Tuning at the Speed of Sound: The Relationship Between Intonation and Tempo

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American String Teachers Association
March 22, 2024

What’s the Big Deal About Intonation?

“It’s out of tune if it sounds out of tune”

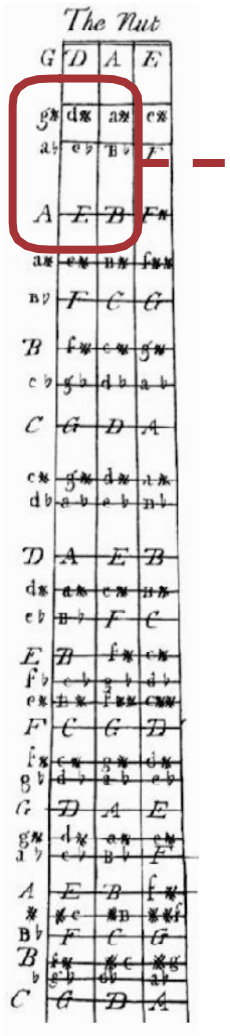
Intonation for Fixed-Pitch Instruments

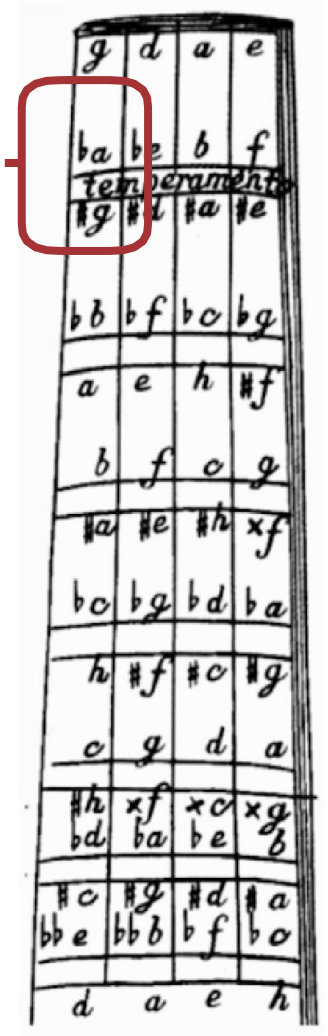
- Pythagorean
- Just
- Equal *temperament*

A Comparison of Just Tuning, Pythagorean Tuning, and Equal Temperament

Interval	Pythagorean tuning		Just tuning		Equal temperament
	ratio	decimal	ratio	decimal	decimal
m2	1 / 1	1.054	16 / 15	1.067	1.059
M2	256 / 243	1.125	9 / 8	1.125	1.123
m3	9 / 8	1.185	6 / 5	1.2	1.189
M3	32 / 27	1.266	5 / 4	1.25	1.26
P4	81 / 64	1.333	4 / 3	1.333	1.335
Tt	4 / 3	1.405	45 / 32	1.406	1.414
P5	1024 / 729	1.5	3 / 2	1.5	1.498
m6	3 / 2	1.580	8 / 5	1.6	1.587
M6	128 / 81	1.688	5 / 3	1.667	1.682
m7	27 / 16	1.778	9 / 5	1.8	1.782
M7	16 / 9	1.898	15 / 8	1.875	1.888
P8	243 / 128	2	2 / 1	2	2

Perception of intonation





*Both examples taken from Duffin (2007)

Prelleur. (1730-1731). *The Modern Musick-Master.*

Campagnoli. (1797?). *Nuovo Metodio della Mecanica Progressive*

Perception of intonation

Expressive intonation

Casals “often referred to the pitch of notes being dependent on the speed of the music.”
(O’Malley, 1983)

Pablo Casals (1876-1973)

Long-held harmonies —> justly tuned thirds to minimize beats

Faster melodic lines —> “major and augmented intervals become extra large, minor and diminished intervals extra small.” (O’Malley, 1983)

“That just intonation in some form was used by the strings when playing alone seems indisputable.” (D. D. Boyden, 'Prelleur, Geminiani, and Just Intonation', JAMS, iv (1951), p.219)

“Casals often referred to the pitch of notes being dependent on the speed of the music. This speed, I believe, lies in the frequency of the harmonic range, or on the extent to which our ear can take in succeeding harmonies. A scale then (which in any case will be played slightly differently in ascent and descent) will vary in intonation according to its speed of execution.” (Hind O’Malley, Pamela. “Cellist Pablo Casals on Expressive Intonation” in The Strad, Oct. 1983.)

Hypotheses

Regarding the tuning of the leading-tone as it approaches tonic resolution:

- **H1 (tempo effect)**: Any main effect of tempo on perception of intonation with other factors constant
- **H2 (harmonic hearing effect)**: Just intonation more in tune at slower tempos and less as tempo increases
- **H3 (melodic hearing effect)**: As tempo increases, sharper intonations more in tune; flatter less in tune
- **H4 (texture effect)**: Just intonation more in tune for harmonic vs. melodic textures; sharper intonations more in tune for melodic vs. harmonic textures

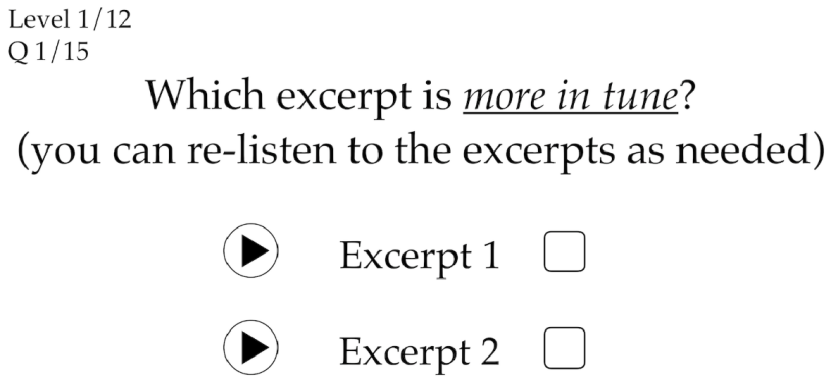
Method: Stimuli

Random variables:

1. Approach to leading-tone:
    - By step from above (do-ti-do)
    - By leap from above (re-ti-do)
    - By step from below (la-ti-do)
    - By leap from below (sol-ti-do)
2. Size of context (three vs. five note melodies)
3. Key of excerpt
    - Melody centered on C5, with four keys above/ below by half-step

Method: Procedure

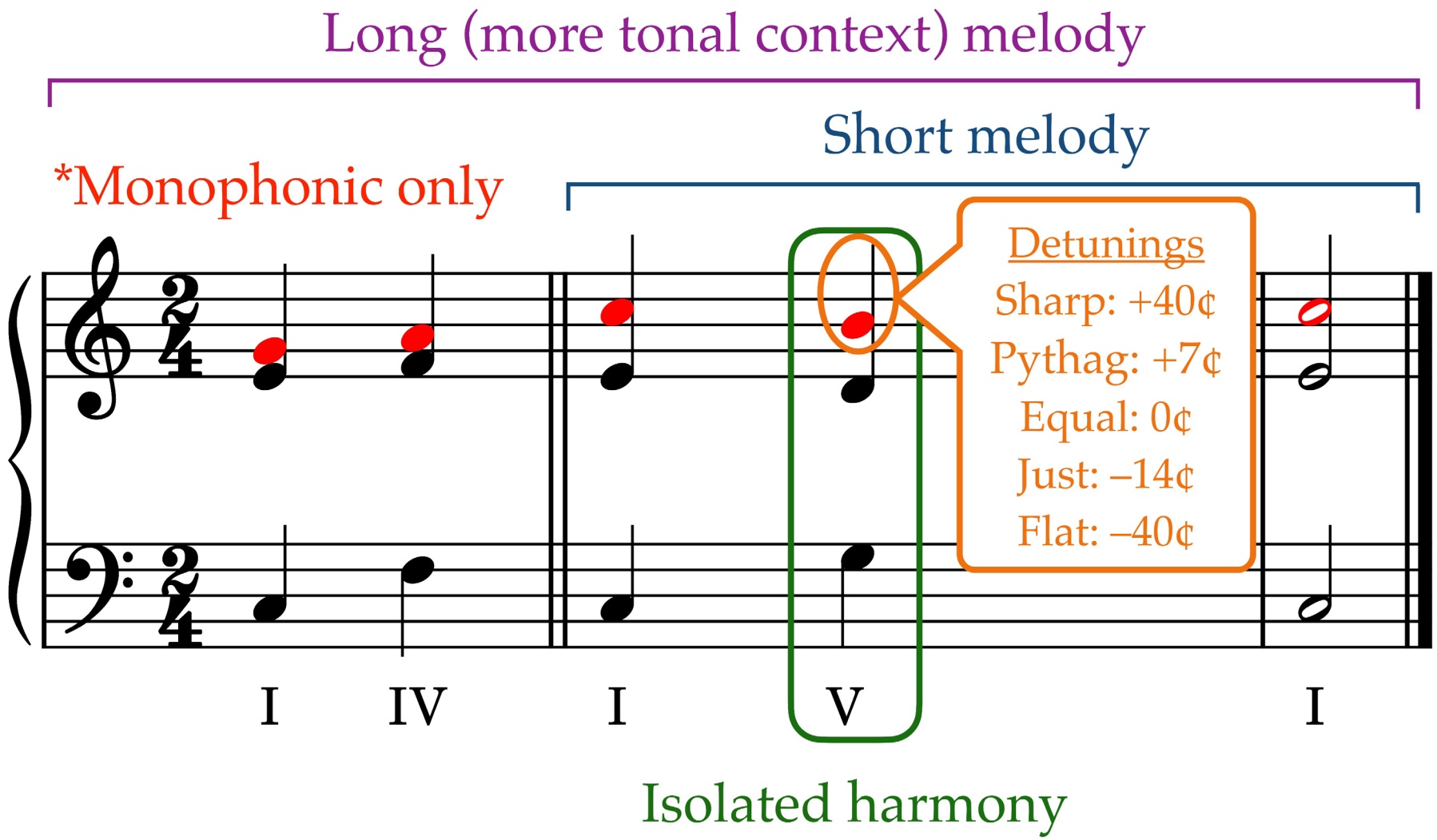
- Forced-choice paradigm
- Balanced design:
  - 10 intonation pairs X
  - 3 textures X
  - 6 tempos = 180 trials



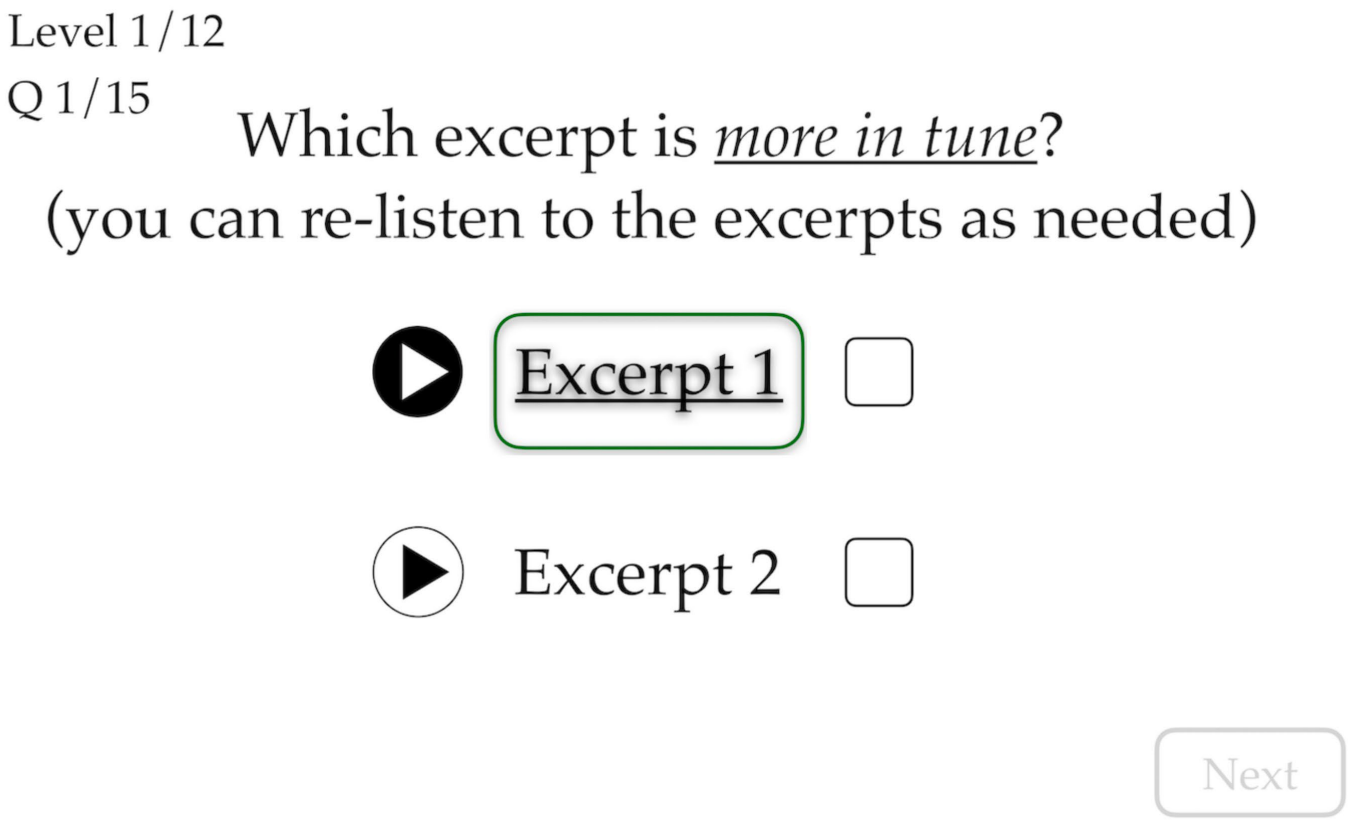
- Keys, size of melodic context, and melodic approach to leading-tone randomly selected (5611)
- Tonewheel electric organ patch (Native Instruments Kontakt VST), generated in Reaper
  - Vibrato disabled, but incorporating tremolo

Method: Participants

- 48 undergraduate freshmen/sophomore music majors at Kent State University
- 17 female, 28 male, 4 other or non-identifying
- Mean age 18.9 (SD = 1.1)
- Goldsmiths Musical Sophistication Index
  - Overall 97.9 (SD = 8.9)
  - Active Engagement 49.2 (SD = 6.1) out of 63
  - Perceptual Abilities 50.1 (SD = 5.7) out of 63
  - Musical Training 37.3 (SD = 3.9) out of 49
  - 34 listed variable-pitched instrument as primary


Long (more tonal context) melody
Short melody
*Monophonic only
Detunings
Sharp: +40¢
Pythag: +7¢
Equal: 0¢
Just: –14¢
Flat: –40¢
I
IV
I
V
I
Isolated harmony

Method: Procedure



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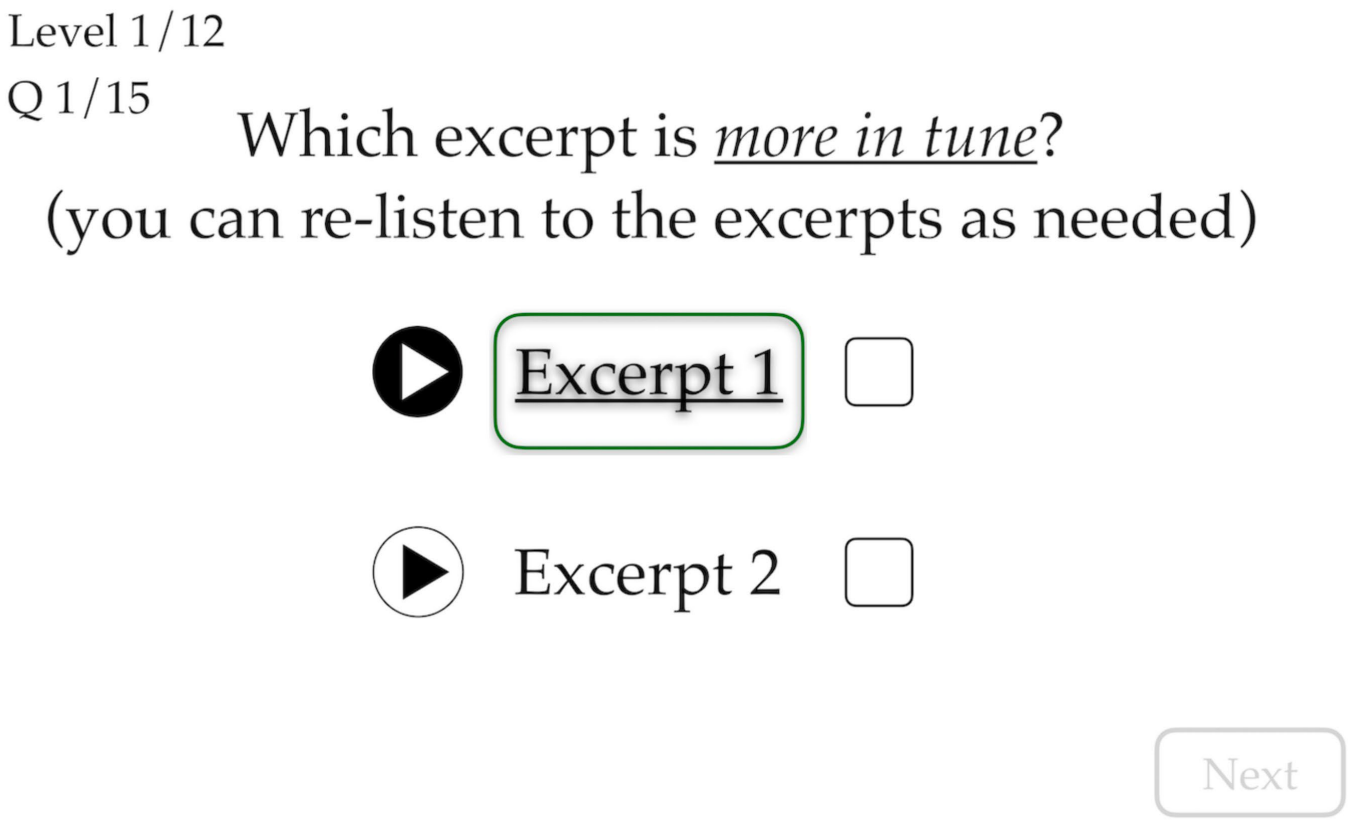

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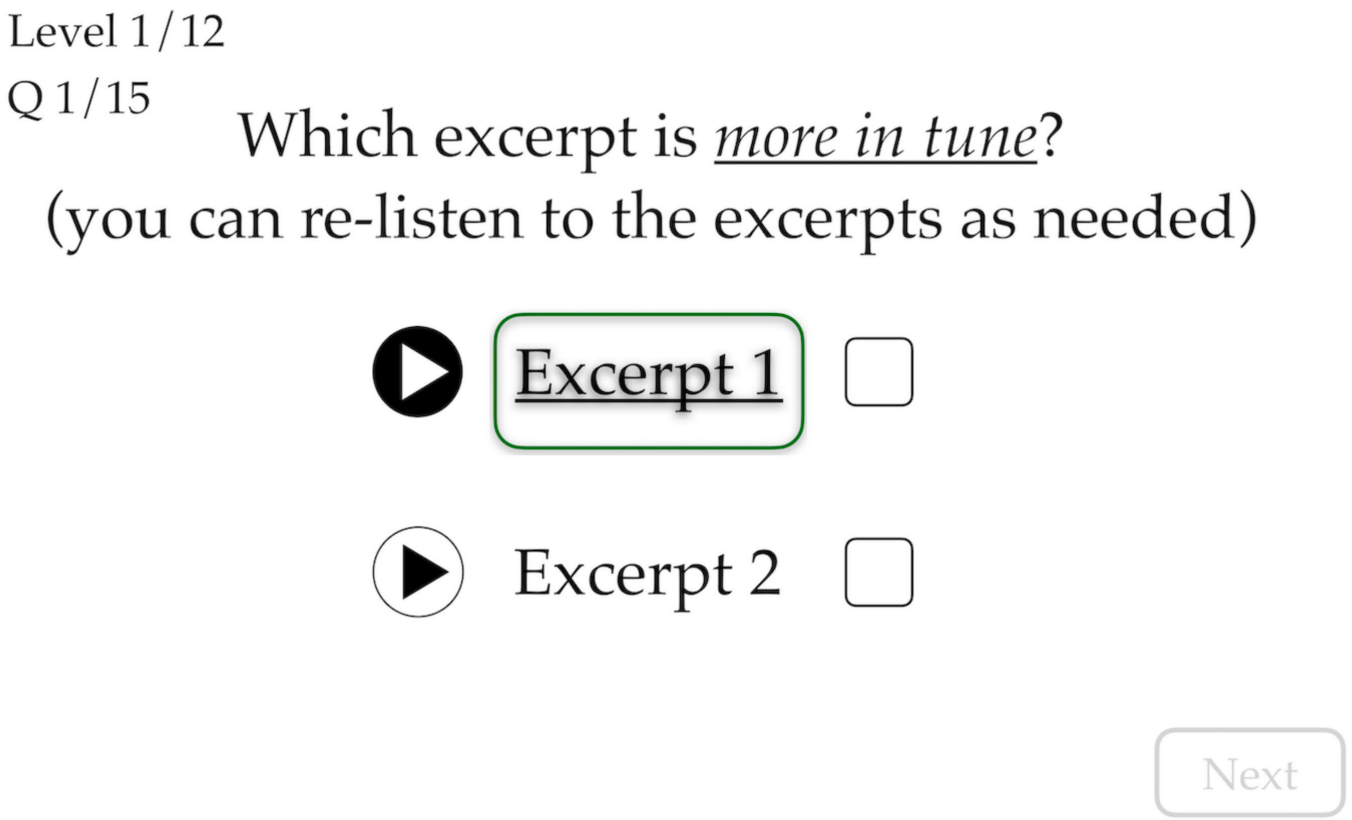
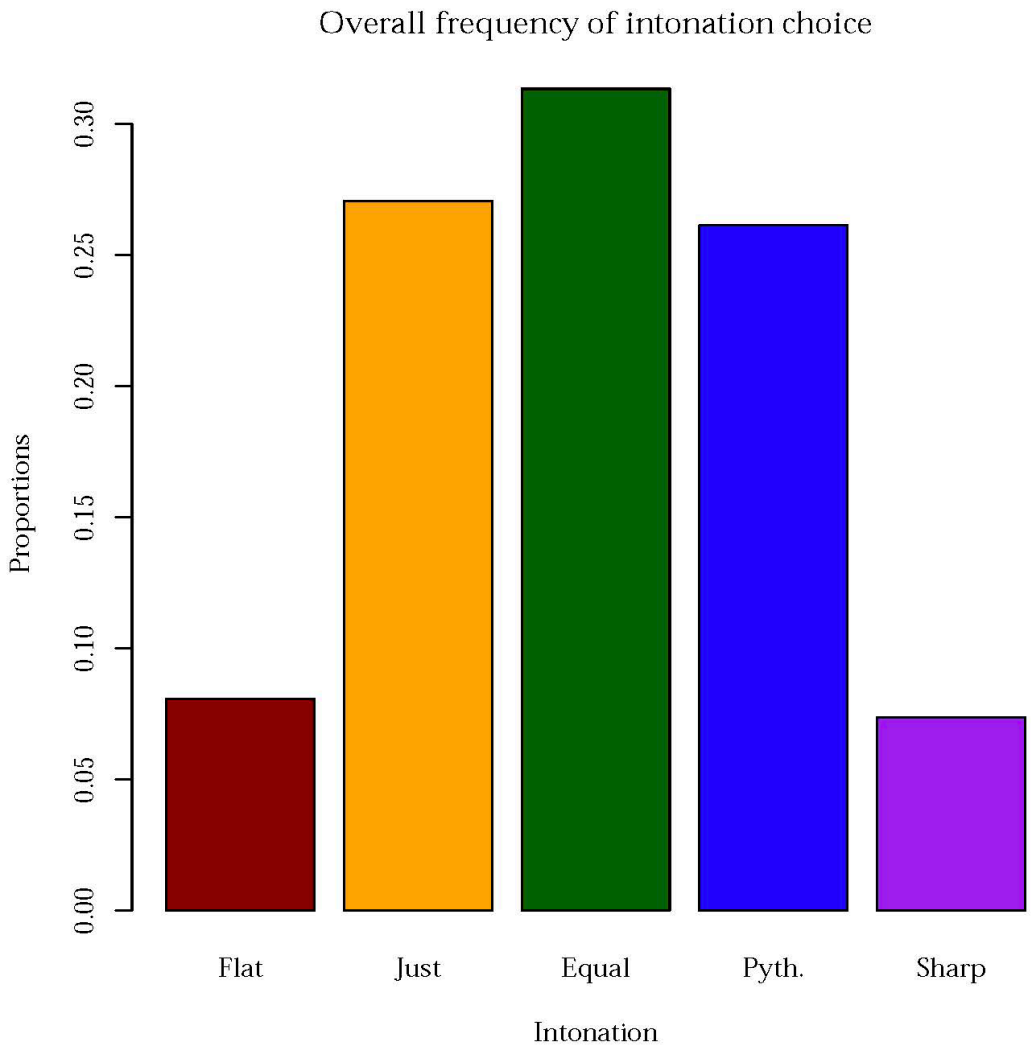


The Conclusions, Pt. 1

This figure shows the relative proportion in which each of the five tunings was selected regardless of tempo or texture. While equal temperament was selected most often, just and Pythagorean scored somewhat similarly well. The highly sharp and flat intonations performed poorly, as was expected.



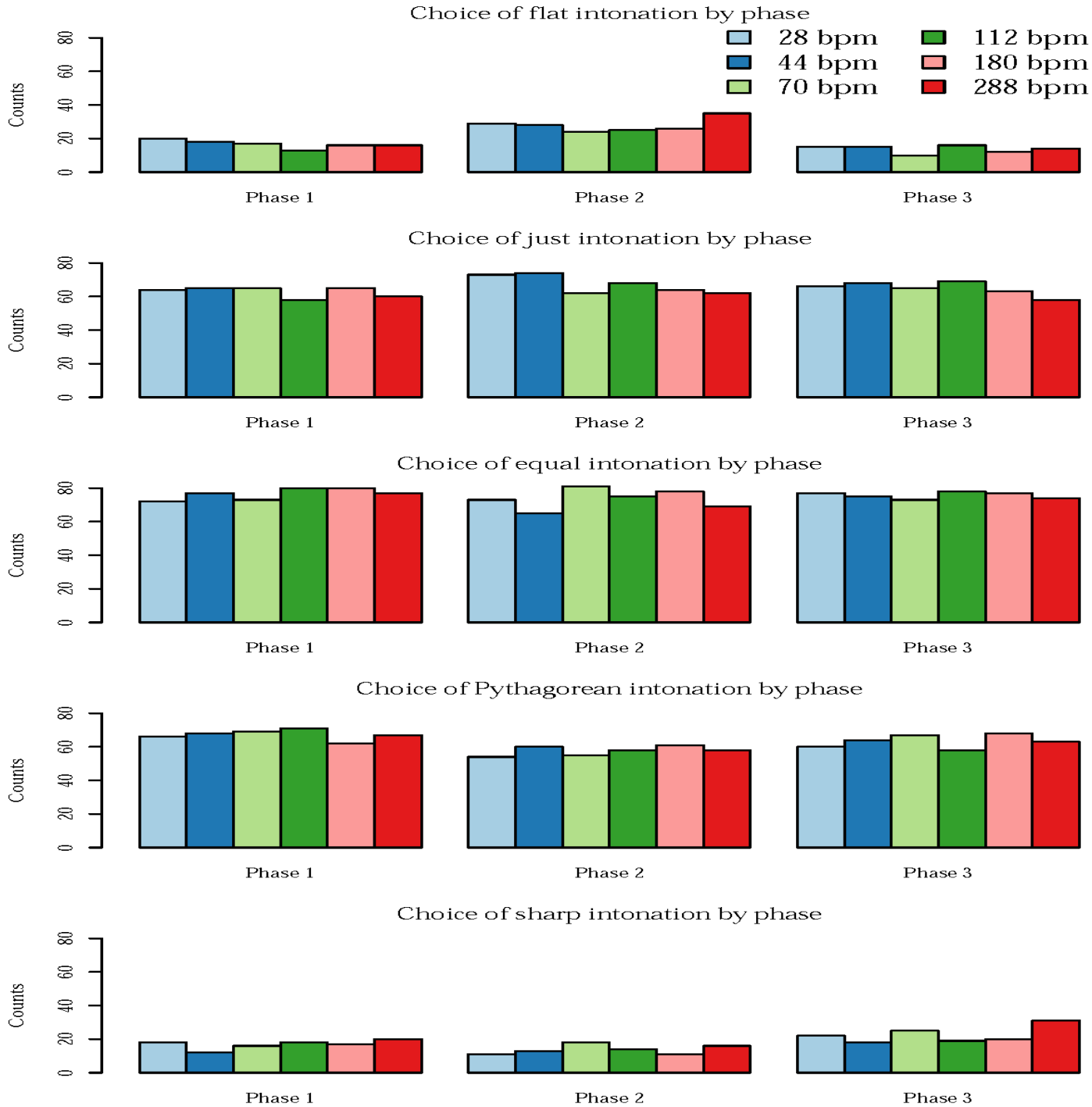
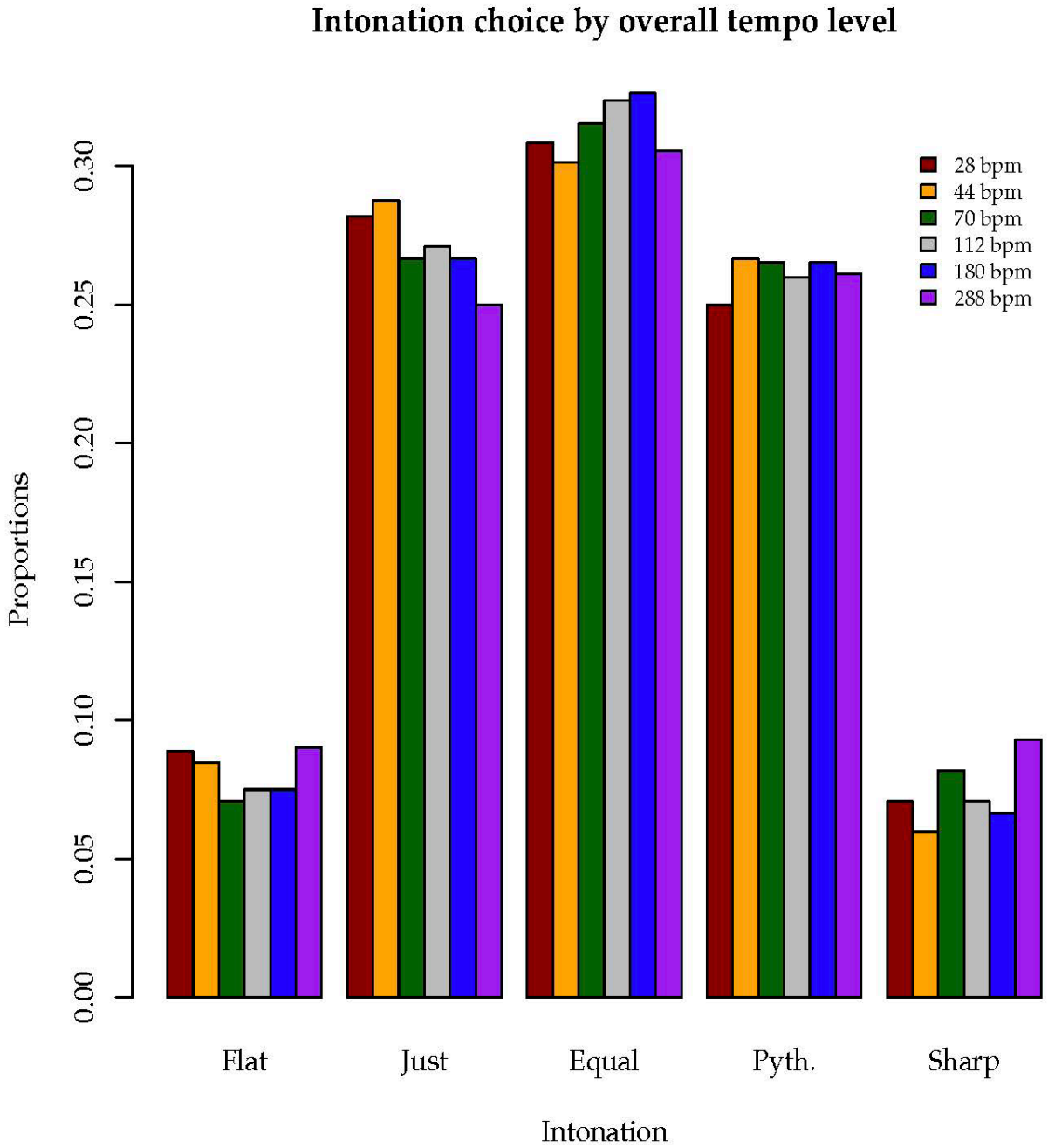


Figure 3 shows the rate at which each tuning was selected as a function of both the tempo and the phase (or texture).
Phase 1 = melody
Phase 2 = isolated harmony
Phase 3 = harmonized melody

Figure 4 shows the relative proportion in which each tuning was selected at each of the six tempi. No main effect of tempo on intonation choice was detected.



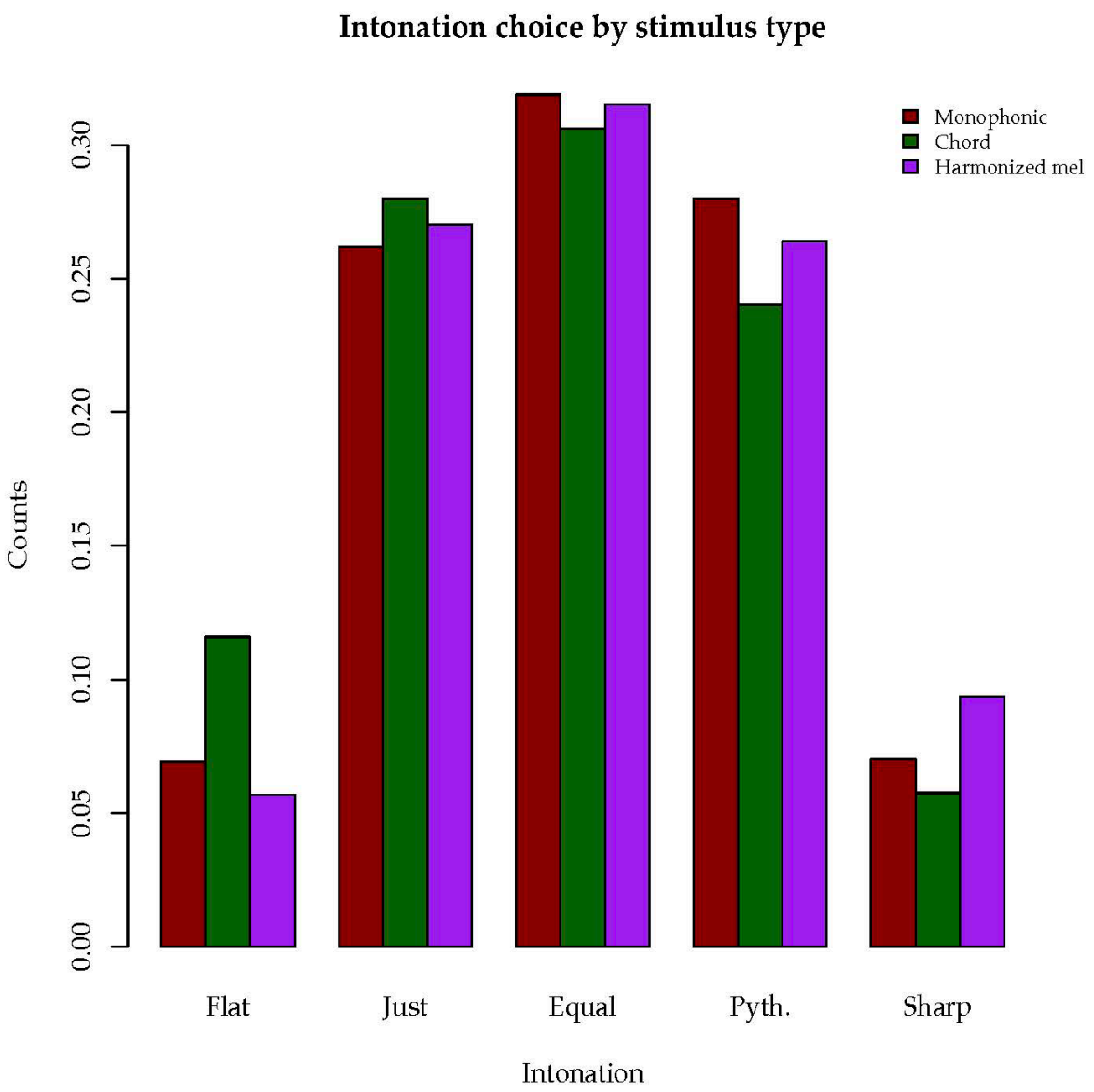


Figure 5 shows the number of times each tuning was selected according to each of the three "phases" or textures. The results show several significant differences. For example:

- Flat and just tunings were most often selected when there was *no* melodic context, and
- Sharp, Pythagorean, and equal were selected most often when there *was* a melodic context.

Conclusion

- Primary effect: Dominance of equal temperament
  - Disappointing, but not surprising
    - Contexts were equal temperament
    - The ubiquity of equal temperament today
    - The special nature of equal temperament: best of both worlds (melodic and harmonic)?

Conclusion

- ~~**H1 (tempo effect)**: Any main effect of tempo on perception of intonation with other factors constant~~
  - Main effect negative results, averaged across all other conditions
  - Caveat: tempo does play a significant role in certain circumstances

Conclusion

- **H2 (harmonic hearing effect)**: Just intonation more in tune at slower tempos and less as tempo increases
  - Significant negative correlation between just intonation selection and tempo
  - Effect strongest in strictly harmonic context, followed by harmonized melody
  - Biggest impact at slowest tempos (<44 bpm, or durations of .73 seconds)

Conclusion

- ~~**H3 (melodic hearing effect)**: As tempo increases, sharper intonations more in tune; flatter less in tune~~

- No statistically significant positive correlation for Pythagorean or sharp intonations

- However, consistent non-significant positive correlations between tempo and sharp selection

Conclusion

- **H4 (texture effect)**: Just intonation more in tune for harmonic vs. melodic textures; sharper intonations more in tune for melodic vs. harmonic textures
  - Melodic textures consistently privilege sharper intonations, penalize flatter intonations (incl. flat)

- Perception of intonation is not affected by tempo but is affected by melodic vs. harmonic context.
- In melodic contexts, smaller pitch distances are preferred.
- Additional research is needed to determine whether or not results would be similar for professional musicians

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Thank you!

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