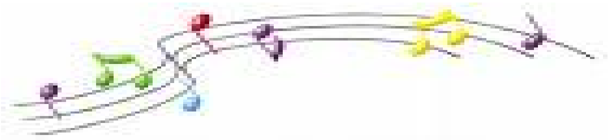

The Singing Power Ratio and Timbre-Related Acoustic Analysis of Singing Vowels and Musical Instruments

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Singing Power Ratio (SPR)

- A measure to quantify **"singer's formant"**
  - the ratio of the highest spectral peak between 2 and 4 kHz to that between 0 and 2 kHz

    (Omori et al., 1996; Lundy et al., 2000; Kenny & Mitchell, 2006; Watts et al., 2006).
  - Normally obtained through: sustained vowel segment, LTAS (long-time average spectrum)
  - The higher the SPR, the more powerful the singer's formant
    - Although may not be consistent with perceptual ratings of voice quality (Kenny & Mitchell, 2006)

Singer’s Formant

- A peak in the spectral envelope around 3 kHz (Bartholomew, 1934; Demitriev, 1979; Seidner et al., 1983; Sundberg, 1987, 1991, 1994, 2000; Sun).
- To project voice by boosting energy in the frequency region where the accompanying orchestra is normally weak (Sundberg & Romedahl, 2008).
- Perceptual correlates: **“Ringing” voice quality (“vocal ring”), “twang”, “resonant voice”**
- Theories of the production of singer’s formant:
  - **Narrowing of the laryngeal vestibule:** Titze, 2001; Master et al., 2008
  - **Pharyngeal widening:** Lessac, 1967; Smith et al., 2005
  - **Nasal resonance (Reduction of F1 energy):** Linklater, 1976; Smith et al., 2005; Sundberg et al., 2007; Jennings & Kuehn, 2008
  - MRI studies: Detweiler, 1994

Studies of Singer's Formant and SPR

- Trained vs. untrained:
  - Different: Omori et al., 1996; Brown et al., 2000
  - No difference: Lundy et al., 2000; Mendes et al., 2003; Watts et al., 2006
- Singing vs. Speaking: Stone et al., 1999; Rothman et al., 2001
  - "Actor's ring": Oliveira Barrichelo et al., 2001; Master et al., 2008
- Other factors:
  - Singing style: Stone et al., 1999, 2003; Cleveland et al., 2001; Sundberg, 2001; Björkner, 2008
  - Vocal effort, vowel, pitch: Bloothooft & Plomp, 1986
  - Gender: Weiss et al., 2001

Timbre

- The aspects of sound quality other than the other five general classes of perceptual attributes (i.e., pitch, loudness, perceived duration, spatial location, and reverberant environment) in an auditory event (Plomp, 1970; McAdams, 1993; Levitin, 1999; Menon et al., 2002)
- Acoustic correlates:
  - Spectral compositions (Helmholtz, 1863/1954, as cited in Menon et al., 2002)
  - Temporal aspect of the tone (Berger, 1964; Grey, 1977; Hajda et al., 1997; Menon et al., 2002), e.g., “attack” quality
- Factors affecting the timbre of musical instruments: structure and usage, e.g.,
  - String: bow shape
  - Flute: blowing skills (Nederveen, 1973)

Research Question

- Does a trained singer's singing voice show a higher SPR than musical instruments in the absence of background music?
  - How is SPR related to formant frequencies?
  - Is there a vowel effect on SPR?
  - Is there a pitch effect on SPR?

Participants

- **Convenience sampling**
- **Subject inclusion criterion:**
  - Singers:
    - Formal training in classical singing
    - Native English speaker
    - No history of vocal pathology
    - Healthy condition
    - No sign of voice problems on the date of recording
  - Players of musical instruments:
    - Able to play a range of musical notes, with each one maintained at a relatively constant pitch and loudness level

Participants - continued

- **Singers:**
  - 1 female (age = 23 years), 1 male (age = 24 years)
  - Native speakers of **New Zealand English**
  - More than 5 years of formal training
- **Players of musical instruments:**
  - All (except for players of guitar and recorder)
    - **Musicians** recruited from Christchurch School of Music
    - More than 5 years of formal training
  - Players of guitar and recorder were **non-musicians** recruited from the University of Canterbury (Christchurch, New Zealand).

Participant's Task

- To sing (standing) or play (sitting) a sound
  - at a **predetermined pitch** level, **each a semitone apart**, on a chromatic scale
    - Singers: /i/, /e/, /a/, /o/, /u/
    - Players: musical note
  - at a **constant loudness** level (sound level meter and microphone placed in front)
    - Singers: ≈ 65 dBA as measured at 1 meter
    - Woodwind, string, piano: ≈ 80 dBA as measured at 1-1.5 meter
    - Church organ: ≈ 90dBA as measured at 6 meters
  - for a **constant duration**
    - Singers: ≈ 1 second
    - Players: ≈ 500 milliseconds (except for percussion)
  - from the lowest to the highest note that can be produced smoothly
  - 3 trials each

Instrumentation

- **Recording device:**
  - Condenser microphone (Sony Electret ECM-MS907)
  - Mini-disk recorder (Sony MZ-RH1):
    - uncompressed linear PCM (Pulse-Code Modulation) format
- **Cueing device:**
  - Sound level meter
  - Electronic keyboard
- **Software for signal normalization (normalized to 80 dB) and segmentation:**
  - Adobe-Audition version 3
- **Software for signal segmentation and analysis:**
  - TF32 (Paul Millenkovic, 2000)

Recording Environment

- **Anechoic room:**
  - Singer
  - Woodwind, string, percussion
- **Sound-treated room:**
  - Piano
- **Empty hall:**
  - Church organ

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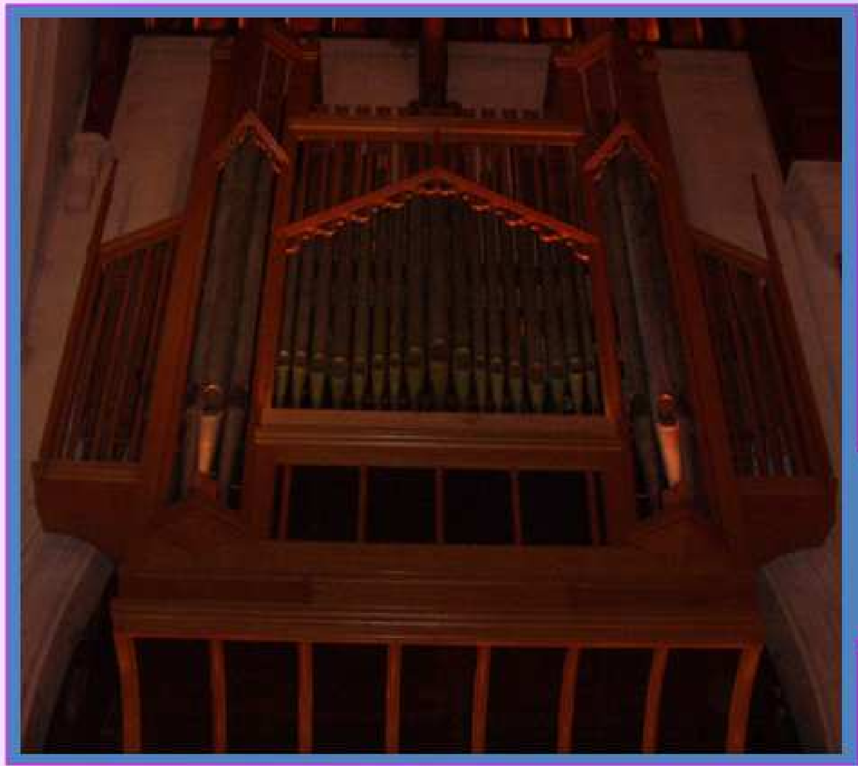
Church Organ

History:

- Built in London, UK: 1880
- Installed in Christchurch, New Zealand: 1881
- Moved to Christchurch cathedral: 1904
- Restoration: 1980
- Reconditioned: 2005



Musical Instruments

- 17 Musical Instruments (only **11 instruments** with comparable output **pitch range** and **duration** (with at least 300 milliseconds of steady portion) were included for statistical analysis:

String

- Violin

- Cello

- Guitar

Woodwind

- Flute

- Oboe

- Clarinet (treble)

- Saxophone (soprano)

Keyboard

- Grand piano

- Upright piano

- Church organ

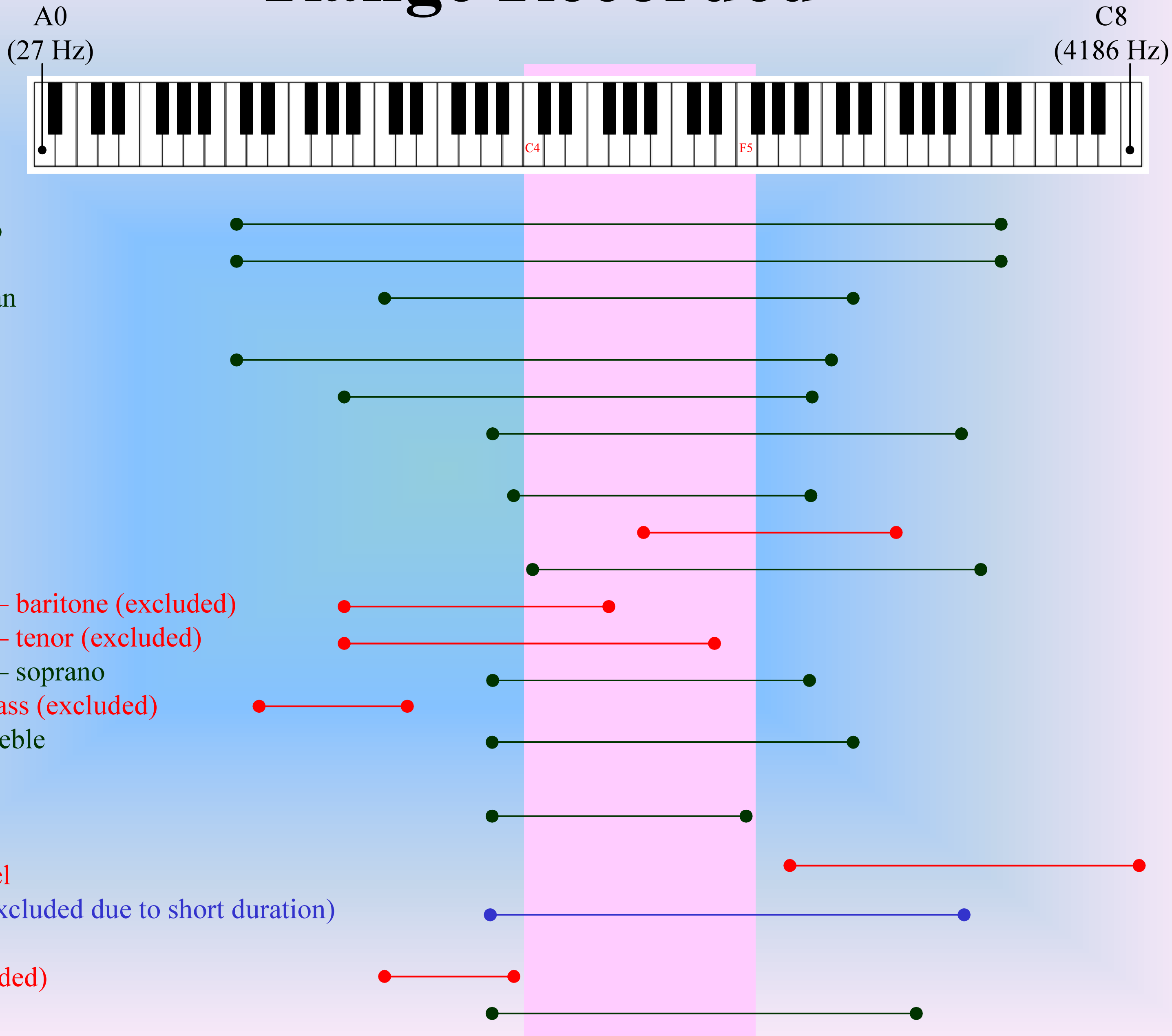
Brass

- Trumpet

Not used:

- Woodwind
  - -recorder
  - -saxophone (baritone, tenor)
  - -clarinet (bass)
- Percussion
  - -glockenspiel
  - -marimba

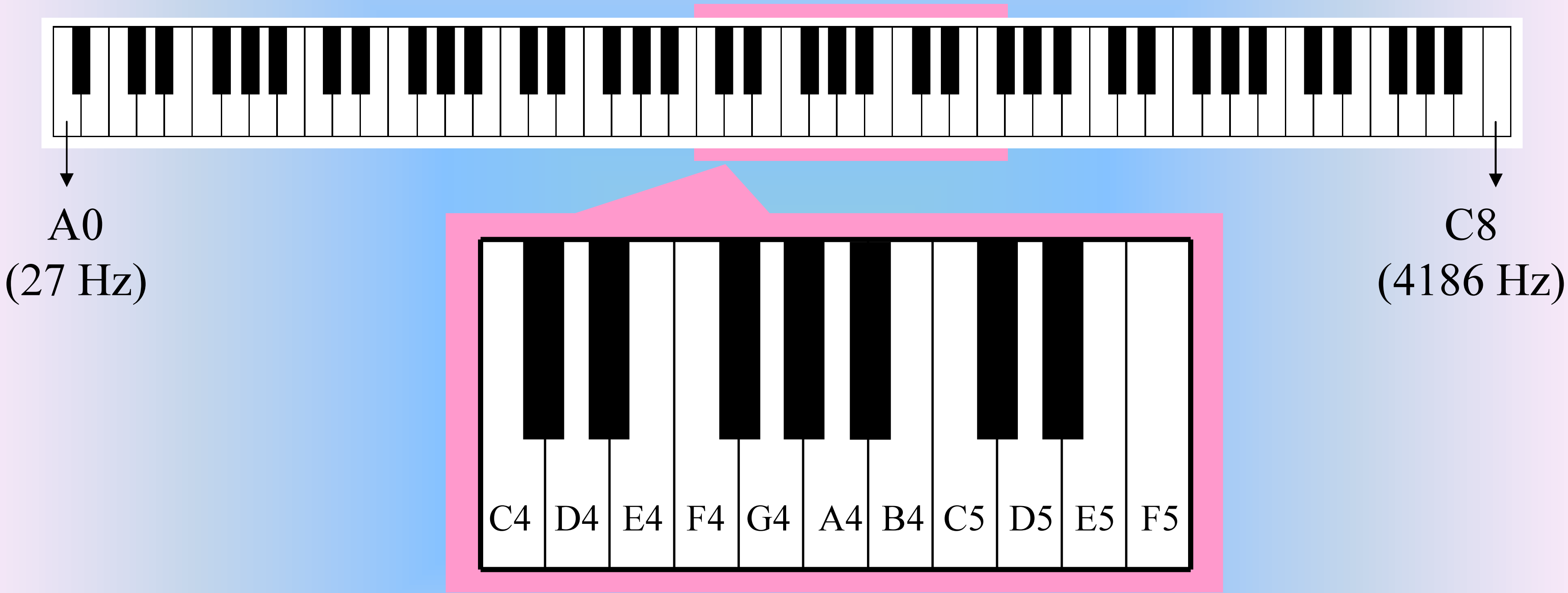
Range Recorded



- **Keyboard**
  - Grand piano
  - Piano
  - Church organ
- **String**
  - Cello
  - Guitar
  - Violin
- **Woodwind**
  - Oboe
  - Recorder
  - Flute
  - Saxophone – baritone (excluded)
  - Saxophone – tenor (excluded)
  - Saxophone – soprano
  - Clarinet – bass (excluded)
  - Clarinet – treble
- **Brass**
  - Trumpet
- **Percussion**
  - Glockenspiel
  - Marimba (excluded due to short duration)
- **Human**
  - Male (excluded)
  - Female

Range for Comparison

- 18 Notes: from C4 (262 Hz) to F5 (698 Hz)

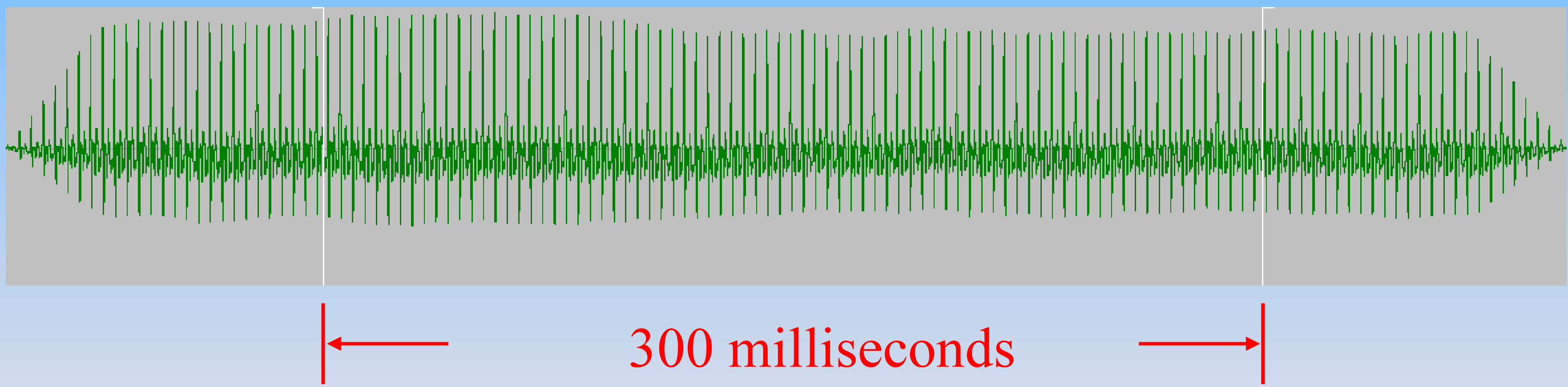


Note	C4	C4#	D4	D4#	E4	F4	F4#	G4	G4#	A4	A4#	B4	C5	C5#	D5	D5#	E5	F5
F0 (in Hz)	262	278	294	312	330	349	371	392	416	440	466	494	523	554	587	622	659	698

- The frequency, f2, that is n semitones above another frequency, f1, is calculated as: $f2 = (1.0595)^n \times f1$

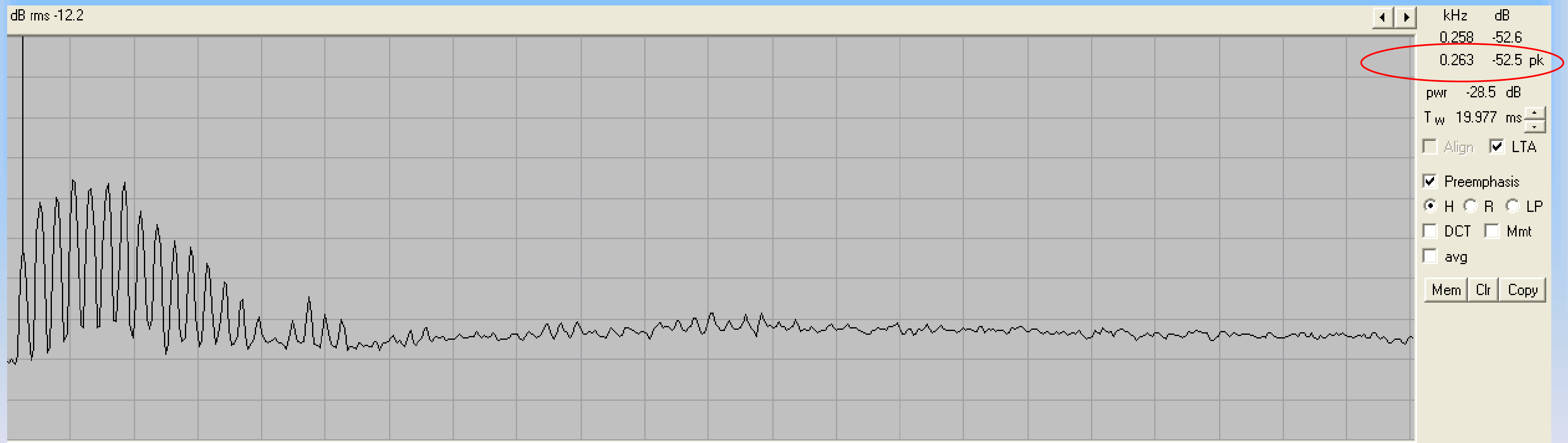
Data Analysis

- **Step 1**: Digitized signals were normalized and then displayed on the computer screen. A mid-portion of the time waveforms was segmented out and saved as wave files for further analysis.



Data Analysis

- **Step 2**: The frequency and amplitude of the spectral peaks between 0 and 5 kHz were measured from the long-time average (LTA) spectrum for the segment.

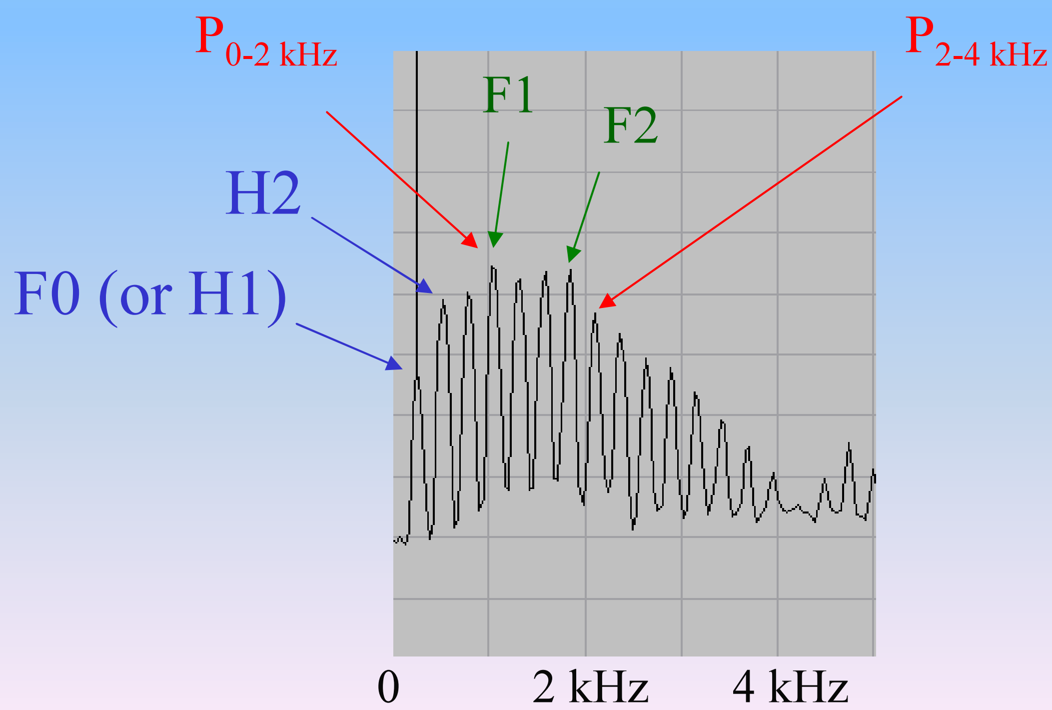


0

5 kHz

Measures for Statistical Analysis

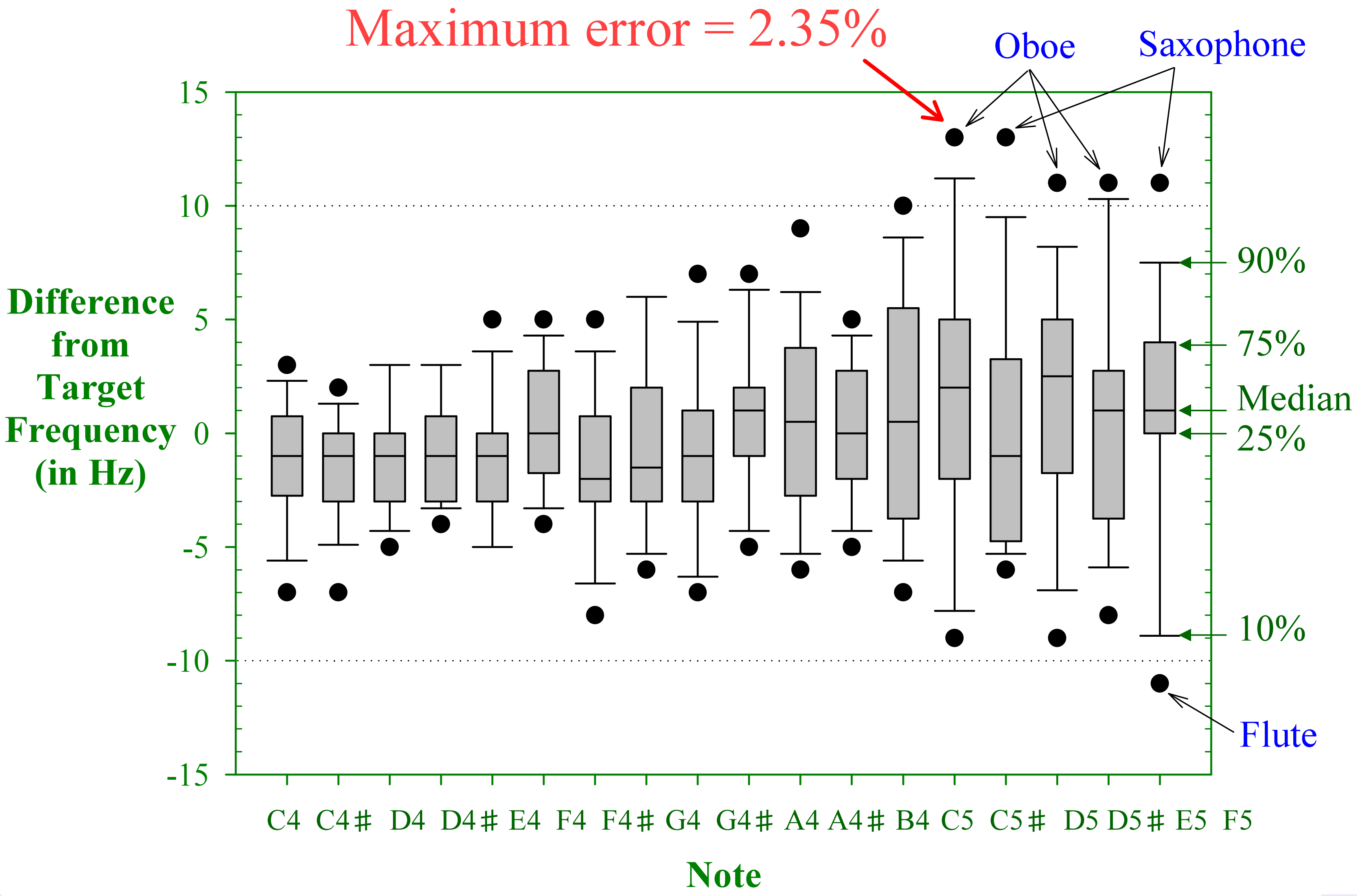
1. **Fundamental frequency (F0):** the first harmonic (H1)
2. **Singing power ratio (SPR):** Amplitude difference (in dB) between the highest spectral peak within the 2 - 4 kHz range and that within the 0 - 2 kHz range
3. **Formant one (F1) frequency:** the first leftmost peak of spectral envelope
4. **F1-F2 slope:** (F1-F2 amplitude difference)/(F1-F2 frequency difference)
5. **H1-H2:** Amplitude difference (in dB) between H1 and the second harmonic (H2)



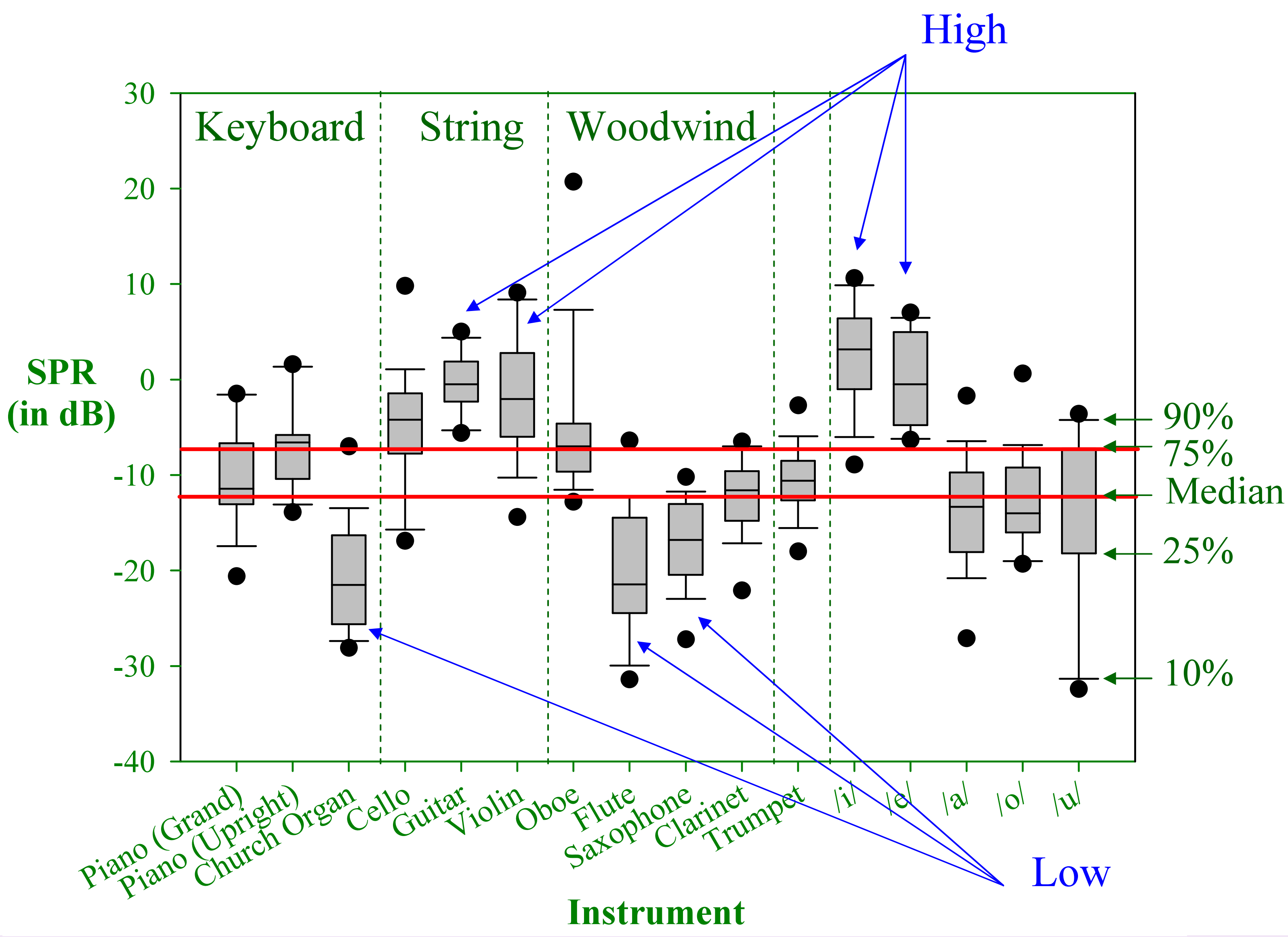
Statistical Analysis

- Descriptive statistics
- Inferential statistics:
  - A series of one-way Repeated Measures (RM) Analysis of Variances (ANOVAs) on Ranks were conducted to determine whether experimental measures varied by instruments.
  - Post-hoc multiple paired comparison procedures with Tukey test were conducted if a significant instrument effect was found.
  - Significance level was set at 0.05

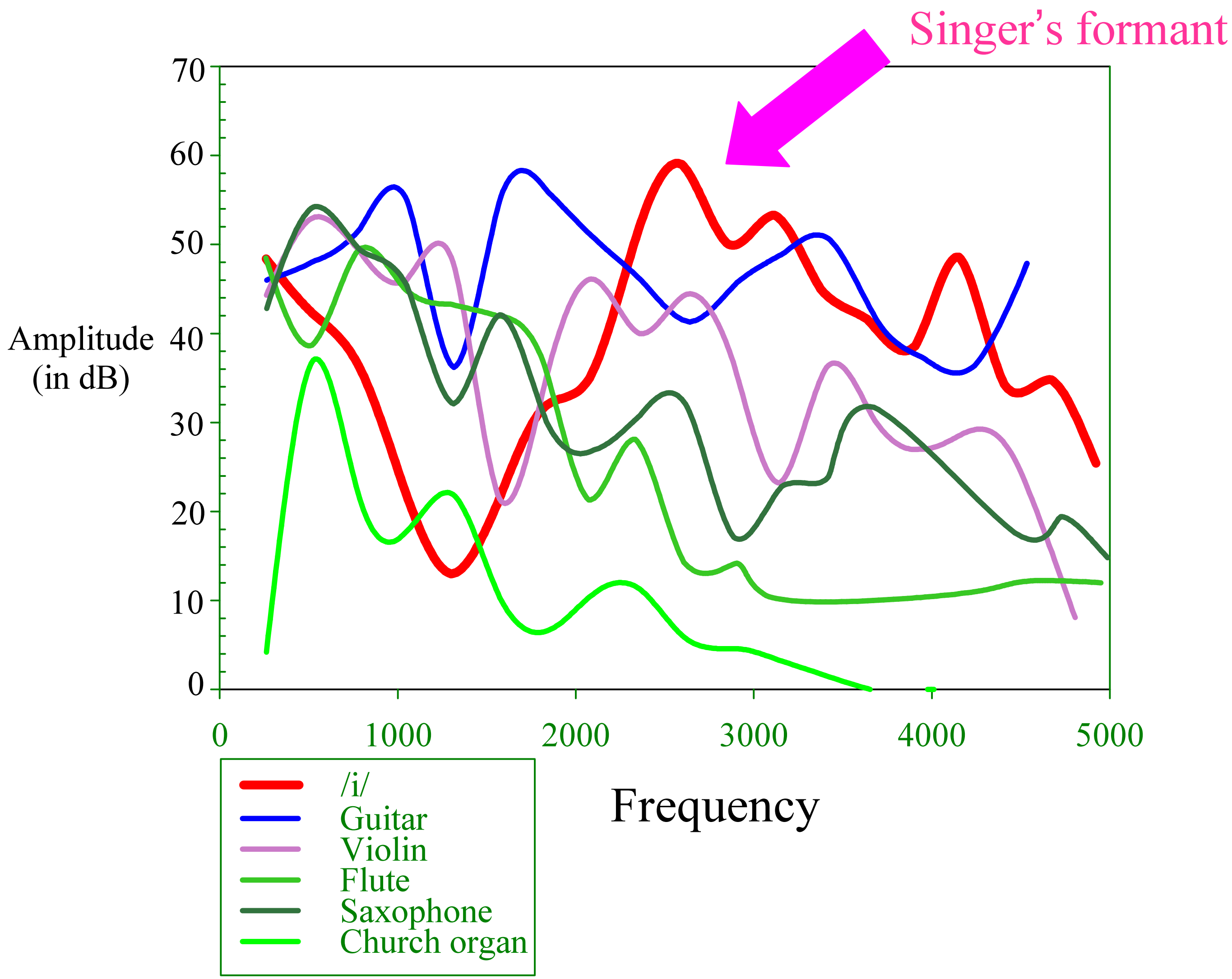
Fundamental Frequency



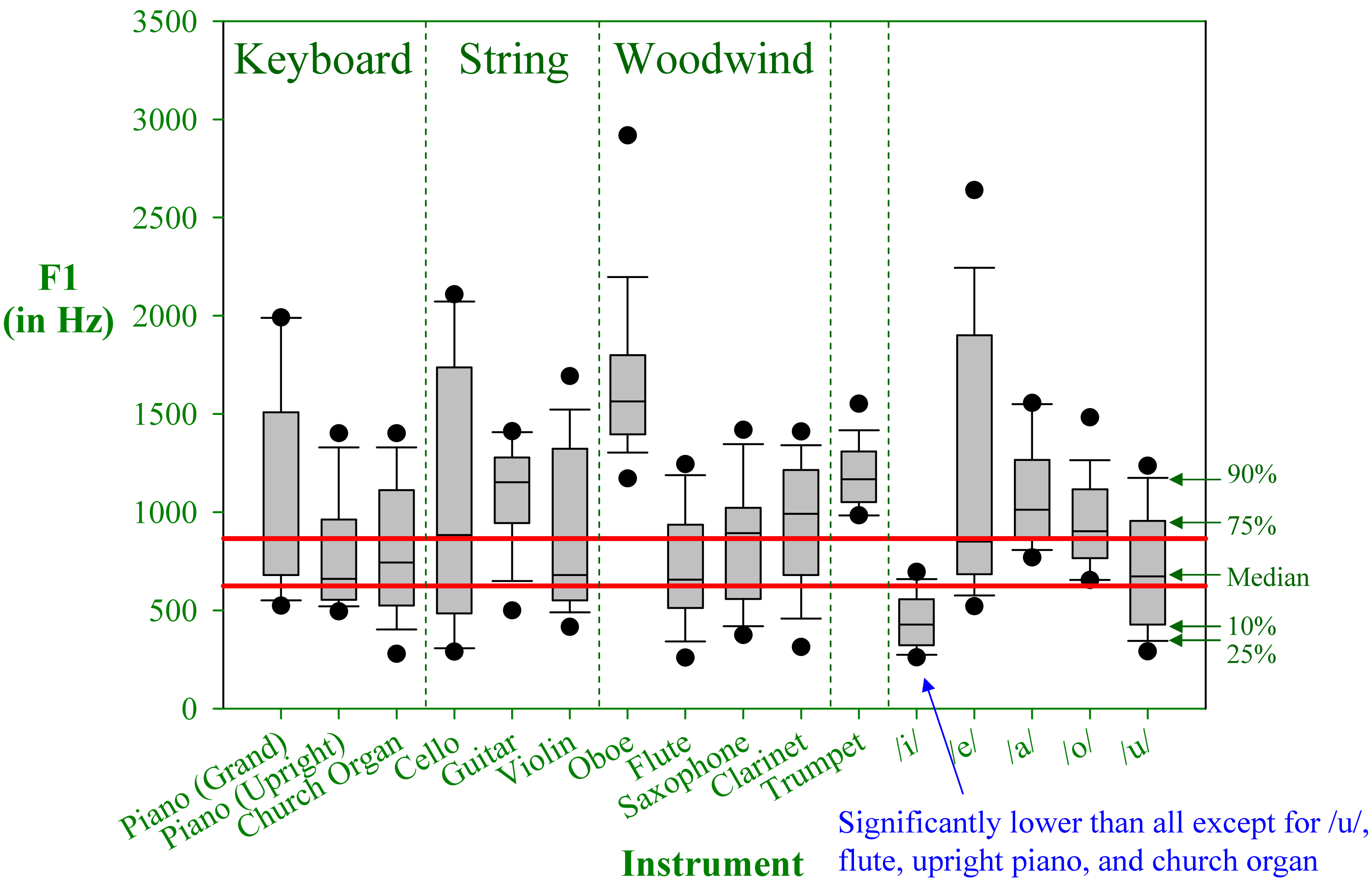
Singing Power Ratio



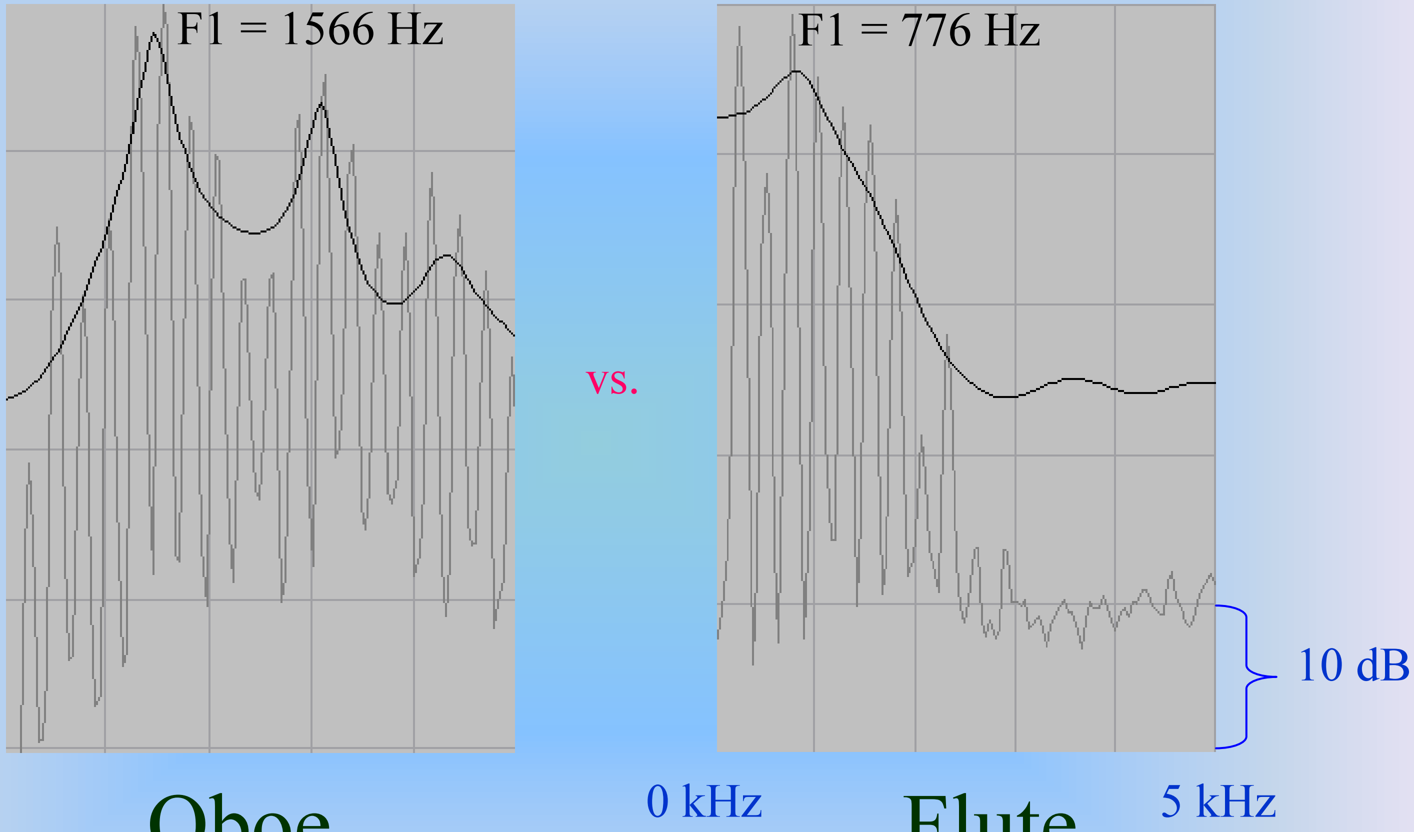
Singing Power Ratio – Examples



F1 Frequency



F1 Frequency – Examples (C4)



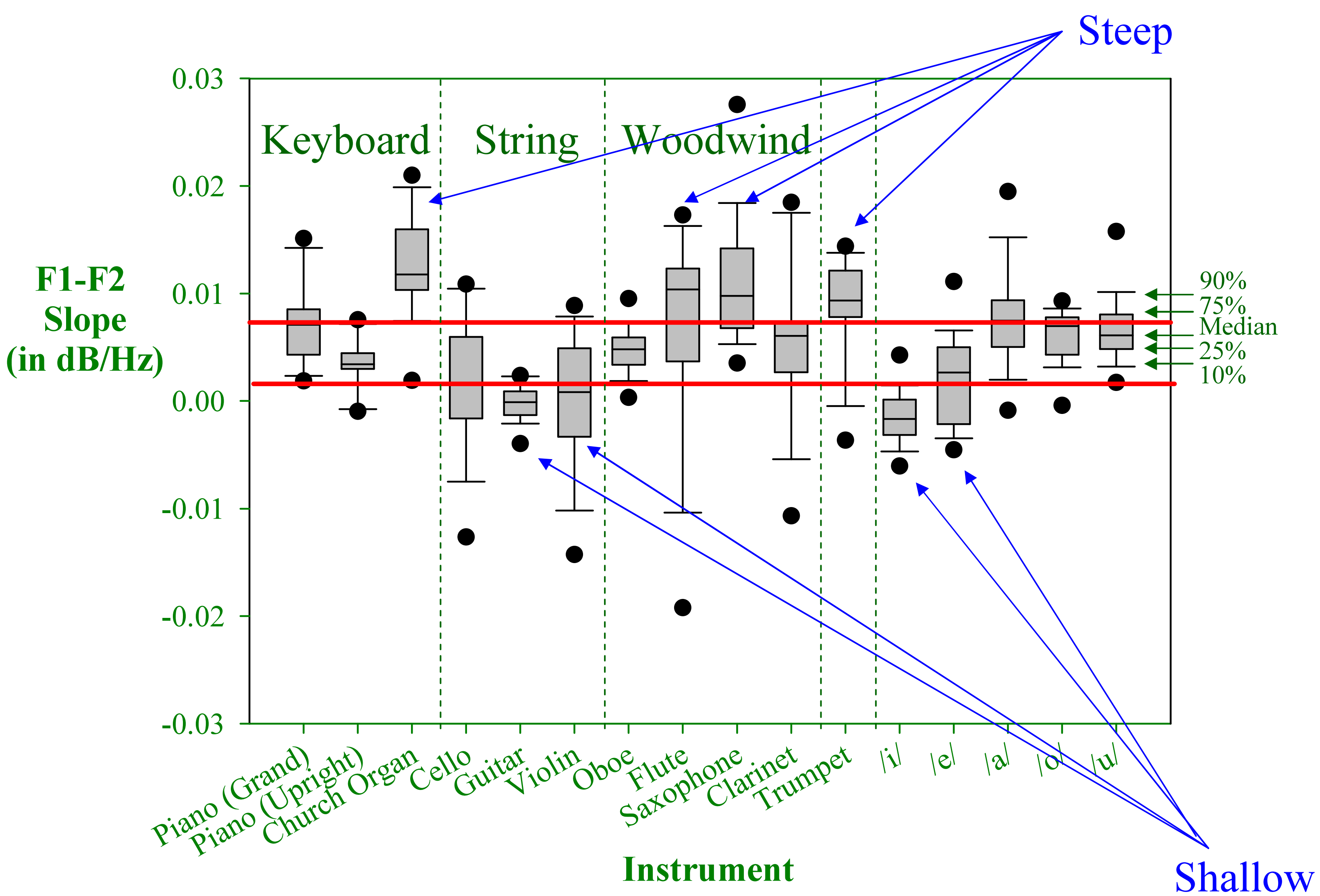
Oboe

Flute

High F1 frequency

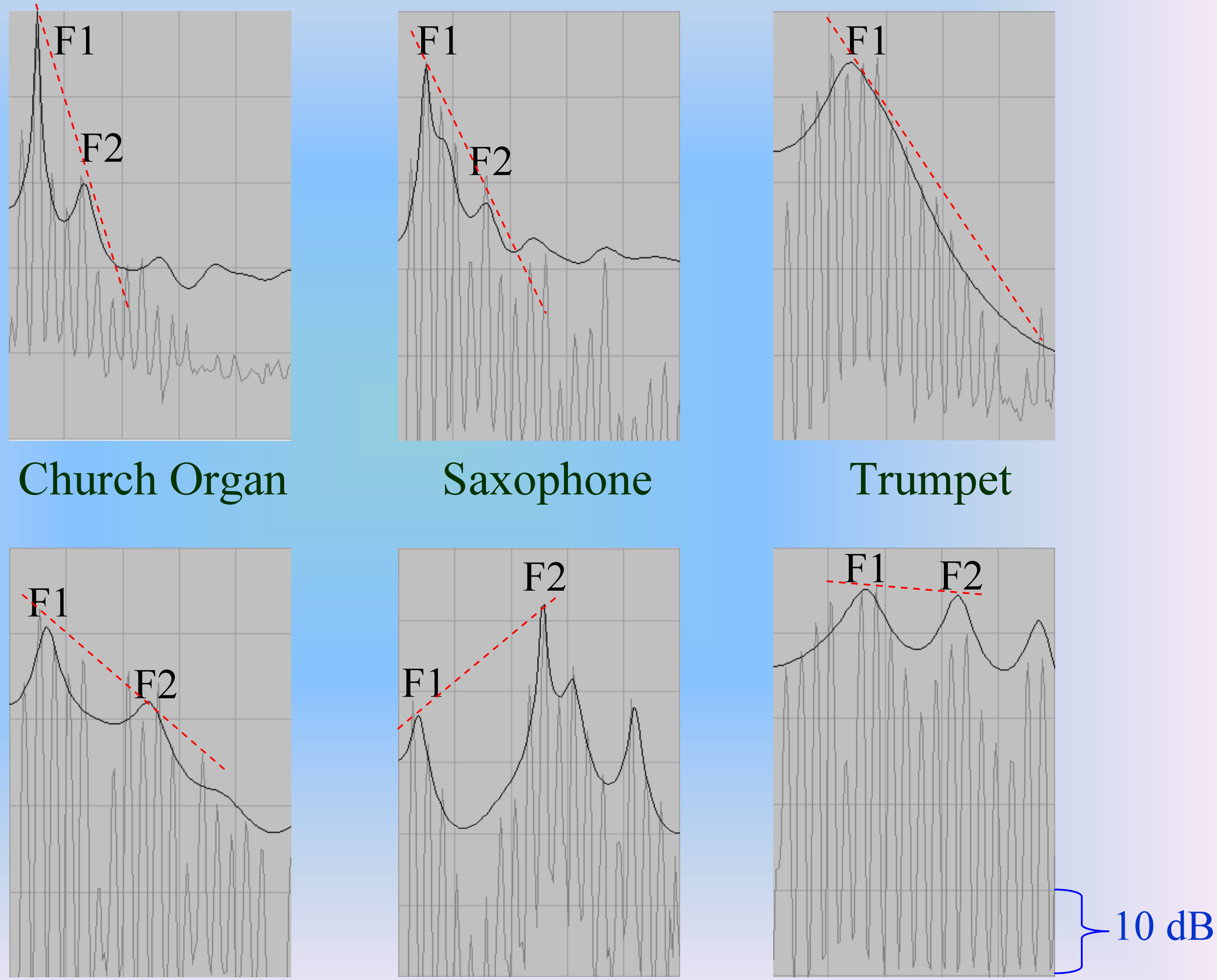
Low F1 frequency

F1-F2 Slope



Steep
Keyboard
String
Woodwind
F1-F2 Slope (in dB/Hz)
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
90%
75%
Median
25%
10%
Piano (Grand)
Piano (Upright)
Church Organ
Cello
Guitar
Violin
Oboe
Flute
Saxophone
Clarinet
Trumpet
/i/
/e/
/a/
/o/
/u/
Instrument
Shallow

F1-F2 Slope – Examples (C4)



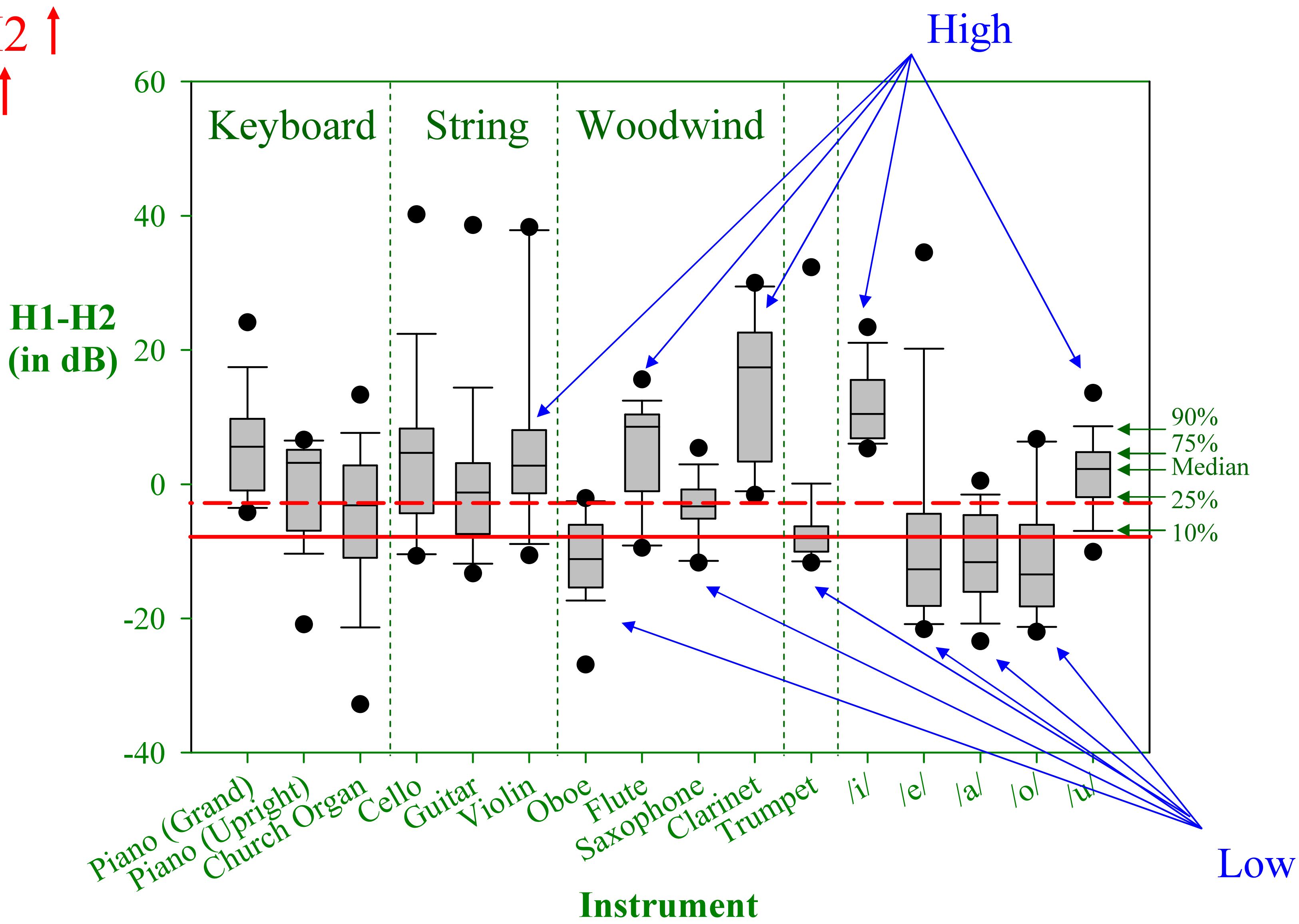
Steep: Church Organ, Saxophone, Trumpet

Shallow: Violin, Guitar

0 kHz /i/ 5 kHz

H1-H2 Amplitude Difference

H1-H2 ↑
Thin ↑

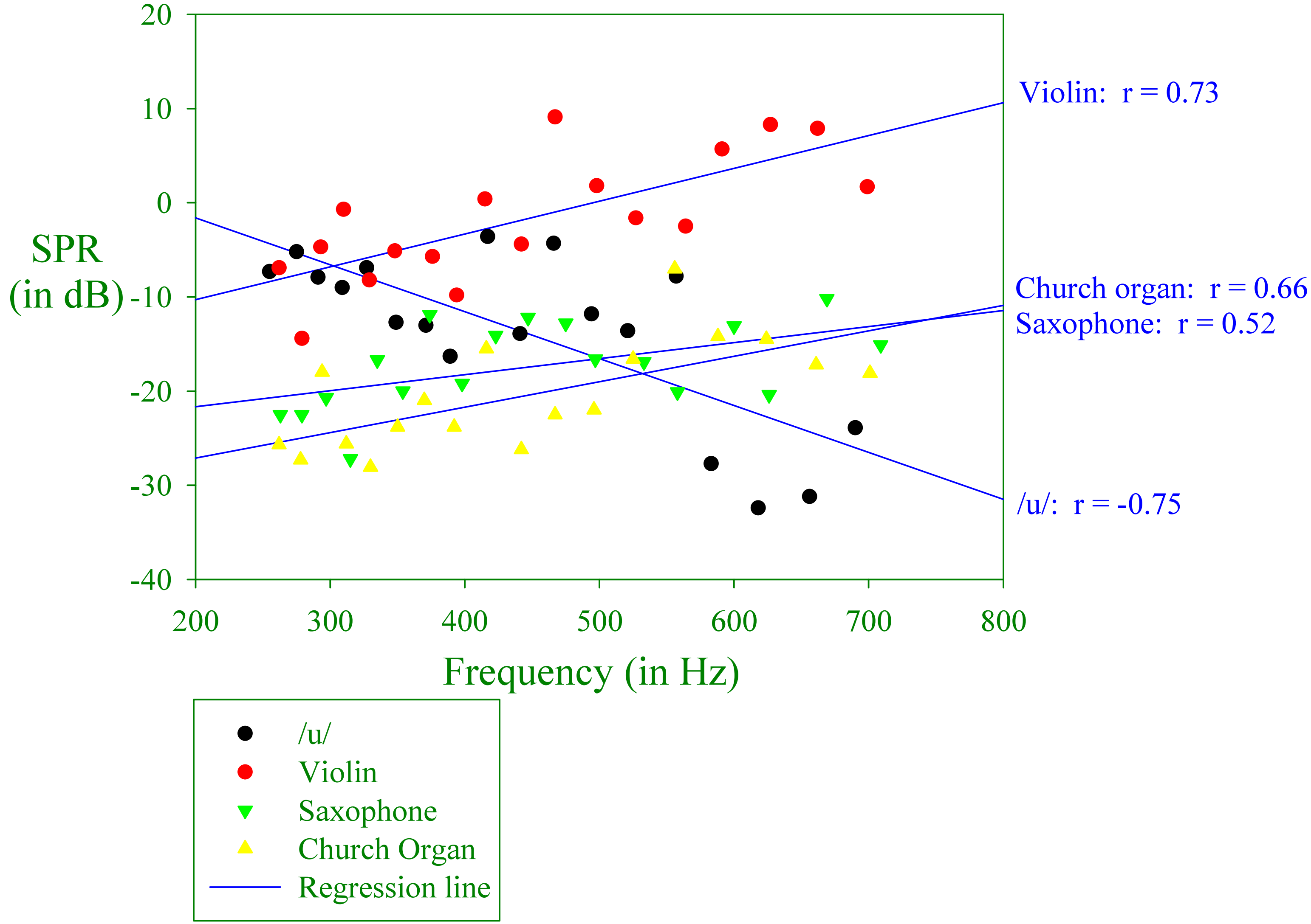


Correlations between Experimental Measures

	SPR	F1 frequency	F1-F2 slope	H1-H2 amplitude difference
F0	-0.028	0.289	0.053	0.220
SPR		0.116	-0.641*	0.121
F1 frequency			0.166	-0.166
F1-F2 slope				-0.232

* Significantly correlated (Pearson's product moment correlation)

Correlations between F0 and SPR



Main Findings

Q: Does a trained singer's singing voice show higher SPR than musical instruments in the absence of background music?

-Is there is vowel effect?

-How is SPR related to formant frequencies?

A: Yes.

- Female singing voice in sustaining front vowels /i/ and /e/ showed significantly higher SPR than all musical instruments except for violin and guitar.
  - Violin and guitar showed significantly higher F1 frequency than /i/ (but not /e/).
  - Violin, guitar, /i/, and /e/ all showed shallow F1-F2 slope.
  - H1-H2 amplitude difference (related to vocal fold thickening):
    - High: for /i/ and violin
    - Low: for /e/ (and all back vowels)
- In general, SPR was inversely related to F1-F2 slope.

Main Findings - continued

Q: Is there a pitch effect on SPR?

A: Yes.

SPR decreased by F0 for /u/ but increased for violin, church organ, and saxophone.

Agrees with previous findings:

- Intensity of singer's formant decreased for increasing F0 (Schultz-Coulon, 1979; Bloothooft & Plomp, 1986)

Conclusion

- String instruments, especially violin and guitar, generate rich high frequency harmonics, and thus the highest SPR amongst the musical instruments investigated in this study.
- Front vowels /i/ and /e/ show the highest SPR, suggesting that the vocal tract configuration (e.g., anterior oral constriction or pharyngeal widening) associated with front vowels may be conductive to SPR.
- SPR decreased with increasing F0 for /u/, suggesting more need for adjustment for projecting this vowel at high pitch range.

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