Extraction of the principal perceptual features of vibrations

Corentin Bernard

Aix-Marseille Université, CNRS, PRISM

Aflokkat , MIRA-Recherche

With Etienne Thoret, Nicolas Huloux and Sølvi Ystad

Thesis overview

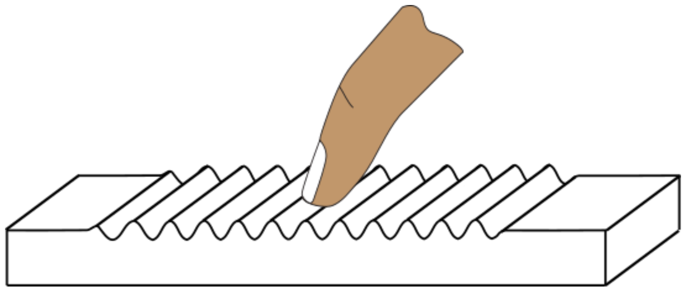
Perception of audio-haptic textures for new touchscreen interactions

Advisors: Sølvi Ystad and Michael Wiertlewski

Lab: PRISM and ISM (Aix-Marseille University, CNRS)

Company: Stellantis (Jocelyn Monnoyer)

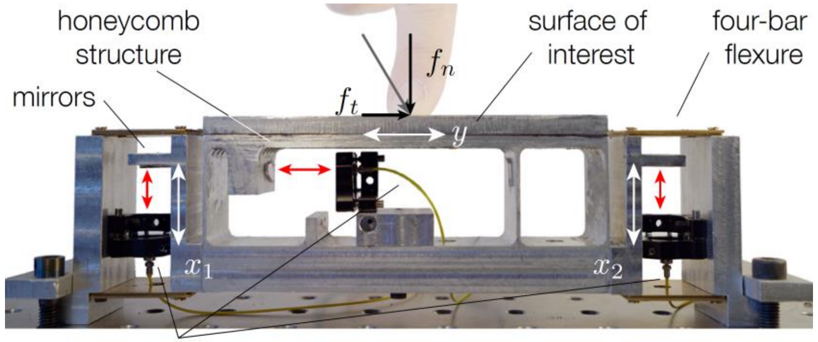
I. Detection threshold



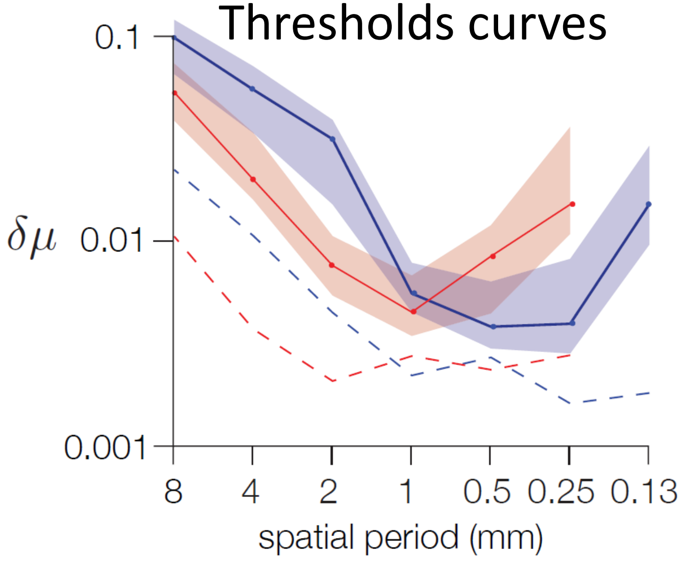
- How detection thresholds evolve with texture spatial frequency ?

(Technology: ultrasonic friction modulation)

Interferometric tribometer



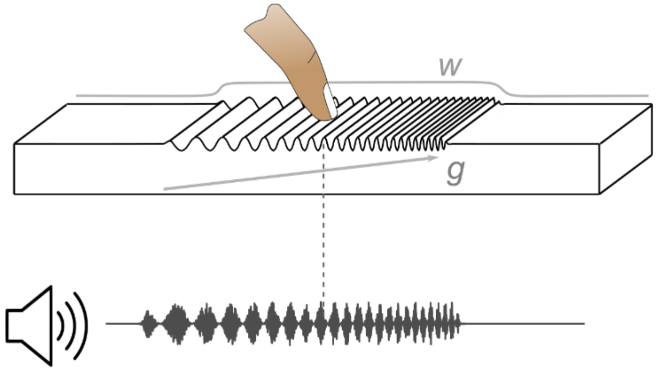
Thresholds curves

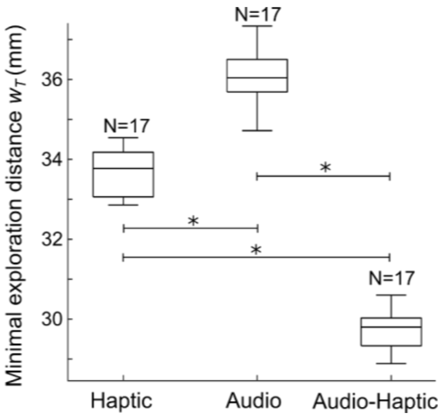


→ Similar to vibrotactile sensitivity

II. Audio-haptic interaction

- How to combine audio and friction modulated haptic feedback?



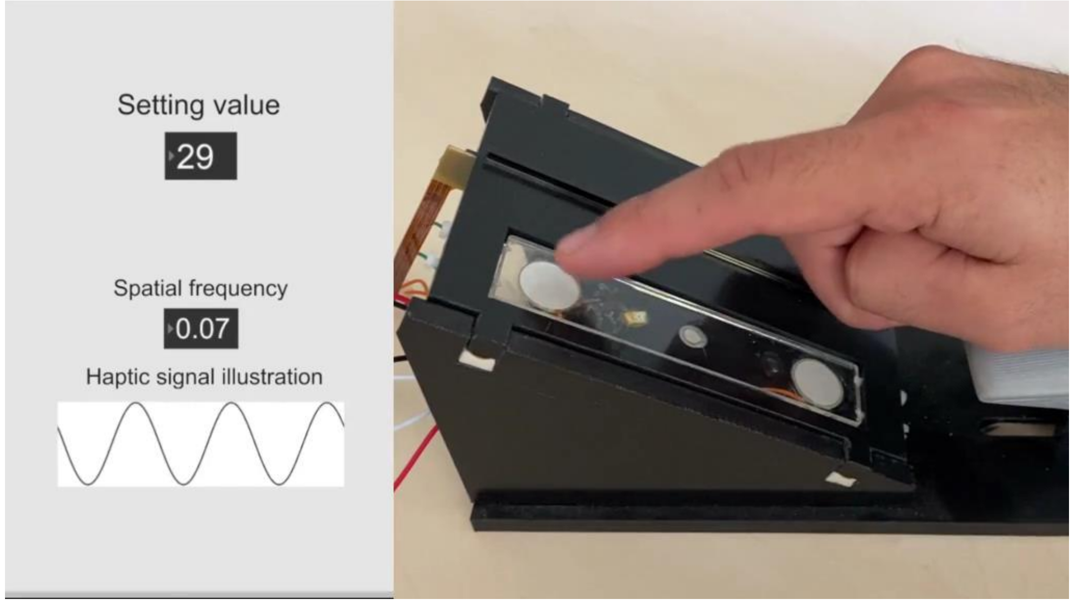


→ Perception of haptic gradients = perception of rhythmic changes

→ Demonstration of audio-haptic integration

III. Eyes-free interaction

- How to provide information of a value to the user?

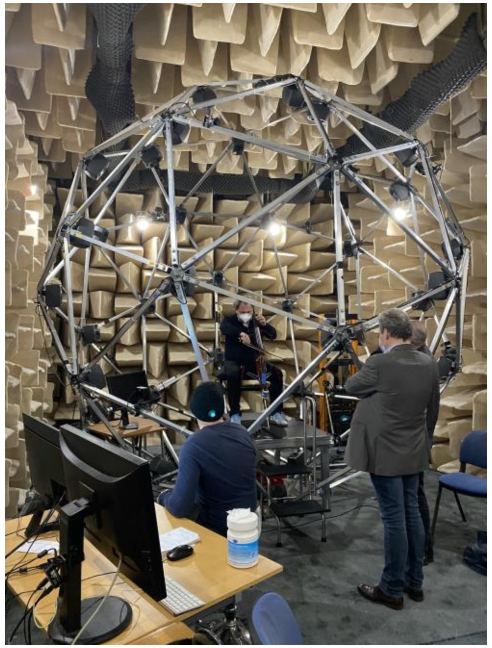


→ Users can adjust a setting without vision

→ Comparison of different learning procedures with multimodal feedback

PRISM
Perception
Representations
Image
Sound
Music

Laboratory in Marseille:
- Auditory perception and sound synthesis
- Immersion, 3D sounds and multimodality



AFLOKKAT
MIXA

Laboratory in Ajaccio:
- Interactive robotics
- Surface Haptics

Principal perceptual features of vibrations

What makes two vibrations feel different?

Motivations:

- Vibrotactile perception better understanding
- Invariant structures research

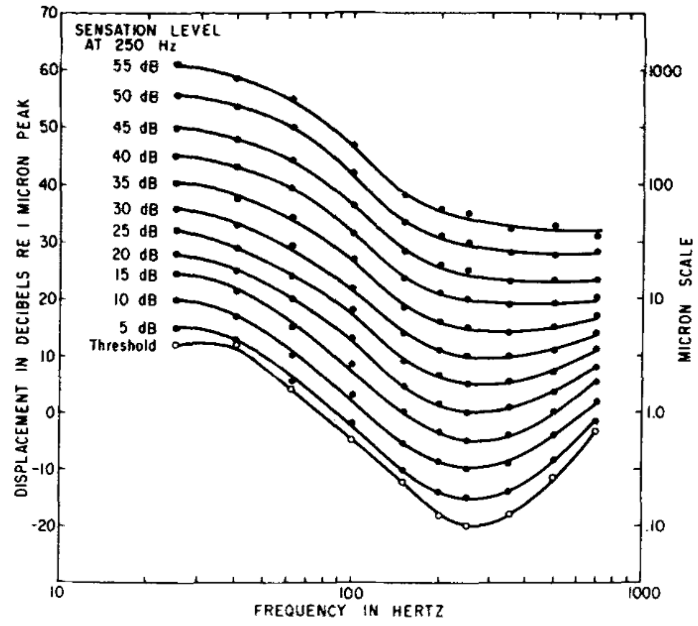
Applications :

- Vibration analysis and synthesis
- Vibrotactile signals compression

State of the art – Vibration attributes

Perception of vibration frequency :

- Independent of the amplitude (Pongrac,2008)
- Weber fraction: between 18% and 20% (Pongrac,2008)



Perception of vibration intensity:

- Perceived intensity varies frequency (Verrillo, 1969)
- Weber fraction varies between studies from 10% to 30%

  (Sherrick, 1950; Schiller, 1953; Craig, 1972; Fucci 1982)

State of the art – Dissimilarities

- Measure of vibration similarity (ST-SIM) based on spectral and temporal similarities, used to assess compression quality. (Hassen and Steinbach, 2020)

- Prediction perceptual similarities between textures from exploration data (forces, vibrations, speed) (Richardson, Vardar, Wallraven and Kuchenbecker, 2022)

- Signal representations to predict musical instrument timbre similarities

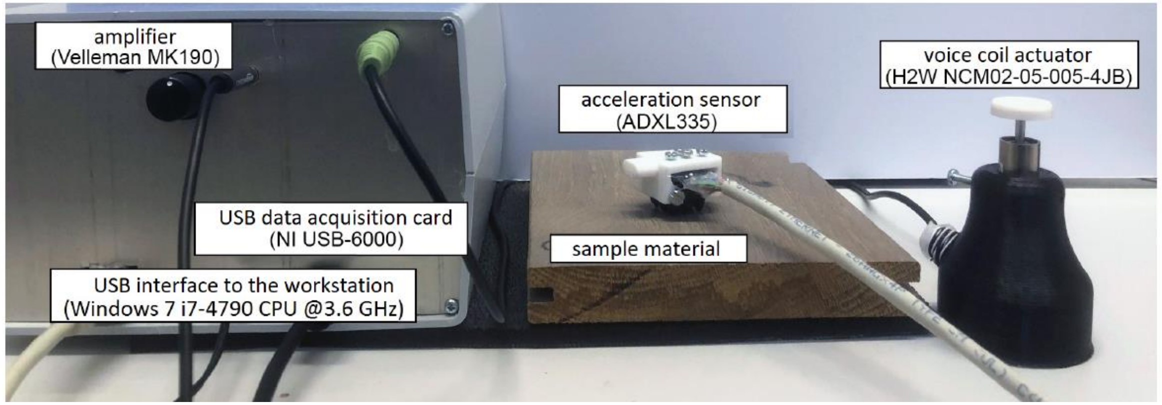
  (Thoret, Caramiaux, Depalle and McAdams, 2020)

Stimuli presentation

18 vibration signals from the Kirsch et al. database
9 textures : rubber, polyester pad, foam, felt, cork, bamboo, baltic brown, anti vib pad, aluminium grid

2 different probes : 

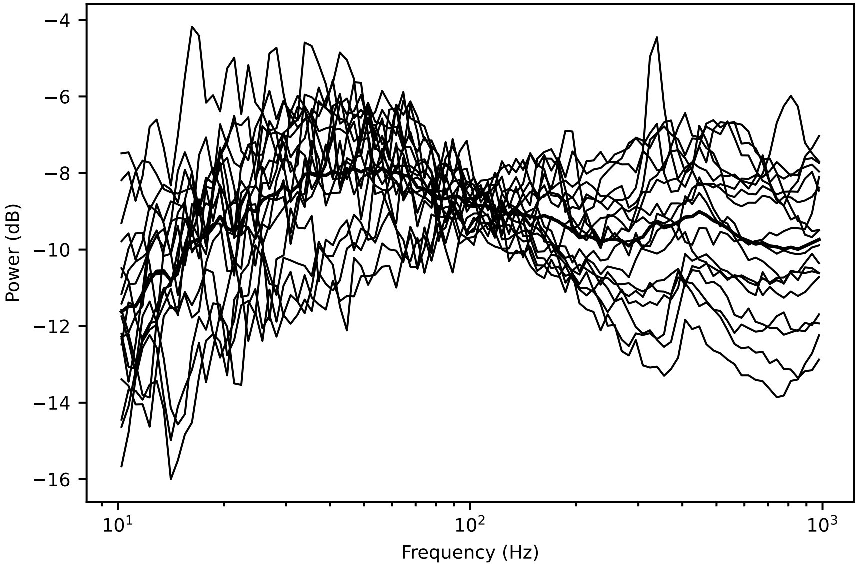
1 scanning speed : 100 – 120 mm/s
Stationary signals, duration **=** 1 sec, sampling rate = 2800 Hz,



(Kirsch, Noll, Strese, Liu and Steinbach, 2018)

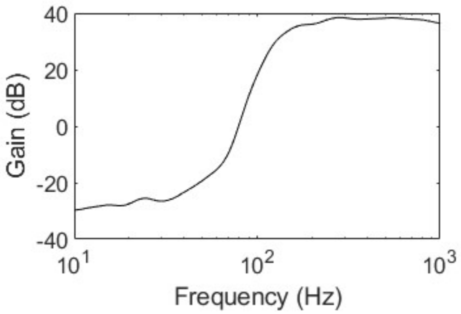
Stimuli rendering

Original stimuli



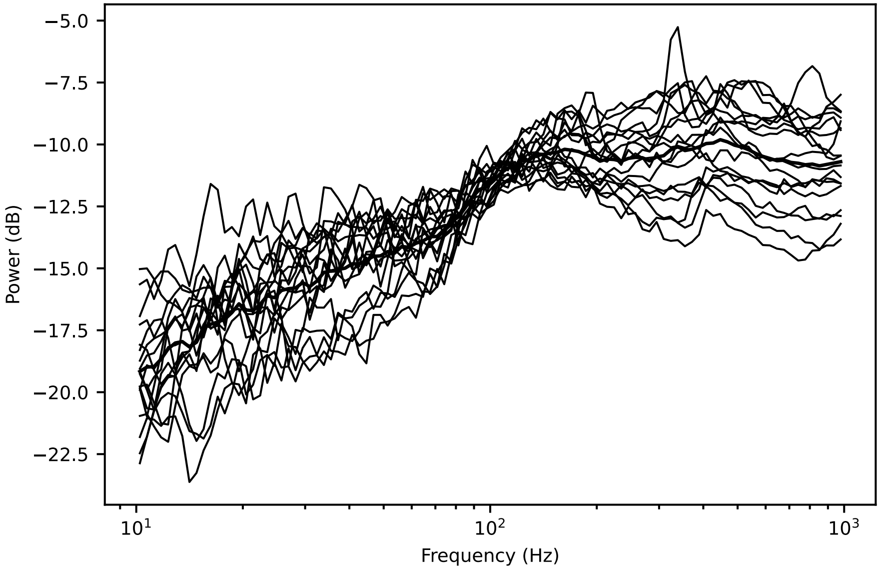
Signals used to produce the stimuli

HapCoil-One (Aktronika)



Actuator frequency response
(actuator held between two fingers)

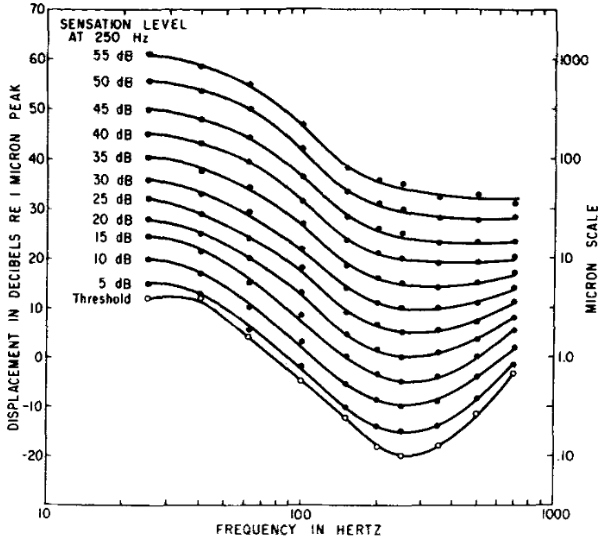
Filtered stimuli



Signals closer to the perceived vibrations - used for the analysis

Preliminary study : intensity equalization

- Vibration intensity is known as a major perceptive attribute
- Intensity equalization is required to investigate other attributes



- Iso-intensity curves for sinusoidal signals (Verrillo,1969)
- Intensity model for sinusoidal signals (Wang et al. 2008)

What about complex/noisy vibrations ?

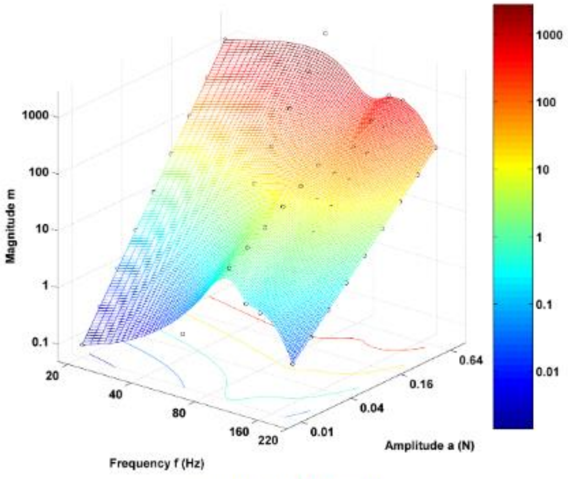
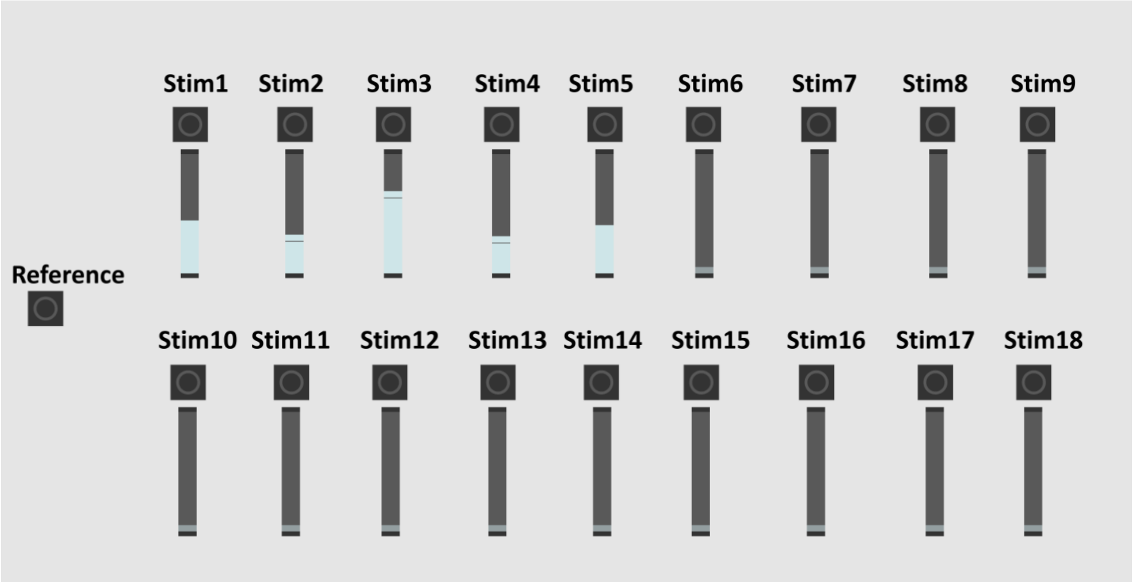


Figure 4: Model II

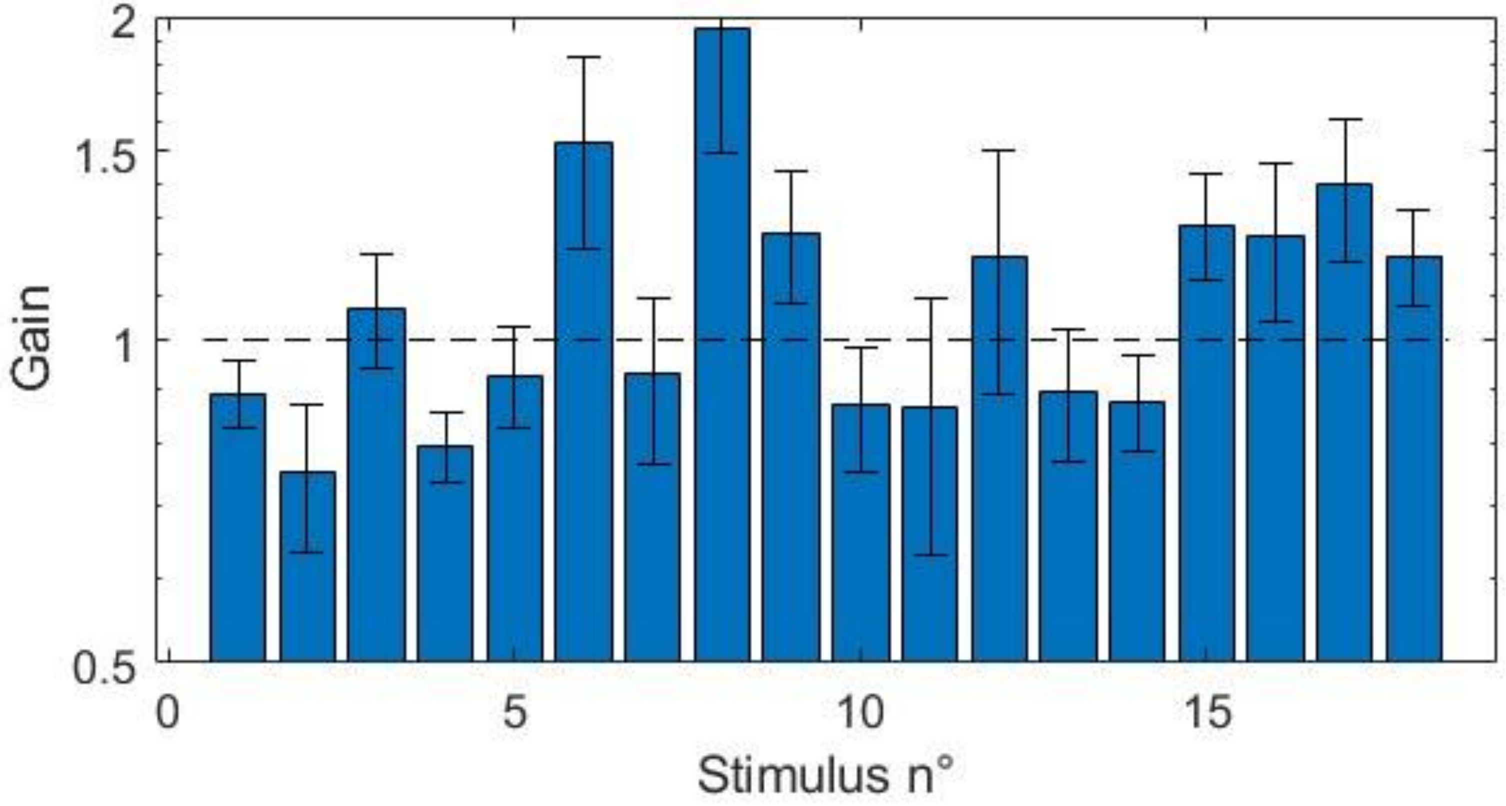
Experimental protocol

- Preliminary mathematical equalization (std)
- Comparison with a reference (white noise)



- 10 participants
- Between-subjects correlations r : mean=**0.82** min=0.60 max=0.97

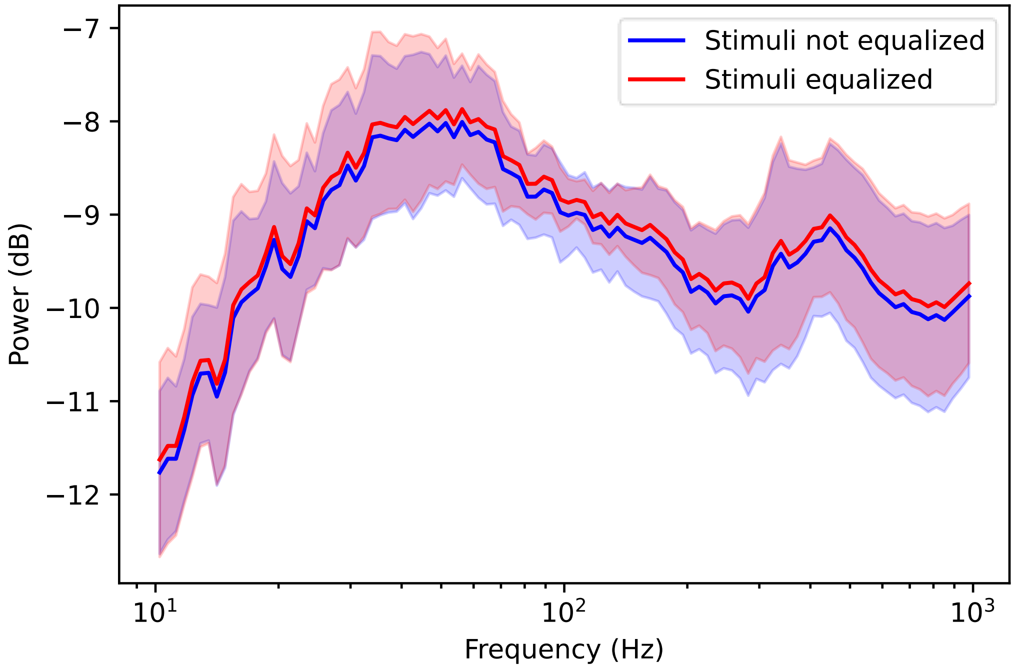
Intensity equalization results



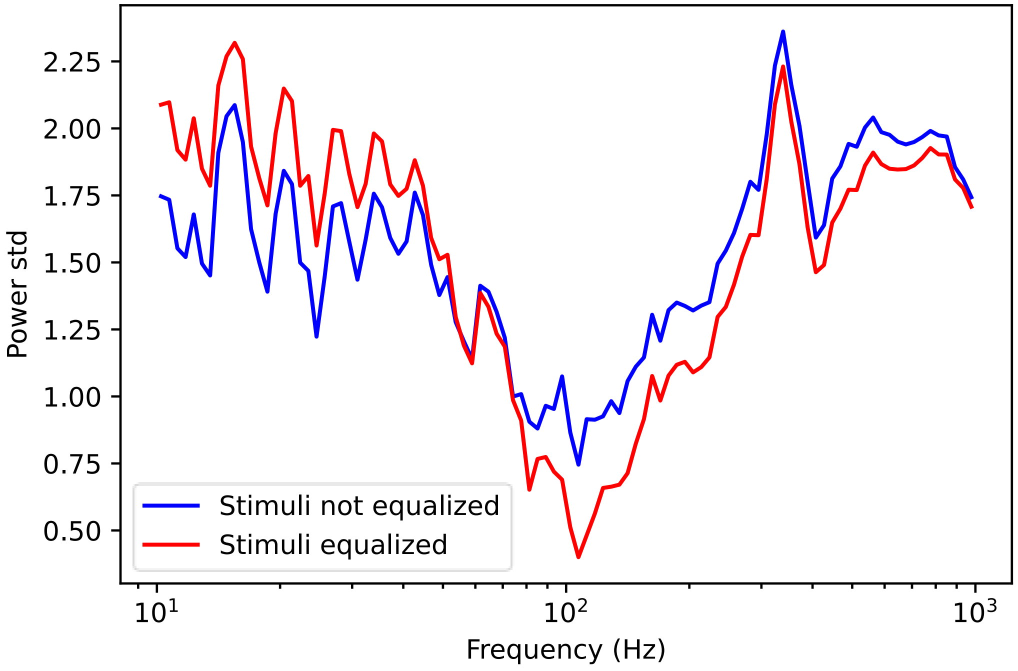
→ Calculation of the mean gain for each stimulus

Intensity equalization results

Stimuli spectra



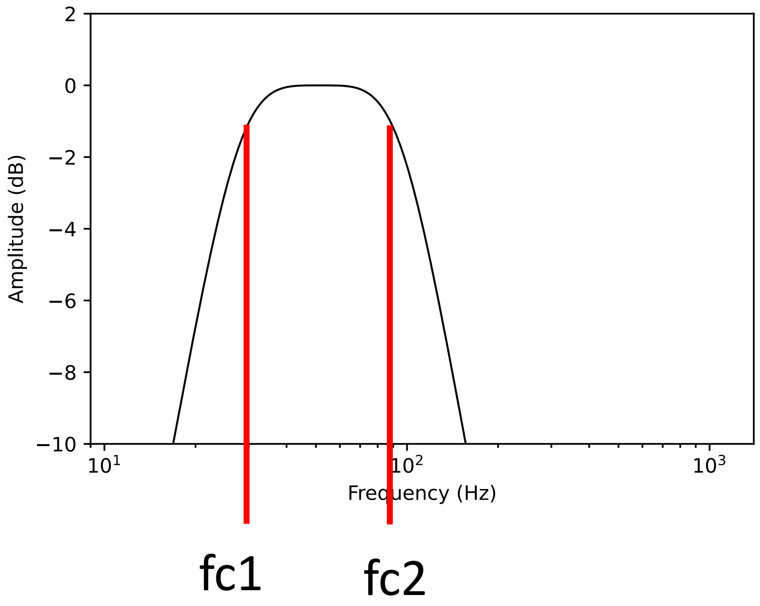
Stimuli spectra std



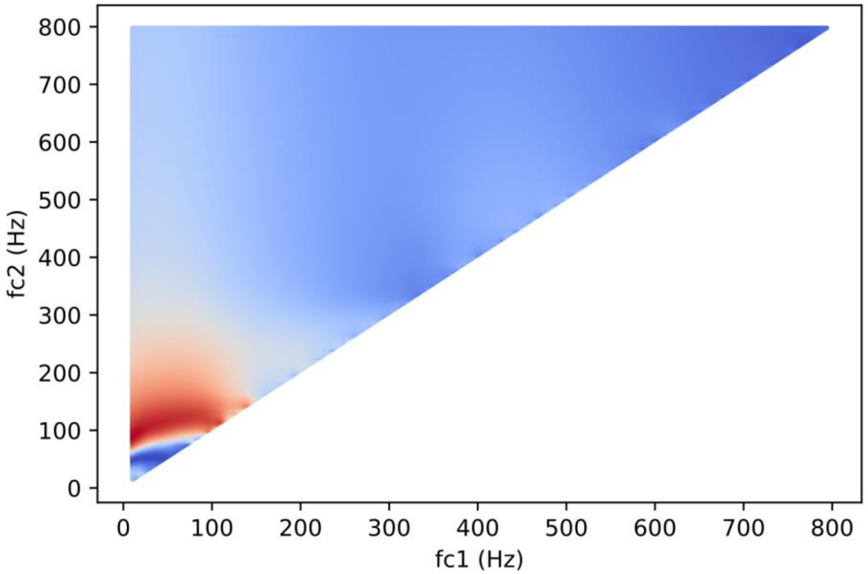
Can we predict the intensity ratings ?

- Looking for the best filter to predict the results

Band pass filter with varying cut-off frequencies



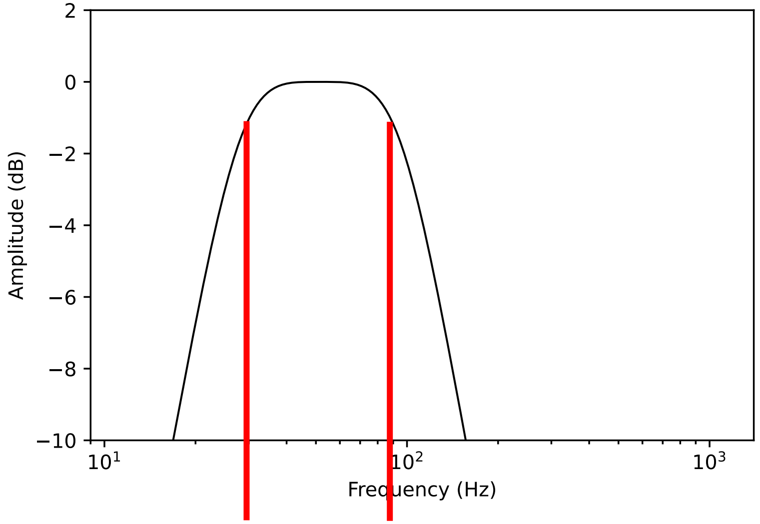
Evolution of the correlation with fc1 and fc 2



Can we predict the intensity ratings ?

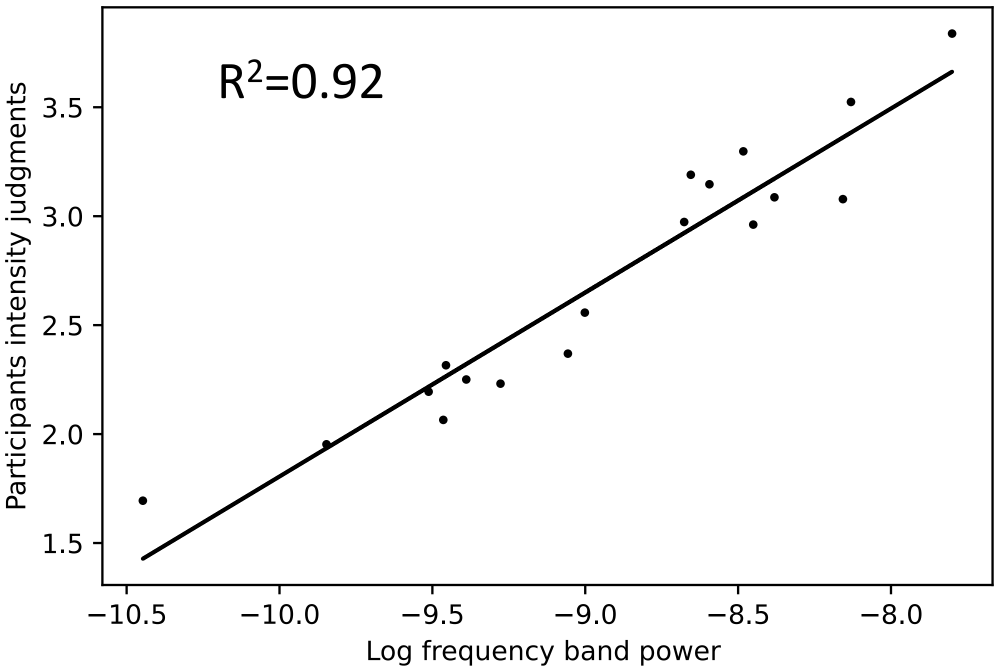
- Looking for the best filter to predict the results

Band pass filter with varying cut-off frequencies



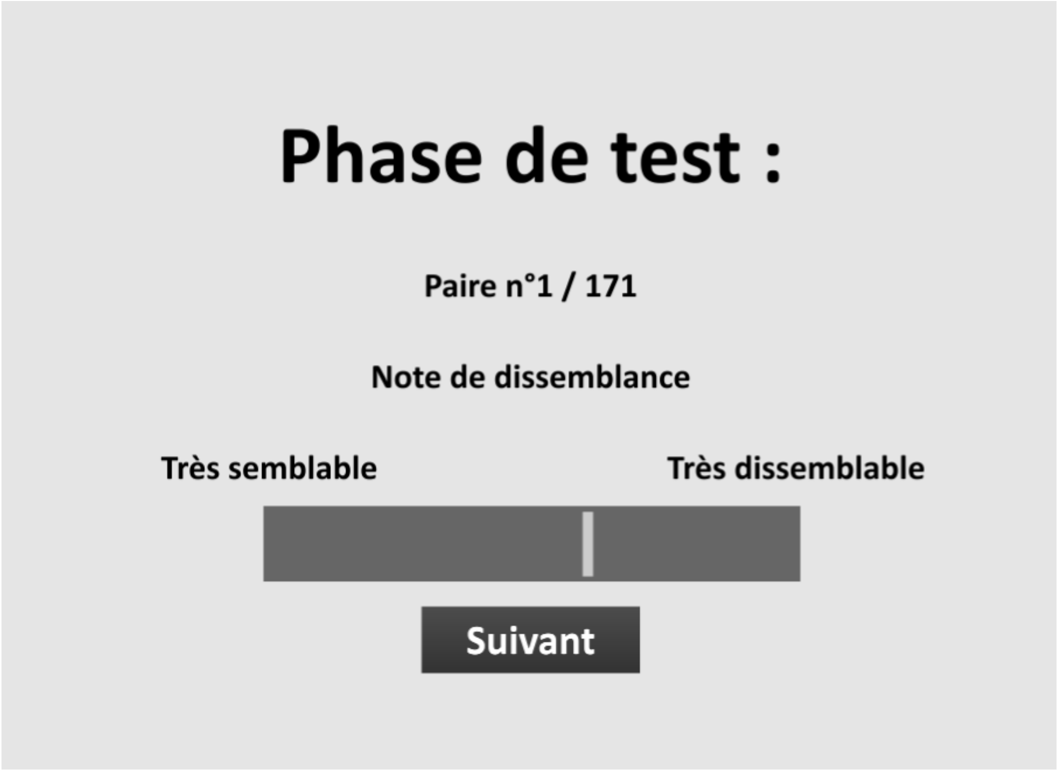
fc1=25 Hz fc2=110 Hz

Linear regression



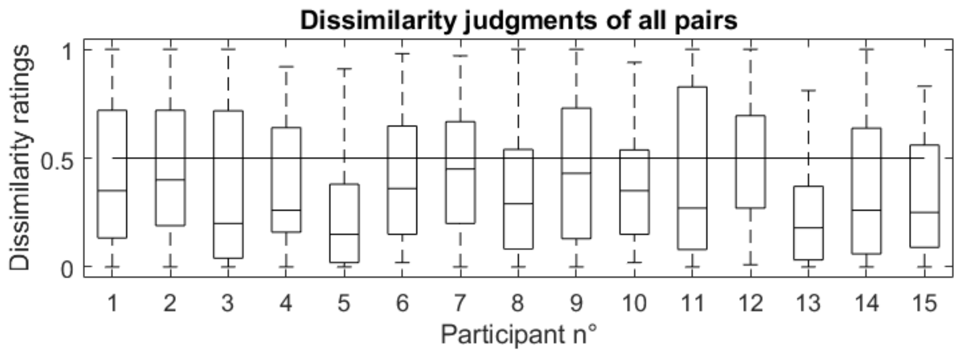
Dissimilarity experiment

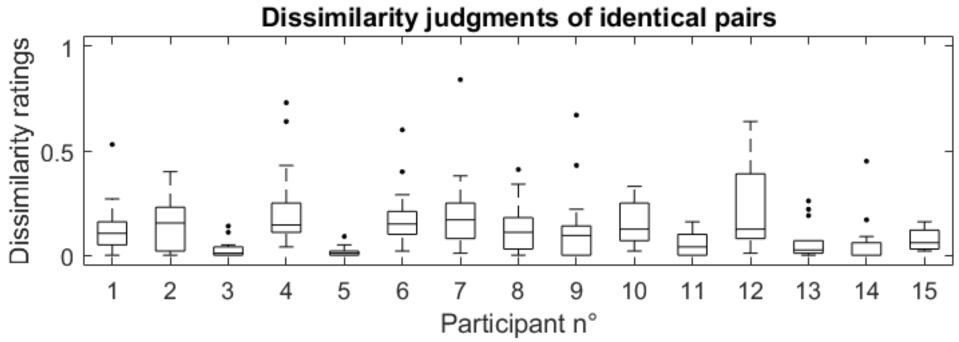
- Judgments of dissimilarities between two vibrations (With equalized stimuli)
- Pair-wise comparison (18 stimuli →171 pairs)
- Training session (30 pairs)



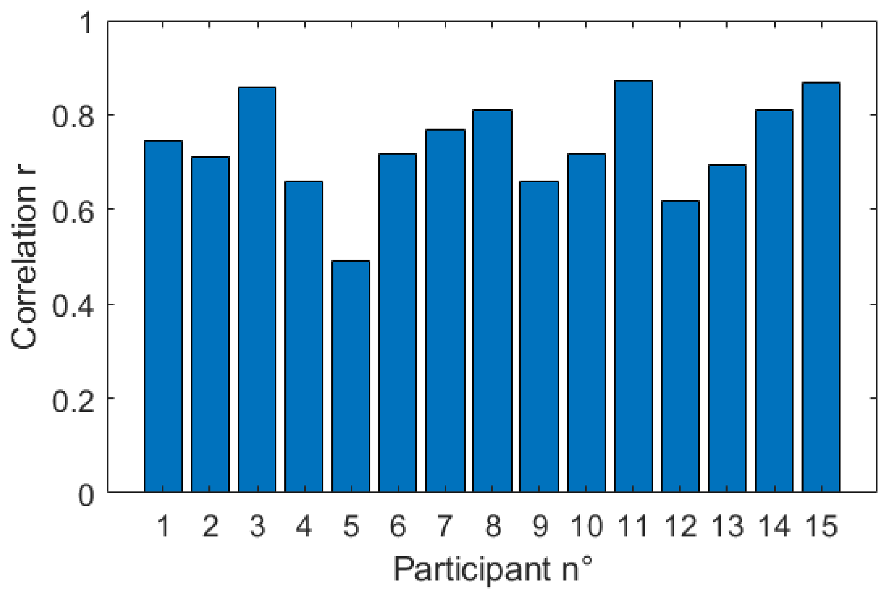
Participants

- 15 participants
- Between-subjects correlations r : mean=**0.51** min=0.17 max=0.84
- Mean judgment of identical pairs: 0.12

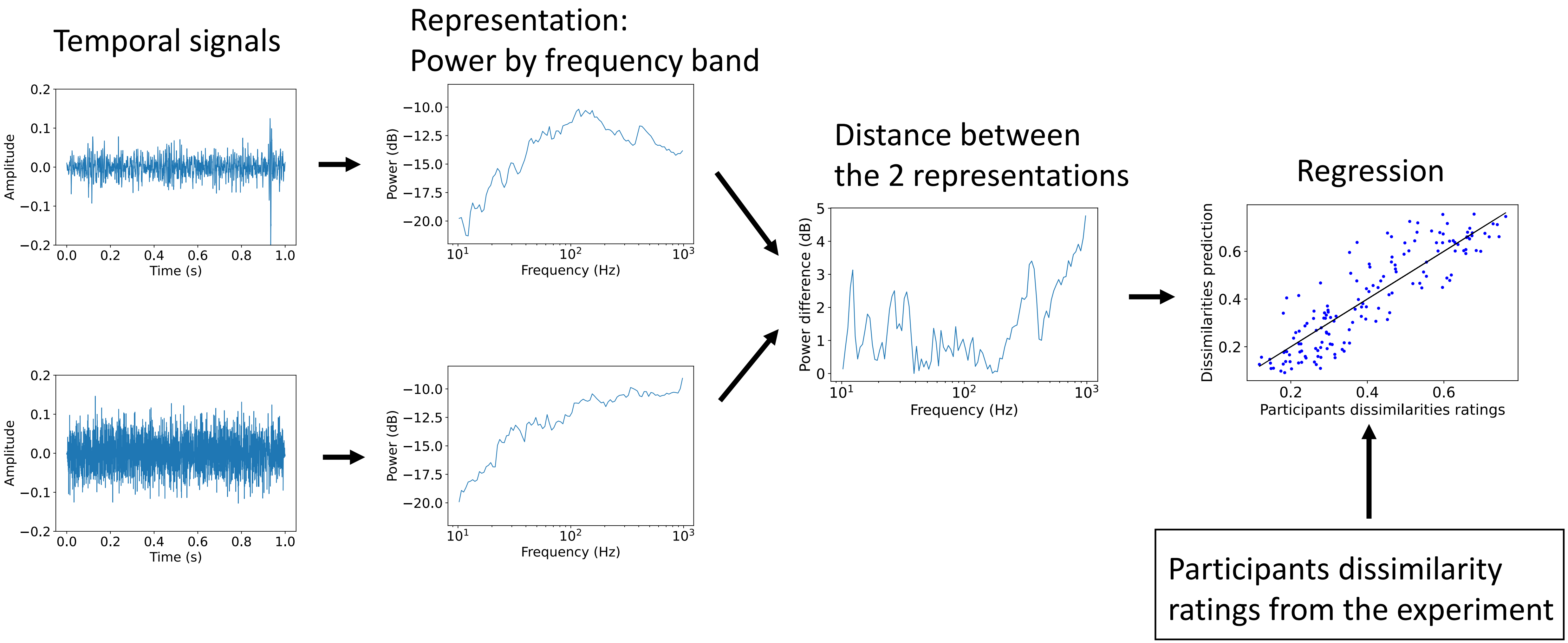




Correlations with mean ratings



Participant ratings prediction methodology



Participant rating prediction methodology

For two vibration signals x and y :

- Calculation of the powers $P_i(x)$ and $P_i(y)$ in each frequency band i.
- Local difference in each frequency band:

$$d_i(x, y) = \sqrt{(P_i(x) - P_i(y))^{\mathbf{2}}}$$

- Global dissimilarity estimation:

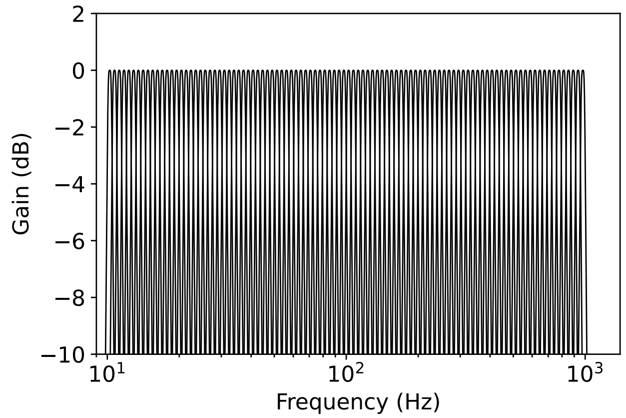
$$\mathrm{D}(x, y) = \sum_i w_i d_i(x, y) \qquad \text{with} \quad w_i > 0$$

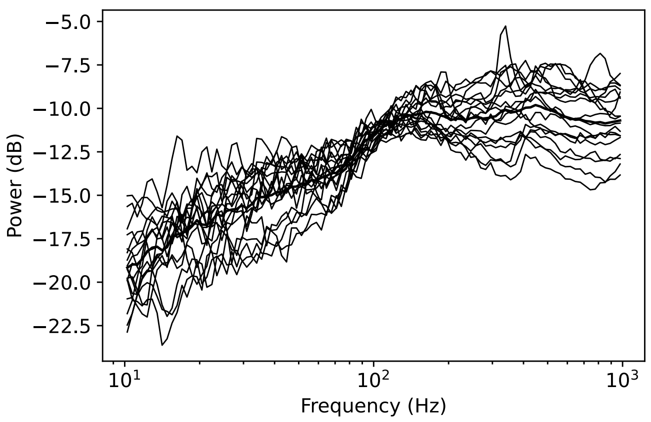
- Analysis to find the optimal weights w_i to fit dissimilarity judgments
  Lasso Regression (regression with regularization)

Can we predict participants ratings ?

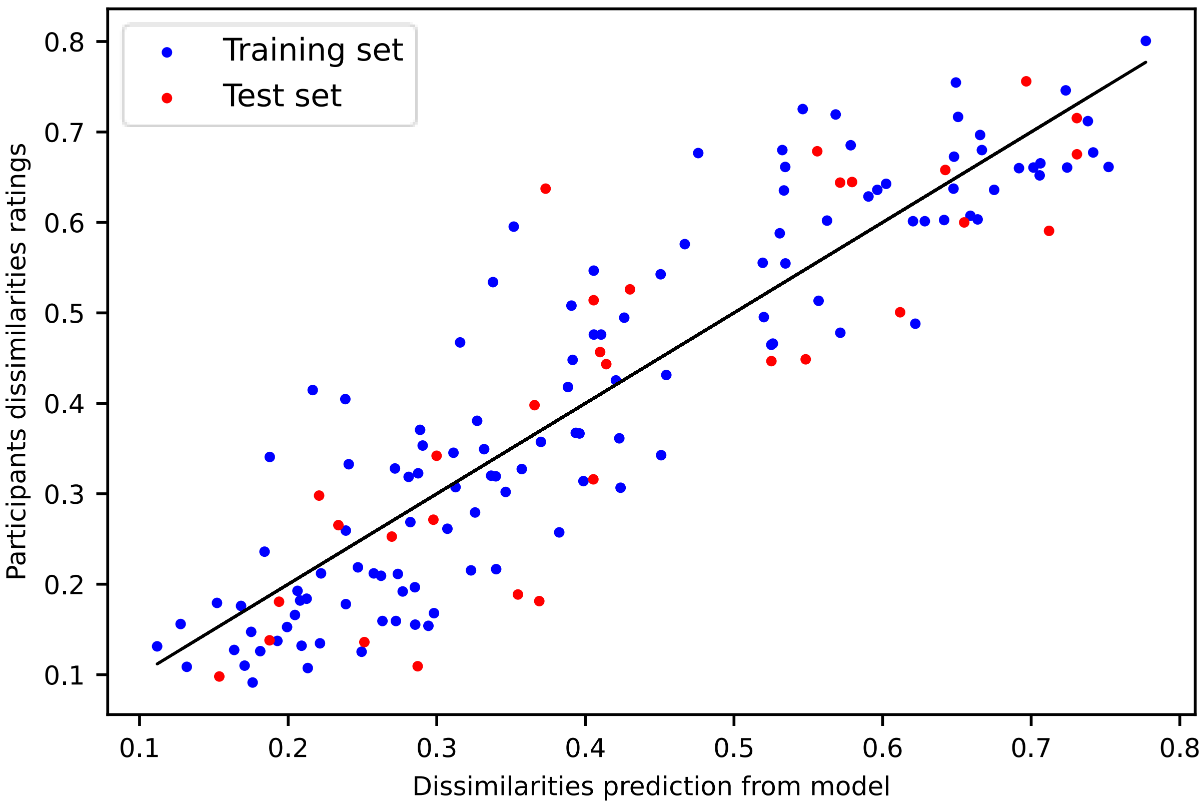
Representation :

Power by frequency band



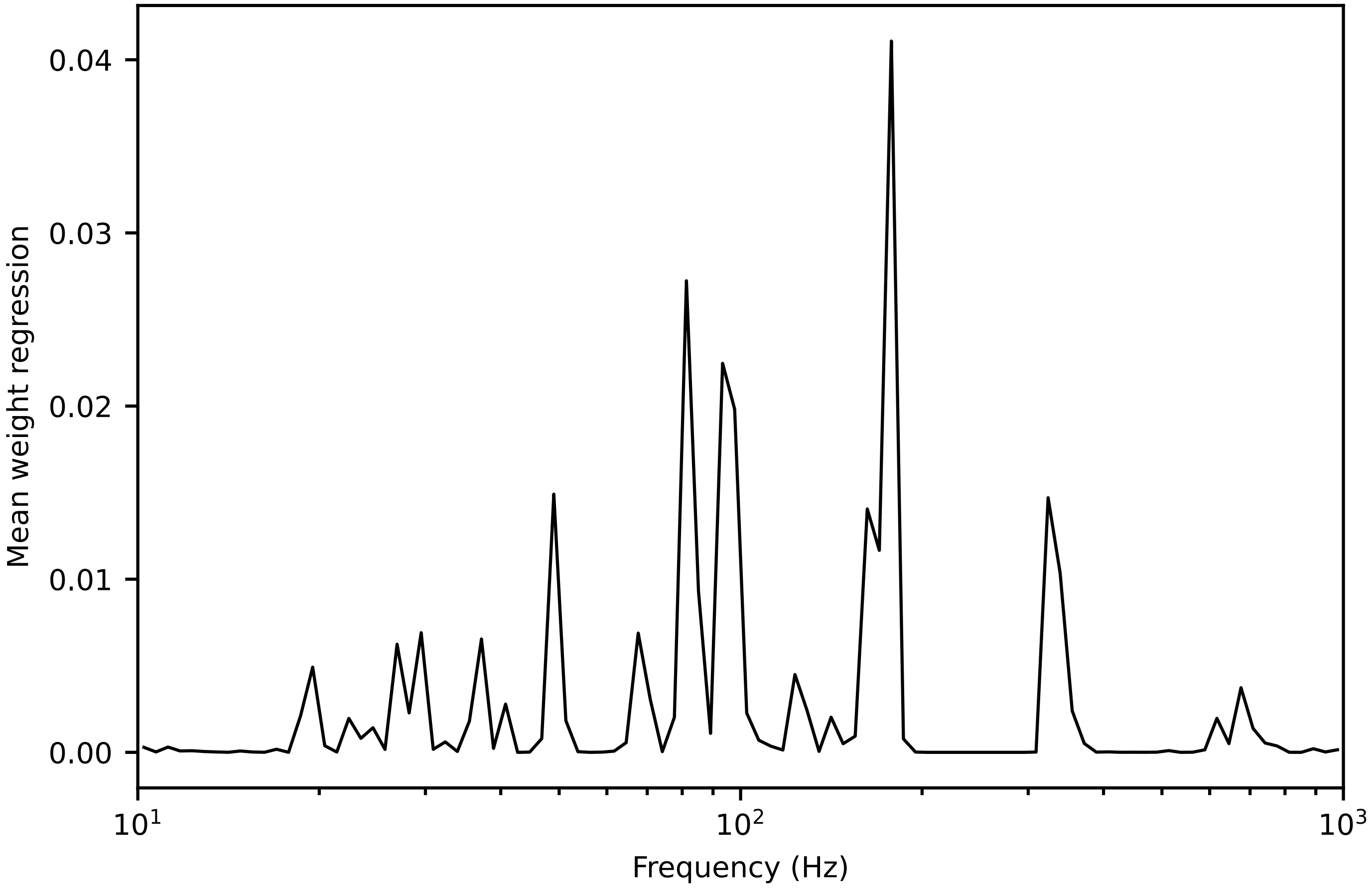


Lasso regression result: mean R^2(test)= 0.77



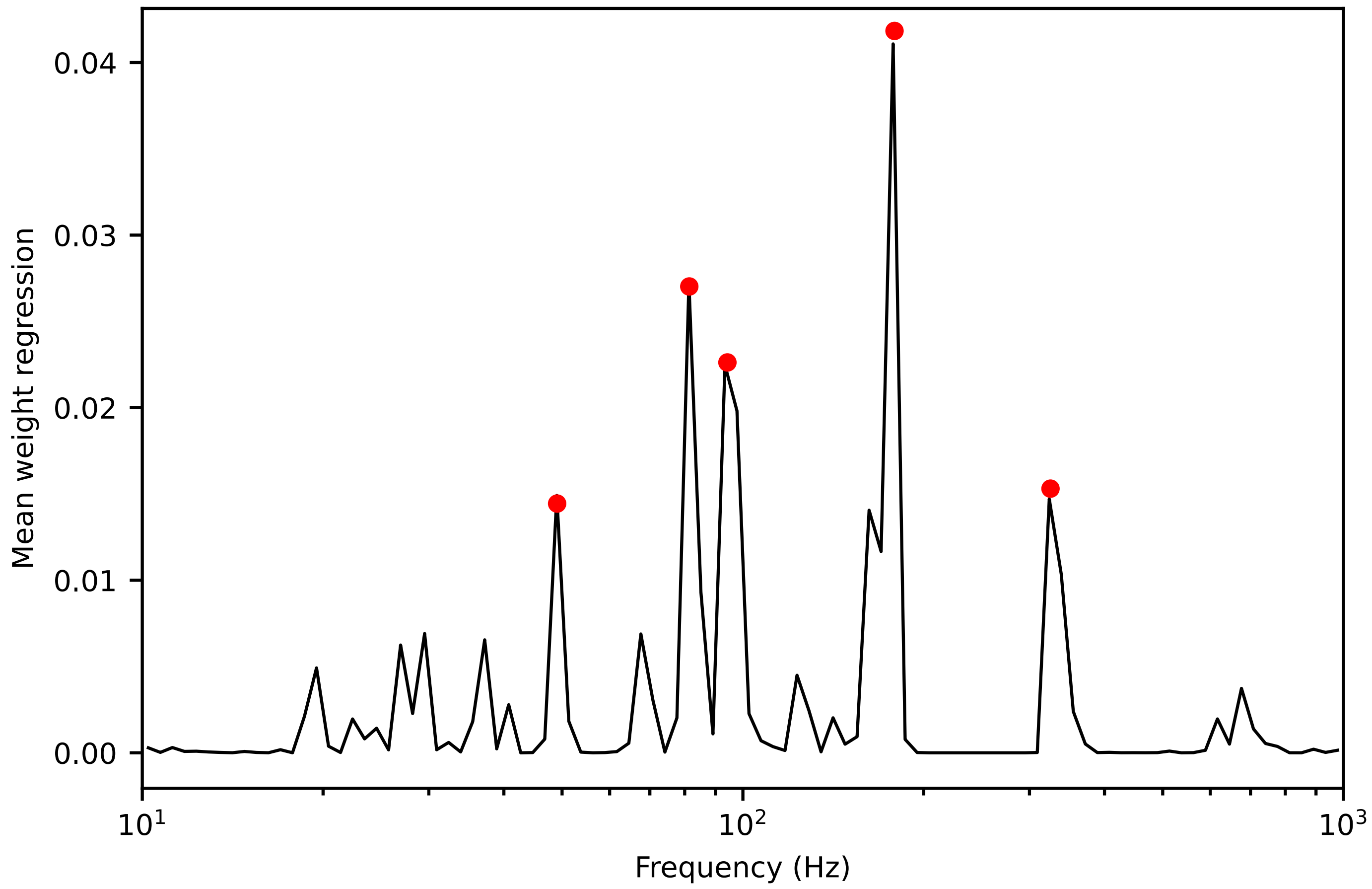
What is used for the prediction ?

Interpretation of the weights w_i applied to each frequency band



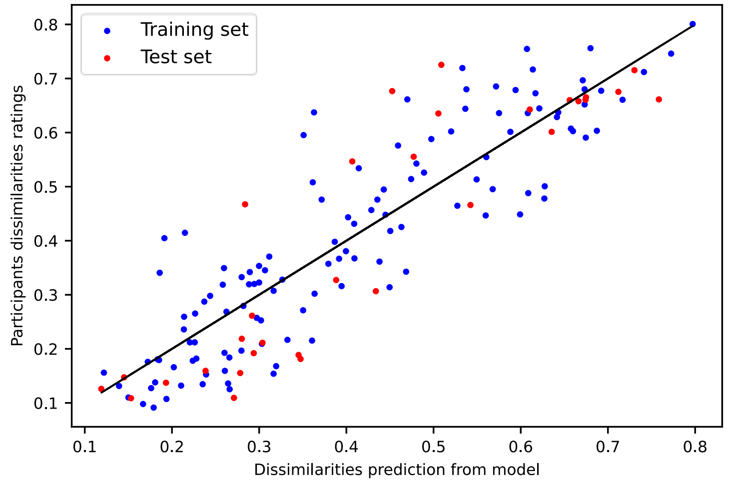
What is used for the prediction ?

Interpretation of the weights w_i applied to each frequency band



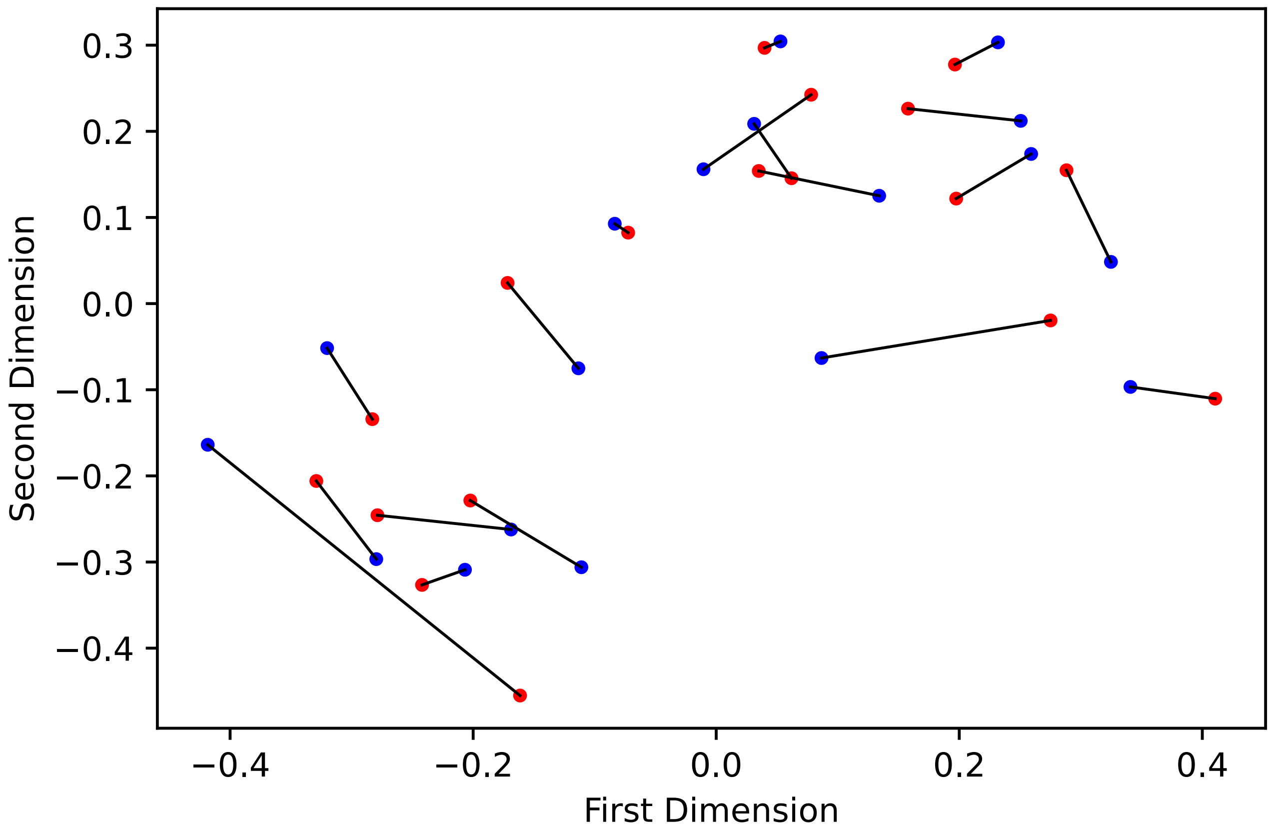
Regression with only 5 frequency bands

Mean R^2(test) = 0.78



Multidimensional scaling (MDS)

Red = participant ratings,   Blue = prediction (model with 5 frequency bands)



Conclusion and discussion

Perception of vibration intensity

- Prediction of participants intensity judgments (R^2=0.92)
- Importance of the 25-110 Hz range

Perception of dissemblance

- Prediction of participants dissimilarity judgments (R^2=0.78)
- Prominence of some frequency bands (50, 80, 100, 180, 330 Hz)
- Potential of the approach for signal compression

Limitations:

- Dependance on the dataset
- Does not consider finger movement

Future work: resynthesis

Are these 5 bands necessary? (substrative synthesis)

Are these 5 bands sufficient? (additive synthesis)