Team A

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## (in)Harmonicity and perceived brightness

###### Your research question

What is the effect of inharmonicity on brightness sensation, if any ?

What is its JND ?

###### A short explanation of it, including a discussion of why this study could be relevant.

Our goal is to test the hypothesis that the concept of (in)harmonicity [1] is directly related to the perception of brightness.

Since, among the scientific community, the perception of brightness is commonly measured with the spectral centroid [2], but we want to measure the subjective perception of brightness depending on the harmonicity/inharmonicity (not on the spectral centroid), we measure and prompt sounds with the same spectral centroid, but different values of inharmonicity.

Identifying a link between the harmonics of a sound and the feel of brightness could be useful for composers, producers, or sound designers: anyone who desires control over the brightness when designing sounds.

###### Which are your variables (the one you manipulate, the one you observe how it is affected by your manipulation)

Chosen (fixed, decided a priori)

* Fundamental frequency (perceived pitch, also noted as F0 -see also Glossary-)
  + 400 hZ
* Number of harmonics above F0
  + 3
* Amplitude of each harmonic -see also Glossary-
  + All normalized between 0. and 1.; F0 has amplitude = 1.0, and all other harmonics have a linearly decreasing amplitude which linearly decreases by 0.1
* Number of tweakable harmonics used to change the (in)harmonicity values
  + 3

Chosen and observed (not fixed, calculated as a result of other sounds’ variables)

* Frequencies of the first 3 harmonics over F0
  + They are tweaked in a way so that they affect the (in)harmonicity value (all sounds have a different (in)harmonicity value), but they don’t affect the spectral centroid value (all sounds have the same spectral centroid value)
* Spectral centroid
  + It affects the scientifically measured brightness, and it’s measured with Udo Zölzer’s spectral centroid formula [3], also used in Essentia’s *centroid()* function [4]. The output result is given in hZ
* (in)harmonicity
  + It is measured with G. Peeters’s function [5], also used in Essentia’s *inharmonicity()* function [6]. The output value is normalized between 0. (purely harmonic signal) and 1. (inharmonic signal)

Measured

* Perceived brightness
* Perceived brightness JND
  + Same scale and measurement as the perceived brightness

Since the first implementations of the procedure to produce data coherent sounds (sounds with the same value of spectral centroid, but different values of (in)harmonicity) were off-line, slow and prune to errors (we were first producing the sounds with a Max 8 patch, then we calculated by inverse formulas the harmonics frequencies values which would produce the wanted values of spectral centroid/harmonicity, then we were analyzing the sounds with the Essentia’s functions -see above and in *References*-), the final implementation consists in a Pure Data patch which encapsulates everything we need (additive synth, spectral centroid calculator, (in)harmonicity calculator) in real time.

Relationship between spectral centroid and harmonicity

Perceived brightness (effect) is the dependent variable, which we are going to measure. Calculated brightness (spectral centroid) is also a dependent variable, but is not changed, is kept fixed across different annotations for the same F0. In fact, the only independent variable is the (in)harmonicity (cause); for the same F0, inharmonic sounds (in each annotation, compared against probe sounds -harmonic-) all have the same spectral centroid, but different values of harmonicity.

###### Subjects (do you need specific subjects? how are you going to recruit them? How are you going to separate them into different groups -if you need that? Do not get nervous about needing “many” subjects, you ‘ll not get them anyway so do not plan many comparisons among types of subjects and take advantage of those you can get -as a rule of thumb, 15 subjects per experimental group -i.e., musicians vs nonmusicians or Chinese versus USAmericans versus Europeans- can be reasonable, but less than that is anyway fine)

Our study requires subjects with normal hearing that are able to understand the concept of brightness. It is not necessary for subjects to have a musical background, but we will take note of individual musical backgrounds in order to later analyze a difference between groups with musical training and those without. We don’t think demographic information such as gender, nationality, or religion will be relevant to our study.

###### Procedure (how are subjects going to proceed through the task? Have in mind that it is very difficult to get them engaged for more than 15 minutes unless you give them some motivational item…) See also Appendix - Procedure

We will conduct a perceptual test that asks participants to listen to pairs of chords and answer which one is "brighter" (by providing a question like; *“Which one, among sound A and B, is brighter ?”*). In this way, we’d achieve a ranking of the sounds in terms of relative perceived brightness (compared to a “probe”, highly harmonic sound) and be able to see how (in)harmonicity relates to perceived brightness. The measurement of a JND is possible by calculating how much the metrics change before participants decide that a sound is less bright or brighter. Before the test, we will define the concept of brightness to the participants.

An annotation -see also Glossary- is the comparison of a pair of sounds and its related test, experiment, and results.

1 F0 is used; 400Hz.

The total number of annotations is 12, so that, since the same annotation has to be repeated 3 times to avoid noisy samples, there are 4 groups of 3 pairs each, randomly mixed; within each group we have exactly the same sounds; different groups of pairs also present the same spectral centroid values, but different (in)harmonicity values.

Each sound contains 3 harmonics, with linearly decreasing amplitude as frequency goes up. We are only tweaking the frequencies of the first 3 harmonics above F0.

Each sound will last 3 seconds.

Each annotation is repeated 3 times (each experiment should at least be sampled 3 times in order to avoid noise in the data. An average is made among the 3 results)

Example of experiment;

* F0 = 400 hZ (all sounds with this fundamental frequency have 4 different values of (in)harmonicity in total, but only 1 unique value of spectral centroid for all sounds)
  + 12 annotations in total (all sounds in all annotations have same value of spectral centroid, all annotations are randomly ordered)
    - 4 groups of 3 pairs of annotations
      * Each group contains exactly the same annotations (same pairs of sounds stimuli, so also same exact values of (in)harmonicity). Each annotation is, basically, repeated 3 times in order to avoid noisy data
      * Each of the 4 groups of annotations, containing 3 annotations each, have different values of (in)harmonicity but same value of spectral centroid
* Series of annotations with F0 = 400 hZ;
  + P = Probe sound (perfectly harmonic)
  + A, B, C, D = (less harmonic sounds)
    - P, C
    - P, A
    - P, A
    - P, B
    - P, D
    - P, B
    - P, C
    - P, D
    - P, C
    - P, D
    - P, A
    - P, B

###### Instructions (be careful writing clear and short -but not too short- instructions)

The “brightness” of a sound is defined as “*an indication of the amount of high-frequency content in a sound*” [7].

In this perceptual test you will be presented with pairs of sounds. For each pair, decide which sound you find to be brighter by replying to the question; *Which one, among sound A and B, is brighter ?”*. Please use headphones during the test. We ask that you respond to at least 12 pairs.

###### Stimuli (Are you going to present sounds? music? Which ones? How are you going to get or create them? How many?)

We will synthesize a set of sounds programmatically using additive synthesis and sine waves. Each sound stimulus is then a sum of sinusoids, a fundamental frequency and its 3 harmonics. The amplitude of those harmonics is constant. The frequency of all harmonics is tweaked in a way so that all the proposed sounds have the same spectral centroid, but different values of (in)harmonicity, which will help us measure the *perceived* brightness, knowing that all sounds have the same *calculated* brightness (participants are not informed about this). Specifically, the harmonics’ frequencies are;

* Fixed for “probe” sounds (the first sound in each pair), which are always perfectly harmonic (the frequency of their harmonics is always an integer multiple of F0)
* Altered (tweaked, in order to obtain different (in)harmonicity values) in the second sound of each pair, but only for the first 3 harmonics above F0.

Sounds are generated with a Pure Data patch file we specifically programmed for the experiment. The program is basically an additive synthesizer which, when triggered, plays and records a sound for 3 seconds, writing it on a .wav file.

Sounds: Each sound is produced with a Pure Data patch, which is an additive synthesizer, with a F0 and 3 harmonics. We are going to tweak the harmonics’ frequencies, which are set as multipliers (either integer or floats) of the F0 frequency. All amplitudes are never changed, and are linearly spaced. So, in order to focus on the extent to which harmonicity affects subjectively perceived brightness, the inharmonic sounds are going to have the same spectral centroid (scientific computation of brightness from a scientific perspective) but different (in)harmonicity values.

###### Devices and software needed to carry out your data collection activities(headphones? A mobile phone? MIDI Keyboard? A survey or experiment online platform?)

Participants only need a pair of headphones (provided). They will be prompted, for each pair of sounds, a computer screen where, using a mouse, they have to tell whether sound A is brighter than sound B. The sounds are automatically played.

###### Would you need other materials for the study?

No

###### How are the subjects’ responses going to be encoded and stored? Provide a mockup of your intended data file

We could store, for each annotation (an annotation is an experiment carried on a pair of sounds) the responses as JSON, for example:

{

sound\_A\_F0: float between 20 and 20000

sound\_A\_h\_1\_f: (frequency of 1st harmonic) float between 20 and 20000

sound\_A\_h\_2\_f: (frequency of 2st harmonic) float between 20 and 20000

sound\_A\_spectral\_centroid: float between 20 and 20000

sound\_A\_inharmonicity: float between 0. and 1.

sound\_B\_h\_1\_f: (frequency of 1st harmonic) float between 20 and 20000

sound\_B\_h\_2\_f: (frequency of 2st harmonic) float between 20 and 20000

sound\_B\_spectral\_centroid: float between 20 and 20000

sound\_B\_inharmonicity: float between 0. and 1.

which\_of\_the\_2\_sounds\_is\_brighter: enum (0 for none -both sounds have equally perceived brightness-, 1 for the first sound is brighter, 2 for the second sound is brighter)

}

Frequencies and spectral centroid values are in hZ.

(in)harmonicity values are normalized between 0. and 1 (0. being perfectly harmonic, 1. being extremely inharmonic).

###### Further data processing you plan to do with the data (i.e., ANOVAs, correlations, spectral analyses of the sound items…)

# References

[1] Inharmonicity - Wikipedia, the free encyclopedia, <http://en.wikipedia.org/wiki/Inharmonicity>

[2] Spectral centroid - Wikipedia, the free encyclopedia, <https://en.wikipedia.org/wiki/Spectral_centroid>

[3] Udo Zölzer (2002). DAFX Digital Audio Effects pag.364-365, <https://picture.iczhiku.com/resource/eetop/sykfGloQfYJRZBcv.pdf>

[4] Essentia - Algorithms Reference - SpectralCentroidTime. <https://essentia.upf.edu/reference/std_SpectralCentroidTime.html>

[5] G. Peeters, "A large set of audio features for sound description (similarity and classification) in the CUIDADO project," CUIDADO I.S.T. Project Report, 2004, p. 17. <http://recherche.ircam.fr/anasyn/peeters/ARTICLES/Peeters_2003_cuidadoaudiofeatures.pdf>

[6] Essentia - Algorithms Reference - Inharmonicity. <https://essentia.upf.edu/reference/std_Inharmonicity.html>

[7] Brightness (sound) - Wikipedia, the free encyclopedia, <https://en.wikipedia.org/wiki/Timbre#Brightness>

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# Glossary

F0

The fundamental frequency of a sound

Harmonic

The concept of “harmonic”, in our Project, is sometimes interchangeable with the one of “overtone”. The former is usually used when the frequency of the partial -sinusoid- we are analyzing is an integer multiple of the frequency of the fundamental partial. The latter is usually used when the frequency of the partial is not an integer multiple of the fundamental frequency. To highlight the concept of (in)harmonicity, we always use the term “harmonic”.

Annotation

Is the smaller unit experiment, that is, a comparison between 2 sounds, among which the participant is asked to choose which one is the brightest.

# Appendix

Procedure

During our early test experiments we found out that;

To produce inharmonic sounds, changing the harmonics’ frequencies by the same amount (e.g. 2nd harmonic - 0.3, 3rd harmonic - 0.3, ecc.) does not actually convey a perceivably less harmonic sound, because the ratio between the harmonics frequencies remains the same, even tough their ratios with F0 changes.

Making perceivably changes in (in)harmonicity with sounds having F0 = 100 hZ is extremely difficult.