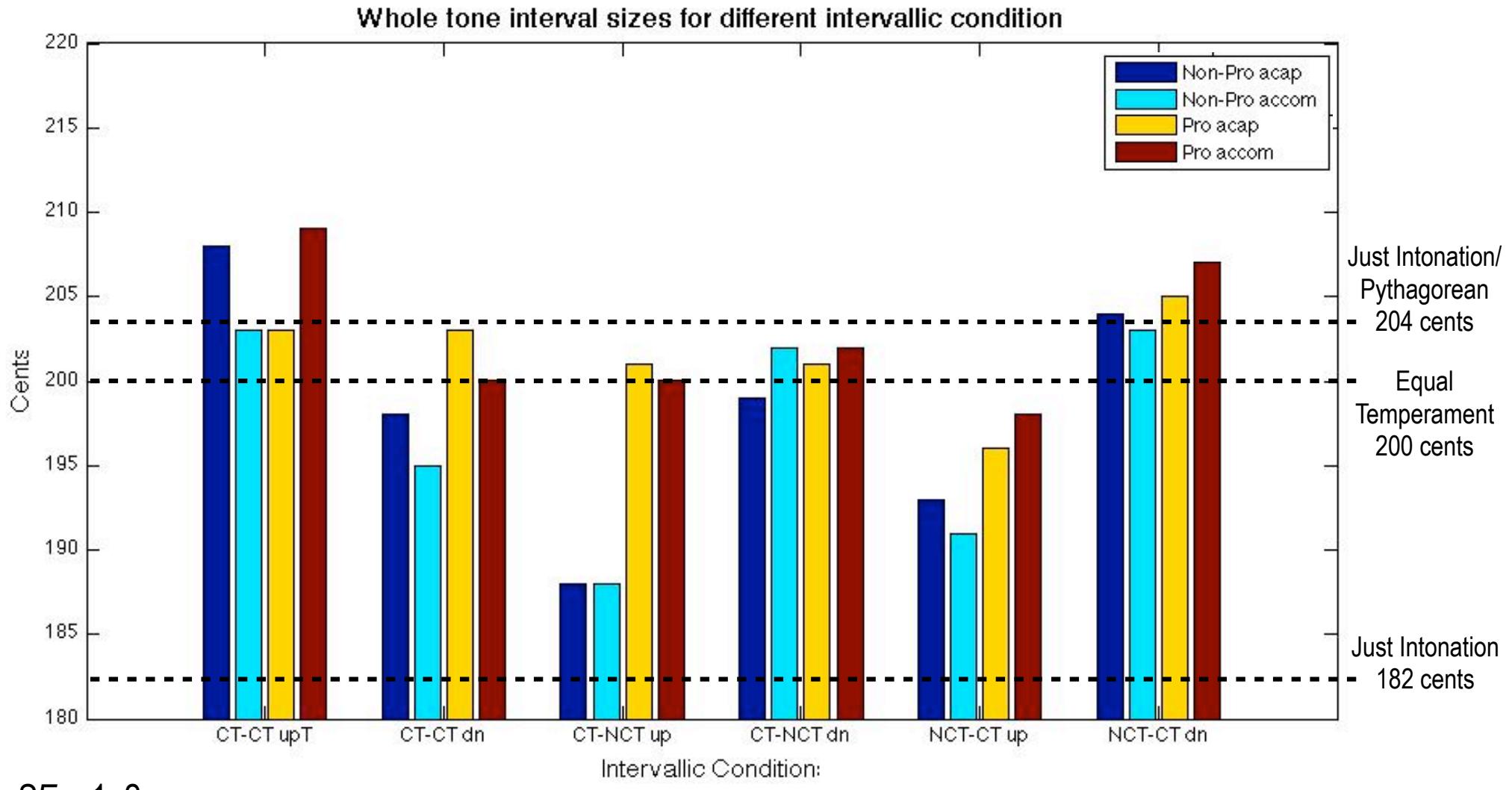
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| Singer Identity | significant for singers 1, 2, 4, and 5 versus singer 6 | <i>No significant Effect</i> |

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| Singer Identity | significant for singers 1, 2, 4, and 5 versus singer 6 | <i>No significant Effect</i> |
| Group Identity | non-professionals' semitones were 6 cents smaller on average | |

Experiment: Results (*Whole Tones*)



Experiment: *Results (Whole Tones)*

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Professionals

Experiment: Results (*Whole Tones*)

| | Non-professionals | Professionals |
|----------------------|------------------------------|------------------------------|
| Accompaniment | <i>No Significant Effect</i> | <i>No Significant Effect</i> |

Experiment: Results (*Whole Tones*)

| | Non-professionals | Professionals |
|----------------------|--|------------------------------|
| Accompaniment | <i>No Significant Effect</i> | <i>No Significant Effect</i> |
| Direction | ascending intervals 5 cents larger on average | <i>No Significant Effect</i> |

Experiment: Results (*Whole Tones*)

| | Non-professionals | Professionals |
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| Accompaniment | <i>No Significant Effect</i> | <i>No Significant Effect</i> |
| Direction | ascending intervals 5 cents larger on average | <i>No Significant Effect</i> |
| Intervalic Conditions | <i>No Significant Effect</i> | <ul style="list-style-type: none">- whole tones starting on a chord tone 5 cents smaller- whole tones ending on a chord tone 7 cents smaller |

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| Singer Identity | significant for singers 3 and 5 versus singer 6 | significant for singers 2 and 5 versus singer 6 |

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| Singer Identity | significant for singers 3 and 5 versus singer 6 | significant for singers 2 and 5 versus singer 6 |
| Group Identity | non-professionals's whole tones were 3 cents smaller on average | |

Experiment: *Discussion*

- ACCOMPANIMENT: Results suggest that singers become more consistent between *a cappella* and accompanied conditions with more training and experience
 - The decrease in SINGER IDENTITY effect in the professional group for semitones also supports this
- DIRECTION: The trend towards larger ascending intervals than descending ones may relate to pitch drift
- LEADING TONES: The absence of an effect for leading tone in the professional group's semitones suggests that either
 - singers acquire greater stability in their production of leading tones with training
 - singers with less training tend to exaggerate them

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Conclusions

- Overall the singers tended more towards equal temperament than Just Intonation or Pythagorean
- With the notable exception of the non-professional group's semitones, which were closer to Pythagorean
- There were significant difference between the non-professional and professional groups that suggests that greater intonational consistency is acquired with training and experience

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