OSHER LIFELONG LEARNING INSTITUTE

Sound of Music

How It Works

Plainsong and Gregorian Chants
Hymn *Lucis Creator* and a Canticle
Beauty in Sound (2019)

Session 7

Singing

OLLI at Illinois
Spring 2020

D. H. Tracy

Reconstruction of Sounds from Roman Cornu Horn

Floor mosaic, Zliten, Libya ca 1st Century CE. Musicians at Gladiatorial Contest with Roman Tuba, Hydraulis pipe organ, two Conua.

Music played on Virtual Cornu using Modalys simulation program.

[René Caussé & team, Institute for Research and Coordination in Acoustics and Music, Paris (2017)]

Cornu dimensions, materials and construction details from Pompei artifacts at Museo Archeologico Nazionale di Napoli.
3.4 m Length, Conical, Sheet metal, Bronze Alloy

From *Physics*, online magazine of the American Physical Society (March 5, 2020)

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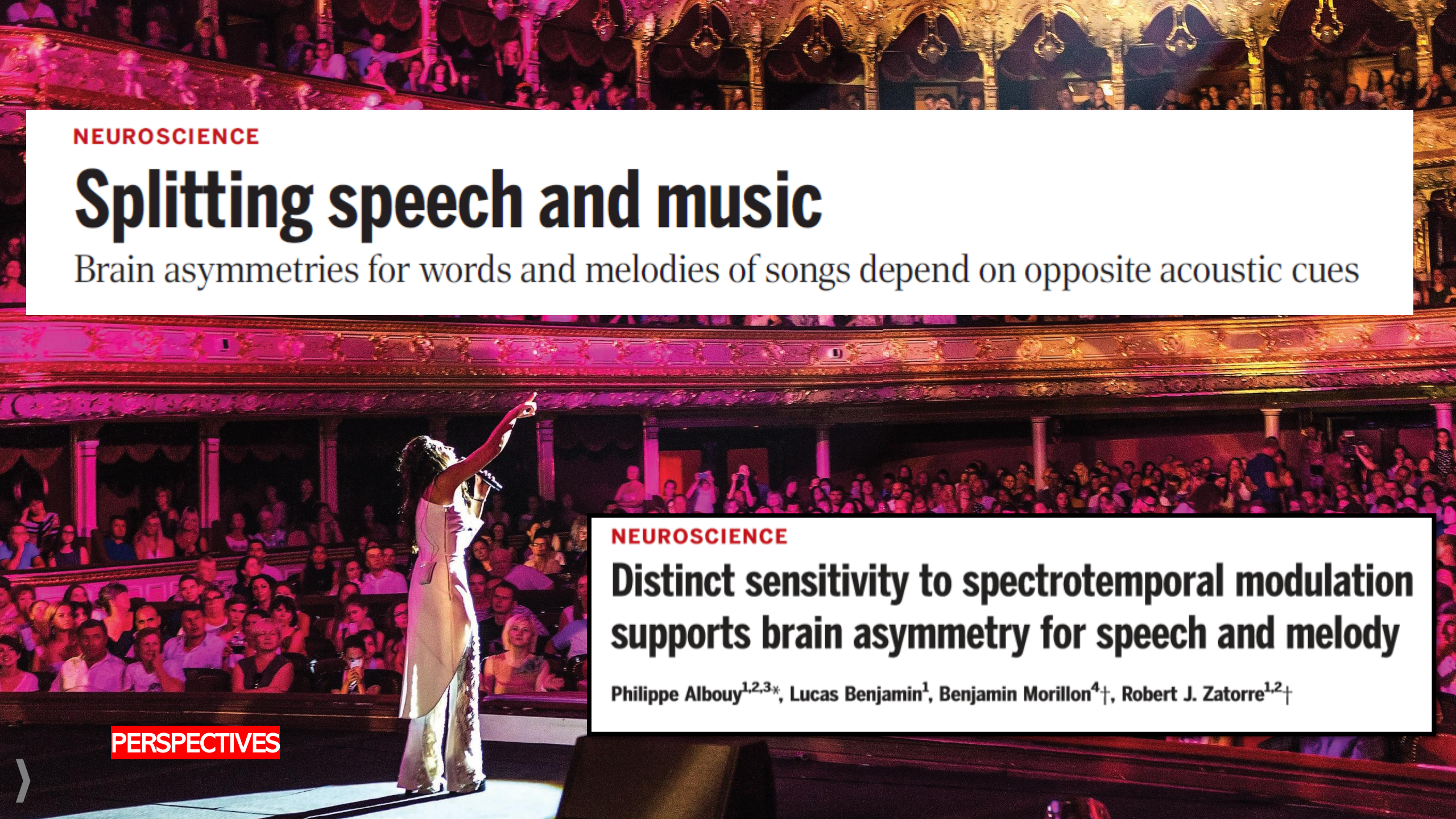
Course Outline

1. Building Blocks: Some basic concepts
2. Resonance: Building Sounds
3. Hearing and the Ear
4. Musical Scales
5. Musical Instruments
6. More Musical Instruments
7. Singing
8. Notation; Harmony and Dissonance

Science

Feb 28, 2020 AAAS

PERSPECTIVES



NEUROSCIENCE

Splitting speech and music

Brain asymmetries for words and melodies of songs depend on opposite acoustic cues

NEUROSCIENCE

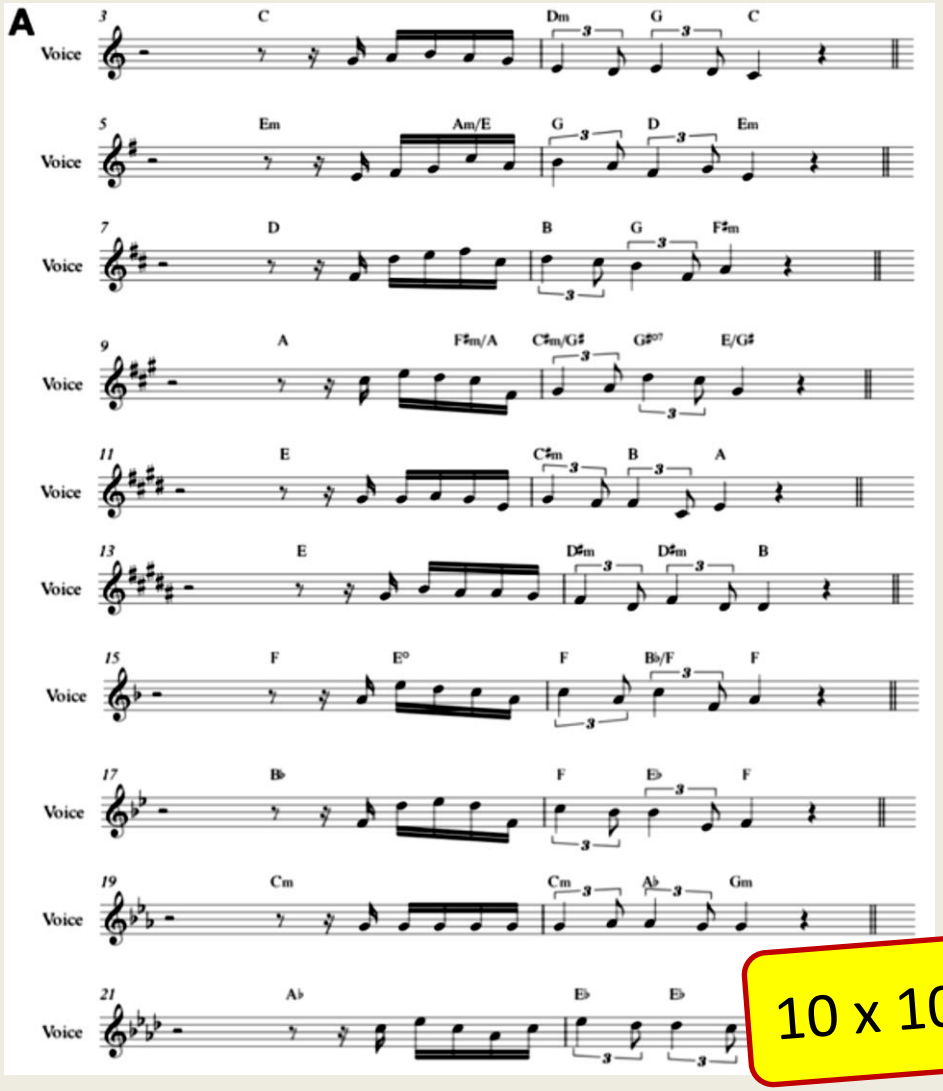
Distinct sensitivity to spectrotemporal modulation supports brain asymmetry for speech and melody

Philippe Albouy[1,2,3]*, Lucas Benjamin[1], Benjamin Morillon[4]†, Robert J. Zatorre[1,2]†

PERSPECTIVES

Albouy *et al*

10 novel Melodies



10 Lyric lines

They said it was a cross they saw in church
The peo - ple thought a coin was hi - den there

The ser - vant came to love the chil - dren's dog
He chose to take a long and lone - ly road

The hall - way leads to doors that let us out
They told them that a tax would sure - ly help

I think Jane has a soft and love - ly voice
Meg-han wan-ted to talk to all the boys

Ma - gi - cians like to trick and fool their fans
Jack Jim and John wear three a-ma-zing hats

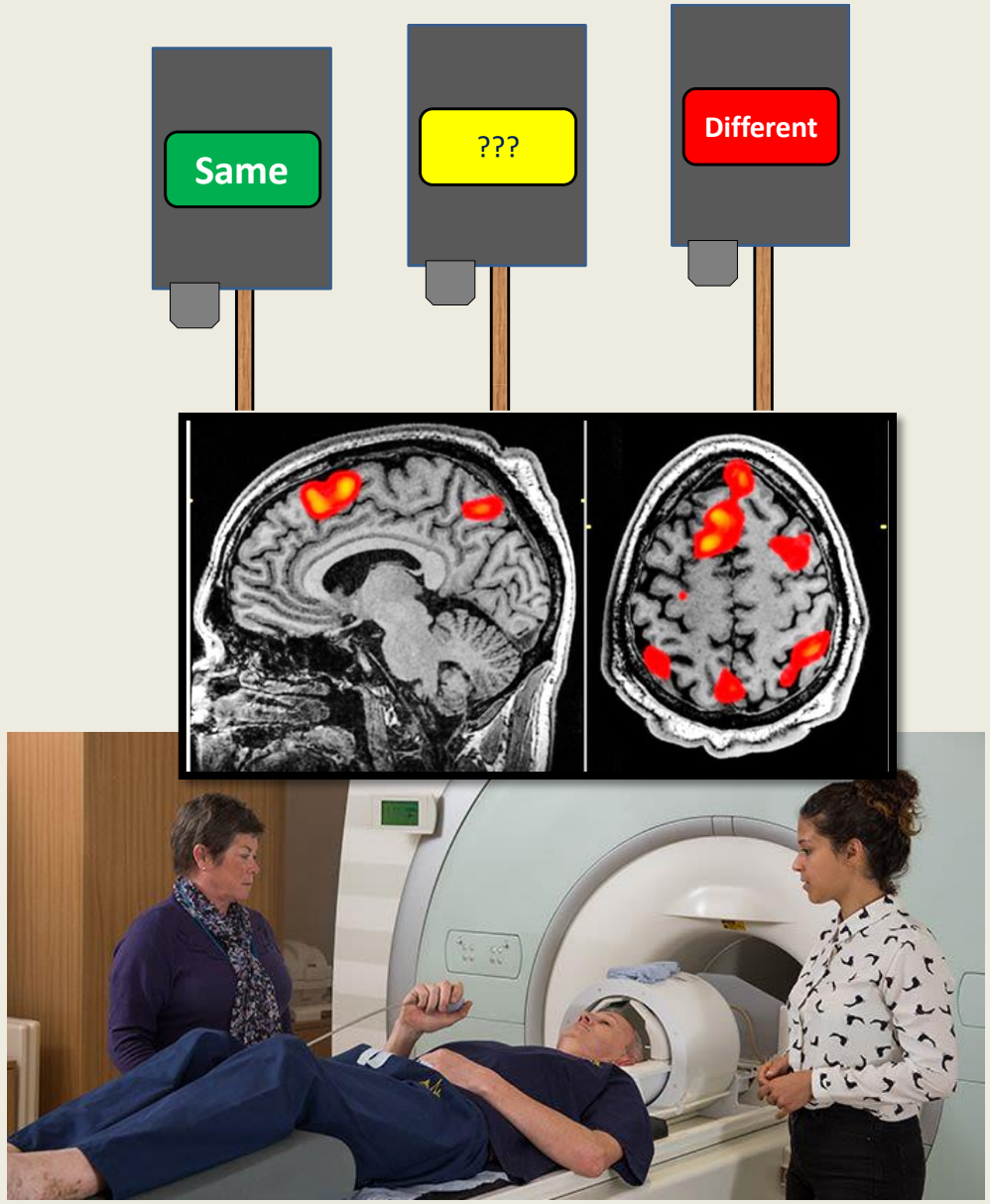
10 x 10 = **100 Songs**

The McGill Experiment

Albouy *et al* *Science* Feb 28, 2020

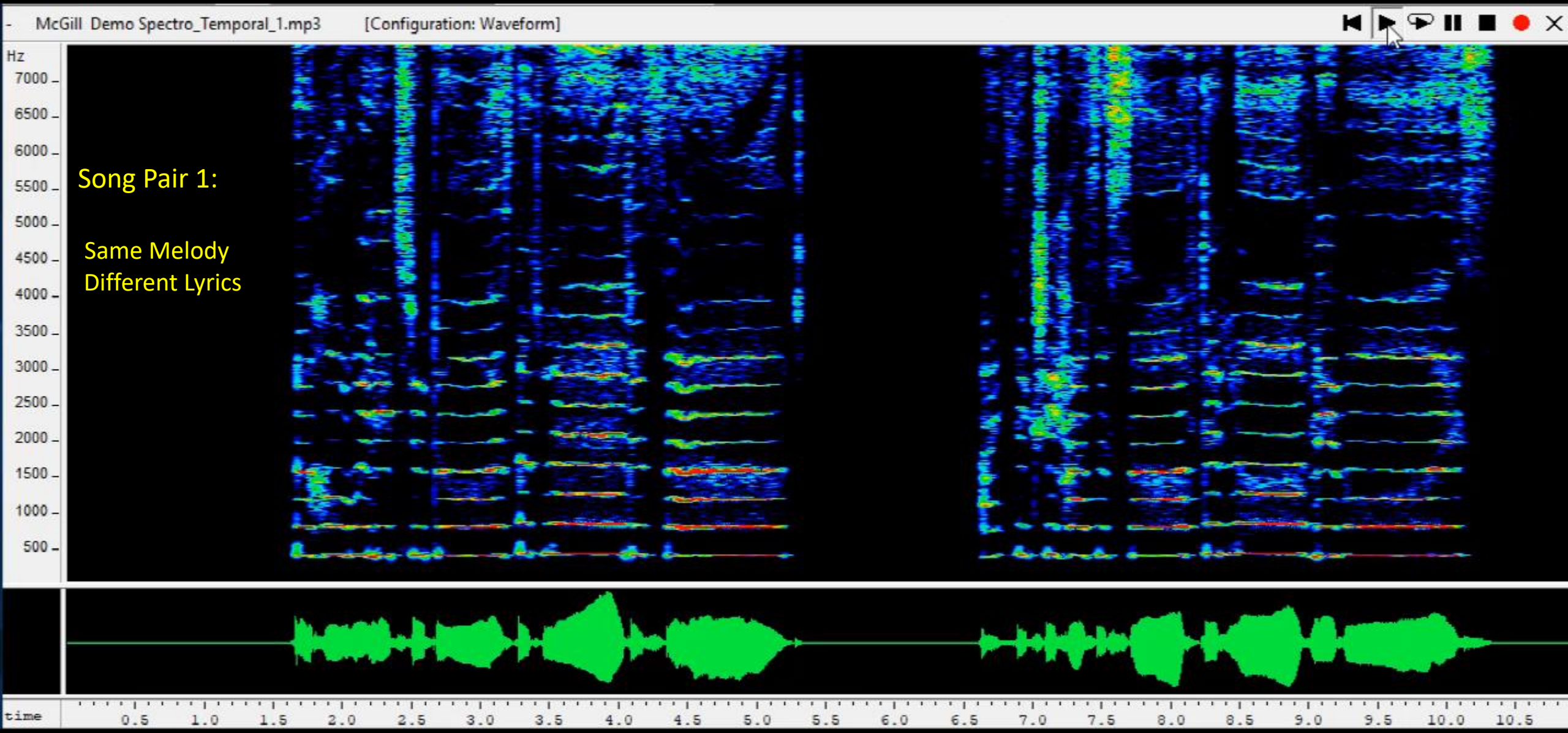
Try the Demo Experiment yourself online at
www.Zlab.McGill.ca/Spectro_Temporal_Modulations/

- Listen to **Pairs** of Songs
- Judge whether either **Melodies** or **Lyrics** are
  - The Same
  - *or* Different
- *Spoiler:* Some Songs may be distorted either
  - **Spectrally** (by smearing Frequencies) *or*
  - **Temporally** (by smearing Time)
- *Note:* You will be lying in a fMRI Machine
  - Just relax!



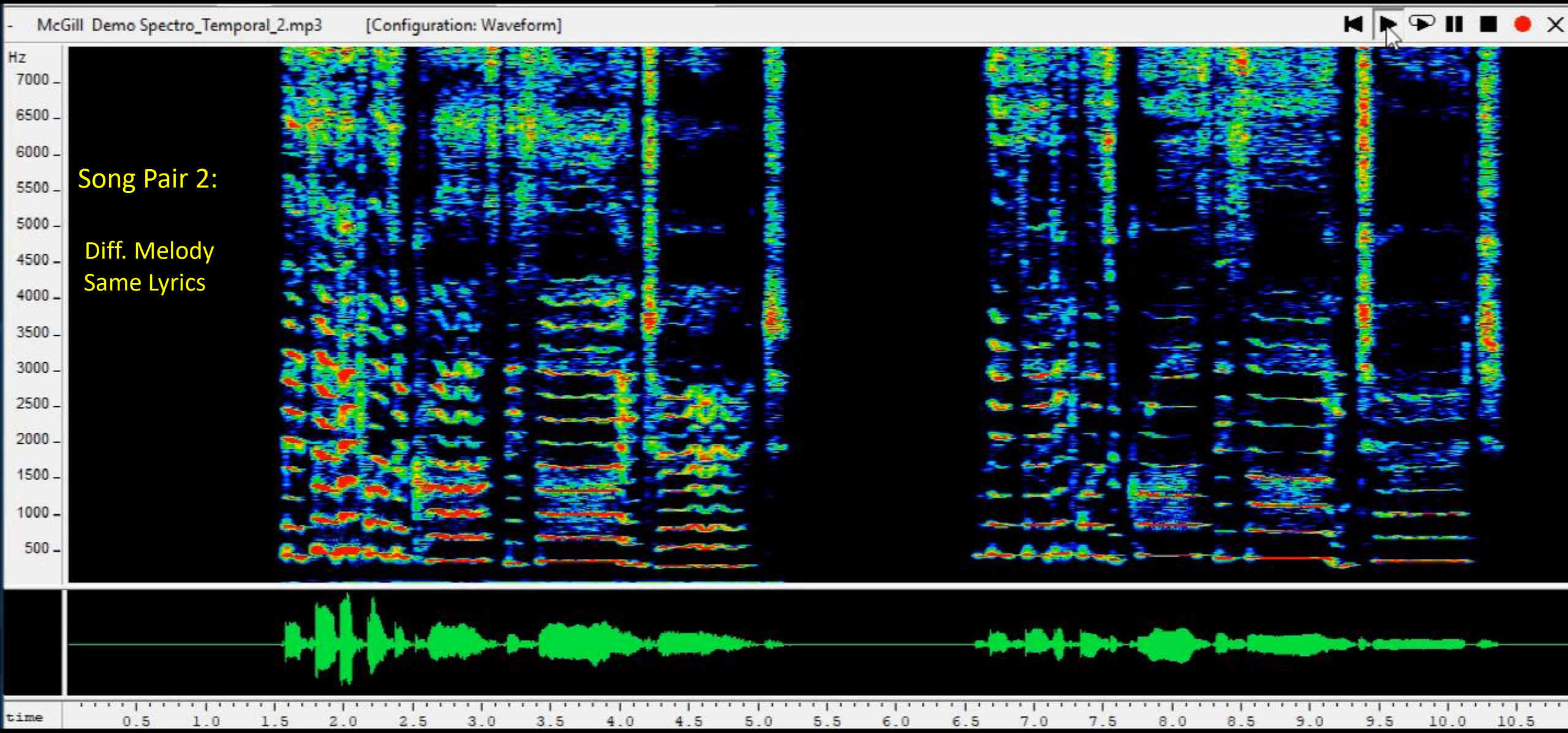
The hall-way leads to doors that let us out

I think she has a soft and love-ly voice



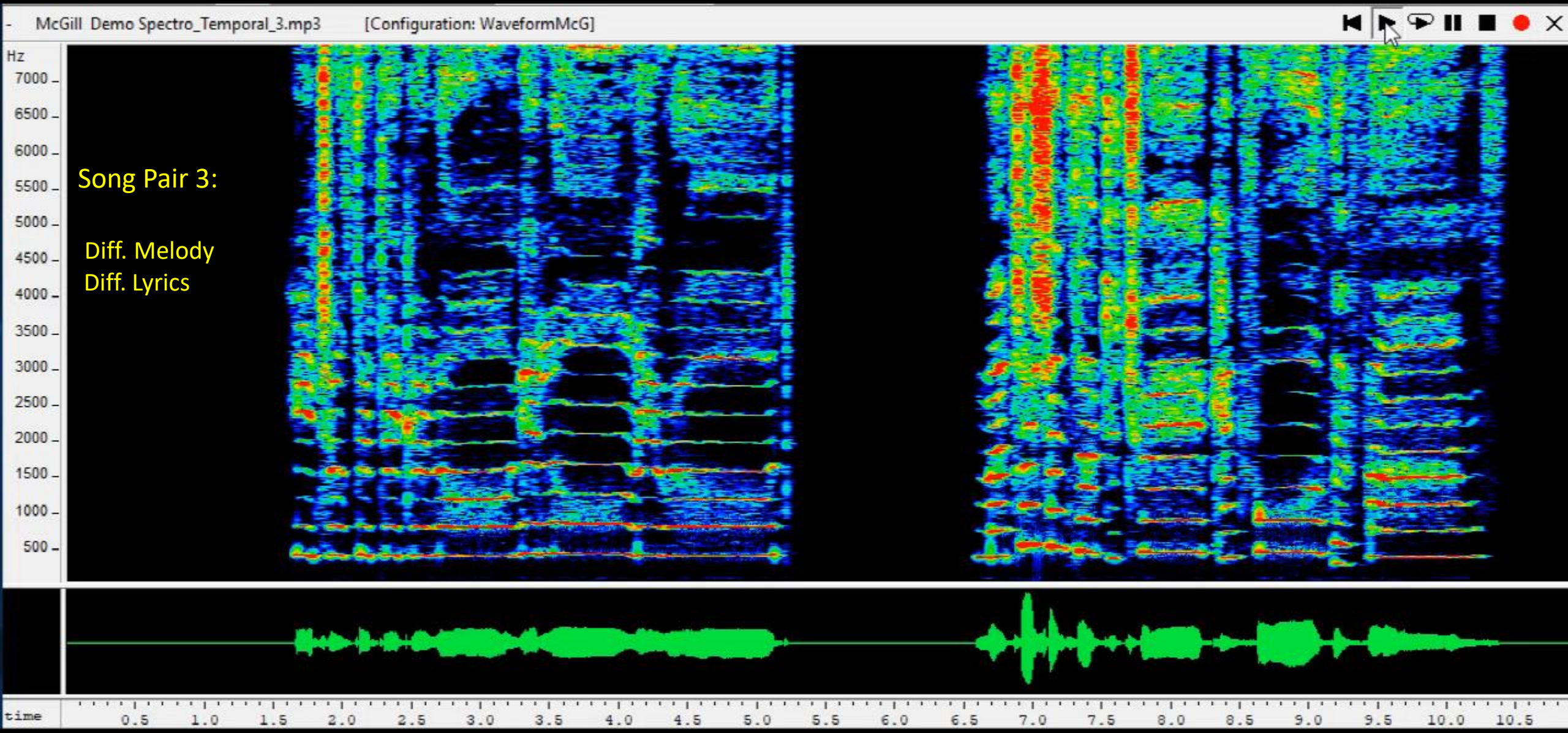
They said it was a cross they saw in church

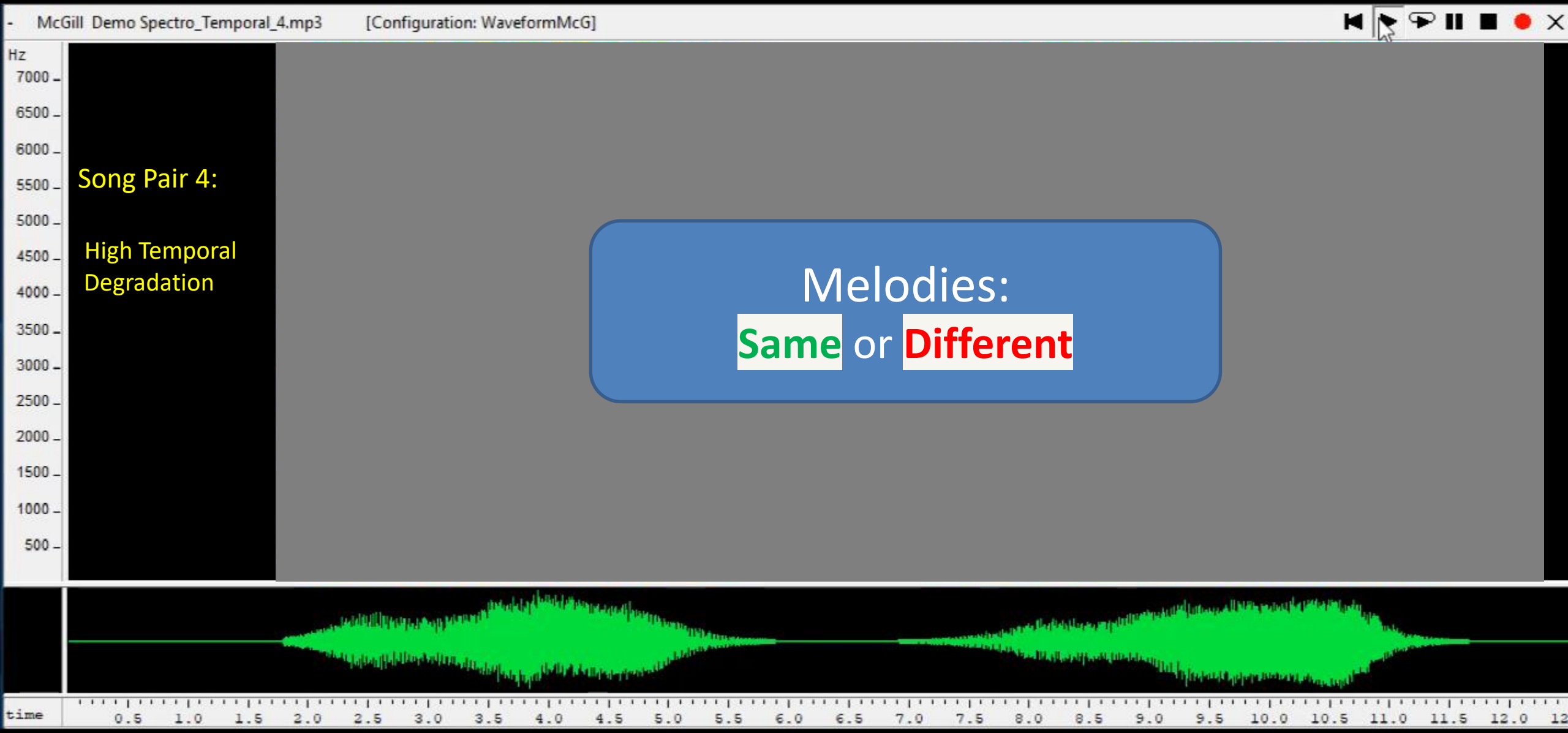
They said it was a cross they saw in church



He chose to take a long and lone-ly road

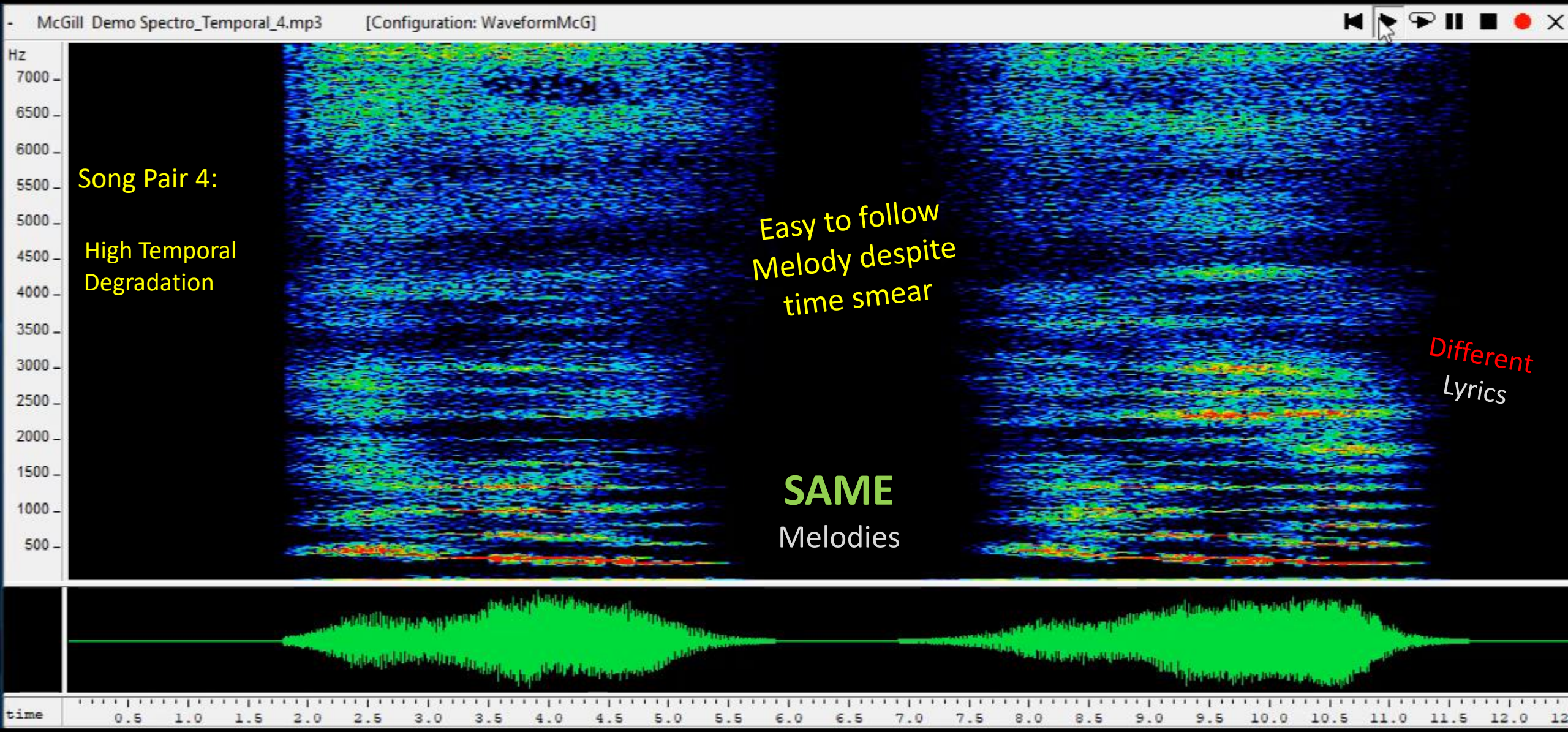
Magicians like to trick and fool their fans

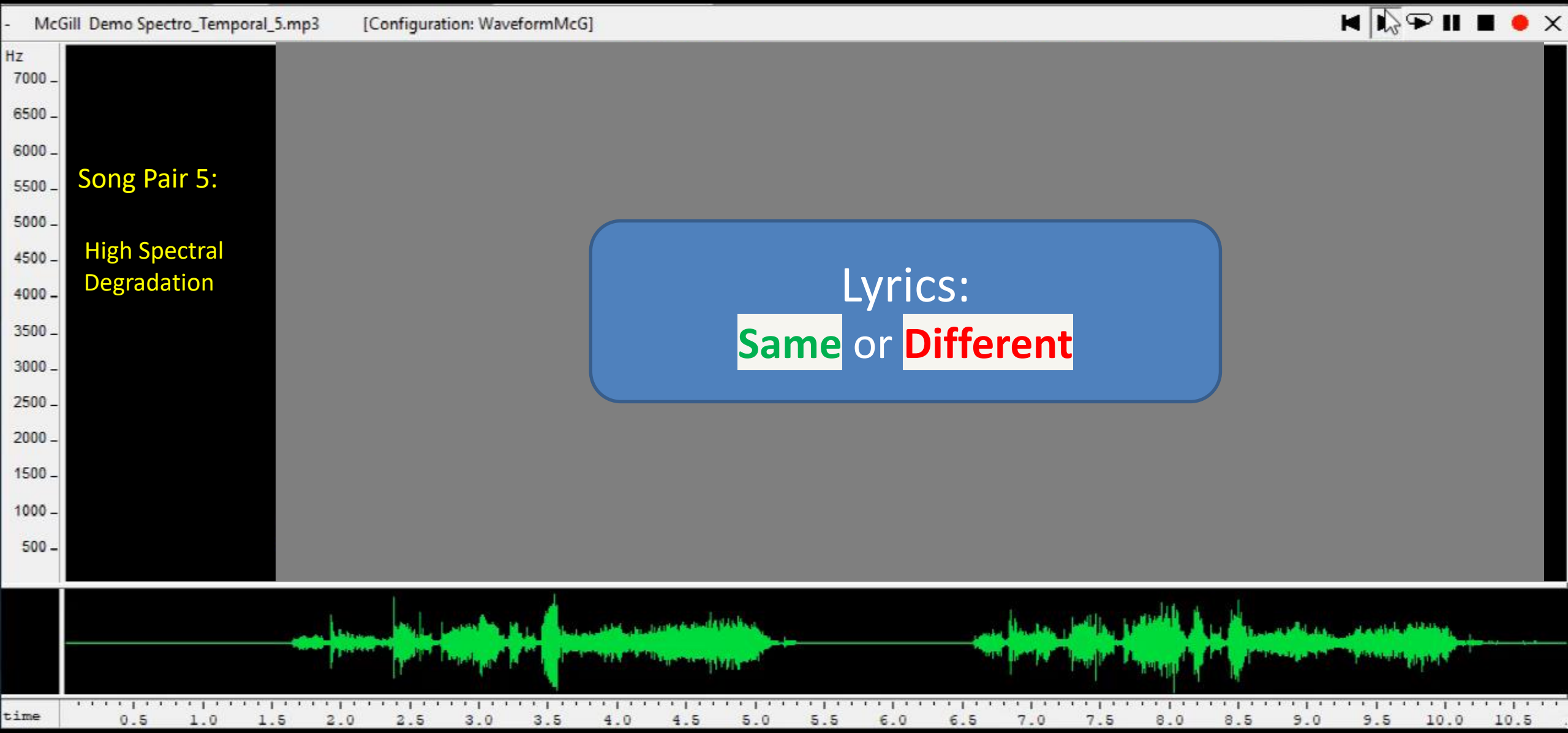



McGill Demo Spectro_Temporal_4.mp3
[Configuration: WaveformMcG]
Hz
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Song Pair 4:
High Temporal Degradation
Melodies:
Same or Different
time
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0

??#%?&!#??

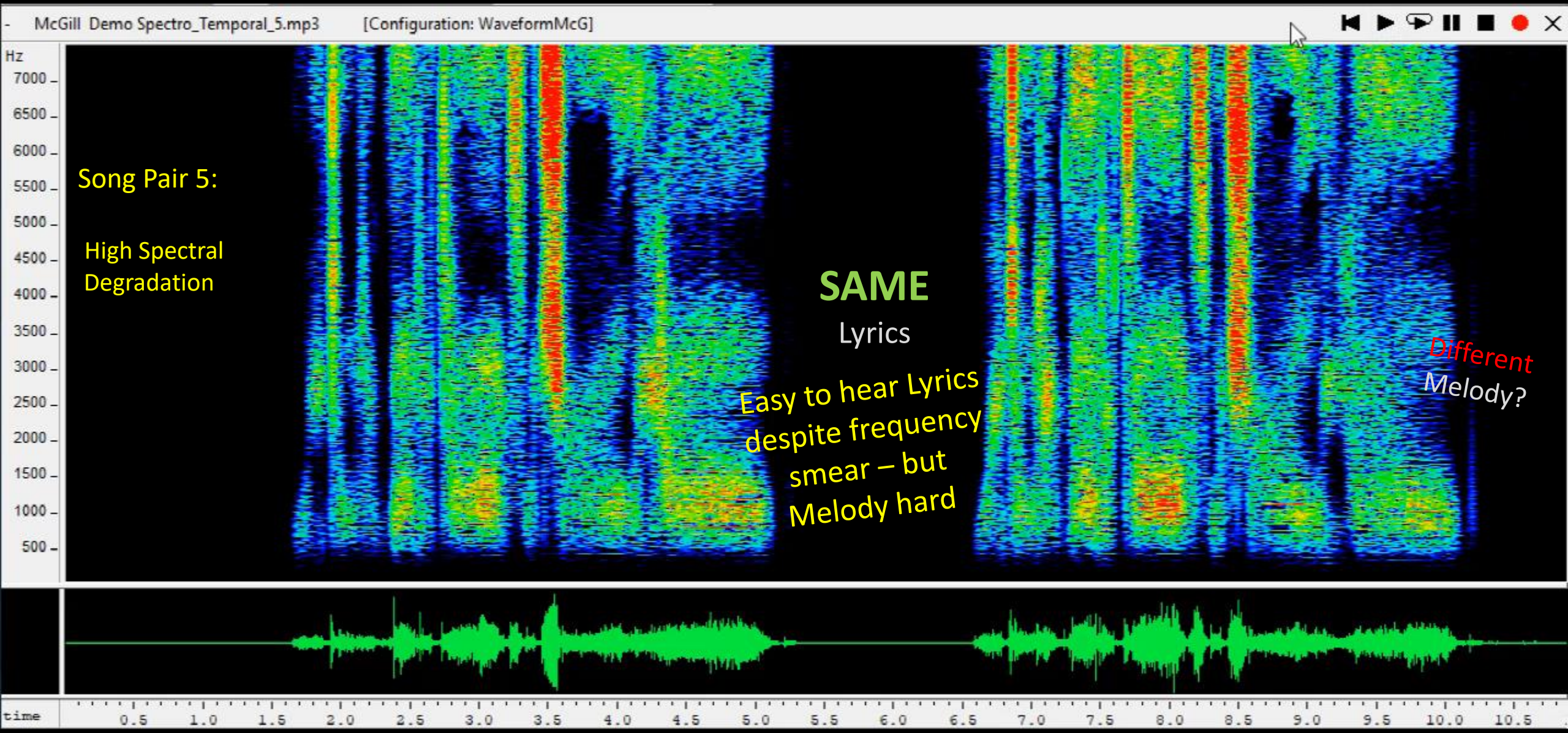
???*%#@%?#

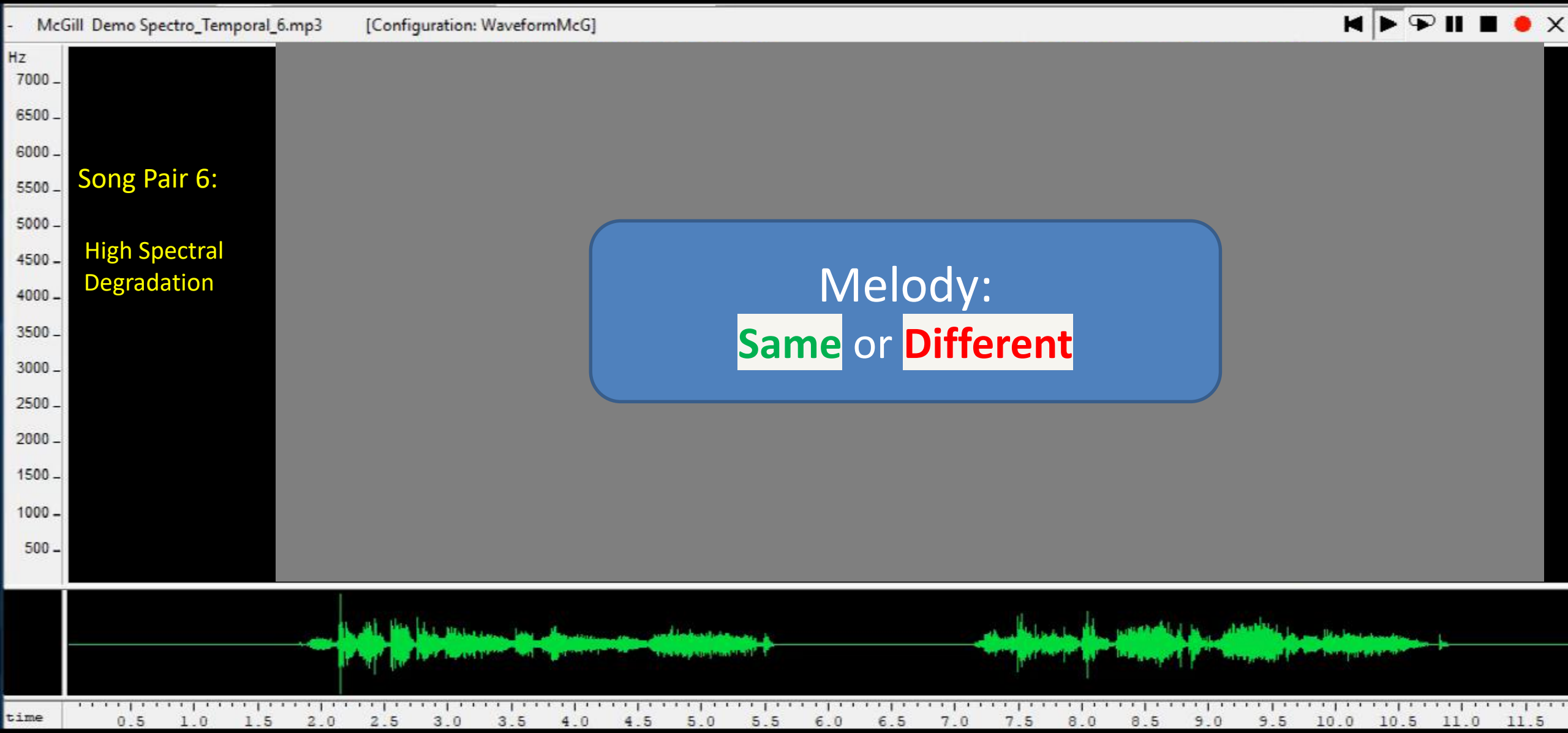

McGill Demo Spectro_Temporal_4.mp3
[Configuration: WaveformMcG]
Hz
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Song Pair 4:
High Temporal Degradation
Easy to follow Melody despite time smear
Different Lyrics
SAME
Melodies
time
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0


McGill Demo Spectro_Temporal_5.mp3
[Configuration: WaveformMcG]
Hz
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Song Pair 5:
High Spectral Degradation
Lyrics:
Same or Different
time
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5

We told them that a tax would sure-ly help

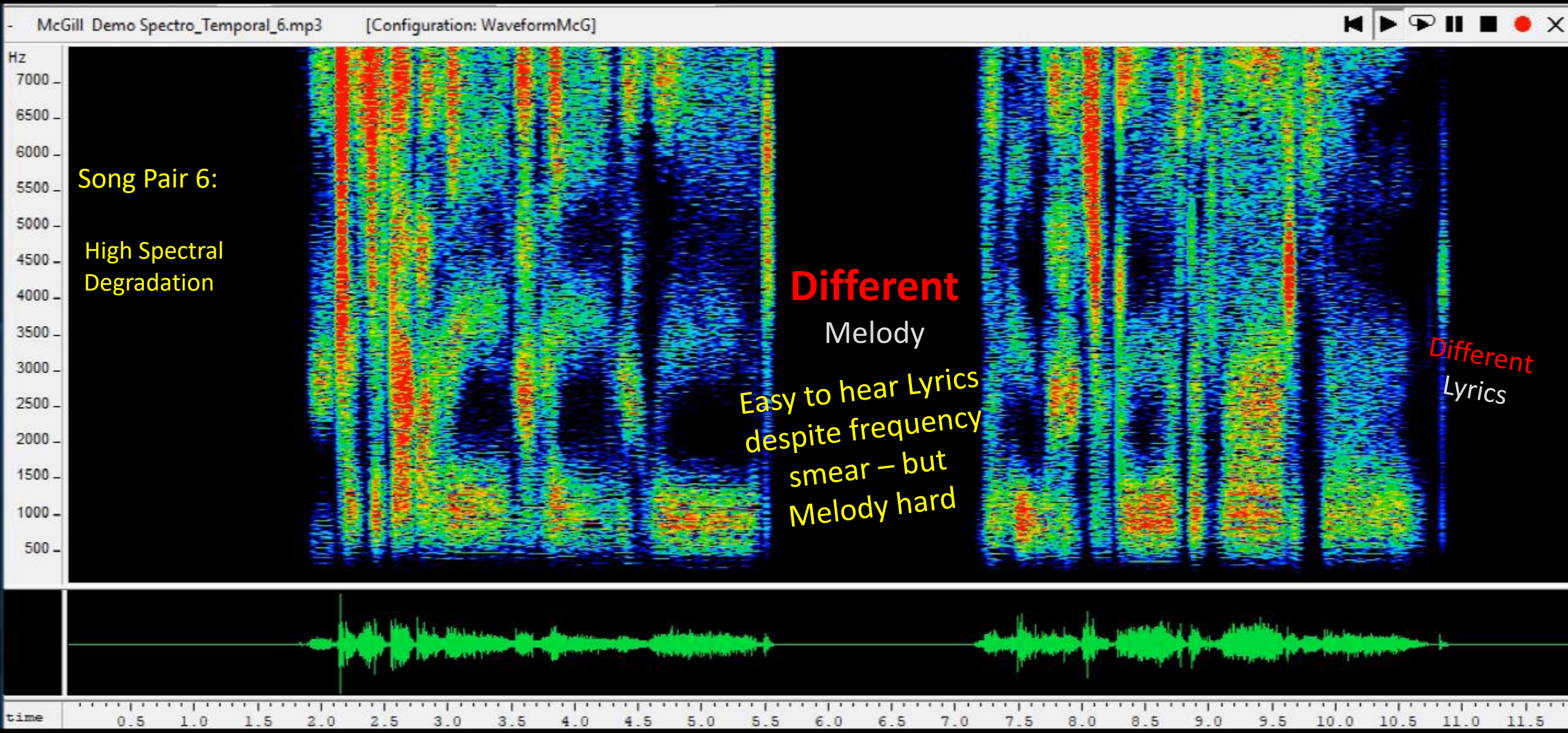
We told them that a tax would sure-ly help

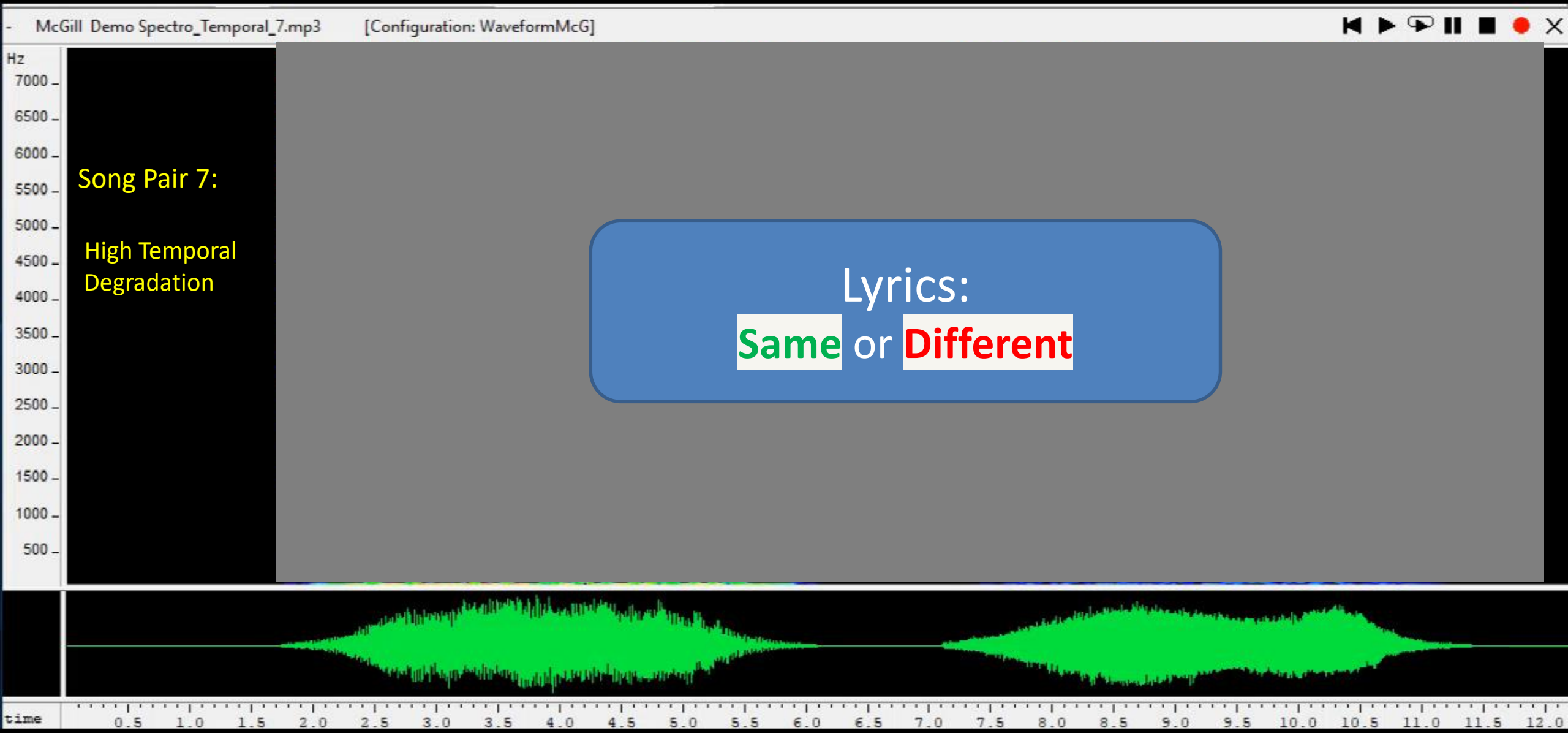



McGill Demo Spectro_Temporal_6.mp3
[Configuration: WaveformMcG]
Hz
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Song Pair 6:
High Spectral Degradation
Melody:
Same or Different
time
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5

He chose to take a long and lone-ly road

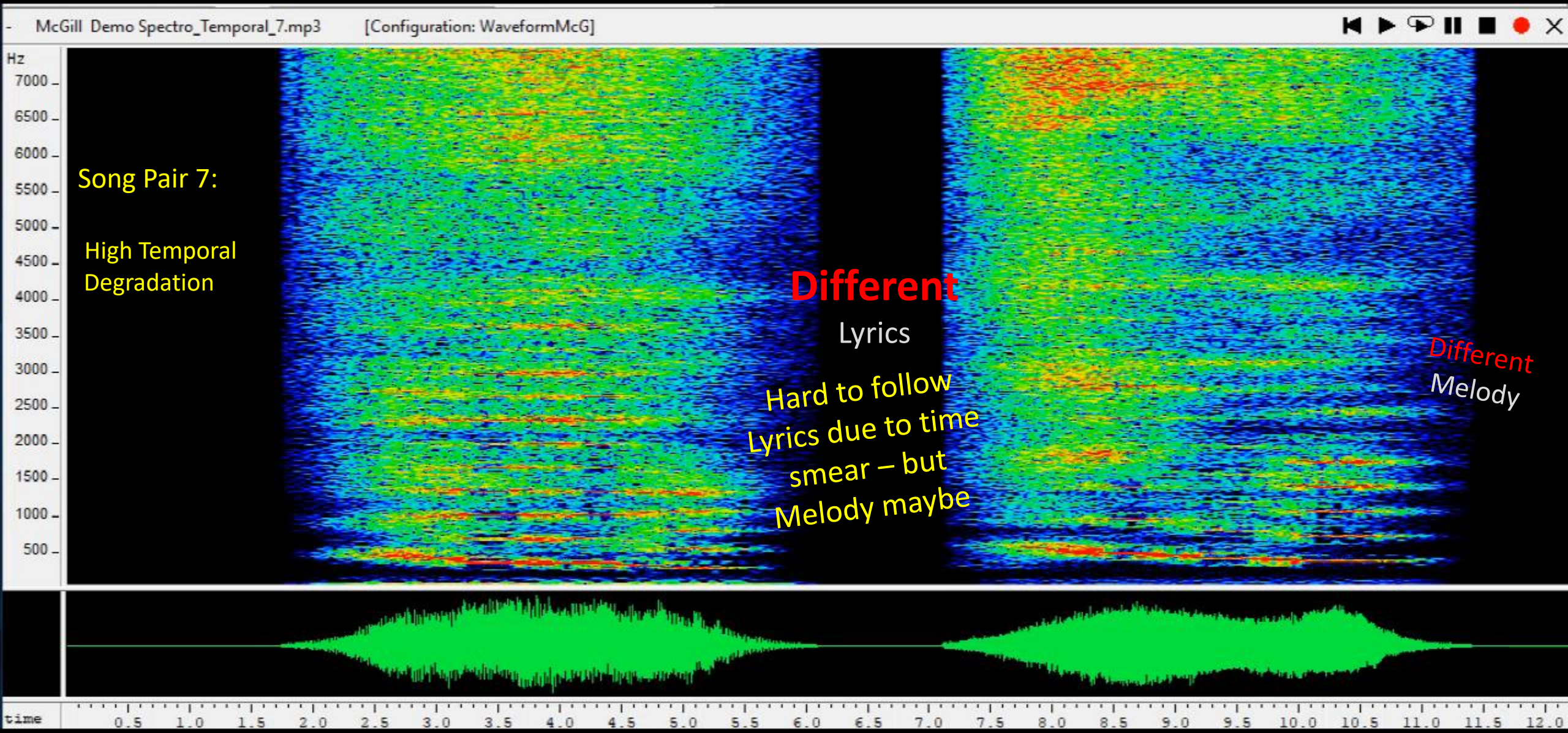
The hallway leads to doors that let us out

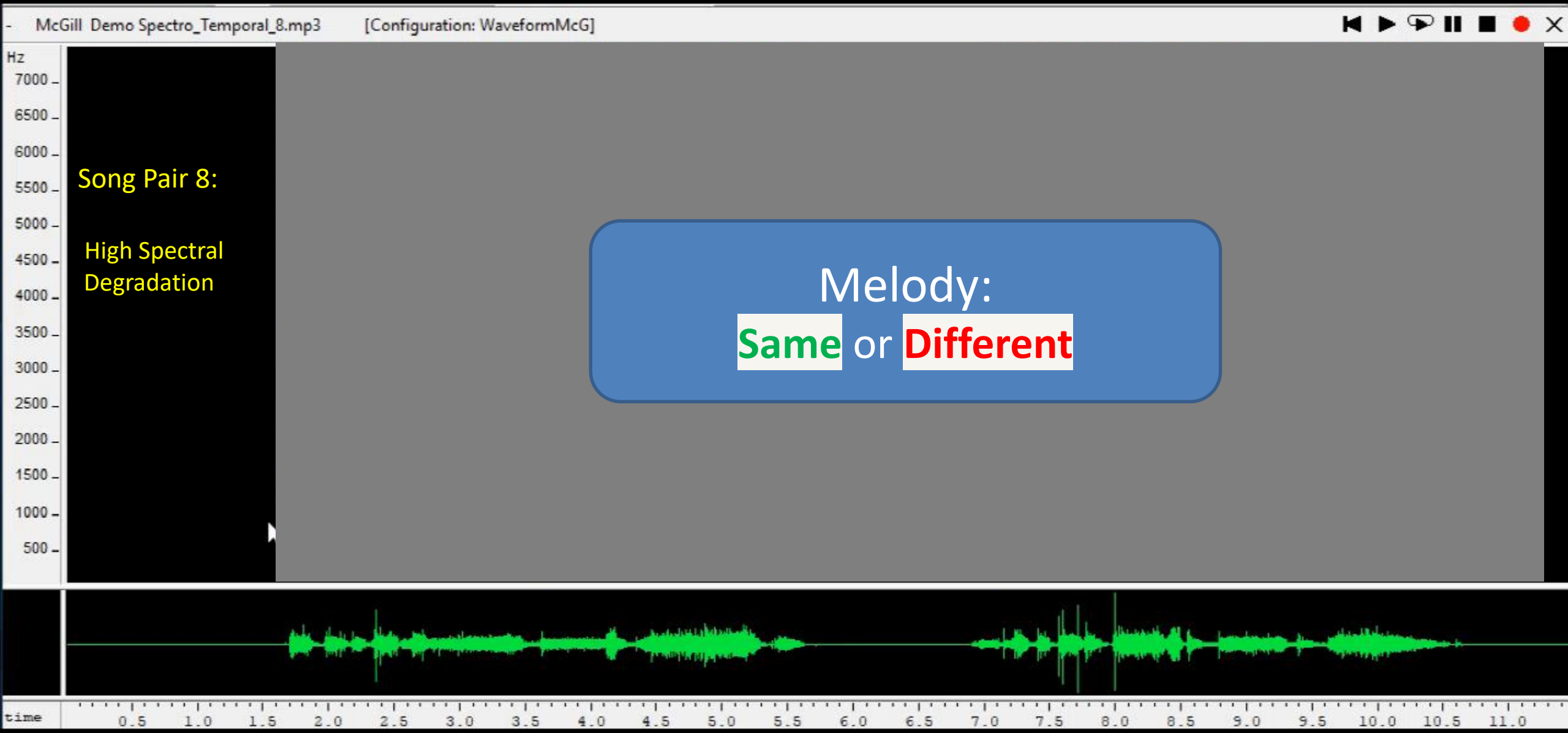



McGill Demo Spectro_Temporal_7.mp3
[Configuration: WaveformMcG]
Hz
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Song Pair 7:
High Temporal Degradation
Lyrics:
Same or Different
time
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0

??#?&*@???

??*$##?@?!


McGill Demo Spectro_Temporal_7.mp3
[Configuration: WaveformMcG]
Hz
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Song Pair 7:
High Temporal Degradation
Different
Lyrics
Hard to follow Lyrics due to time smear – but Melody maybe
Different
Melody
time
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0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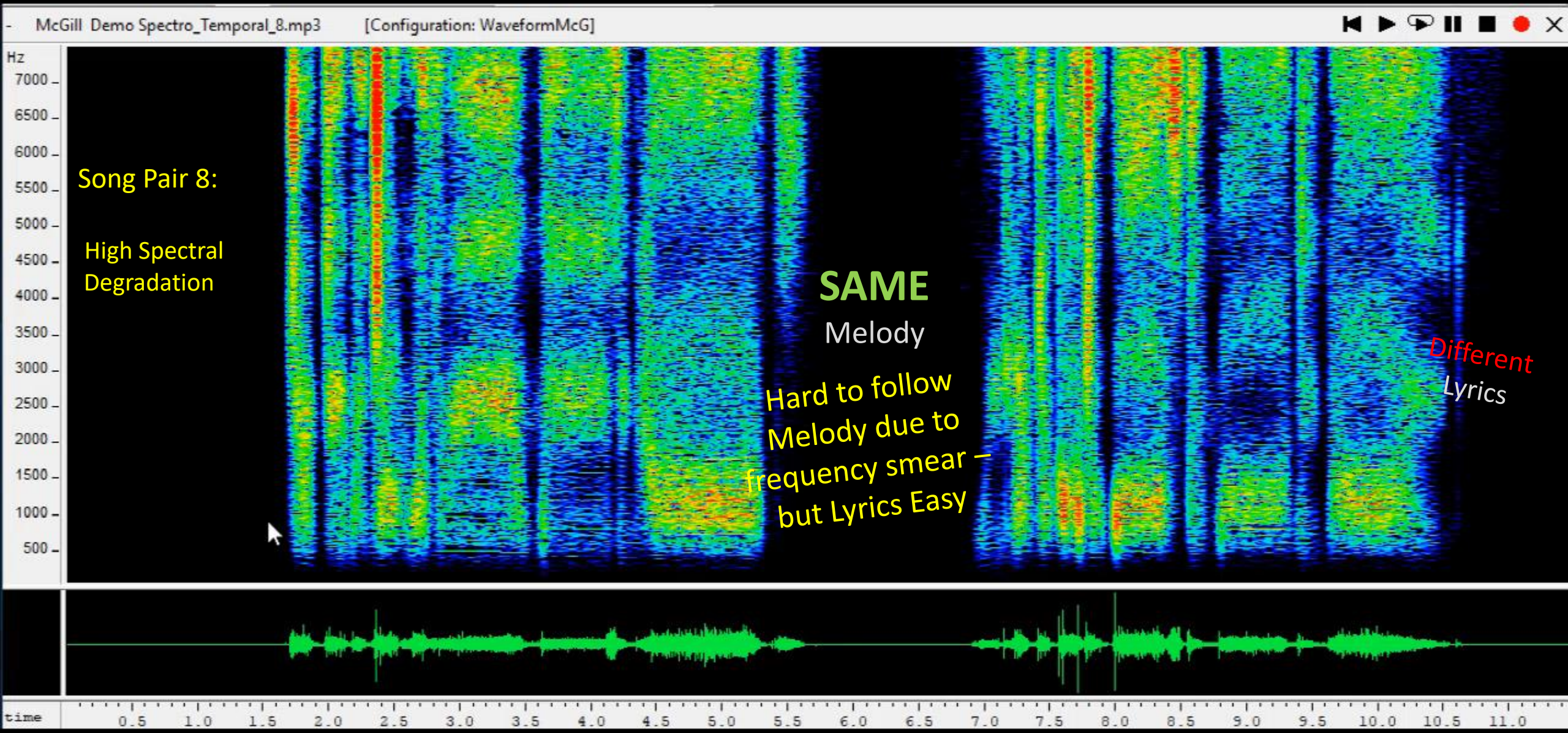
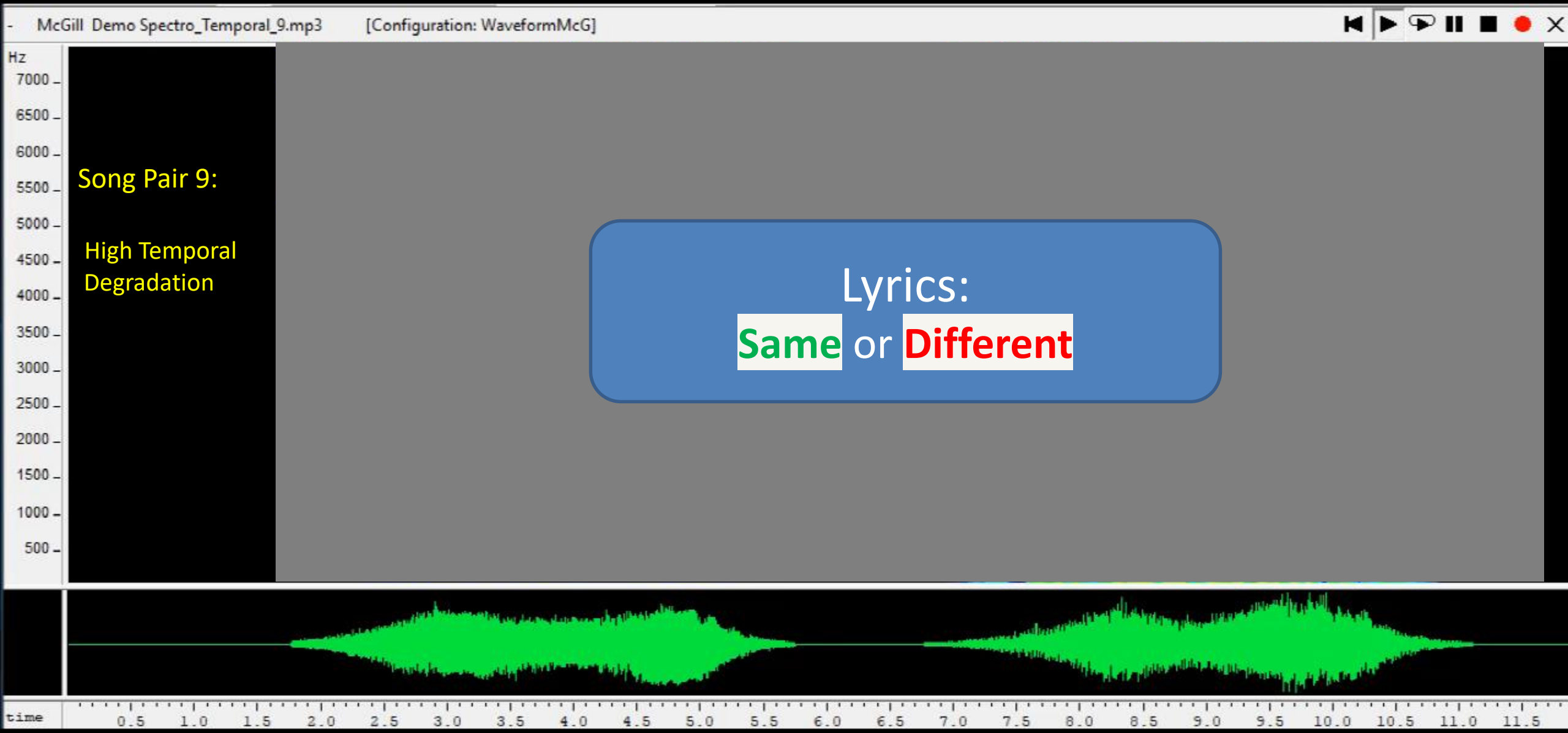
[Configuration: WaveformMcG]
Hz
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Song Pair 8:
High Spectral Degradation
Melody:
Same or Different
time
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0

Jack Jim and John wear three a-ma-zing hats

We'd like to go to Boston Monday night




McGill Demo Spectro_Temporal_9.mp3
[Configuration: WaveformMcG]
Hz
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Song Pair 9:
High Temporal Degradation
Lyrics:
Same or Different
time
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
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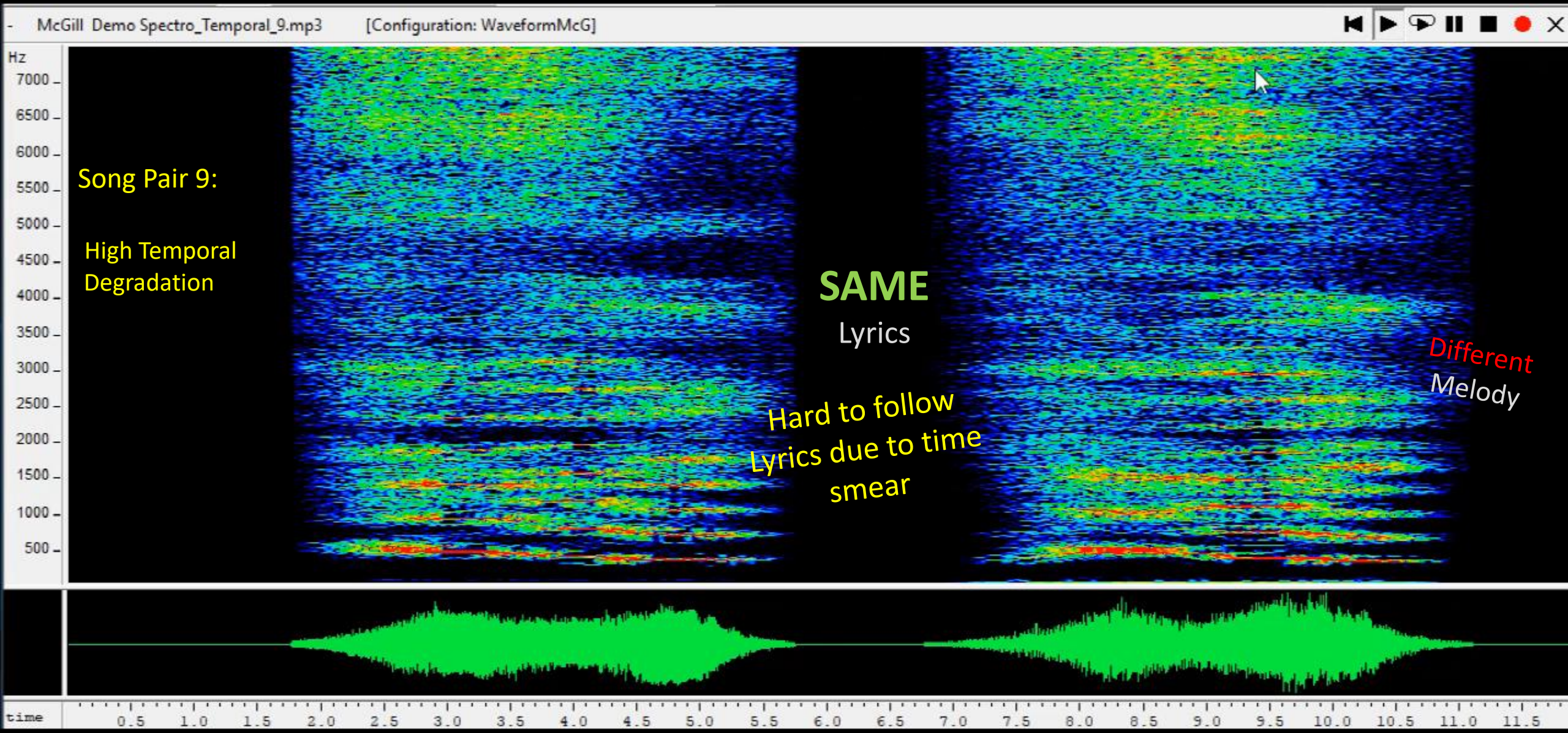
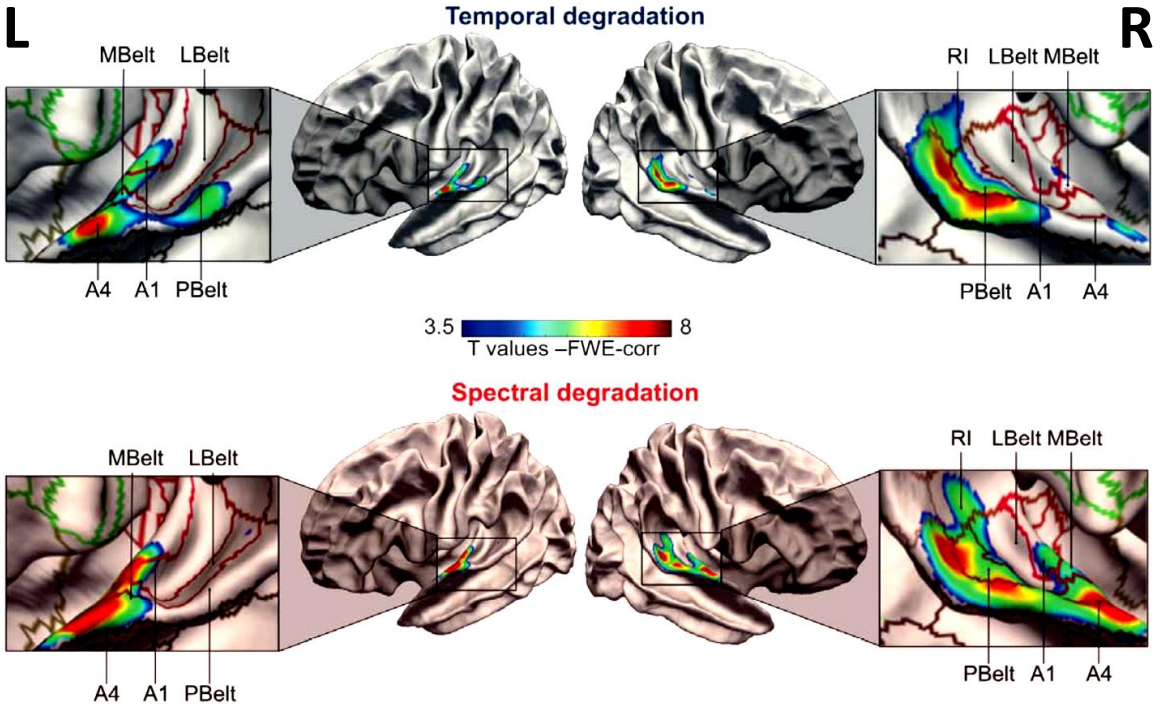
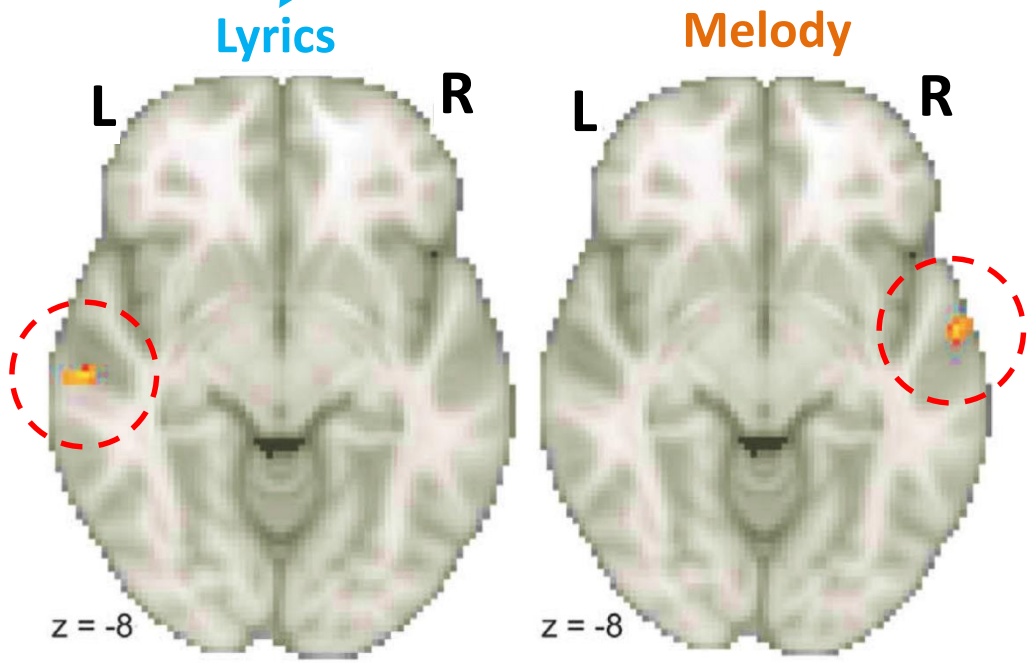
9.0
9.5
10.0
10.5
11.0
11.5


McGill Demo Spectro_Temporal_9.mp3
[Configuration: WaveformMcG]
Hz
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Song Pair 9:
High Temporal Degradation
SAME
Lyrics
Hard to follow Lyrics due to time smear
Different
Melody
time
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5

McGill Results (for Right-handed People)

- Spectral Degradation hurts Melody recognition
- Temporal Degradation hurts Lyric recognition
- Right Auditory Cortex primarily decodes Melody
- Left Auditory Cortex primarily decodes Lyrics





Singing

Coloratura Soprano
Audrey Luna

Audrey Luna (2010)
singing *Mad Scene* from
Donizetti's
Lucia di Lammermoor (1835)

Listen carefully
to the lyrics….

Coloratura
Audrey Luna

Audrey Luna (Nov. 2017)
hits A6 at the Met
in Thomas Adès's
The Exterminating Angel

She actually hit <u>above</u>
A#6
(1910 Hz)

Coloratura
Audrey Luna

Audrey Luna (Nov. 2017)
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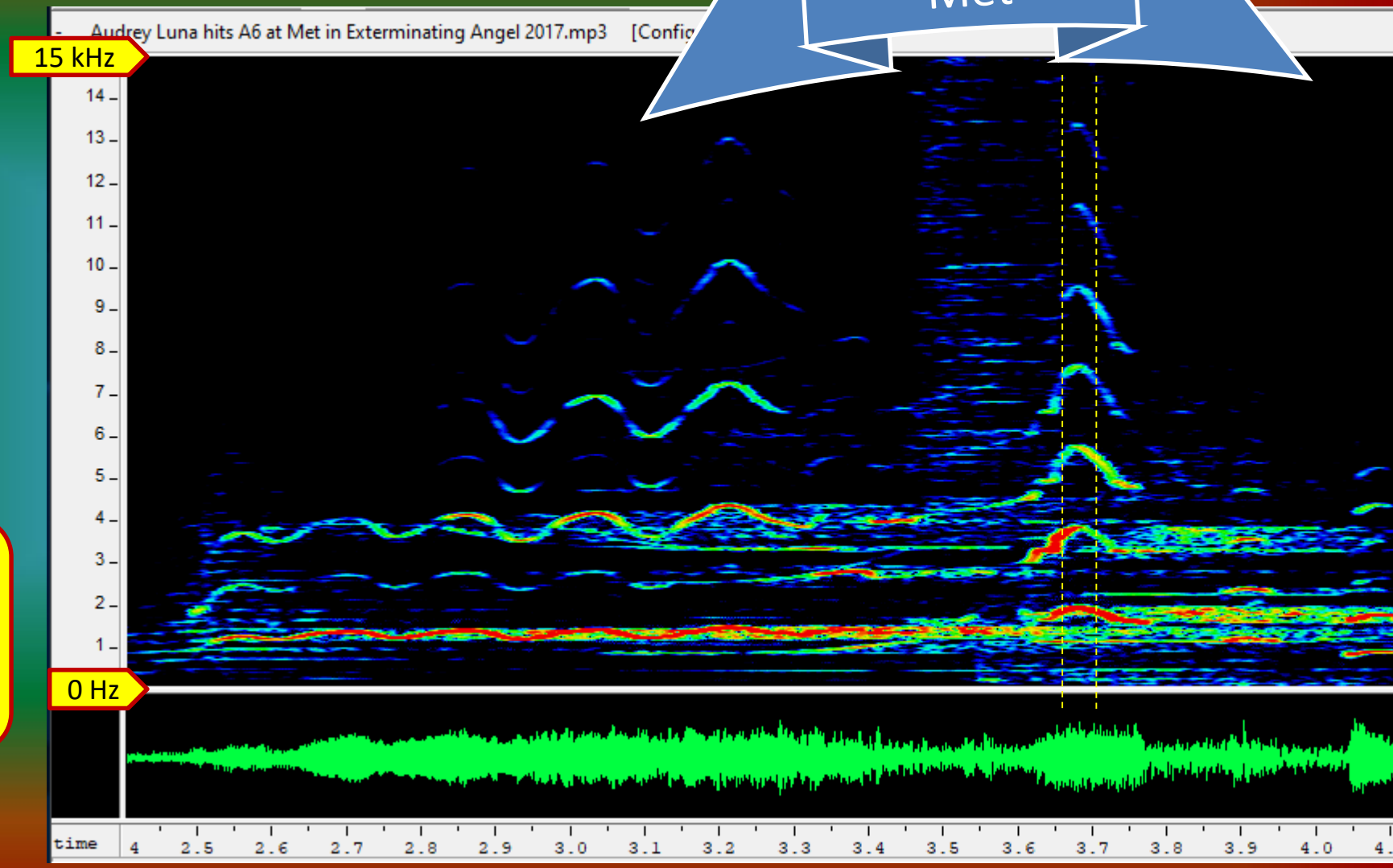
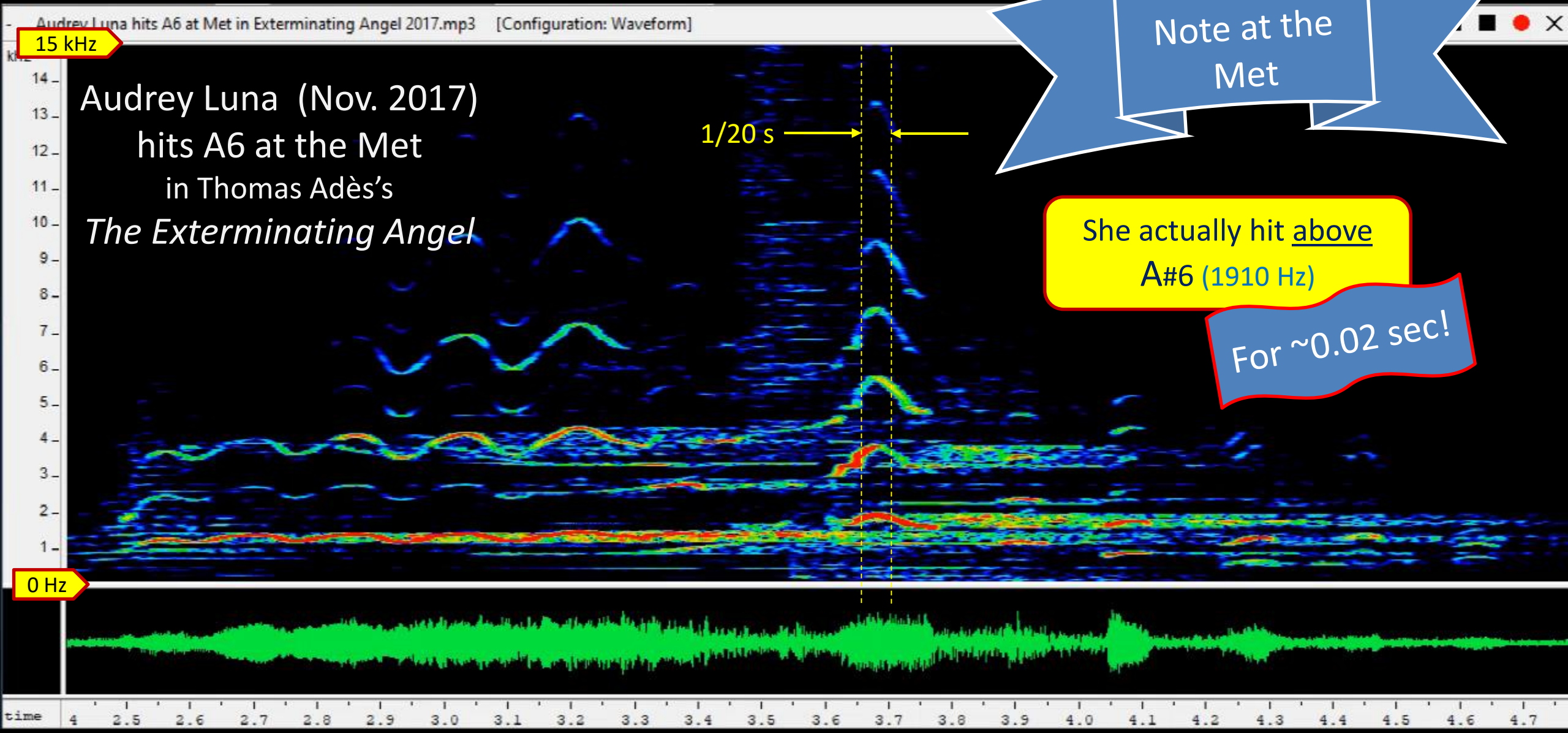
The Exterminating Angel

She actually hit <u>above</u>
A#6
1910 Hz

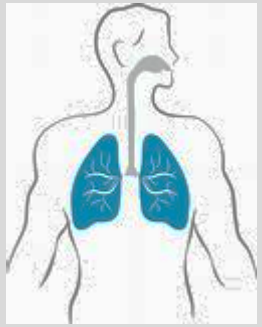


Coloratura Audrey Luna



The Singing Voice as a Musical Instrument

Source of **Air** Pressure



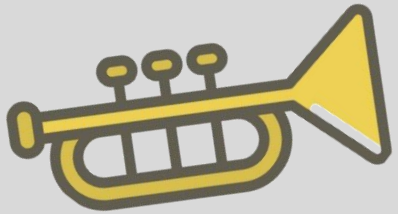
+

Controllable Vibrating **Valve**

Lips

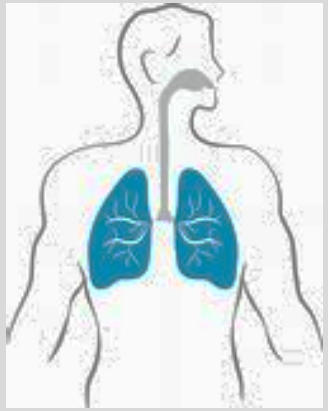
+

Variable Acoustic **Resonator**

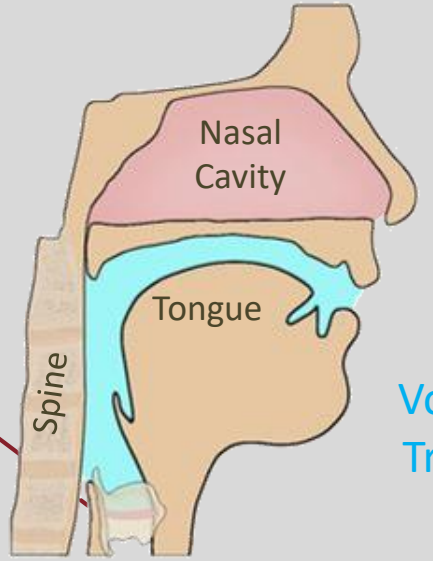


f_1 + Harmonics

Selects desired harmonics

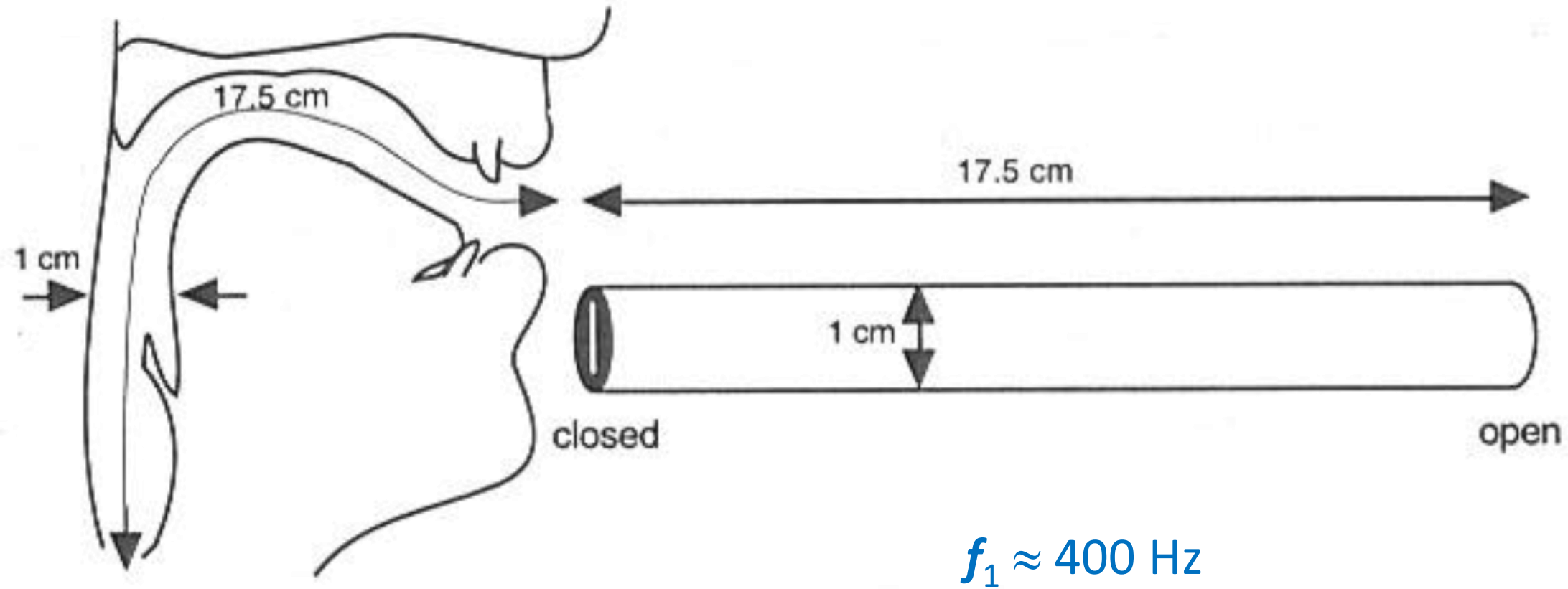


Vocal Folds



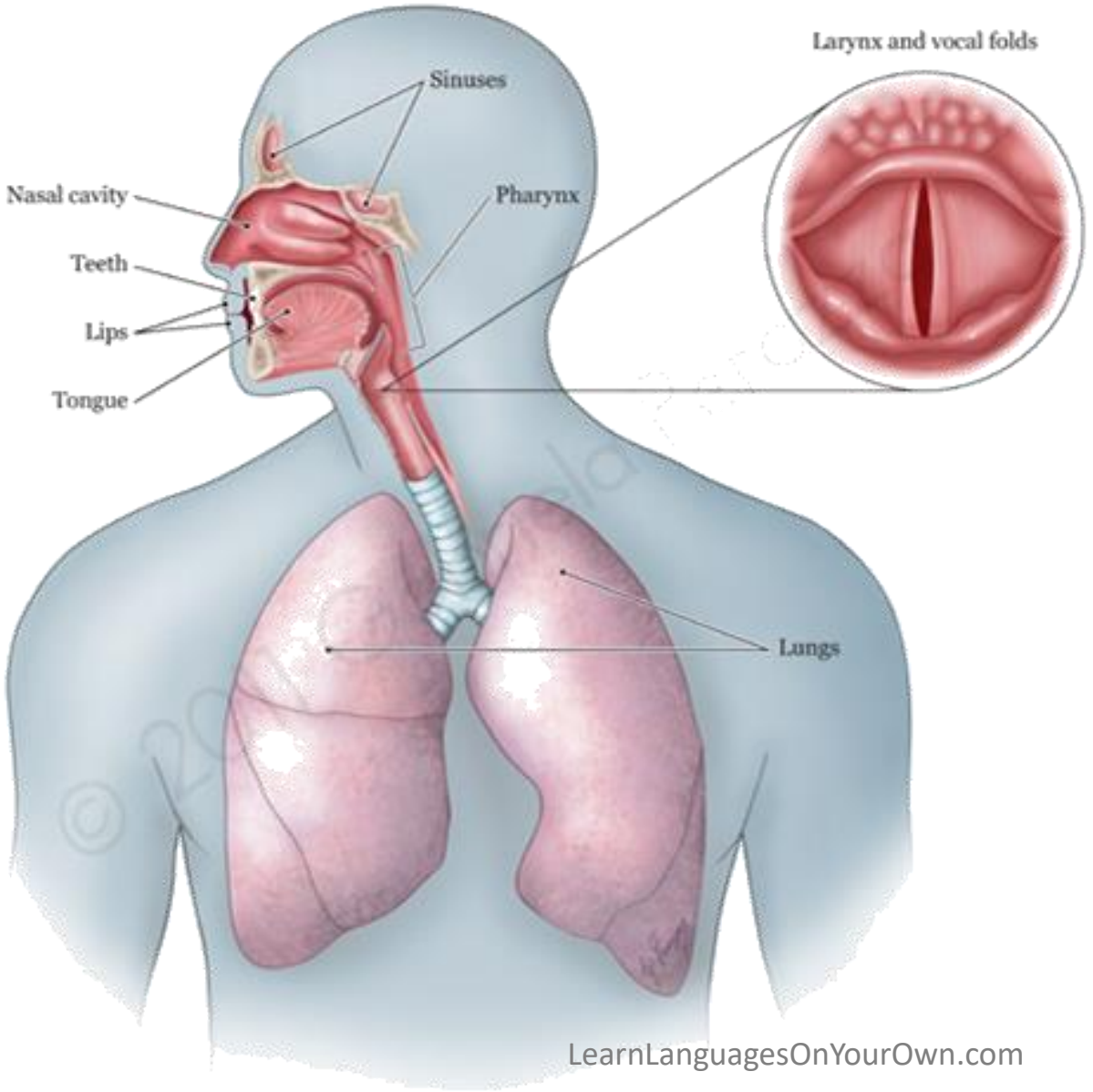
Vocal Tract

Vocal Tract Crudely Similar to Closed/Open Pipe



$f_1 \approx 400$ Hz

The Overall Voice Apparatus



LearnLanguagesOnYourOwn.com

But Not All Sounds are Voiced using Vocal Folds

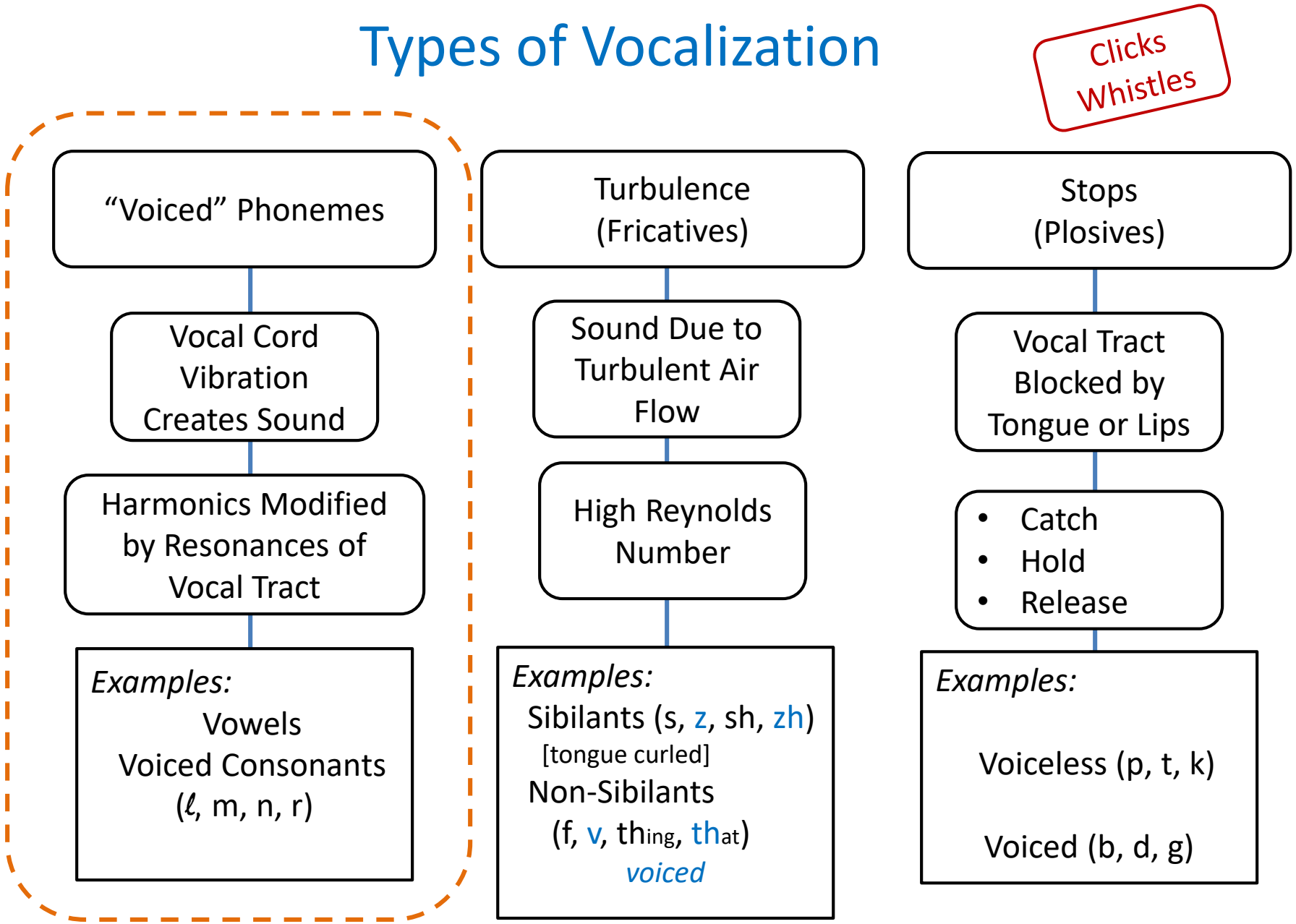
Also:

- Sounds produced by turbulent flow
  - sss, shh, fff, th
  - *Frictive*
- Sounds produced by sudden release of pressure
  - t , k, p
  - *Plosive*
- Combinations of these with Voicing
  - z, v, b, d, g

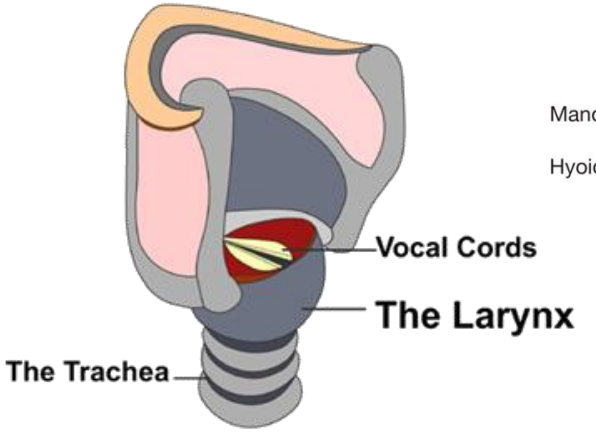
These are not very musical
—
De-emphasized in Singing

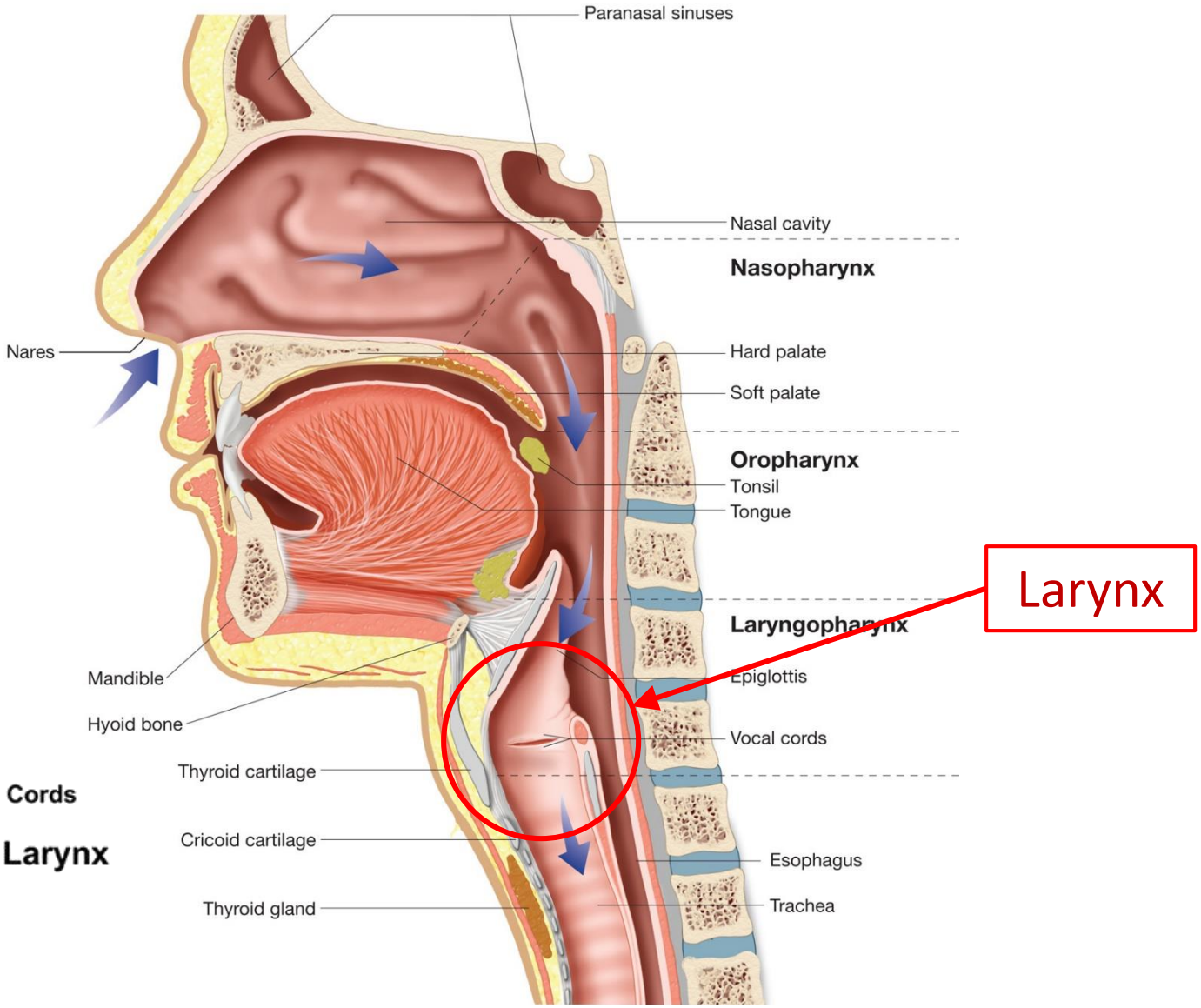
also:
- *Clicks*
- *Whistles*

Types of Vocalization

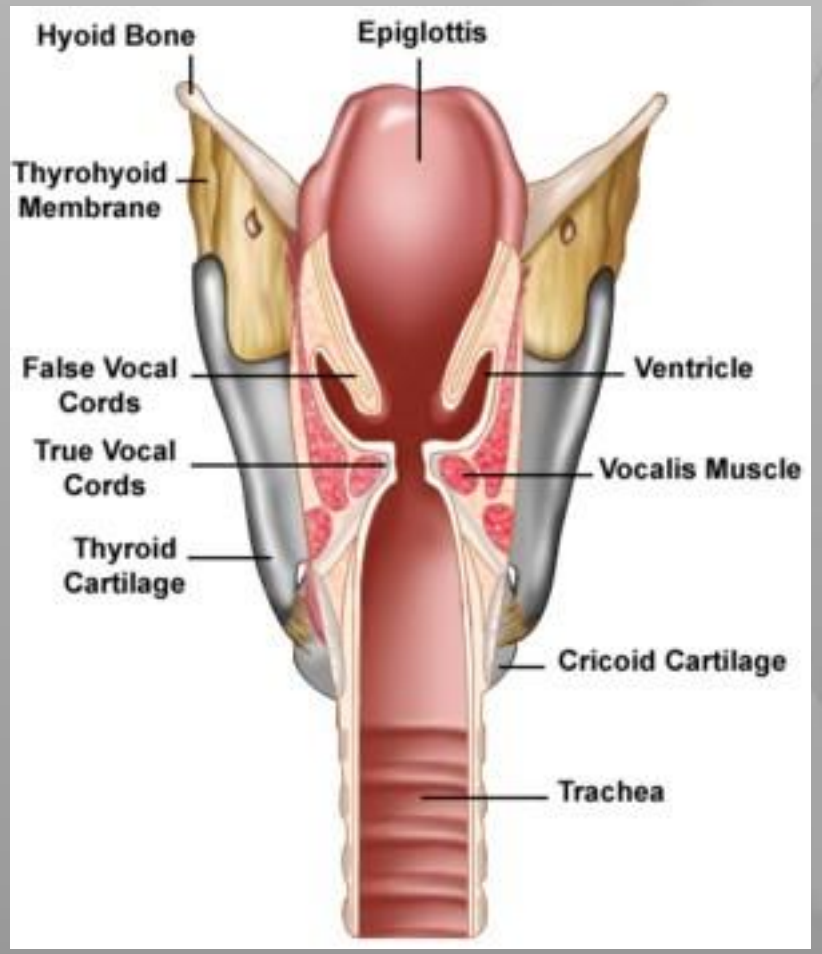


Vocal Tract


Vocal Cords
The Larynx
The Trachea


Paranasal sinuses
Nasal cavity
Nasopharynx
Nares
Hard palate
Soft palate
Oropharynx
Tonsil
Tongue
Laryngopharynx
Epiglottis
Vocal cords
Mandible
Hyoid bone
Thyroid cartilage
Cricoid cartilage
Thyroid gland
Esophagus
Trachea
Larynx

Larynx 3D Model



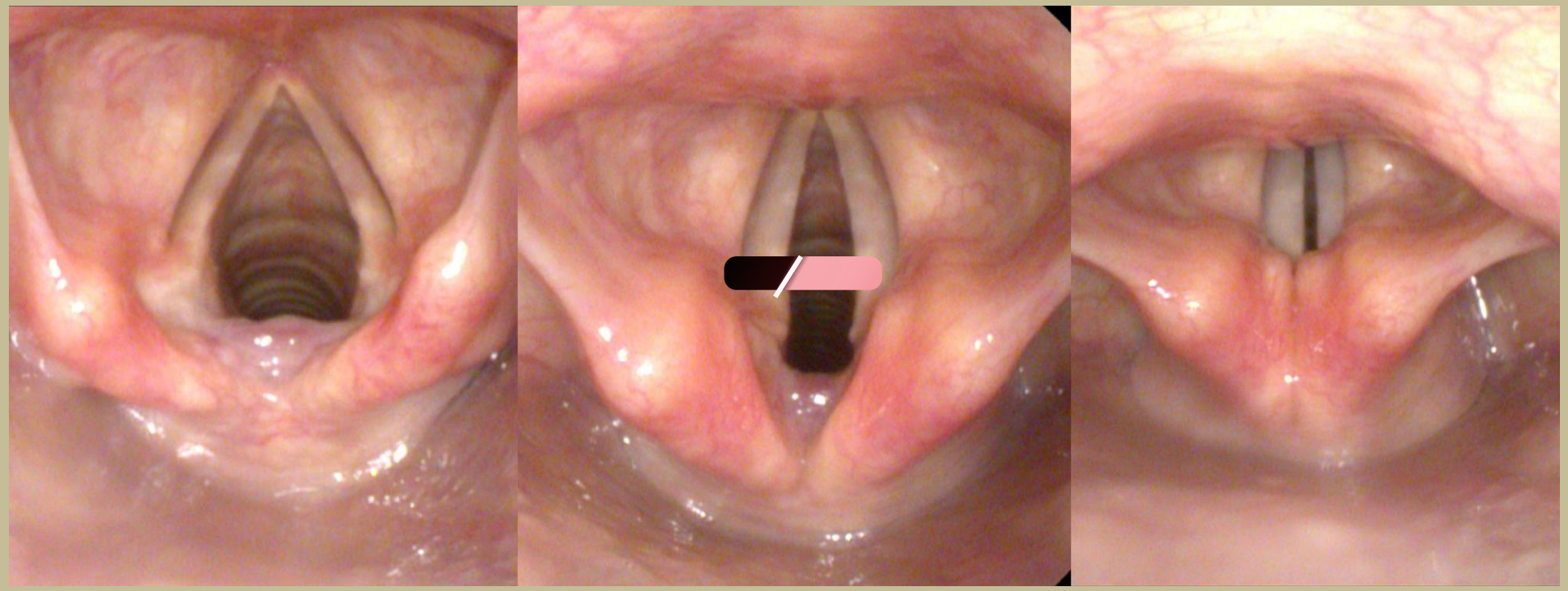
Top View

Rear View

Vocal Folds (Cords): Top View

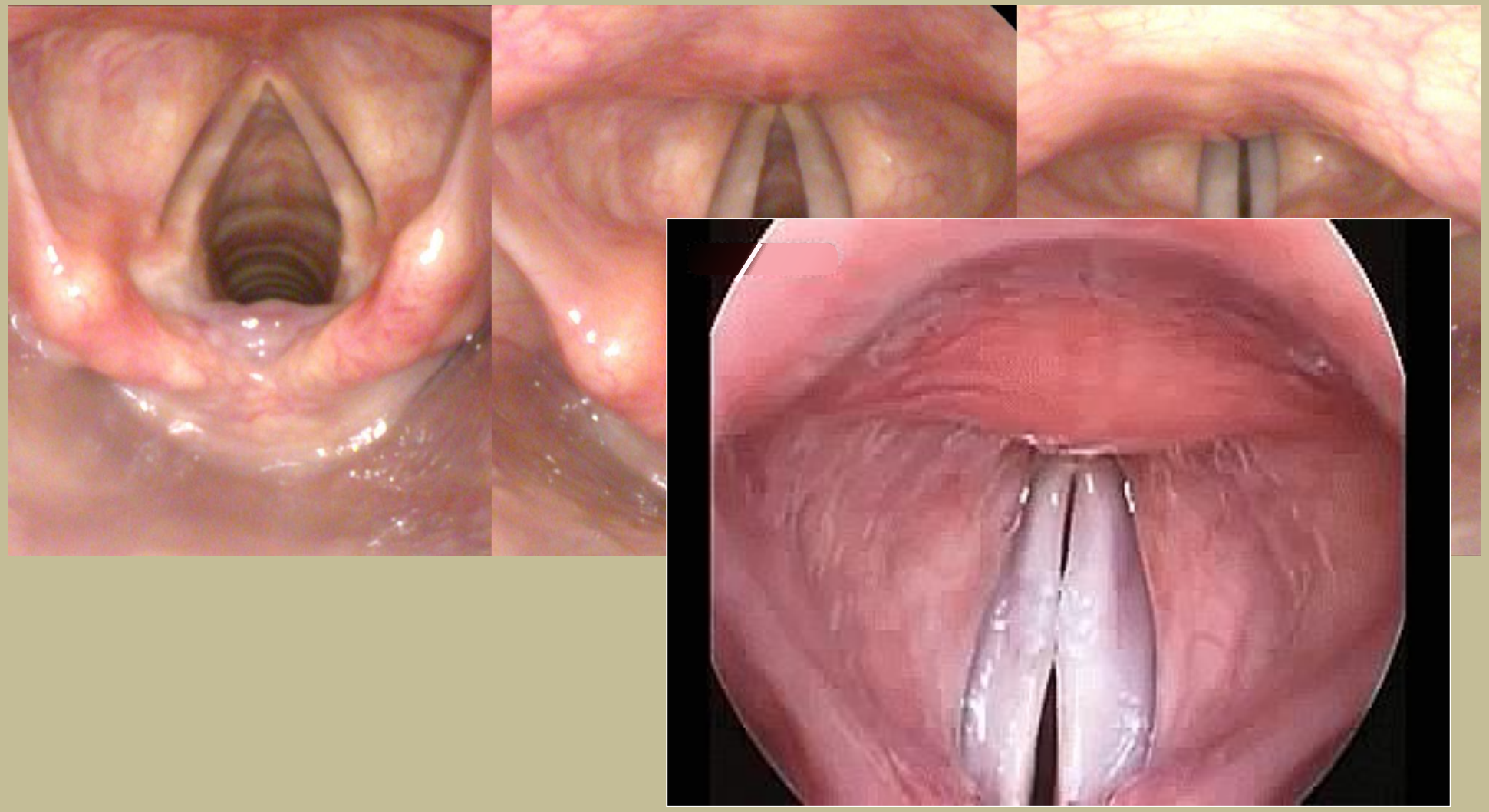
Open *vs* Closed

Front

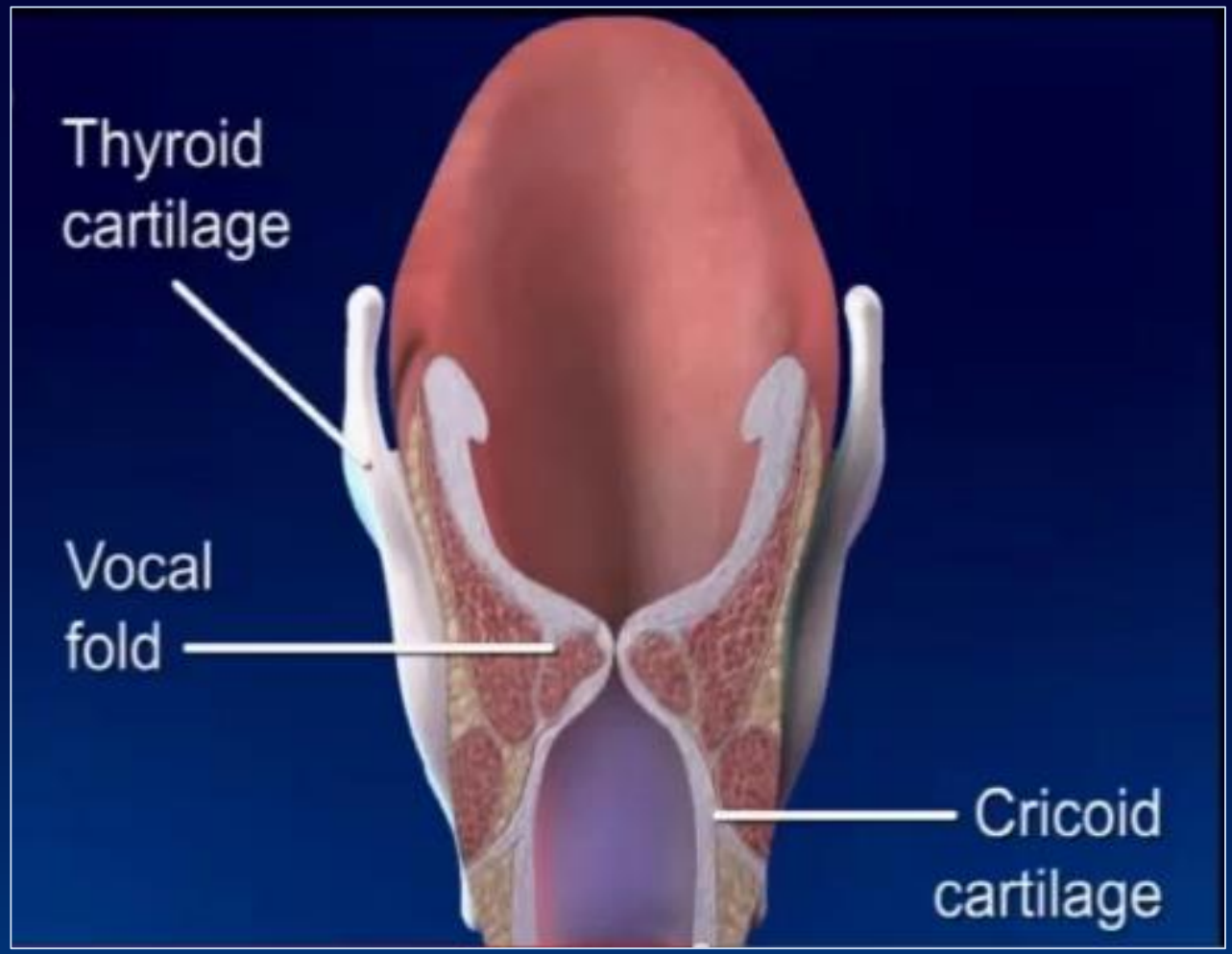


Vocal Folds (Cords): Top View

Open *vs* Closed



Phonation:
Generating Chopped Glottal Air Flow via Vocal Fold Vibrations



Phonation Types:

1. **"Breathy"**
   Folds do not close
   Weak harmonics

2. **Modal** (flow, normal)

3. **"Pressed"**
   Folds tightly squeezed
   Shrill sound

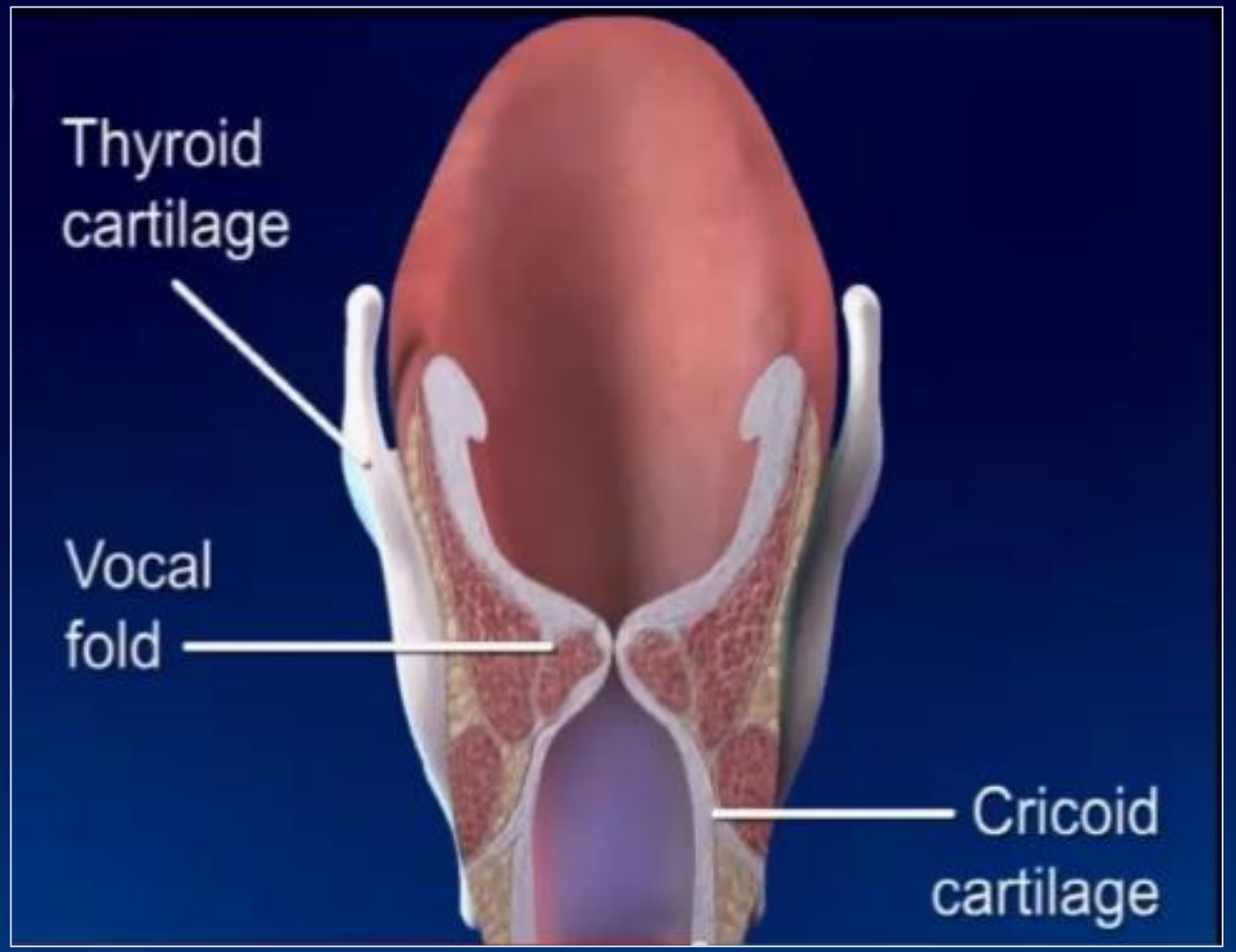
Power to Sing

Phonation:

What if we Eliminated the Vocal Tract?

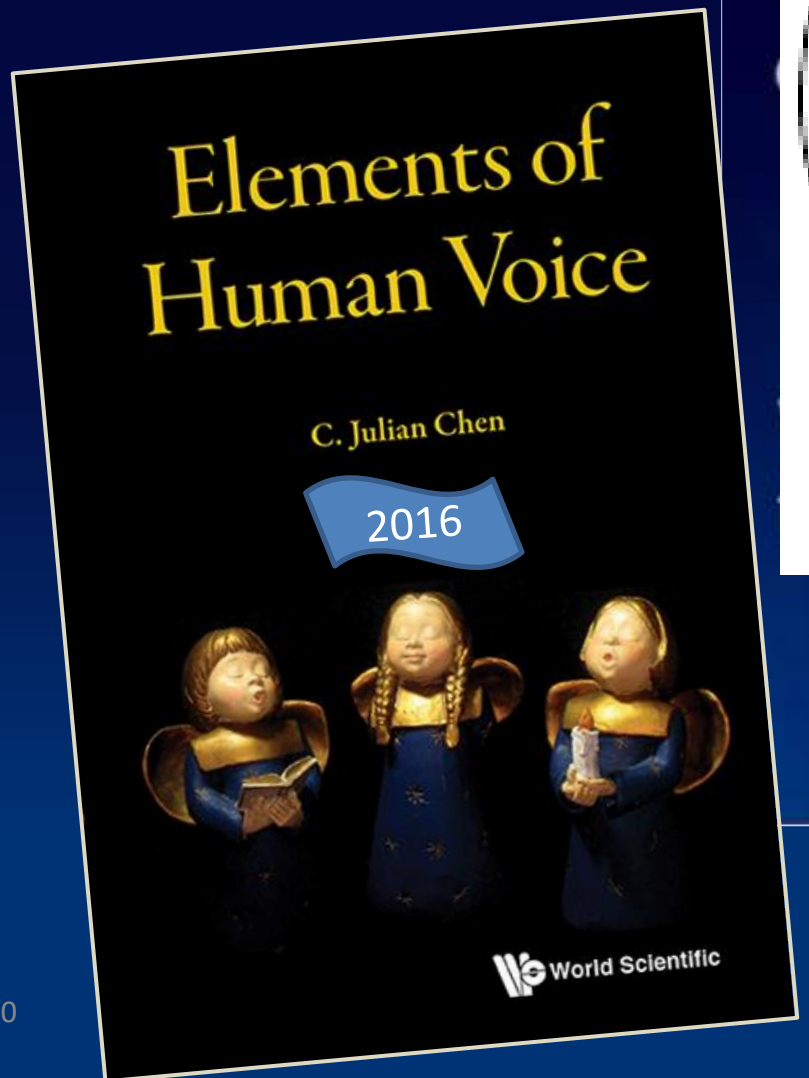
Estimated Vocalization without Modification by Vocal Tract

1. **Synthetic voice** (glissando)
2. **Male speech voice** (based on EGG)
3. Singing (Modal Phonation)
   - 100 Hz
   - 260 Hz
   - 750 Hz

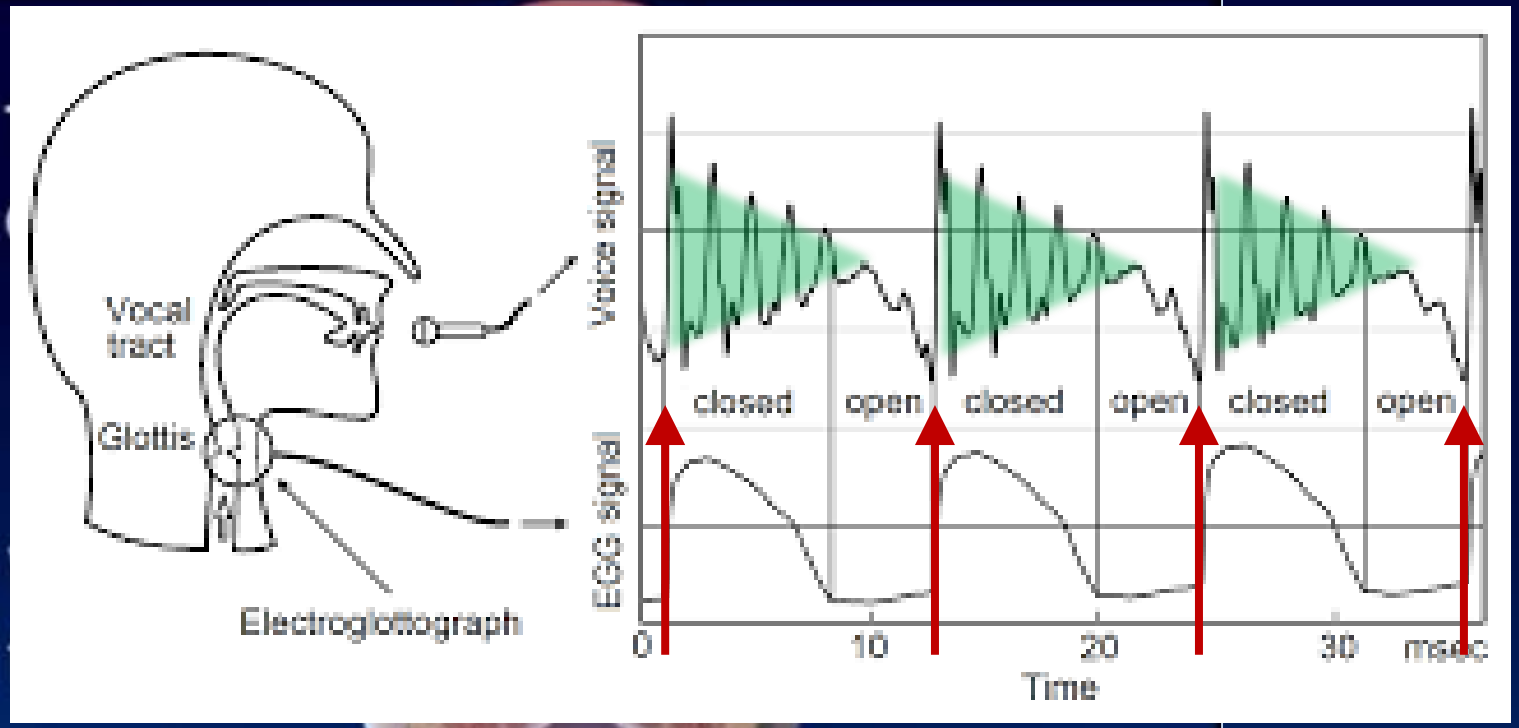


Power to Sing

Vibration of Vocal Fold



Glottal Closings Generate Most Sound

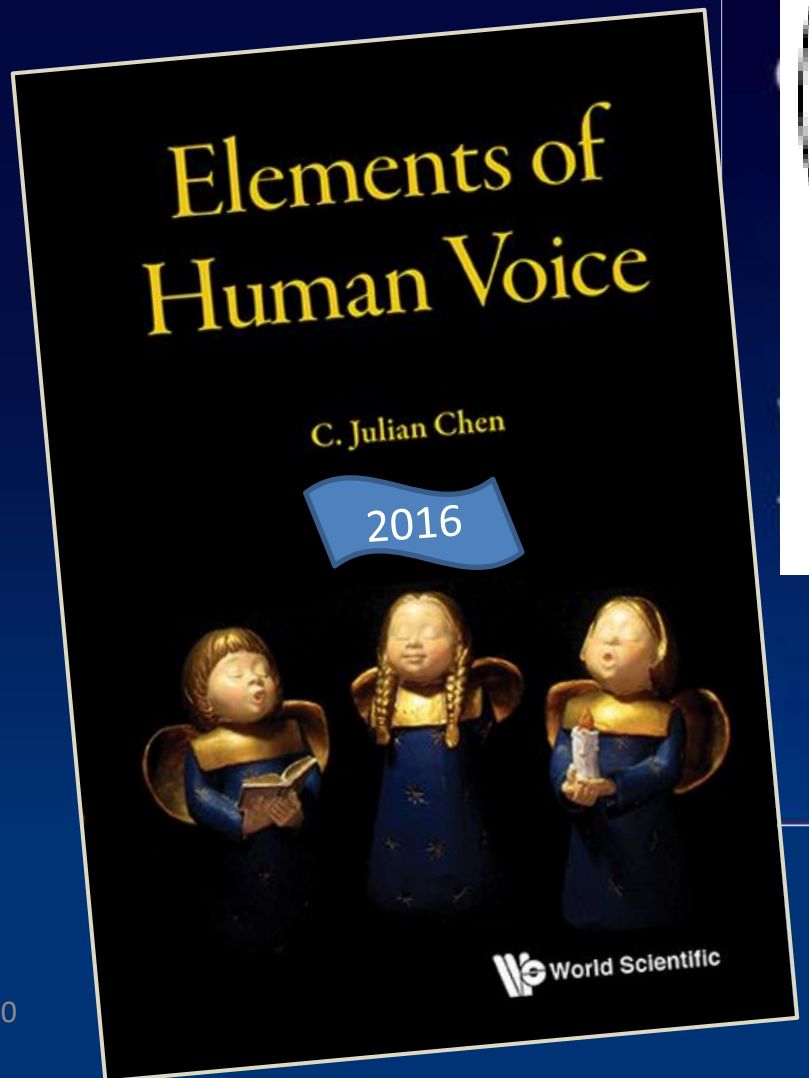


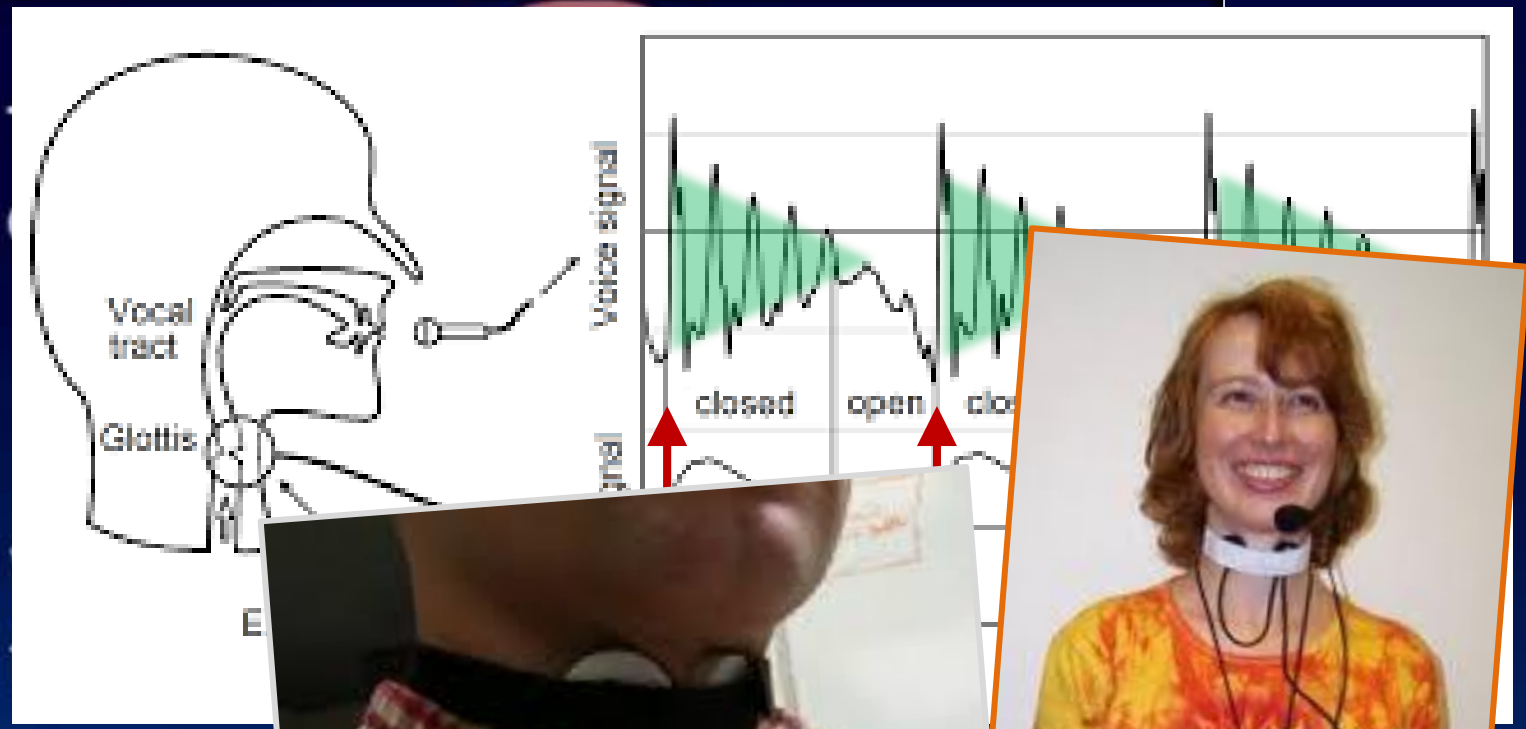
Google: Columbia
"Human Voice" pdf

Power to Sing

Vibration of Vocal Fold

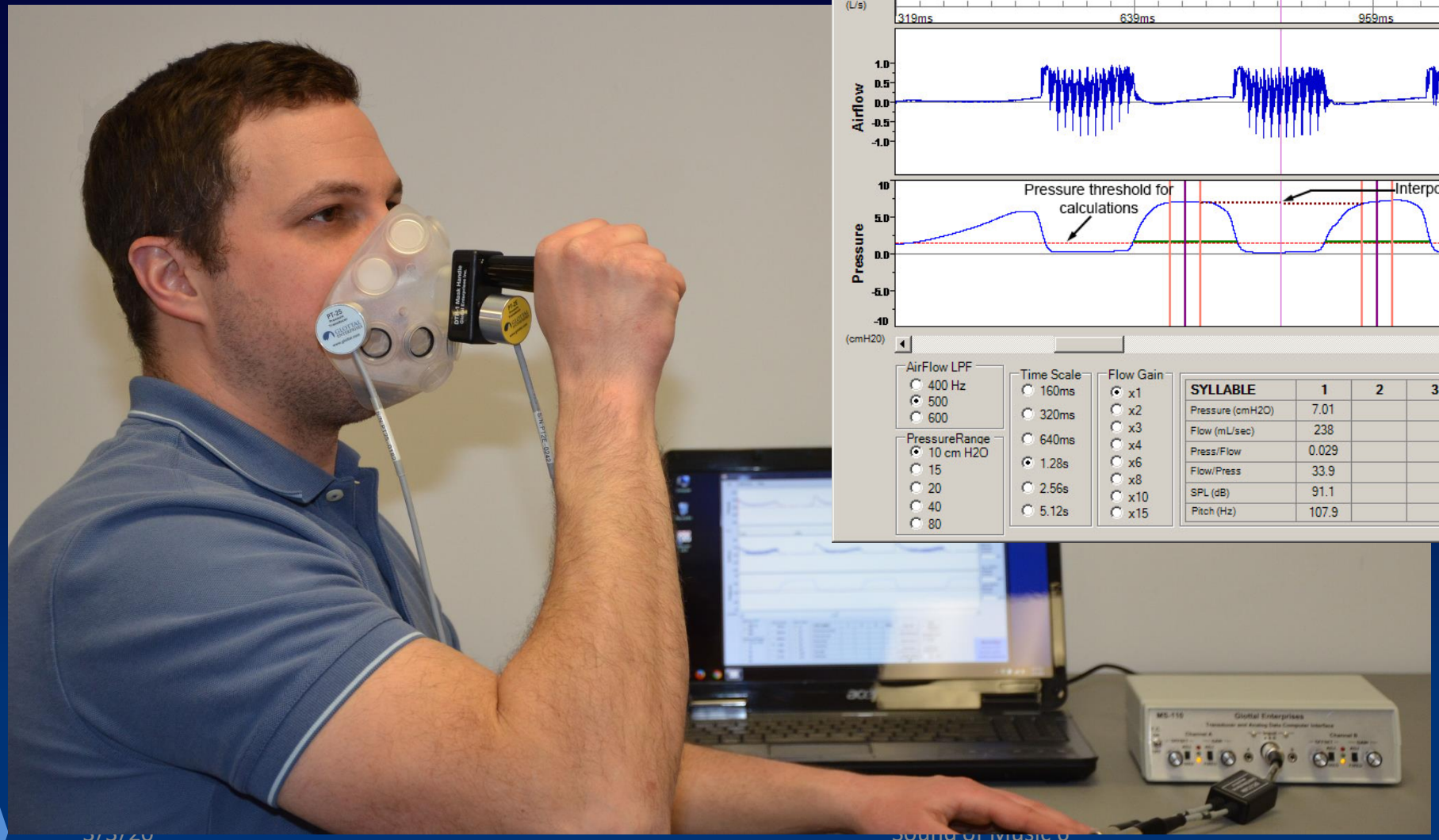
Glottal Closings Generate Most Sound

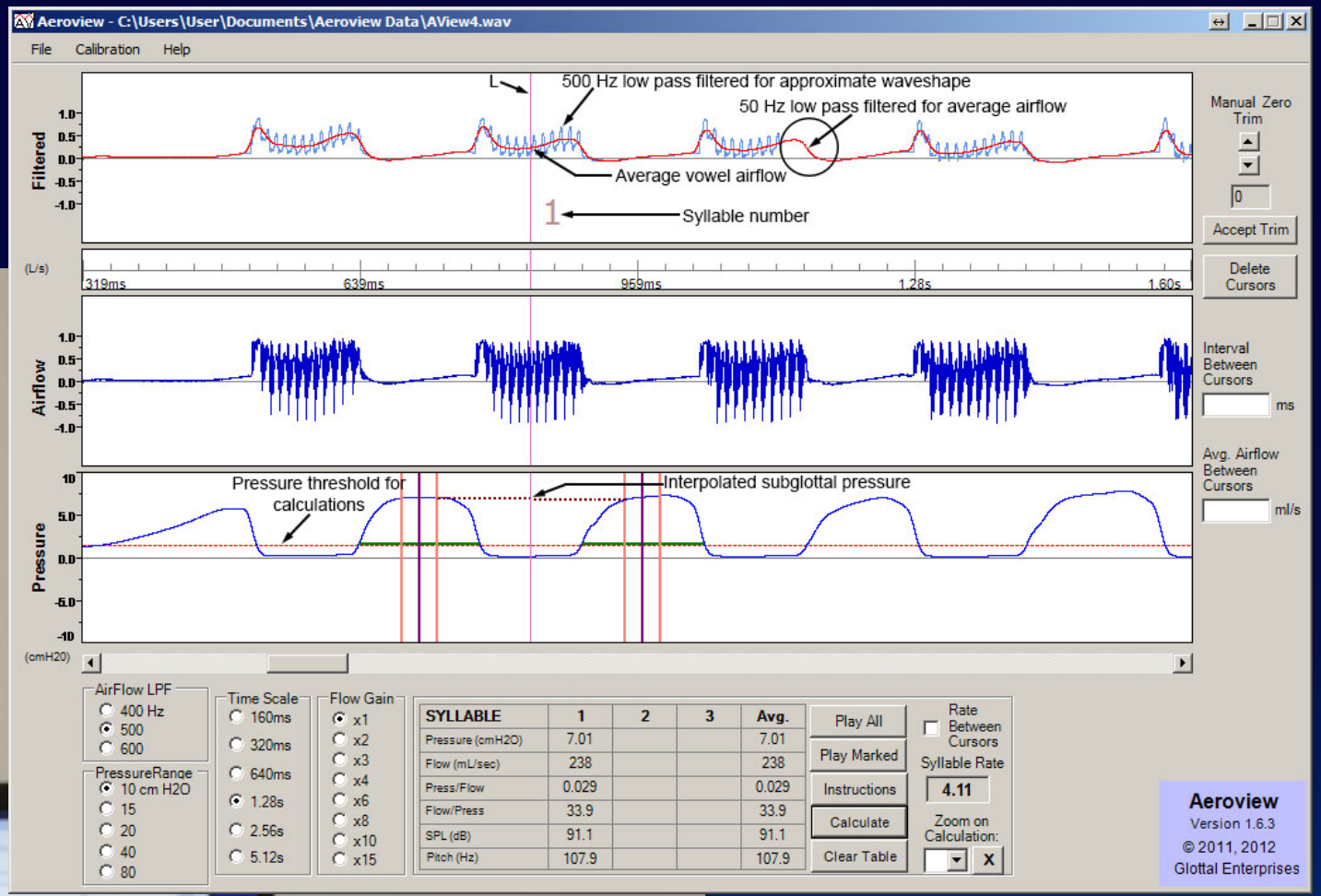




Google: Co
"Human Vo

Glottal Airflow Mask System





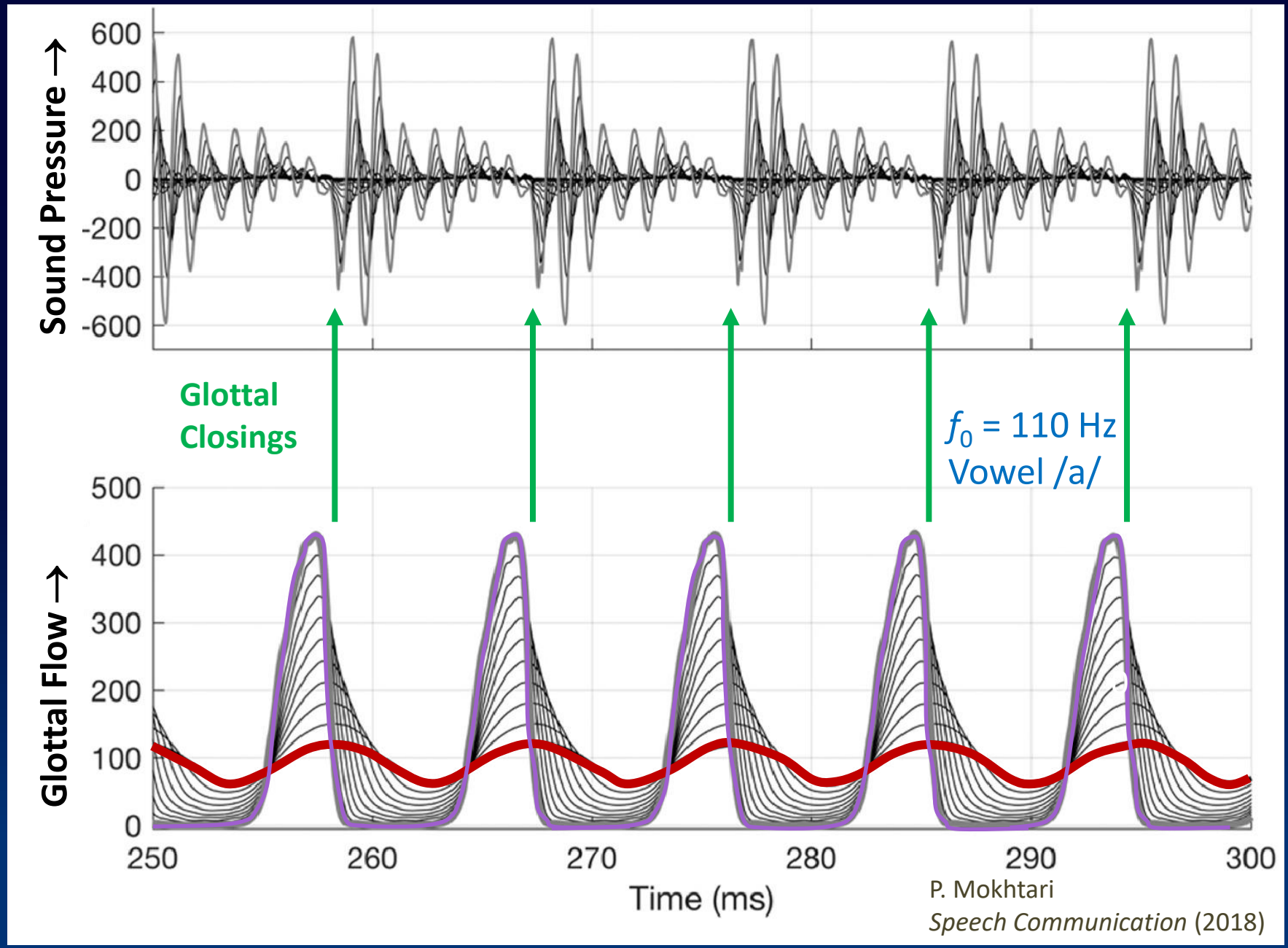
Electroglottograph

Phonation:

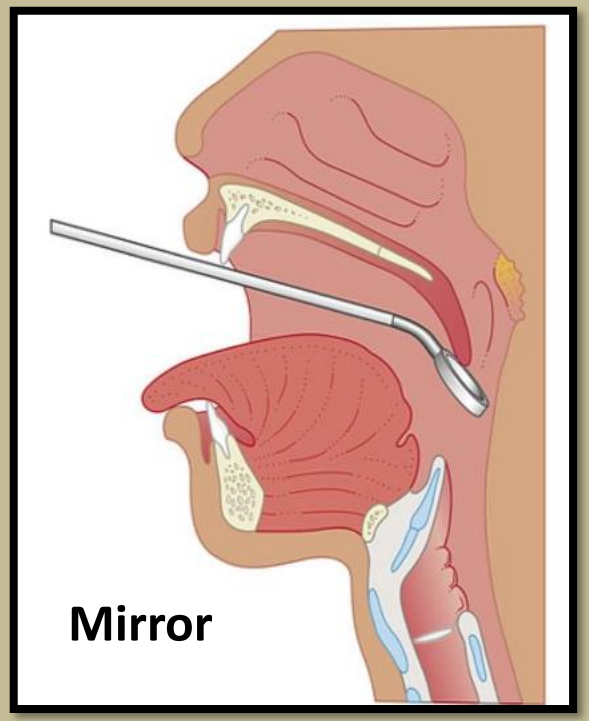
Glottal Flow and Resulting Sound

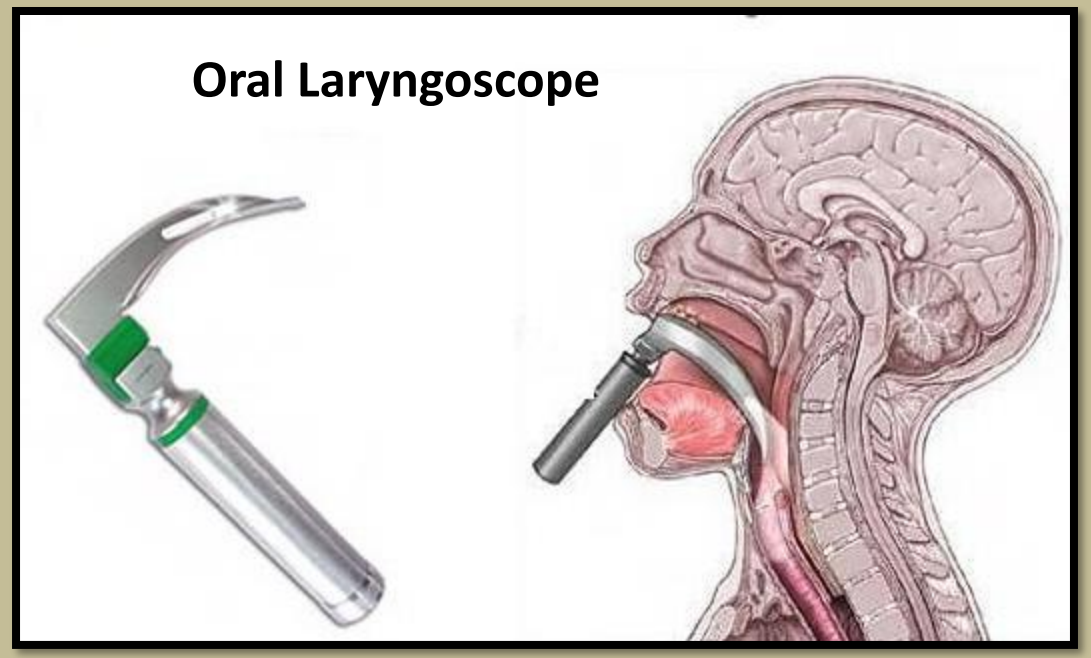
Pressed Phonation

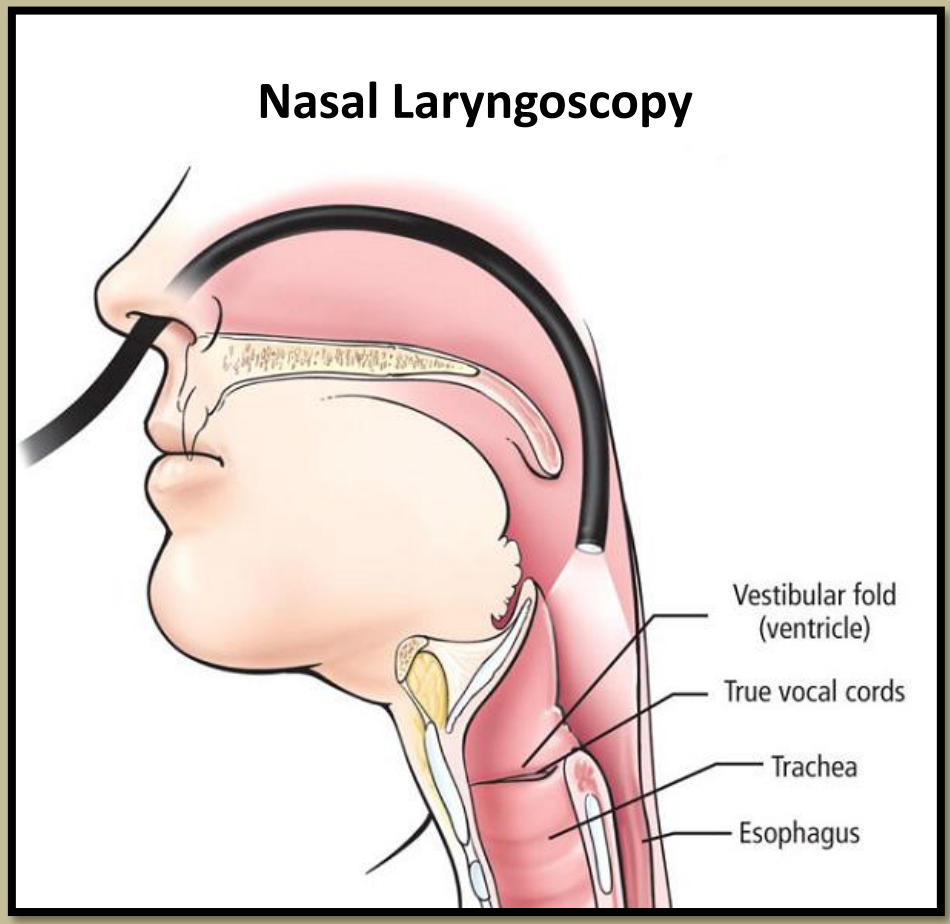
Breathy Phonation



Laryngoscopy: Viewing the Vocal Folds

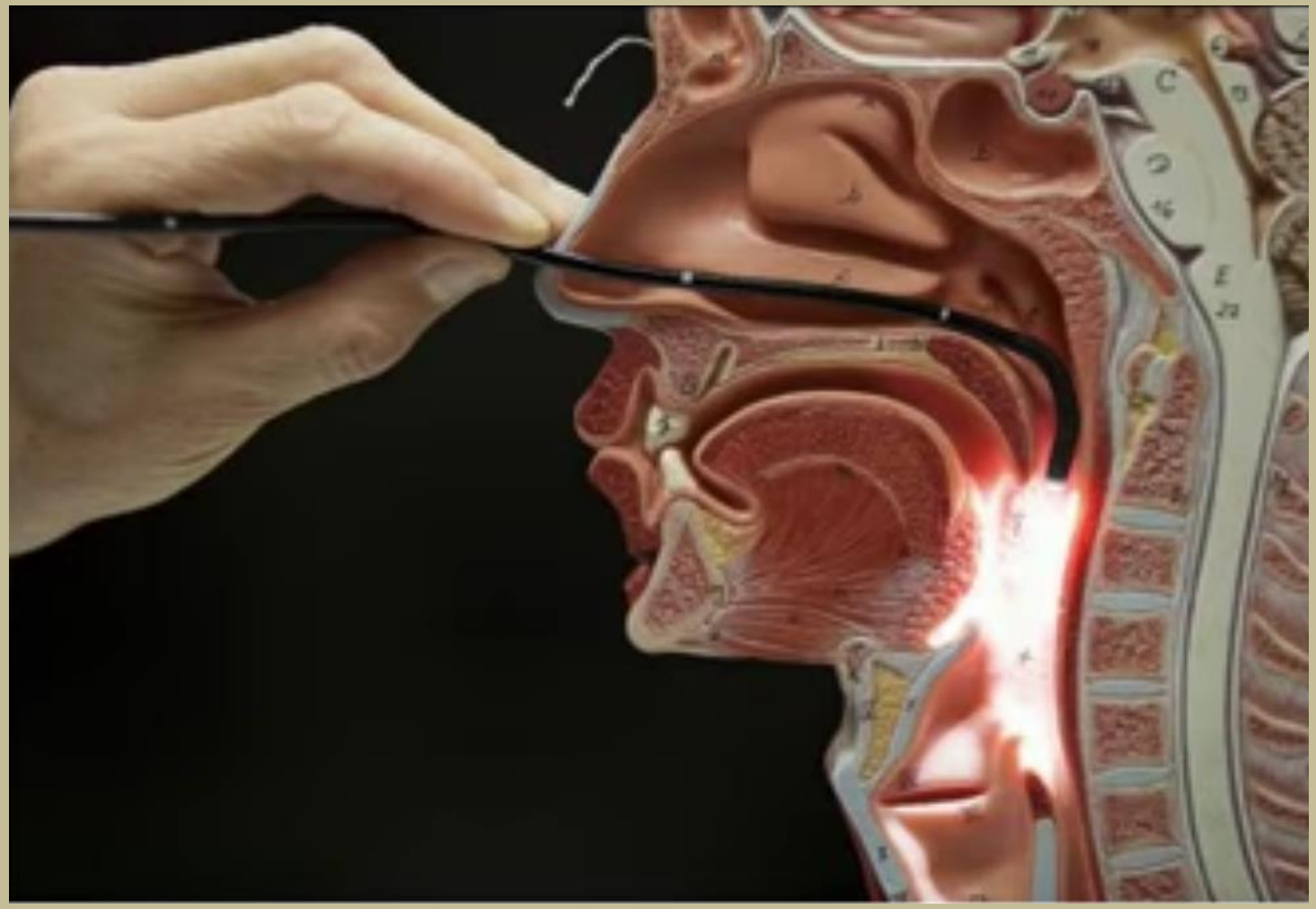






Laryngoscopy: Viewing the Vocal Folds

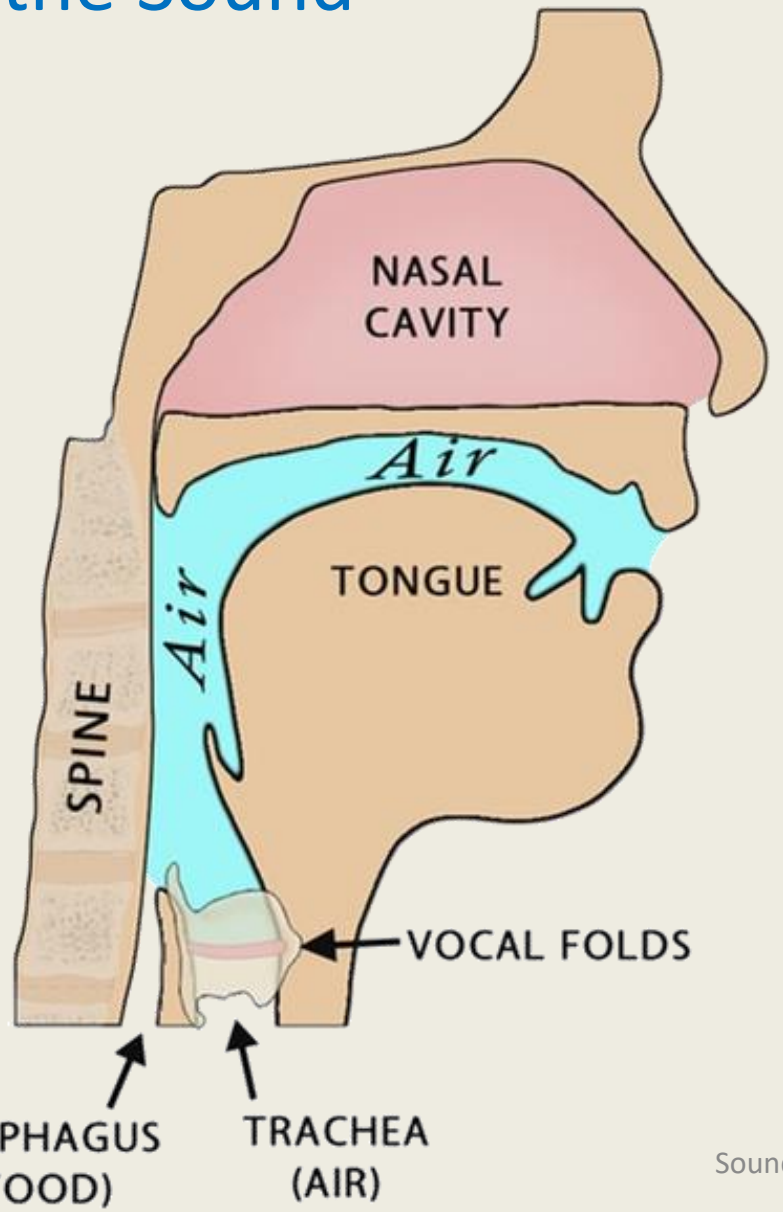
Using a Stroboscopic Lamp flashing at the vibration rate of the vocal folds freezes the action

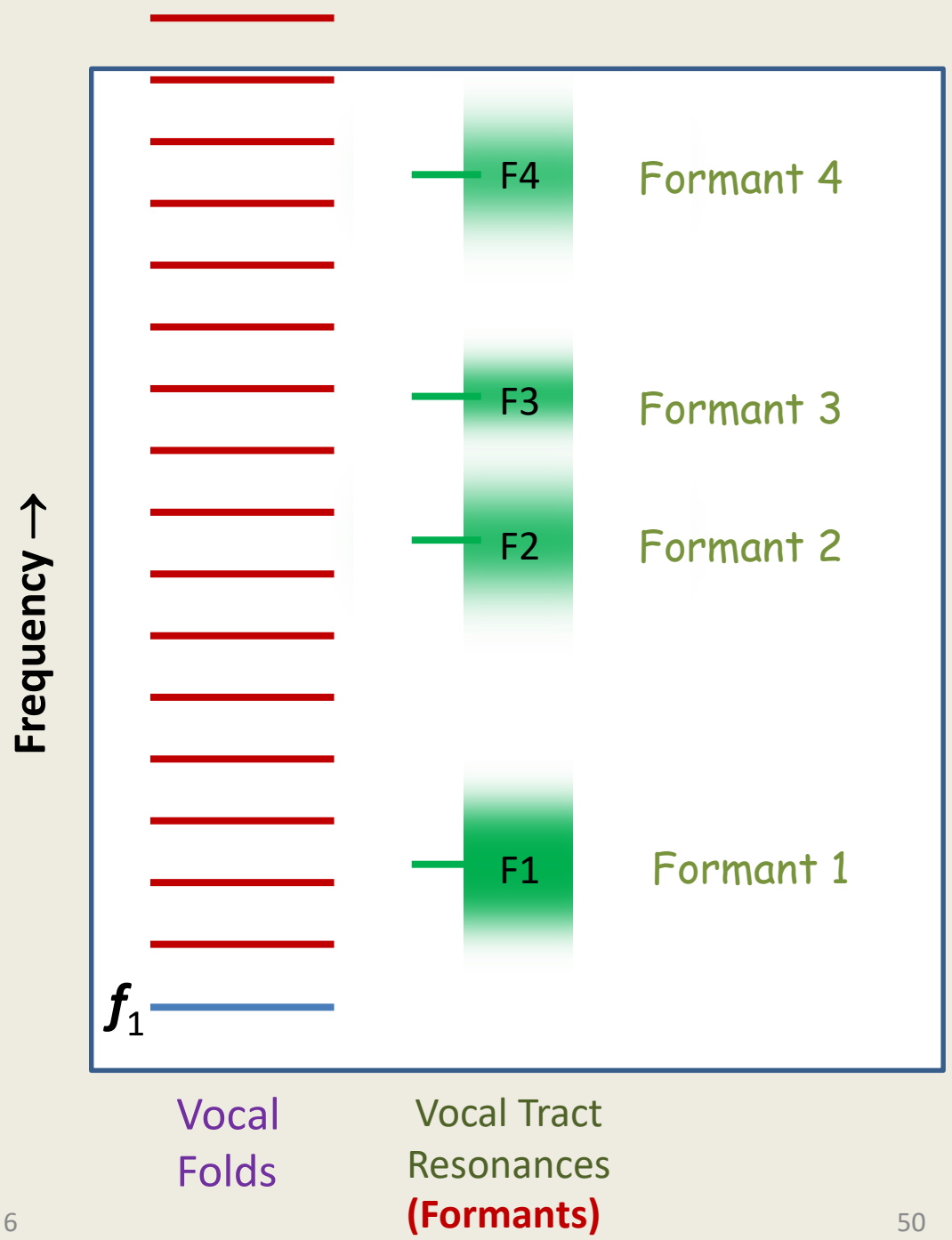



Power to Sing

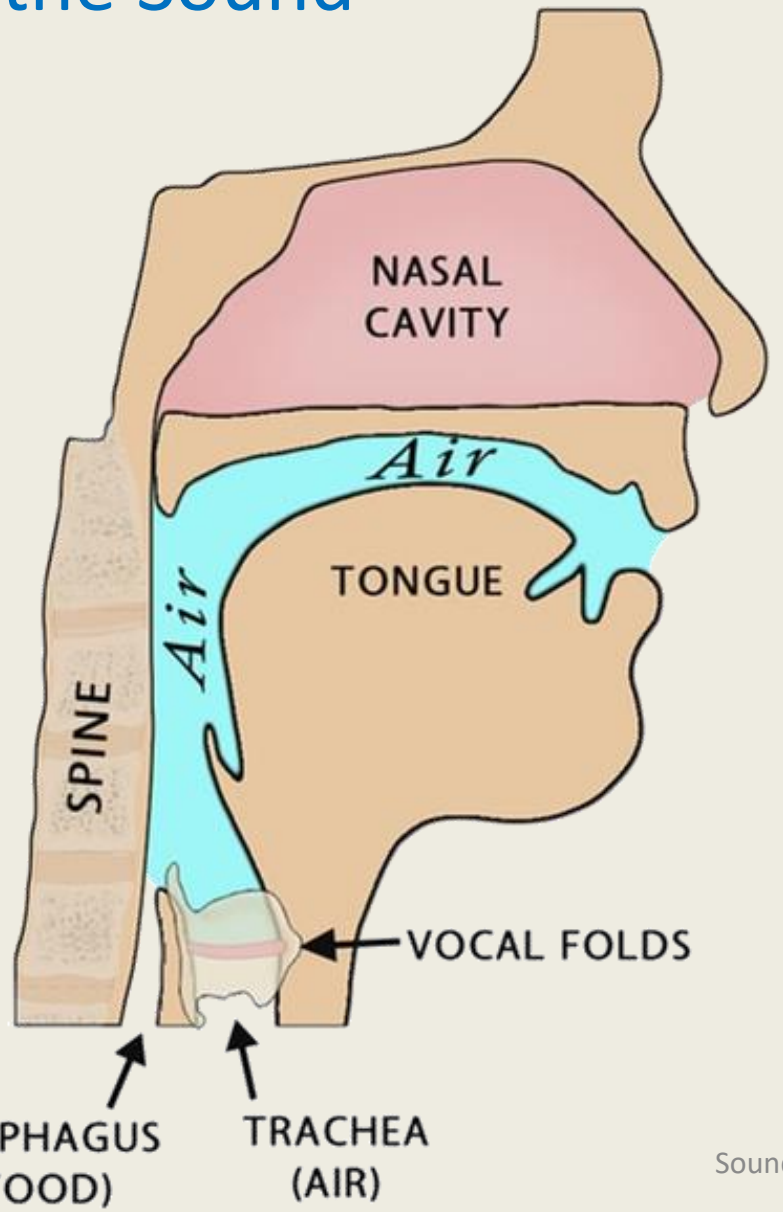
Action of Vocal Folds While Singing

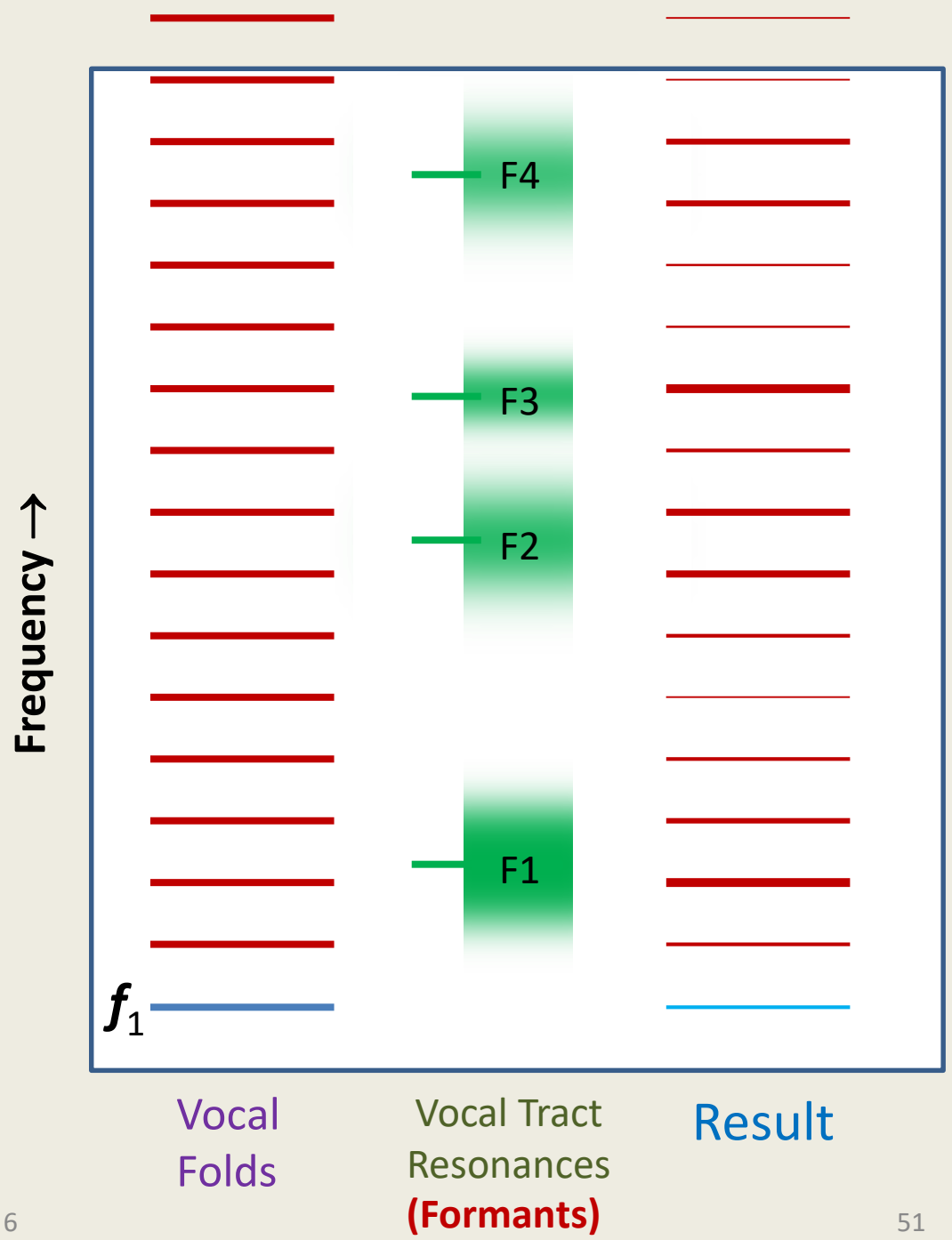
The Vocal Tract Modifies the Sound



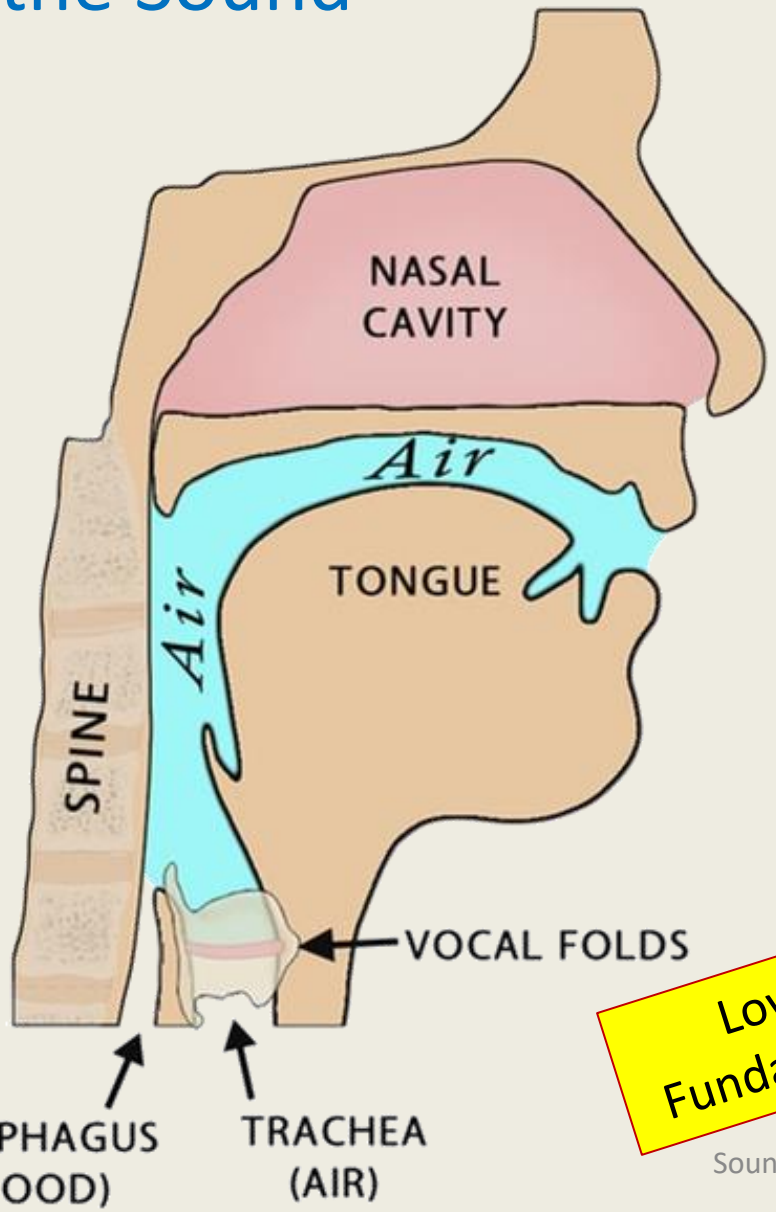


The Vocal Tract Modifies the Sound

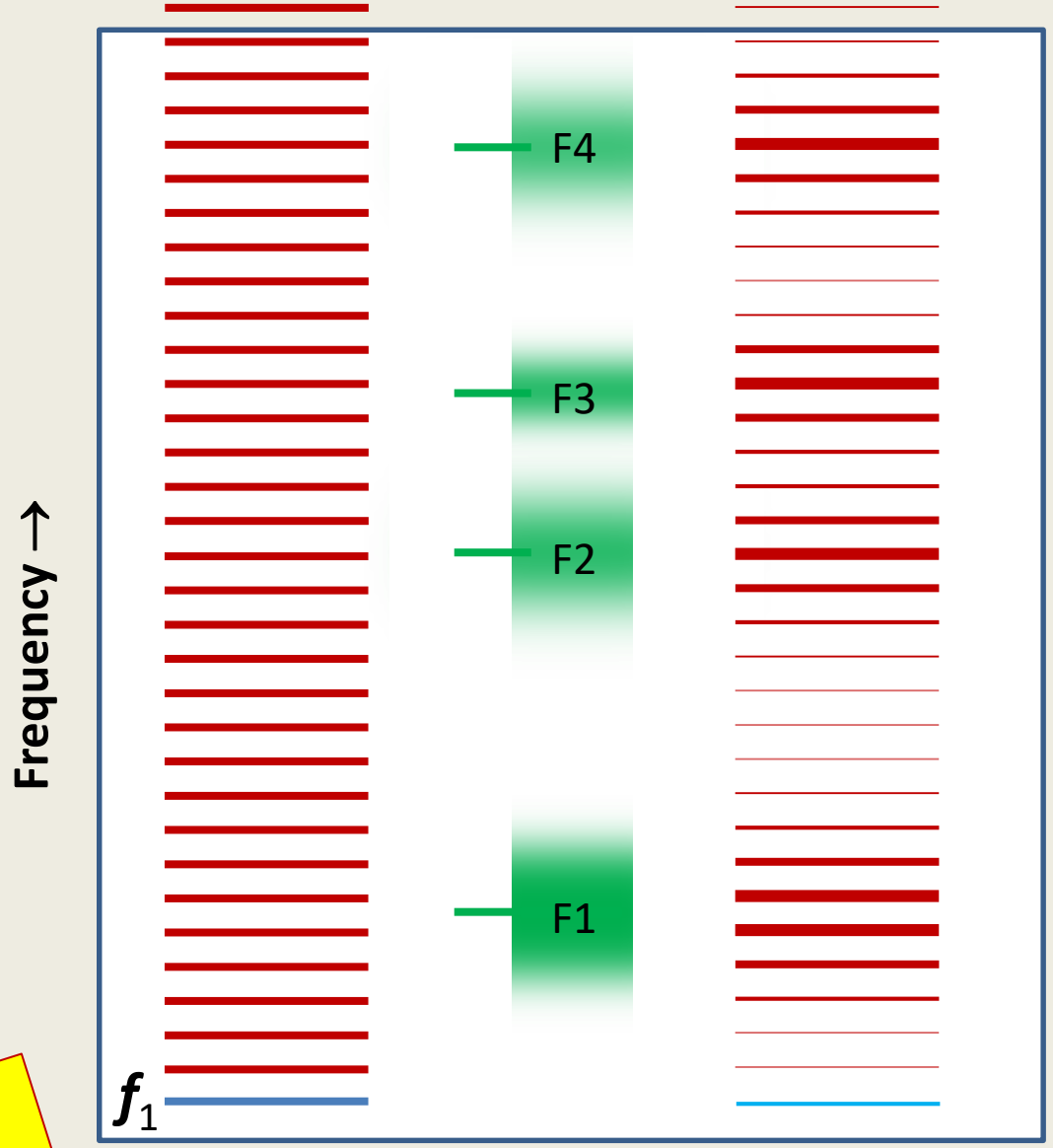




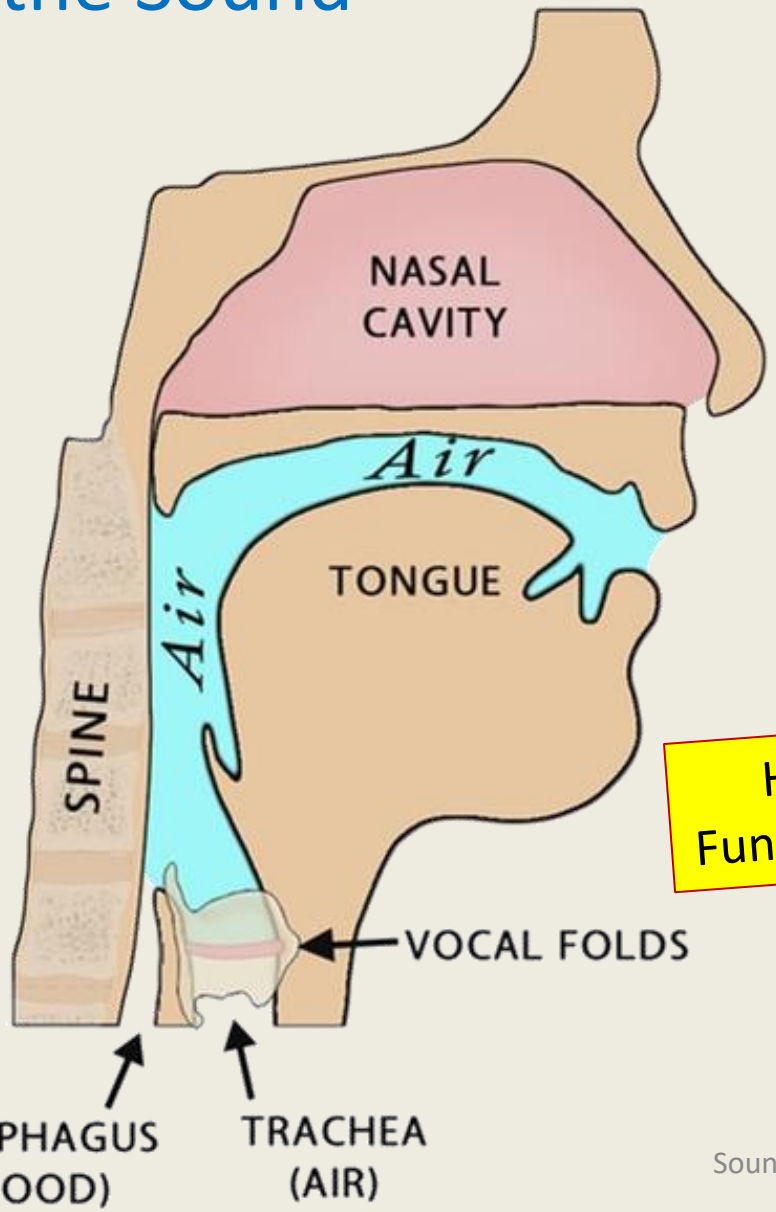
The Vocal Tract Modifies the Sound

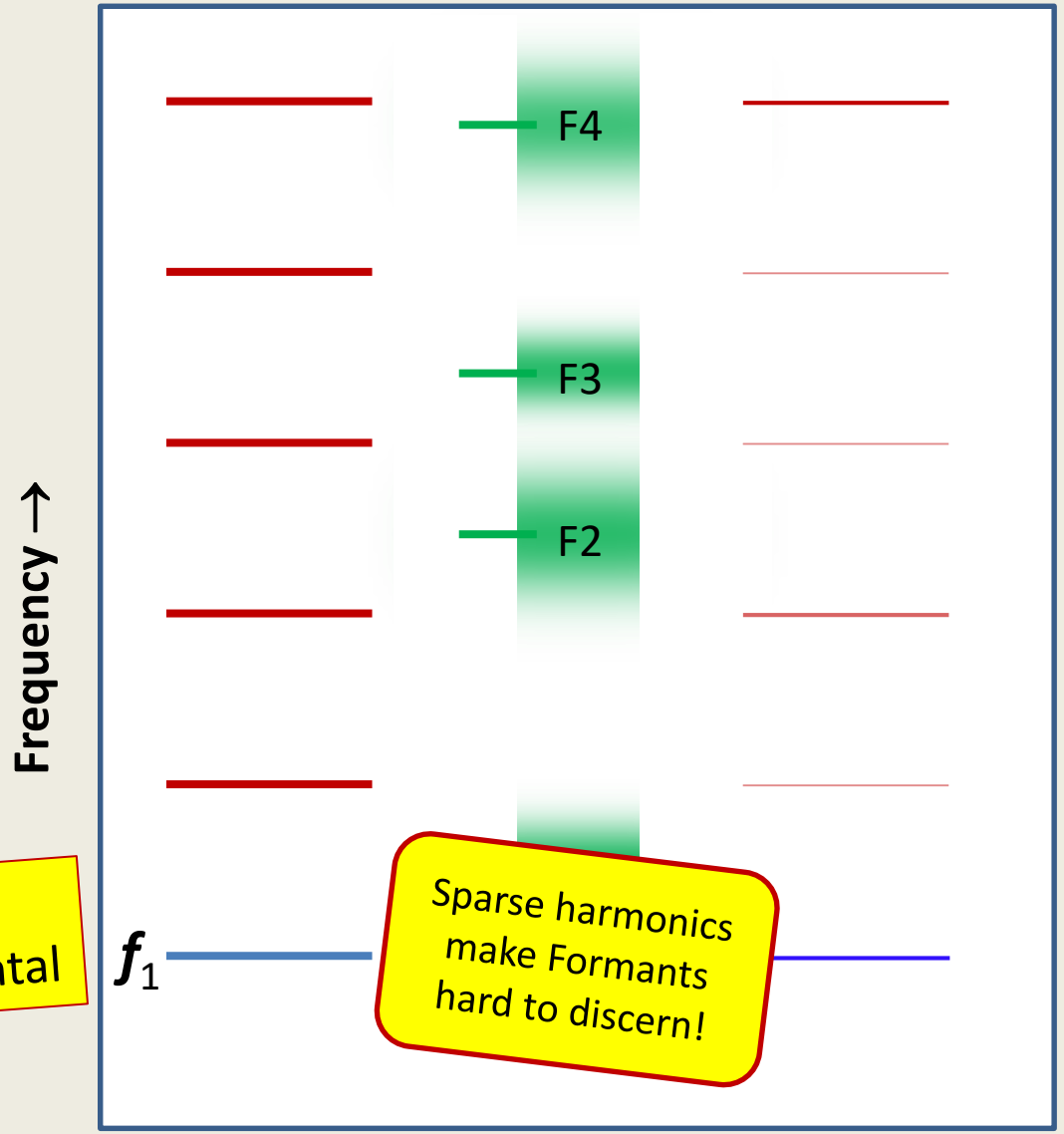


Lower Fundamental

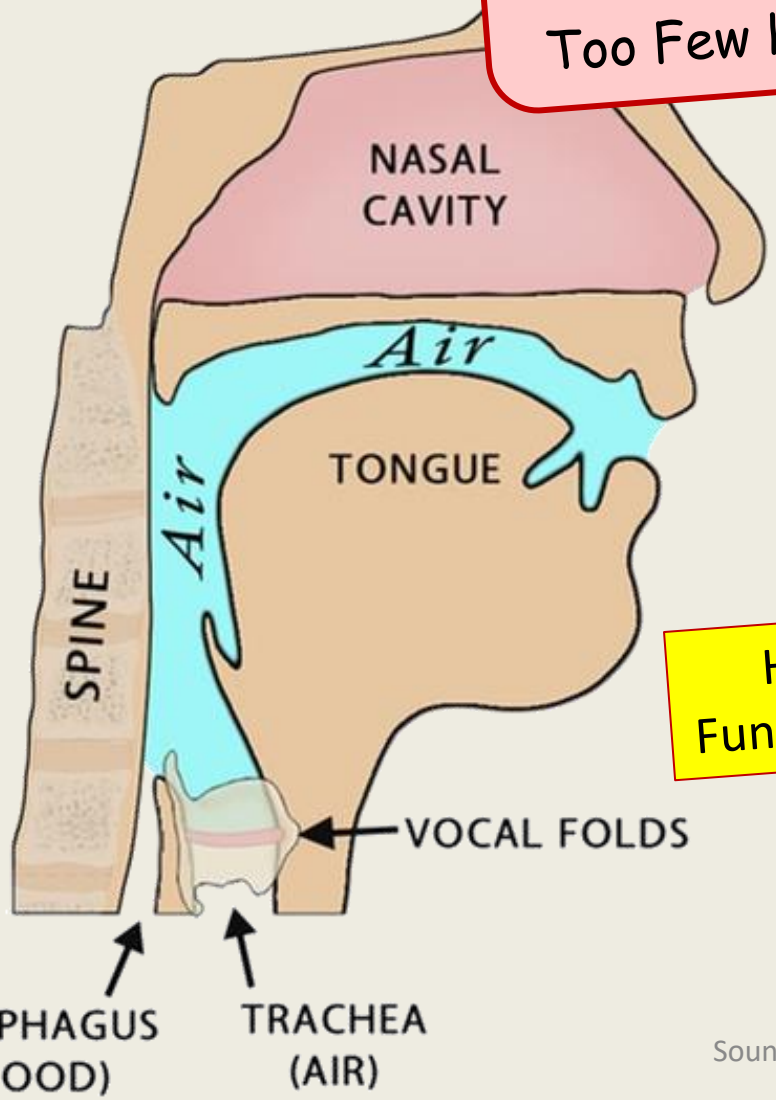


The Vocal Tract Modifies the Sound

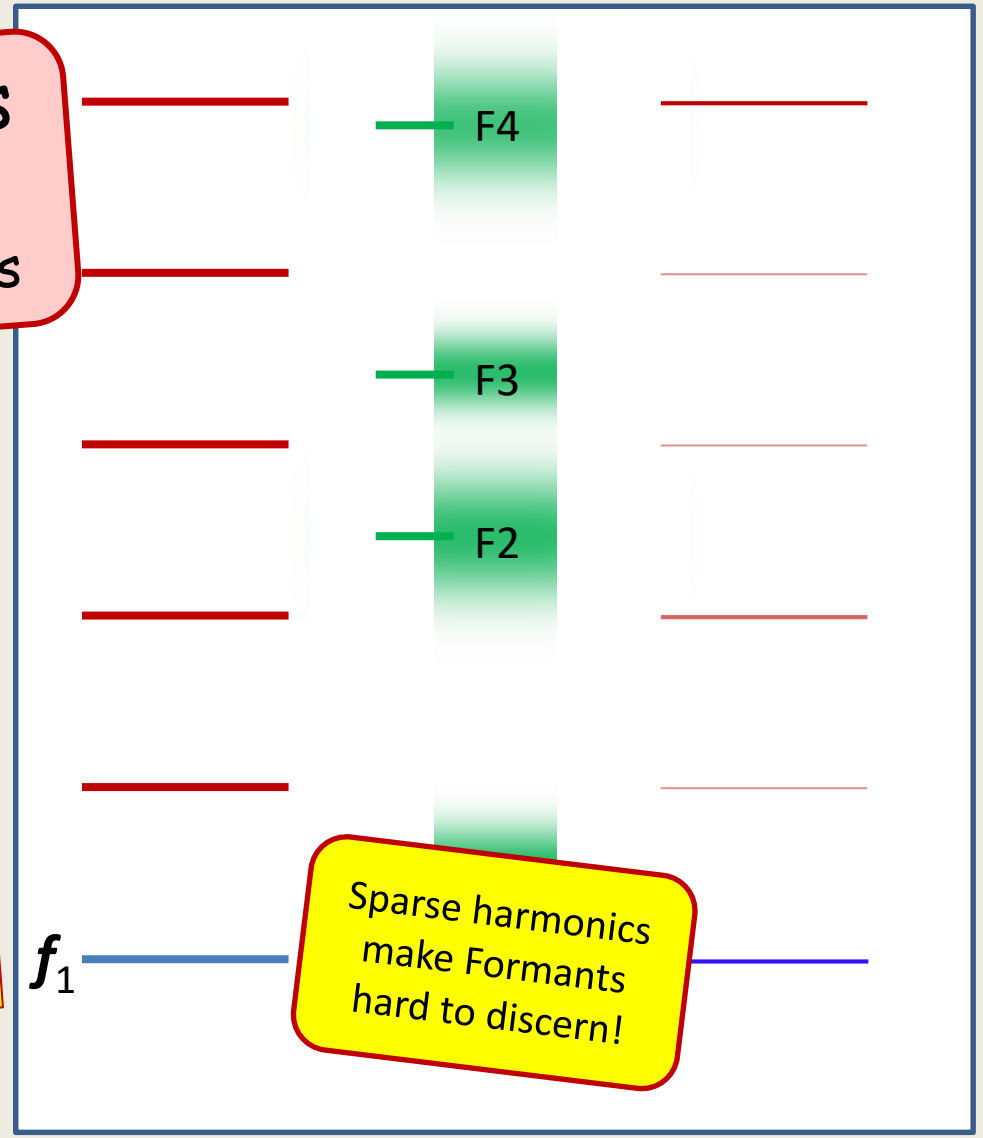




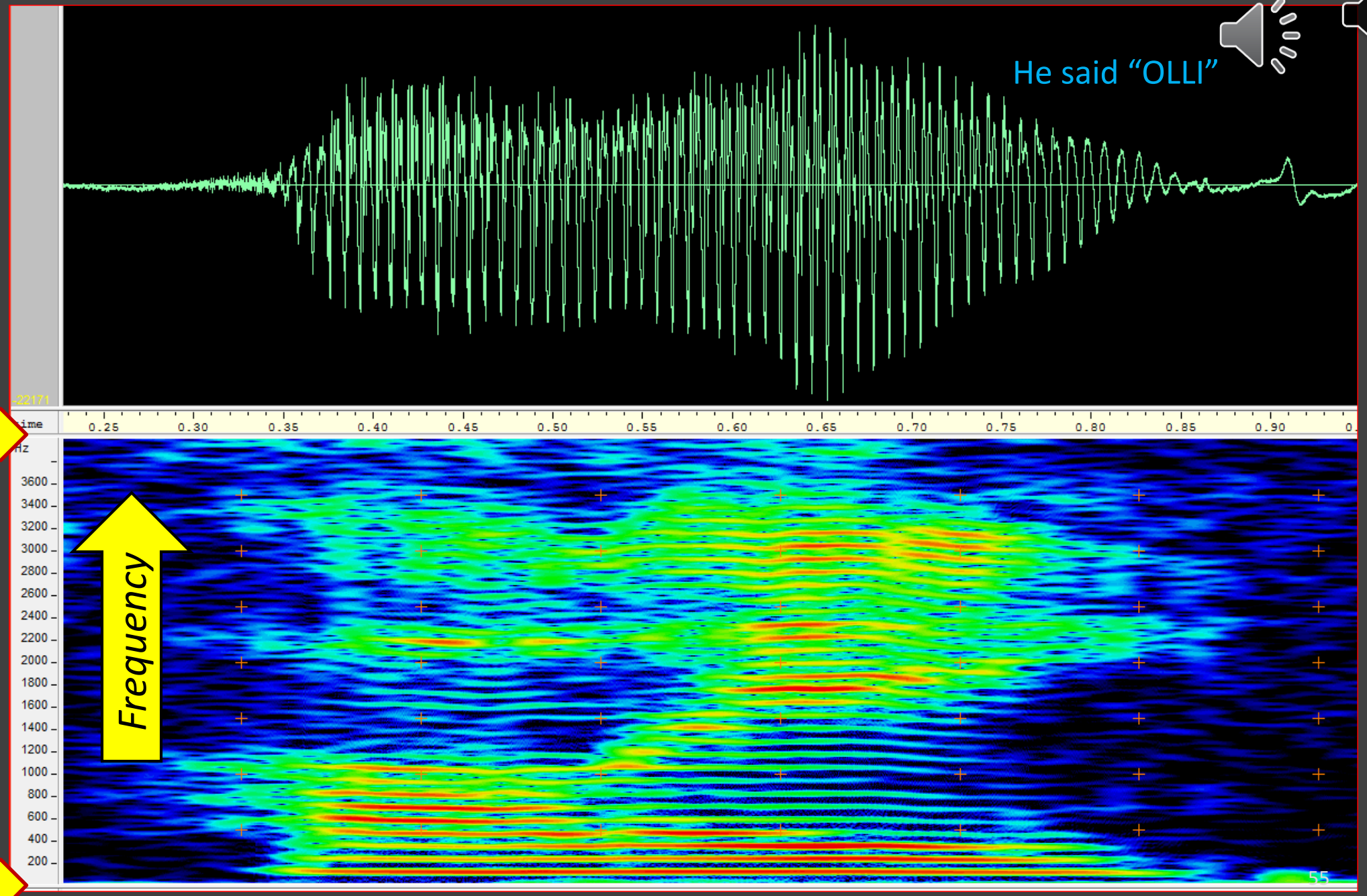
The Vocal Tract Modifies the Sound



The Soprano's Dilemma:
Too Few Harmonics



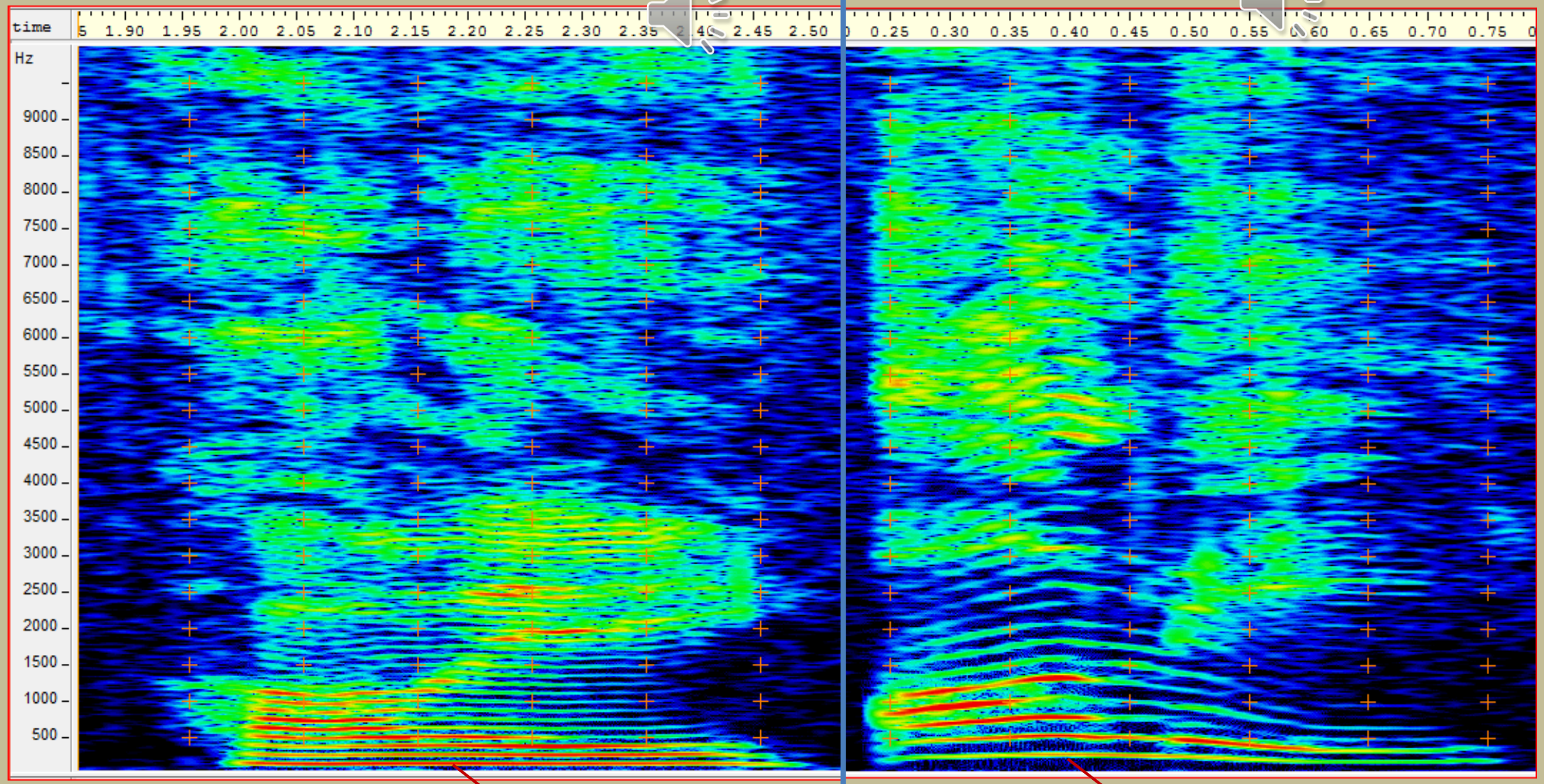
Speaking “Olli”



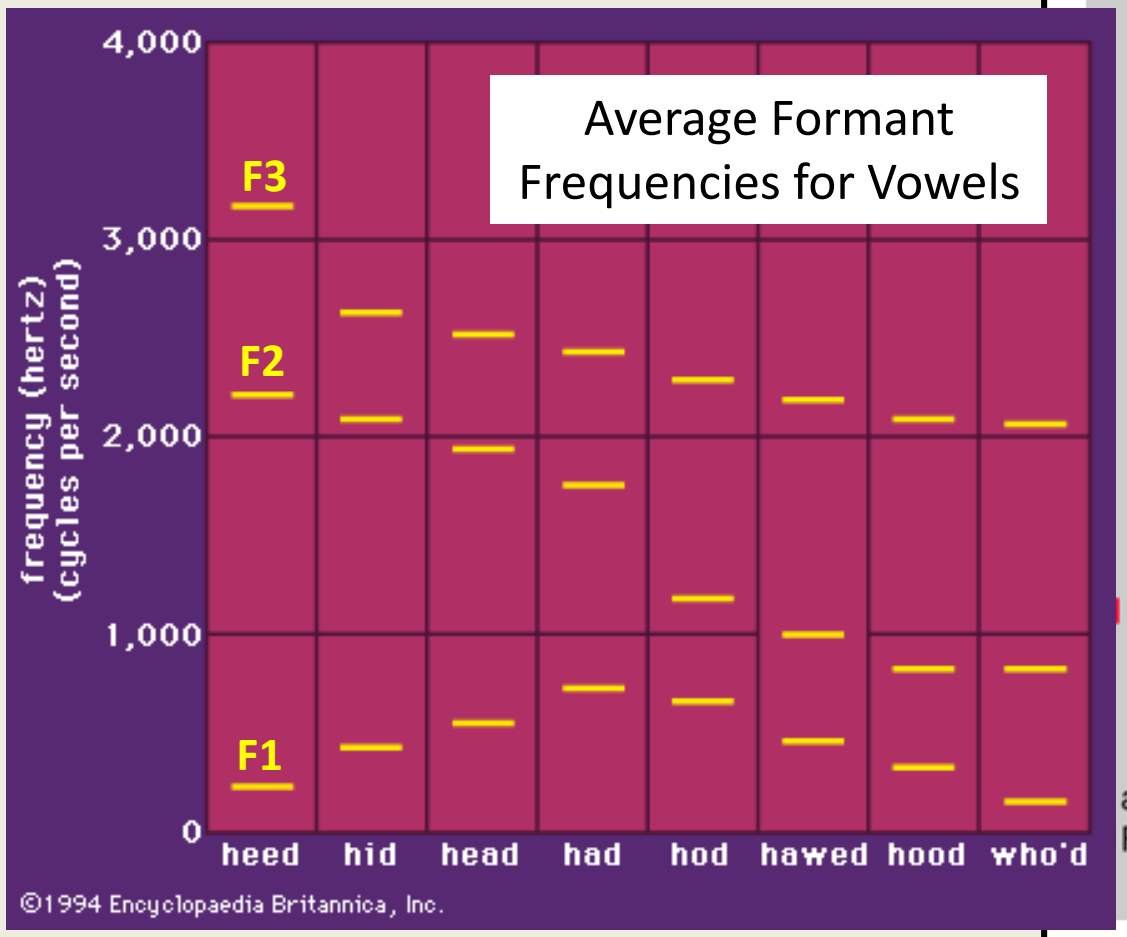
Speech Formants: “Olli”

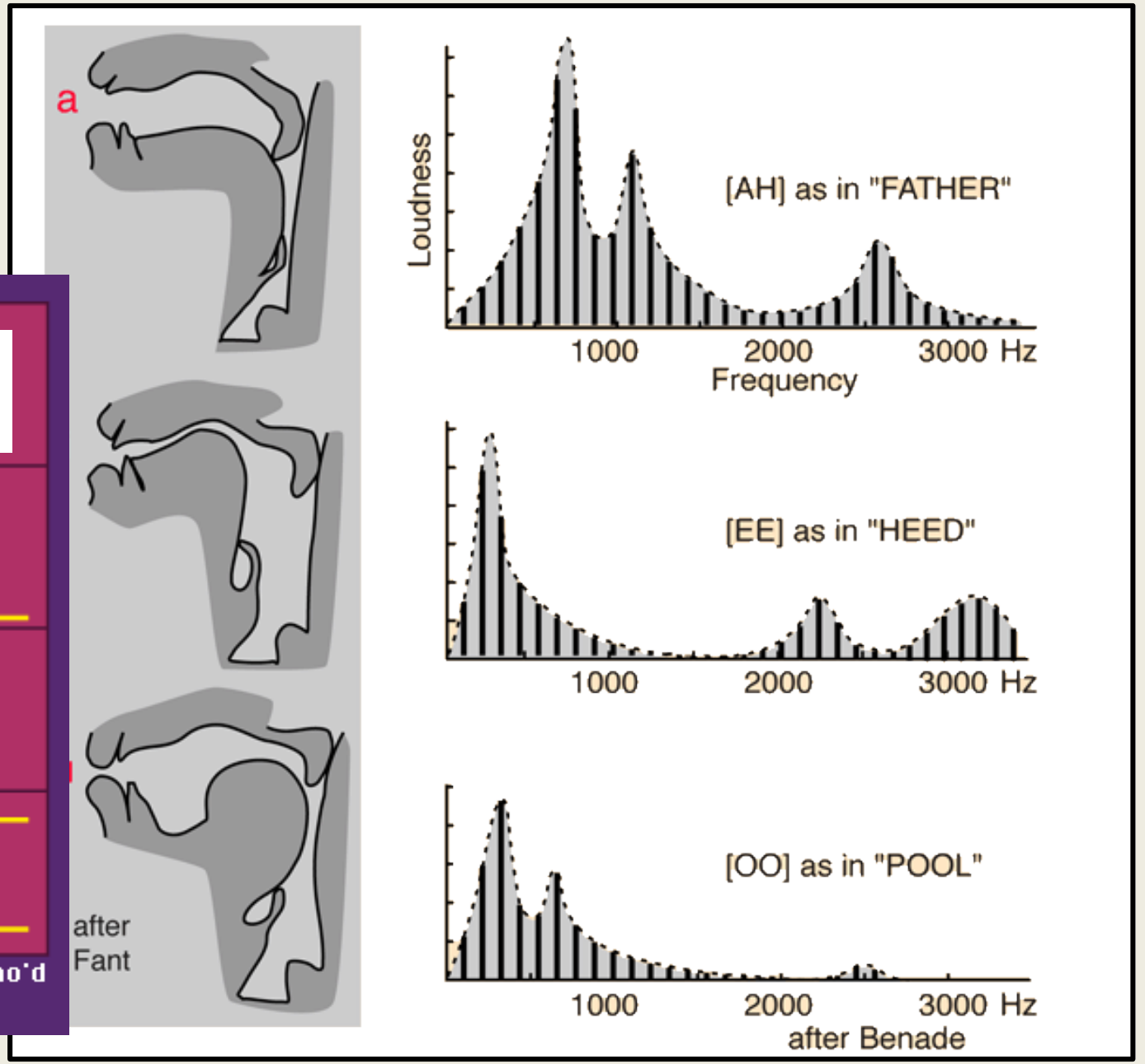
He said “OLLI”

She said “OLLI”

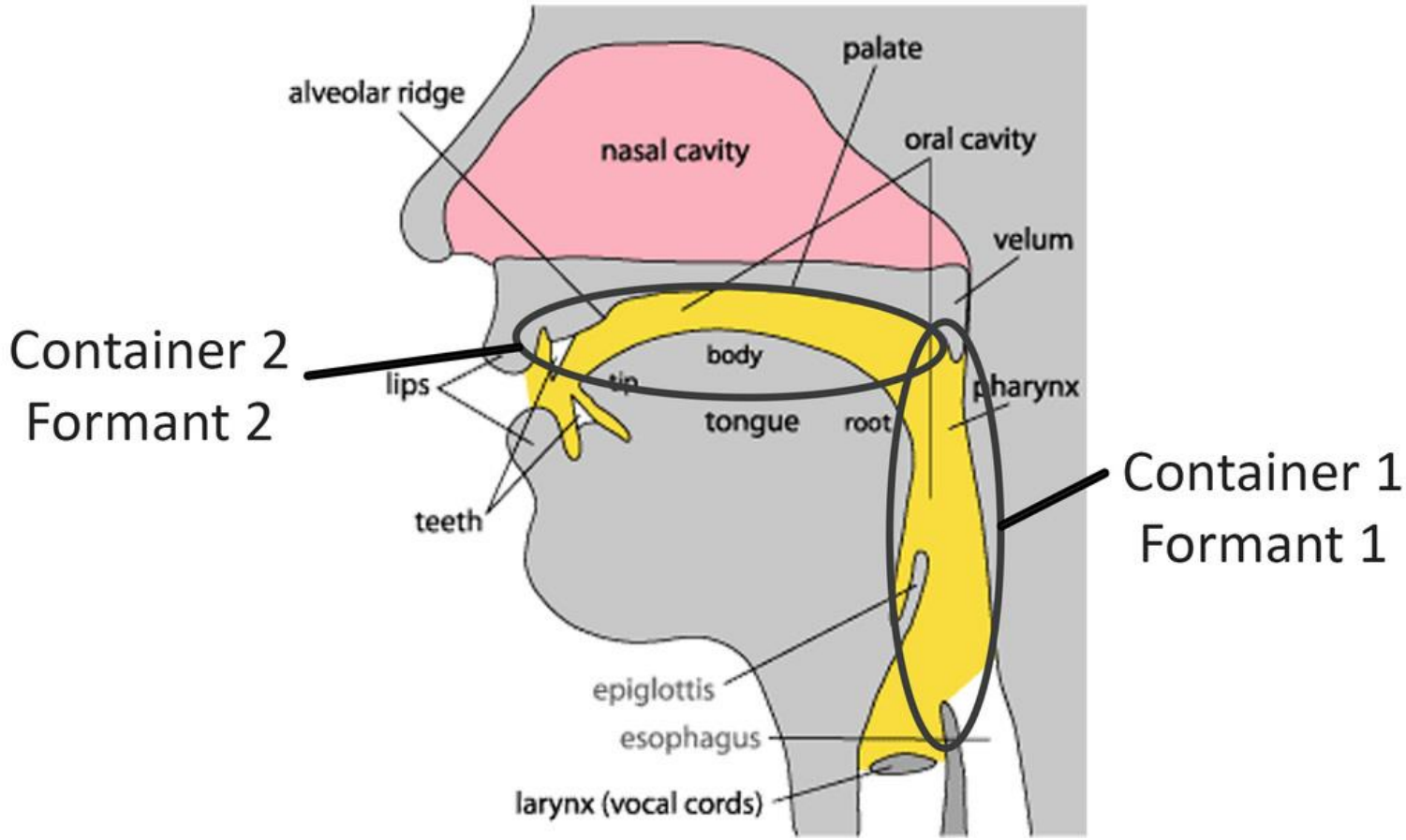


Harmonics of Voice Fundamental Shaped by Formants





Approximate Locations of First 2 Formants



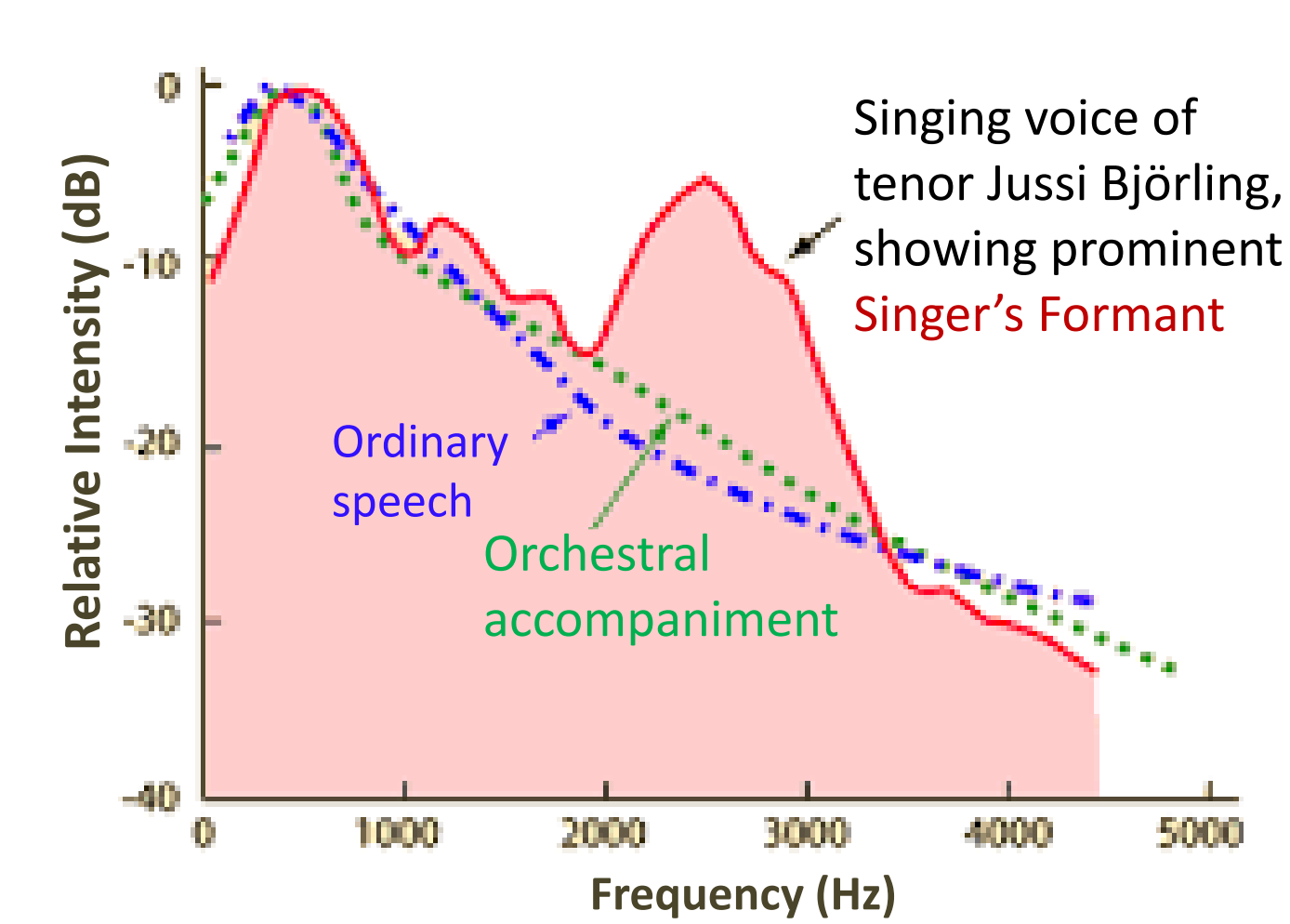
The “Singer’s Formant”

To Compete with Orchestra:

Singers try to shift their Vocal Tract Formants to maximize power around 2 to 3 kHz .

Tricky since each note has *different harmonics* which need to coincide with a Formant.

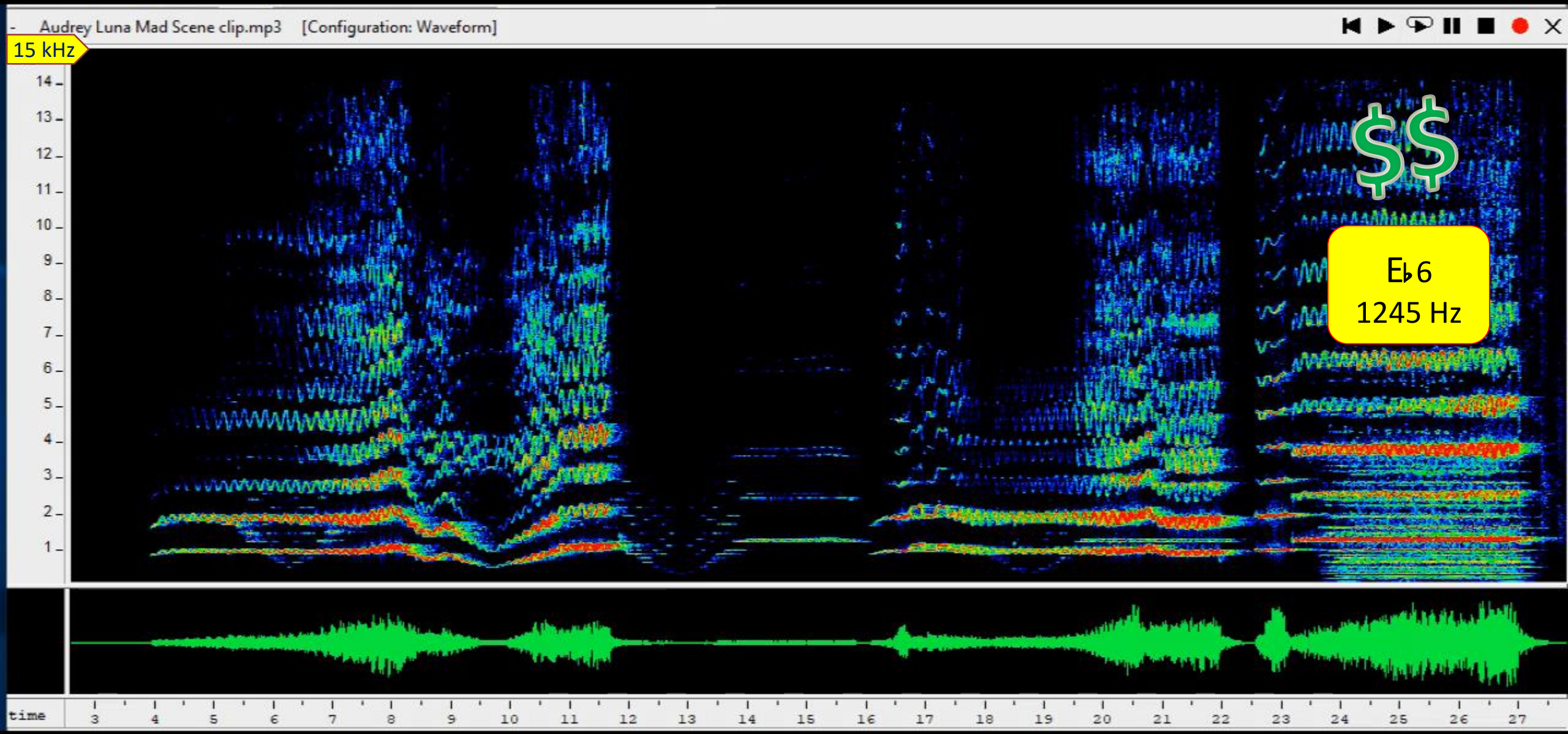
Even Trickier if lyrics must be understood



HyperPhysics: after Sundberg, The Acoustics of the Singing Voice

1911-1960

Audrey Luna hits E♭6 in *Lucia di Lammermoor*



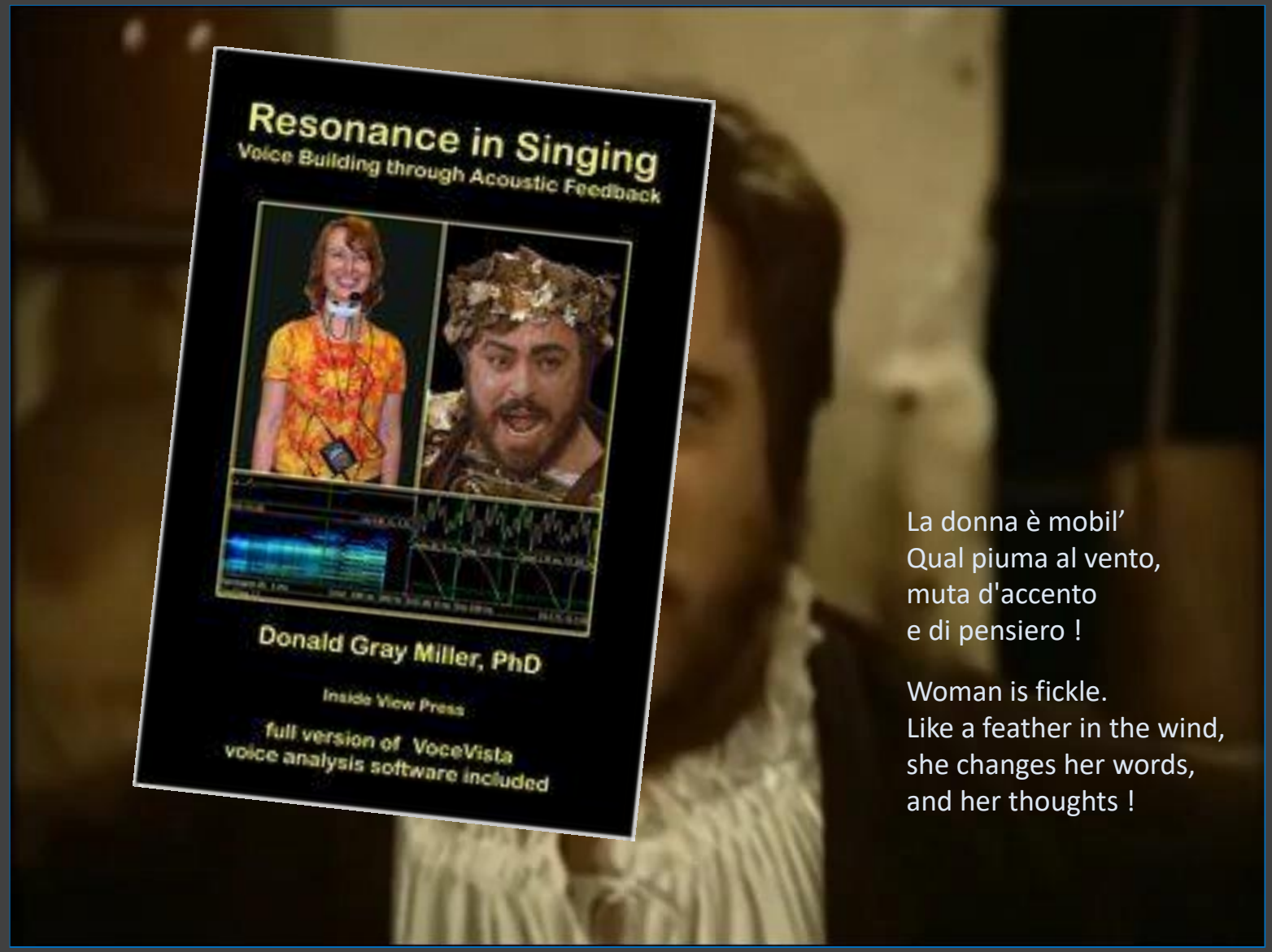
King of High C's

Luciano Pavarotti (1935-2007)
as the Duke of Mantua
in Verdi's Rigoletto
singing *La Donna È Mobile*
[Opera Film *Rigoletto* (1982)]

King of ~~High C's~~

2nd Formant Tuning*

Luciano Pavarotti (1935-2007)
as the Duke of Mantua
in Verdi's Rigoletto
singing *La Donna È Mobile*
[Opera Film *Rigoletto* (1982)]



*According to D.G. Miller, *Resonance in Singing* (2008)

King of ~~High C's~~

2nd Formant Tuning*

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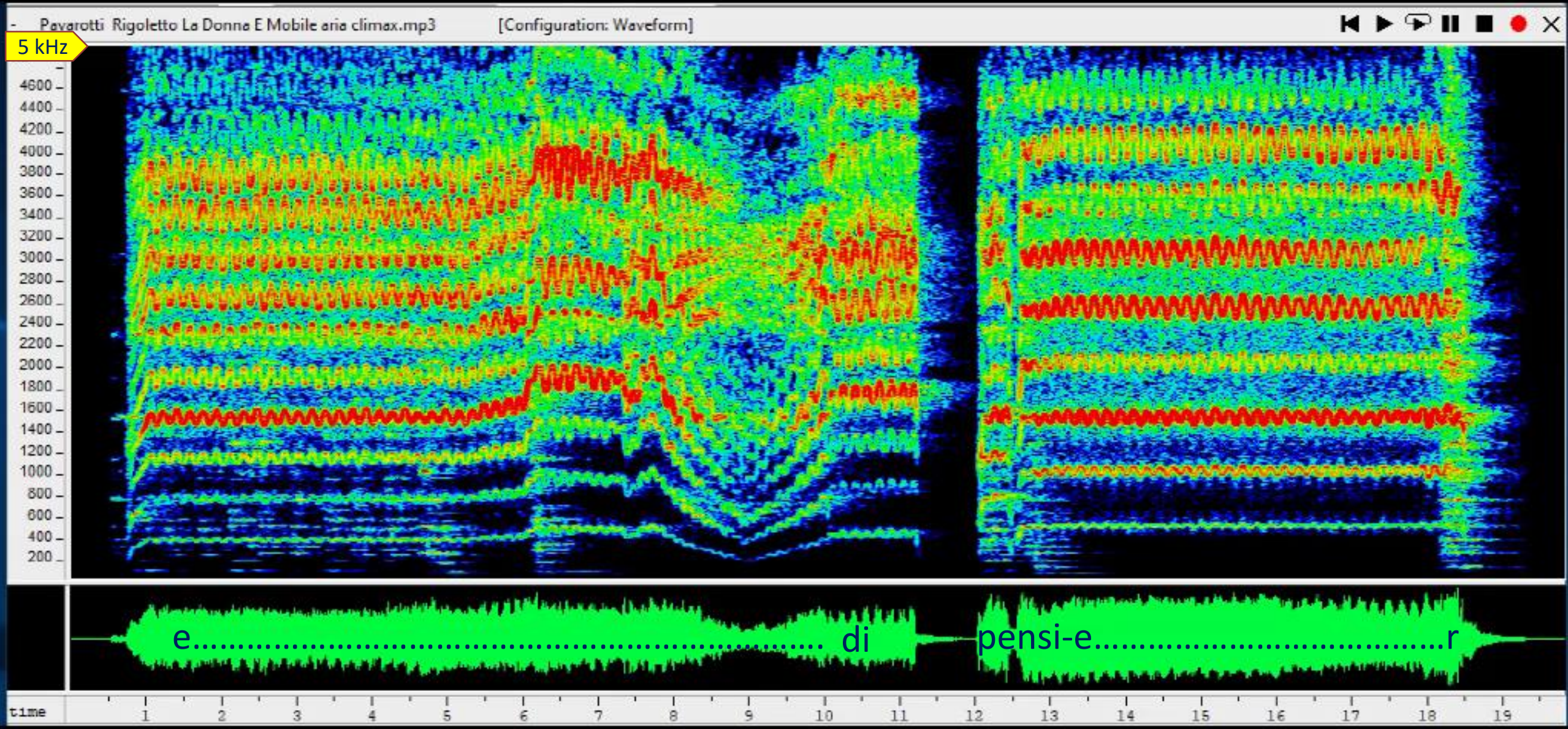
Opera Film *Rigoletto* (1982)

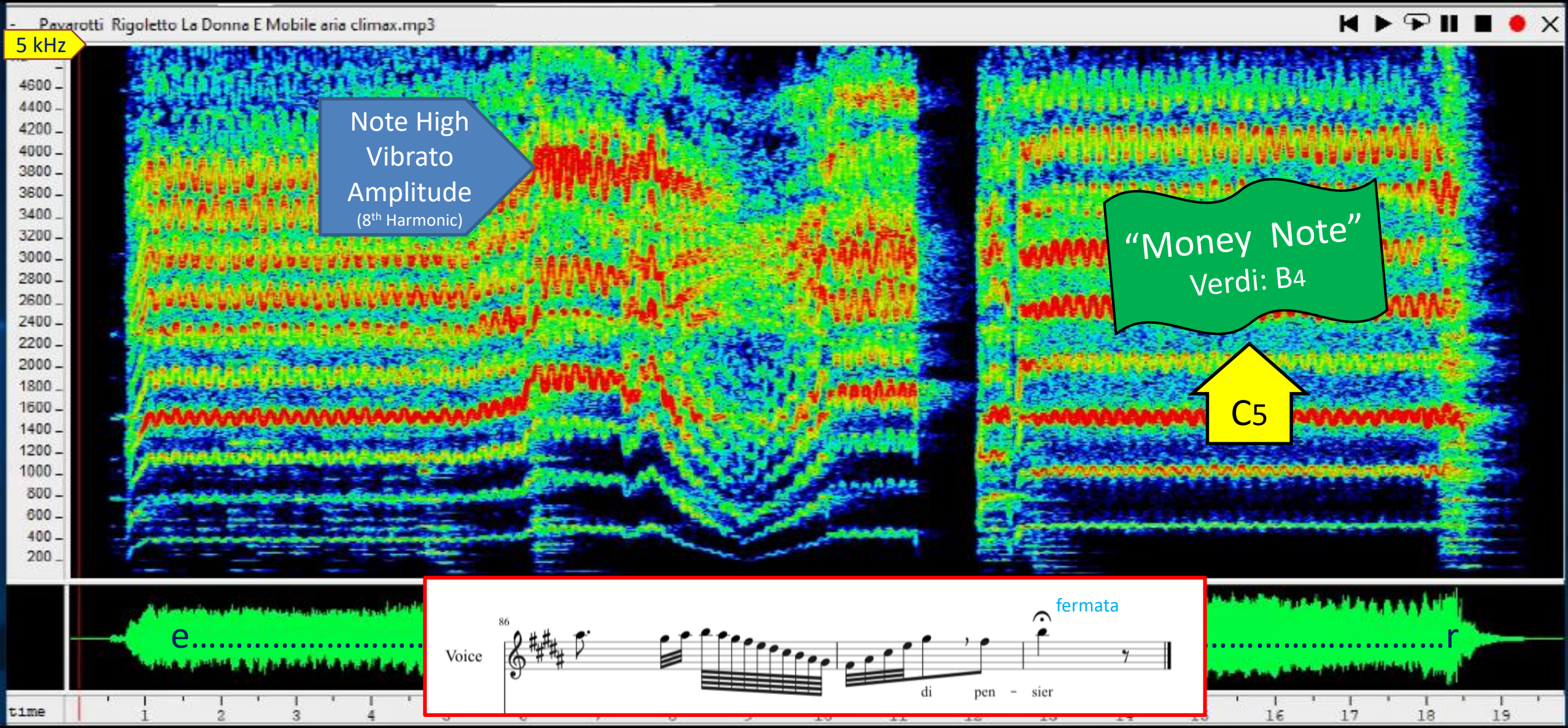
*According to D.G. Miller, *Resonance in Singing* (2008)

e di pensier' !
and her thoughts !

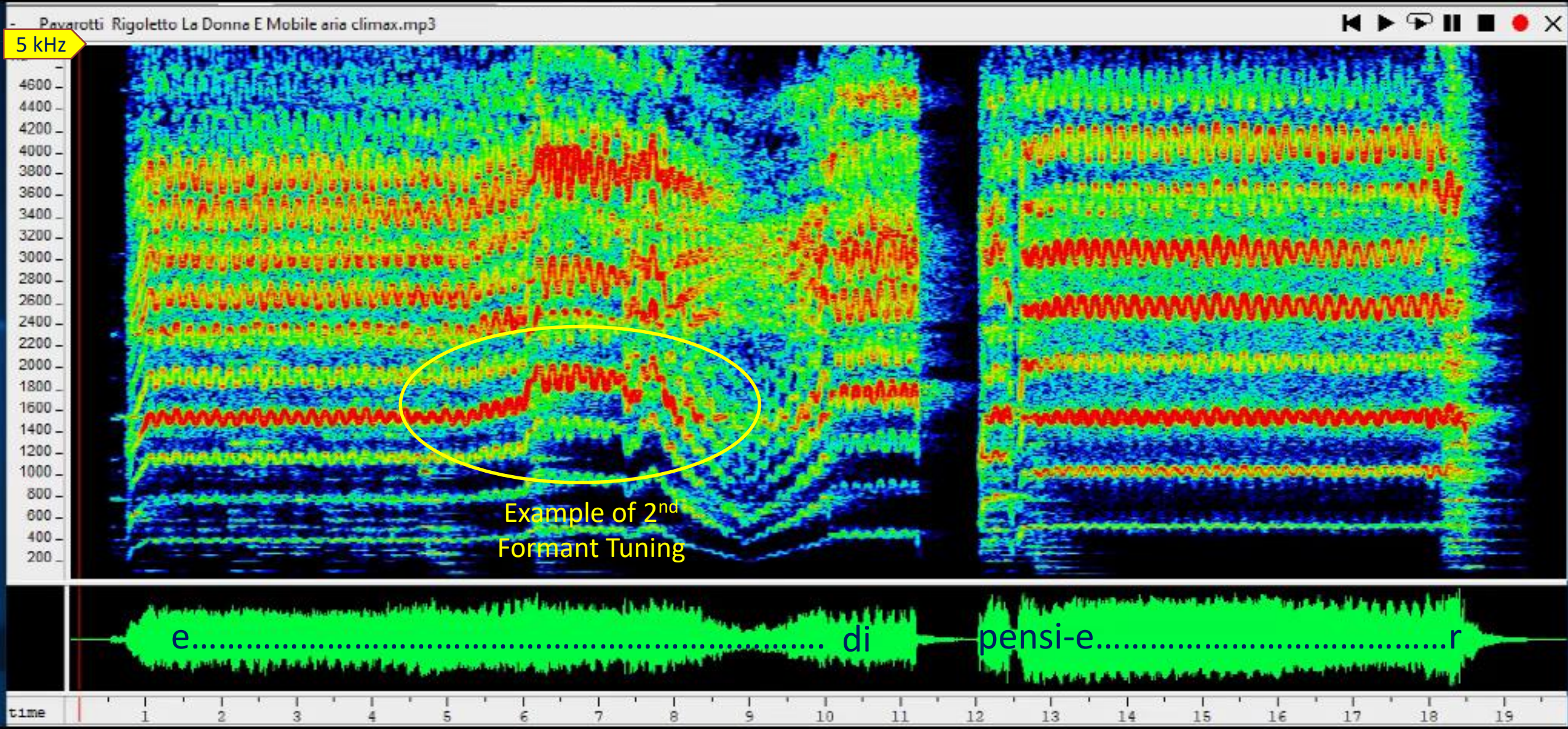
Pavarotti: Rigoletto -- La donna è mobile



Pavarotti: Rigoletto -- La donna è mobile



Pavarotti: Rigoletto – King of 2nd Formant Tuning



A Music Lesson

Chest Voice
vs
Head Voice

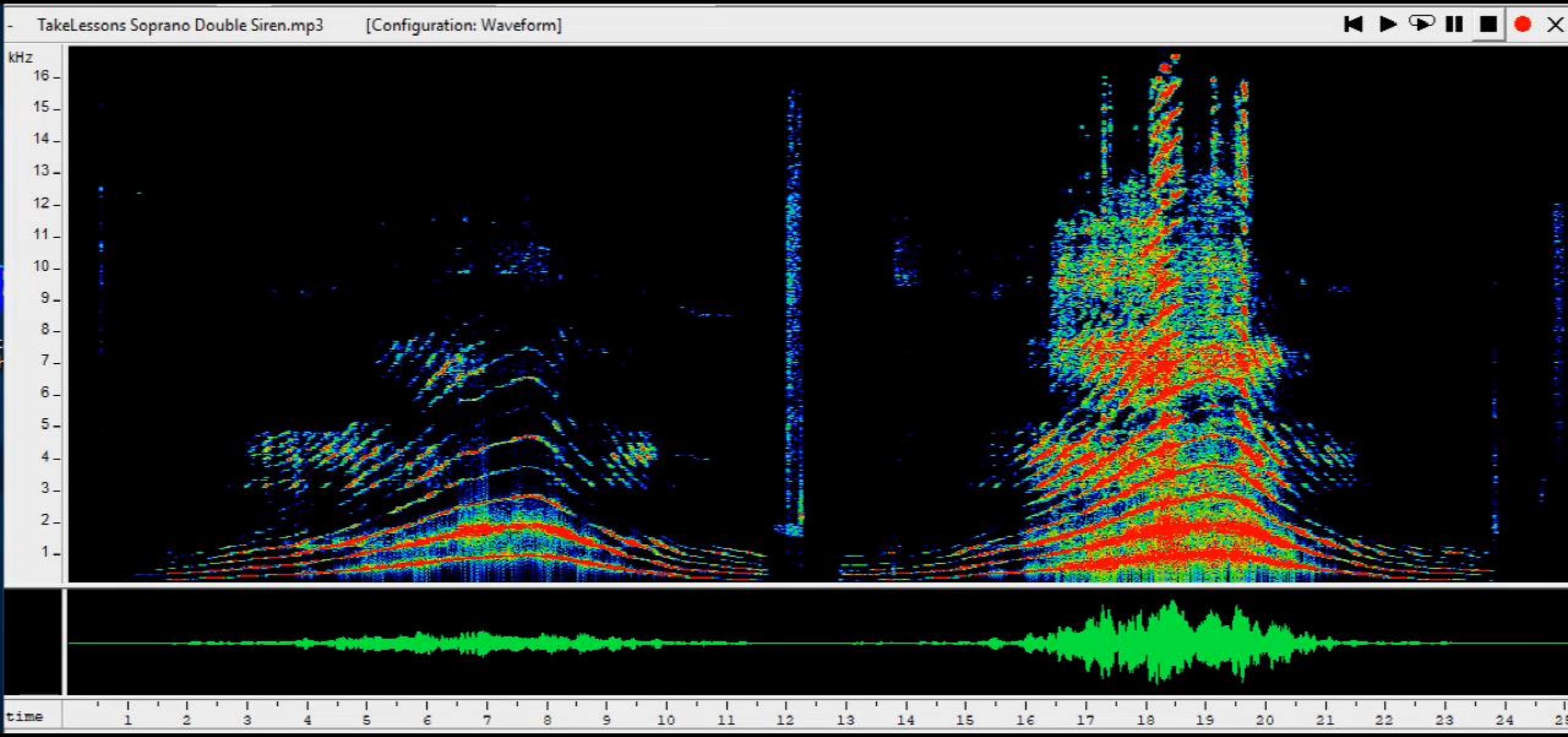
Vocal Warmups for Singing: The 7 Best Exercises (2018)
TakeLessons.com

A Music Lesson

Siren Singing:
Vowel changes
from who to ahh

Vocal Warmups for Singing: The 7 Best Exercises (2018)
TakeLessons.com

“Siren”


TakeLessons Soprano Double Siren.mp3
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12
11
10
9
8
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3
2
1
time
1
2
3
4
5
6
7
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19
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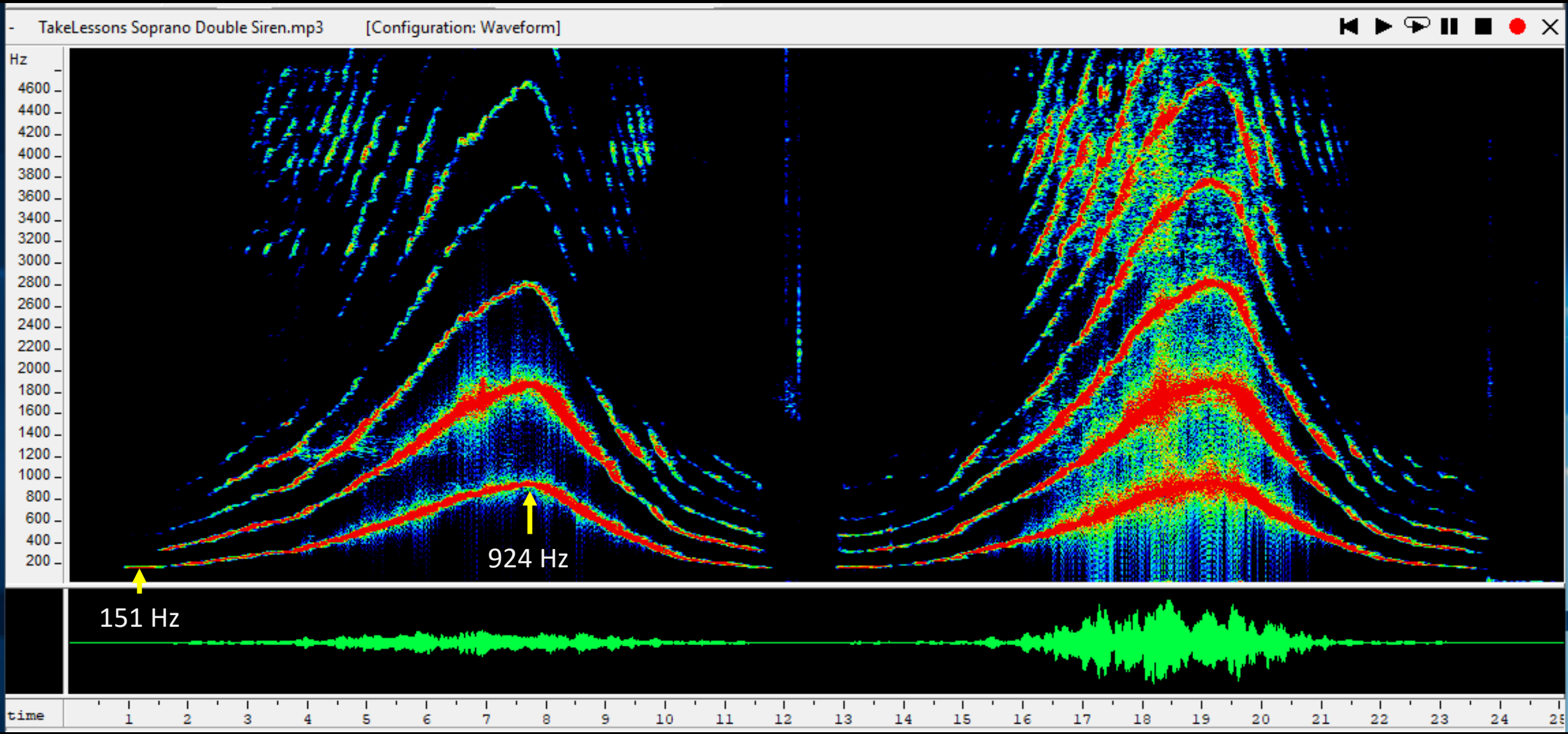
23
24

“Siren”


- TakeLessons Soprano Double Siren.mp3 [Configuration: Waveform]
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4200
4000
3800
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3400
3200
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2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
924 Hz
151 Hz
time
1
2
3
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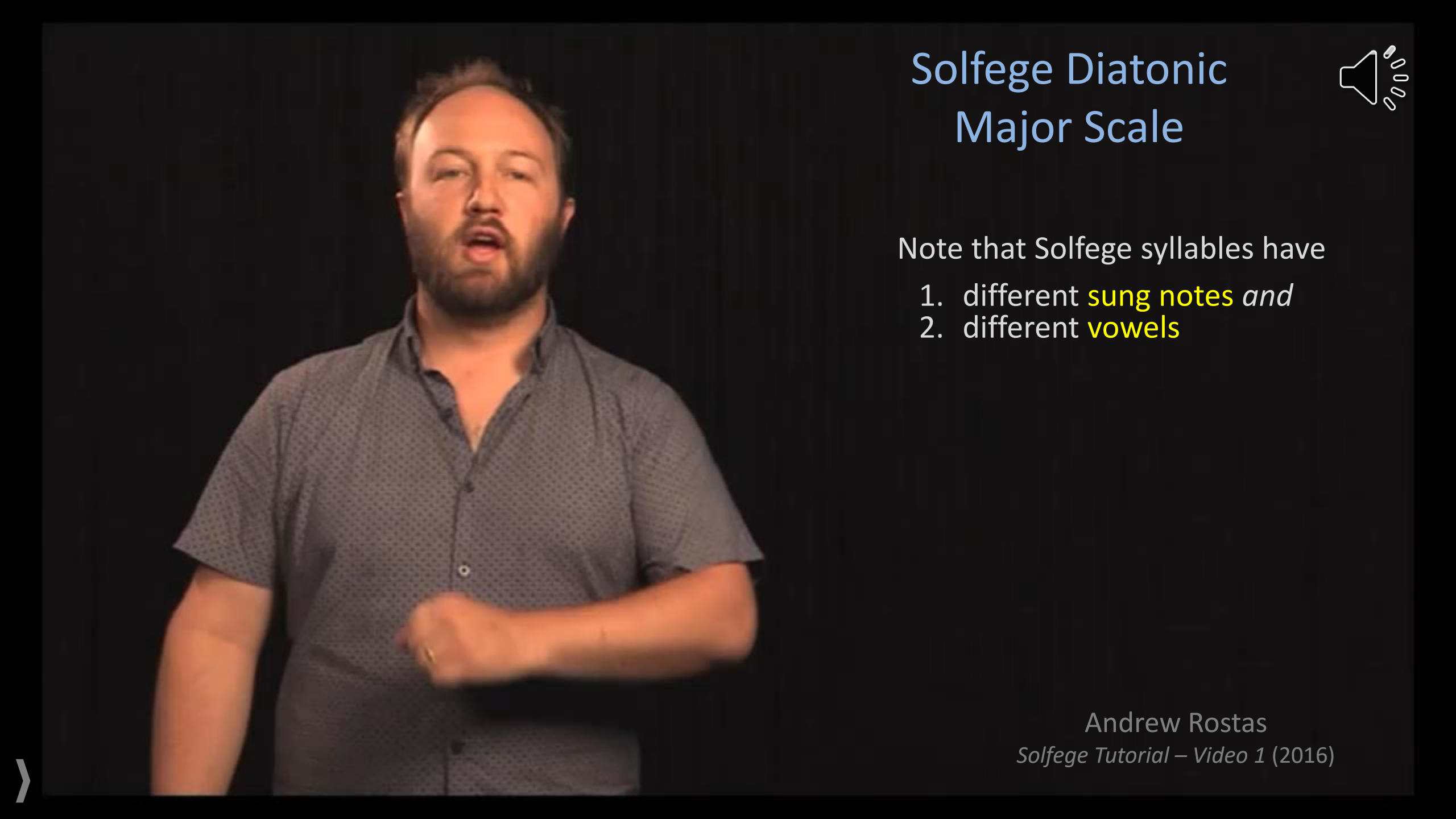


Solfege Diatonic Major Scale

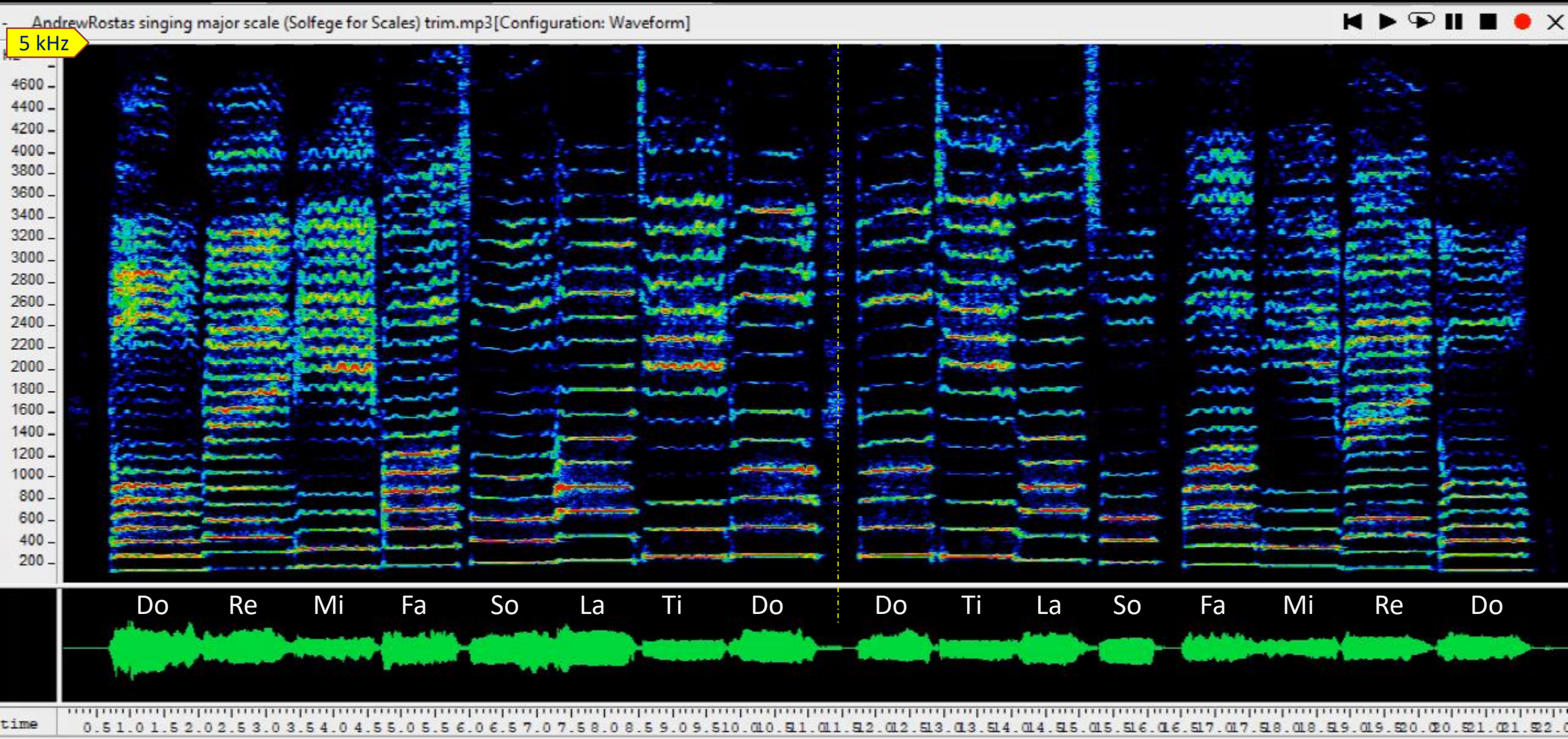
Note that Solfege syllables have

1. different sung notes *and*
2. different vowels

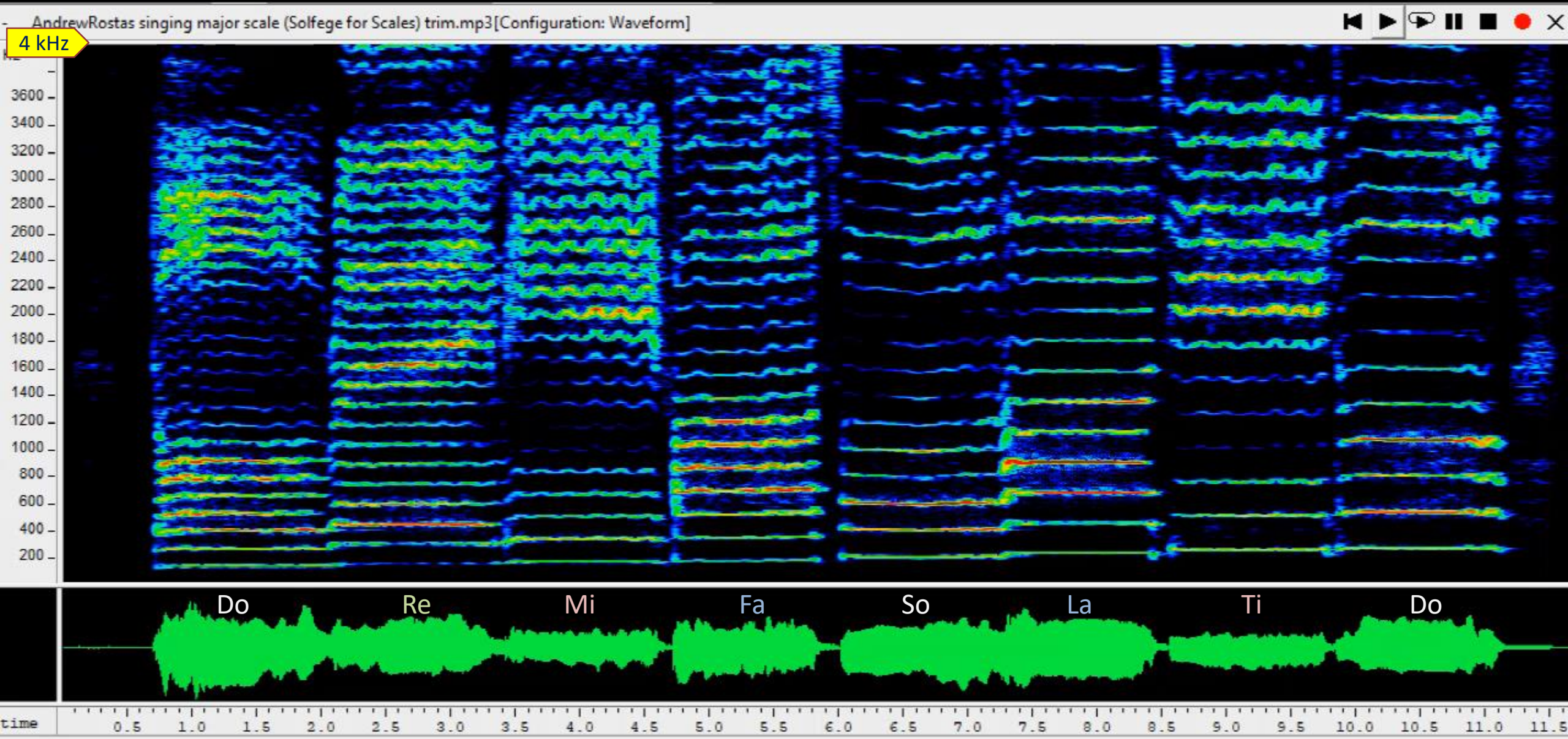
Andrew Rostas

Solfege Tutorial – Video 1 (2016)

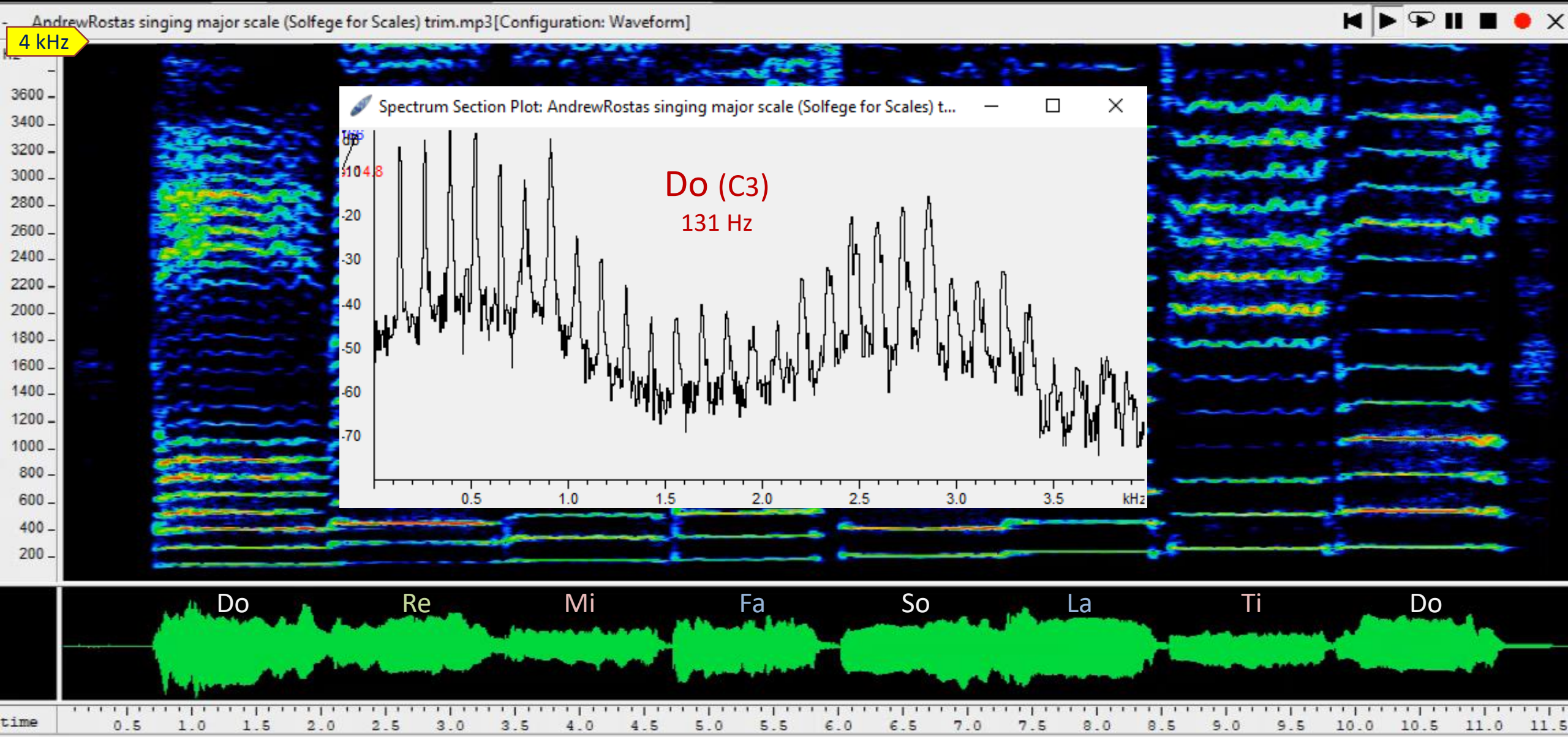
Solfege: Diatonic C Major Scale [C3 to C4]



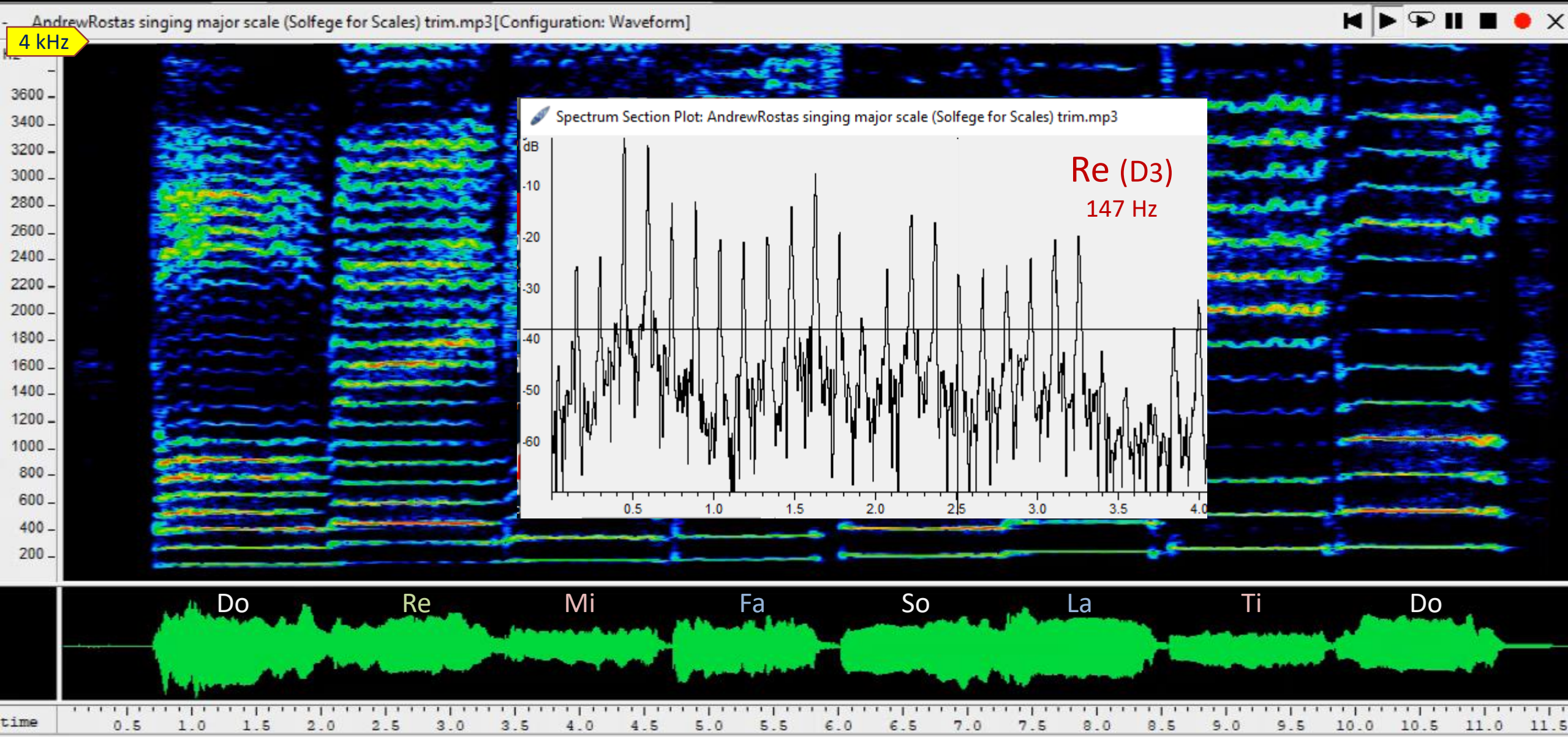
Solfege: Diatonic C Major Scale [C3 to C4]



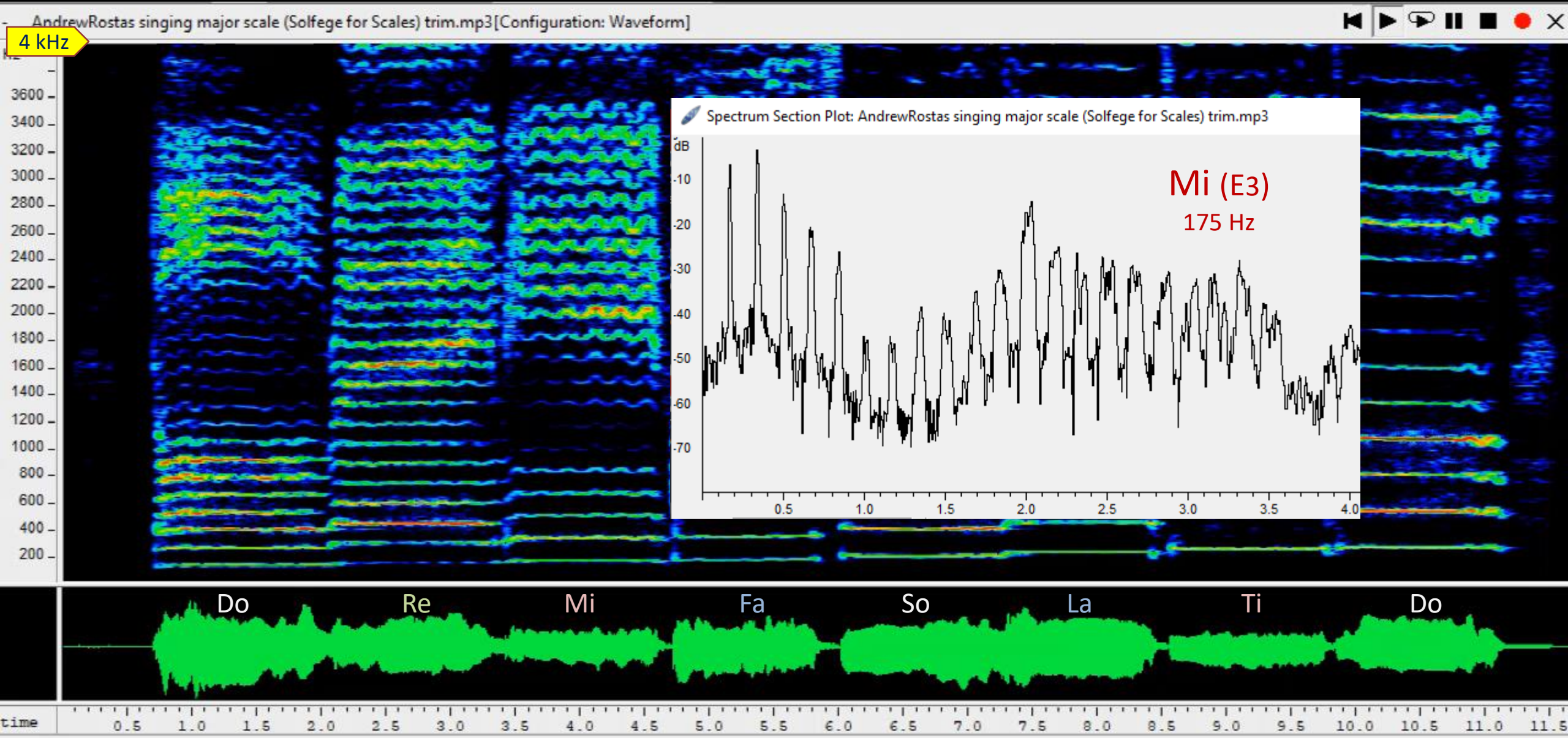
Solfege: Diatonic C Major Scale [C3 to C4]



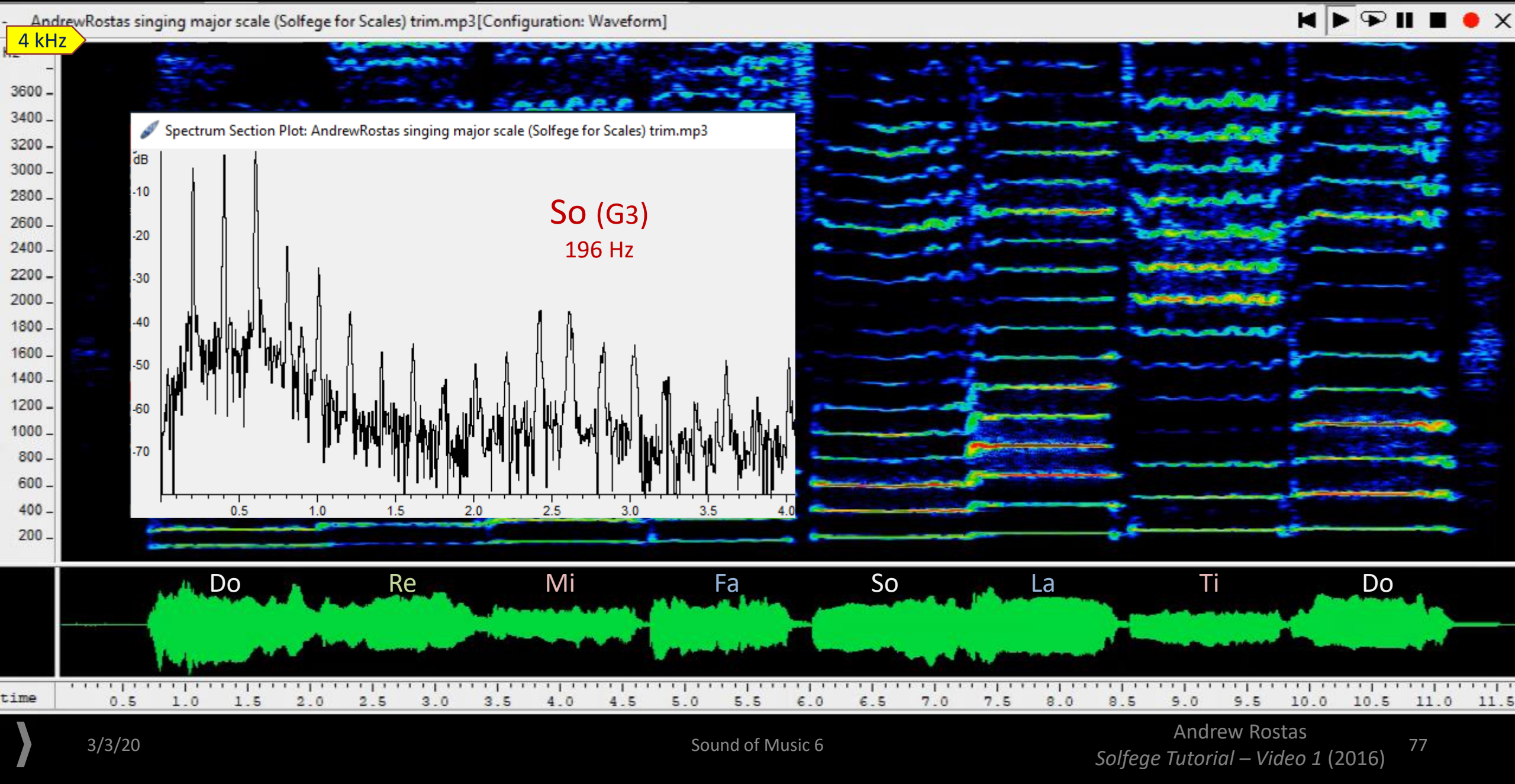
Solfege: Diatonic C Major Scale [C3 to C4]



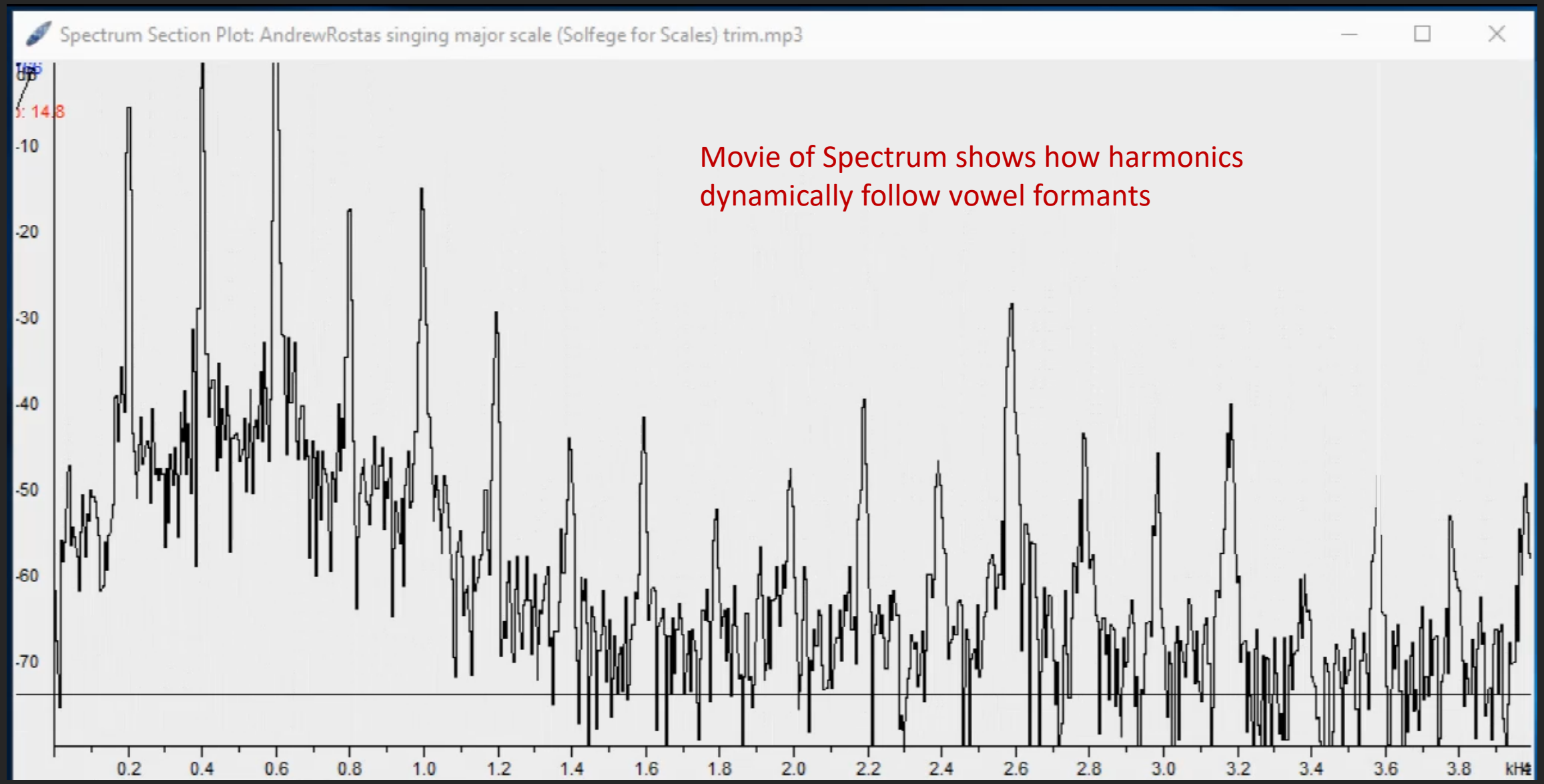
Solfege: Diatonic C Major Scale [C3 to C4]



Solfege: Diatonic C Major Scale [C3 to C4]



Solfege: Diatonic C Major Scale [C3 to C4]



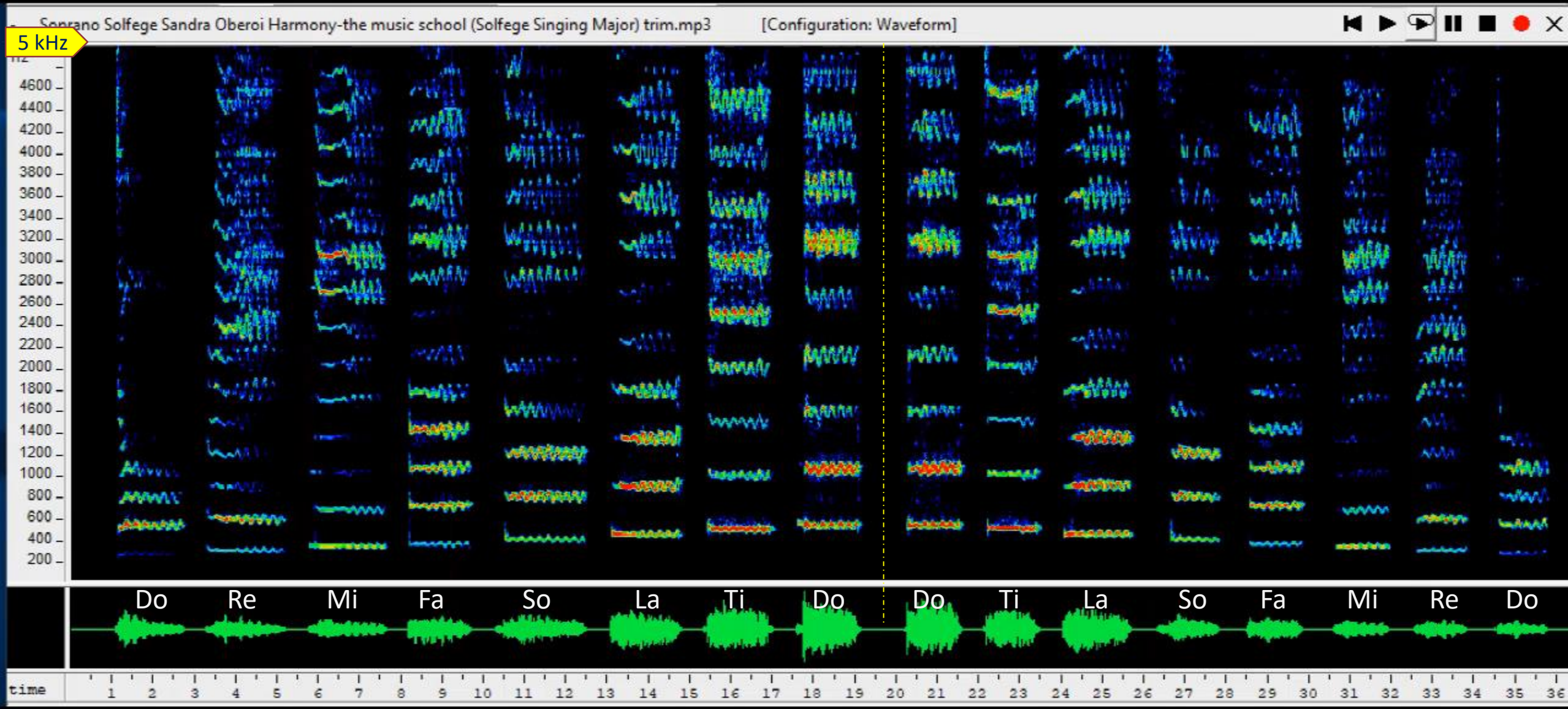
Solfege Diatonic Major Scale

Sandra Oberoi

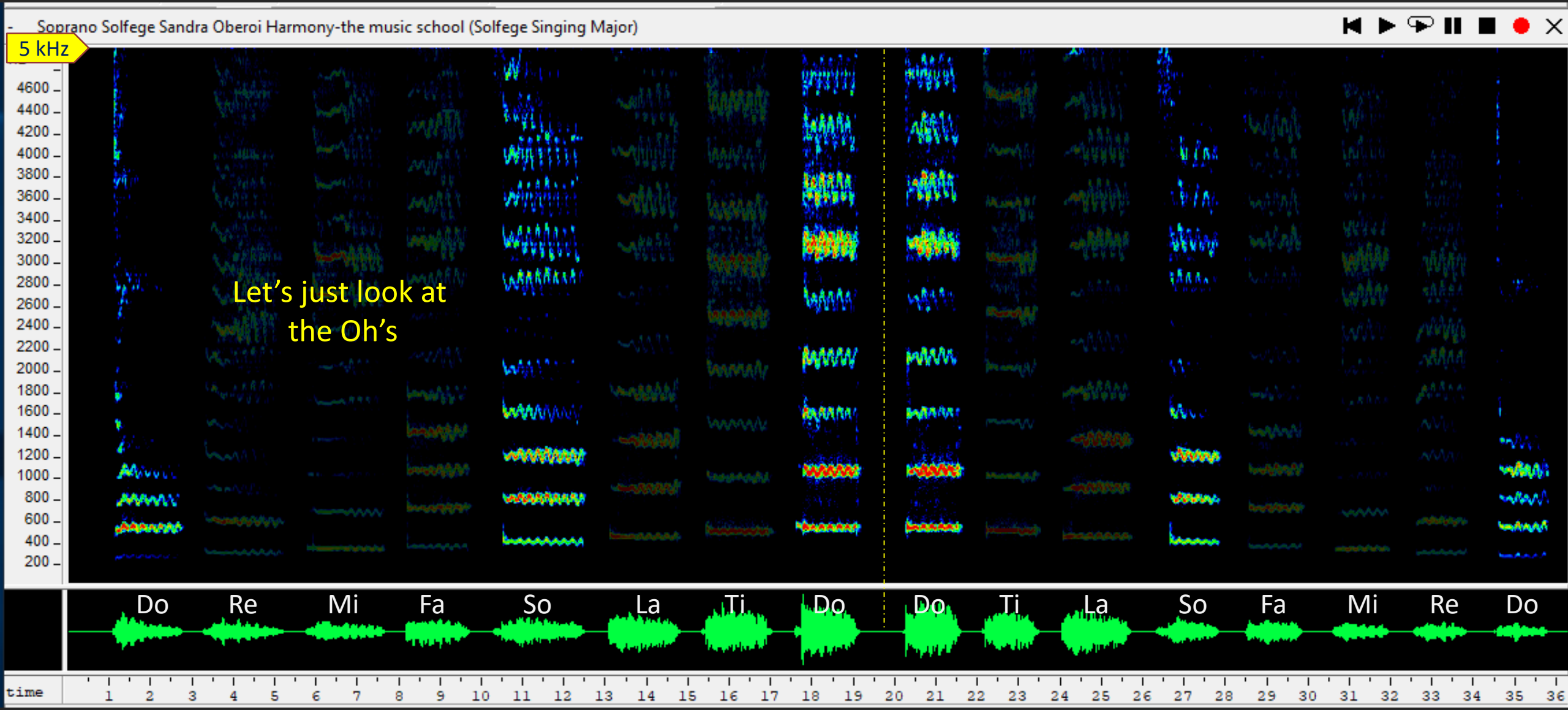
Solfege Singing: Major Scale and Intervals (2013)

Harmony – the music school

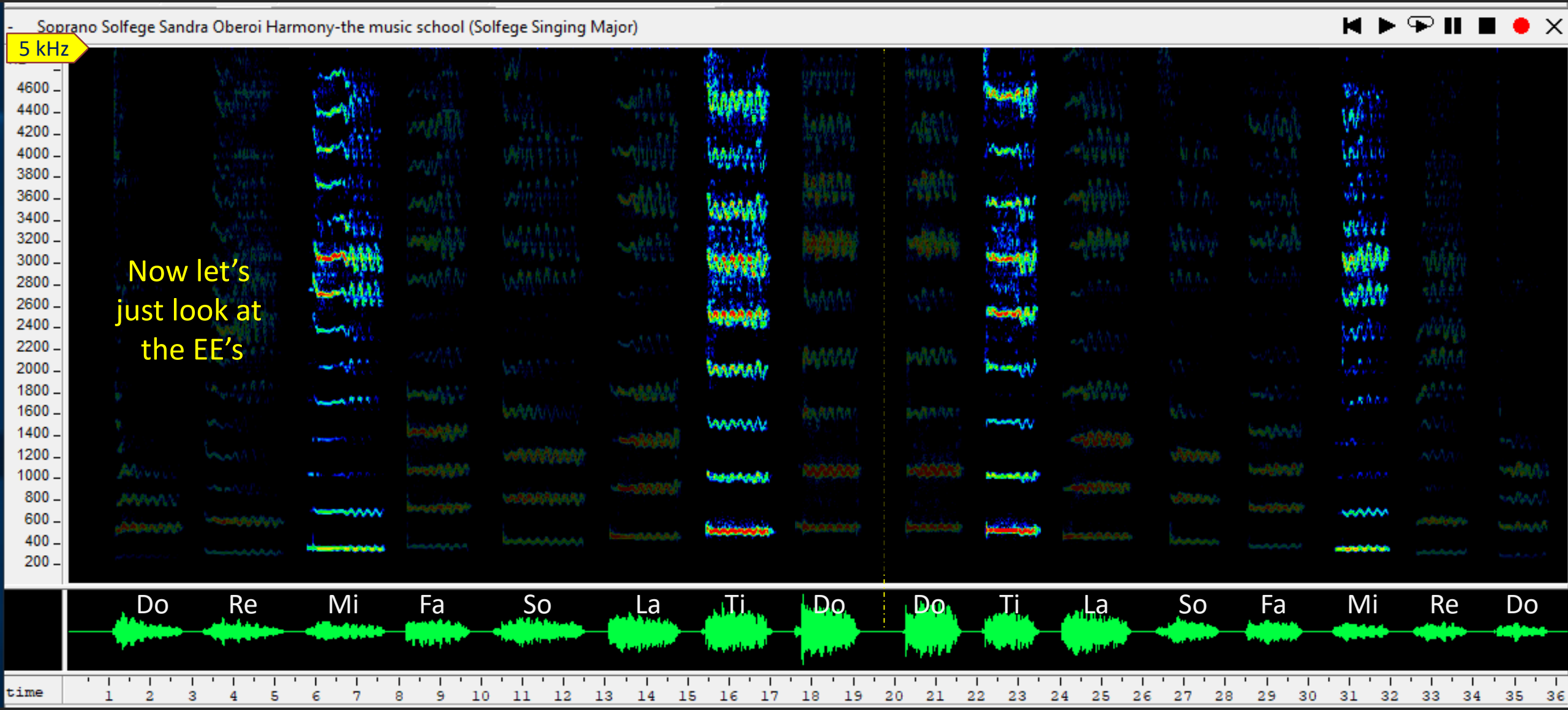
Solfege: Diatonic C Major Scale [C4 to C5]



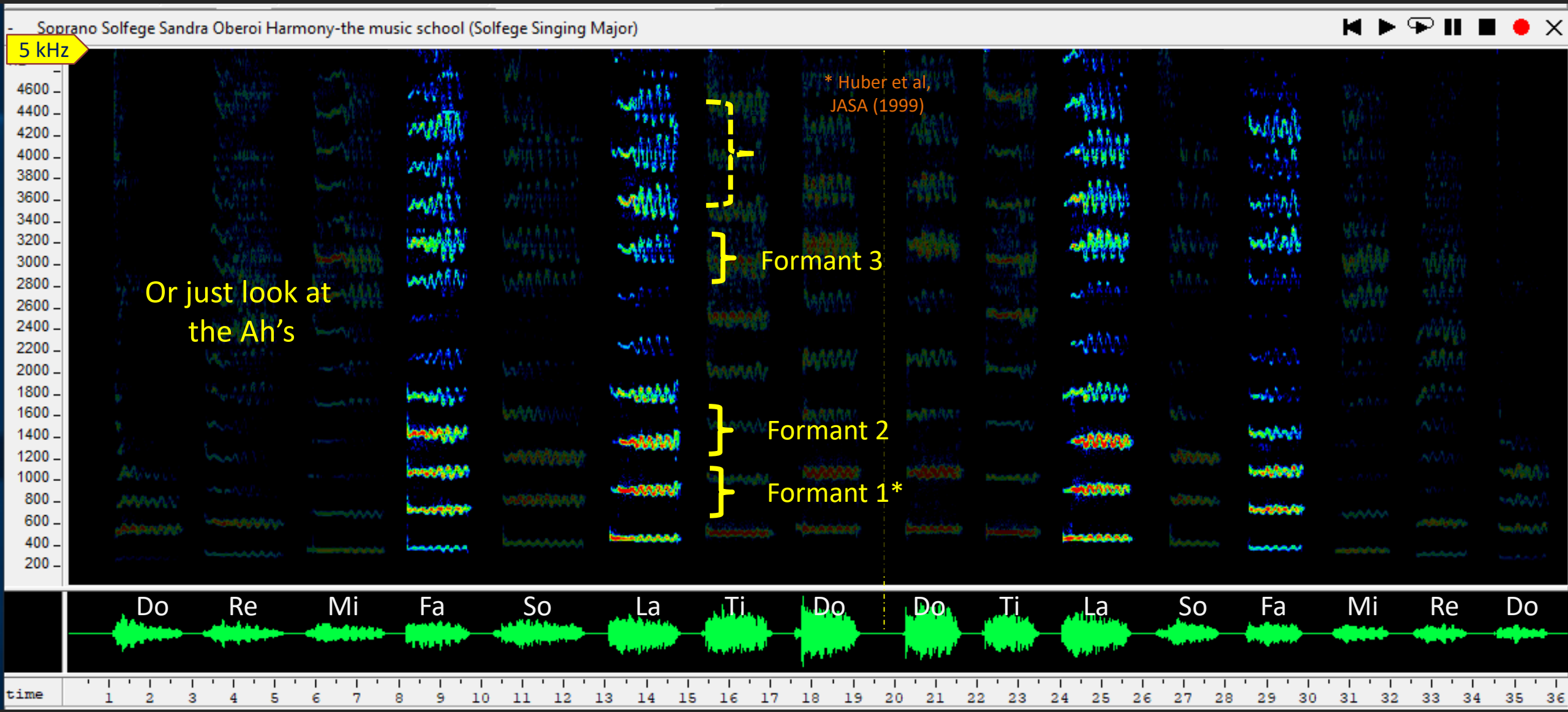
Solfege: Diatonic C Major Scale [C4 to C5]



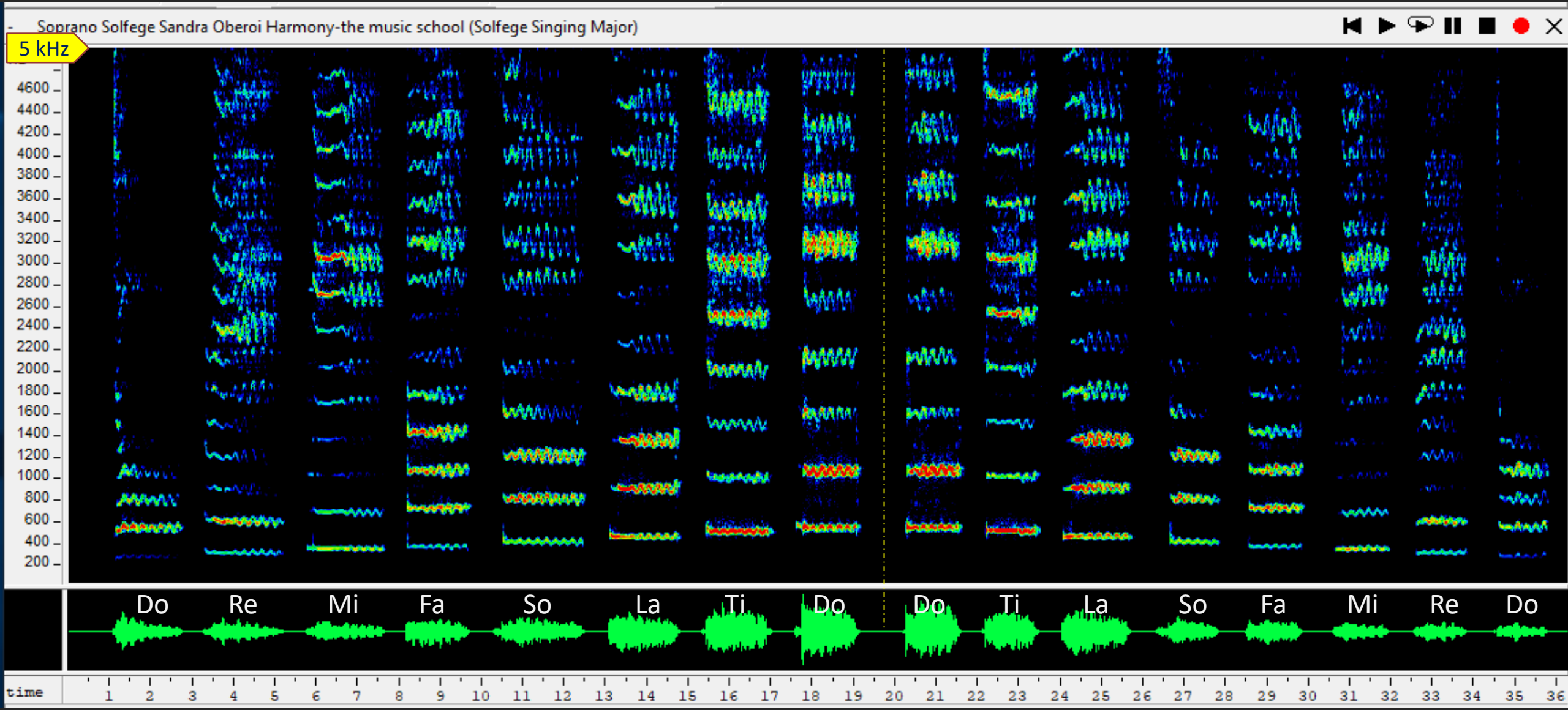
Solfege: Diatonic C Major Scale [C4 to C5]



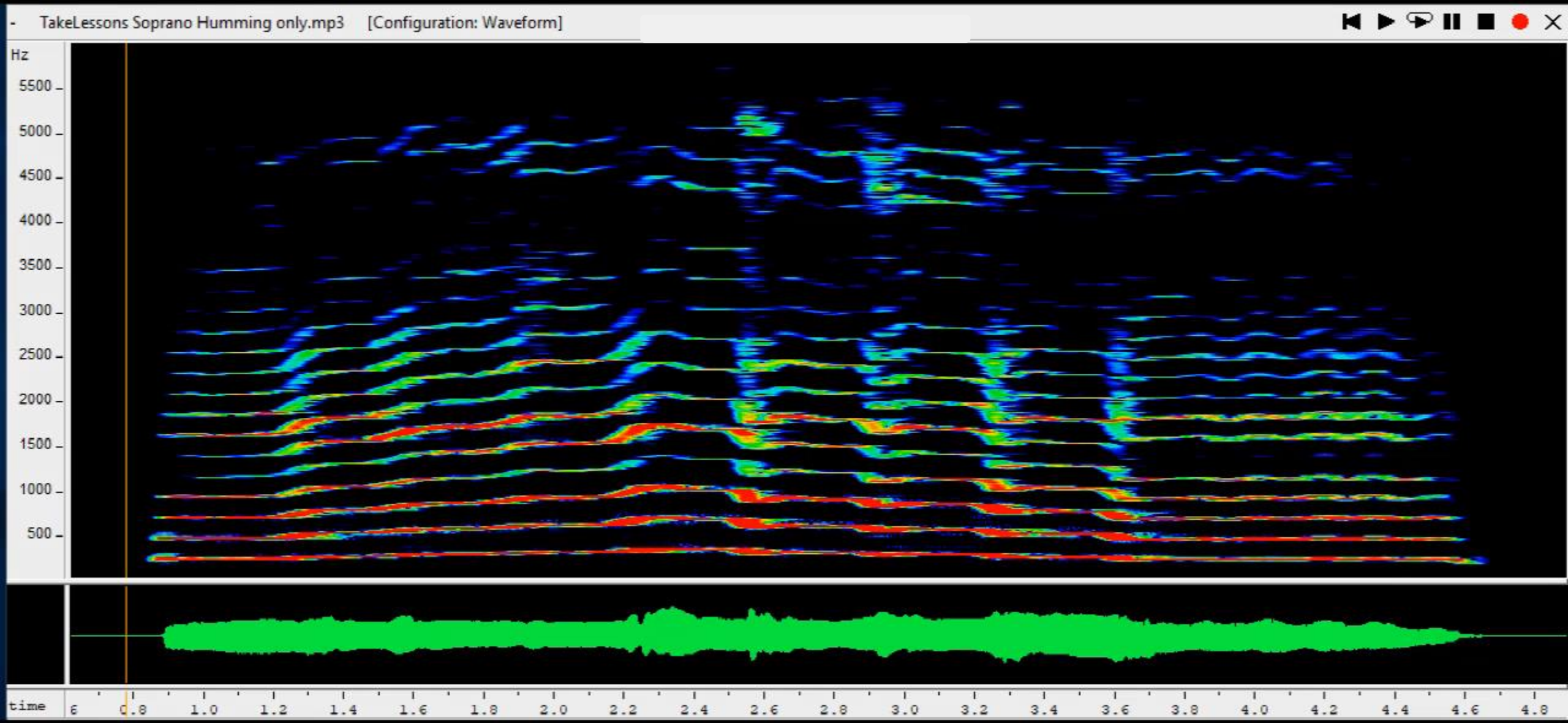
Solfege: Diatonic C Major Scale [C4 to C5]



Solfege: Diatonic C Major Scale [C4 to C5]



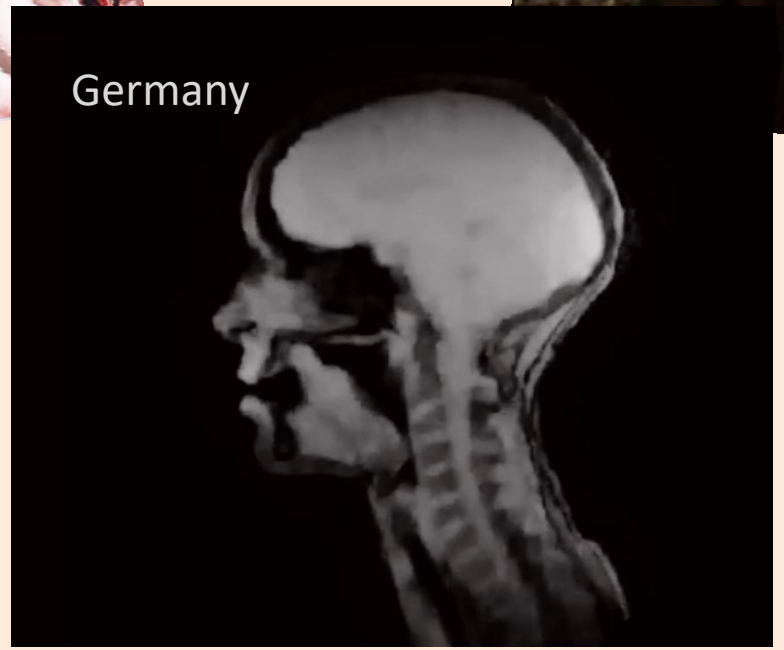
Female Voice Humming a Scale



Throat Singing
a.k.a. Overtone Singing

Canadian Arctic

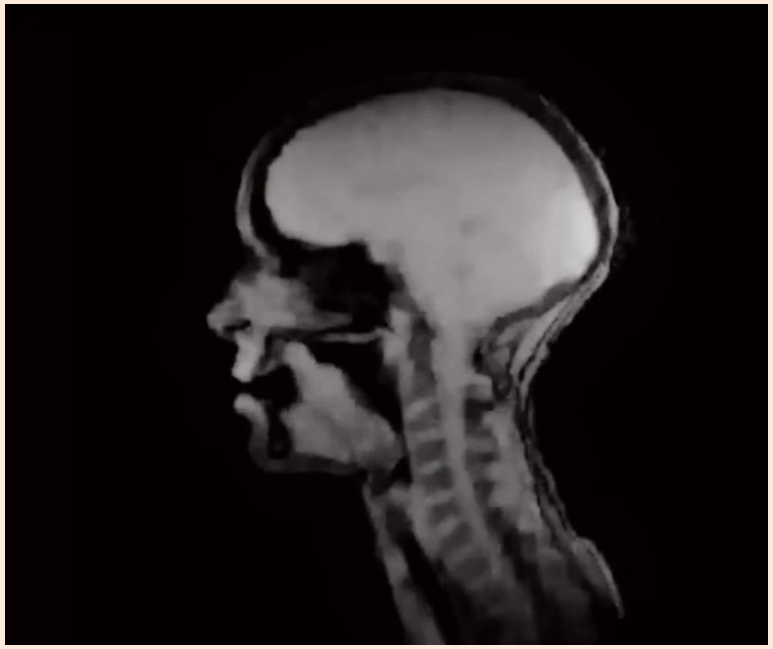
Tuva & Mongolia



Overtone Singing Example

- Anna-Maria Hefele
- Music Video 2017
  - Regular singing
  - Harp
  - Overtone singing
- Song:

  By This River (Brian Eno)
- MRI Sequences:
  - Prof. Bernhard Richter et. al.
    Freiburg Institute for Musician's Medicine
    (University of Music Freiburg)

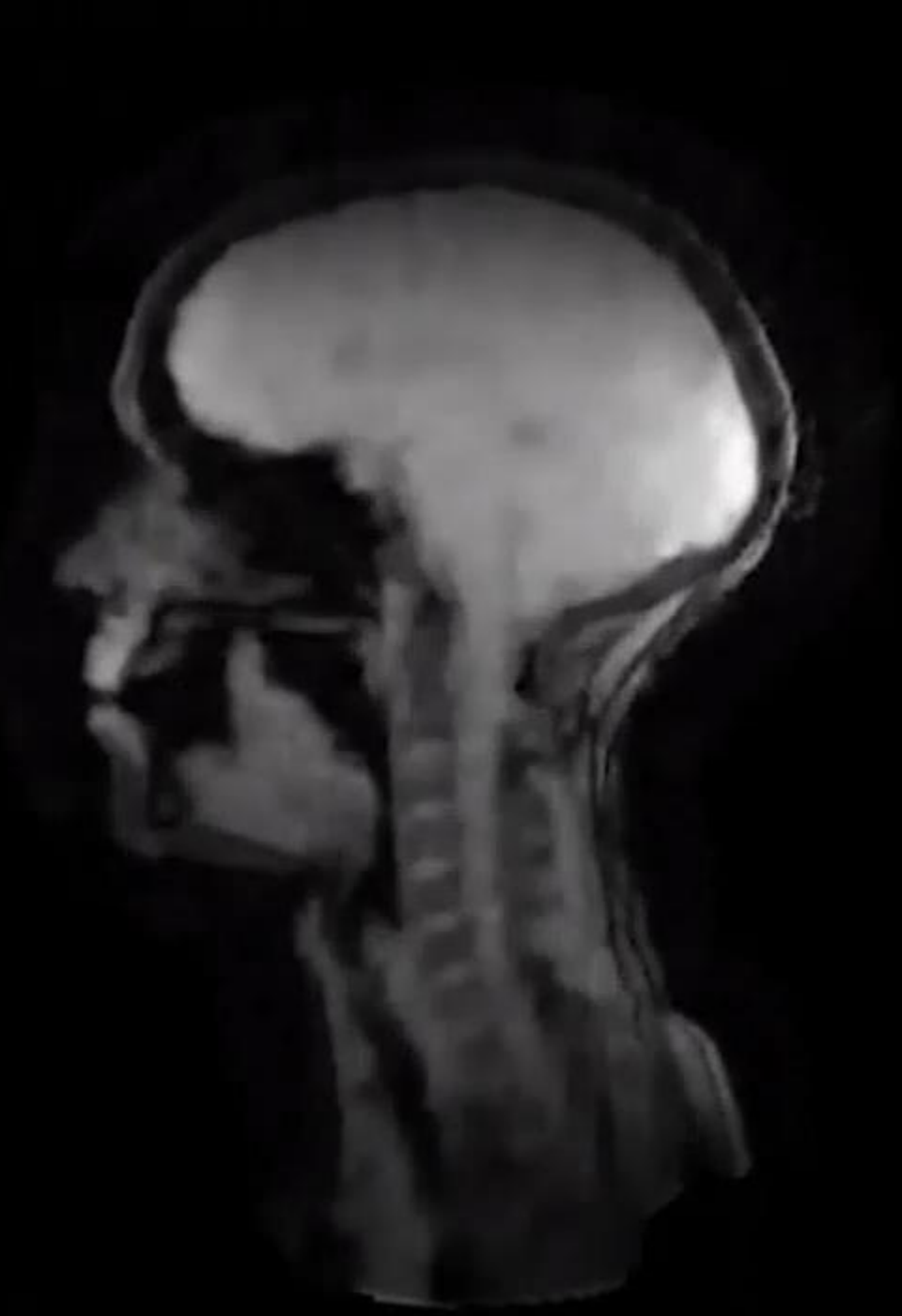


Overtone Singing

Anna-Maria Hefele 2017

Overtone Singing

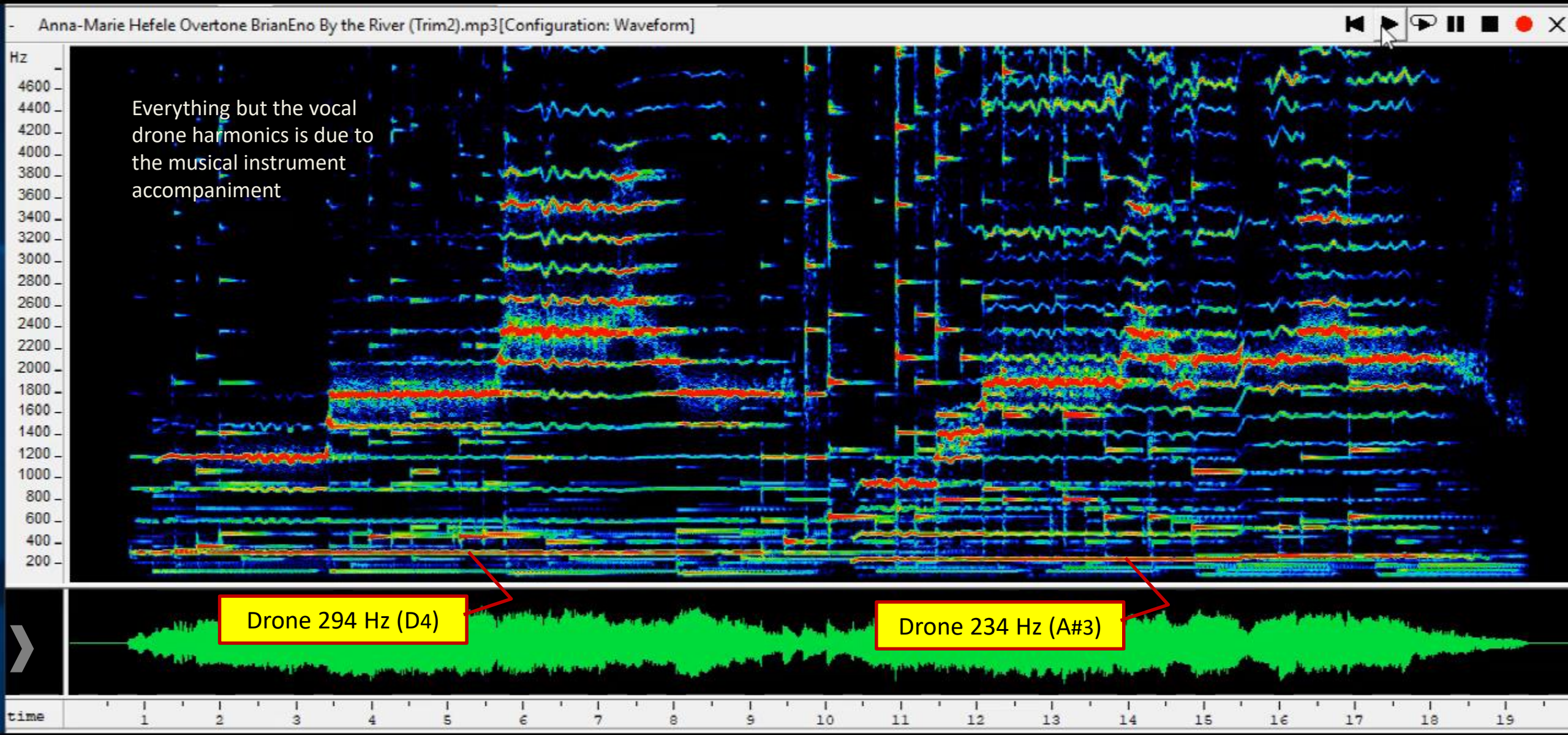
MRI Showing tongue creating a a special formant, isolating one drone harmonic



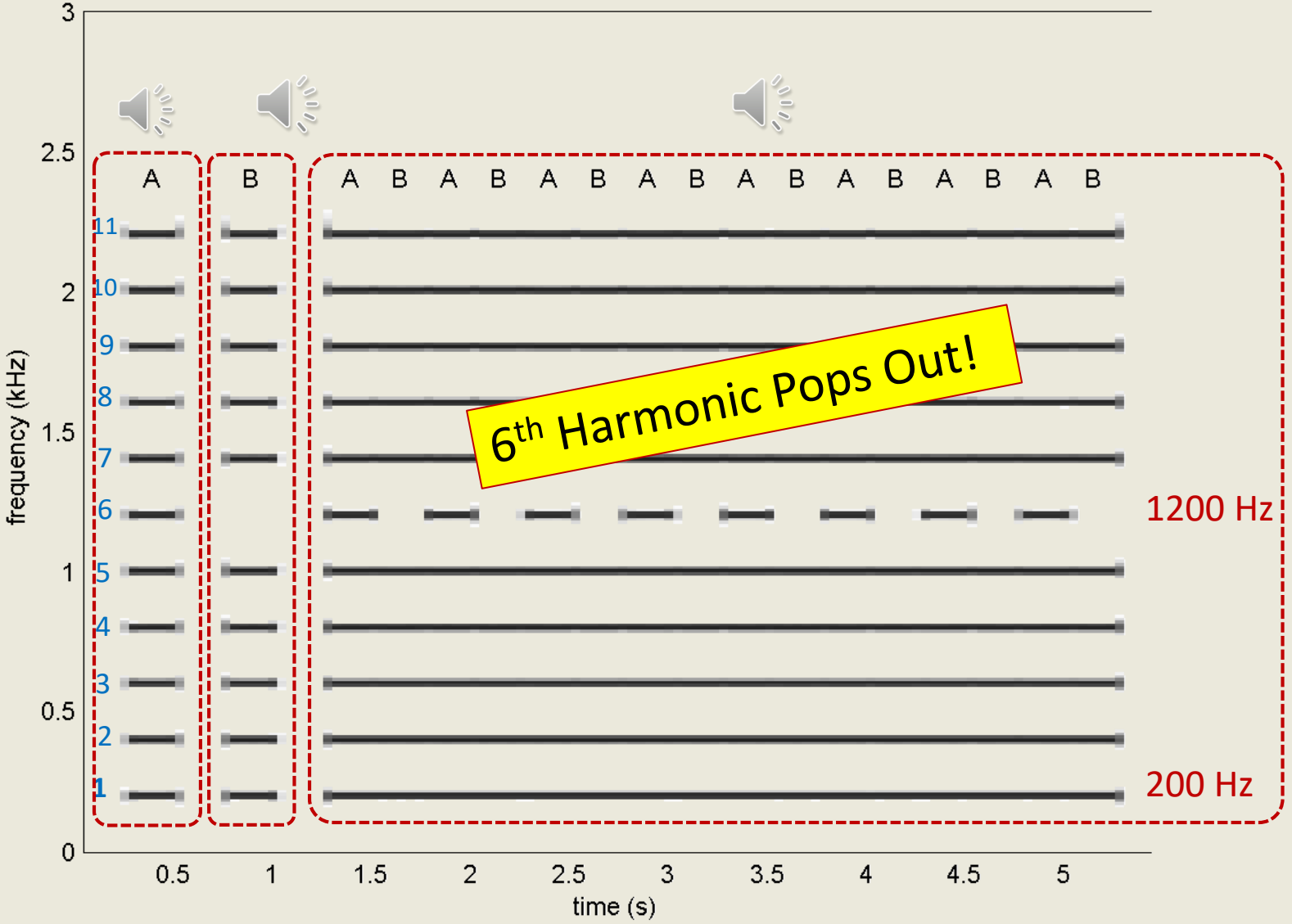
Anna-Maria Hefele 2017

Anna-Marie Hefele overtone singing

Isolated vocal fold harmonics sound disconnected from the fundamental drone, since they pop up suddenly. Perceived as entirely separate tones.



Missing Harmonic Hardly Noticed…



NOW can you hear it?
Hear the Difference?

Harmony

- Human Voice can only play one note at a time
  - with harmonics, of course…
- Solution:
  - Multiple Voices
- Examples:
  - Quartets
  - Choruses

Signature: 2019 International Barbershop Quartet Champions

Salt Lake City

Vocal Ranges

- Soprano: the highest female voice, being able to sing C_4 to C_6 , and possibly higher.
- Mezzo-soprano: a female voice between A_3 and A_5 .
- Contralto: the lowest female voice, F_3 to E_5. Rare contraltos possess a range similar to the tenor.
- Tenor: the highest male voice, B_2 to A_4 , and possibly higher.
- Baritone: a male voice, G_2 to F_4 .
- Bass: the lowest male voice, E_2 to E_4 .

Course Outline

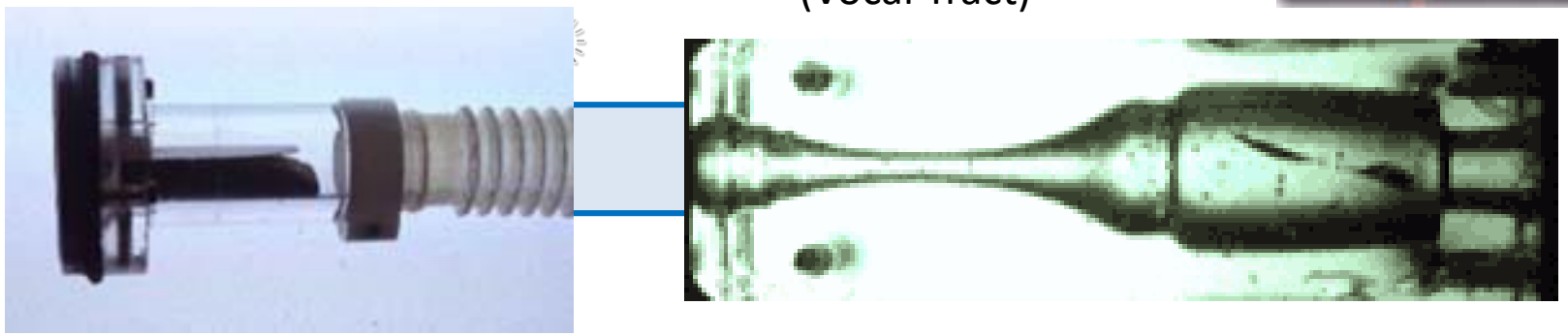
1. Building Blocks: Some basic concepts
2. Resonance: Building Sounds
3. Hearing and the Ear
4. Musical Scales
5. Musical Instruments
6. More Musical Instruments
7. Singing
8. Notation; Harmony and Dissonance

San Francisco Exploratorium Exhibit

Attempting to Simulate Human Voice

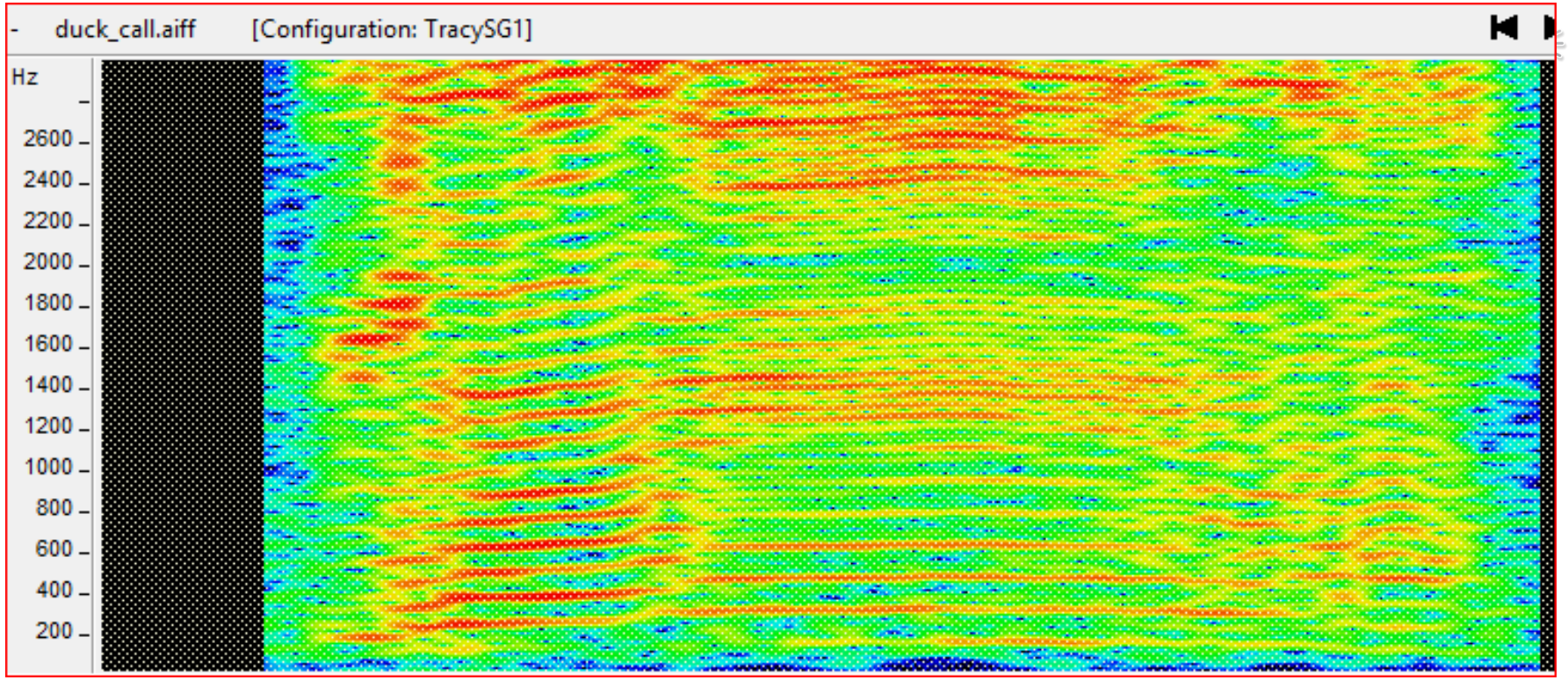
Duck Call
(Glottis)

Resonant Tube
(Vocal Tract)



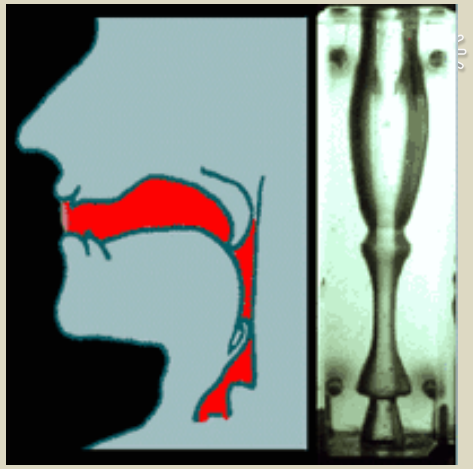
"Clarinet"

Duck Call Spectrogram

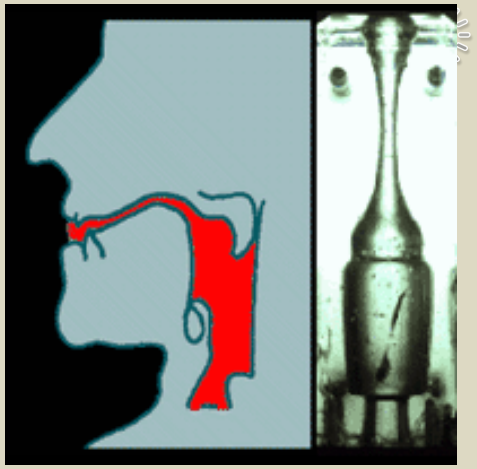


San Francisco Exploratorium Exhibit: Vowels

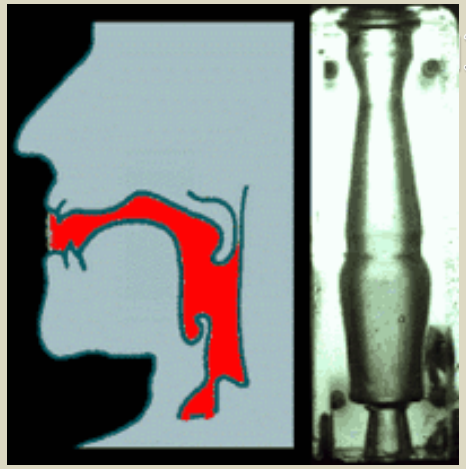
Ah



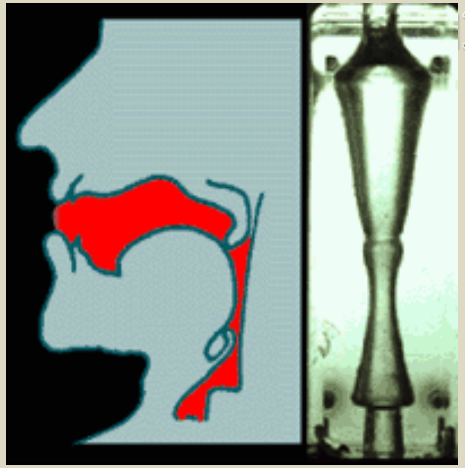
Ee



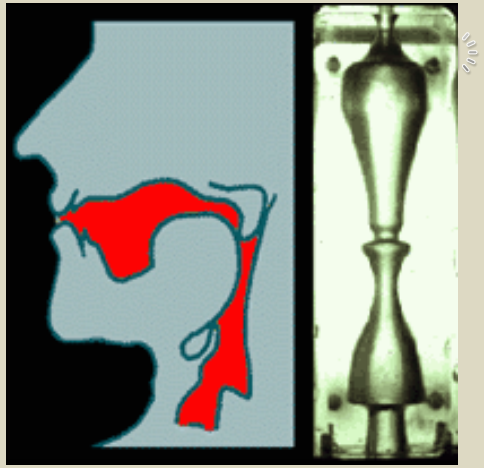
Eh



Oh



Oo



Vowels with Male and Female Voices

Female

Male