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# PSÝCHOACOUSTIC ASPECTS ON THE SPEED OF MELODÝ PERFORMANCE

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#### A physics' topic: pendulum motion

The experience of Foucault's pendulum is the most evident proof of Earth's rotation around its axis.

It is based on the pendulum's property of preserving its oscillation plane, when submitted only to the gravitational force.

In 1851, **Jean Bernard Foucault** hung a 67 meter pendulum to París' Pantheon ceílíng. The pendulum oscillation plane seemed apparently rounding with a period:

T = 24h / sin f.

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#### A physics' topic: pendulum motion



#### From physics to psychophysics: Paolo Bozzi's research on penduli

✓ <u>PHYSICS</u>: pendulum oscillation frequency is fixed by a universal mathematical relationship:

$$T = 2\pi \sqrt{\frac{l}{g}}$$

• <u>PERCEPTION</u>: pendulum oscillating motion exhibits features which cannot be objectively described by the observer, i.e. its typical character of 'quickness', or 'slowness', or better oscillations 'adequacy' (all these properties depend on the pendulum structure) (P. Bozzi, Osservazioni sulla percezione del moto pendolare armonico).



Fig. 2. In questo diagramma è rappresentata la curva delle frequenze fisiche di oscillazione dei pendoli con cui veniva condotto l'esperimento. I rettangoli in grigio indicano invece la gamma delle frequenze "naturali" degli stessi pendoli, così come sono state viste dai 14 soggetti intervistati. Il valore superiore è trovato a partire dalle oscillazioni più rapide, quello inferiore a partire da quelle più lente.

#### MAIN RESULTS:

- 1. As the pendulum's length increases, the values of "natural" frequencies decrease.
- 2. These frequencies are always lower than those of an identical, freely oscillating pendulum.
- 3. As pendulum's length increases, this discrepancy lowers.

**Bombi** showed that the effect is reversed for 2.5 meters pendula: "natural" motion is perceived only when pendula are forced to oscillate at a frequency greater than the one they would assume during free motion.

| soggetti | frequenze<br>viste fenomenic                             | differenze<br>tra le due ampiezze |   |
|----------|--|-----------------------------------|---|
|          | con ampiezza<br>di oscillazione 10°                      |                                   |   |
| А        | $\begin{cases} \downarrow 58 \\ \uparrow 47 \end{cases}$ | ↓ 39<br>↑ 40                      | $\begin{pmatrix} - & 19 \\ - & 7 \end{pmatrix}$ |
| В        | {↓ 60<br>↑ 40  | ↓ 39<br>↑ 31                      | $\begin{pmatrix} - & 21 \\ - & 9 \end{pmatrix}$ |
| С        | (↓ 60<br>↑ 63  | ↓ 60<br>↑ 60                      | $-\frac{-3}{3}$                                 |
| D        | {↓ 54<br>↑ 43  | ↓ 36<br>↑ 34                      | $\begin{pmatrix} - & 18 \\ - & 9 \end{pmatrix}$ |
| E        | {↓ 71<br>↑ 56  | ↓ 56<br>↑ 47                      | $\begin{pmatrix} - & 15 \\ - & 9 \end{pmatrix}$ |
| F        |  | ↓ 70<br>↑ 70                      | <u>=</u> }                                      |
| G        |  | ↓ 40<br>↑ 30                      | - 25<br>- 11                                    |
| н        |  | ↓ 42<br>↑ 36                      | $-\frac{13}{2}$                                 |
| I        | {↓ 41<br>↑ 31  | ↓ 35<br>↑ 29                      | — 6<br>— 3                                      |
| L        | {↓ 51<br>↑ 36  | ↓ 36<br>↑ 30                      | — 15<br>— 6                                     |
| М        | (↓ 41<br> ↑ 29   | ↓ 30<br>↑ 26                      | $\begin{pmatrix} - & 11 \\ - & 3 \end{pmatrix}$ |
| Ν        | (↓ 48<br> ↑ 27   | ↓ 40<br>↑ 27                      | — <u> </u>                                      |
| 0        | (↓ 75<br>↑ 65  | ↓ 48<br>↑ 48                      | -27   |
| Р        |  | ↓ 68<br>↑ 38                      | - 12  |

Tab. 1. Incidenza dell'ampiezza di oscillazione sulla frequenza propria per il pendolo da 40 cm. Come si vede, l'oscillazione di 60° è vista troppo rapida su quella frequenza stessa che per l'oscillazione di 10° è giudicata "naturale". La frequenza è espressa in oscillazioni complete al minuto. Le frecce verticali indicano che il valore è stato determinato a partire o da frequenze "troppo lente" (freccia verso l'alto) o da frequenze "troppo rapide" (freccia verso il basso).

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#### **Dependence on frequency:**

Oscillation at 60° is perceived as "too fast" at the same frequency which is judged as "natural" for the oscillation of 10°:

- 1. When the oscillation amplitude is "natural" the increased. phenomenological behavior of the pendulum occurs at lower frequencies.
- 2. This means that, in order to maintain the "natural" character of a certain frequency unchanged, one has to lower (raise) the physical frequency the of as oscillation pendulum. its amplitude is raising (lowering).

 $A = k\omega$ , where k represents the *"expressive"* character of motion, A is the oscillation amplitude and  $\omega$  is the physical frequency of the pendulum as set by operative measurements.

| soggetti | frequenze<br>viste fenomenic                                       | differenze<br>tra le due ampiezze   |   |
|----------|--|-------------------------------------|---|
|          | con ampiezza<br>di oscillazione 10°                                | con ampiezza<br>di oscillazione 60° |   |
| A        | $ \begin{cases} \downarrow 58 \\ \uparrow 47 \end{cases} $         | ↓ 39<br>↑ 40                        | $\begin{pmatrix} - & 19 \\ - & 7 \end{pmatrix}$ |
| в        | $ \begin{pmatrix} \downarrow & 60 \\ \uparrow & 40 \end{pmatrix} $ | ↓ 39<br>↑ 31                        | $\begin{pmatrix} - & 21 \\ - & 9 \end{pmatrix}$ |
| С        | {↓ 60<br>↑ 63  | ↓ 60<br>↑ 60                        | $-\frac{-3}{3}$                                 |
| D        | $ \begin{pmatrix} \downarrow 54 \\ \uparrow 43 \end{pmatrix} $     | ↓ 36<br>↑ 34                        | $\begin{pmatrix} - & 18 \\ - & 9 \end{pmatrix}$ |
| Е        | {↓ 71  | ↓ 56                                | - 15  |

Correspondence in exchanges of heterogeneous properties of visual phenomena:

an object moving at a physically defined velocity is perceived to move more slowly, if its size is bigger (Brown, 1931).

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## From physics to music perception

**Research Question:** 

Does make it sense to define a "correct" speed in melody performance?

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## "Correct" performance speed

#### Literature:

- Quínn & Watt, 2004:
  - a) listeners are able to judge if a musical piece is played at a "correct" speed;
  - b) agreement among listeners is greater than expected;
  - c) the "correct" tempo depend on the piece.

#### - Lapídakí, 2000:

a) a better familiarity with the piece and the musical style yields a greater consistence in experimental results.

### **Experiment**

- Research questions:

- does it exist a "correct" performing speed?
- in positive case, what does it depend on?
- Set up:
  - pieces
    - *baroque* and *classical* styles;
    - short extracts, at least one musical period
  - varíables
    - rhythmic structure
    - musical parameters (timing, dynamic, articulation)

#### - Desígn:

- preliminary test with few subjects
- real experiment with **18 subjects** (all musical trained)



### <u>Methodology</u>

- *Two* separated experiments:
  - rhythmic structure (3 trials)
  - musical expression (4 trials)
- Incoming variables:
  - speed range
  - scale



- Method of constant stimuli:
  - two different sequences of 7 randomized velocities (2 + 5 + 2)
  - the second time pieces were presented in a different order (the same for all subjects)
- Subjects were asked to mark trials
  - according with their preference
  - more than one preference per column was allowed

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## **Methodology**

| Piece 1 | extremely<br>slow | a little too<br>slow | slow, but<br>acceptable | ок | fast, but<br>acceptable | a little too<br>fast | extremely<br>fast |
|---------|-------------------|----------------------|-------------------------|----|-------------------------|----------------------|-------------------|
| 1       |                   |                      |                         |    |                         |                      |                   |
| 2       |                   |                      |                         |    |                         |                      |                   |
| 3       |                   |                      |                         |    |                         |                      |                   |
| 4       |                   |                      |                         |    |                         |                      |                   |
| 5       |                   |                      |                         |    |                         |                      |                   |
| 6       |                   |                      |                         |    |                         |                      |                   |
| 7       |                   |                      |                         |    |                         |                      |                   |
| 8       |                   |                      |                         |    |                         |                      |                   |
| 9       |                   |                      |                         |    |                         |                      |                   |

## Musical structure

Linguistic (Chomsky) and musical structures (Schenker)
 surface and deep structures, a parallelism (J. Sloboda)
 Search of 'universals' in linguistic and music
 results already achieved in figurative arts (Zeki's 10 rules of art)

Grouping in music perception (Deutsch)

Gestalt perception organization, e.g. 'closure' law (Kanizsa, Bregman:



## Musical structure

Grouping rhythmic structures (Fraisse)

- the two factors which characterize a rhythmic group are the duration of the interval between the notes and the total number of elements.
- the lower limit in the duration of intervals should allow a clear distinction of subsequent elements, while the upper limit is set by the requirement of connecting elements to each other.
- The greater the interval between two sounds, the lower the number of elements a listener can perceived in series (Fraisse, 1938)

## Musical structure

#### Structure and tempo

- When the tempo is accelerated (decelerated), if compared with "spontaneous" tempo, the distinction between long and short tempos is less evident. When the tempo is speeded up, short tempos vary less than longer ones (because of closeness to perception limits).
- > What is the role of *pauses* between structures?
  - psychological (Fraisse), psychophysical (von Békésy), motorial (Paillard)
  - analysis: short tempos are always exactly reproduced, while long ones may change their duration at the time of perception reorganization.
- Simple rhythms are expected to allow for more timing variation than more complex ones (Honing, 2005).

### Experiment A: musical structure

#### Scarlattí Sonatas:



### Experiment A: musical structure

### Technique:

## Speed sequences:

Incoming variables
 nominal tempo

| Speed range<br>(metronomic) |  |  |
|-----------------------------|--|--|
| 60                          |  |  |
| 68,25                       |  |  |
| 77,63                       |  |  |
| 88,31                       |  |  |
| 100,5                       |  |  |
| 114,3                       |  |  |
| 130                         |  |  |

4 6 2 5 7 1 3 4 6 1 5 3 6 4 2 7 1 5

5 2 4 7 3 6 1 5 2 7 3 1 2 6 4 5 7 3

3 4 6 1 5 7 2 3 4 2 1 5 4 7 3 6 2 1

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## Experiment B: expressive musical performances

 Bach – Partita BWV 1013, Allemande (flute)
 2 fast pieces

 Beethoven – String Quartet op. 18 no. 4, 1<sup>st</sup> movement
 2 fast pieces

 Bach – Partita BWV 1031, Sicilienne (flute + harpsichord)
 2 slope

Haydn – String Quartet op. 76 n°, 2<sup>nd</sup> movement

2 slow pieces



How can be music performance be scientifically studied?

Musícal parameters:

- Тетро
- Tone duration and Articulation

IOI: inter-onset interval Dur: duration



- Dynamícs
- Phrasing
- Transpose
- Harmonic and melodic tension
- Metrical patterns and grooves, accents

## Experiment B: expressive musical performances

## **Instrument**

#### 'Director Musices' code

| Director Musices 2.7.1 compiled:  | 14/8/2007 16:43  |                |
|---|--|----------------|
| File Edit Rules Display Play Tools Help   | ρ  |                |
| 🔇 Mozart-Amaj.mus   |  | <i>₩</i> 2.    |
| Type Active Name<br>Mono-Track ♥ V1<br>Mono-Track ♥ V2<br>Mono-Track ♥ V3   | Instrument type     Channel     Synth     BankMSB BankLSB     Program     Volume     Pan     Reverb     Delay       String     1     SBlive     Image: Channel     Image: Channel |                |
| -   | Start time (ms) 0  |                |
| Play performed         1.0         0         4           Play nominal         1.0         0         4           Init&Apply         1.0         0         4           Apply         1.0         0         4           Scale:         1.5         1.0         0           Iog to file         1.5         0         4           Mo-Sync         0         0         0         0 | <pre>     High-Loud     High-Loud     Melodic-Charge :Amp 1 :Dur 1 :Vibfreq 1     Harmonic-Charge :Amp 1 :Dur 1 :Vibfreq 1     Duration-Contrast :Amp 1 :Dur 1     Duration-Contrast :Amp 1 :Dur 1     Duration-Contrast-Art     Double-Duration     Punctuation :Dur 1 :Duroff 1 :Markphlevel7 Nil     Phrase-Arch :Phlevel 5 :Turn 0.3 :Mext 1.3 :Amp 2     Phrase-Arch :Phlevel 6 :Turn 0.3 :Amp 2 :Last 0.2     Normalize-St     Normalize-Dr </pre>   |                |
| Simple-Mel-Sy 1.0 0 ◀   | ✓ Final-Ritard<br>Zoom<br>Y-axis + - x-axis + -  | →<br>Show Vars |

DM is a program that allows 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.

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![](_page_25_Figure_1.jpeg)

![](_page_26_Figure_1.jpeg)

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![](_page_27_Figure_1.jpeg)

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![](_page_28_Figure_1.jpeg)

## Conclusions

- Participants show a clear tendency to choose a "preferred" speed in performed melodies.
- The range of "accepted" velocities depends on the piece structure: more structured pieces allow a lower acceptance range;
- The range of "accepted" velocities does not depend on expressive features of the piece.
- Mean "preferred" velocity does not depend on the structure of piece, but
- Participants' judgments are differently distributed around mean values: more structured pieces correspond to narrower distributions (smaller standard deviations).

# THANK YOU