GRAZER INSTITUT FÜR PHYSIK

April 3rd 2008

SOUND, MUSIC AND SCIENTIFIC EDUCATION

Erica Bisesi

Acoustic teaching

- Conceptual and disciplinar problems:
  - * preliminary mathematics and physics knowledges

- Learning problems:
  - * students' difficulties in understanding and fixing some concepts (literature analysis: Wittmann, 1996; Staver, 1997; Hrepic & al, 2003; Bellomonte & al, 2004).

Oscillations and sound waves: learning problems

1. **Sound as an oscillating phenomenon:**

   there exists a conceptual jump between description of oscillations in an elementary system, like harmonic oscillator or simple pendulum, and the wave motion the sound production is based on.

2. **Wave oscillations** are not only temporal point-like phenomena, but they also propagate towards space:
   - ♪ Conflict between concepts of stationary wave and perturbation propagation along a vibrating string;
   - ♪ What is really propagating?
   - ♪ Where the propagation occurs?
   - ♪ What is the origin of “sound”?

Oscillations and sound waves: learning problems

3. **<u>Graphic representation of a sound:</u>**

   temporal domain

   frequency domain

Oscillations and sound waves: learning problems

4. Where is the link between normal modes of oscillation of a vibrating string and "qualities" of the produced sound?
   - ♫ timbre of musical instruments;
   - ♫ families of musical instruments;
   - ♫ consonance and dissonance of musical sounds.

5. Where is the link between normal modes of oscillation of a vibrating string and the basis of tonal harmony?
   - ♫ musical intervals;
   - ♫ musical scales.

Oscillations and sound waves: learning problems

6. In general, sound is a feeling rising when a mechanical perturbation propagates in an elastic medium, putting it into vibration. Students often are not able to understand the difference between concepts of mechanical perturbation and physiological feeling.

7. Different physical aspects of sound - in particular frequency and intensity - are confused each other.

Oscillations and sound waves: new didactic strategies

Transversality (http://fisicaondemusica.unimore.it/Percezione_del_suono.html)

Sound experience is originated by the interaction of many different phenomena occurring at many different levels:

- **the physical level of the vibrating medium and sound wave propagation;**
- **the physical-physiological level of the interaction between the sound wave and the ear;**
- **the physiological level of signal processing by sensorial apparatus and nervous system;**
- **the physiological-psychological level of signal and emotional correlates cognition;**

and, carrying on to music:

- **the cognitive-linguistic level of sound interpretation and ascribing of a meaning;**
- **the linguistic-formal level of sound and music structure recognition;**
- **the antropological-cultural level regarding development of peculiar musical forms and languages by different human societies.**

Oscillations and sound waves: new educational strategies

- **physics:** sound is a vibration propagating in an elastic medium.
  To produce a sound we require a **vibrating body** and an **elastic medium** able to transmit vibrations generating the **sound wave.**

- **music:** sound is an auditory sensation produced by acoustic vibrations *(International Vocabulary of Electroacoustics).*

Sound:
- **agreeable sensations**
- **meaning**
- **periodic waves**

Noise:
- **disagreeable sensations or irritation**
- **lack of periodicity**

Sound properties:

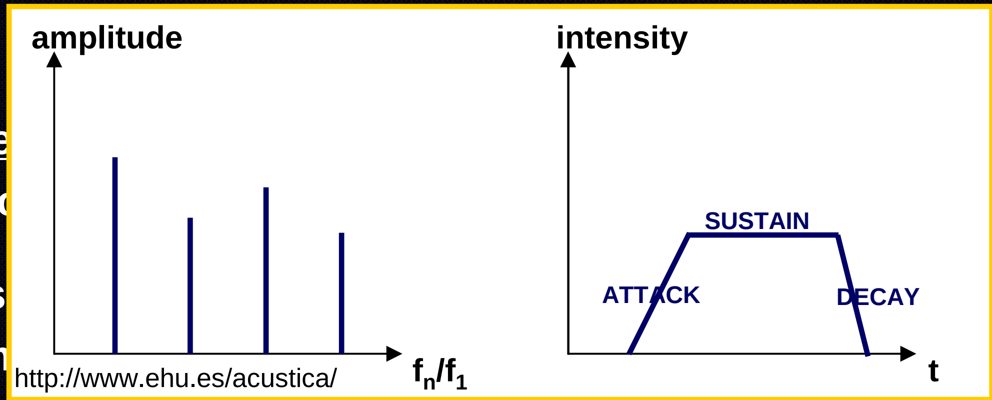
Sound wave physical parameters:

♪ amplitude	the maximum molecules displacement from their rest position, connected to pressure variation in a medium;
♪ frequency	the number of times a molecule oscillates in an unit time;
♪ spectrum	every sound may be got as a partial series addition (Fourier theorem); in such a kind of picture, amplitudes of every sound component are drawn as a function of frequency;
♪ envelope	this is the curve obtained from the wave representation: it determines the wave profile;
♪ duration	the time interval between physical start and end of a sound.

Sound properties:

Sound wave physical parameters:

- **amplitude** — the maximum molecules displacement from their rest position, connected to pressure variation in a medium;
- **frequency** — the number of times a molecule oscillates in an unit time;
- **spectrum** — every ... urier theore... y sound comp...
- **envelope** — this is ... : it determ...



- **duration** — the time interval between physical start and end of a sound.

Sound properties:

Sound physiological parameters:

Physical parameter		Physiological parameter	Description
♪ pressure	→	loudness	weak and strong sounds
♪ frequency	→	pitch	high and low notes
♪ spectrum	→	timbre	sounds of equal intensity and frequency, produced by two different sources
♪ envelope	→	timbre	
♪ duration	→	duration	the time interval a sound persists without discontinuity

Correspondence between physical and musical parameters

Loudness mainly depends on sound pressure, but also on spectrum and duration. For a pure tone, **pitch** is mostly determined by frequency, but it may also vary with pressure and envelope.
Timbre is originated because a sound is not a pure tone, being characterized by a spectral composition. In the meantime, it is largely influenced by envelope and frequency.
Physical and perceived **duration** are strictly related, also if they are not properly the same thing.

	Physical parameters				
Musical parameters	Pressure	Frequency	Spectrum	Envelope	Duration
Loudness	ddd	d	d	d	d
Pitch	d	ddd	d	d	d
Timbre	d	dd	ddd	dd	d
Duration	d	d	d	d	ddd

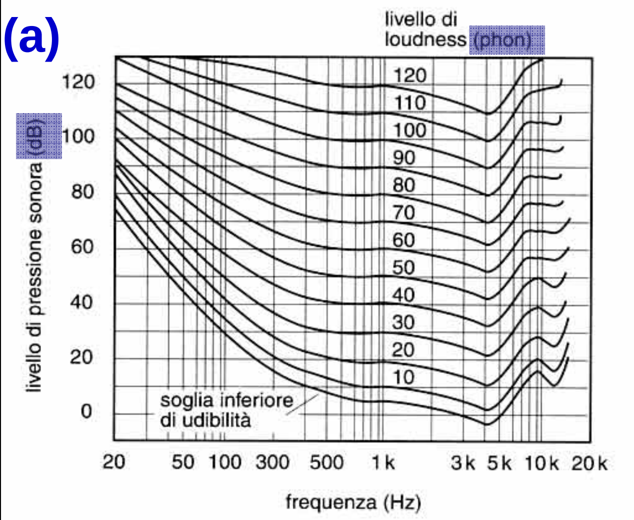
ddd	strongly dependent
dd	dependent
d	weakly dependent

http://www.ehu.es/acustica/

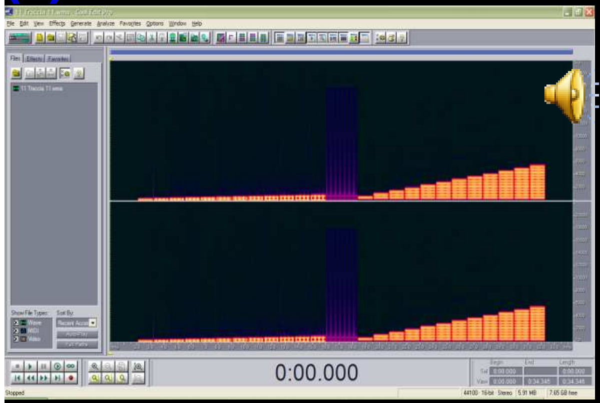
Corrrespondence between physical and musical parameters

Loudness mainly depends on sound pressure, but also on spectrum and duration **(a)**.
For a pure tone, **pitch** is mostly determined by frequency, but it may also vary with pressure and envelope **(b)**.
Timbre is originated because a sound is not a pure tone, being characterized by a spectral composition **(c)**. In the meantime, it is largely influenced by envelope and frequency.
Physical and perceived **duration** are strictly related, also if they are not properly the same thing.

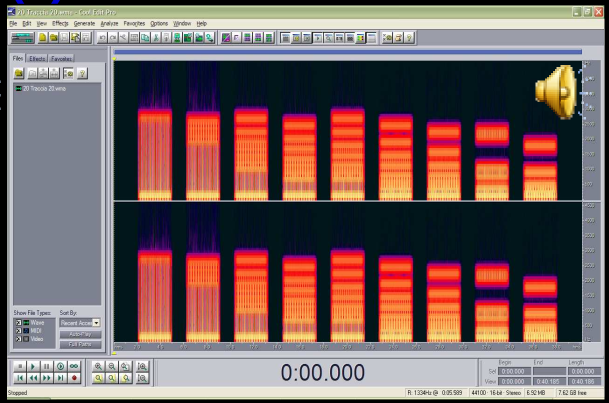
(a)



(b)



(c)



P. COOK, *Music, Cognition and Computerized Sound. An Introduction to Psychoacoustics,* MIT Press, 1999

Corrrespondence between physical and musical parameters

<u>Loudness</u> mainly depends on sound pressure, but also on spectrum and duration **(a)**.
For a pure tone, **<u>pitch</u>** is mostly determined by frequency, but it may also vary with pressure and envelope **(b)**.
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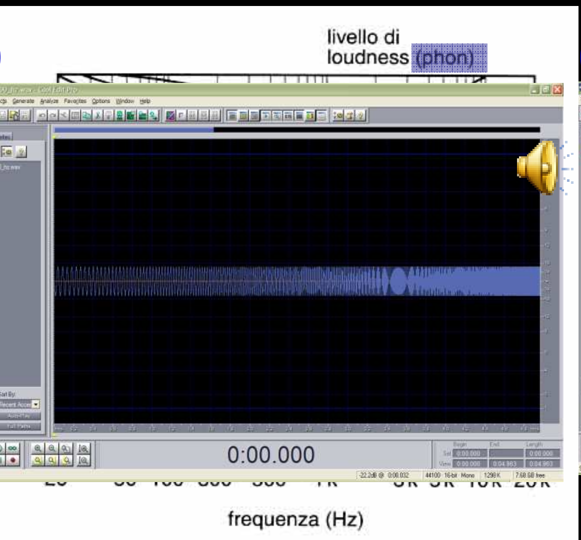
(a)



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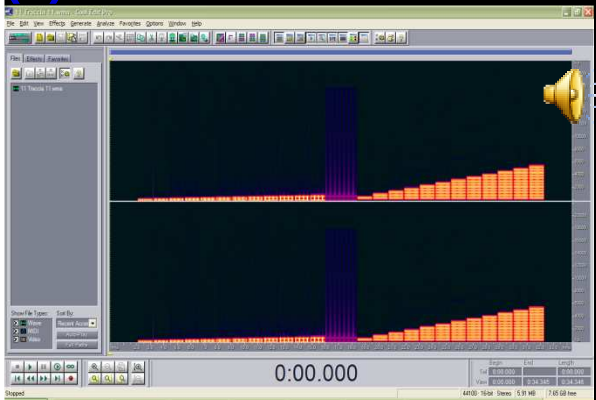
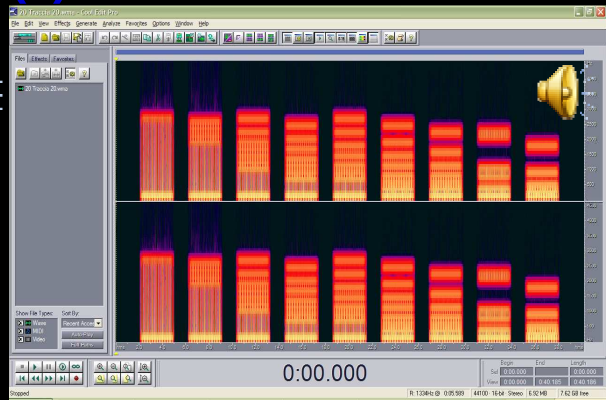


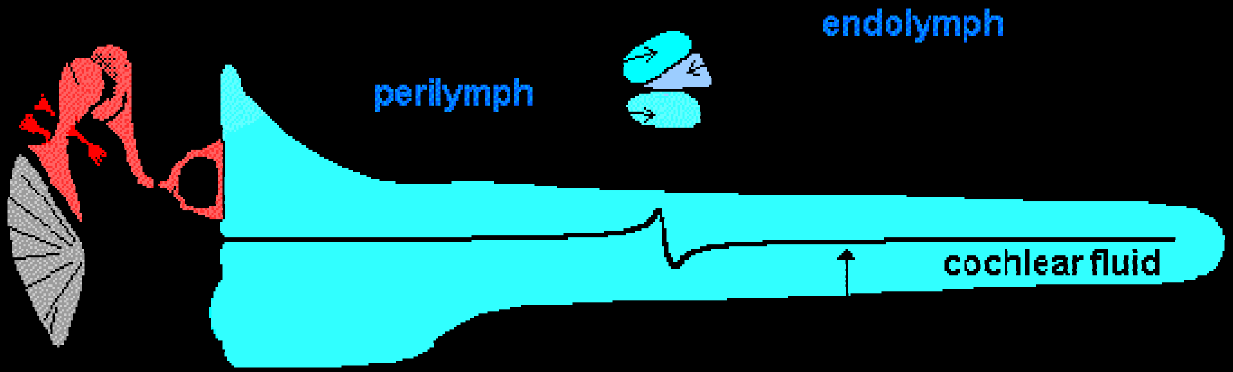
(c)



P. COOK, *Music, Cognition and Computerized Sound. An Introduction to Psychoacoustics,* MIT Press, 1999

Hearing processes:

(pictures taken by
“Mente e Cervello”, n° 14, year III,
Eckart Altenmüller,
“La musica in testa”)



http://147.162.36.50/cochlea/cochleapages/overview/history.htm

Hearing processes:

(pictures taken by
“Mente e Cervello”, n° 14, year III,
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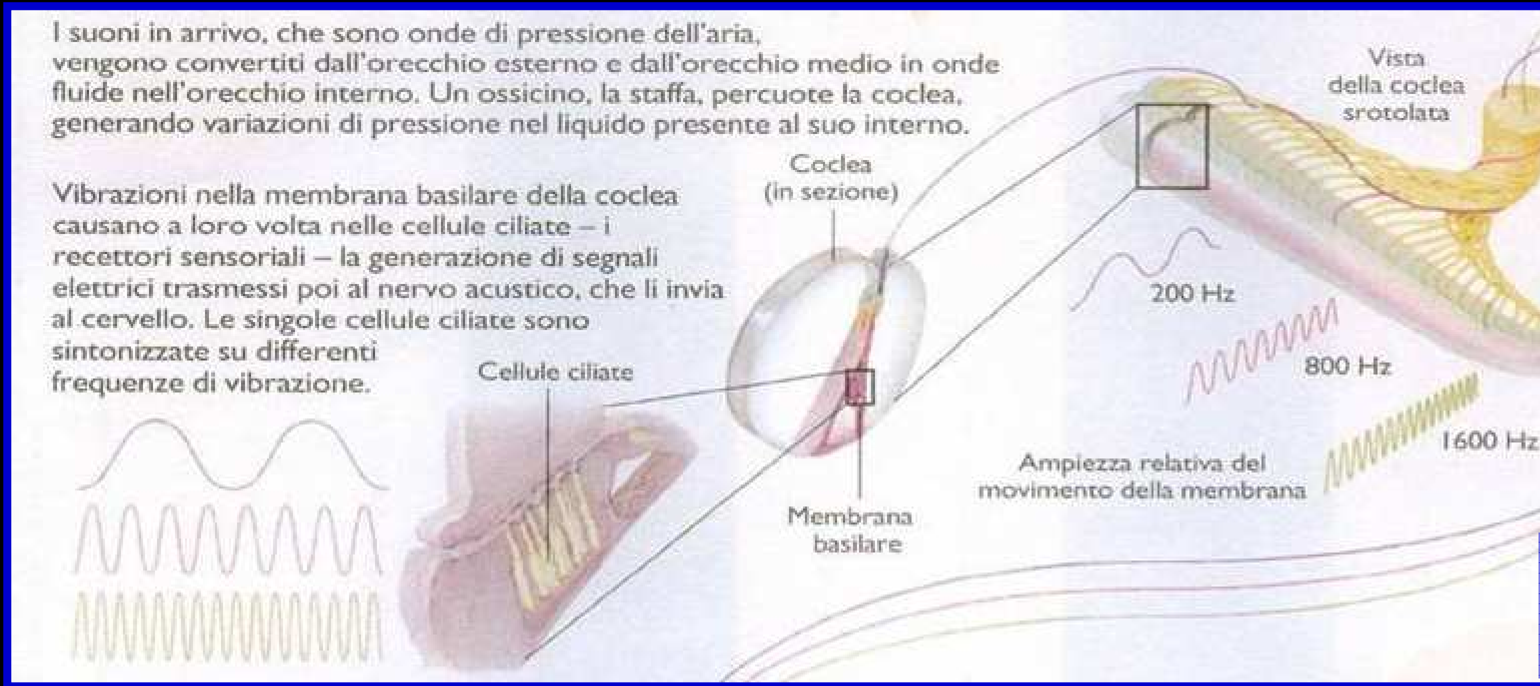
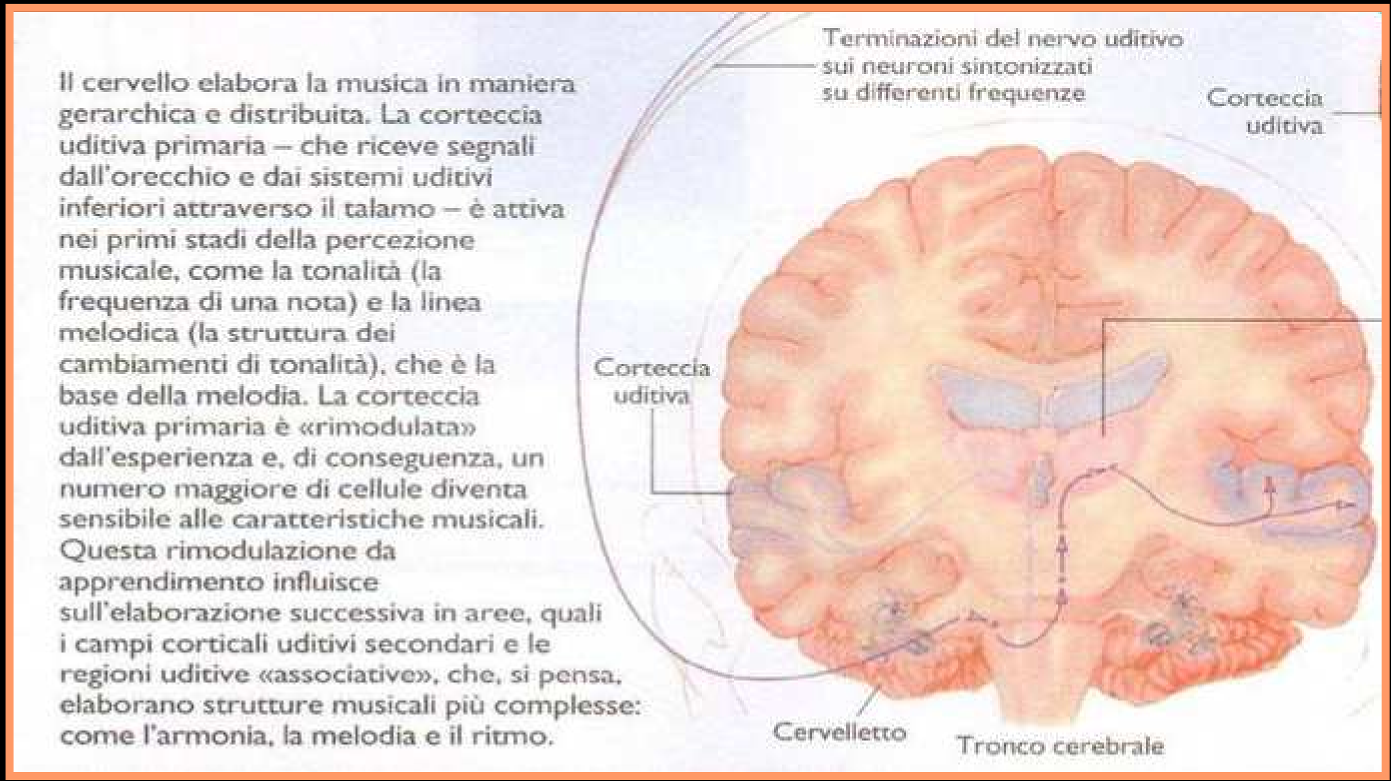


$$\nu = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

The musical brain:

(pictures taken by
“Mente e Cervello”, n° 14, year III,
Eckart Altenmüller,
“La musica in testa”)


Il cervello elabora la musica in maniera gerarchica e distribuita. La corteccia uditiva primaria – che riceve segnali dall'orecchio e dai sistemi uditivi inferiori attraverso il talamo – è attiva nei primi stadi della percezione musicale, come la tonalità (la frequenza di una nota) e la linea melodica (la struttura dei cambiamenti di tonalità), che è la base della melodia. La corteccia uditiva primaria è «rimodulata» dall'esperienza e, di conseguenza, un numero maggiore di cellule diventa sensibile alle caratteristiche musicali. Questa rimodulazione da apprendimento influisce sull'elaborazione successiva in aree, quali i campi corticali uditivi secondari e le regioni uditive «associative», che, si pensa, elaborano strutture musicali più complesse: come l'armonia, la melodia e il ritmo.

The musical brain:

(pictures taken by
“Mente e Cervello”, n° 14, year III,
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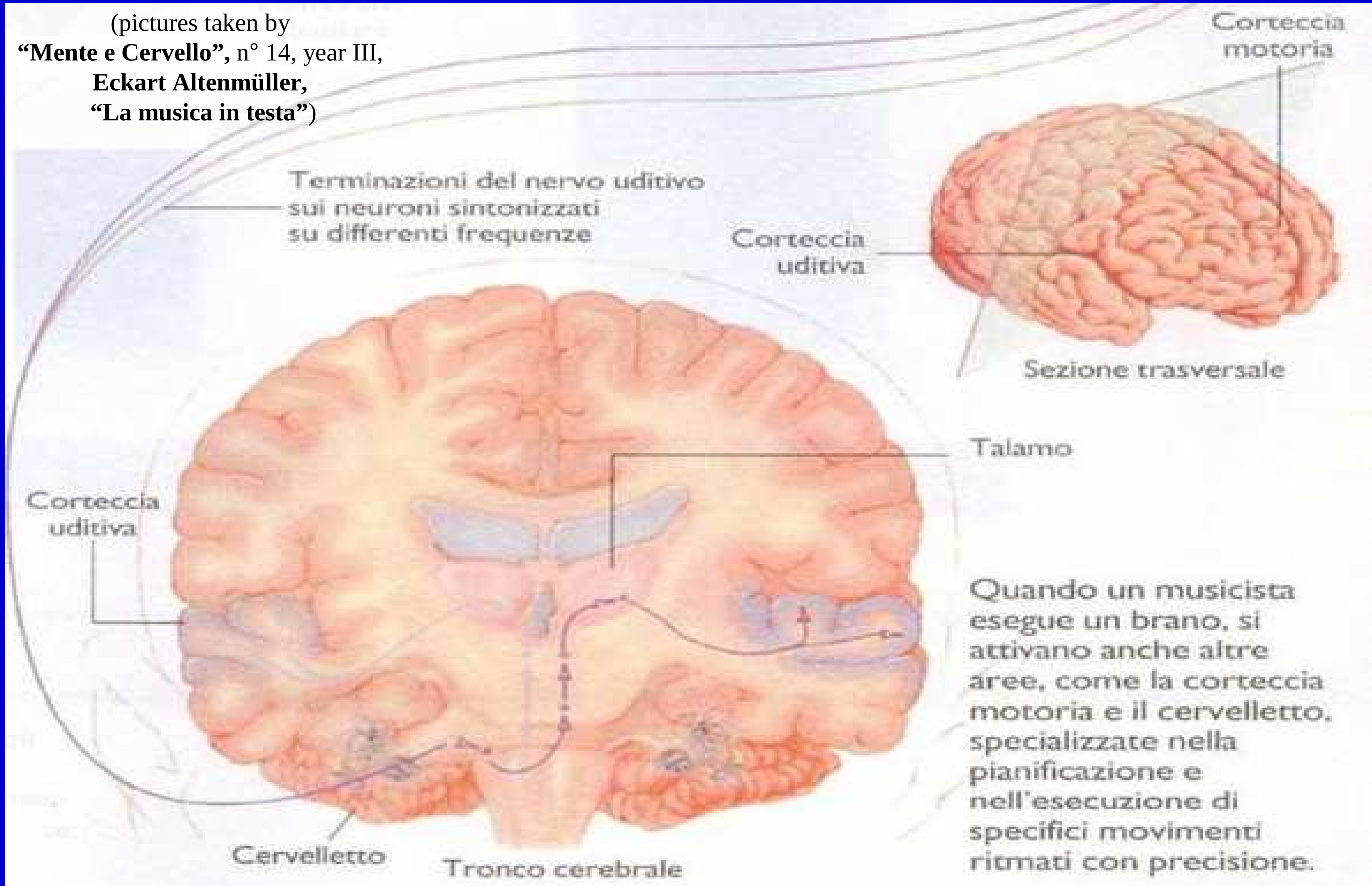


Neurophysiological foundations of musical hearing

(taken by **"Mente e Cervello",** n° 14, year III – **Eckart Altenmüller, "La musica in testa"**)

After sound reception by the **ear,** the **acoustic nerve** transmits stimula to the **cerebral trunk,** where it passes throughout almost **four sorting stations,** which:

- **filter signals,**
- **recognize their schemes,**
- **calculate the difference between sound arrival times at the two ears,**
- **allowing us to locate its spatial origin.**

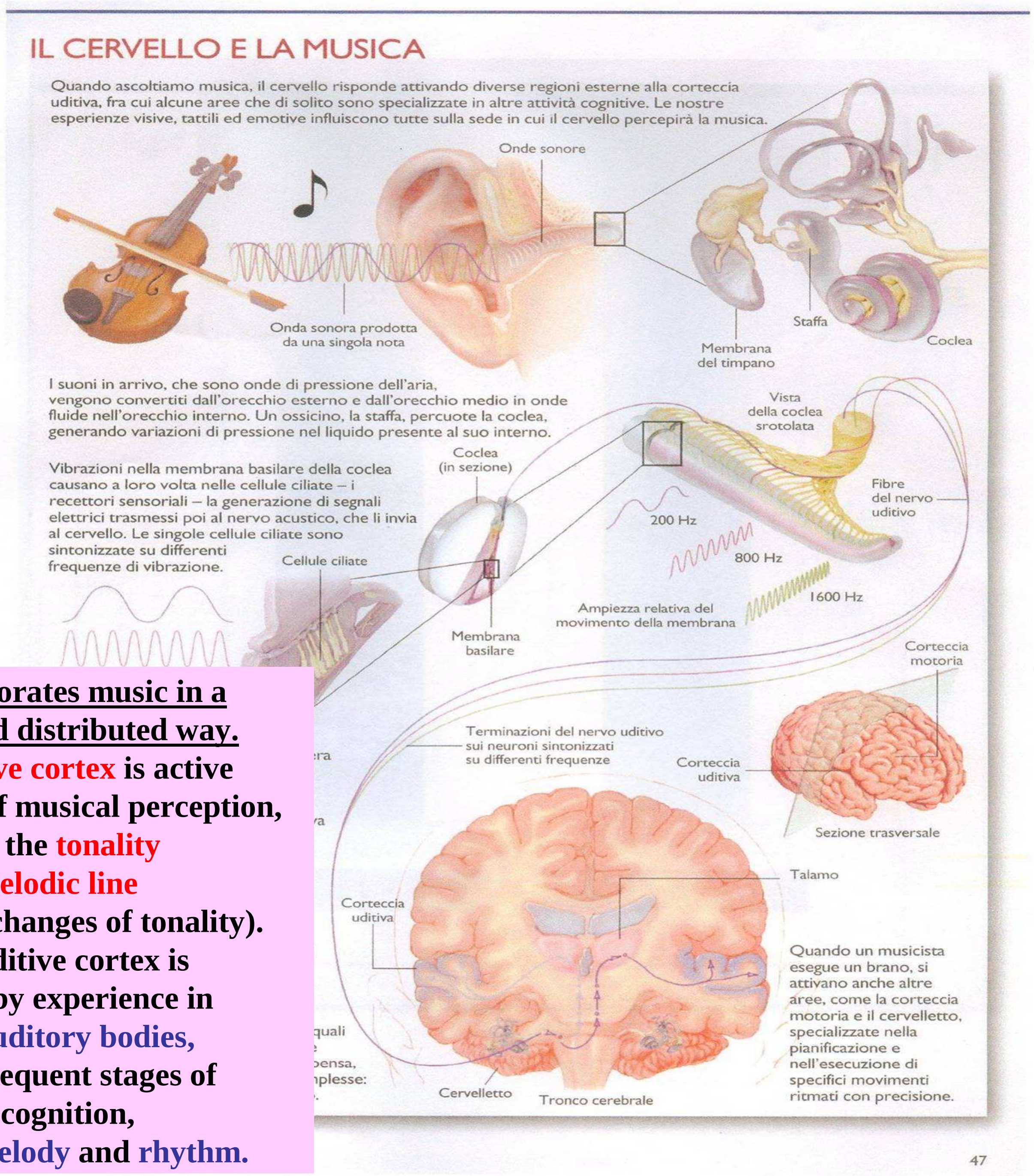
Afterwards, the **thalamus** trasfers informations to the **cerebral cortex (auditive cortex** in the **temporal lobe),** or rejects them as well.

Along this **“auditory track”,** rising from the internal ear up to the auditory cortex, informations are **analyzed** one by one, according to more and more complex schemes. At the same time, thay are also **processed in parallel.**

Cochlear nucleus is the first commutation station.
It carries on many tasks: while the greatest part of nervous cells in its **anterior part** react only to **individual sounds** and retransmits unchanged signals, the **posterior part** is involved in working out **acoustical schemes,** like the beginning or the end of a stimulus, as well as frequency variations.

Different areas in the brain attend to the same information in different ways.

The end point of the auditory track is the **primary auditory cortex,** lied on the **transversal circonvolution** or **Herschl turning.** This is the place where a lot of nervous cells react not only to **sinusoidal sounds**, but also to complex acoustical stimula, like **multiple sounds** and **timbre.**



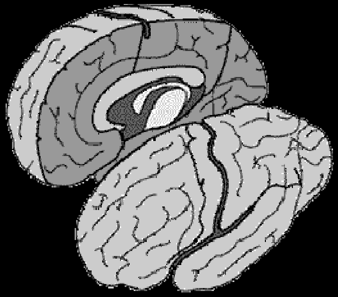
<u>The brain elaborates music in a hierarchical and distributed way.</u>

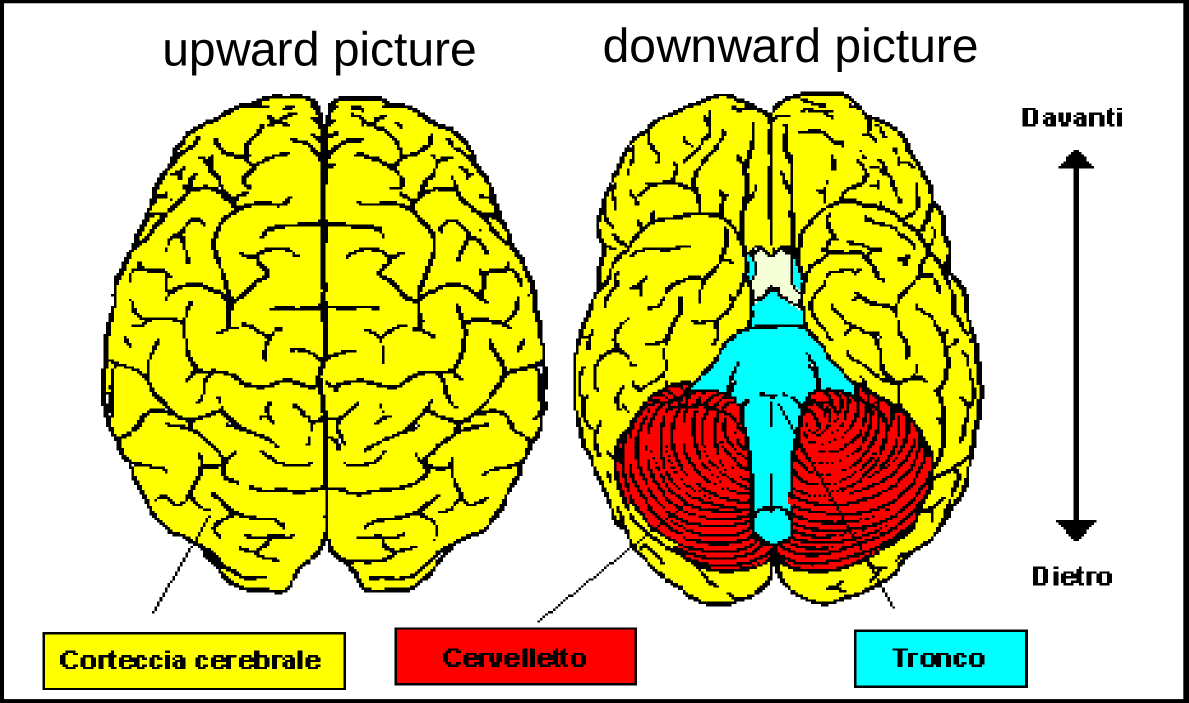
Primary auditive cortex is active at the first stages of musical perception, regarding the tonality or the melodic line (the structure of changes of tonality).

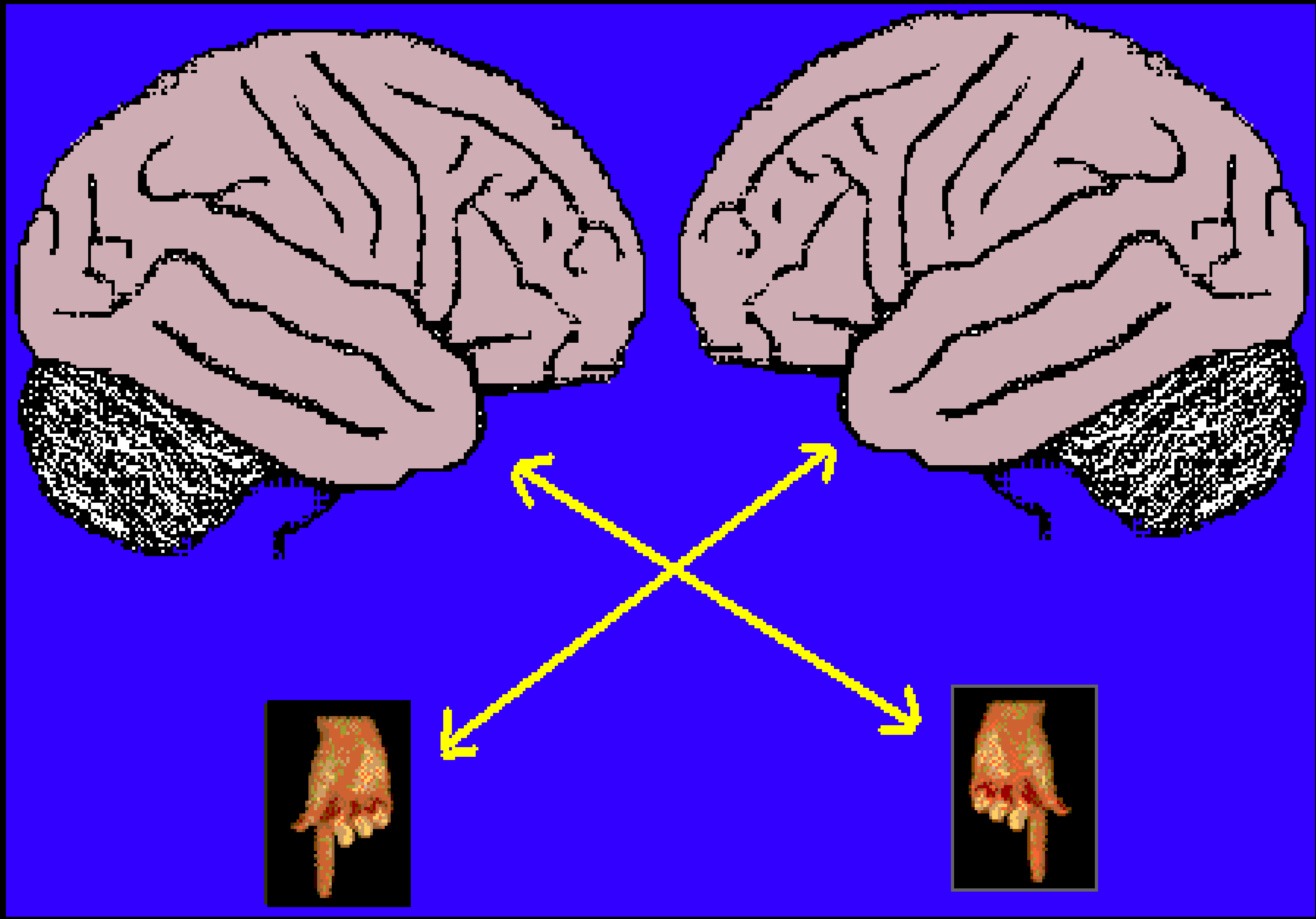
Primary auditive cortex is remodulated by experience in secondary auditory bodies, acting on subsequent stages of musical cognition, like harmony, melody and rhythm.

(taken by **"Mente e Cervello",** n° 14, year III – **Eckart Altenmüller, "La musica in testa"**)

Brain hemispheres







(taken by **A. Lombardini, “Ragionare a tutto cervello”,** I.S.A. – Roma (2005))

Left hemisphere	Right hemisphere
Word	**Image**
Analysis	**Synthesis**
Mathematics	Geometry
Serial reasoning	**Parallel reasoning**
Sequence processing	**Global vision**
Scientific thought	**Artistic and musical capabilities**
Convergent thought	Divergent thought
Deduction	**Metaphoric**
Rational	**Intuitive**
Realistic	**Impulsive**
Objective	**Subjective**
Detailed	**Global, olistic**
Explicit	Implicit
Linear way	Landscape, space
Tactics	Strategy
Reasoning with algorithms	Heuristic reasoning
Digital language	Analogic language

Four brains in one ?

(taken by **A. Lombardini, "Ragionare a tutto cervello",** I.S.A. – Roma (2005))

The speech on brain specialization rests on two theoretical basis **(Mac Mean, 1949):**

- the theory of brain stratification;
- the theory of specialization of brain hemispheres.

- HORIZONTAL APPROACH: LEFT BRAIN, RIGHT BRAIN

- VERTICAL APPROACH: THE THREE BRAIN CAPS

~~Reptilian brain~~

Limbic system

Cerebral cortex

(taken by **A. Lombardini, "Ragionare a tutto cervello",** I.S.A. – Roma (2005))

CORTICAL
reasoning

LEFT
structured verbality

RIGHT
not verbal, existential

LIMBIC
tradition, emotions

LEFT CORTICAL

Analysis
Logical thought
Sequential reasoning
Word and language
Quantitative reasoning
Reasoning with algorithms
Techniques definition
Repetition training

RIGHT CORTICAL

Synthesis
Global vision
Parallel reasoning
Artistic and musical creation
Divergent thought
Heuristic and strategic thought
Innovative ideas
Risk of changing

LEFT LIMBIC

Organization
Procedures and homologation methods
Catalogue, preserve
Well-known fixing
Laws and religious rules
Order and justice
Rituals
Long-term memory (perhaps)

RIGHT LIMBIC

Emotion
Sensations
Human relations
Feeling, passion
"Visceral" intuitions
Magic and myth
Ecstasy
Musical feeling

… and switching to education

(taken by **A. Lombardini, “Ragionare a tutto cervello”,** I.S.A. – Roma (2005))

CORTICAL
reasoning

ANALYTIC DIDACTICS

Basic ideas
Knowledges
Algorythms and Formulas
Analysis
Words
Going in deep

VISUAL AND GLOBAL DIDACTICS

Discovering
Audiovisual means
Examples and Methaphora
Euristic strategies
Global vision

LEFT
structured
verbality

RIGHT
not verbal,
existential

KNOWLEGDE REINFORCING

Classifications
Procedures
Methods
Knowledge and ability reinforcing
Learning tests

EMOTIONAL AND RELATIONSHIP DIDACTICS

Active methods
Group working
Responsibility
Motivation
Emphaty

LIMBIC
tradition,
emotions

Educational applications (1)

teaching sound to scientists

- **Enpowering intuitive and creative strategies in scientific education**

Planning curricular proposals on sound and music with perspective secondary-school teachers

E. BISESI & M. MICHELINI

Abstract

Sound is a preferred context to build foundations of wave phenomena, one of the most important disciplinary referents in physics. It is also one of the best-set frameworks to achieve transversality, overcoming scholastic level and activating emotional aspects which are naturally connected with every-day life, as well as with music and perception. Looking to sound and music in a transversal perspective – a border-line approach between science and art, is the adopted statement for a teaching proposal using meta-cognition as a strategy in scientific education. This work analyses curricular proposals on musical acoustics, planned by perspective secondary-school teachers in the framework of a formative intervention module answering the expectation of making more effective teaching scientific subjects by improving creative capabilities, as well as leading to build logical and scientific categorizations able to consciously discipline artistic activity in music students. With this aim, a particular emphasis is given to those concepts – like sound parameters and structural elements of a musical piece, which are best fitted to be addressed on a transversal perspective, involving simultaneously physics, psychophysics and music.

Educational applications (2)

teaching sound to musicians

(**Battel G. U., & Friberg A.** (2002). *Structural Communication*.
In R. Parncutt & G. E. McPherson (Eds.), The Science and Psychology of Music Performance: Creative Strategies for Teaching and Learning.
New York: Oxford University Press (2002))

- **Analytical teaching of music;**
- **Performance studies**

Music is expressive.

Different uses of the word "expression" in the literature on music performance:

- ♪ **Systematic variations** in timing, dynamics, timbre, pitch that form the *microstructure* of a performance, differentiating it from another performance of the same music (Palmer, 1997)
- ♪ **Emotional qualities** of music, as perceived by listeners (Davies, 1994)
- ♪ **Musical sensitivity of the performer** (London)

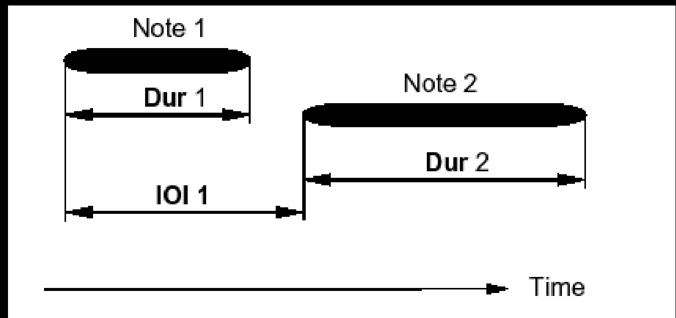
Question: are these three senses of the word related to each other?

How can music performance be studied scientifically?

Musical cues: (**Battel G. U., & Friberg A.** (2002). *Structural Communication*.
In R. Parncutt & G. E. McPherson (Eds.), The Science and Psychology of Music Performance: Creative Strategies for Teaching and Learning. New York: Oxford University Press (2002))

- **Tone duration and Articulation**

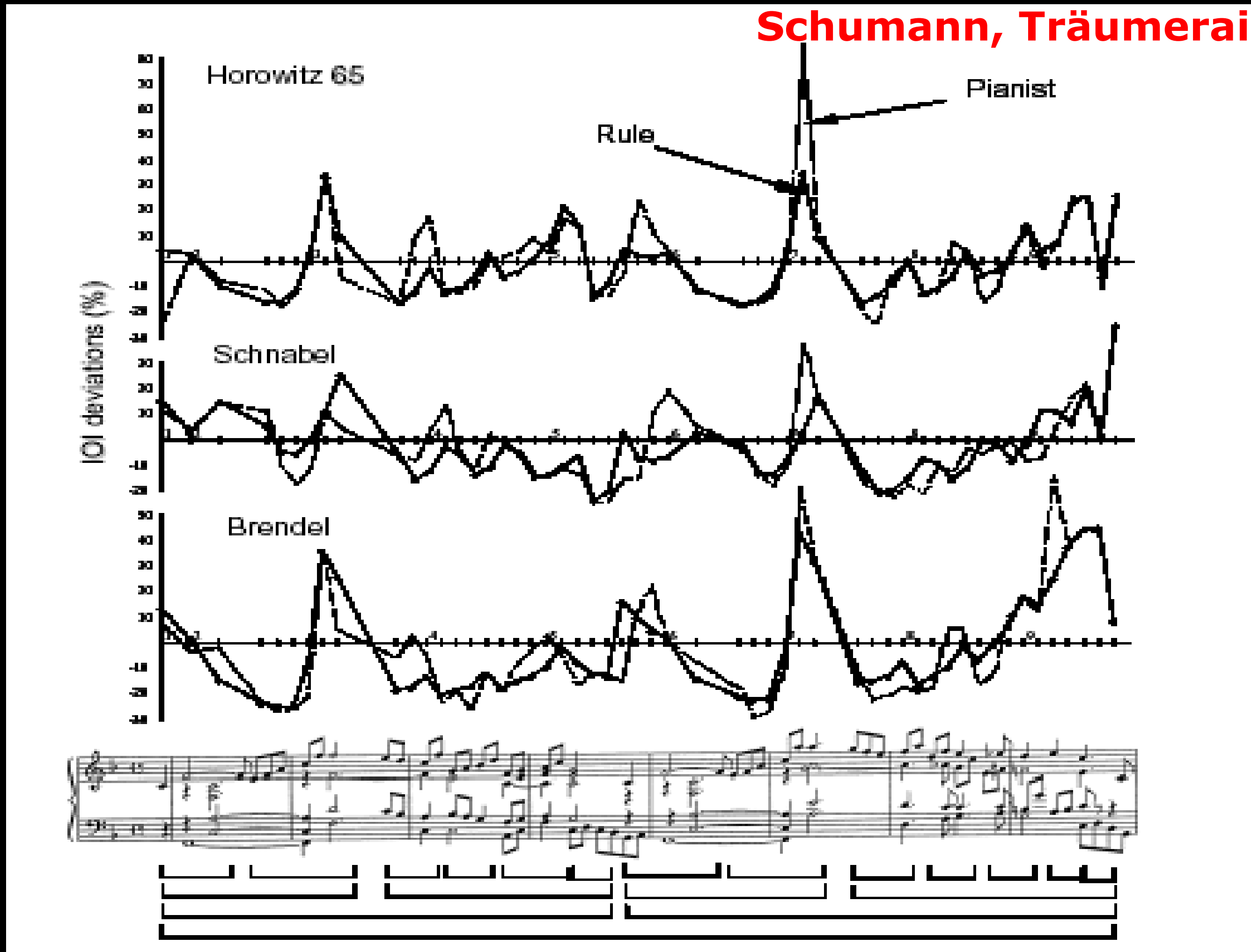
IOI: interonset interval
Dur: duration



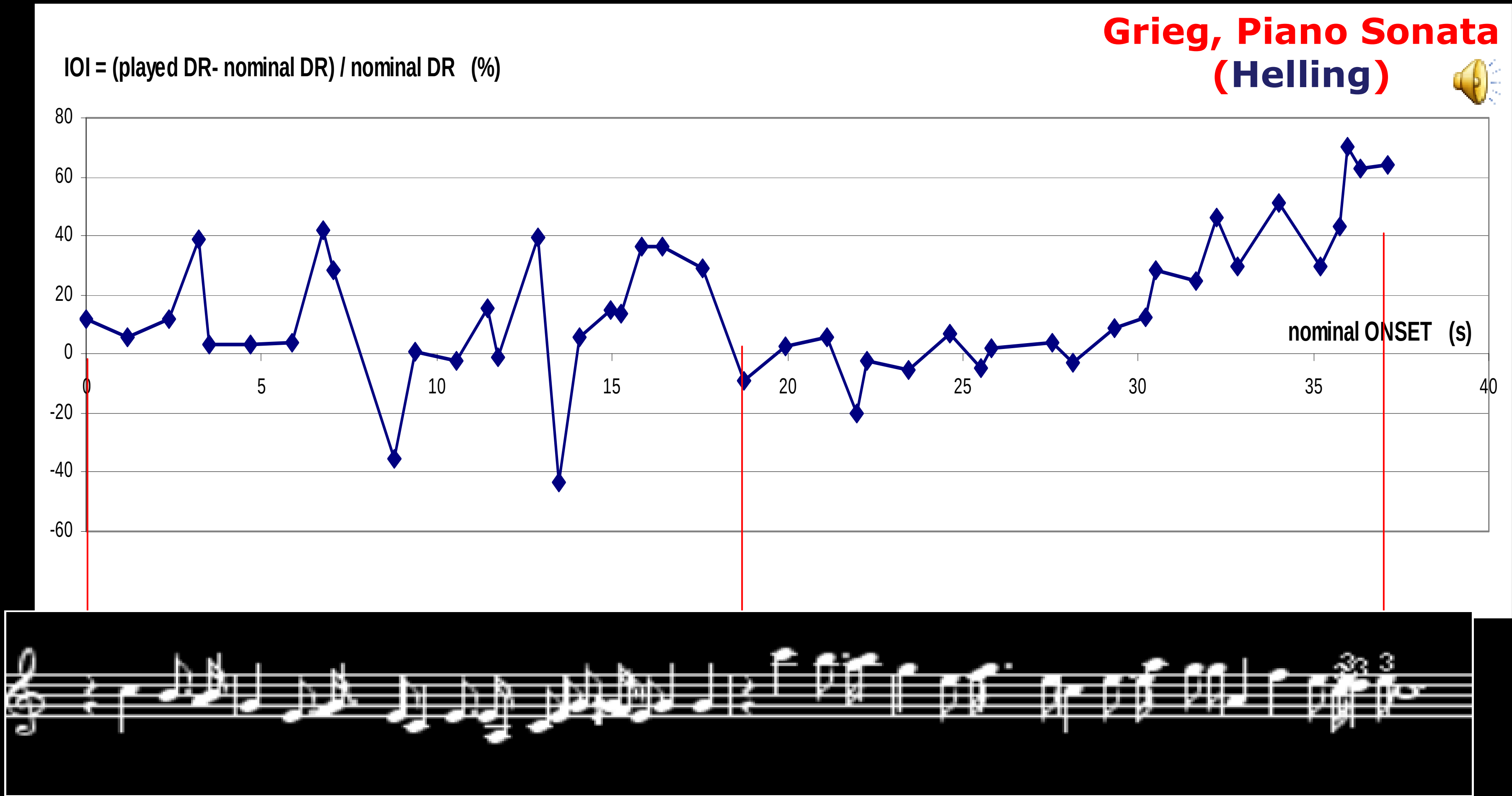
- **Dynamics**

Some quantitative studies:

(**Battel G. U., & Friberg A.** (2002). *Structural Communication*.
In R. Parncutt & G. E. McPherson (Eds.), The Science and Psychology of Music Performance: Creative Strategies for Teaching and Learning.
New York: Oxford University Press (2002))



Erica Bisesi, 2007 – KTH, Stockholm



Musical cues:

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- **Phrasing**
- **Harmonic and melodic tension**

Table 1. A list of tonal relationships contributing to melodic and harmonic tension.

Case	Relationship	Increased tension for:
1	between keys	(i) a modulation to a key that is distant on the circle of fifths, or (ii) to a scale with few tones in common with the original scale
2	between chords; chord relative to key	(i) chords more distant to the key on the circle of fifths (comparing roots) (ii) chromatic chords, or chords that include tones foreign to the prevailing scale (iii) successive chords having few tones in common
3	tone relative to chord	(i) tones that are more distant on the circle of fifths from the root of the chord (ii) tones foreign to the diatonic scale associated with the chord
4	simultaneous tones in a chord	chords containing more dissonant intervals
5	melodic contour	unexpected melodic turns

Musical cues:

(**Battel G. U., & Friberg A.** (2002). *Structural Communication*.
In R. Parncutt & G. E. McPherson (Eds.), The Science and Psychology of Music Performance: Creative Strategies for Teaching and Learning. New York: Oxford University Press (2002))

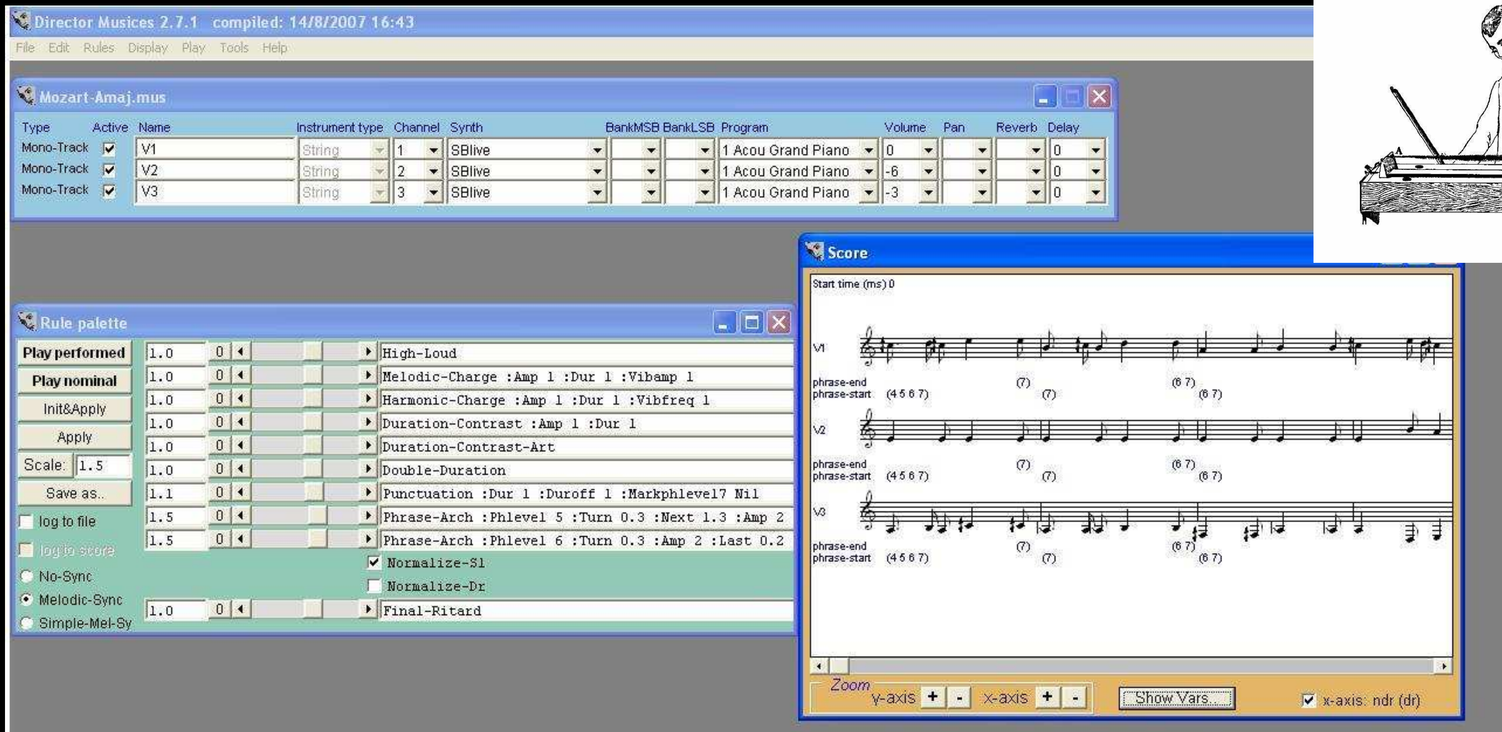
– Metrical patterns and grooves, accents

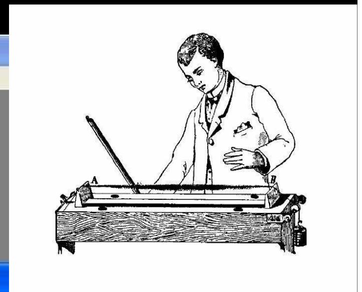
Figure 2. Phrase structure and metrical structure in an excerpt from Haydn's Symphony no. 104. The dots represent the hierarchical metrical structure. The top level in the figure is the beat level, the second the measure level, and the third and fourth are hypermetric levels. The hierarchical phrase structure is shown with brackets. The top level in the figure is the fastest, with only a few tones in each phrase or group. The slowest level corresponds to the whole phrase. (From Lerdahl and Jackendoff, 1983. Copyright 1983 by MIT Press. Used by permission.)

Educational applications (3)

teaching sound to scientists and musicians

'Director Musices' code





DM is a program that allows you to change the performance of a music score.
It contains a set of rules that changes the duration, sound level,etc. of the notes.
These rules mimic performance principles used by real musicians.
The rules are a result from a long-term research project at the **KTH, Stockholm**
(Anders Friberg, Lars Frydén & Johan Sundberg).

Music listening

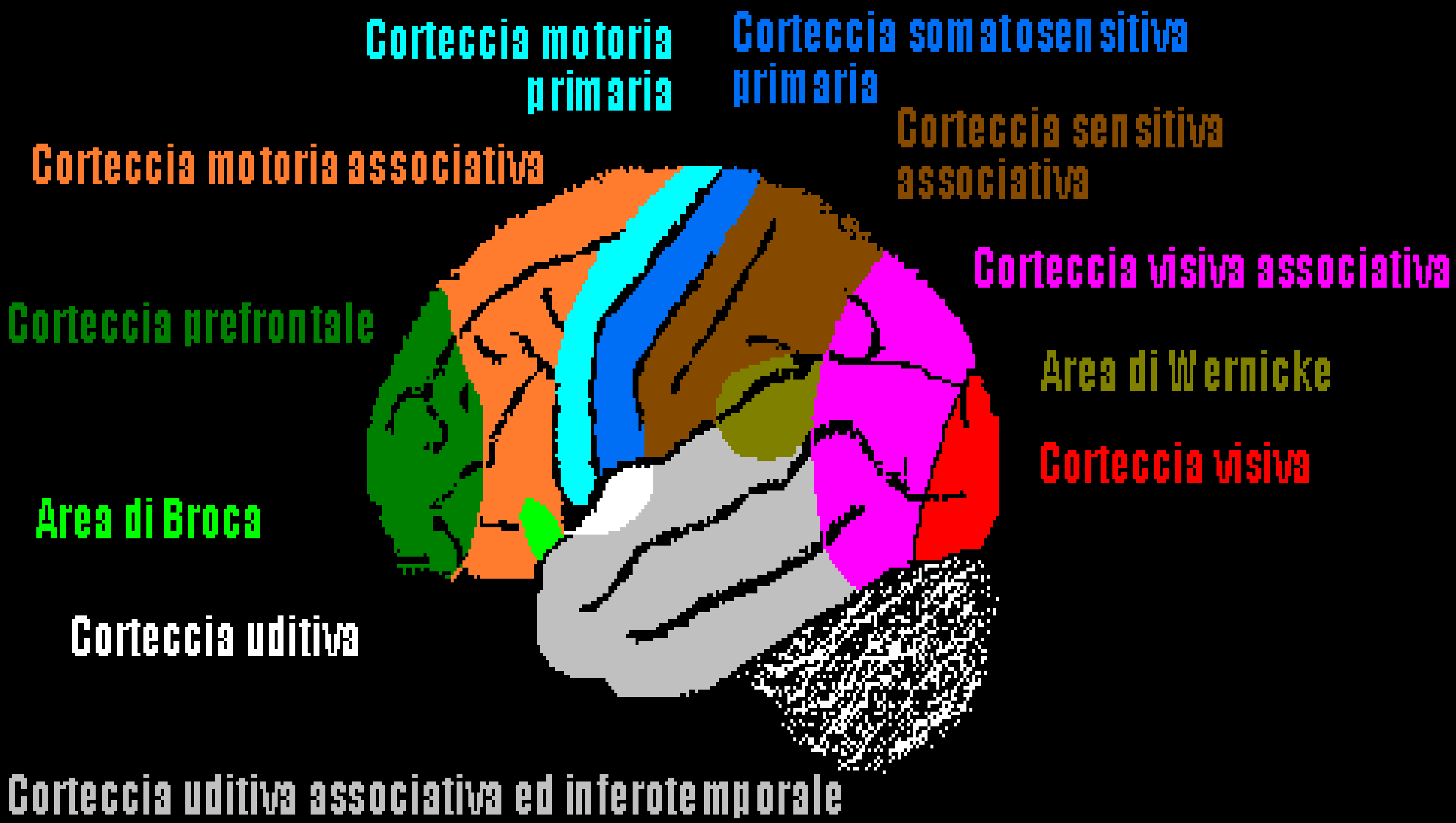
What happens

in the brain

when listening

to the music?

Cerebral cortex



Auditory cortex

(taken by **"Mente e Cervello",** n° 14, year III – **Eckart Altenmüller, "La musica in testa"**)

The **left auditory primary cortex** elaborates **quite fast informations,** while the **right one** is mainly involved in **frequency spectrum** and **timbre.**

Secondary auditory areas lie on a semicircular line rounding the auditory cortex and **elaborate more complex schemes.**

Moreover, behind and laterally, there are **areas devoted to auditory association.** Among them, the **Wernicke area** in the left hemisfere carries out a basic role into **language perception.**

Music perception seems to be organized in a hierarchical way:

we can suppose that the right hemisphere catches, at a first time, music structure approximately, on which the left hemisphere performs a more precise analysis only at a subsequent stage.

Music hearing

(taken by **"Mente e Cervello",** n° 14, year III – **Eckart Altenmüller, "La musica in testa"**)

- **First levels in elaboration of music perception,** like differencies in sound pitch and volume, always occur in the primary and secondary auditory cortex of both hemispheres.

- **Next elaboration levels** and **definition of more complex schemes,** like the **perception of melodies** and **temporal structures,** belong to brain areas that - almost partially - vary from person to person.

- The peculiarity of music hearing consists in a special capability to move among **different perception modes.** Again, our auditory system is shaping, and **brain plasticity** plays a primary role.

Music hearing

- A musical composition consists of a series of expressive and intelligible sounds, with a definite structure and meaning, in agreement with **melody, harmony** and **rhythm** laws.

- A **melody** is a succession of sounds with **tonal and rhythmic structures,** based on a **musical scale.**

- When more than one melody are played together, many different frameworks possibly occur:
  - **counterpoint**
  - **harmony**
  - **serialism**
  - **alea**
  - **…**

Counterpoint and harmony

Counterpoint:

J.S.Bach: Four Duets BWV 802-805

Harmony:

E.Grieg: Sonata in E minor op. 7, second movement

A melody **accompanying** is a **chord** series.

Harmony is the chord reference framework. Its building blocks are **consonance** and **dissonance.**

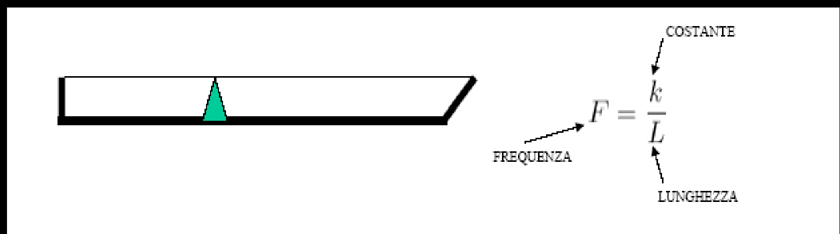
Ancient Greeks:

sound pitch is inversely proportional to string lenght

Pithagoric school:

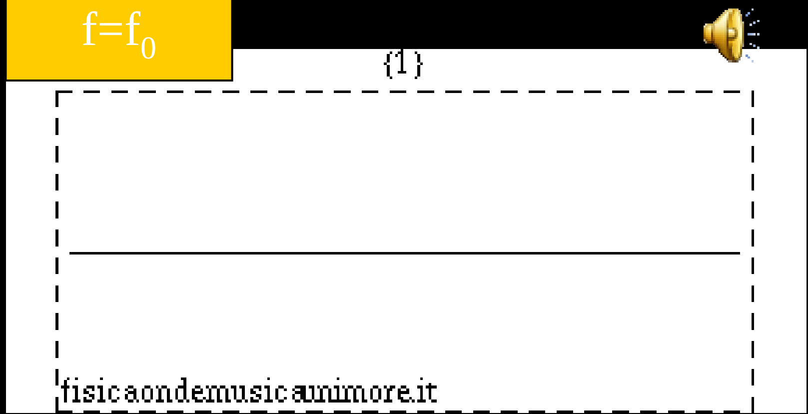
2/1	**15/8**	**5/3**	**3/2**	**4/3**	**5/4**	**9/8**	**1**	**INTERVAL**
DO (C)	**SI (B)**	**LA (A)**	**SOL (G)**	**FA (F)**	**MI (E)**	**RE (D)**	**DO (C)**	**NOTE**

DO (C) – DO (C) = **unisonous (consonant)**
DO (C) – RE (D) = **second (dissonant)**
DO (D) – MI (E) = **third (consonant)**
DO (E) – FA (F) = **fourth (consonant)**
DO (F) – SOL (G) = **fifth (consonant)**
DO (G) – LA (A) = **sixth (consonant)**
DO (A) – SI (B) = **seventh (dissonant)**
DO (C) – DO (upper C) = **octave (consonant)**



The vibranting string

$f=f_0$



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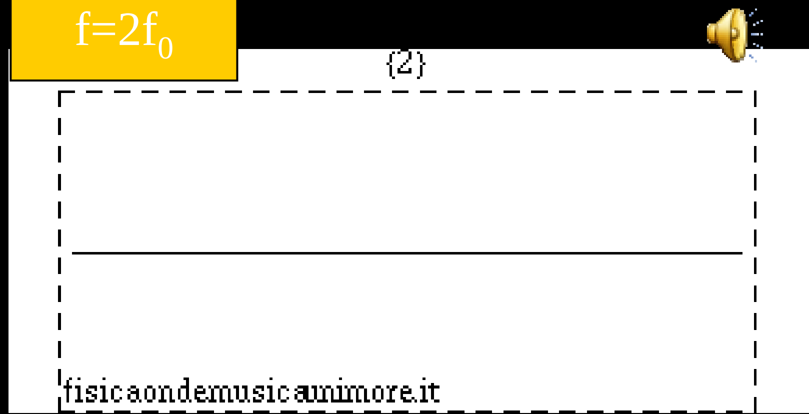

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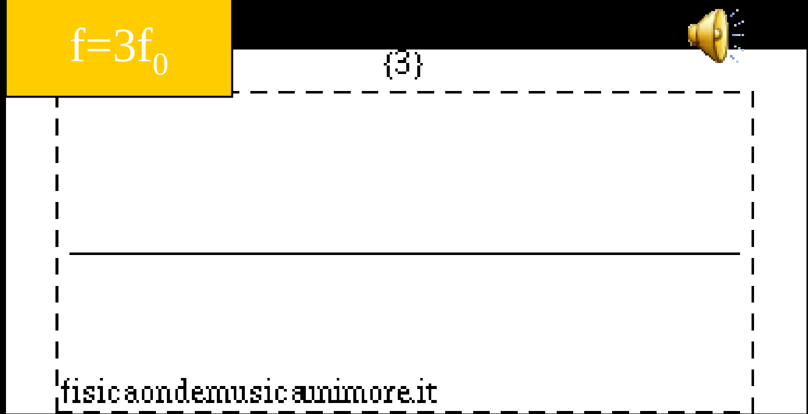
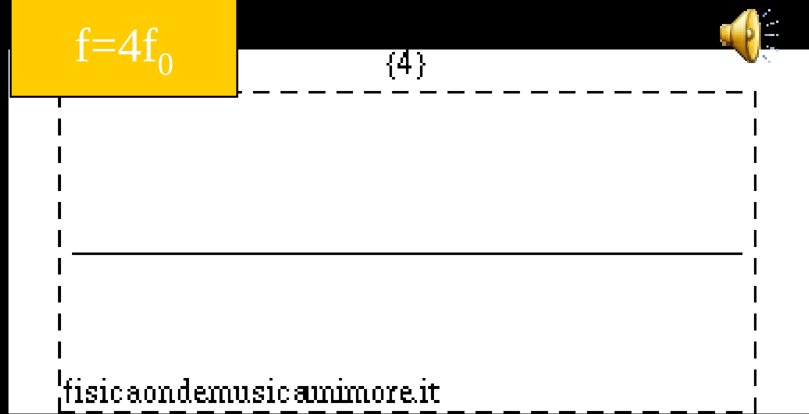
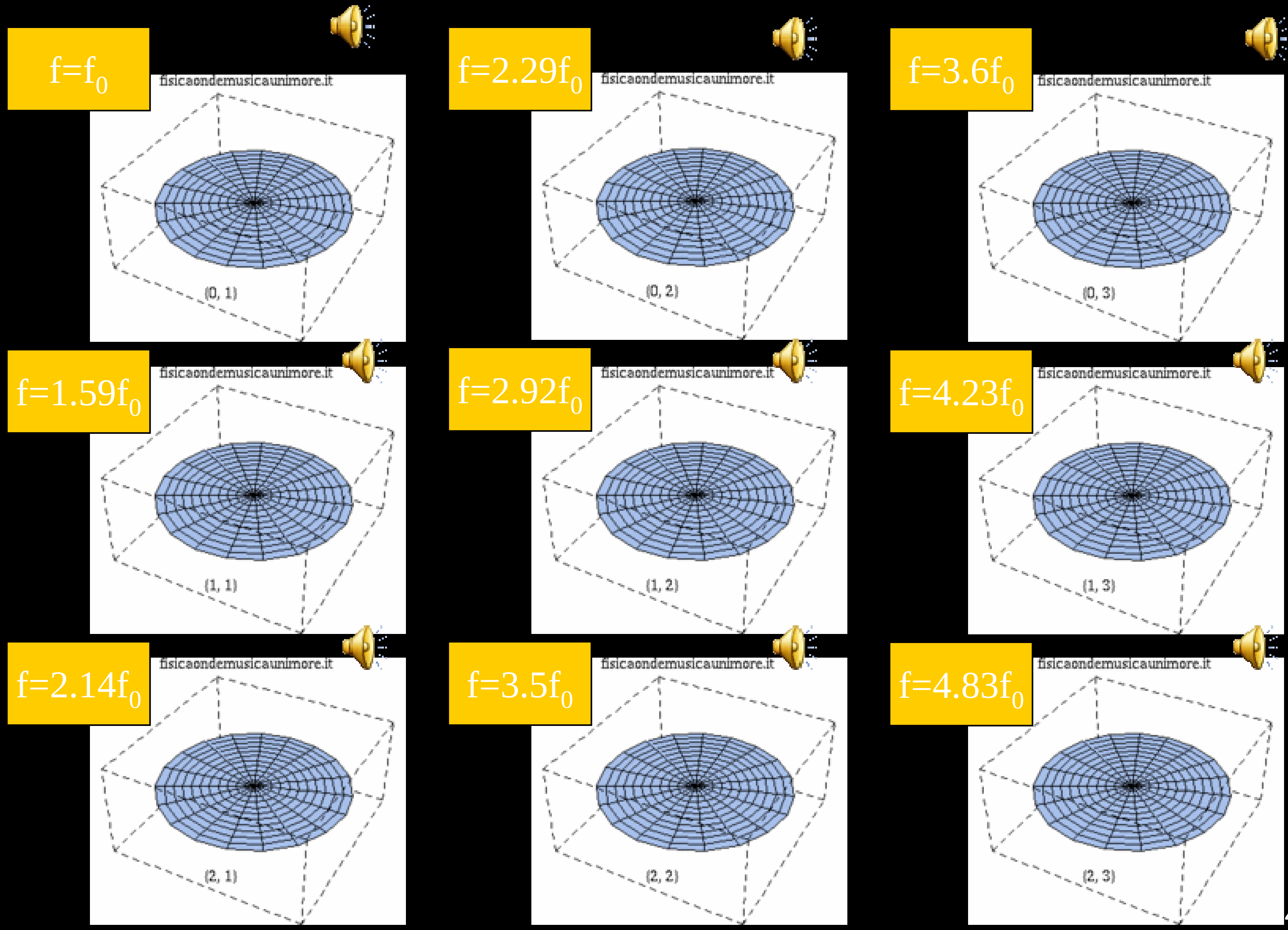


$f=4f_0$



The vibrating membrane



Timbre

Synthesis:

Building every complex oscillation by the superposition of simple harmonic oscillations.

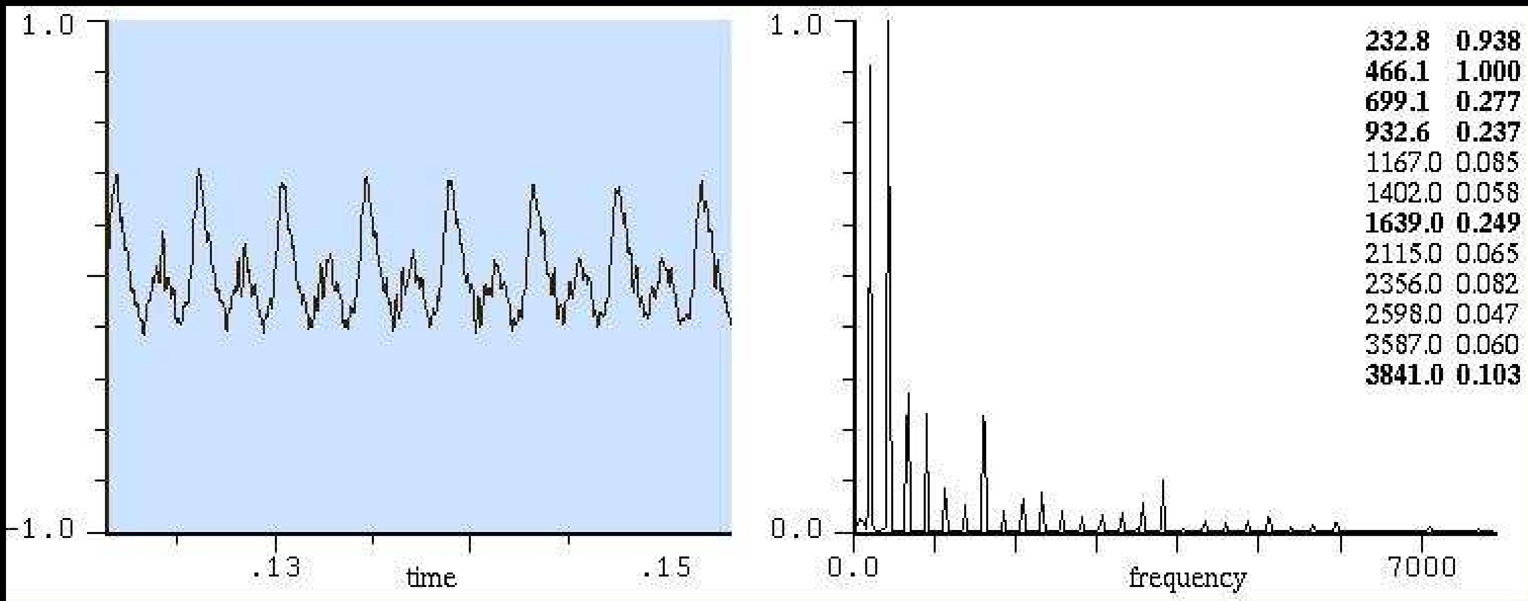
Spectral analysis:

The inverse procedure, i.e. the possibility of decoupling a complex oscillation in its harmonic components.

a) understanding musical instruments timbre;
b) recognition and vocal synthesis;
c) spectroscopy techniques in physics (chemical-physical analysys, astronomy and astrophysics searches, electromagnetic waves on the whole spectrum, …)

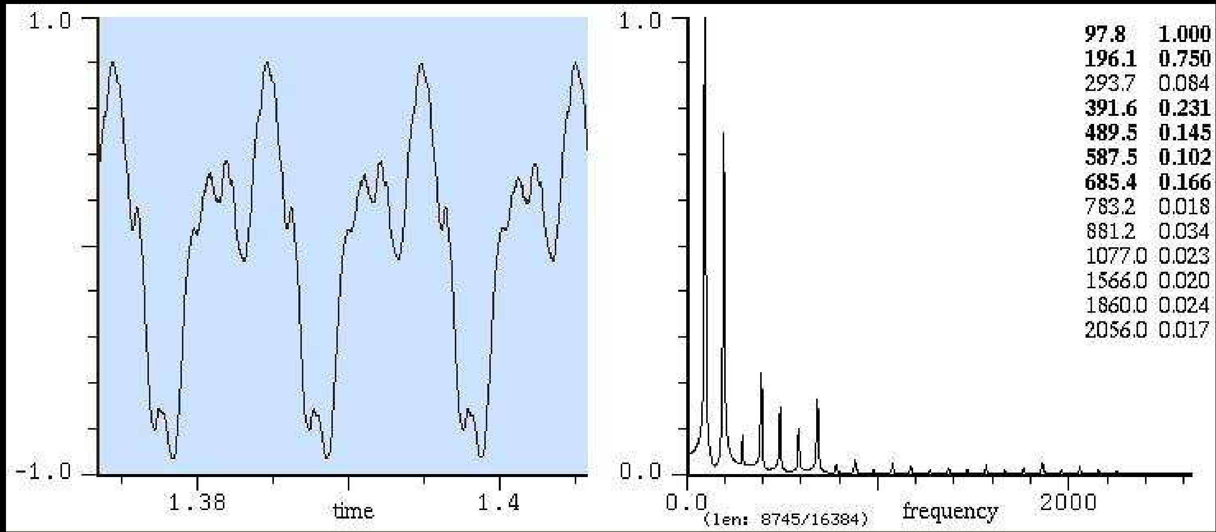
Timbre

Piano – B flat

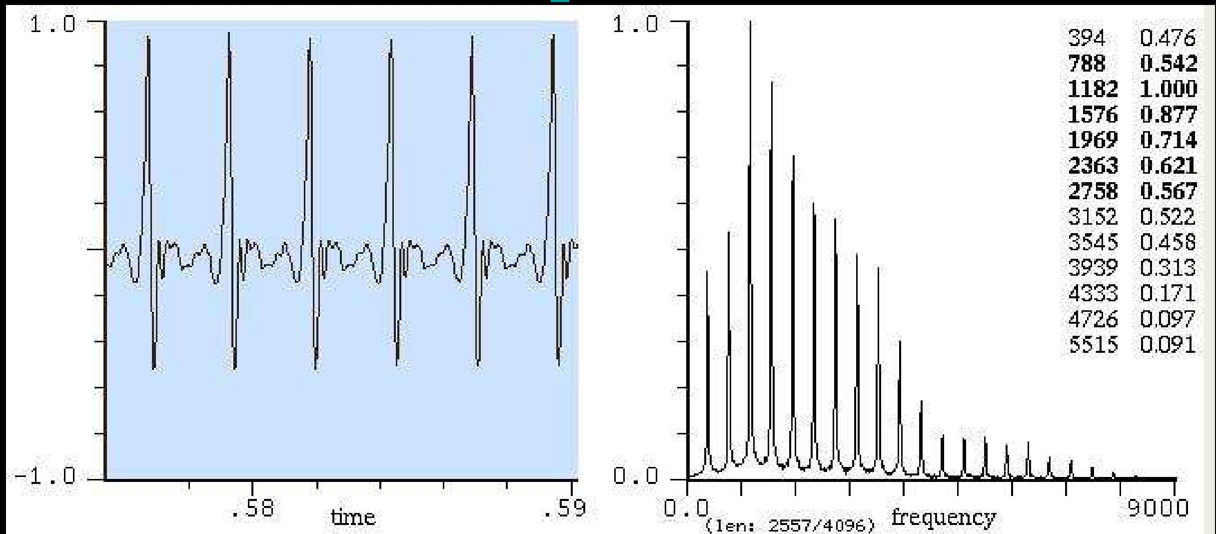


http://www.maurograziani.org/text_pages/acoustic/acustica/MG_Acustica06.html

Cello – G

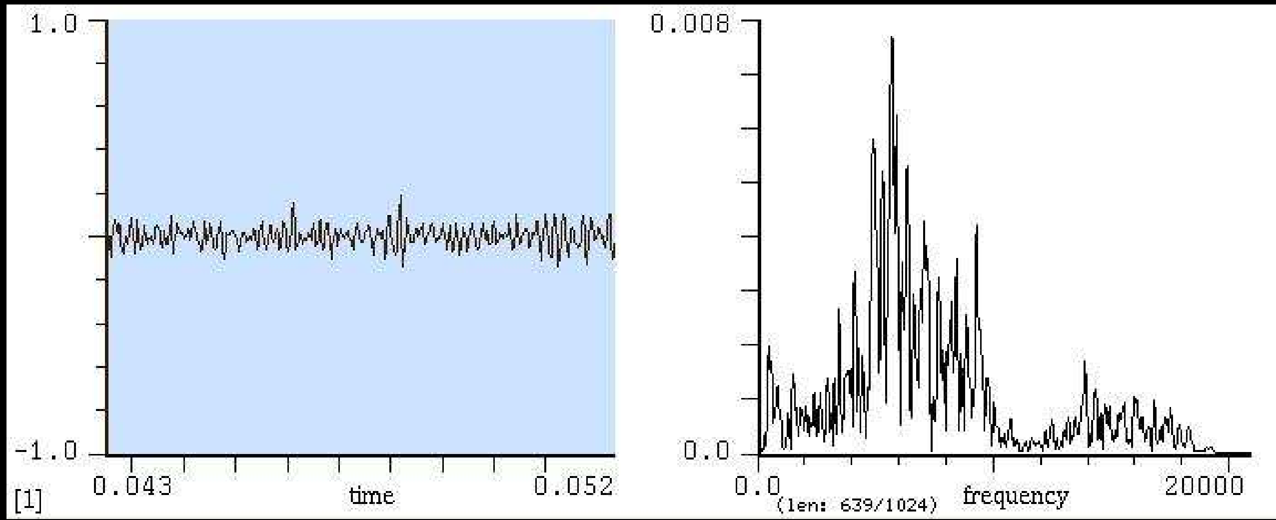


Trumpet – G

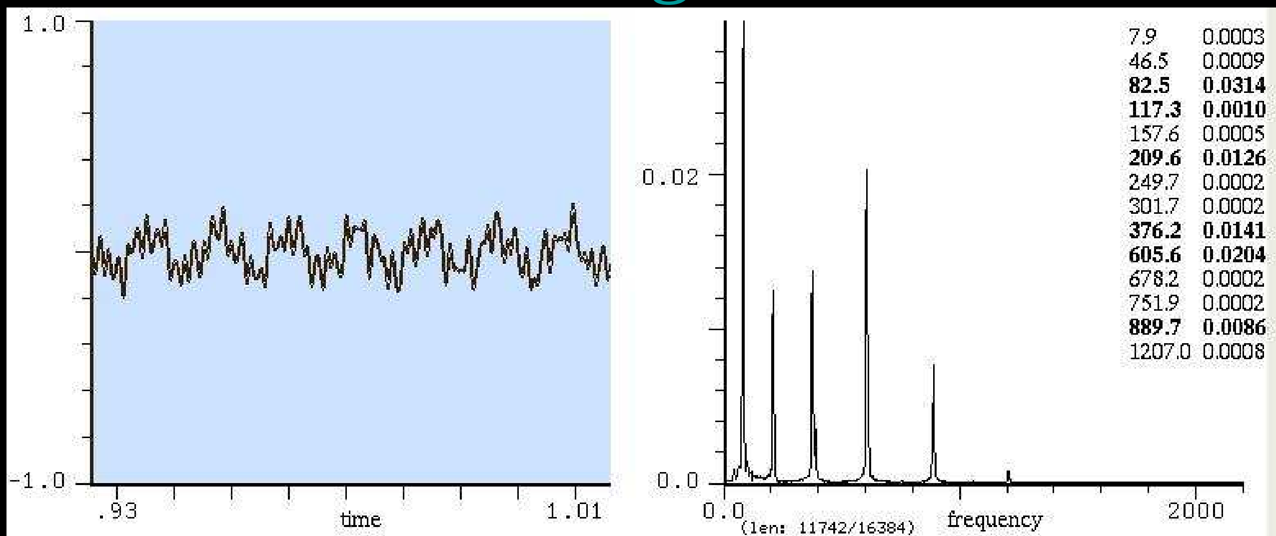


http://www.maurograziani.org/text_pages/acoustic/acustica/MG_Acustica06.html

Dishes



Gong



http://www.maurograziani.org/text_pages/acoustic/acustica/MG_Acustica06.html

Relationships between vibrating lenghts and frequencies

Vibrating lenght (string, reed)	Frequency	Interval
L	*f*	—
5L / 6	*6f / 5*	**Third minor**
4L / 5	*5f / 4*	**Third major**
3L / 4	*4f / 3*	**Fourth (exact)**
2L / 3	*3f / 2*	**Fifth (exact)**
L / 2	*2f*	**Octave (exact)**

Consonance and dissonance

- **Pythagoras: sounds are consonant** if their pitches correspond to string lenghts whose ratios are simple: **2:1, 3:2, 4:3.**
- **Zarlino -** ***Istitutioni Harmoniche*** **(1558):** in the XII century, poliphony development required **new consonant intervals,** extending phytagoric *tetractys* with **major third (5:4), minor third (6:5), major sixth (5:3)** and **minor sixth (8:5).**
- **G. Galilei –** ***Discorsi intorno a due nuove scienze*** **(1638):** pendulum isochronism law.
- **H. von Helmholtz:** human physiology,
  - **acoustic Ohm law:** ear processes complex sounds with a spectral Fourier analysis;
  - **dissonances are due to beats among partials.**

Towards the solution…

- **Jean Philippe Rameau – *Traité de l’harmonie* (1722):**
  - notes in a chord has to **share** a high number of superior **partials;**
  - they must produce to the ear, as **combination sounds,** other partials which are not emitted by the source, generating the **fundamental bass** – the linking-key of the whole musical discourse.

↓

Gravitation laws of harmony

Structure of musical models:

(taken by **"Mente e Cervello",** n° 14, year III – **Eckart Altenmüller, "La musica in testa"**)

- **melodic structure;**
- **temporal structure;**
- **harmonic and vertical structure;**
- **dynamical structure.**

horizontal structure:

melody as a whole

fragmentation into components → musical **interval**

↓

melodic **line** → musical **period** (**simmetry** rules)

a **rhythm** arises by temporal succession of almost three events

vertical structure:

timbre and harmony

Picking up ideas…

(taken by **"Mente e Cervello",** n° 14, year III – **Eckart Altenmüller, "La musica in testa"**)

- **Horizontal dynamics** describes **volume inside a group of subsequent sounds,** strongly influencing **listener sensibility** with an immediate effect on **emotions.**

- **Vertical dynamics** indicates **volume ratios inside a single sound.** It distributes each **voice,** putting it in a first or less important level in the sound space, according with the musical context.

THANK YOU