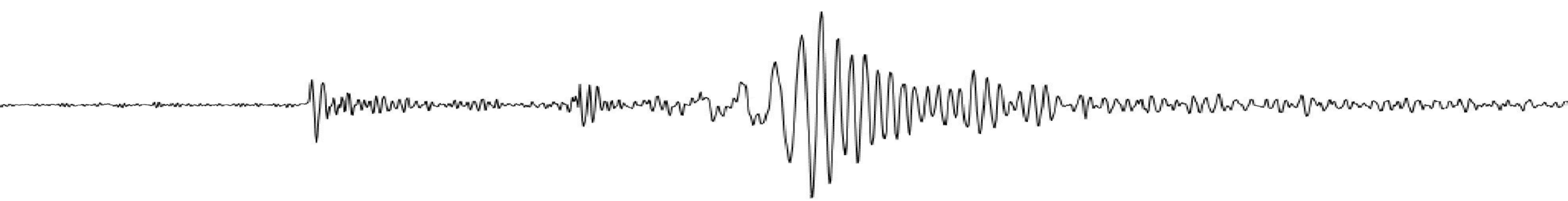
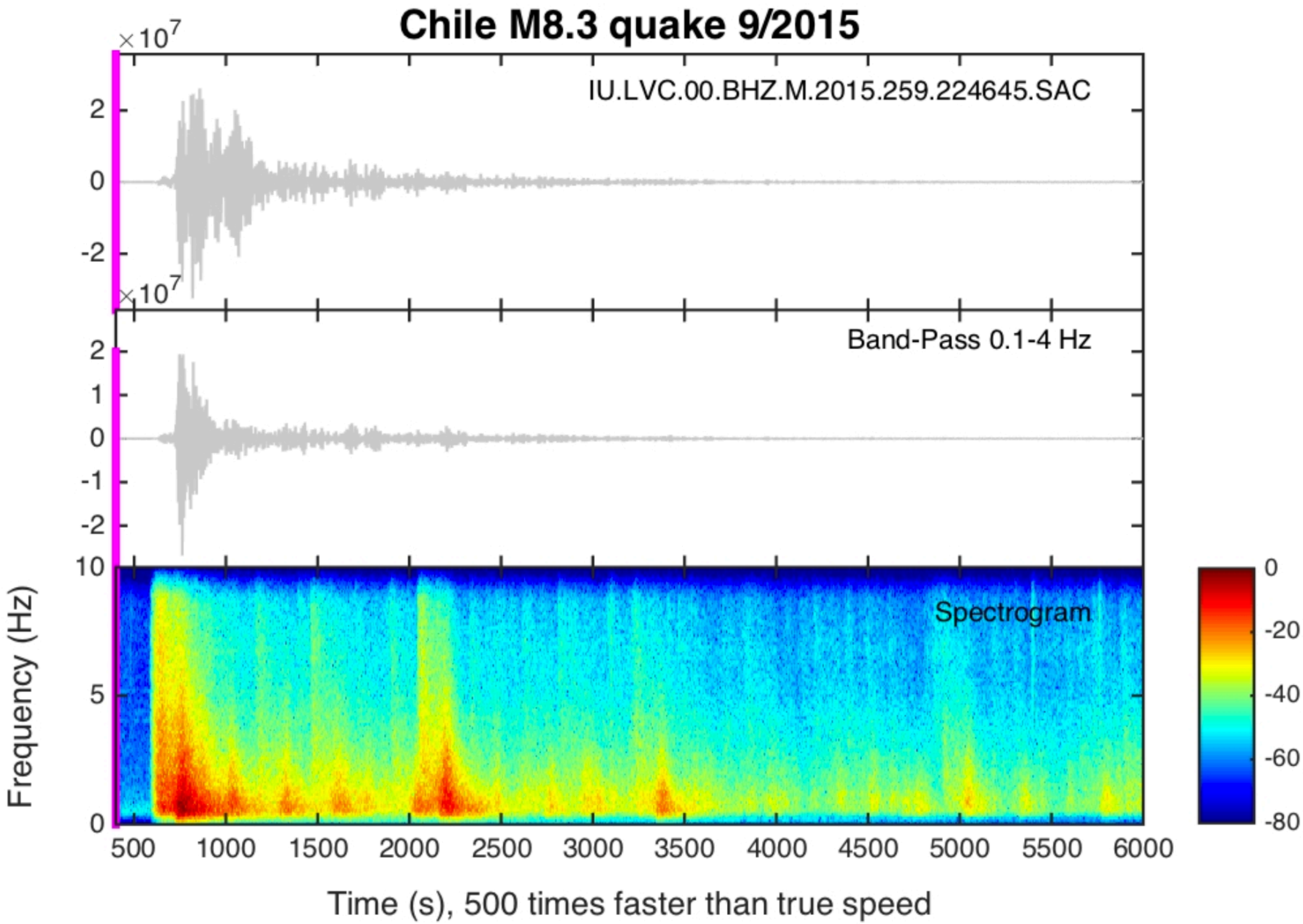
on the perception of audified seismograms



L. Boschi, Université Pierre et Marie Curie, Paris, France
With: Arthur Paté, Ben Holtzman (Lamont); Jean-Loïc le Carrou, Claudia Fritz, Danièle Dubois (UPMC); Laurianne Delcor (UPMC/LVA/Airbus); Piero Poli (MIT)



data from IRIS, software by Zhigang Peng

literature on sonification in seismology and why it was abandoned

Speeth, Sheridan D., 1961. Seismometer sounds. J. Acoust. Soc. Am. 33 (7), 909–916.

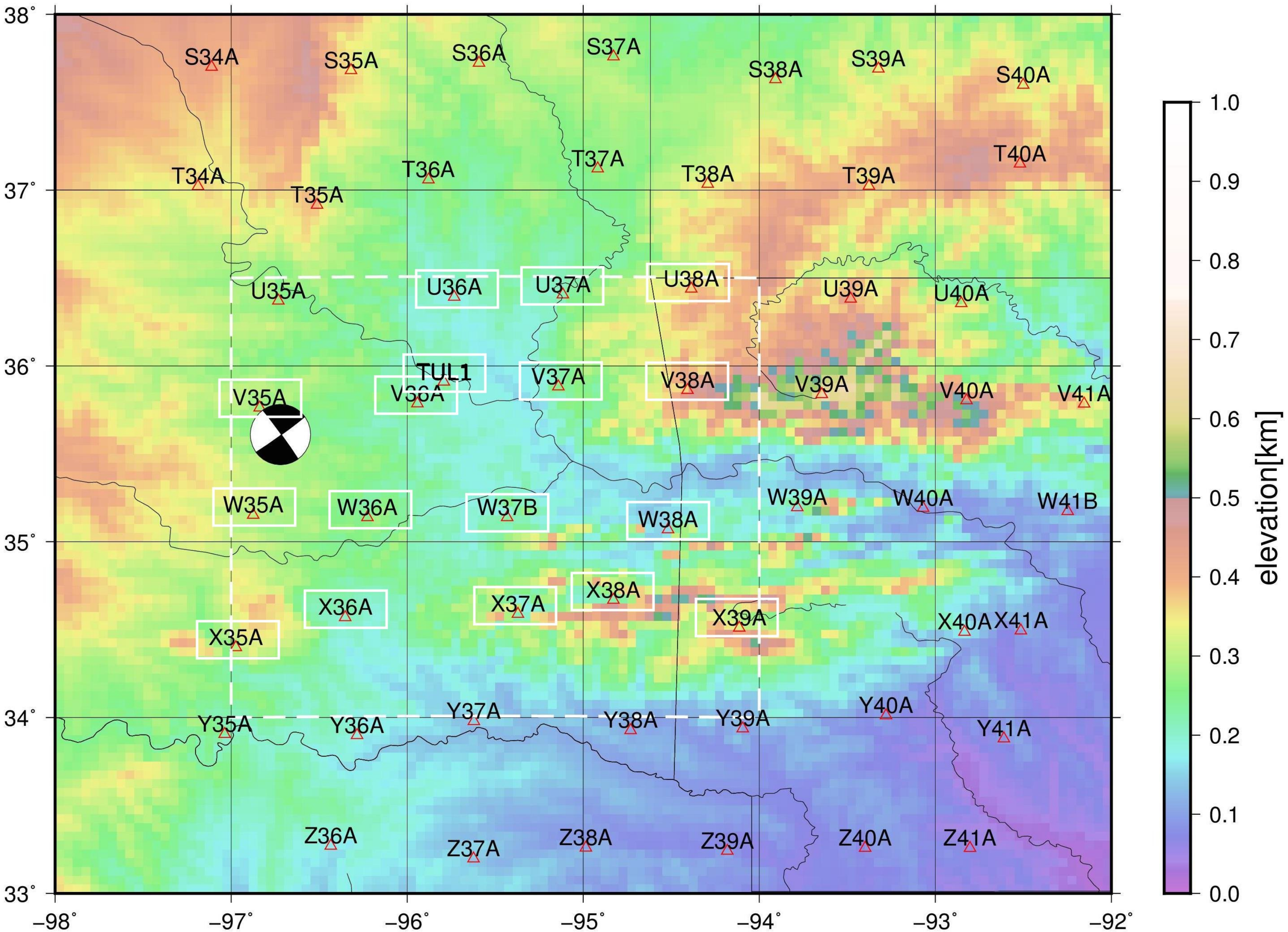
Frantti, G.E., Levereault, L.A., 1965. Auditory discrimination of seismic signals from earthquakes and explosions. Bull. Seismol. Soc. Am. 55 (1), 1–25.

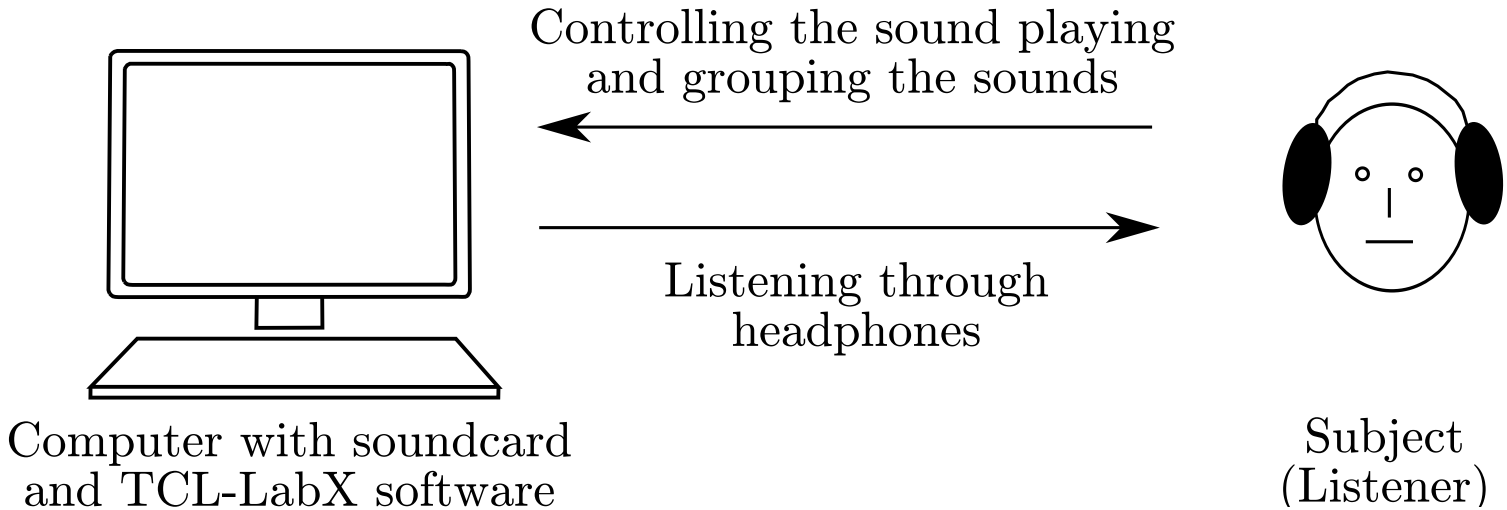
Listening to the Cold War:
The Nuclear Test Ban Negotiations, Seismology, and Psychoacoustics, 1958–1963

*by Axel Volmar**

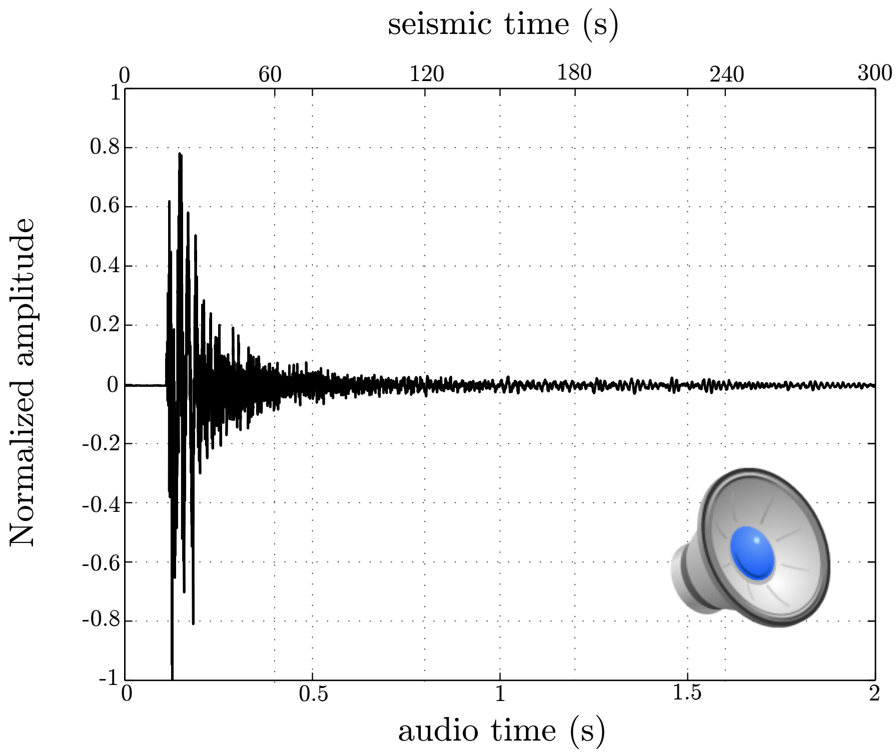
OSIRIS 2013, 28 : 80–102

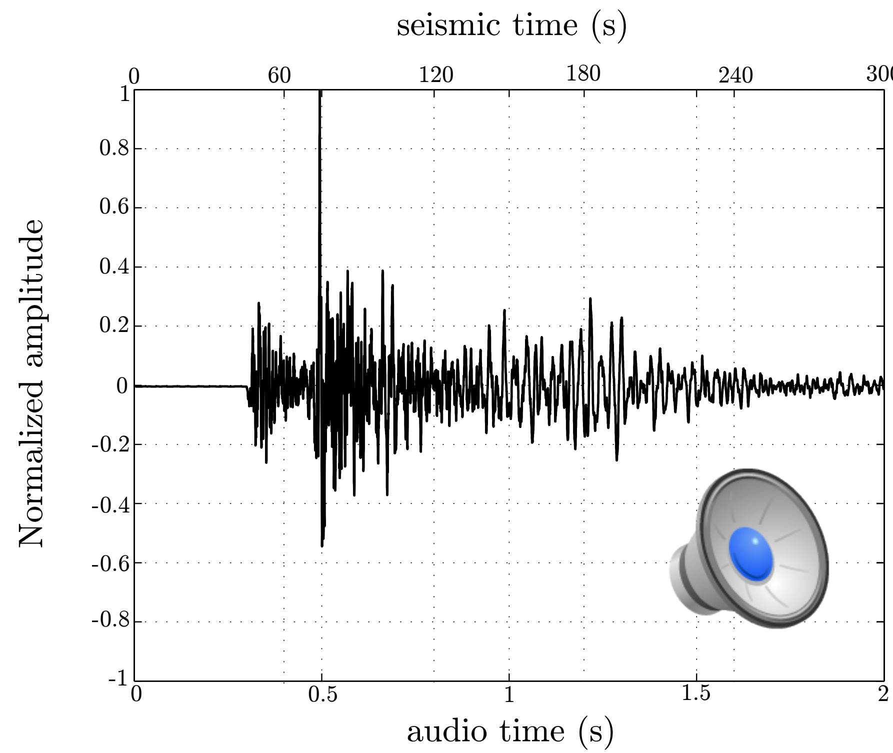
well-studied magnitude-5.6 Oklahoma event, Nov 6, 2011



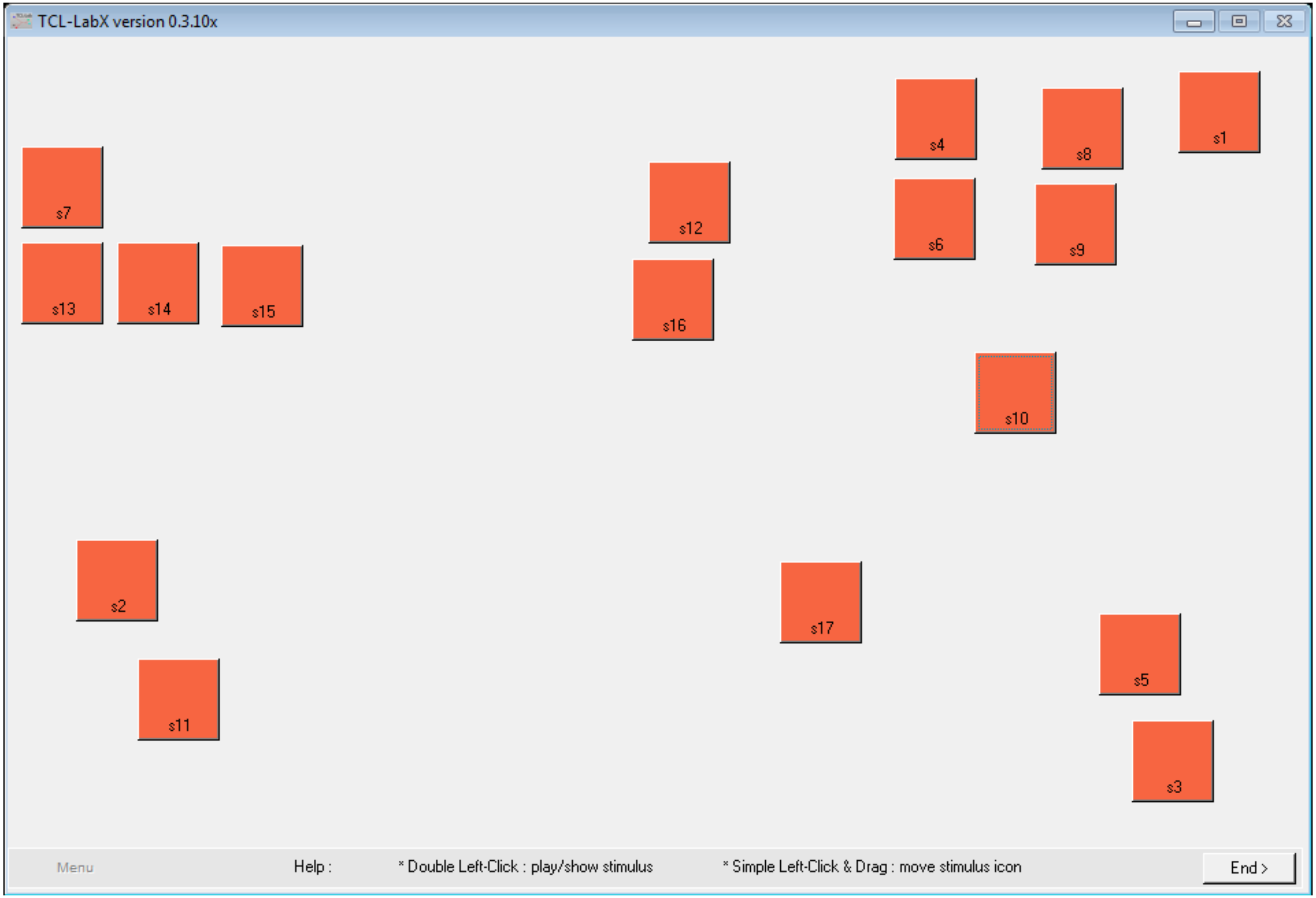

Controlling the sound playing
and grouping the sounds
Listening through
headphones
Computer with soundcard
and TCL-LabX software
Subject
(Listener)

signals audified via Matlab <u>audiowrite</u>, speed up factor = 150





free-categorization task: TCL-LabX interface

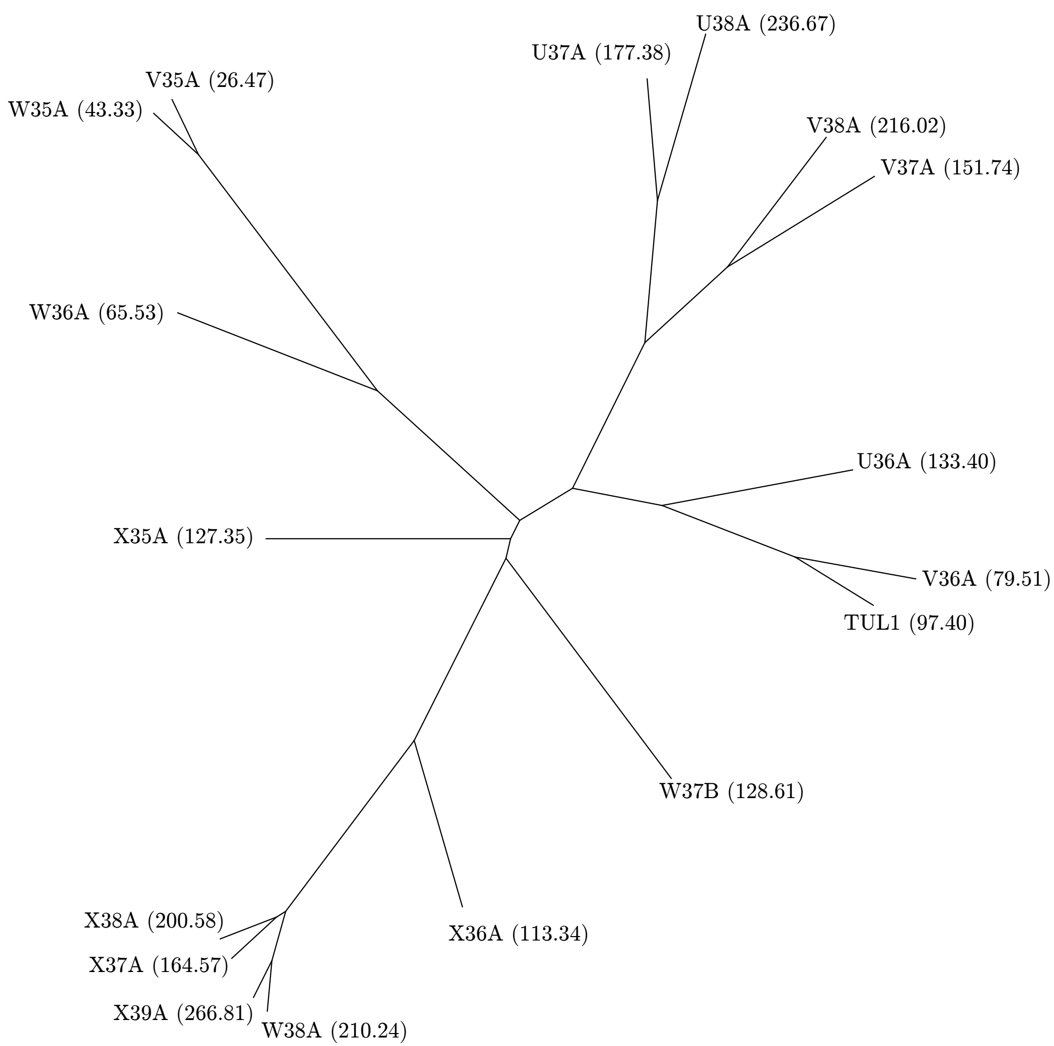


during one realization of the experiment...

free-categorization task: TCL-LabX interface

...and at the end of one realization of the experiment

summary of free-categorization results: "tree" analysis



4.2. Tree analysis

The tree analysis aims at defining a perceptual distance between stimuli, and to represent this distance on an "additive tree". We follow the classic criteria described by, *e.g.*, Paté et al. (2014) and Guastavino (2003), which can be summarized as follows:

(i) Compute an "individual" co-occurrence matrix M^k (square matrix whose size is defined by the number of stimuli, *i.e.* 17 × 17 in the present case) for each subject k ($k = 1, 2, \dots, 24$):
- $M^k_{ij} = 1$ if stimuli i and j are in the same group according to subject k;
- $M^k_{ij} = 0$ if stimuli i and j are in different groups according to subject k.

(ii) Calculate the total co-occurrence matrix, defined as the sum of all K individual co-occurrence matrices: $M_{ij} = \sum_{k=1}^{K} M^k_{ij}$ (M_{ij} is large if stimuli i and j are often grouped together, and 0 if they are never grouped together).

(iii) Convert the co-occurrence measure into the distance matrix D such that $D_{ij} = 1 - M_{ij}/17$ (D_{ij} is small if M_{ij} is large; $D_{ij} = 0$ if stimuli i and j are always grouped together, and 1 if they are never grouped together).

The matrix D is a "consensual" measure of perceptual distance, since it expresses a consensus among subjects, and smooths the differences between subjects. The information contained in D can be visualized by a "tree," as described by Barthélémy and Guénoche (1991): each sound stimulus is represented by a "leaf," and leaves are linked together through "branches," whose length is proportional to the perceptual distance D between leaves/stimuli. For instance, if one has to climb (or descend) along many and/or long branches to go from leaf A to leaf B, that means that stimuli A and B have been perceived as very different by the subjects. We find the best-fitting tree to our D via Jacques Poitevineau's *Addtree* software (Poitevineau, 2014a).

summary of free-categorization results: "tree" analysis

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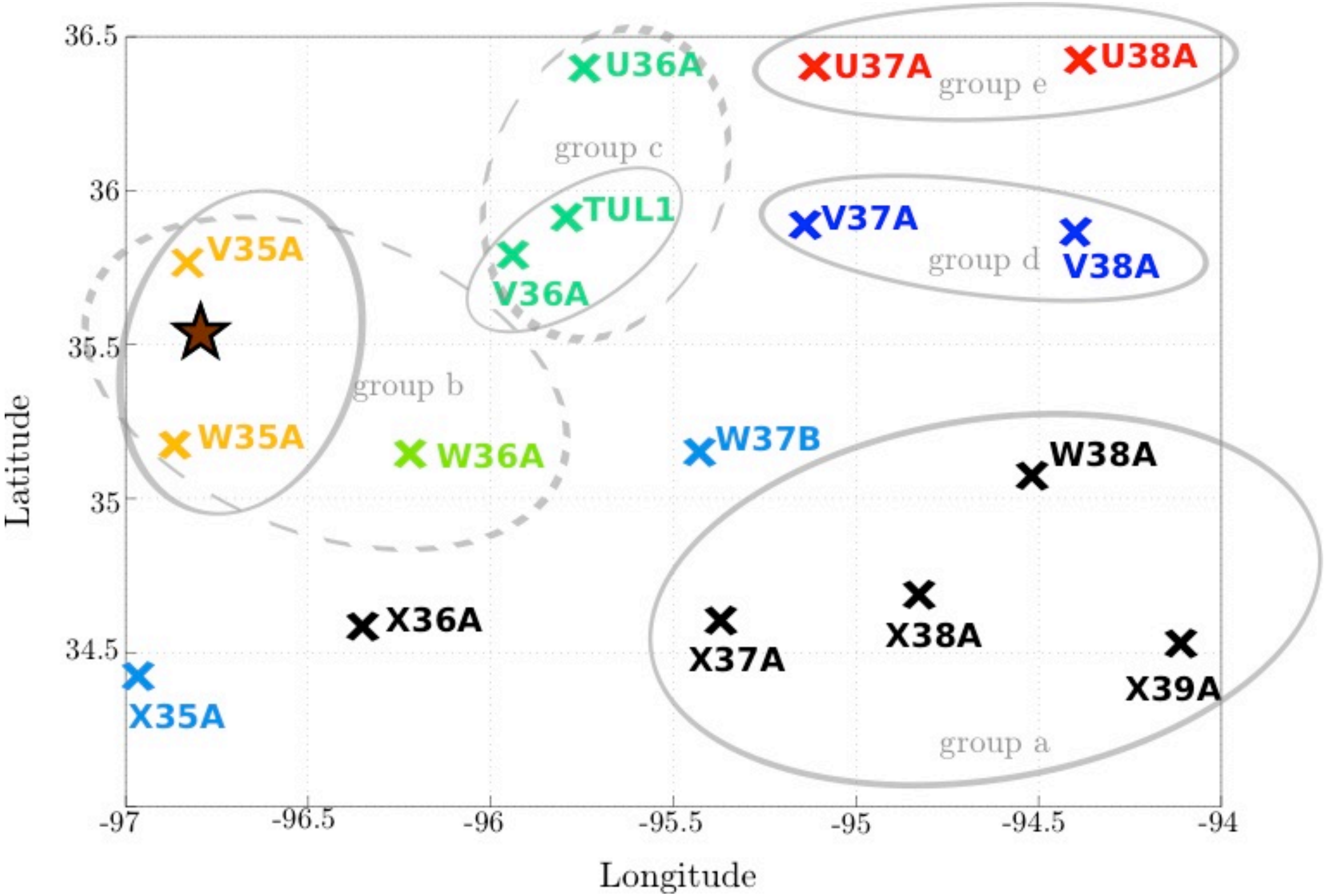
summary of free-categorization results: what do the groups correspond to?



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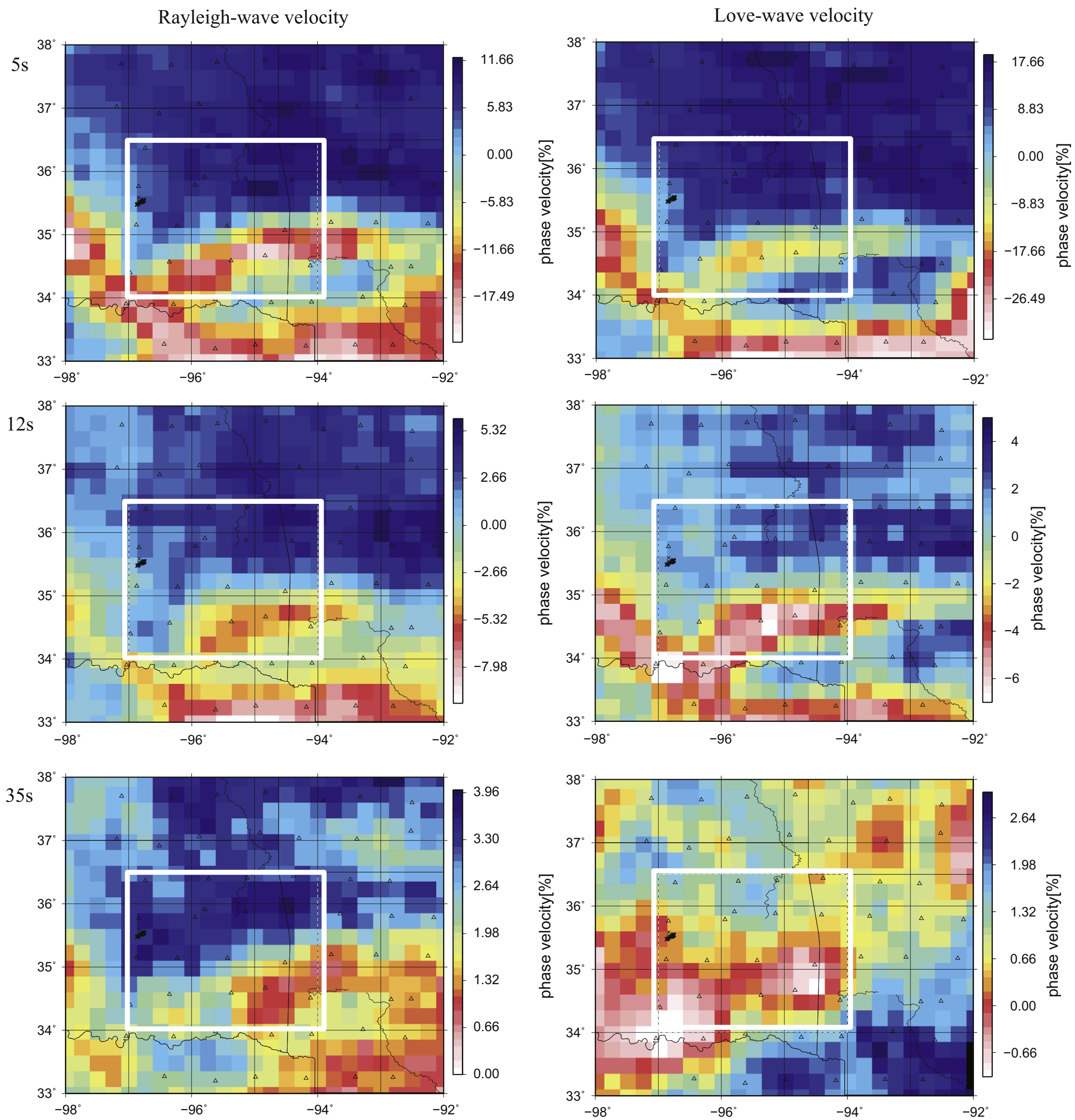
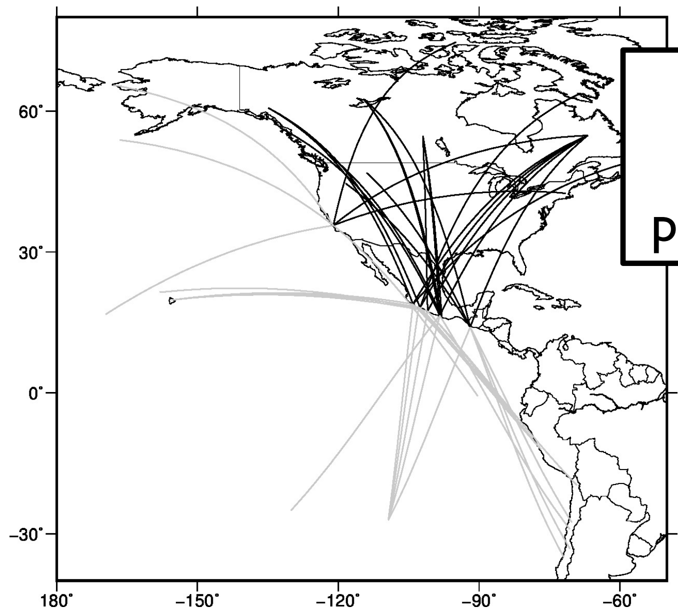


phase velocities in the region of study (model by Göran Ekström)

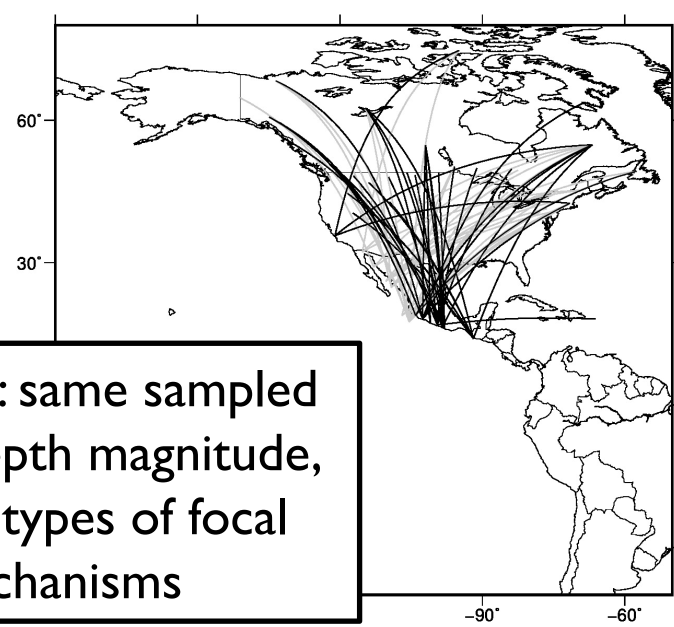
summary of free categorization test (Paté et al., 2016)

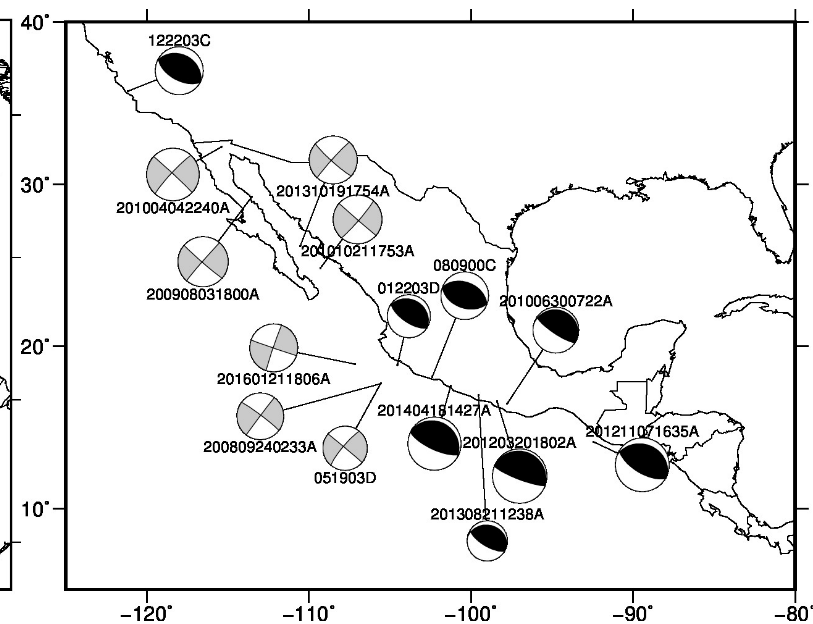
1. subjects behave similarly and some coherent categories emerge
2. those categories can be explained in terms of several geological features
3. we are unable to disentangle those geological features from one another

second experiment: constrained categorization



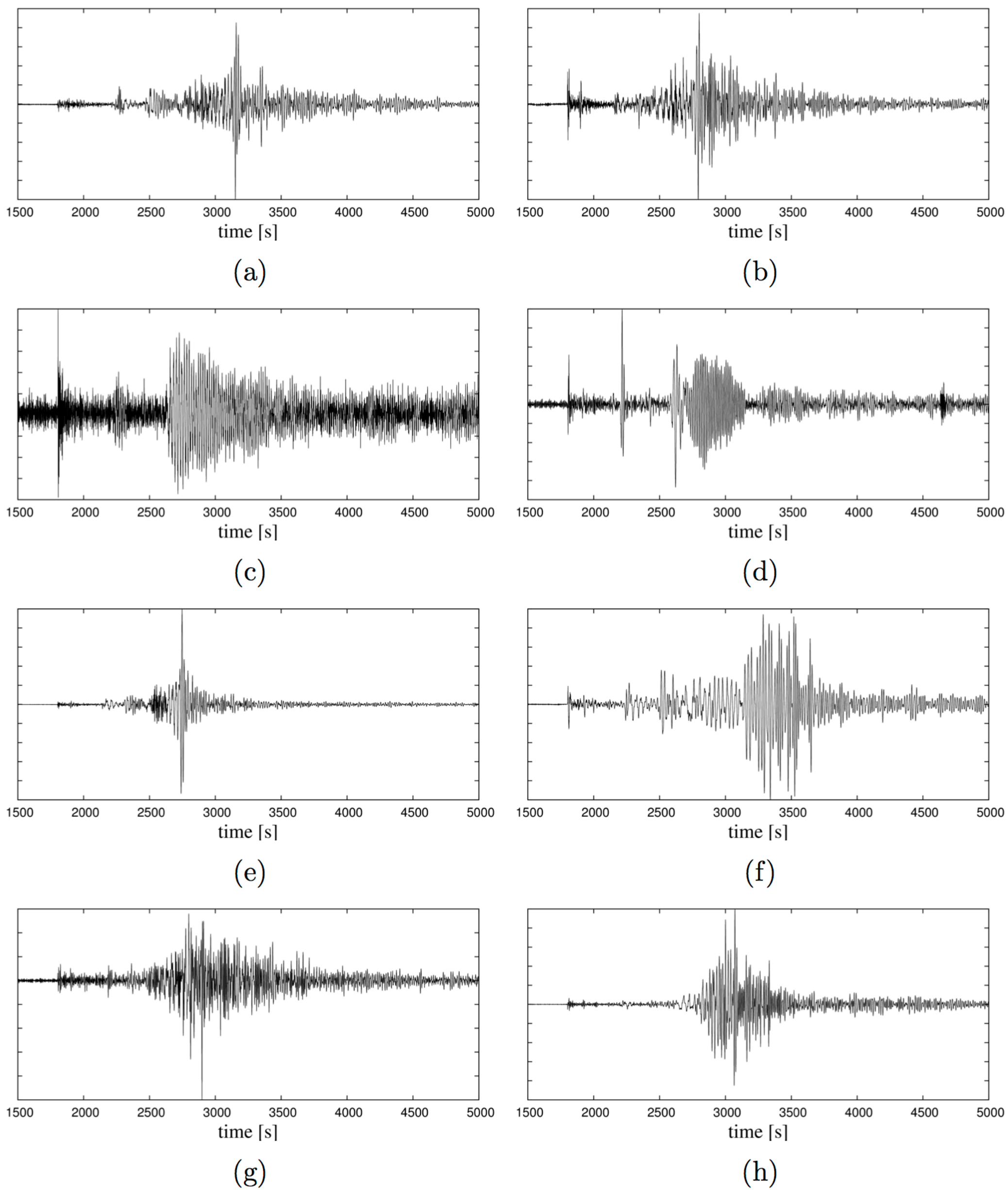
data set 1: same kind of focal mechanism, depth magnitude, but path can sample ocean.OR.continent





data set 2: same sampled terrain, depth magnitude, but two types of focal mechanisms

second experiment: examples of traces



data set 1, continental paths

data set 1, oceanic paths

data set 2, thrust faults

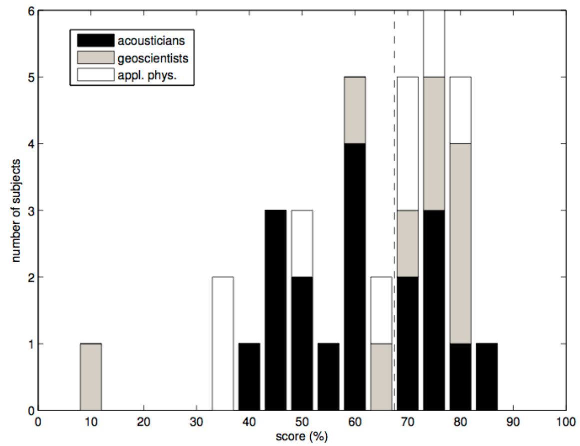
data set 2, strike-slip faults

Table 1: Summary of listening experiments.

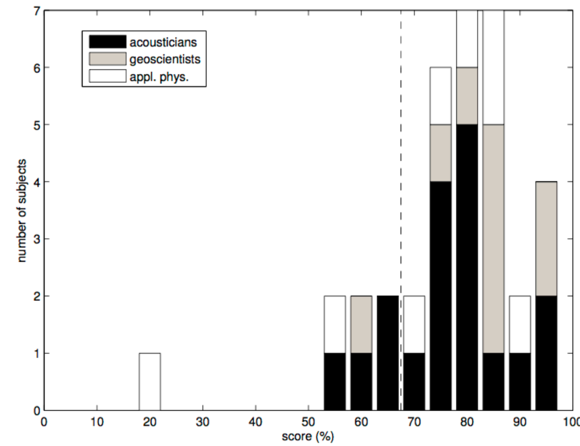
data set	number of waveforms	subjects			audio	visual	training
		A	G	P			
DS1	40	18	9	8	yes	yes	no
DS2	40	15	5	7	yes	yes	no
DS2	36	10	3	4	yes	no	yes

The first two columns to the left indicate how many signals from which data set were presented to the subjects. The letters A, G and P stand for "acousticians," "geoscientists" and "physicists," respectively; "audio" and "visual" indicate which type(s) of data were provided to the subjects; "training" refers to whether subjects were trained before taking the test.

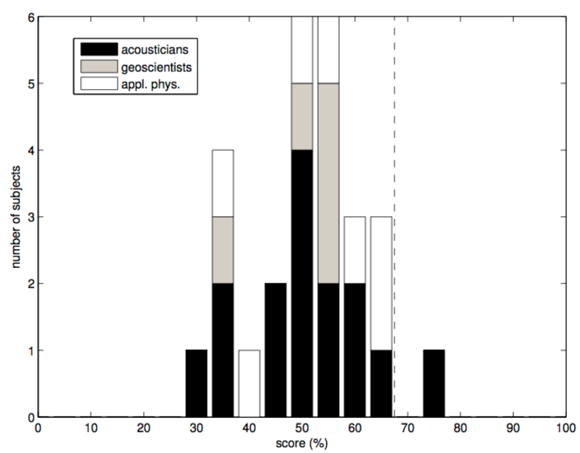
constrained categorization: summary of results



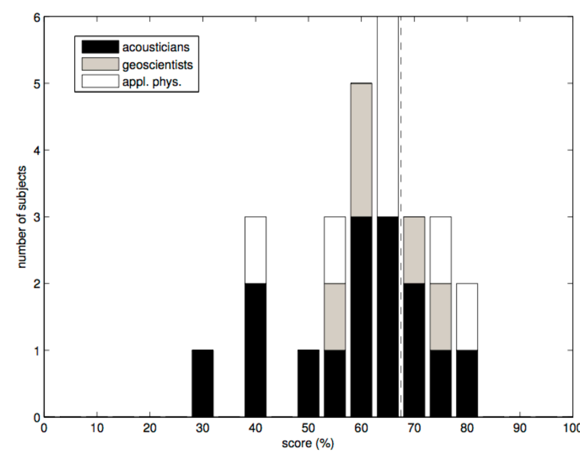
(a) DS1, auditory



(b) DS1, visual

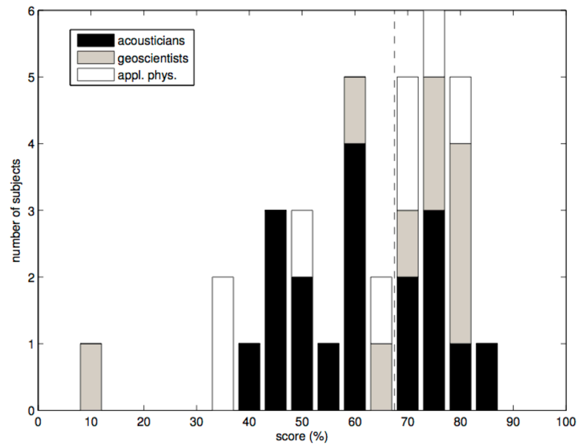


(c) DS2, auditory

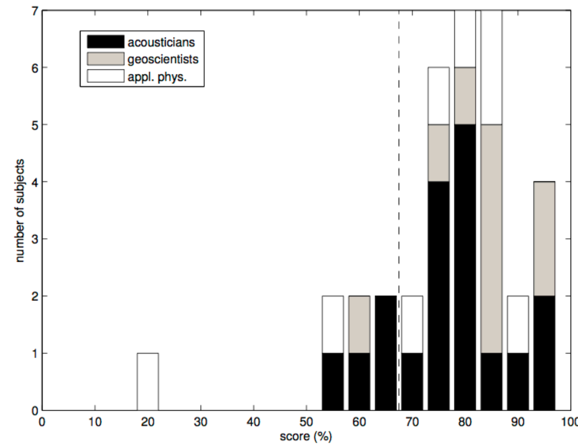


(d) DS2, visual

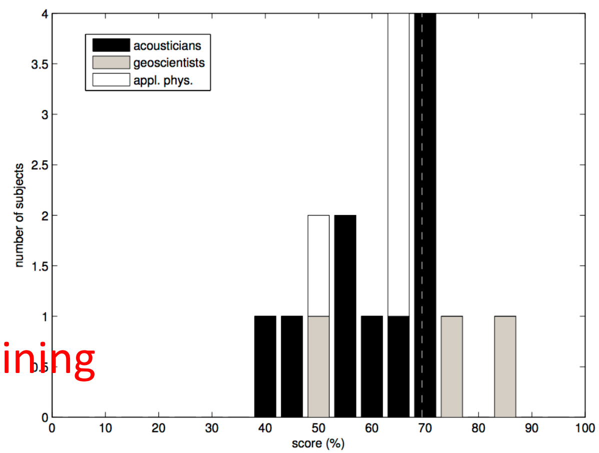
constrained categorization: summary of results after training



(a) DS1, auditory

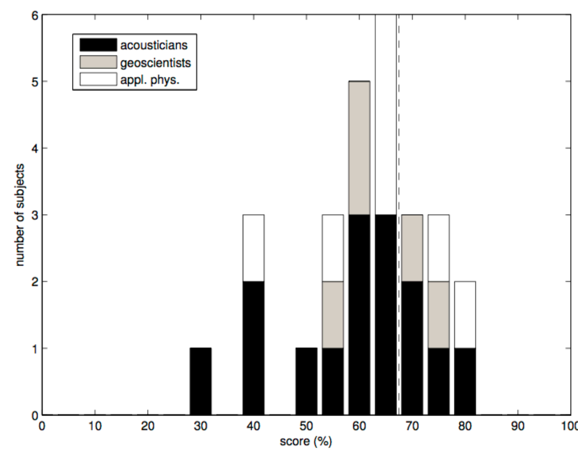


(b) DS1, visual



after training

(c) DS2, auditory



(d) DS2, visual

constrained categorization: verbal data

Table 2: Listeners' comments on DS1.

Family A (oceanic paths)	Family B (continental paths)
second shock very close to the first	echo of the first impact's sound
with an echo / rebound	small rebounds
a lot of background noise	little background noise
high-pitched background noise	low-pitched background noise
background noise	shorter and duller sound
longer signal	sharper and shorter
	rising perceived frequency
	faster arrival
	buzz or intense reverberation after the explosion

Summary of written, verbal explanations given by 5 subjects (scoring ≥80%) concerning their auditory cateogorization of DS1. All text was originally in French and has been translated into English as literally as possible.

Table 3: Listeners' comments on DS2.

Family A (strike-slip events)	Family B (thrust events)
first shock weaker than second one	louder low frequencies
wave of rising frequency louder than the first heard shock	first shock louder than the second one
after the detonation, sound decays more slowly	first shock louder than the wave
faster attack and decay	more powerful and present sound
significant intensity even after a long time	sound decays quickly after the detonation
lower-frequency shock	slower decay
duller signal	
higher frequencies	

Summary of written, verbal explanations given by 8 subjects (scoring ≥80%) for the auditory cateogorization of DS2 before (4 subjects scoring > 55%) and after training (4 subjects scoring > 72%). Again, the original French text was translated into English.

constrained categorization: do verbal data correspond to quantitative features of traces?

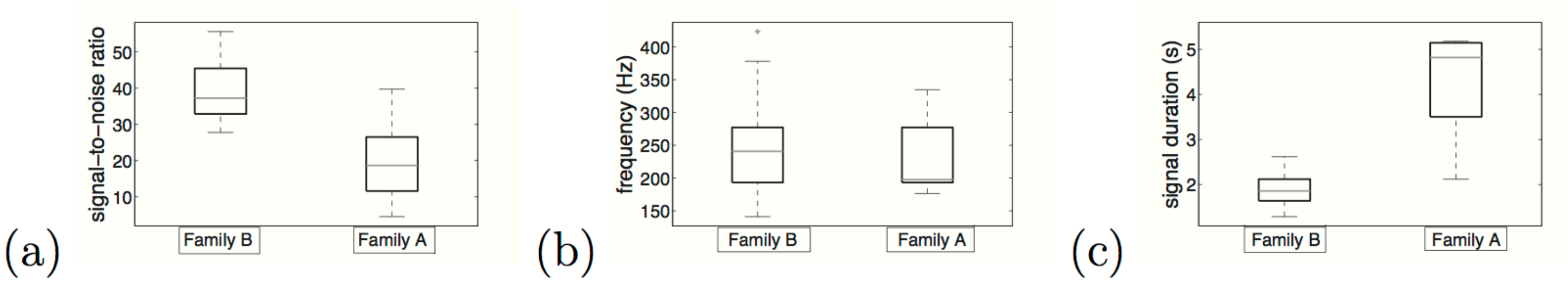


Figure 6: Distributions, shown as box-plots, of three physical parameters, corresponding to properties of the signal that subjects tend to describe as important: (a) SNR; (b) dominant frequency of background noise; (c) duration of meaningful signal. For each parameter, the distributions of parameter values for oceanic-path ("Family A) and continental-path ("Family B) signal are shown separately. Distributions are summarized by their median (thick grey segments), first and third quartiles (upper and lower sides of boxes), and minimum and maximum values (endpoints of dashed lines). Values that we neglect as outliers (their absolute value is more than 1.5 times the interquartile distance) are denoted by grey crosses.

constrained categorization: do verbal data correspond to quantitative features of traces?

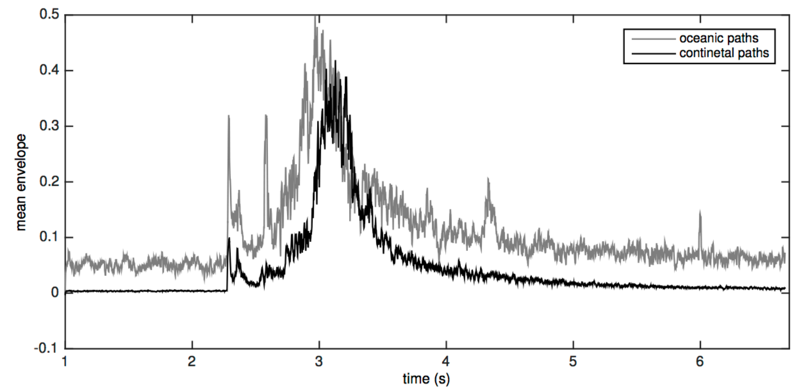


Figure 7: Signal envelope averaged over all DS1 audified seismograms corresponding to continental (black line) vs. oceanic (grey) paths. Each envelope is the average of 20 seismograms, used in actual tests and not as preliminary examples. Seismograms were aligned according to the P-wave arrival.

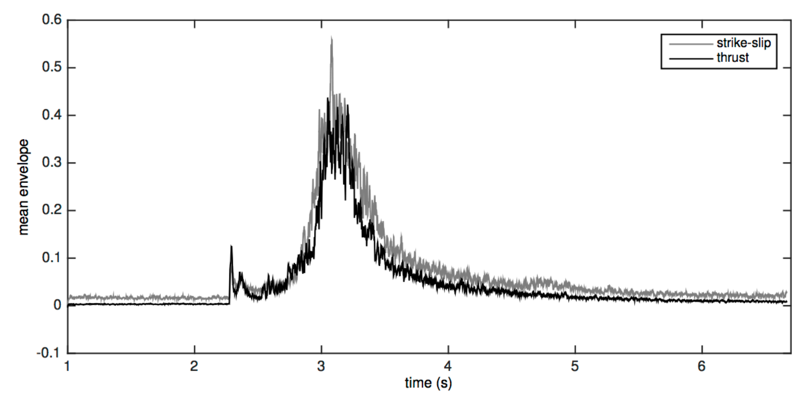


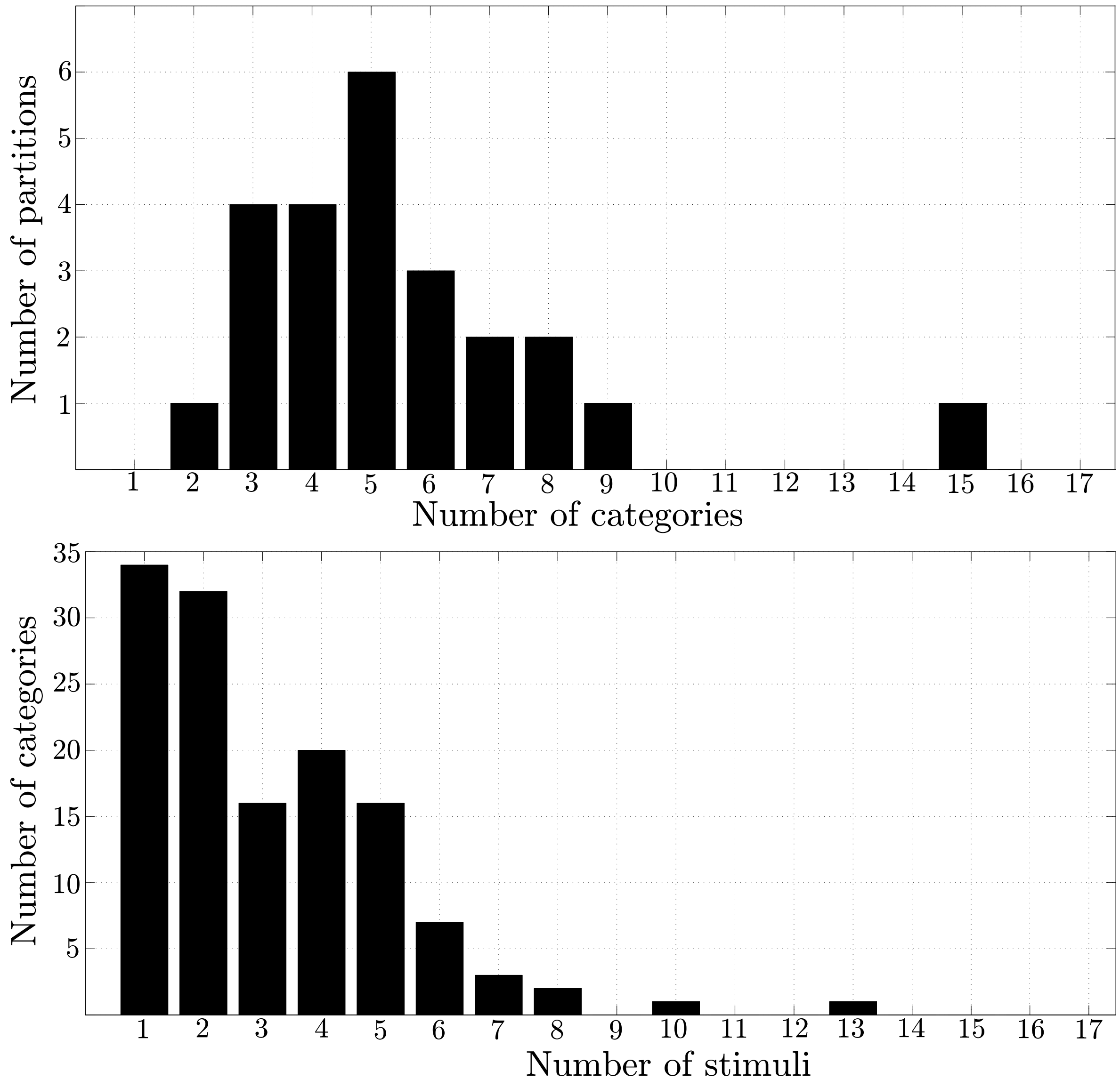
Figure 8: Same as Fig. 7, but envelopes are averaged over all DS2 signals originated from thrust (black line) vs. strike-slip (grey) events.

summary of constrained categorization test (Boschi et al., submitted to SRL)

1. on average, subjects are able to correctly classify seismograms by audition

2. their performance is improved by training

3. criteria that subjects claim to follow correspond to quantitative features in data



Number of partitions
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Number of categories
Number of categories
35
30
25
20
15
10
5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Number of stimuli

MAGNITUDE-5.6 OKLAHOMA EVENT, NOV 6, 2011