The Interaction Between Sound and Food

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Cooperating with…

Barilla

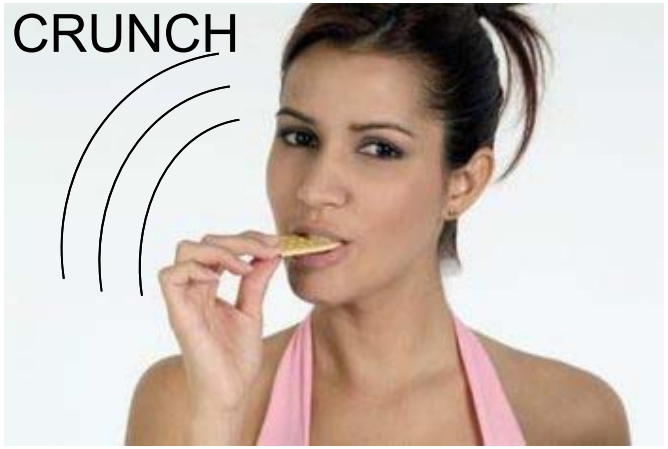
Mulino Bianco

Cavalier Umberto Boschi

istituzione casadellamusica parma

casadelsuono

The Interaction Between Sound and Food



Three ways food and sound interact

Food sound in marketing

Part 1
Testing food quality by listening at their sound

Testing food quality by listening at their sound

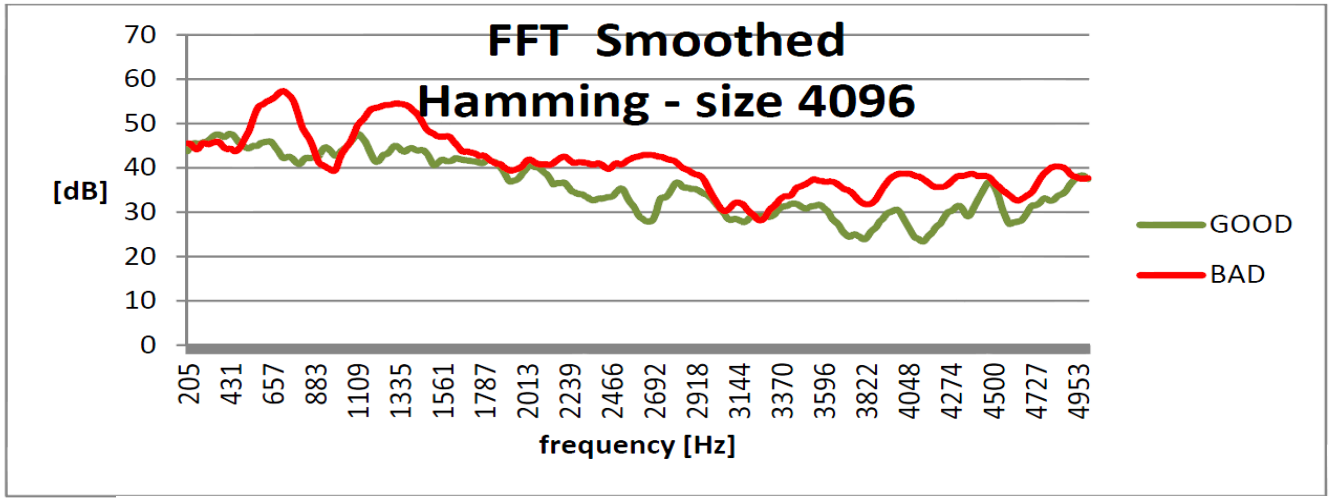
Testing food quality by listening at their sound

Testing food quality by listening at their sound

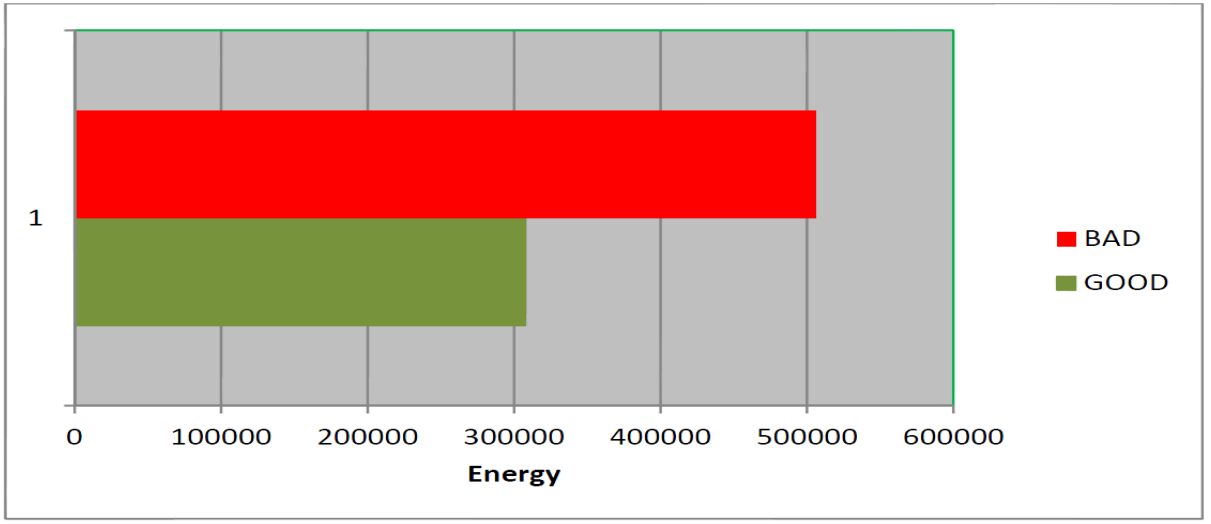
TEST FOR QUALITY CHECK OF SALAMI

TARGET

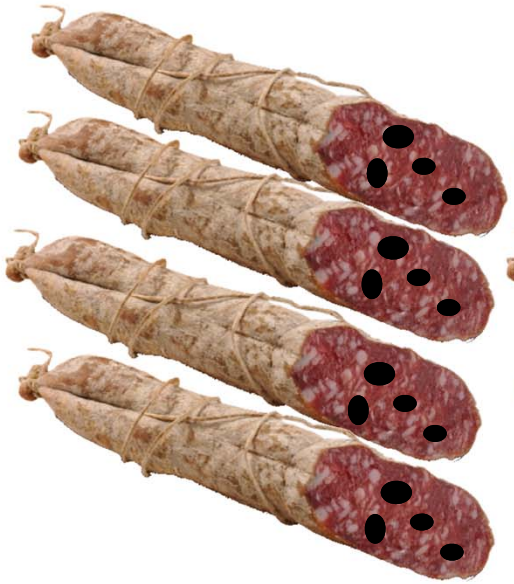
Feasibility study for a compact real time sound-analyzer to help the expertizer in selecting defected pieces

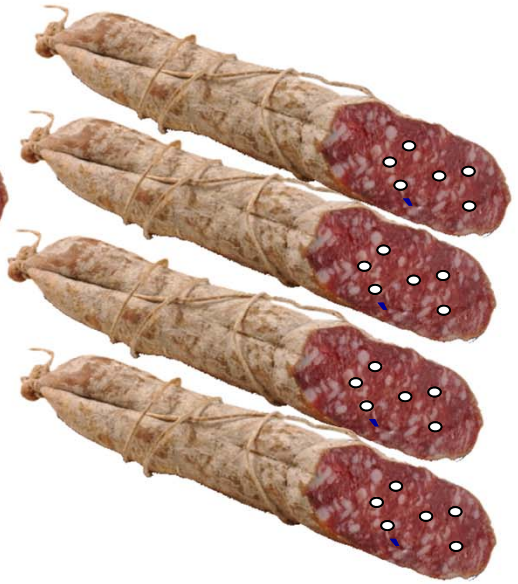


PRELIMINARY TEST



PROCEDURE





20 HEALTHY PIECES (N)

20 CORRUPT PIECES (B)

"holed": localized problem

20 CORRUPT PIECES (G)

"fat": diffuse problem

previously selected by an expertiser (@ half of seasoning)

PROCEDURE

CONDITION OF TESTS

NOISY ENVIRONMENT & SILENT ENVIRONMENT

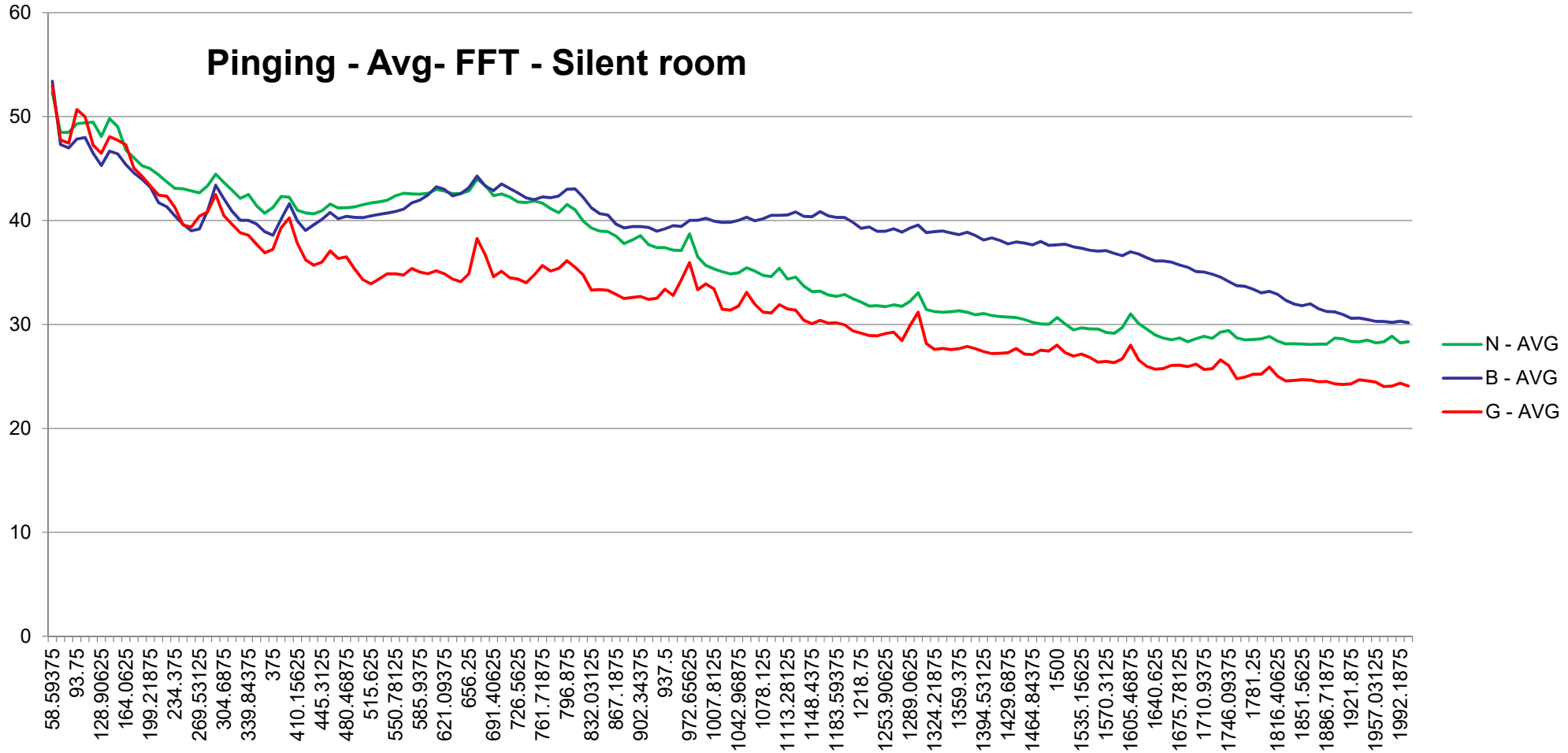
PINGING WITH FINGERS & USING INSTRUMENTED HAMMER (Force Gauge)

20 HEALTHY PIECES (N)

20 CORRUPT PIECES (B)
"holed": localized problem

20 CORRUPT PIECES (G)
"fat": diffuse problem

previously selected by an expertiser (@ half of seasoning)


Pinging - Avg- FFT - Silent room
60
50
40
30
20
10
0
58.59375
93.75
128.90625
164.0625
199.21875
234.375
269.53125
304.6875
339.84375
375
410.15625
445.3125
480.46875
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550.78125
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761.71875
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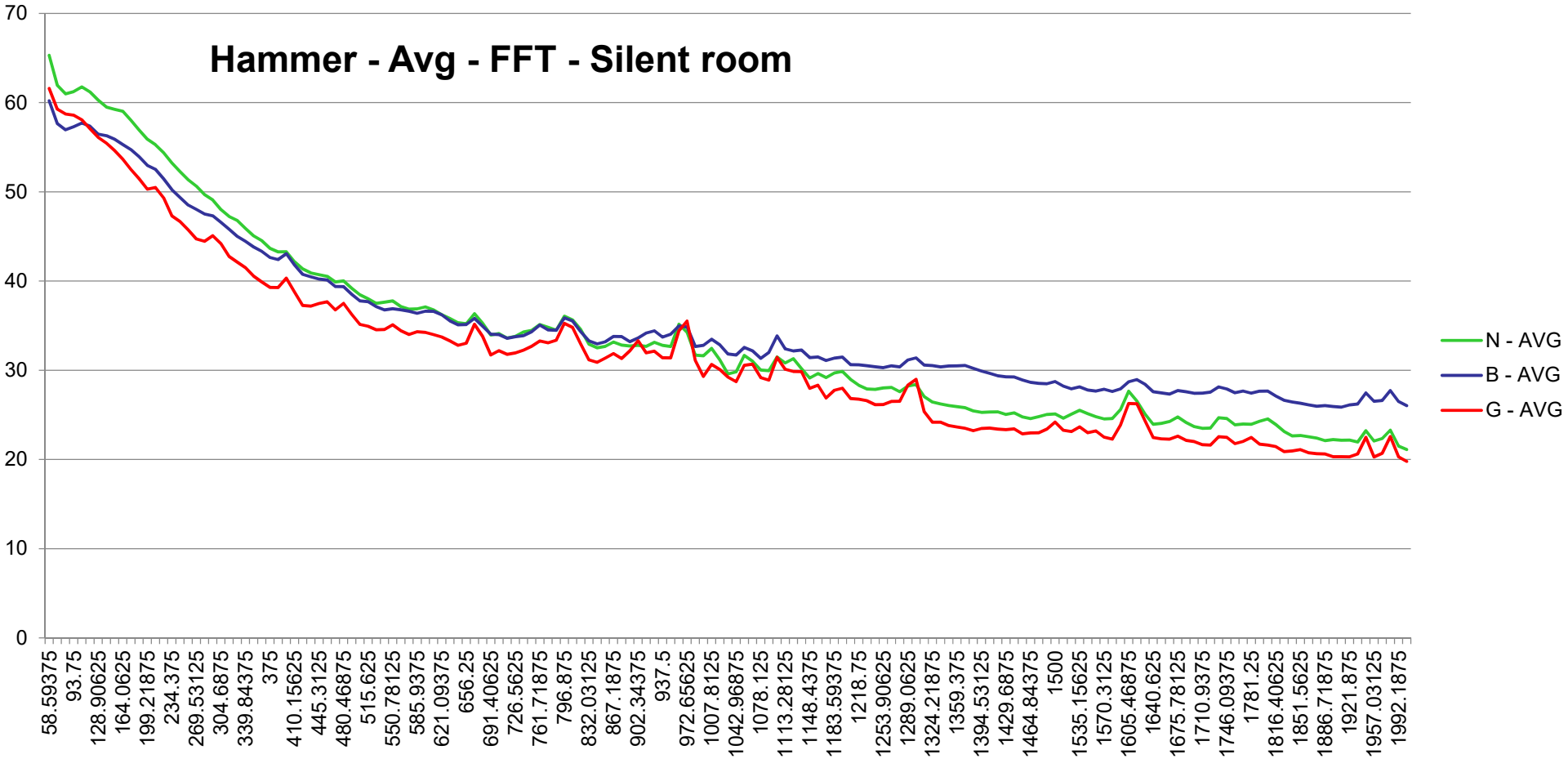
832.03125
867.1875
902.34375
937.5
972.65625
1007.8125
1042.96875
1078.125
1113.28125
1148.4375
1183.59375
1218.75
1253.90625
1289.0625
1324.21875
1359.375
1394.53125
1429.6875
1464.84375
1500
1535.15625
1570.3125
1605.46875
1640.625
1675.78125
1710.9375
1746.09375
1781.25
1816.40625
1851.5625
1886.71875
1921.875
1957.03125
1992.1875
N - AVG
B - AVG
G - AVG


Hammer - Avg - FFT - Silent room
70
60
50
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30
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58.59375
93.75
128.90625
164.0625
199.21875
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269.53125
304.6875
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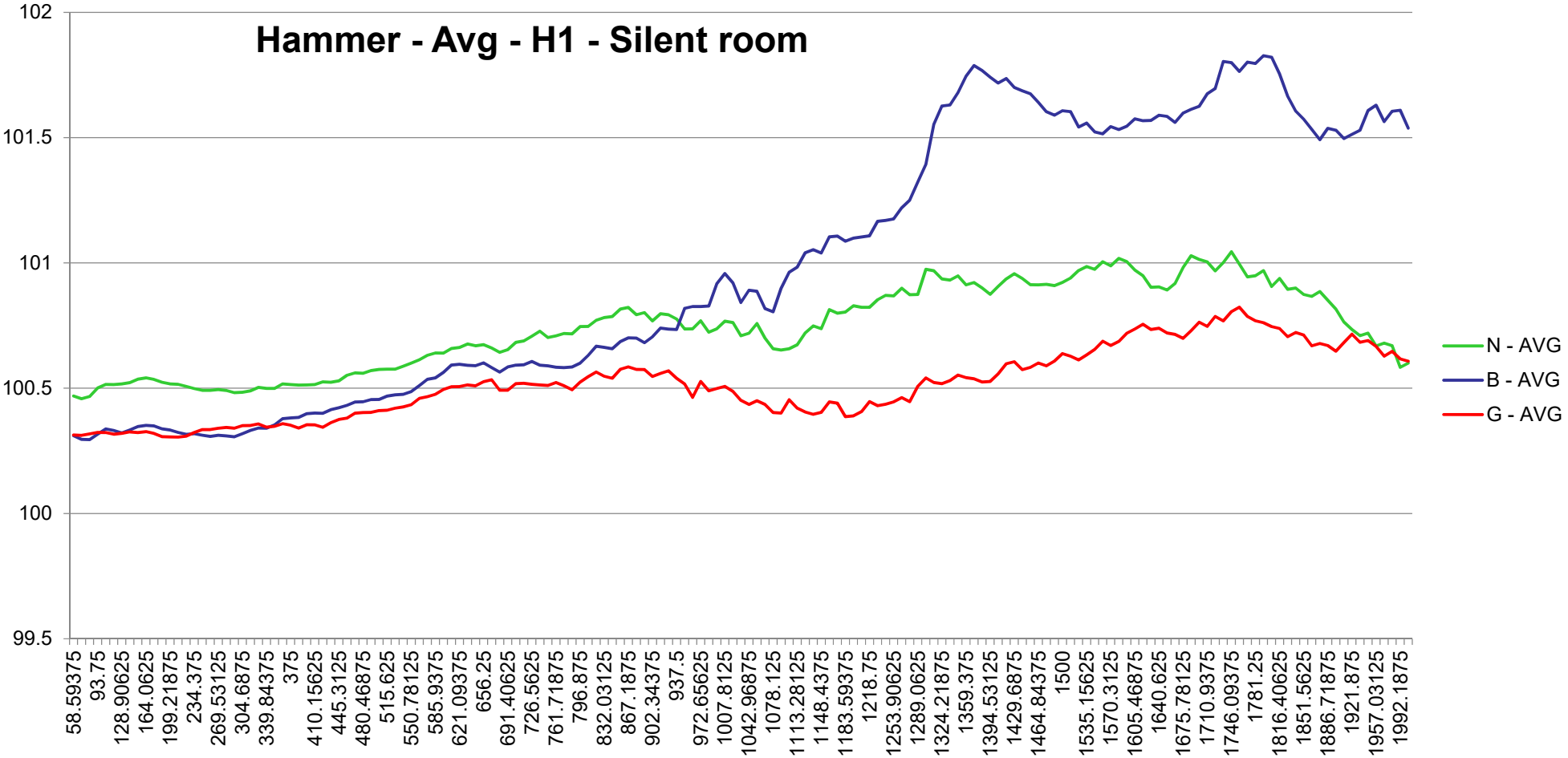
1851.5625
1886.71875
1921.875
1957.03125
1992.1875
N - AVG
B - AVG
G - AVG


Hammer - Avg - H1 - Silent room
102
101.5
101
100.5
100
99.5
58.59375
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128.90625
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199.21875
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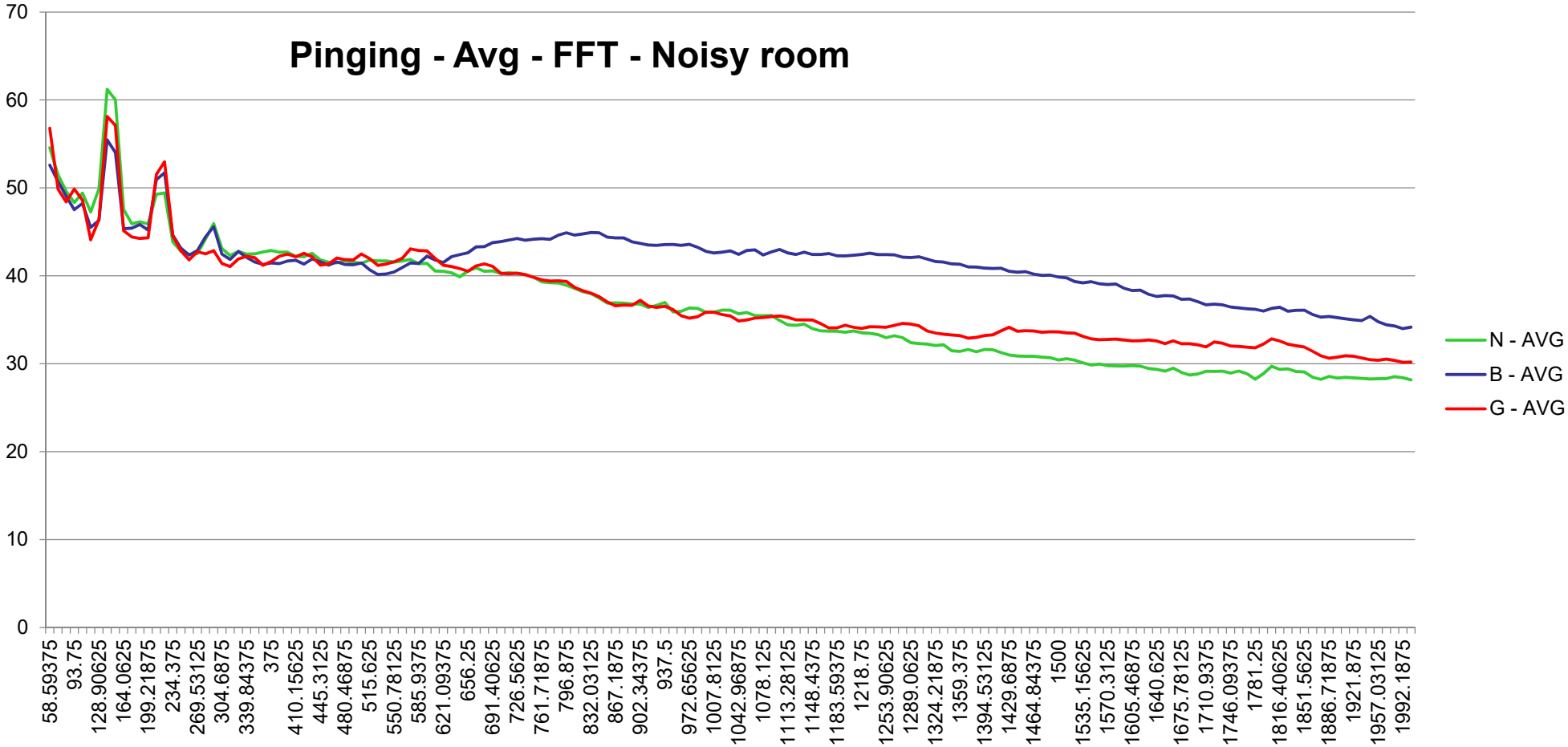
1921.875
1957.03125
1992.1875
N - AVG
B - AVG
G - AVG


Pinging - Avg - FFT - Noisy room
70
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269.53125
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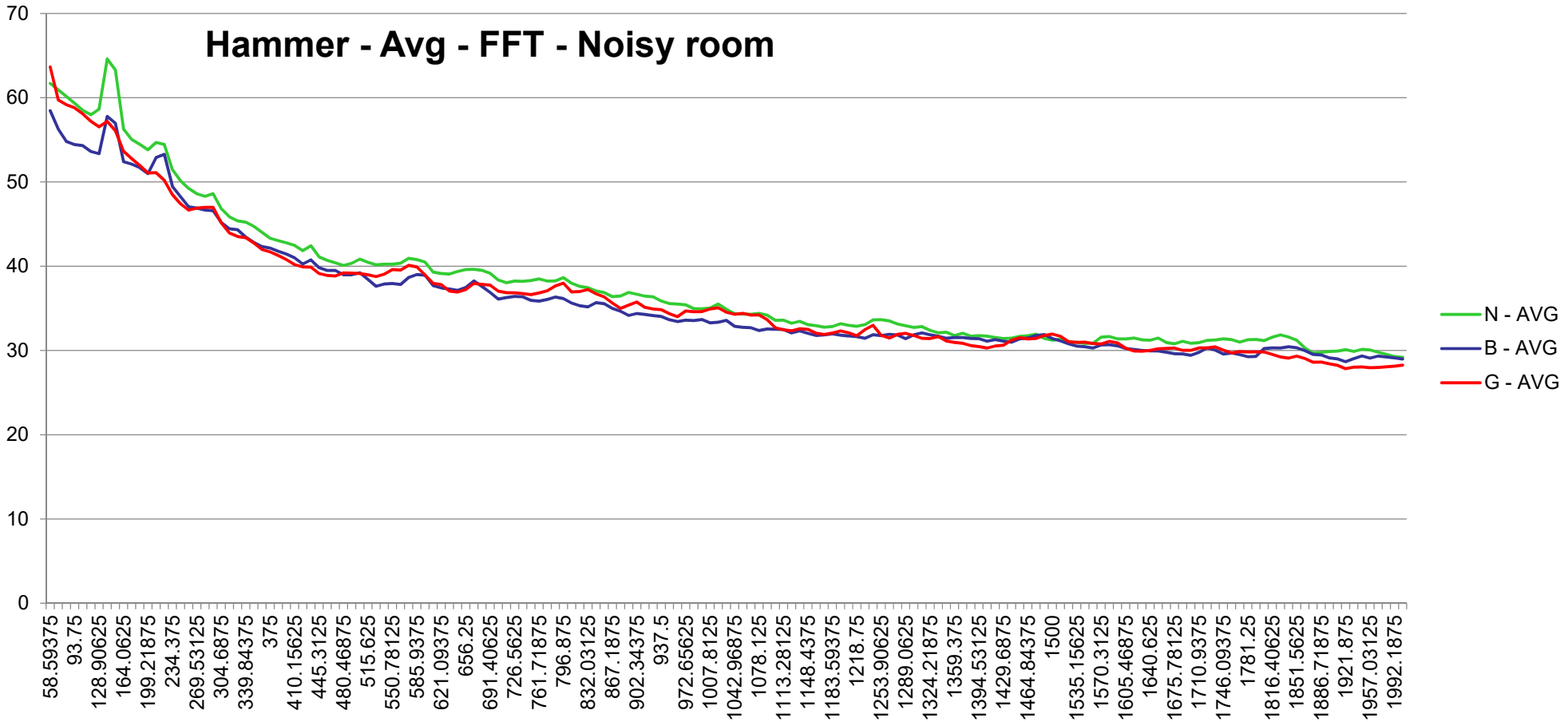
1886.71875
1921.875
1957.03125
1992.1875
N - AVG
B - AVG
G - AVG


Hammer - Avg - FFT - Noisy room
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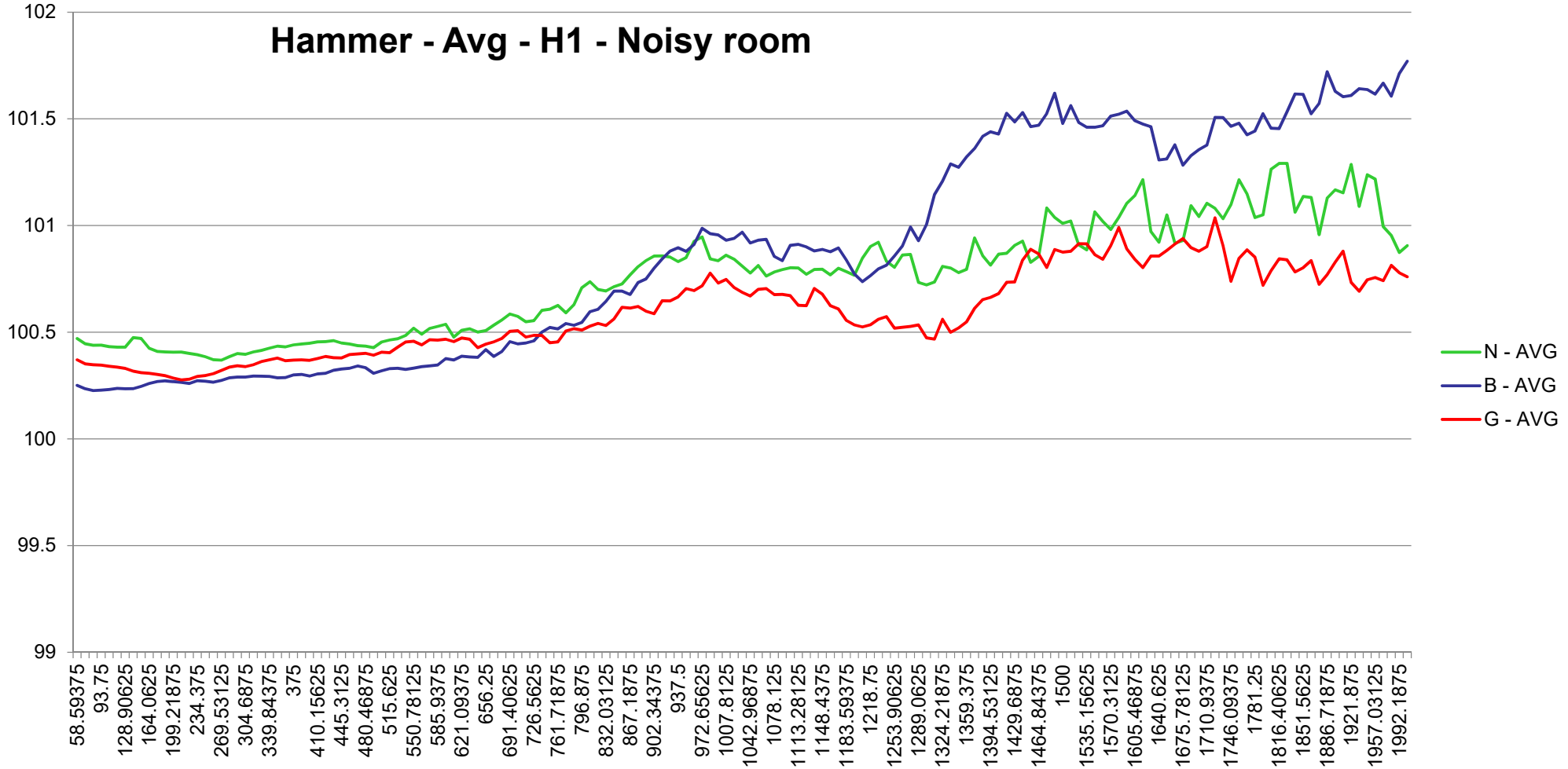
Hammer - Avg - H1 - Noisy room
102
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1781.25
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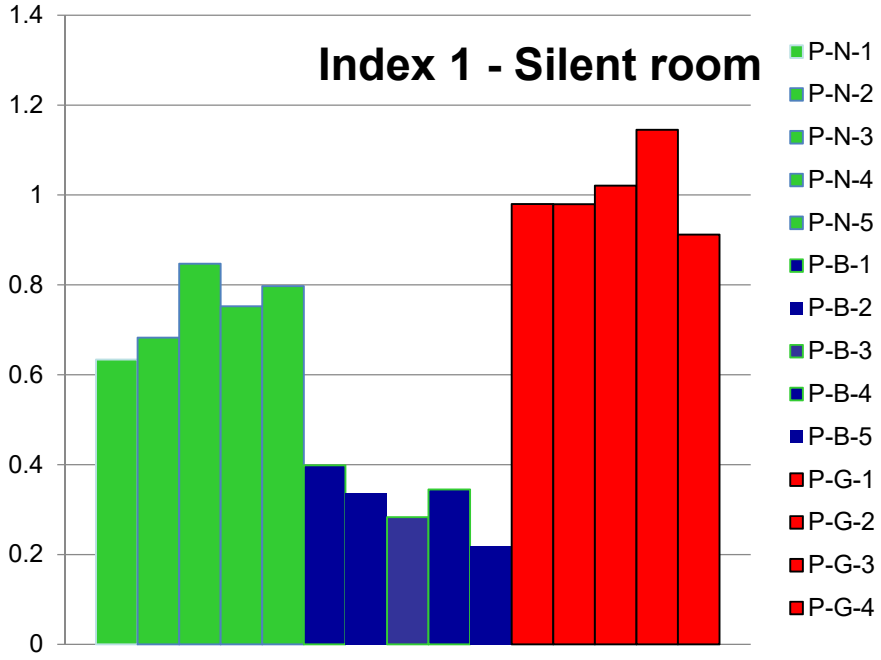
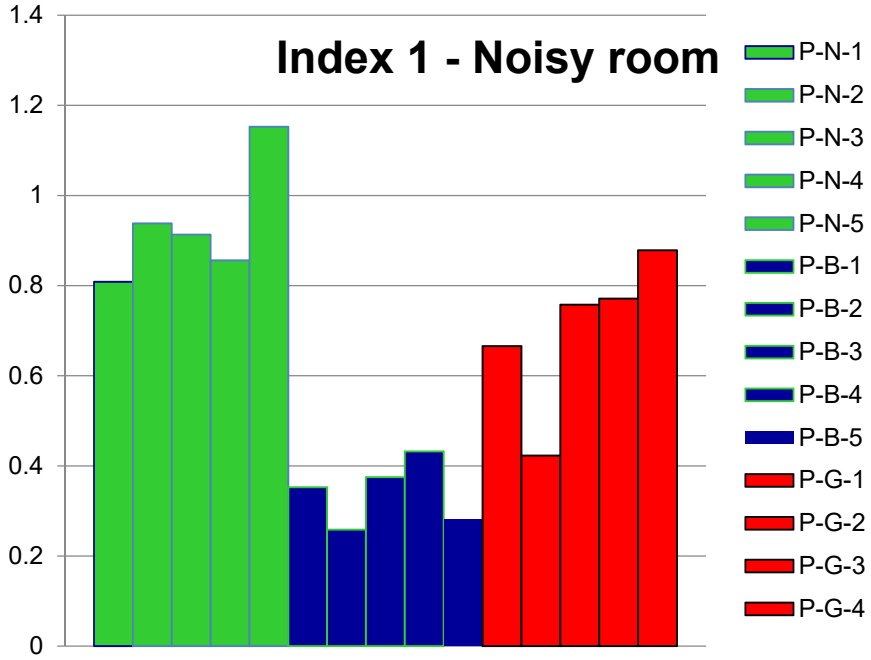
1851.5625
1886.71875
1921.875
1957.03125
1992.1875
N - AVG
B - AVG
G - AVG

$$INDEX1 = \left(\frac{\sum f_{lower}^2}{\sum f_{higher}^2}\right)^2$$

$$f_{lower} < f_{cross} < f_{higher}$$





IT IS POSSIBLE TO DISTINGUISH [B] EITHER IN SILENT OR IN NOISY ROOMS, WHILE [G] CAN B DISCRIMINATED ONLY IN SILENT ROOM

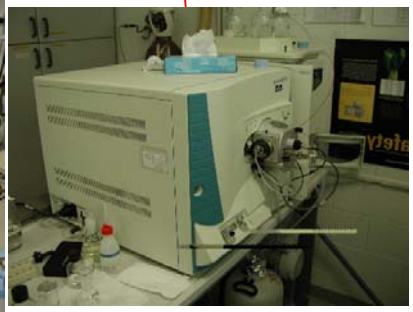
Part 2
Evaluating human perception of food's sound

Electronic Nose

Texture Rheology

Barilla Polysensorial Laboratories

SEM



Mass Spectrometry HPLC

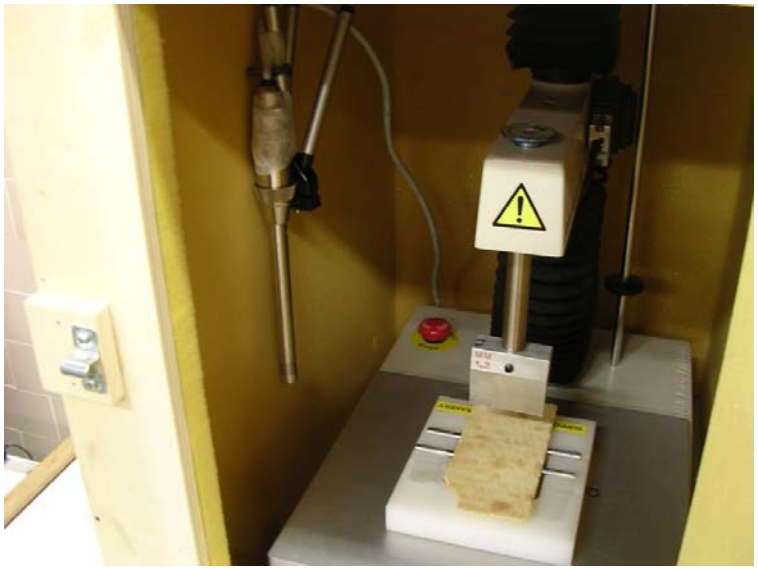
Barilla

MULINO BIANCO
Barilla

Scheme of the sound perception process

- Mechanical action over the product applied by teeth
- The product breaks, producing sound and vibrations
- These physical stimuli affect the human sensorial system, both through acoustical propagation and bone transmission
- The brain elaborates these stimuli, translating then into perceptual sensations, and later on in emotions (not analyzed yet)

Measurement of the fracture sound



- Instron texturimeter
- Bruel & Kjaer mic
- Soundproof enclosure
- Temporal/spectral analysis of the waveform

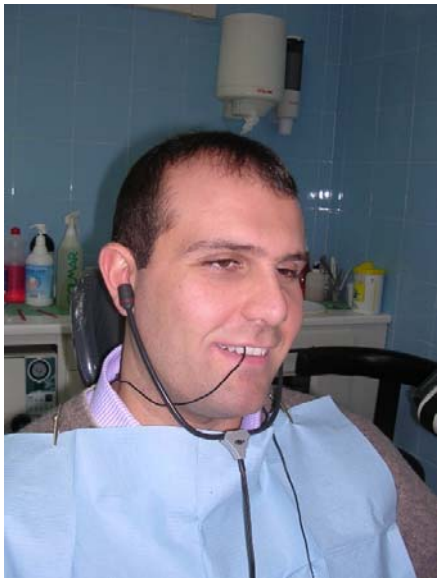
Measurement of crunching sound of bread substitutes

- Binaural microphones
- Webcam recording
- 8 subjects
- 6 products, not pre-breaked (the first sound comes from breaking the product with front teeth).
- 3 pieces for each product

Measurement of teeth vibrations

- Small piezoelectric transducers
- Glued on the side of teeth by means of a professional cement
- The signal is recorded as a “guitar pickup” signal

Measurement of teeth vibrations

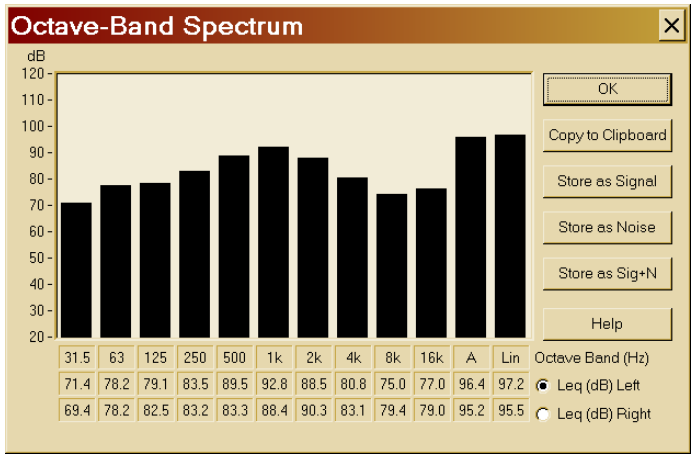


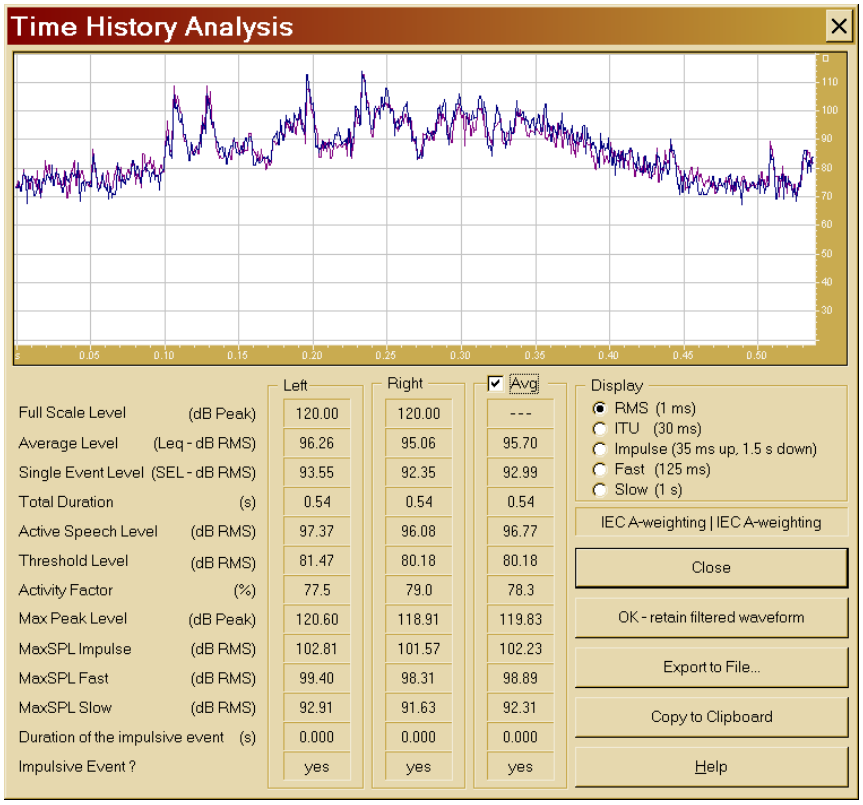
- 4 subjects
- 6 products tested
- Simultaneous recording of vibrations and sound (through binaural microphones)

Signal analysis – steps:

- Segmentation in single crunches
- Spectral analysis in octave band
- Temporal analysis (A-weighted)
- Feature extraction: octave band levels, peakiness, impulsiveness, tonal ratios, decay time, etc.
- All the processing done within specially-developed plugins for Adobe Audition, initially developed for speech analysis and speech intelligibility measurement

Aurora plugins



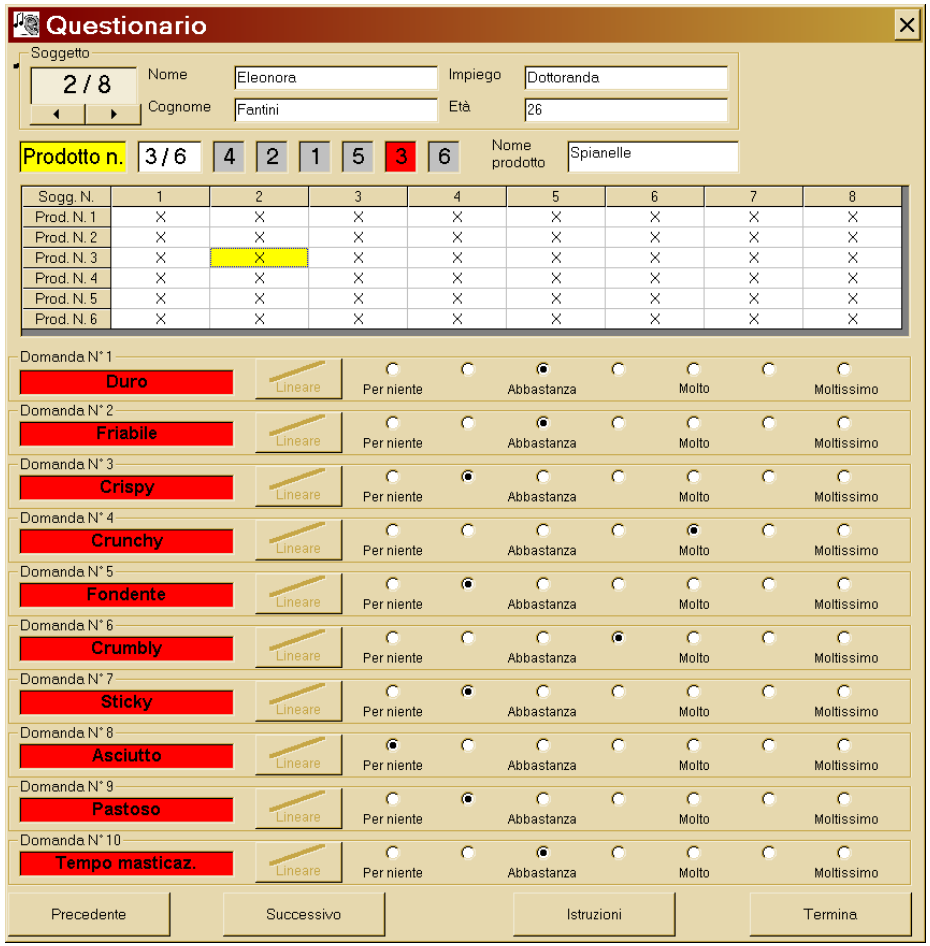


Spectral and temporal analysis

Subjective questionnaires

- Compiled in a not-stressing, silent environment
- 8 subjects
- 6 products
- 10 attributes on 7-marks scale
- Collection of answers through a specific software tool

Questionnaire software

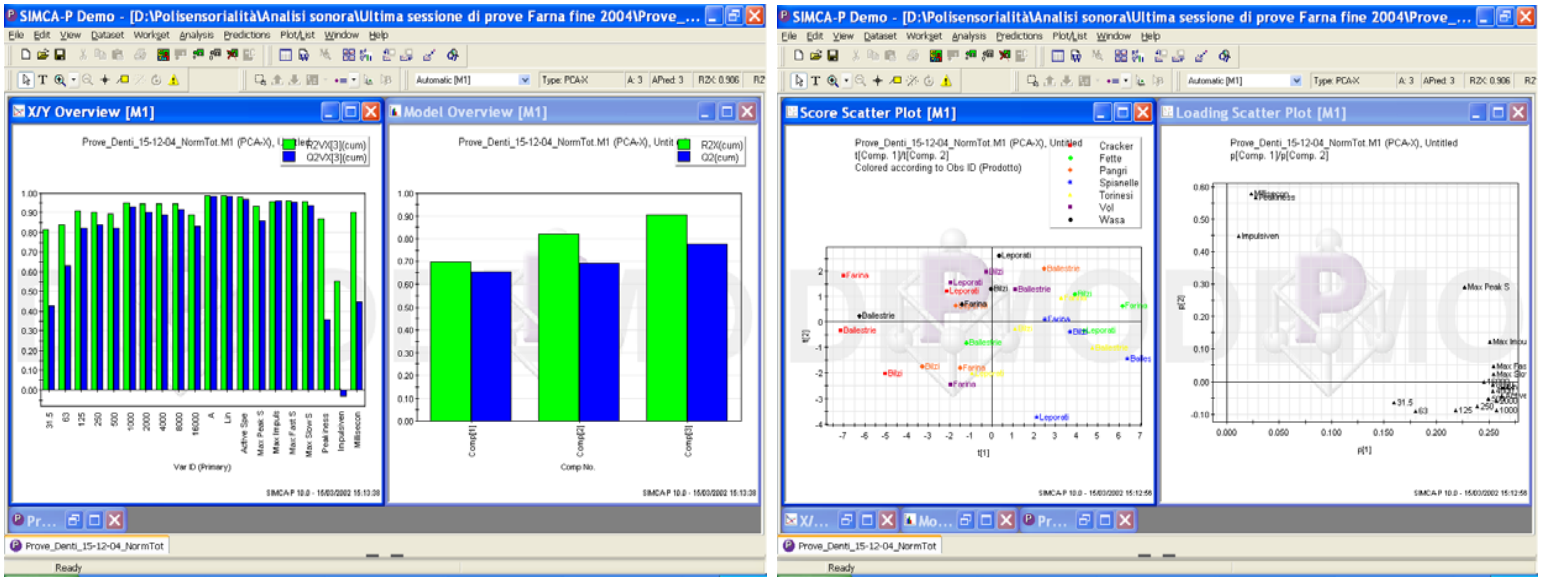


- Subjects forced to complete the whole form
- All the scales forced to linear
- No request of assessing “pleasantness”

Statistical analysis

- PCA of objective results from measurements, both from microphones and from teeth sensor
- PCA of subjective responses to questionnaires
- PLS for analyzing the interrelation between objective data and subjective responses
- De-meaning was required both on objective and subjective data, for removing inter-individual differences

Objective parameters PCA

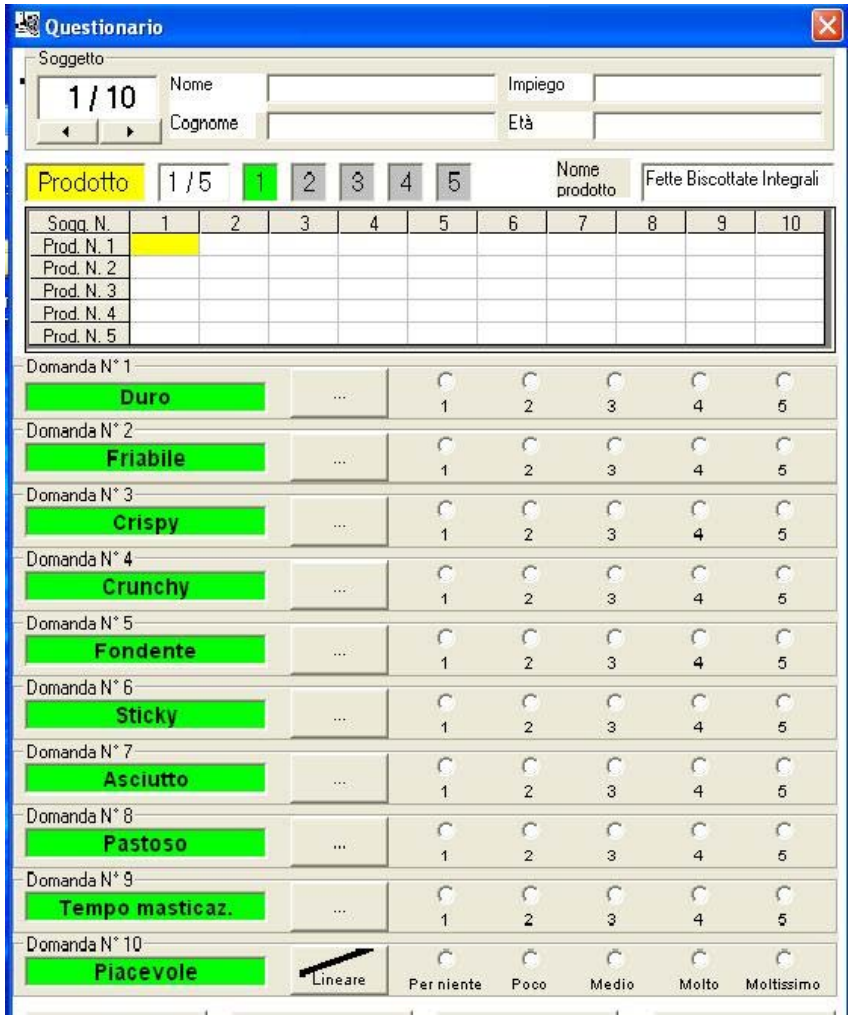


- 1° Component: loudness
- 2° Component: peakiness
- 3° Component: spectral slope

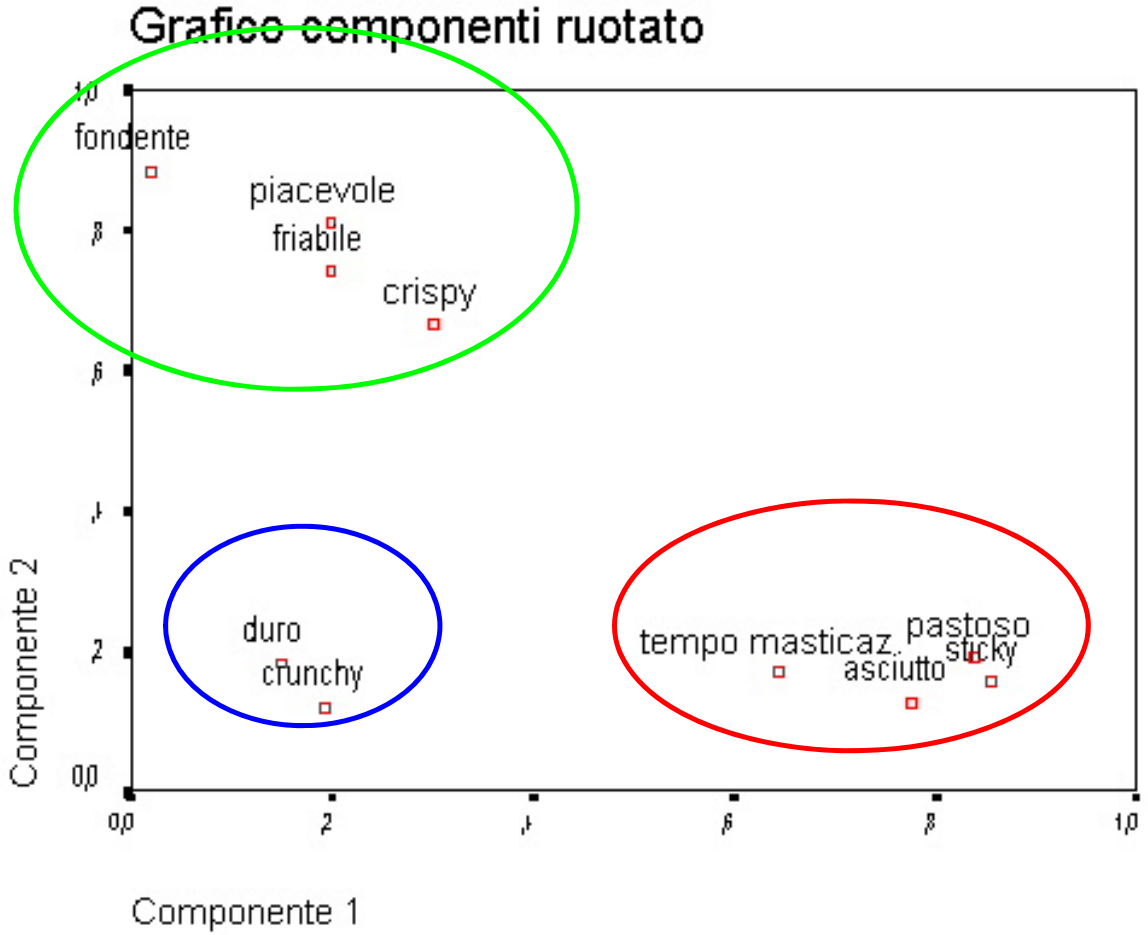
Conclusions

- The bread substitute products appear reasonably differentiated both in objective and subjective analysis
- Despite this, the correlation between objective and subjective data is generally weak.
- The weak point appears to be in the formulation of the questionnaires and in the linguistic barrier when describing crunching-related perceptions

Sensory Panel: crackers



Principal Component Analysis



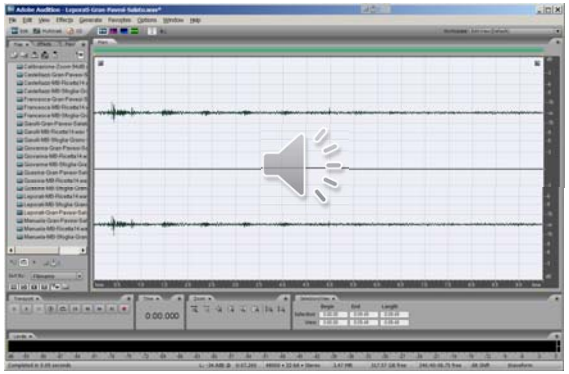
- sound quality analysis of Barilla - Mulino Bianco crackers and bread substitutes

Fette Biscottate Classiche

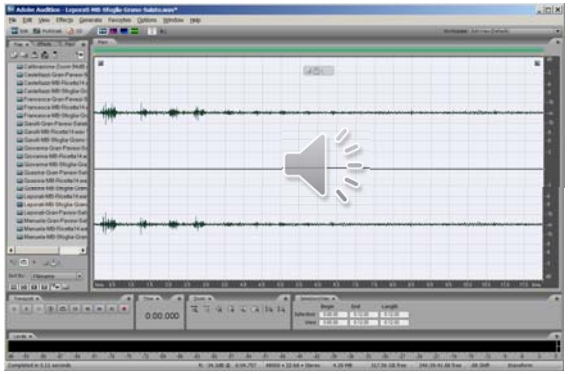
Spianelle

02/10/2018

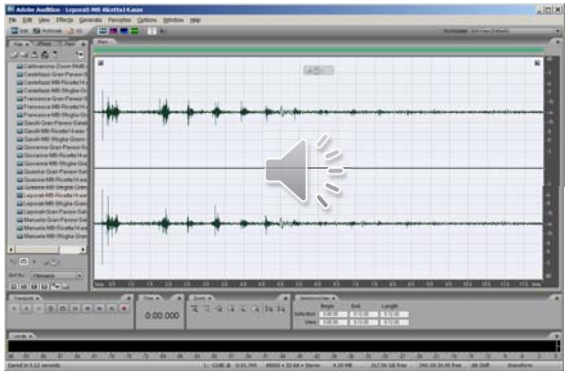
Binaural recordings of crackers:



Gran Pavesi Salato

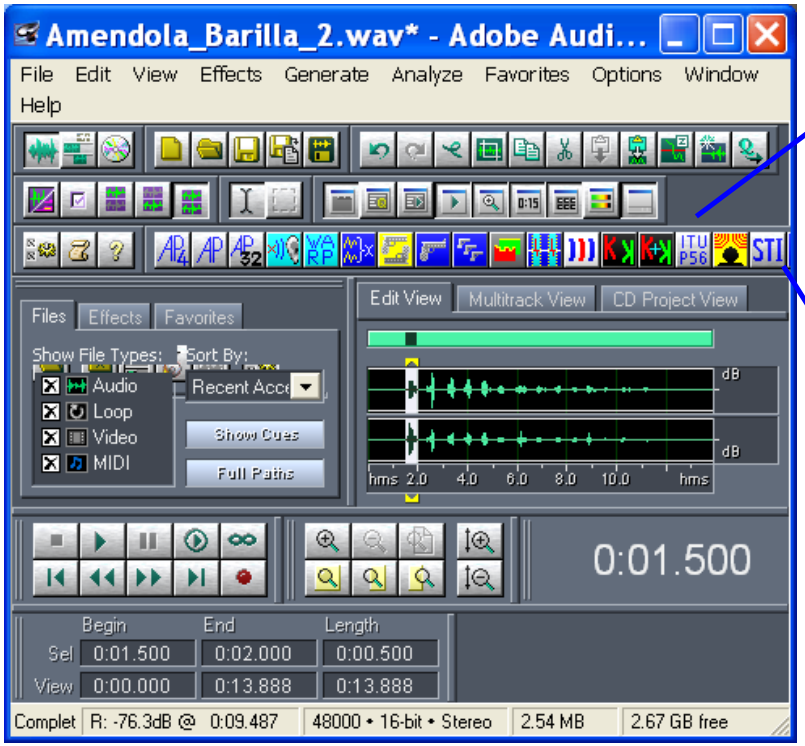


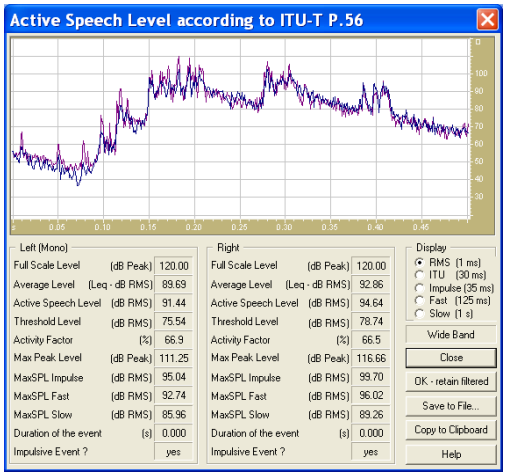
MB Sfoglia Di Grano



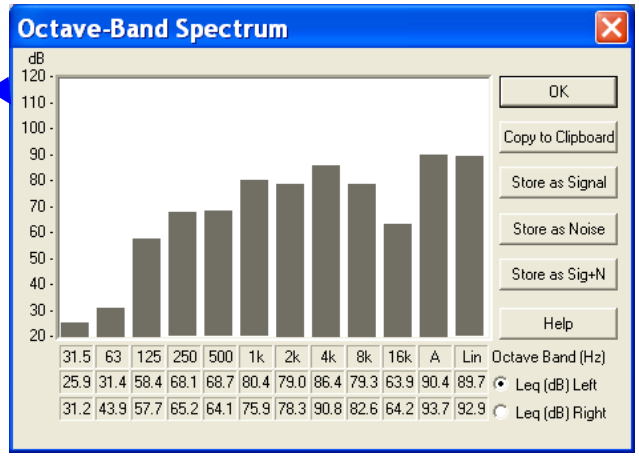
Ricetta 14

Sound processing with Aurora plugins



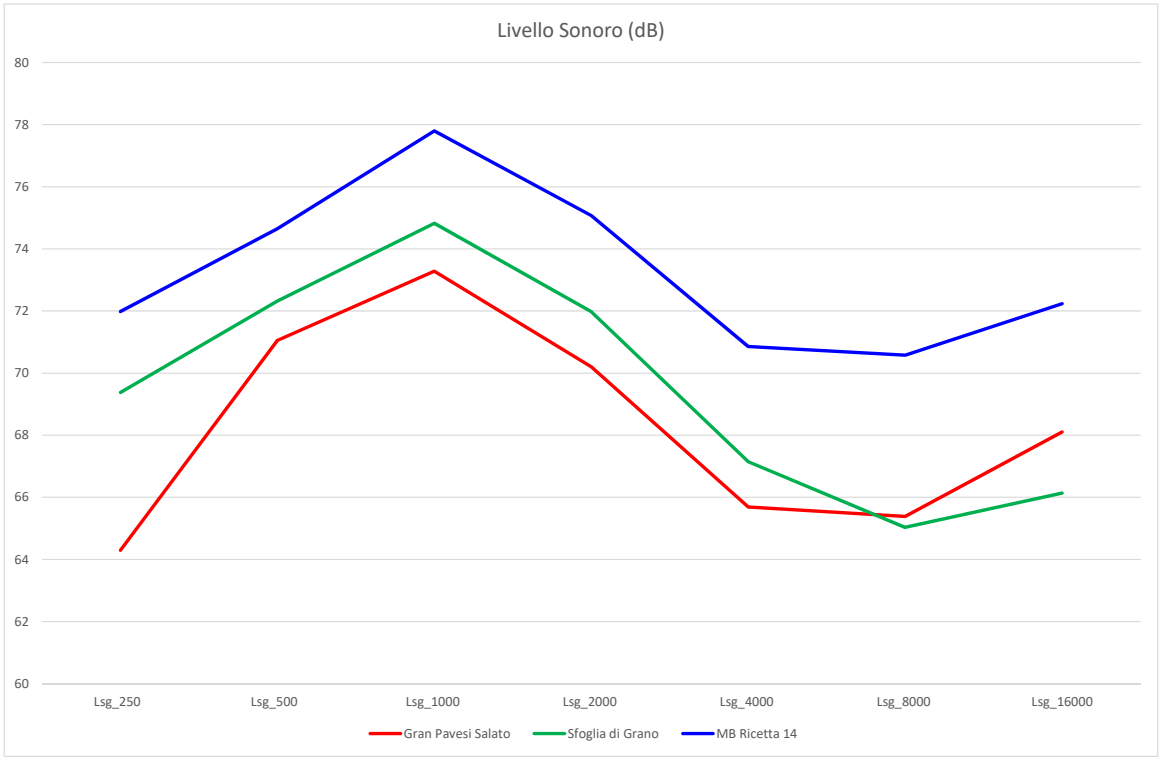


Temporal Analysis

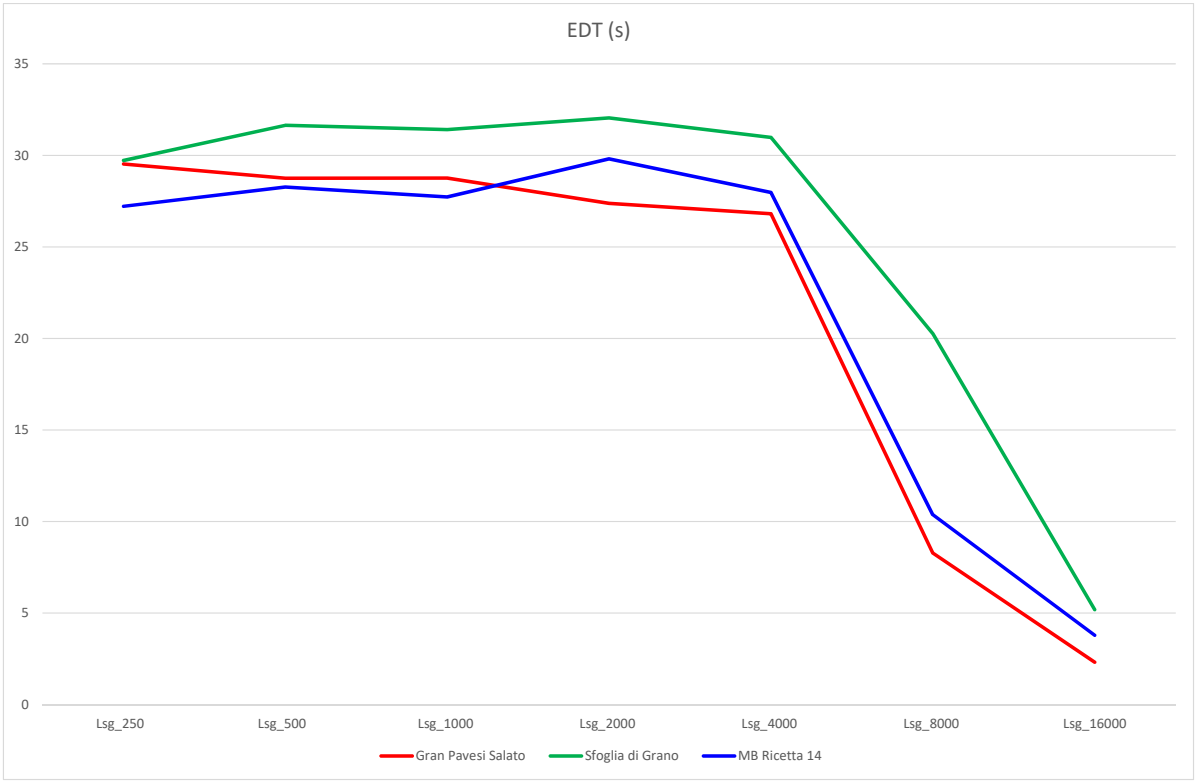


Spectral Analysis

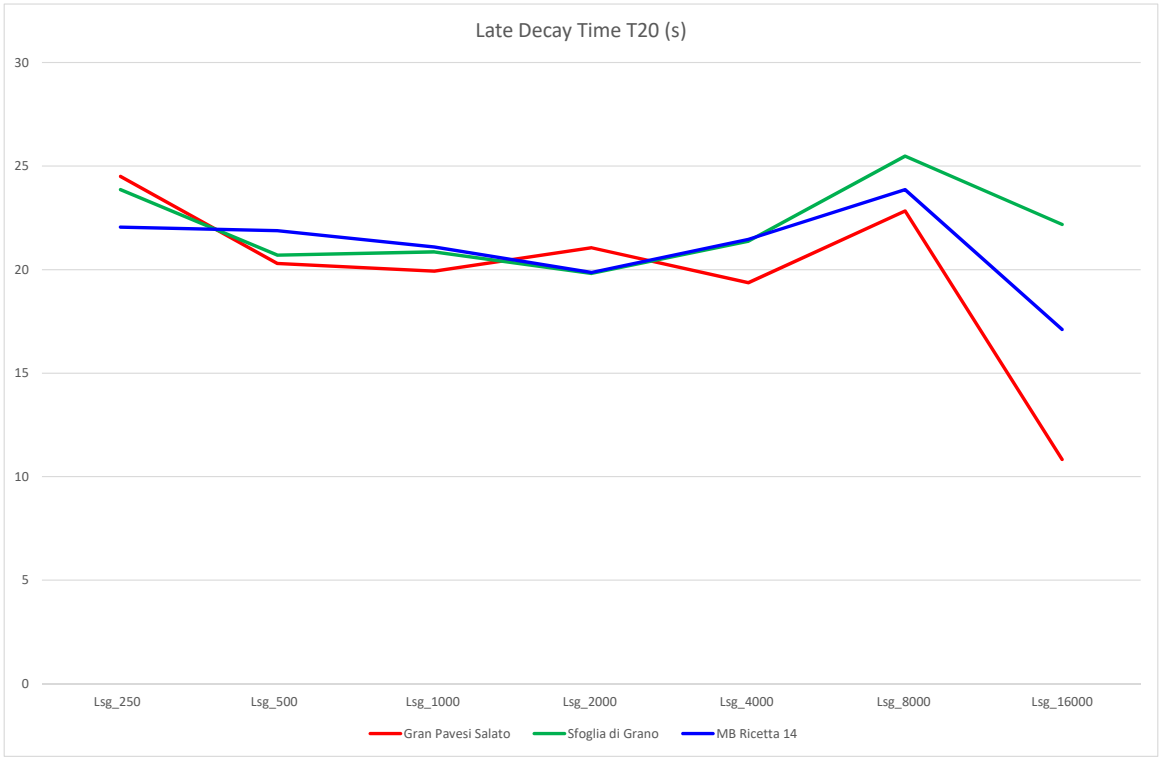
Spettro Livello Sonoro



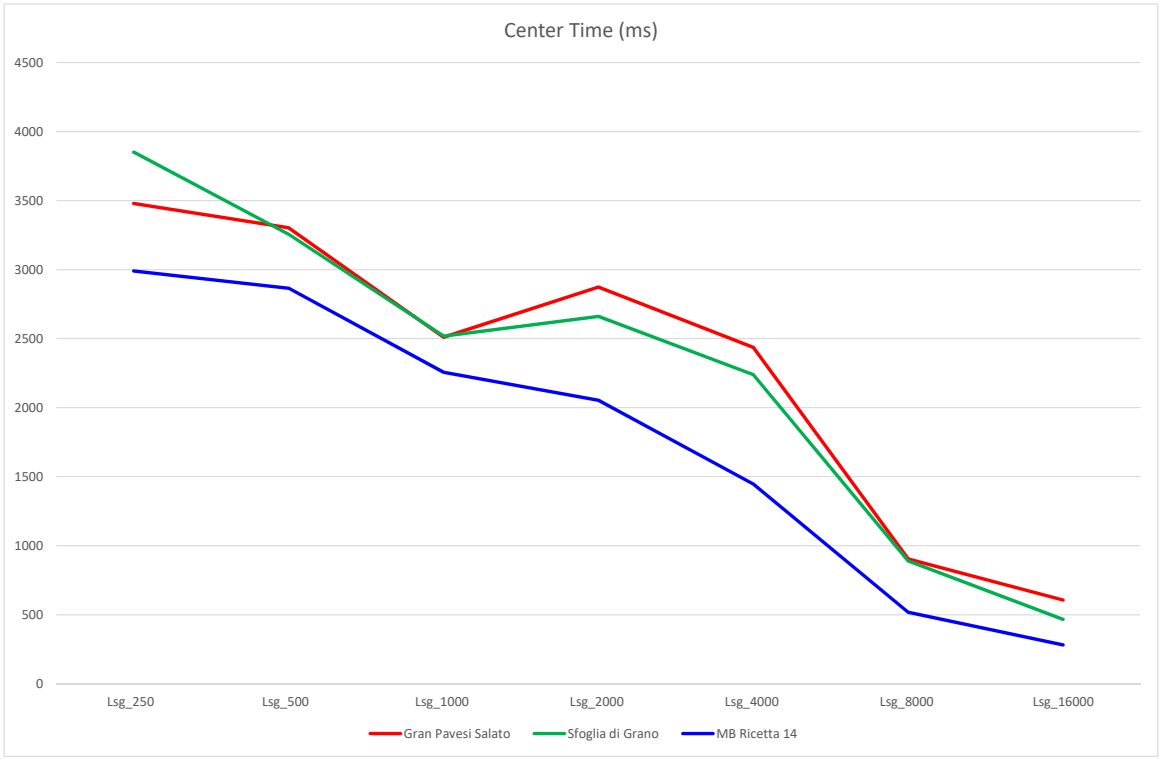
Spettro Tempo Decadimento EDT



Spettro Tempo Decadimento T20



Spettro Center Time

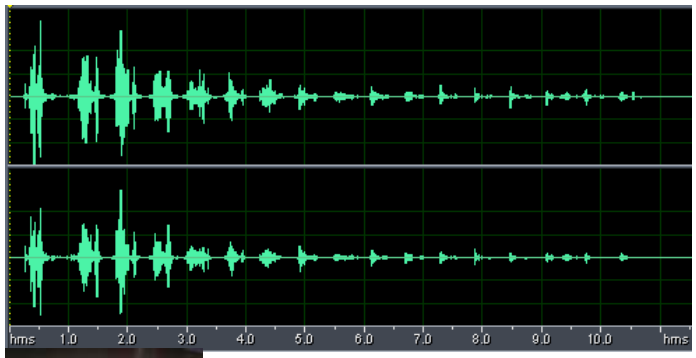


Test on potato chips:

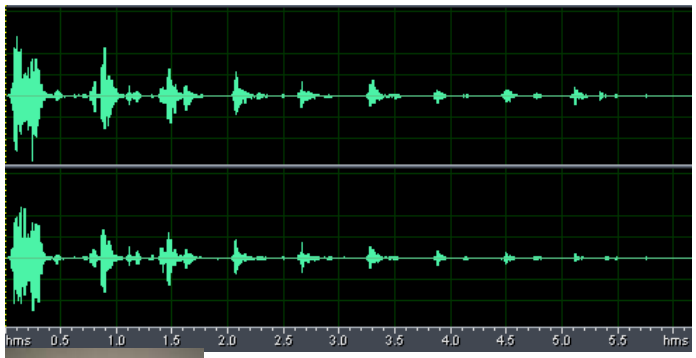
Binaural microphone recordings

Three samples for every subject for every product

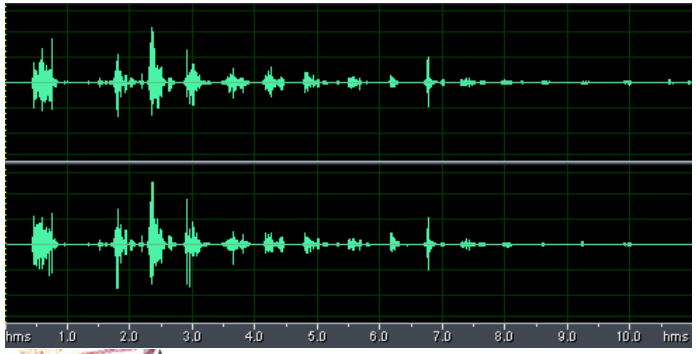
Analysis with Adobe Audition + Aurora software



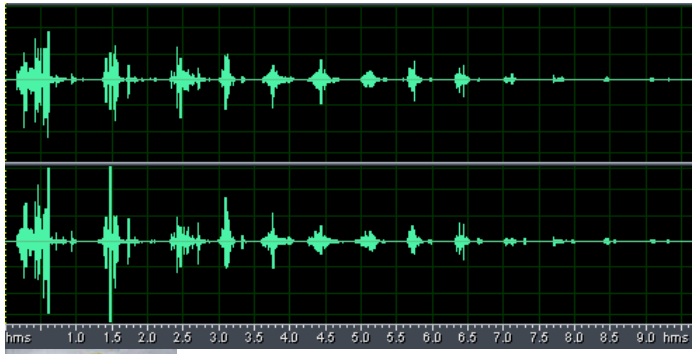
Barilla



Cipster

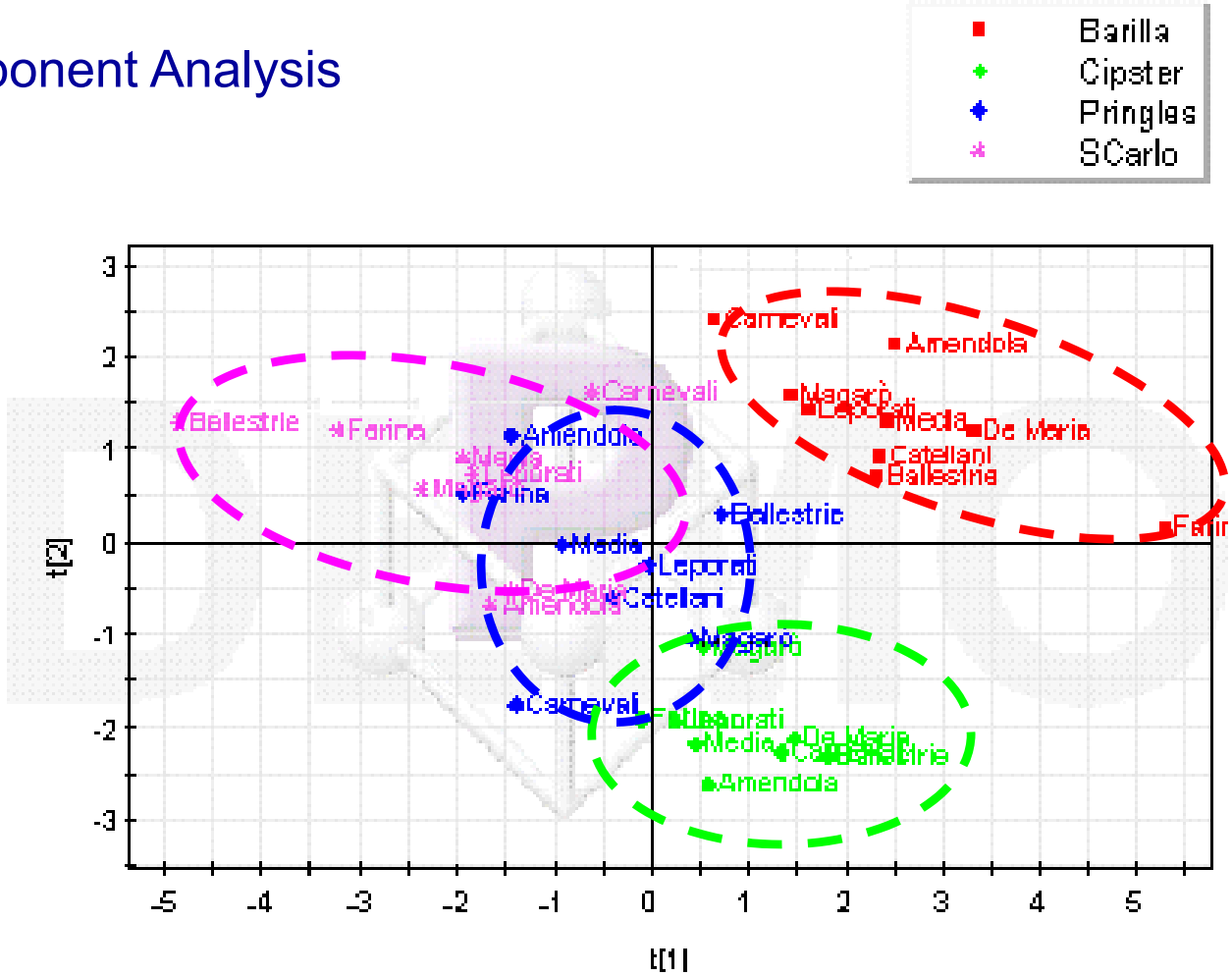


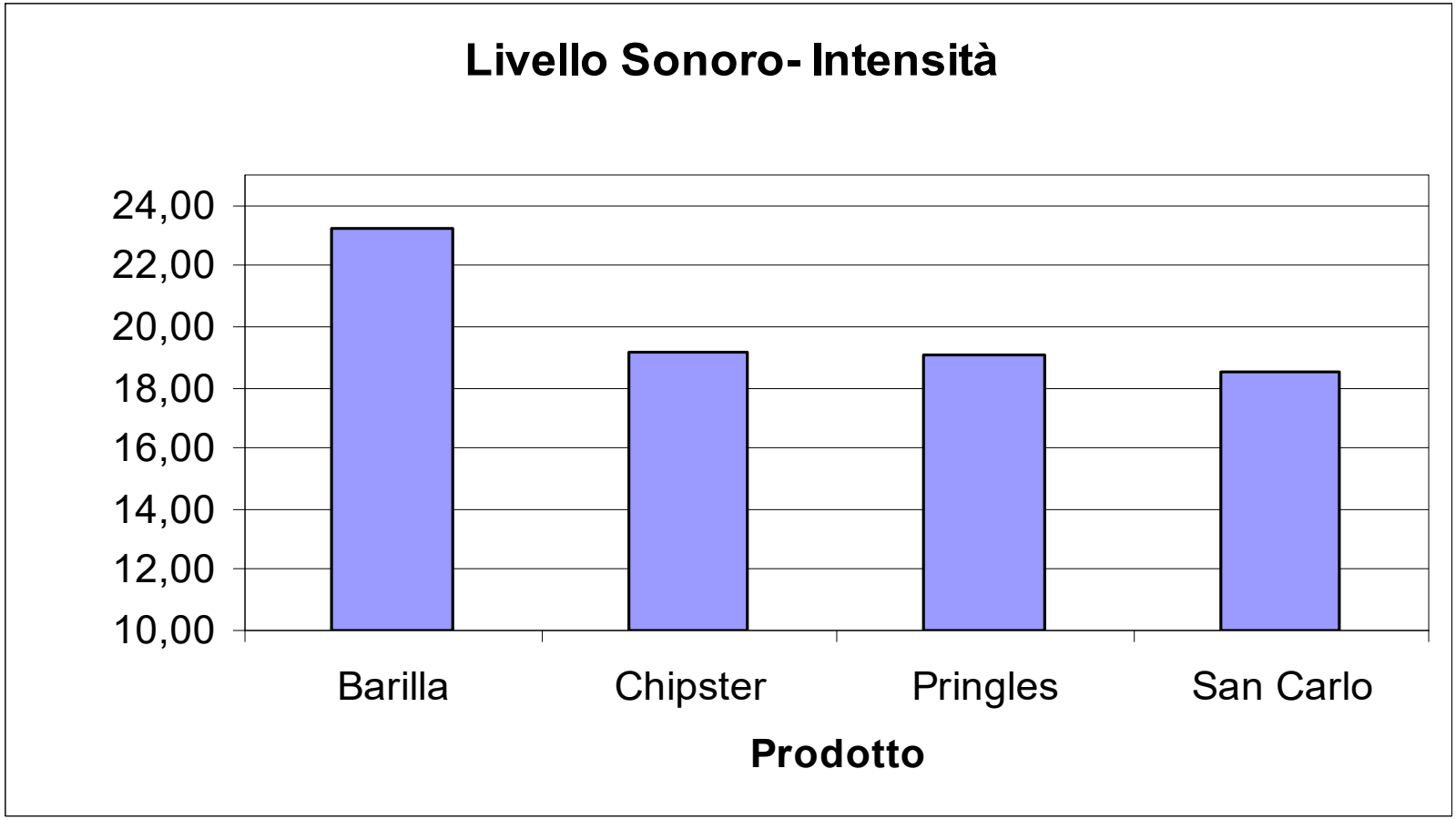
Pringles

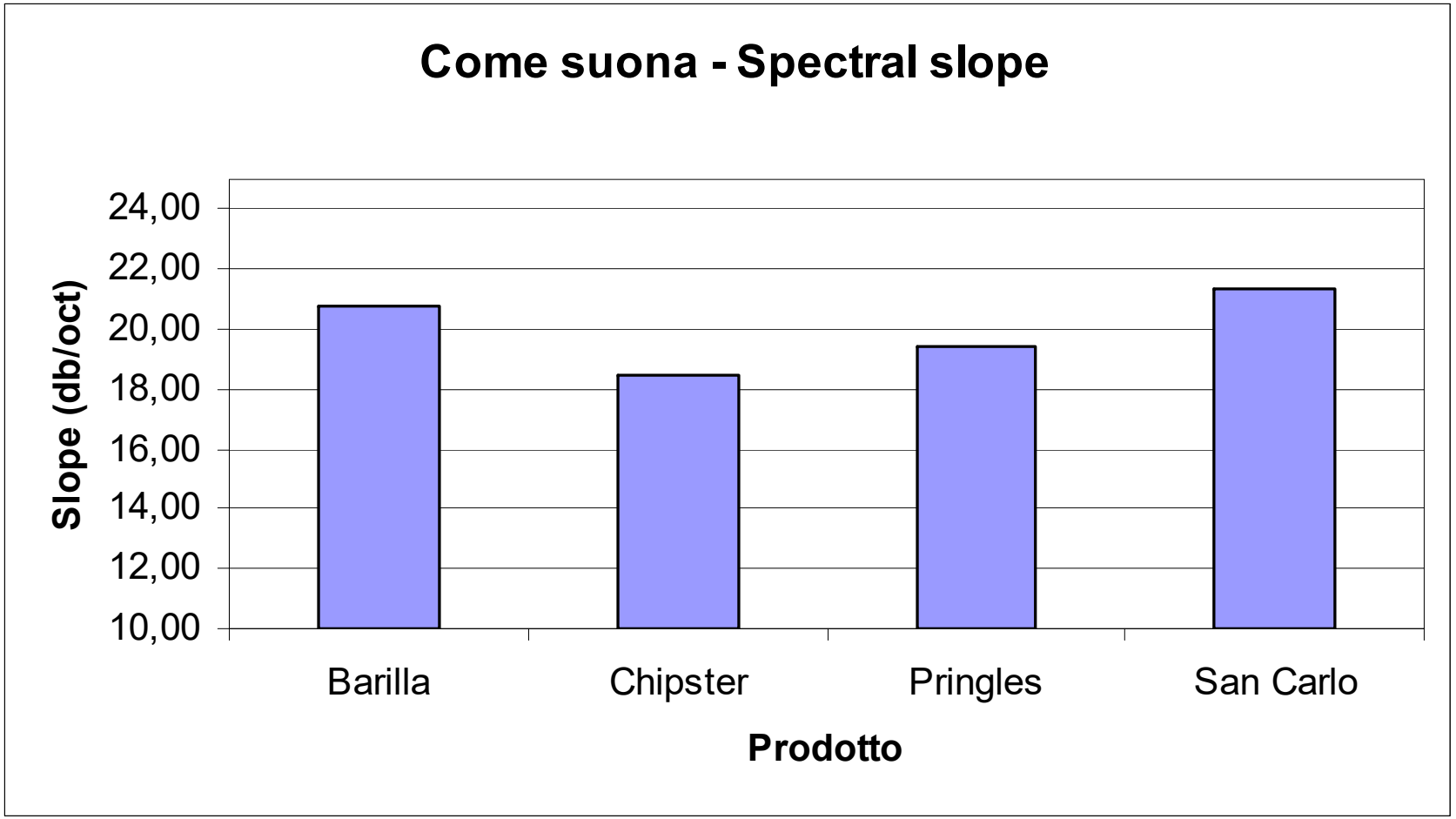


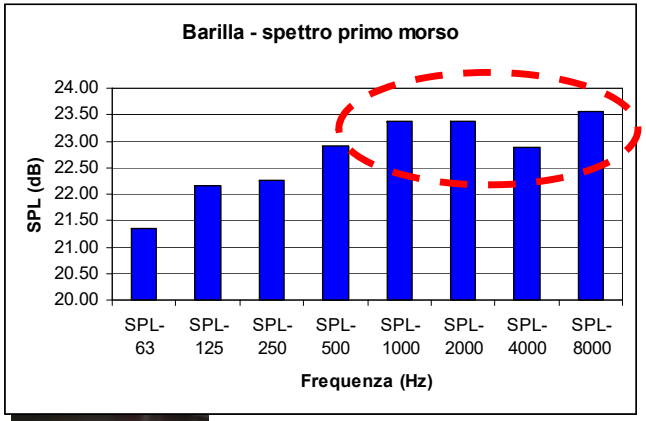
San Carlo

Principal Component Analysis

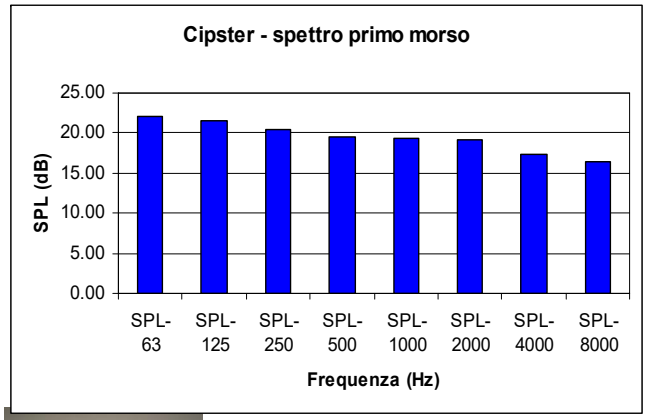



Livello Sonoro- Intensità
24,00
22,00
20,00
18,00
16,00
14,00
12,00
10,00
Barilla
Chipster
Pringles
San Carlo
Prodotto

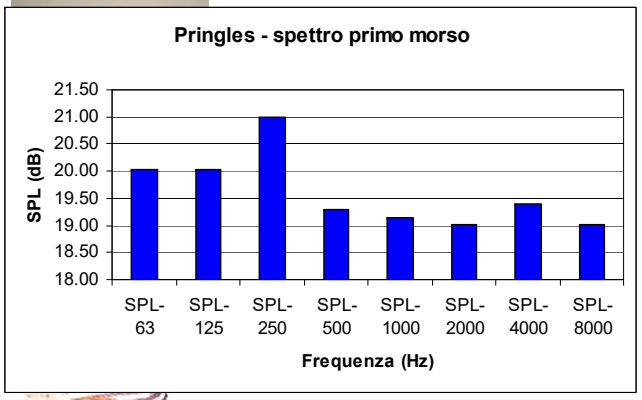

Come suona - Spectral slope
Slope (db/oct)
24,00
22,00
20,00
18,00
16,00
14,00
12,00
10,00
Barilla
Chipster
Pringles
San Carlo
Prodotto



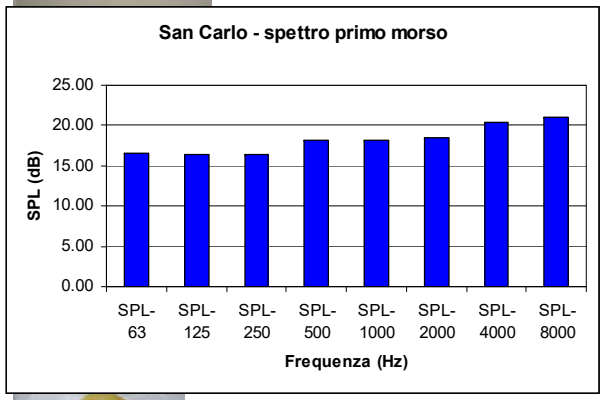
Barilla

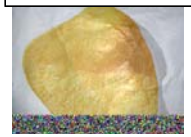


Cipster

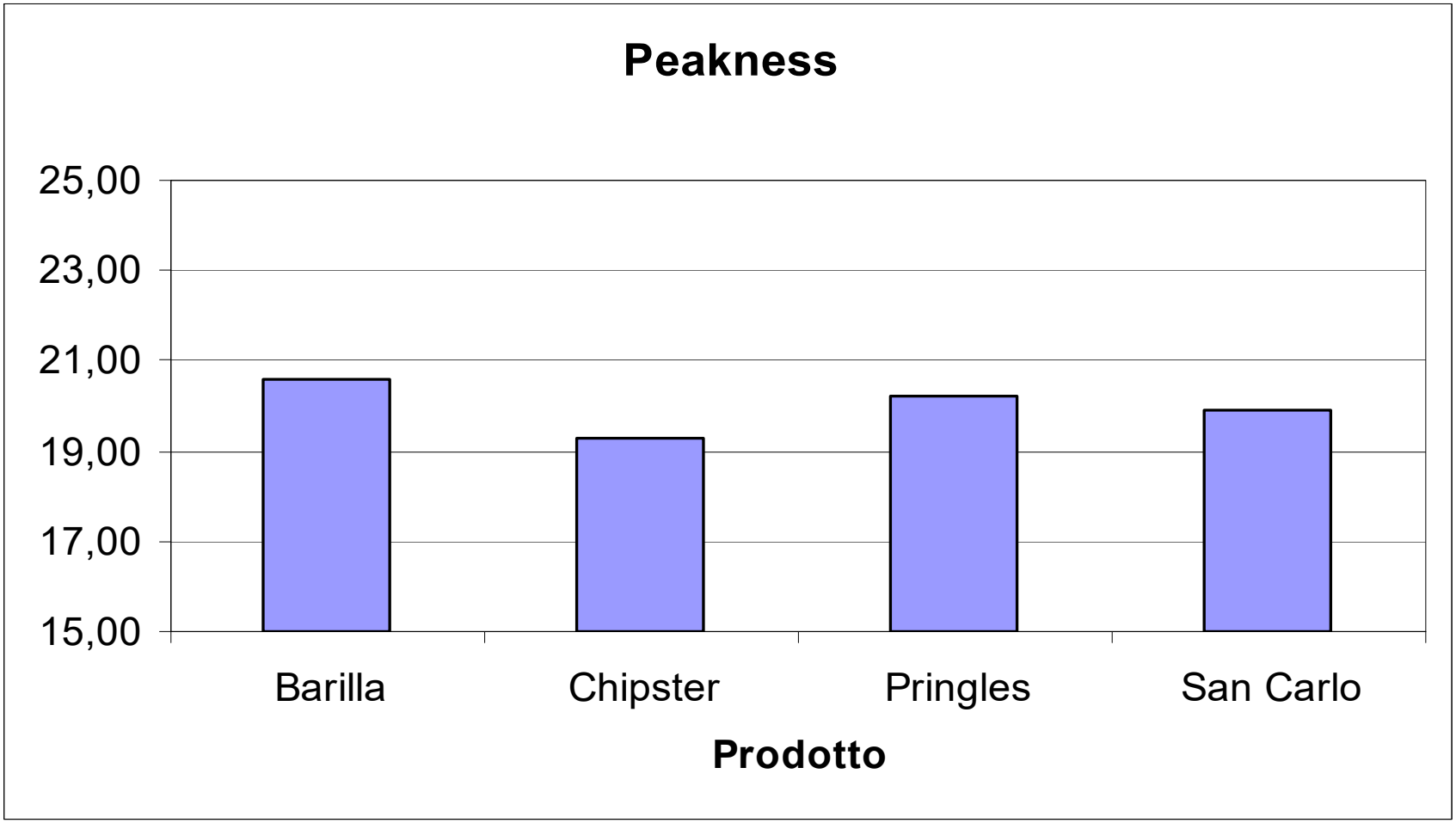


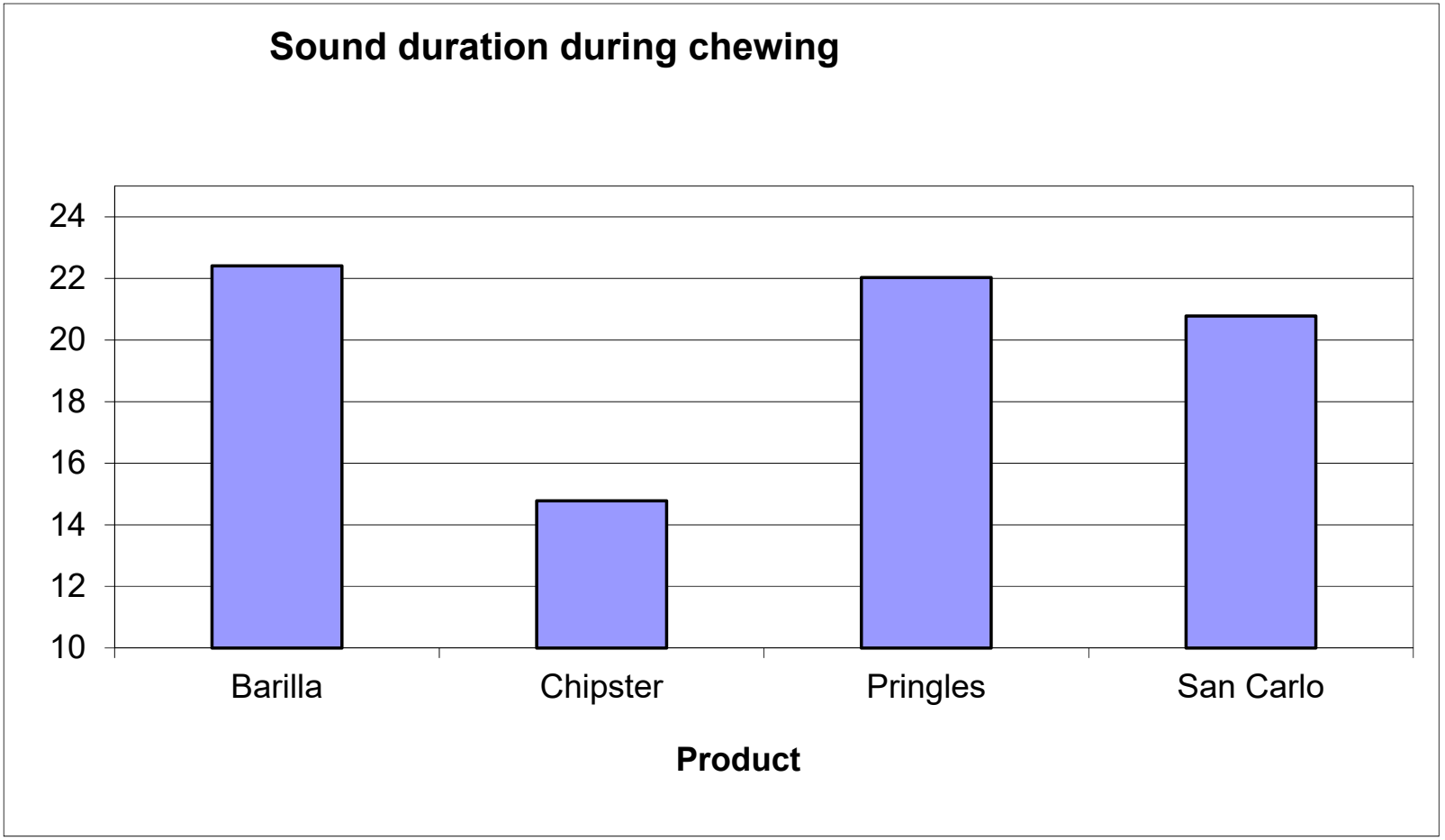
Pringles





San Carlo


Peakness
25,00
23,00
21,00
19,00
17,00
15,00
Barilla
Chipster
Pringles
San Carlo
Prodotto


Sound duration during chewing
24
22
20
18
16
14
12
10
Barilla
Chipster
Pringles
San Carlo
Product

- Project #4 – biscuits for breakfast

GOALS:

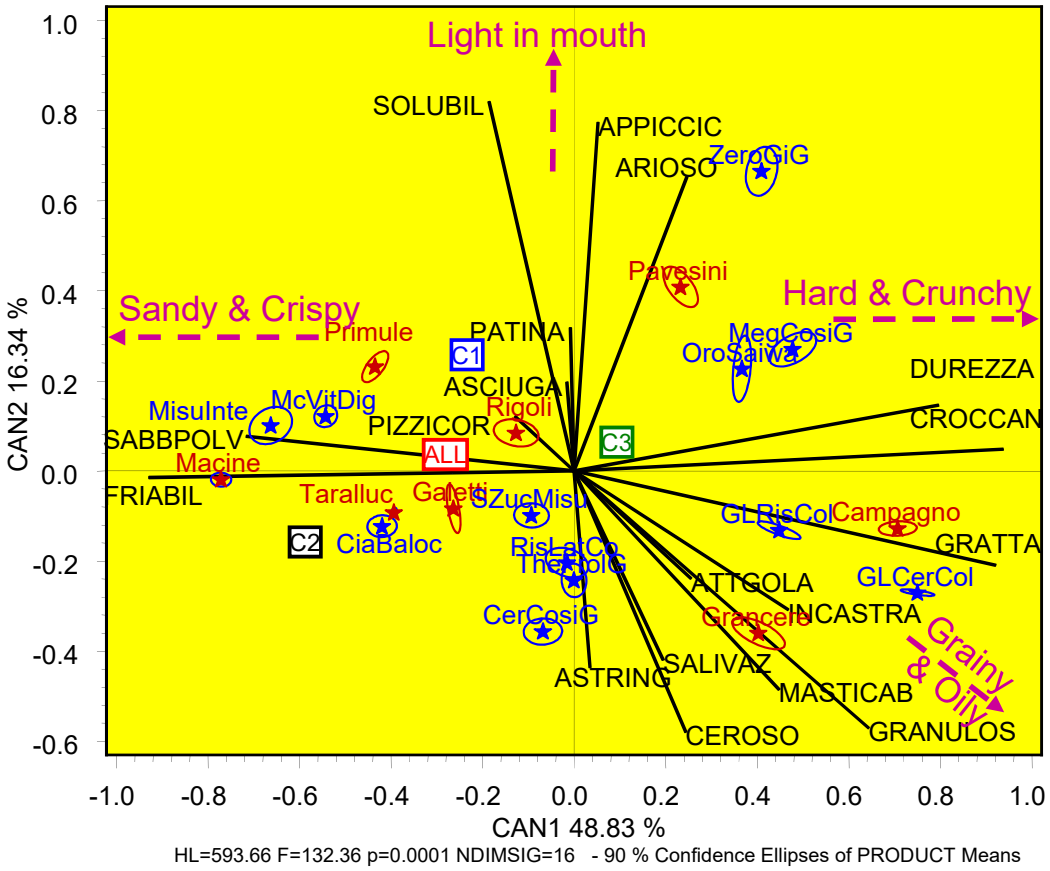
To develop analytical methods for biscuit texture, by means of advanced objective instrumental methods correlating with sensory characteristics.

BACKGROUND

Preference Mapping Study: study the Competitive set of Products (Mulino Bianco, Key Italian Competitors, Private Labels).

Liking assessment of the same 20 products by 250 Consumers and Sensory Maps.

Statistical correlation of Sensory & Consumer data.



HL=593.66 F=132.36 p=0.0001 NDIMSIG=16 - 90 % Confidence Ellipses of PRODUCT Means

BACKGROUND

Three Sensory Liking Segments

C1: light, airy in mouth, sandy and crispy texture

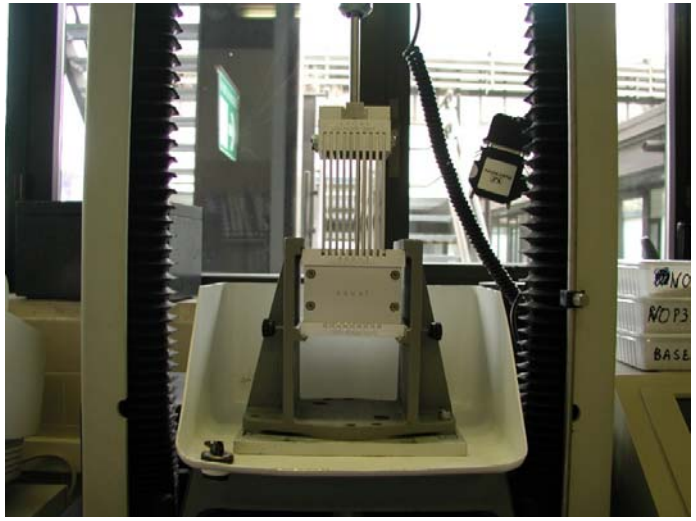
C2: more crispy, sandy cookies and less soluble/air

C3: slightly hard and crunchy

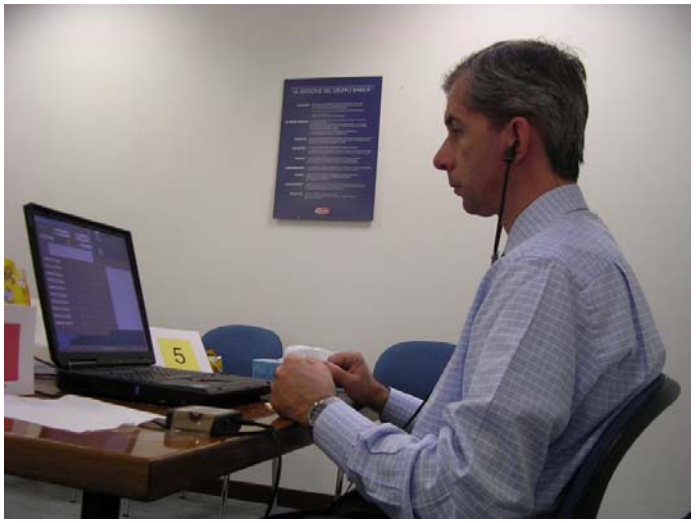
Methods

Developing new methods for texture evaluation:

Texture Analyser

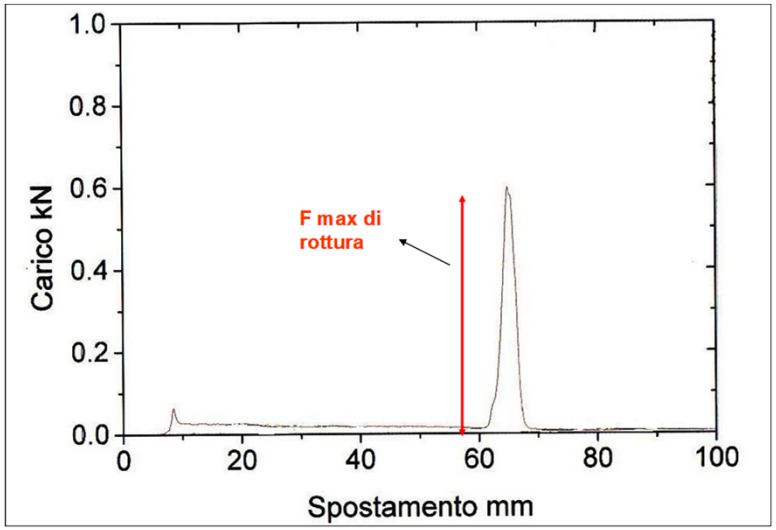


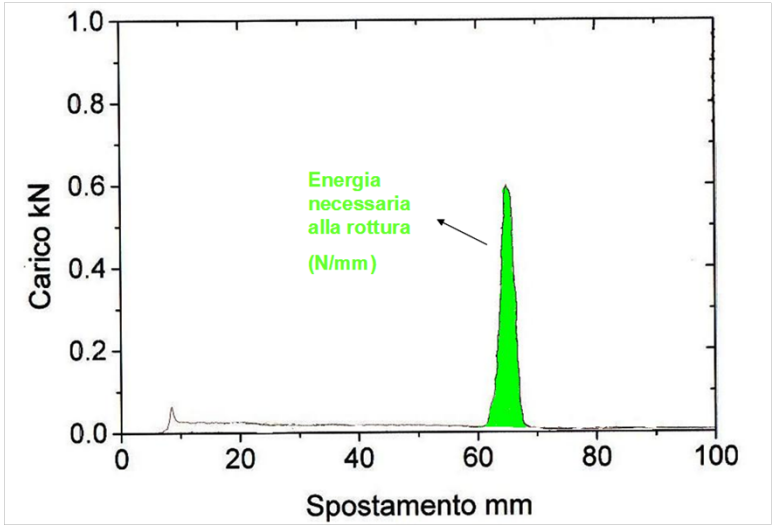
Acoustics methods



Texture Analyzer

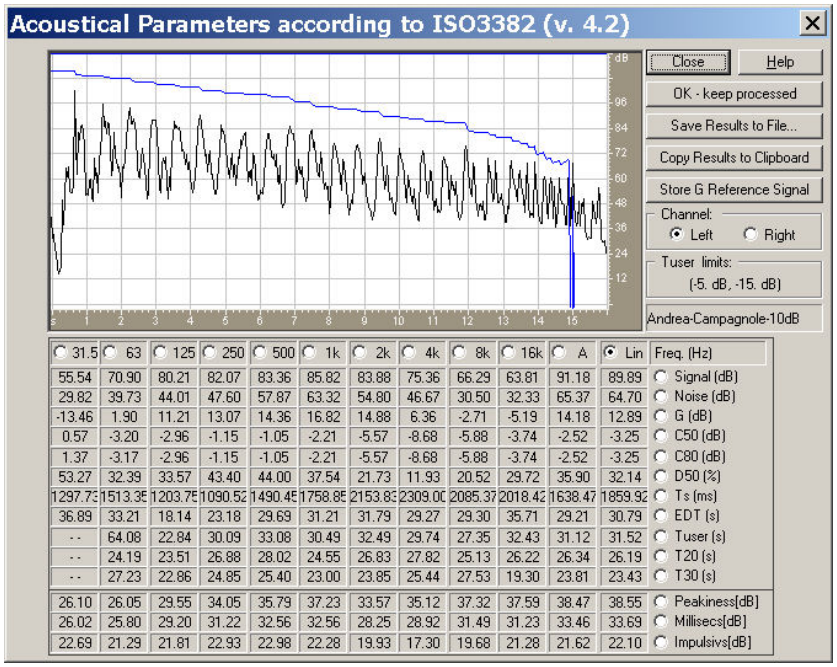
Mechanical properties derived by a fracture test





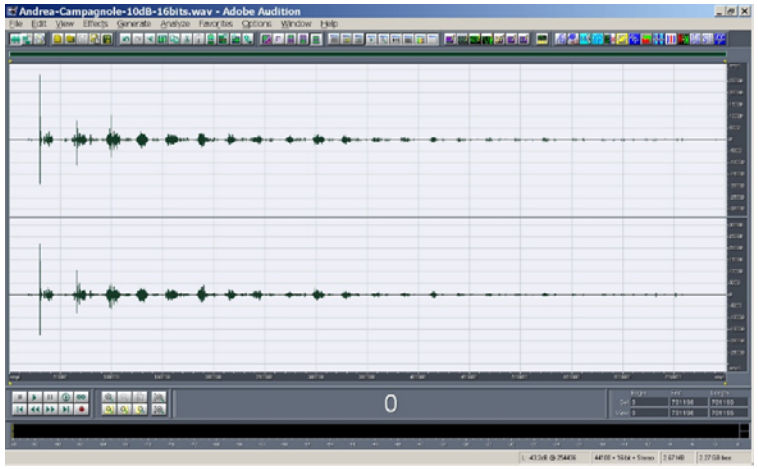
Acoustics Methods

Acoustical Parameters computed from binaural recordings (8 parameters in 10 frequencies)

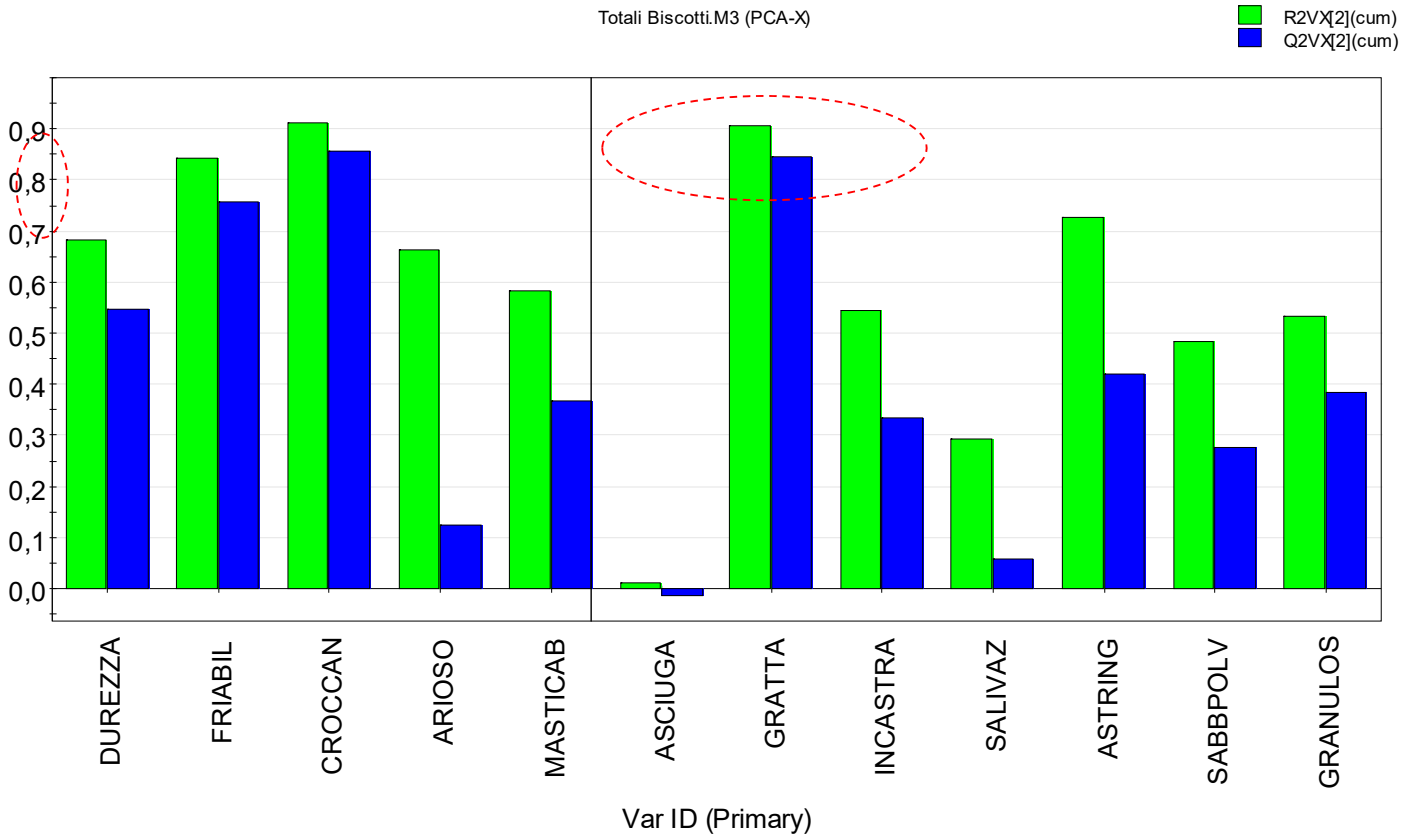


Sound recording

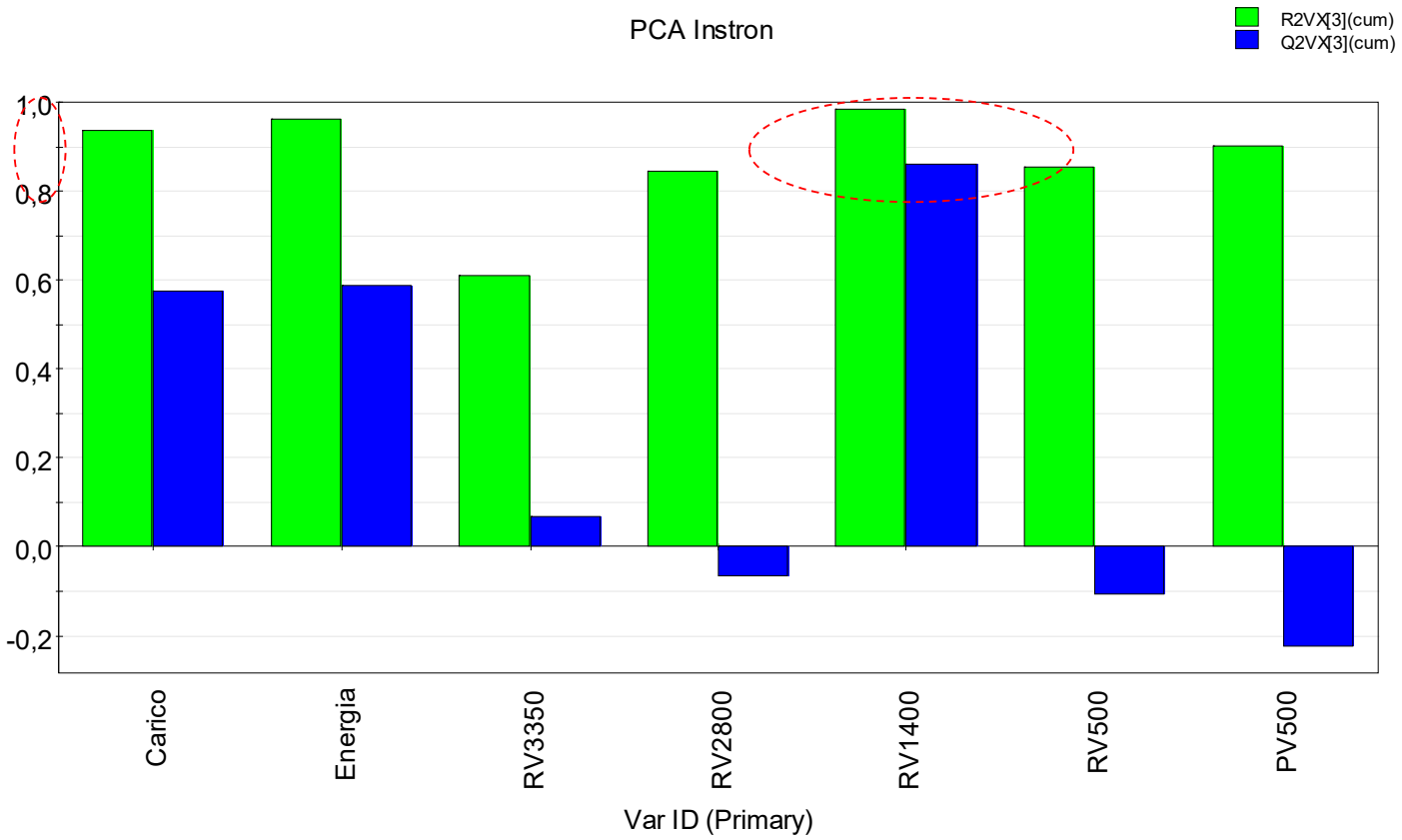
Campagnole vs Primule



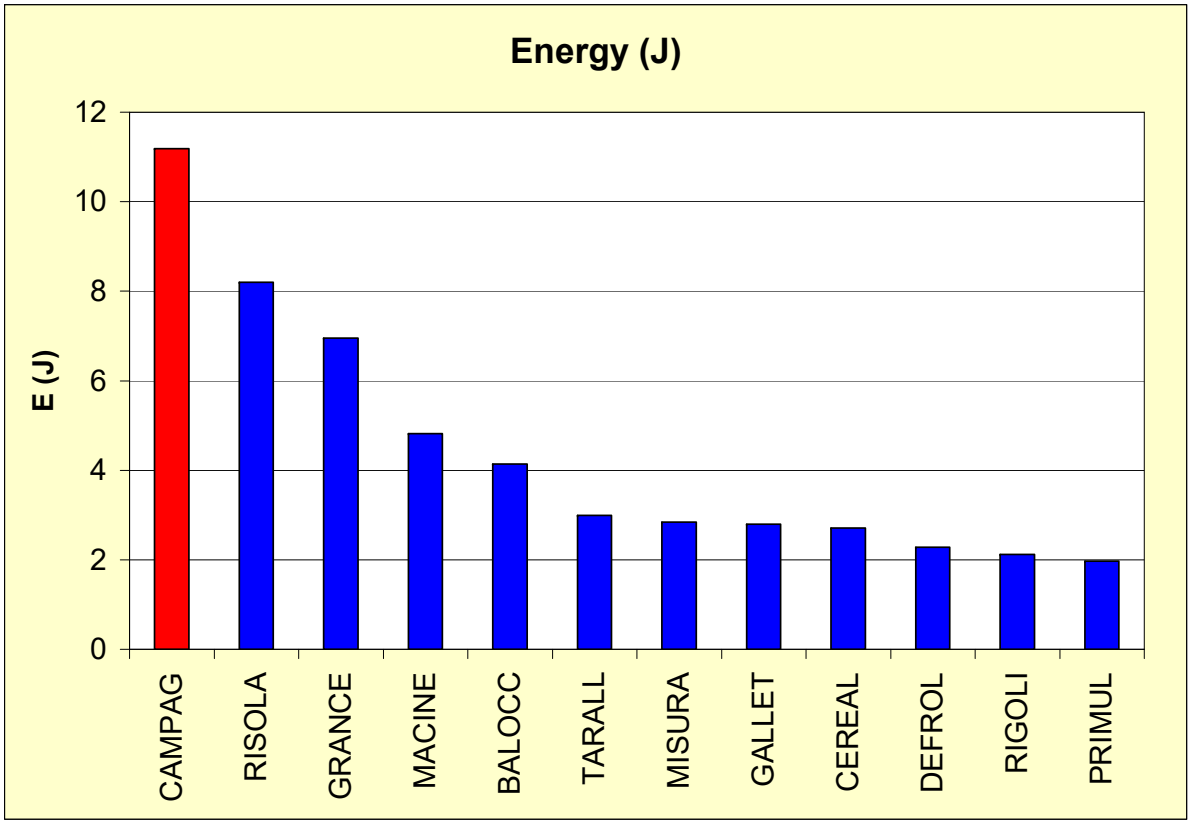
PCA Panel


Totali Biscotti.M3 (PCA-X)
R2VX[2](cum)
Q2VX[2](cum)
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
DUREZZA
FRIABIL
CROCCAN
ARIOSO
MASTICAB
ASCIUGA
GRATTA
INCASTRA
SALIVAZ
ASTRING
SABBPOLV
GRANULOS
Var ID (Primary)
SIMCA-P+ 11 - 22/05/2007 17.06.59

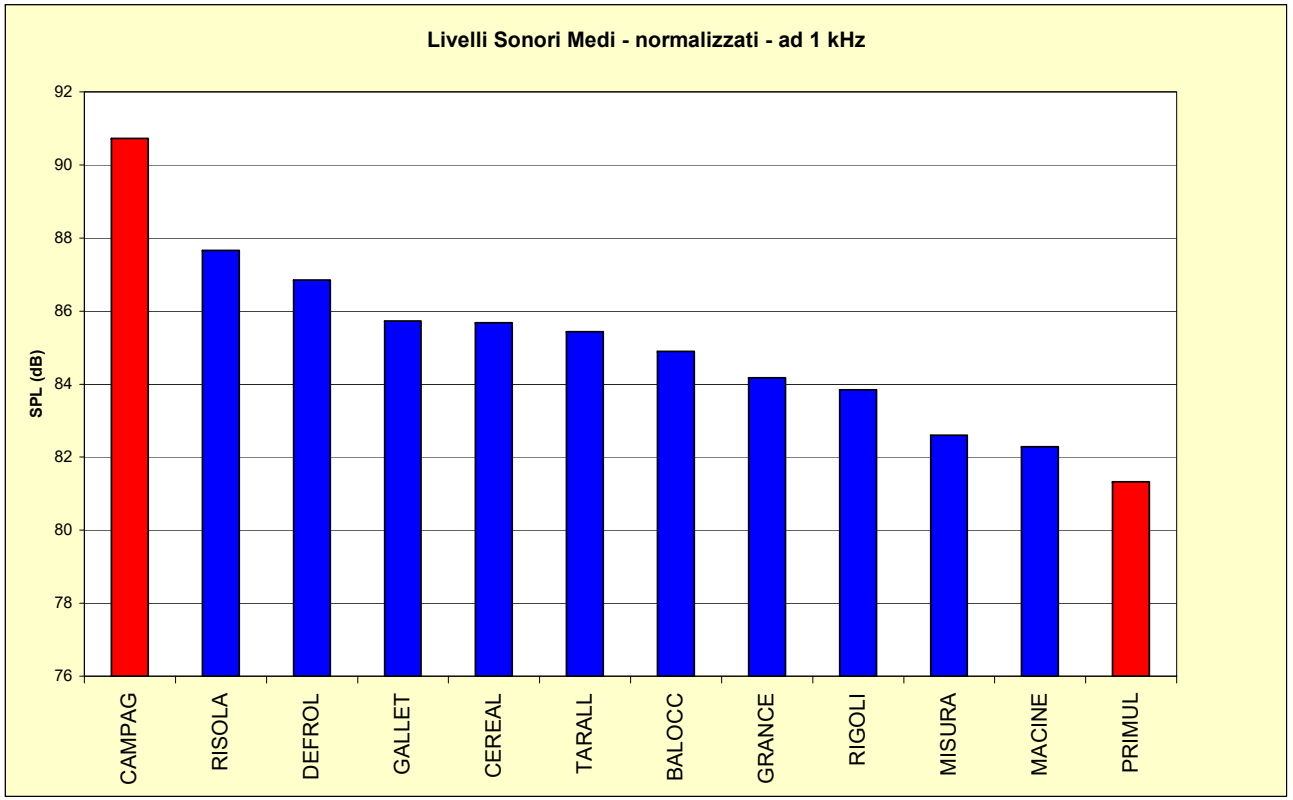
PCA Mechanical Parameters



Energy - Mechanical Parameters

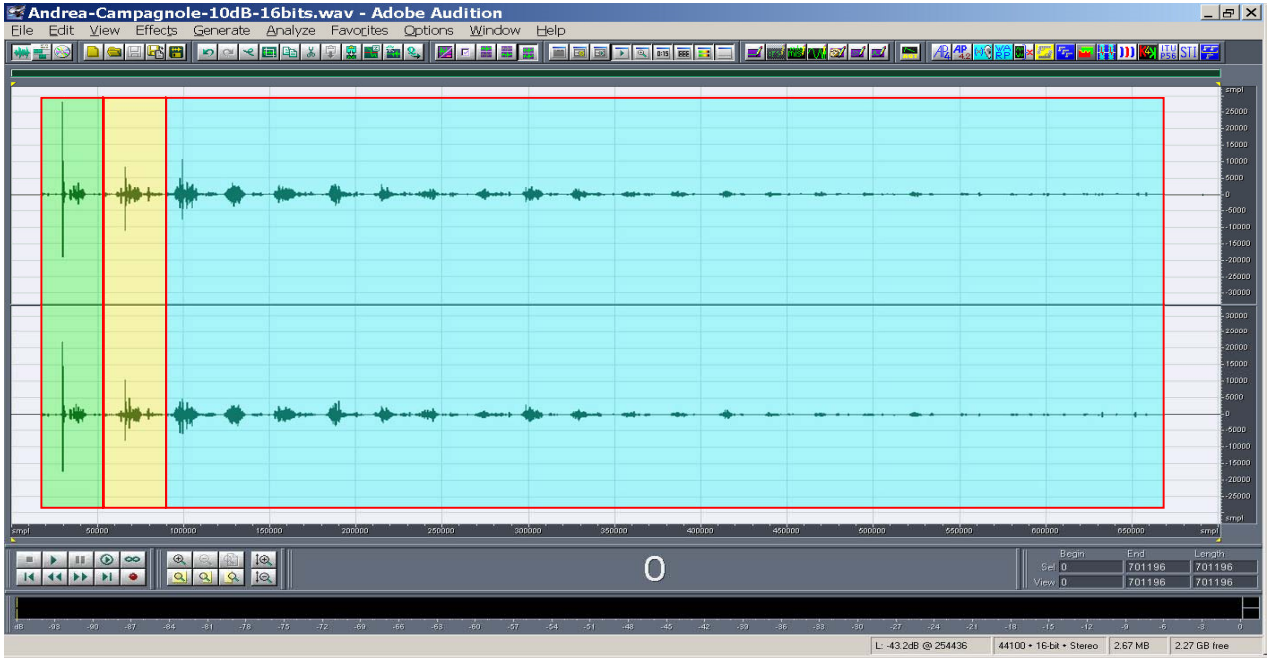


Sound Pressure Level- Acoustic Parameters

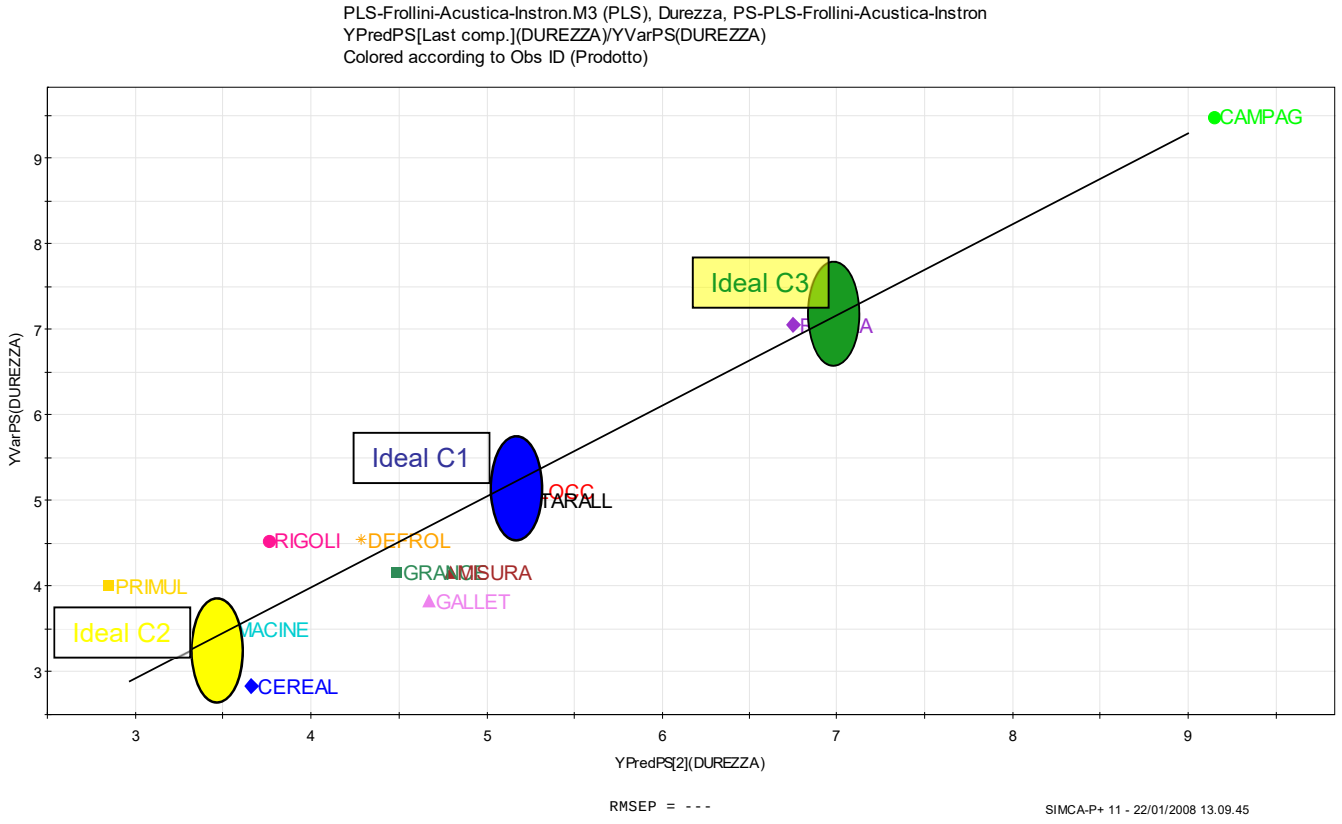


Separate Acoustic Parameters

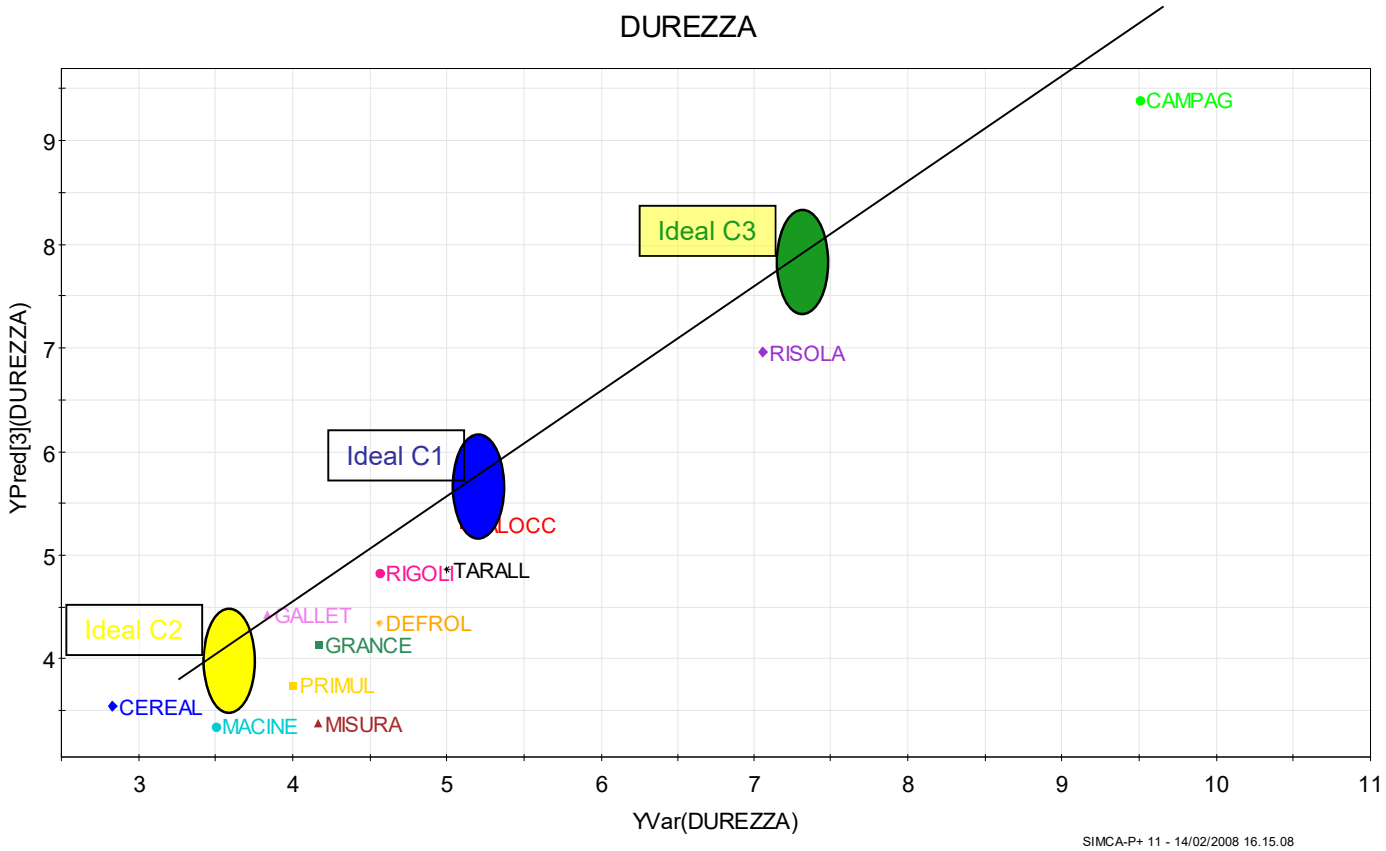
Acoustical analysis was performed separately for the first bite, the second bite and the following crunching



Predictivity from Mechanical Parameters- Hardness

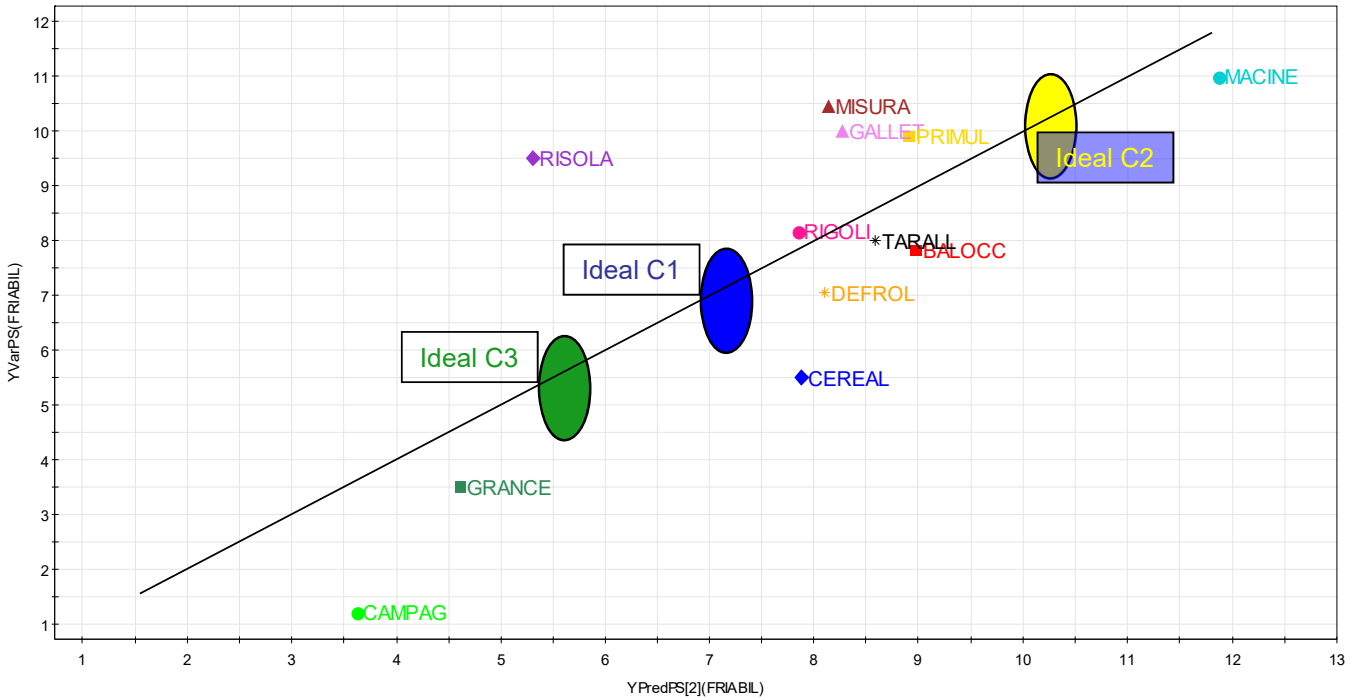


Predictivity from Acoustic Parameters - Hardness



Predictivity from Mechanical Parameters- - Friability

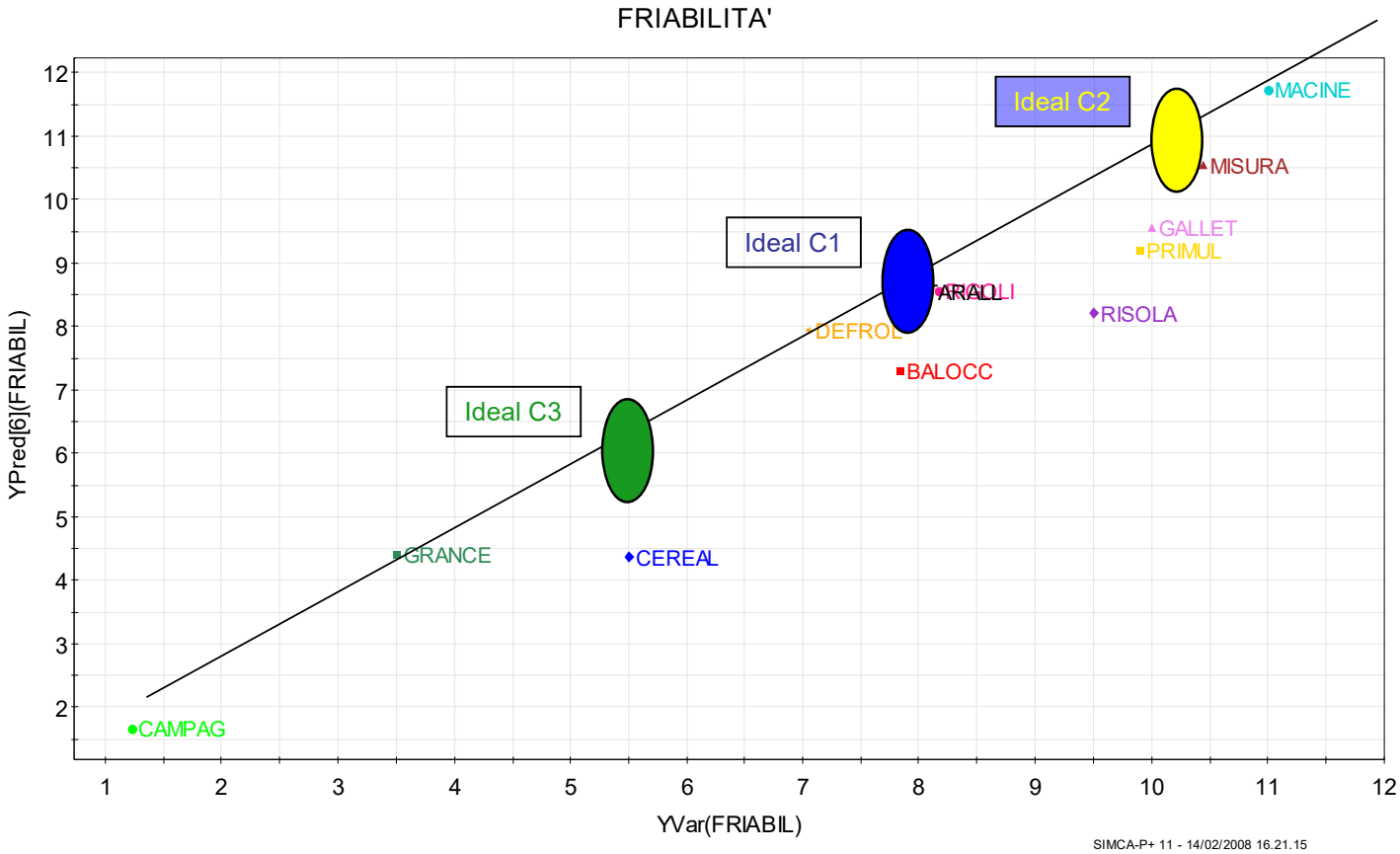
PLS-Frollini-Acustica-Instron.M2 (PLS), Friabilità, PS-PLS-Frollini-Acustica-Instron
YPredPS[Last comp.](FRIABIL)/YVarPS(FRIABIL)
Colored according to Obs ID (Prodotto)



RMSEP = ---

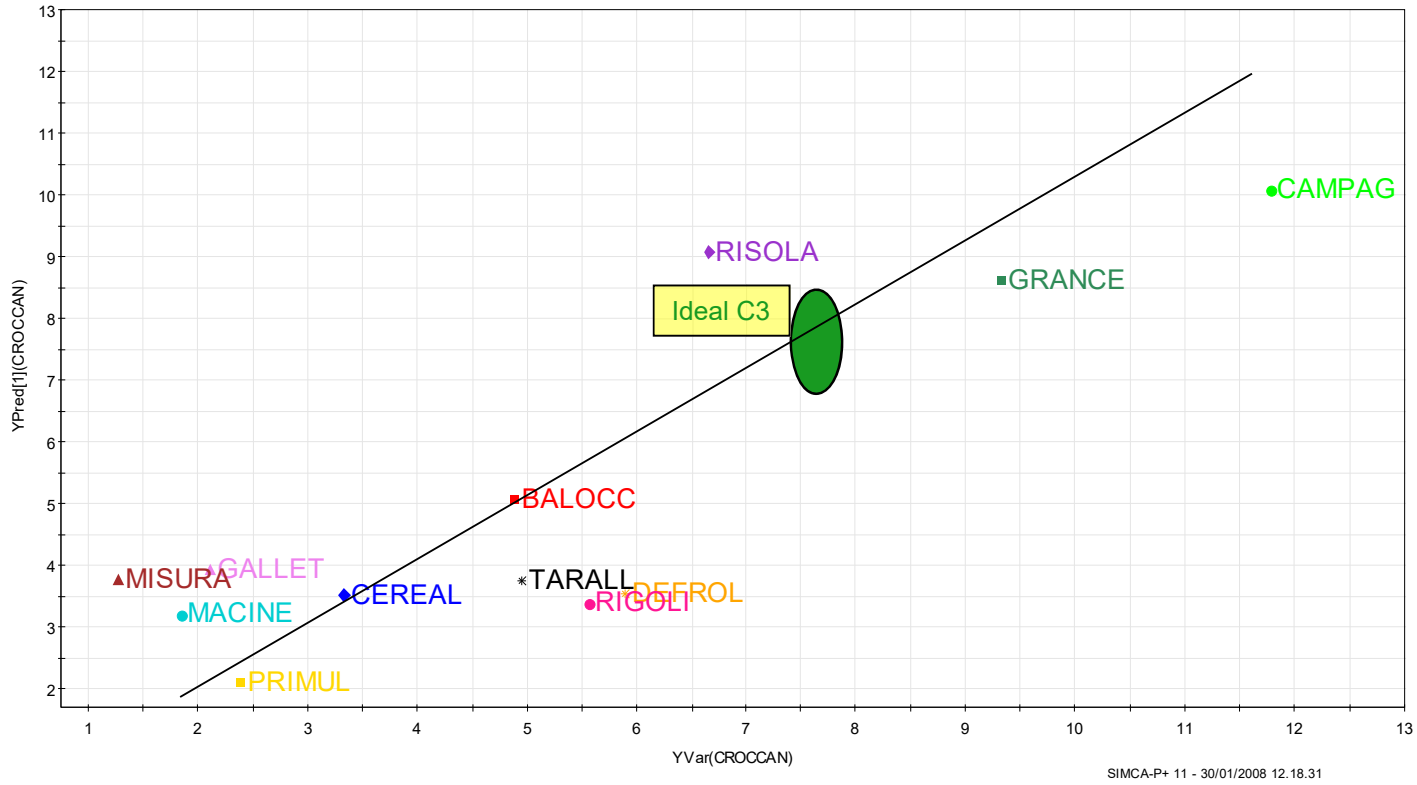
SIMCA-P+ 11 - 22/01/2008 13.12.01

Predictivity from Acoustic Parameters - Friability

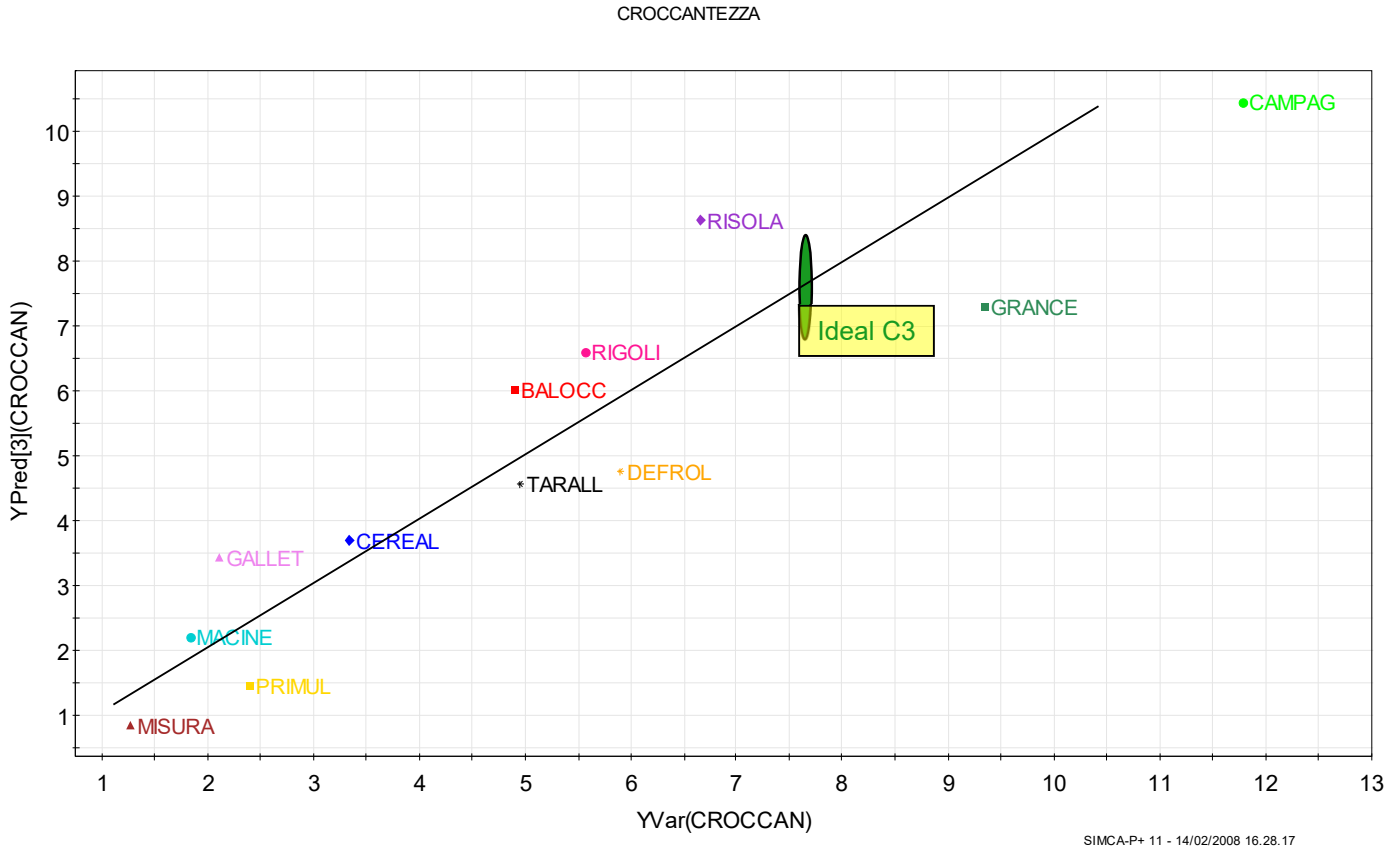


Predictivity from Mechanical Parameters- - Croccantezza

PLS-Frollini-Instron.M4 (PLS), Croccantezza
YVar(CROCCAN)/YPred[Comp. 1](CROCCAN)
Colored according to Obs ID (Prodotto)



Predictivity from Acoustic Parameters - Croccantezza



Conclusion

From mechanical and acoustical parameters, we got good prediction of:

Hardness(Durezza)

Crunchiness,

Crispiness (friabilità sabbpolv),

airy in mouth (arioso)

Chewiness(masticabilità)

drying in mouth (asciuga)

scratching the tongue (Gratta)

toothpaking

make you salivate (salivazione)

Grainy (granuloso)

Sticky (appiccica)

Solubilità

Fragrance

Part 3
How the soundscape affects food consumption

Effect of acoustical environment on food consumption

Effect of acoustical environment on food consumption

Music for food at Yamaha Conference Dinner

First Course

1. Bambino Dallda 3'30
2. Bycyclette Yves Montant 4'02
3. Americano Renato Carosone 3'25
4. Au suivant Brel 3'05
5. Petit loup Pierre Perret 4'52
6. Madeleine Brel 4'23
7. El Pompopera Enrico Macias 4'22
8. Paris s eveille dutronc 4'45
9. Amants de st jean lucien delylle 4’20
10. Emmenez moi Aznavour 3"52
11. rdv avec vous Brassens 3'12
12. Padam Piaf 3'05
13. Nationale 7 trenet 2'55
14. Petit papiers Serge Gainsbourg 5'45
15. Tps de fleur Dalida 4'12

Second Course

1. Cour de loup Philippe Lafontaine 4'25
2 Parking des anges Marc Lavoine 4' 12
3. Voyage desireless 4'54
4. Sans contrefacon Mylene Farmer 4'15
5. La Gitane Felix Gray 5'10
6. Macumba mader 4'40
7. Cargo Axel Bauer 3'25
8. Démons de minuit Image 4'25
9. Plus pres des etoiles gold 5'10

Effect of acoustical environment on food consumption

- Does the environmental noise or background music affect food consumption?
- How to test different acoustic soundscapes while eating food in controlled conditions?
- Answer: perform sensory panels inside a virtual acoustics room, where recorded soundscapes are played, while everything else is under control

Urban Soundscapes:
Typical panoramic views of Parma

Urban Soundscapes:
Typical panoramic views of Parma

Urban Soundscapes:

Typical panoramic views of Parma

Urban Soundscapes:

Typical panoramic views of Parma

SOUND RECORDING EQUIPMENT

EIGENMIKE™ by MH Acoustics

- Spherical Array with 32 condenser capsules of good quality, frequency response up to 20 kHz (14 mm each)
- Preamplifiers with digital gain control and A/D converters inside the sphere, with ethernet interface
- Large windshield for outdoor operation with camera support

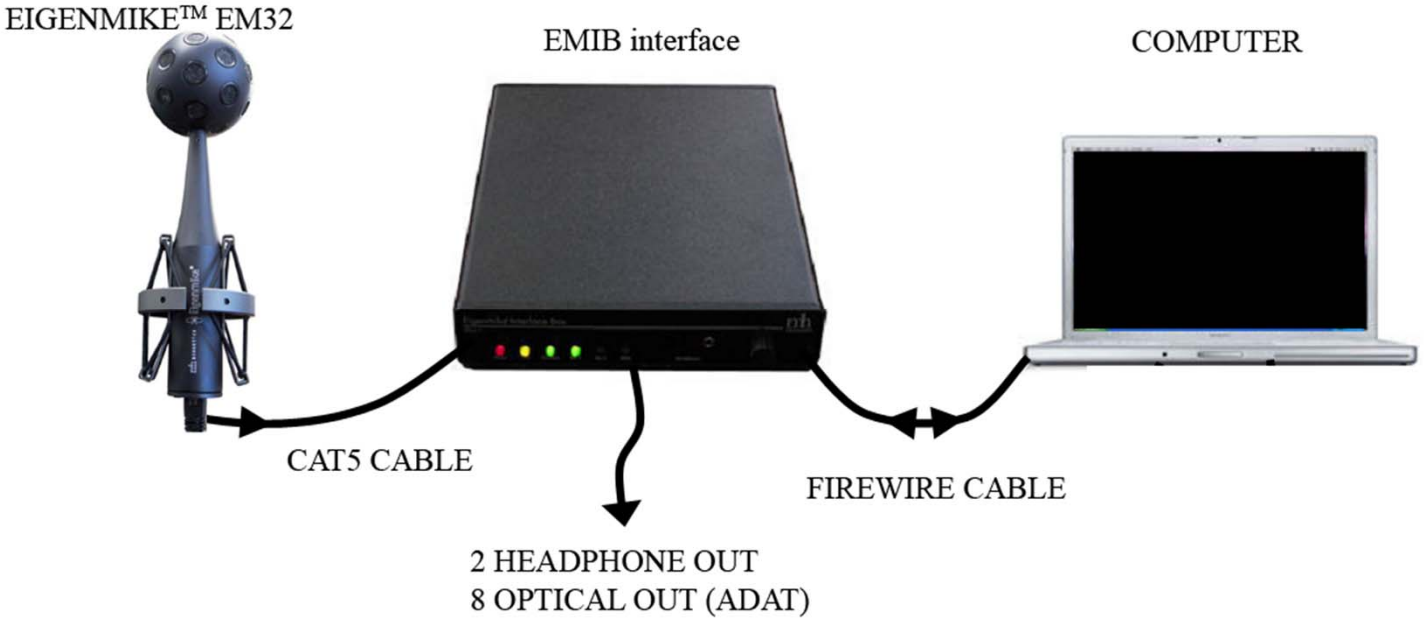
SOUND RECORDING EQUIPMENT

Cylindrical Arrays by AIDA and RAI

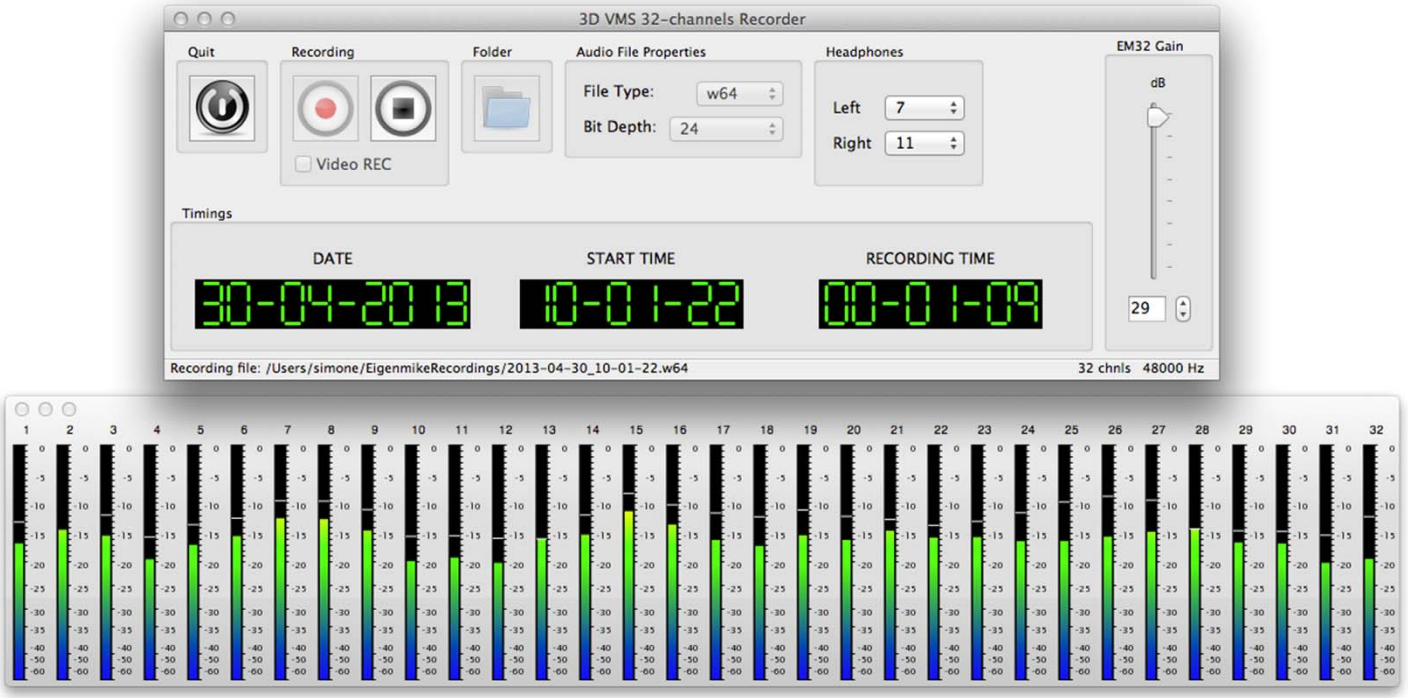
- Various sizes for different frequency ranges
- One model includes a 5Mpixels panoramic mirror camera
- They operate with the same interface and software as the Eigenmike
- The cylindrical shape favours horizontal resolution
- They can be easily installed inside standard Rycote windshields

SOUND RECORDING EQUIPMENT

- Computer: Mac Book Pro 13”
- Software: Plogue Bidule, or our own 3DVMS Recorder software
- 12V lead-acid battery powering the EMIB and the computer



THE RECORDING SOFTWARE: 3DVMS



- Works as front-end for Ecasound (partially customized...)
- Embedded gain control for the Eigenmike EM32
- VU meters with true peak indicators
- Output as W64 (WAV file with 64-bit header) for very long recordings (more than 2^{32} samples)

VIDEO RECORDING EQUIPMENT

Array of 8 GoPro cameras

- 1920x1440 pixels, 29.97 FPS, H264 x 8
- Autopano Video software for stitching
- Resulting resolution for mono: 5648x2824
- Resulting resolution for stereo: 5648x5648

Samsung Gear 360 camera

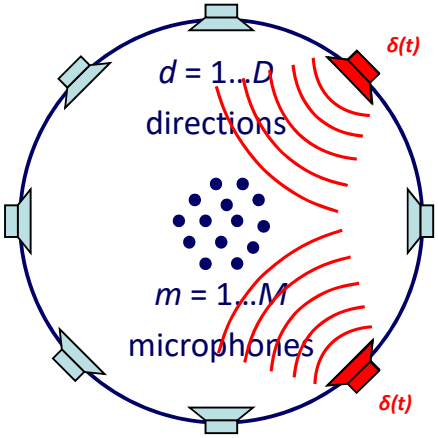
- 3840x1920 pixels, 29.97 FPS, H265
- Samsung S7 smartphone for stitching
- Resulting resolution for mono: 3840x1920

PROCESSING OF THE AUDIO RECORDINGS

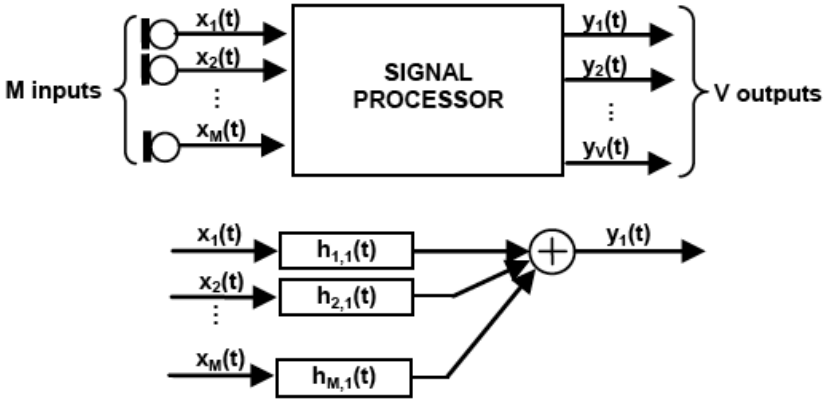
VIRTUAL MICROPHONES

The 3DVMS processing technique was developed by the RAI Research Center in Turin and by AIDA, a spinoff of the University of Parma.

We don't assume any theory for computing the filters: they are derived directly from a set of anechoic measurements.

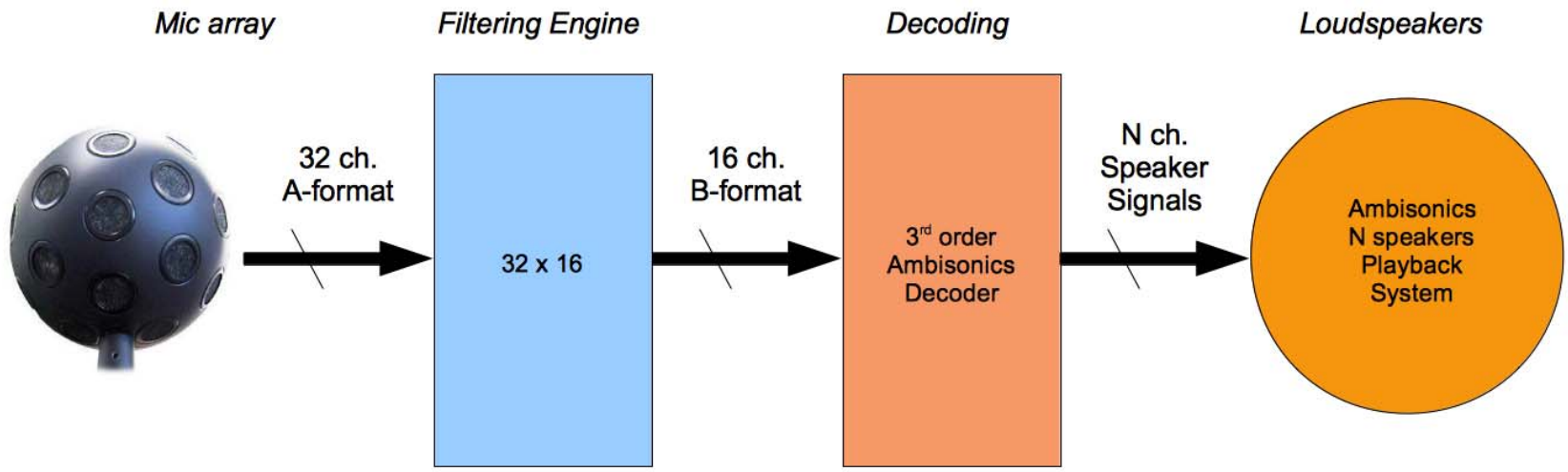


A matrix of measured impulse response coefficients is formed and the matrix has to be numerically inverted



V = 16 virtual microphones

Method 1: 3rd Order AMBISONICS

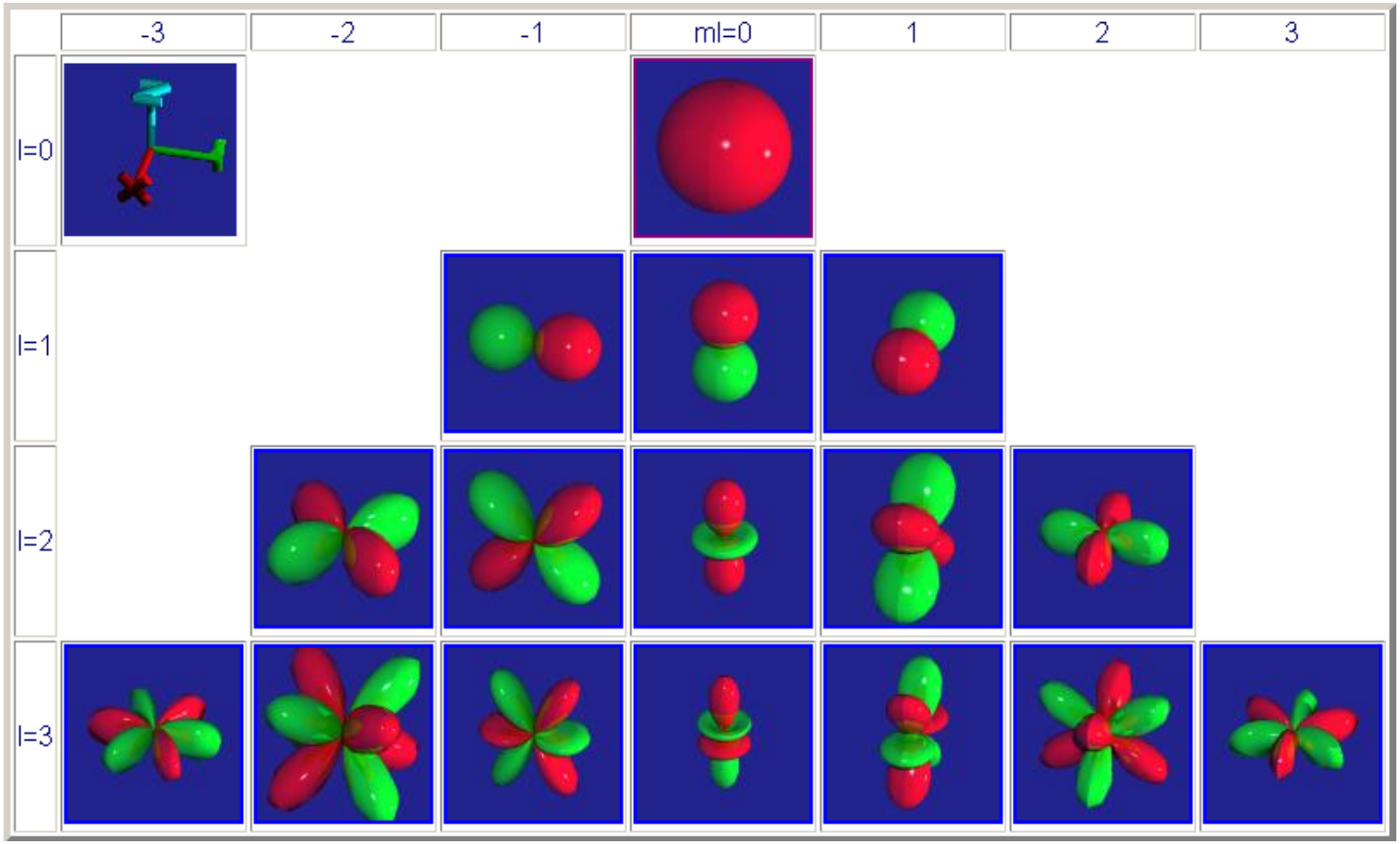


The 32x16 A to B-format filter matrix has been calculated with Matlab starting from a measurement set of 362 directions in the anechoic room

The Ambisonics decoder is Rapture3d by Richard Furse

Method 1: 3rd Order AMBISONICS

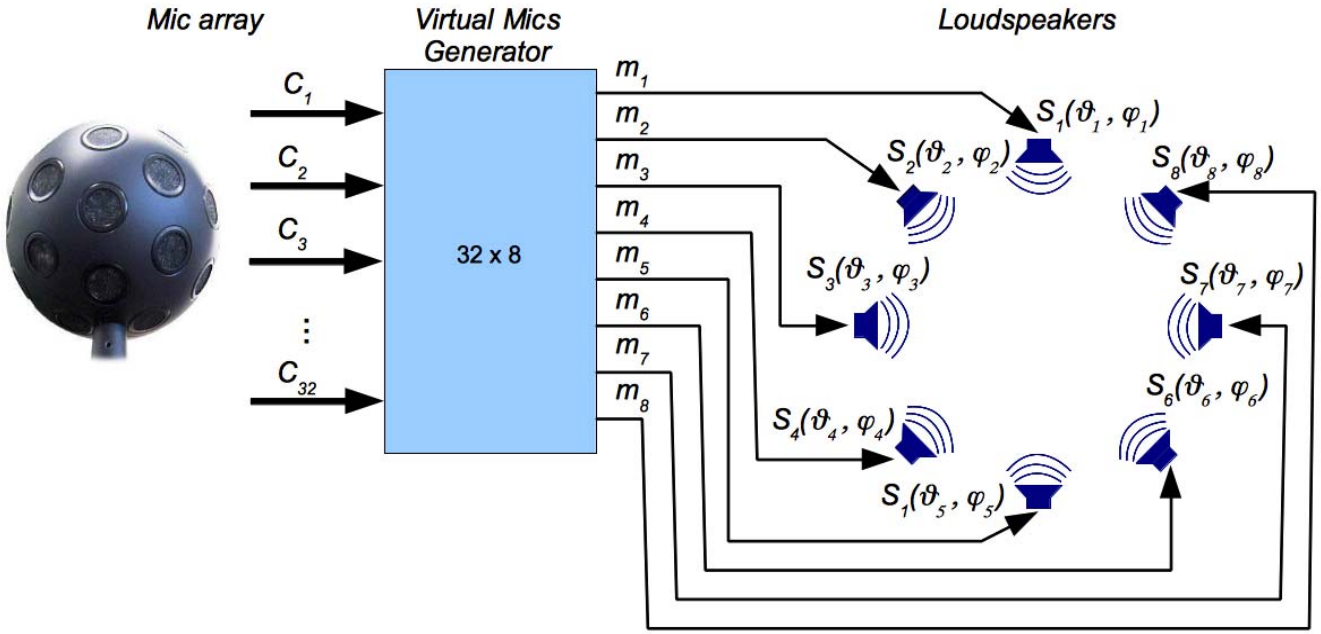
The patterns of the 16 virtual microphones correspond to spherical harmonics of orders 0, 1, 2 and 3:



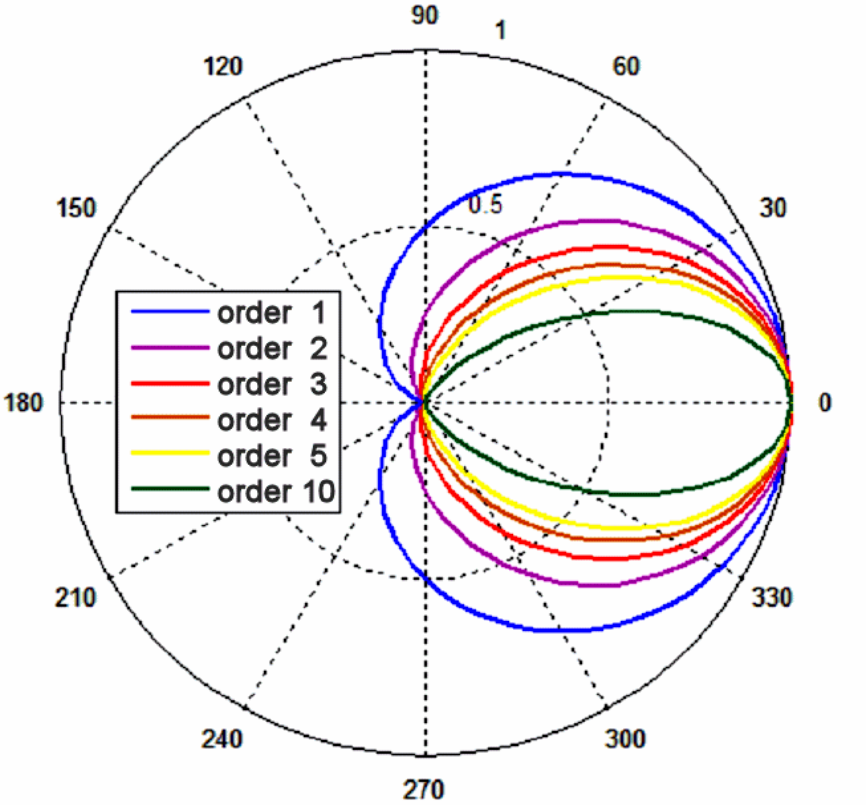
METHOD 2: DIRECT SYNTHESIS OF VIRTUAL MICROPHONES

Feed every speaker with a single (virtual) microphone.

- Define the (regular) layout of the V loudspeakers
- Create an ultradirective virtual microphone focused in the direction of every speaker



METHOD 2: TARGET DIRECTIVITY



Our synthetic, "virtual" microphone is chosen among a family of cardioid microphones of various orders:

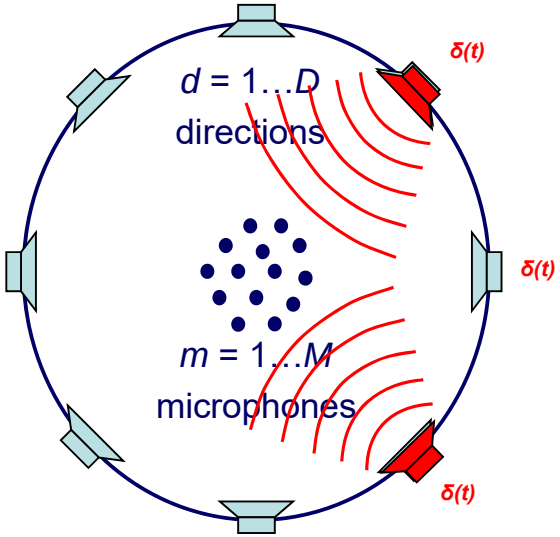
$$P_D(\vartheta,\varphi) = \left[0.5 + 0.5 \cdot \cos(\vartheta) \cdot \cos(\varphi)\right]^n$$

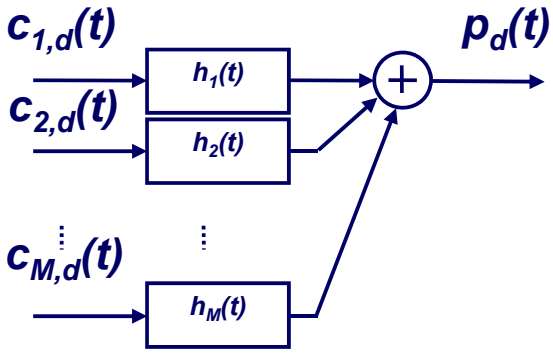
Where ***n*** is the directivity order of the microphone – normal cardioid microphones are just 1st-order…

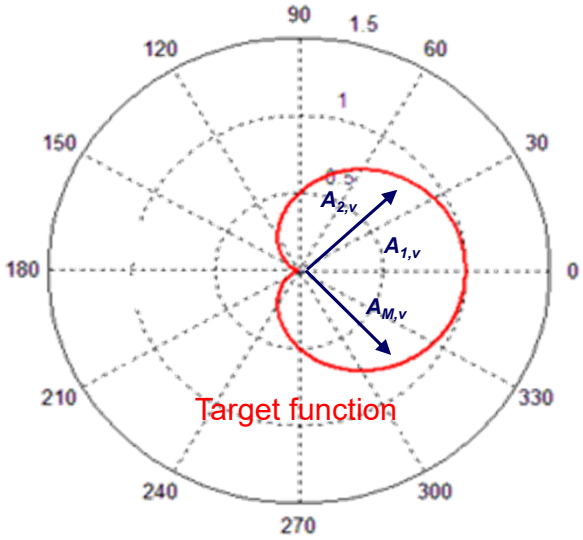
4th-order microphones are typically used for a ring of 16 virtual cardioids

LEAST-SQUARES METHOD FOR FILTER COMPUTATION

We impose that applying the filter matrix H to the measured impulse responses C, the system should behave as a virtual microphone with wanted directivity





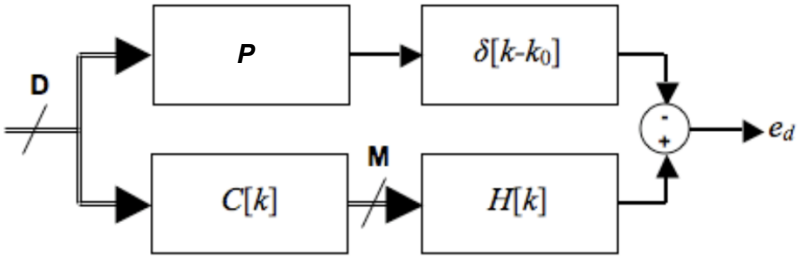


$$\sum_{m=1}^{M} c_{m,d} * h_m \Rightarrow p_d \qquad d = 1..D$$

But in practice the result of the filtering will never be exactly equal to the prescribed directivity functions p_d…..

LEAST-SQUARES METHOD FOR FILTER COMPUTATION

We compare the results of the numerical inversion with the theoretical response of our target microphones for all the D directions, properly delayed, and sum the squared deviations for defining a total error:



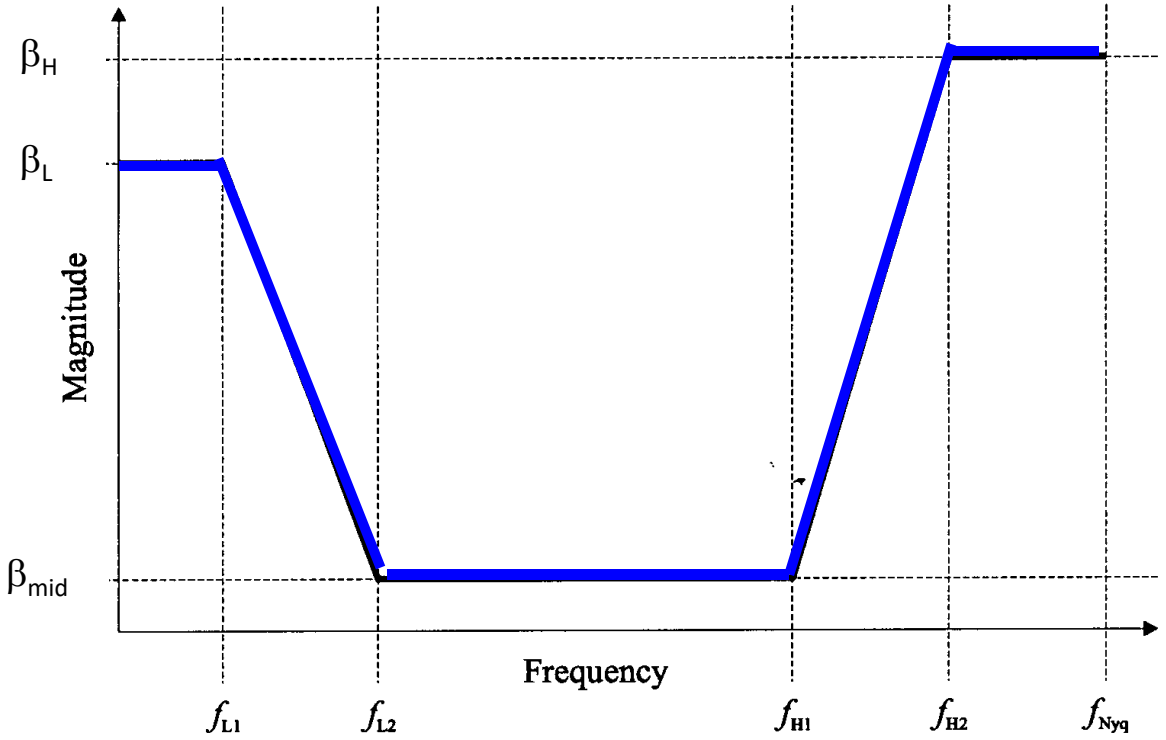
The inversion of this matrix system is performed adding a regularization parameter β, in such a way to minimize the total error (Nelson/Kirkeby approach):

$$[H_k]_{MxV} = \frac{e^{-j\pi k} \cdot [C_k]^*_{MxD} \times [Q]_{DxV}}{[C_k]^*_{MxD} \times [C_k]_{DxM} + \beta_k \cdot [I]_{MxM}}$$

It revealed to be advantageous to employ a frequency-dependent regularization parameter β_k.

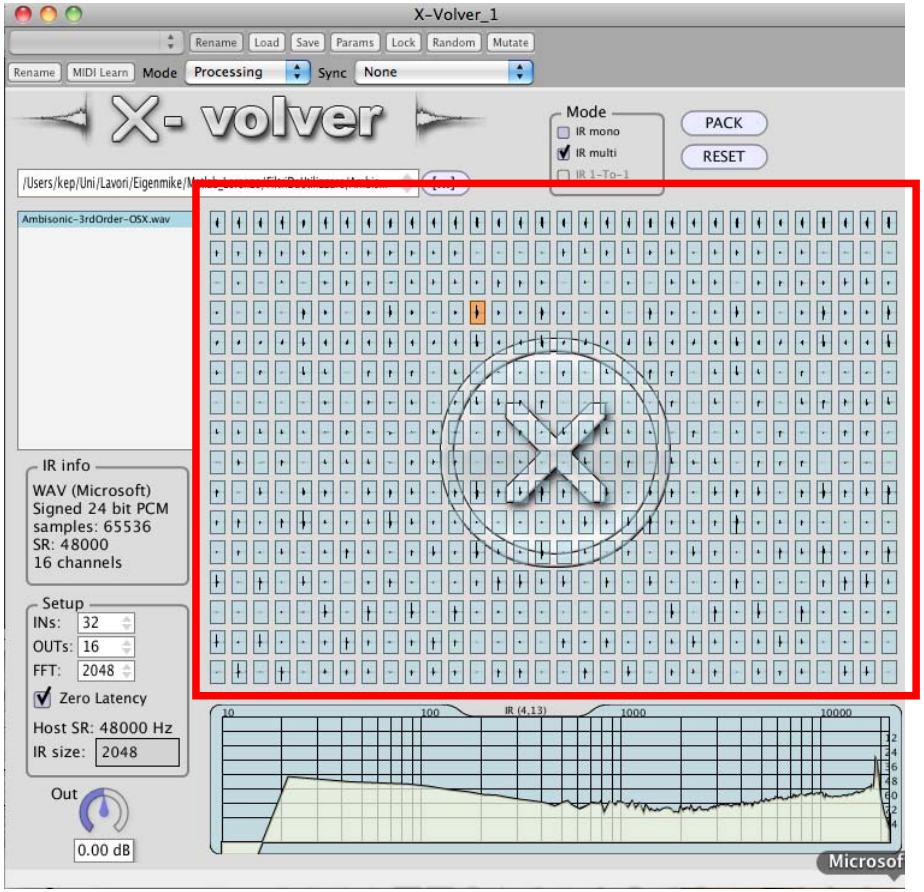
Spectral shape of the regularization parameter β_k

- At very low and very high frequencies it is advisable to increase the value of β.



X-Volver VST plugin for realtime FIR filtering

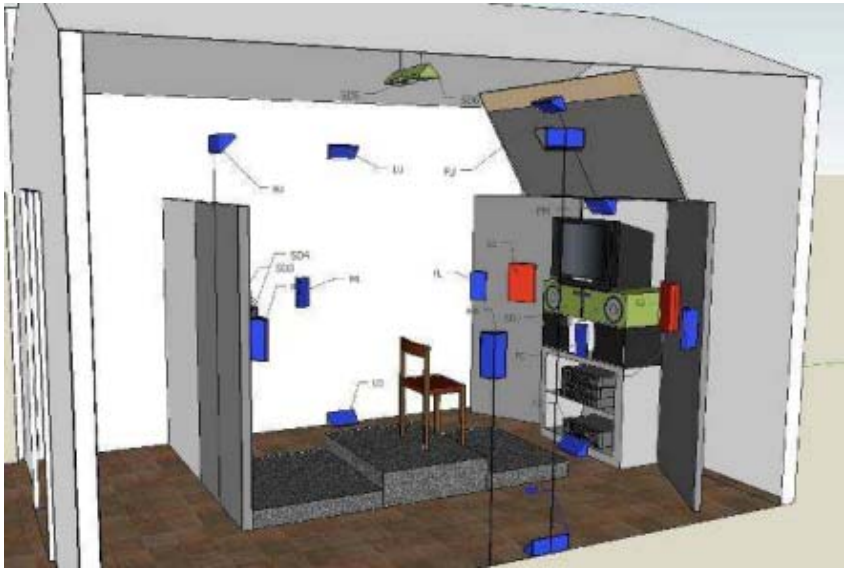
- Realtime fast convolution of the 32 microphone signals with the matrix of 32x16 FIR filters



32x16 FIR Matrix:

- 2048 samples
- 48kHz – 24bit

Playback system #1: 3D Ambisonics room

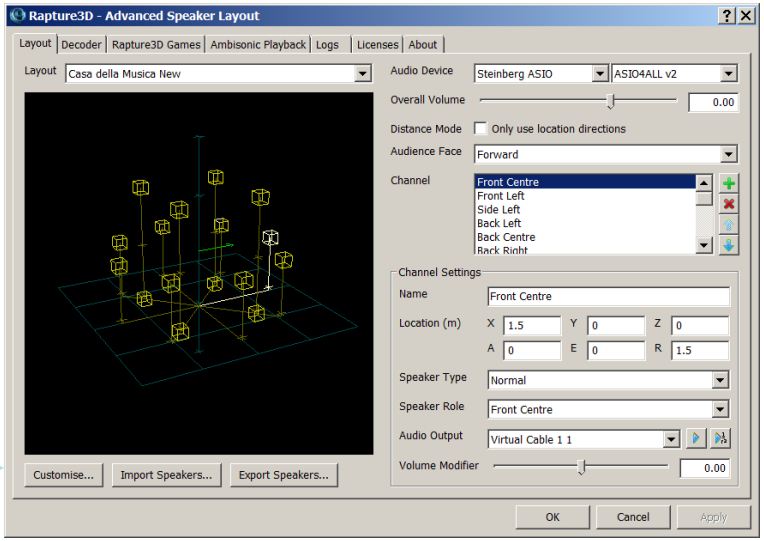


Performed in a threated room equipped with:

- Desktop PC
- RME Hammerfall audio interface
- Apogee DA-16x digital-to-analog converter
- N.2 QSC CX168 power amplifiers
- N.16 Turbosound Impact 50 speakers

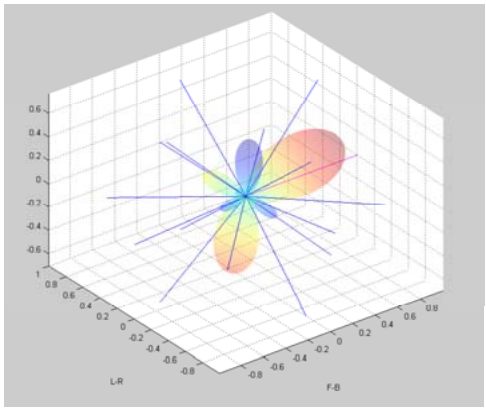
PLAYBACK SOFTWARE:

- Windows 7
- Plogue Bidule
- Rapture3D decoder by Richard Furse
- Novel alternative decoder based on Filippo Fazi's theory

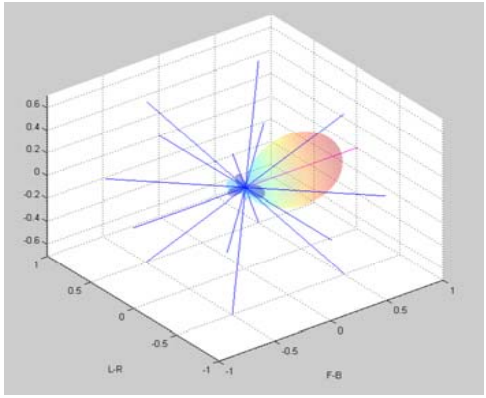


Playback system #1: 3D Ambisonics room

- Modifying the geometry of the loudspeaker array, it became possible to employ a simpler Ambisonics decoder, with frequency-independent coefficients, providing better reconstruction



Original Geometry



Modified Geometry

Playback system #2: the WFS «white room»

Wave Field Synthesis room, named “Sala Bianca”, in “Casa del Suono” museum.

- Dimensions: 7.5 x 4.5 x 4.5 meters
- Number of speakers: 189
- 4 Optoma Full-HD projectors

The Wave Field System is used for simulating 16 “virtual” speakers placed on a regular octagon at a distance of 15 meters from the centre of the room.

A set of 16 4th-order virtual cardioid microphones are synthesized for feeding these 16 virtual loudspeakers

Playback system #2: the WFS «white room»

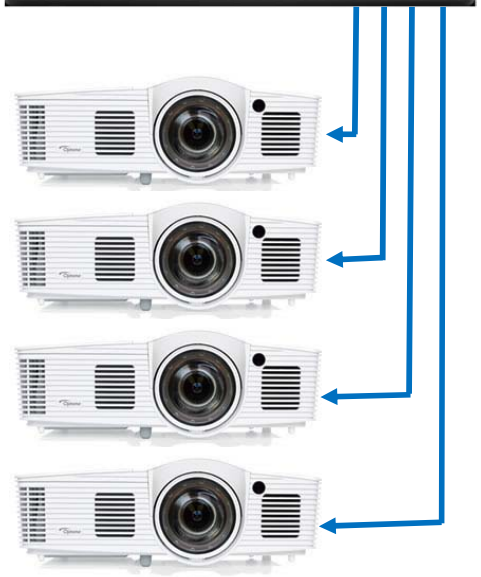
Hardware:

MAC PRO

Remote control of VLC over Ethernet

RME MADIFACE XT

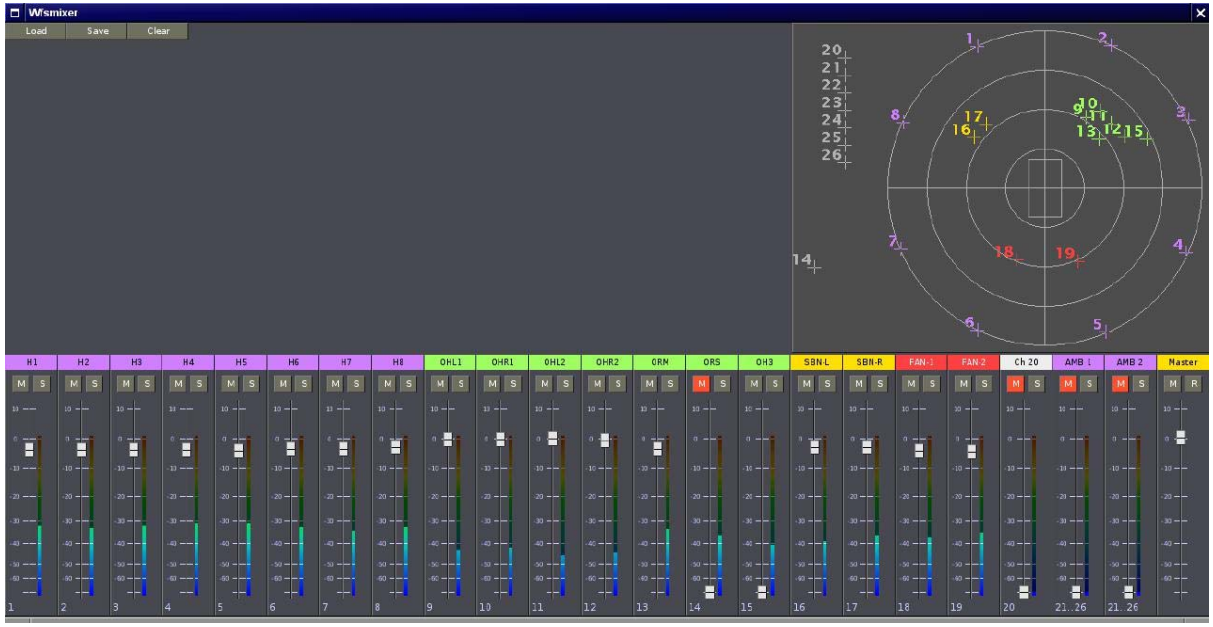
HP Prodesk 400 with
Nvidia Quadro NV-510



3x RME ADI 648
24x Aphex 141 D/A
24x QSC CX 168 amplifiers

4x Optoma GT1070X

THE WFS SOFTWARE by Fons Adriaensen

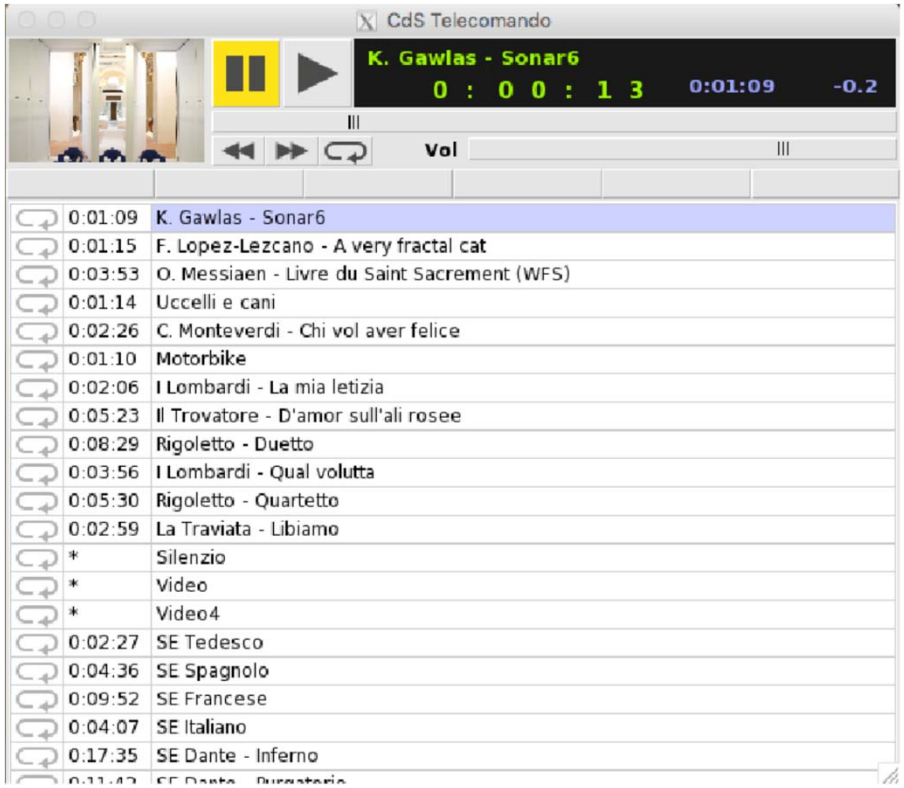


Virtual Sources Mixer

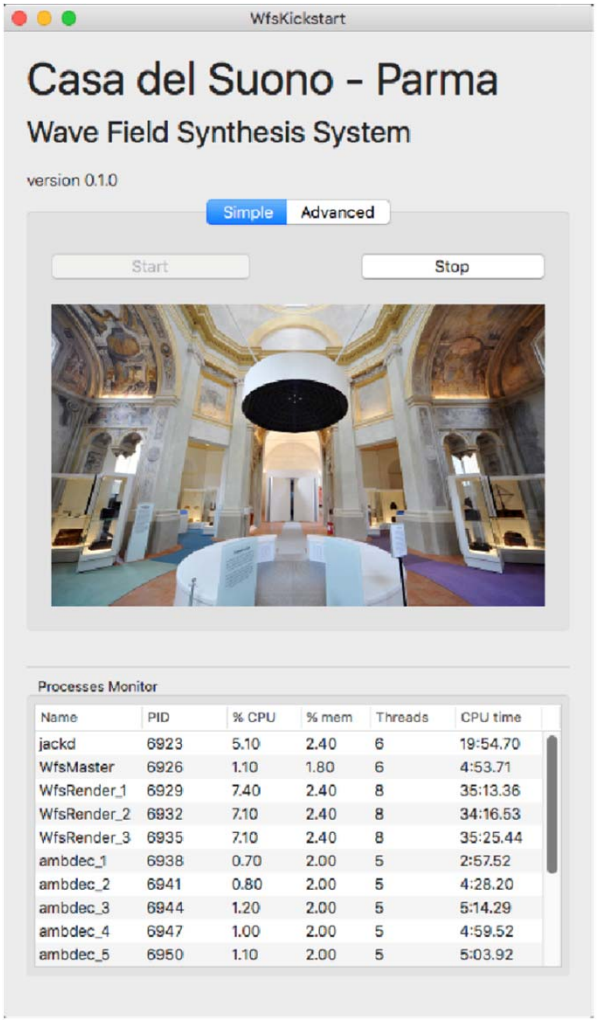
WFS Realtime Monitoring

WFS system VU Meters

THE WFS SOFTWARE by Fons Adriaensen



Remote Control



WFS Kickstarter

RESULTS

- A complete workflow for panoramic audio and video recording / processing / playback has been set up and successfully employed
- The resulting quality has been judged perfectly satisfying by opera lovers
- The recordings can be released in various formats and are compatible with many platforms:
  - Youtube (Ambix 1st order, 4 channels)
  - Facebook (TBE 2nd order, 8 channels)
  - Jump Inspector (Ambix 3rd order, 16 channels)
  - 3DVMS (WFS, ring of 16 “sound objects”, 4th order)
  - SPS (Spatial PCM Sampling, 32 channels/objects, 4th order)

Food consumption tests inside the Ambisonics room with different soundscapes

Effect of acoustical environment on food consumption
CONCLUSIONS

- The research is still running
- some preliminary available results demonstrate some modification in the subjective responses depending on the acoustical environment being recreated
- The lack of visual reproduction in the Ambisonics room is still limiting the illusion of “being there”
- So the research will transfer inside the White Room (WFS), equipped with panoramic projectors, for a better immersive experience