MULTIPLE LEVELS OF BRAIN SIGNALS

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SAPIEN LABS

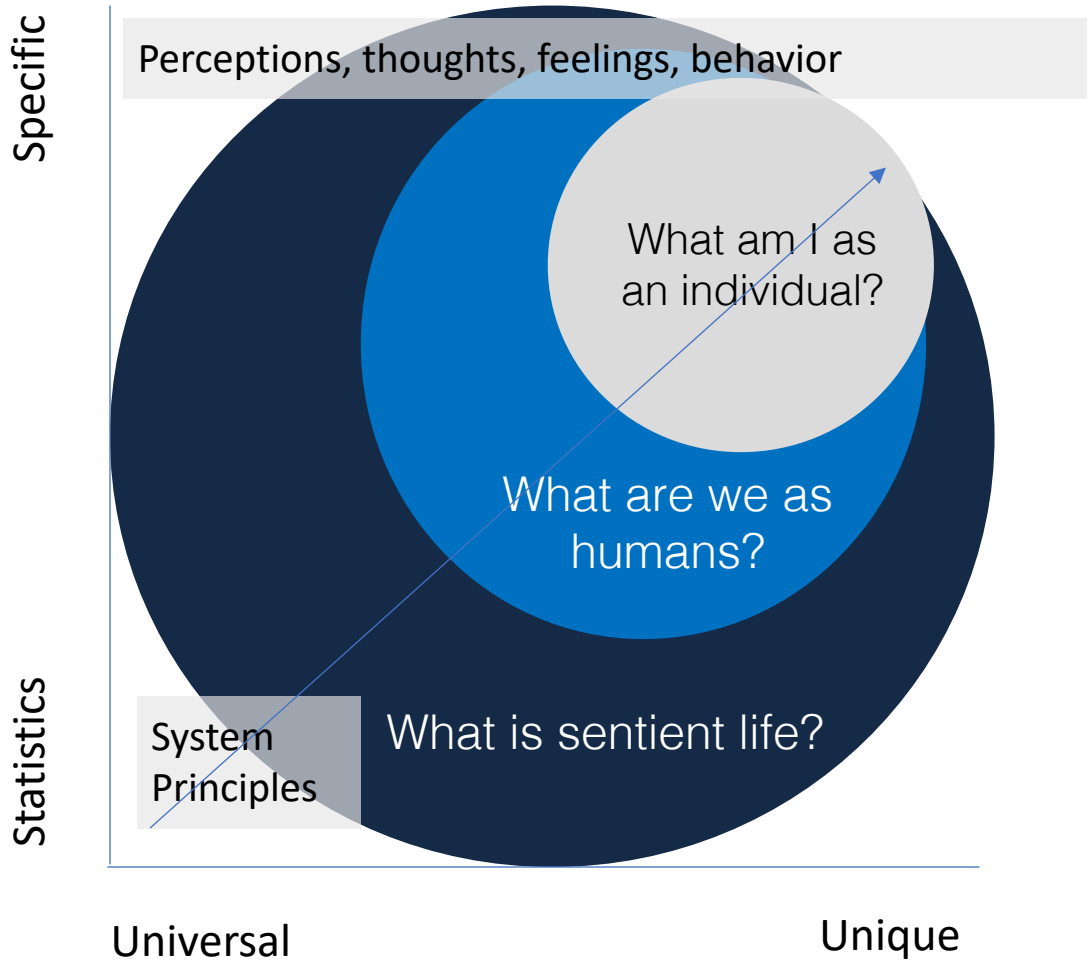
EEG
Scalp Surface
7-10 mm diam
100k+ neurons + 4x glia

ECOG
Brain Surface
2-4 mm diam 1 cm apart

~ 1000-10,000 neurons in the field + 4x glia

Local Field Potential (LFP)
Transverse plane
Microelectrode arrays 30 um diam 1 mm apart

~ 10-100 neurons in the field + 4x glia


Specific
Perceptions, thoughts, feelings, behavior
What am I as an individual?
What are we as humans?
What is sentient life?
System Principles
Statistics
Universal
Unique

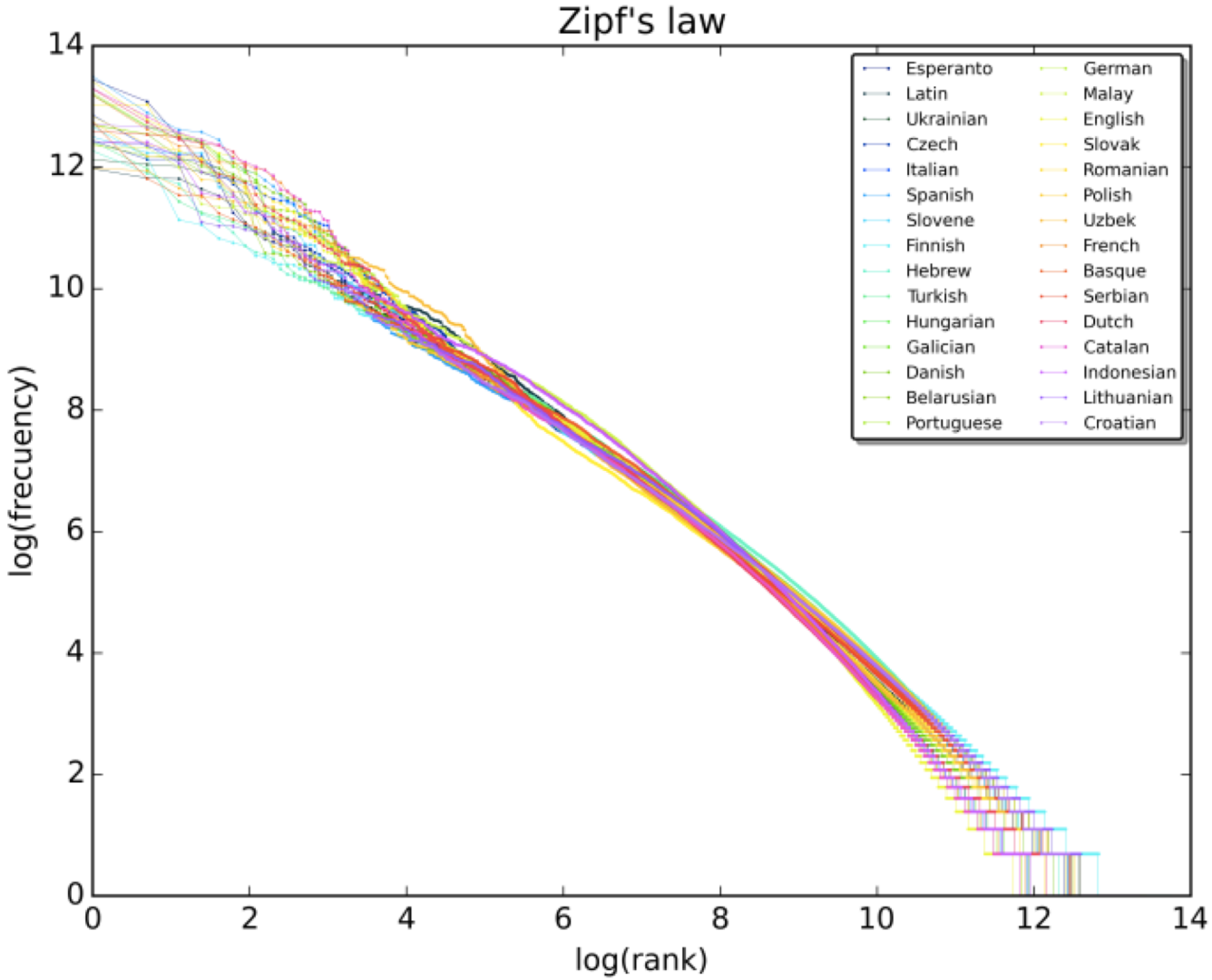
Example of universal system property of language

Zipf's law

From Wikipedia, the free encyclopedia

Zipf's law (/ˈzɪf/) is an empirical law formulated using mathematical statistics that refers to the fact that many types of data studied in the physical and social sciences can be approximated with a Zipfian distribution, one of a family of related discrete power law probability distributions. *Zipf distribution* is related to the zeta distribution, but is not identical.

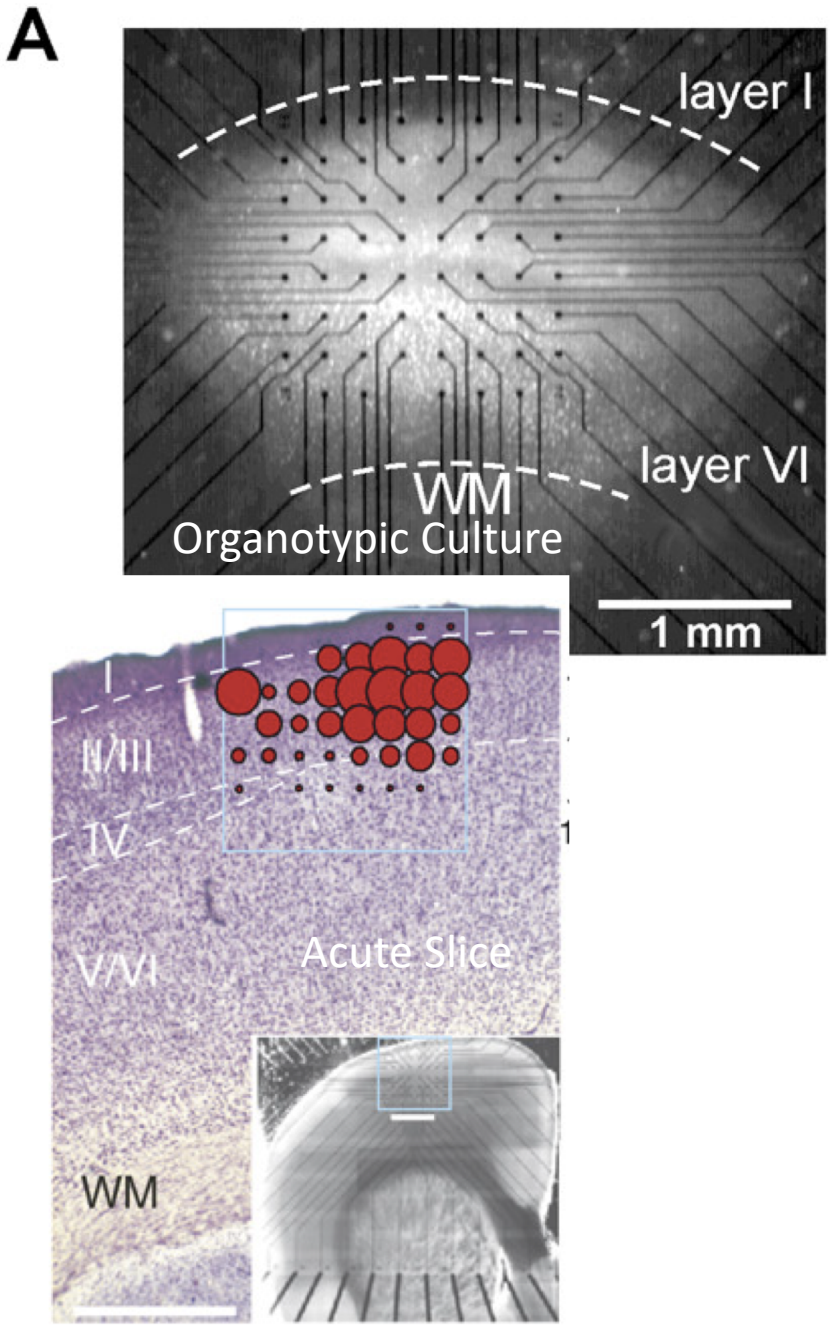
For example, Zipf's law states that given some corpus of natural language utterances, the frequency of any word is inversely proportional to its rank in the frequency table. Thus the most frequent word will occur approximately twice as often as the second most frequent word, three times as often as the third most frequent word, etc.: the rank-frequency distribution is an inverse relation. For example, in the Brown Corpus of American English text, the word "the" is the most frequently occurring word, and by itself accounts for nearly 7% of all word occurrences (69,971 out of slightly over 1 million). True to Zipf's Law, the second-place word "of" accounts for slightly over 3.5% of words (36,411 occurrences), followed by "and" (28,852). Only 135 vocabulary items are needed to account for half

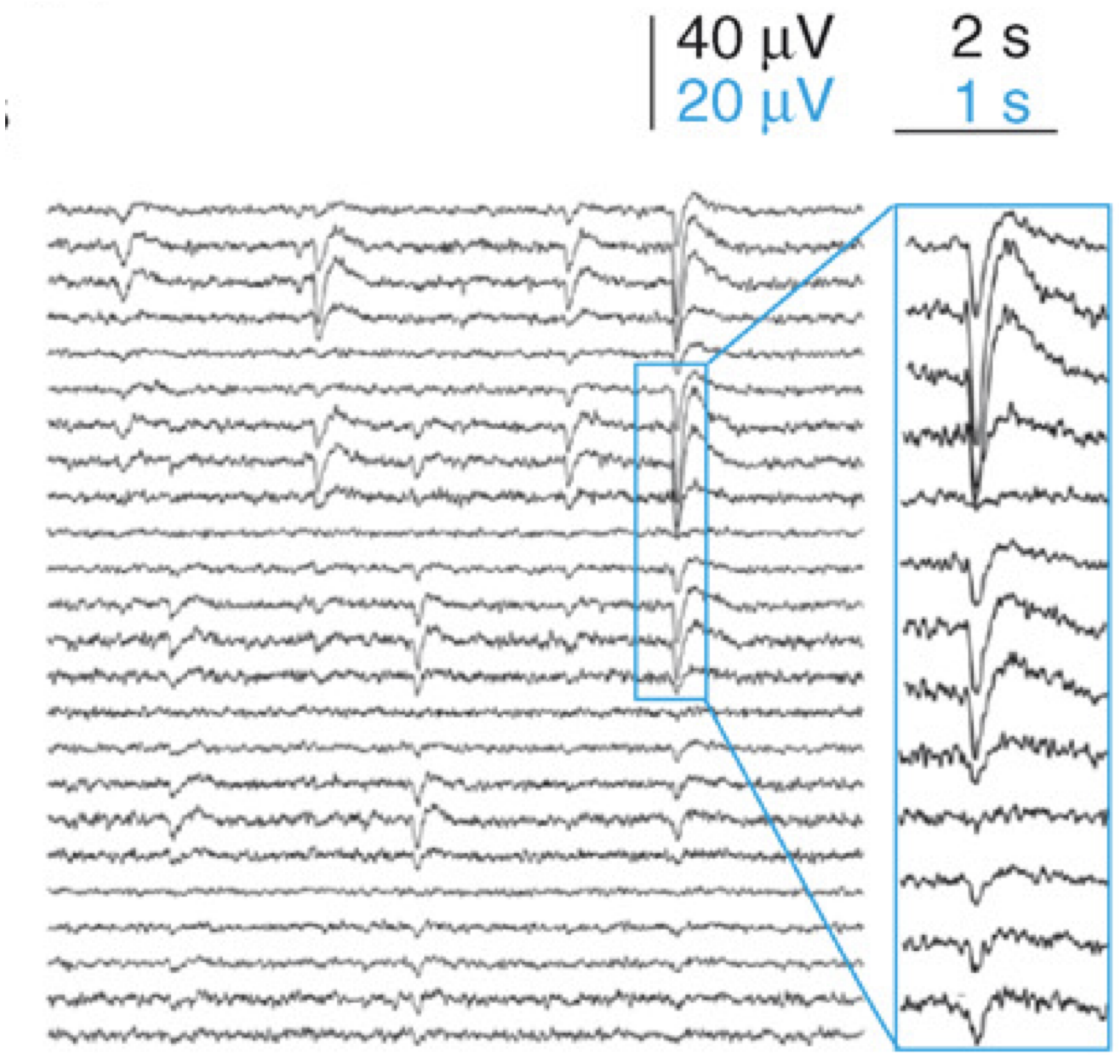


slump and stump

What if you didn't know words were symbolic concepts and studied them based on image characteristics?

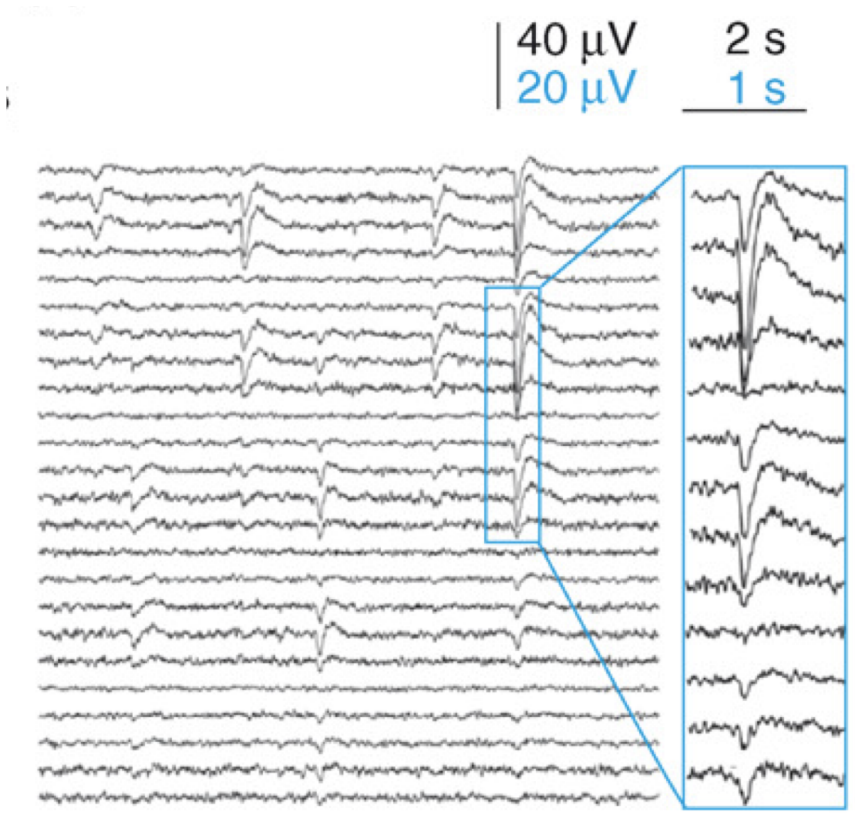
A primer on avalanches

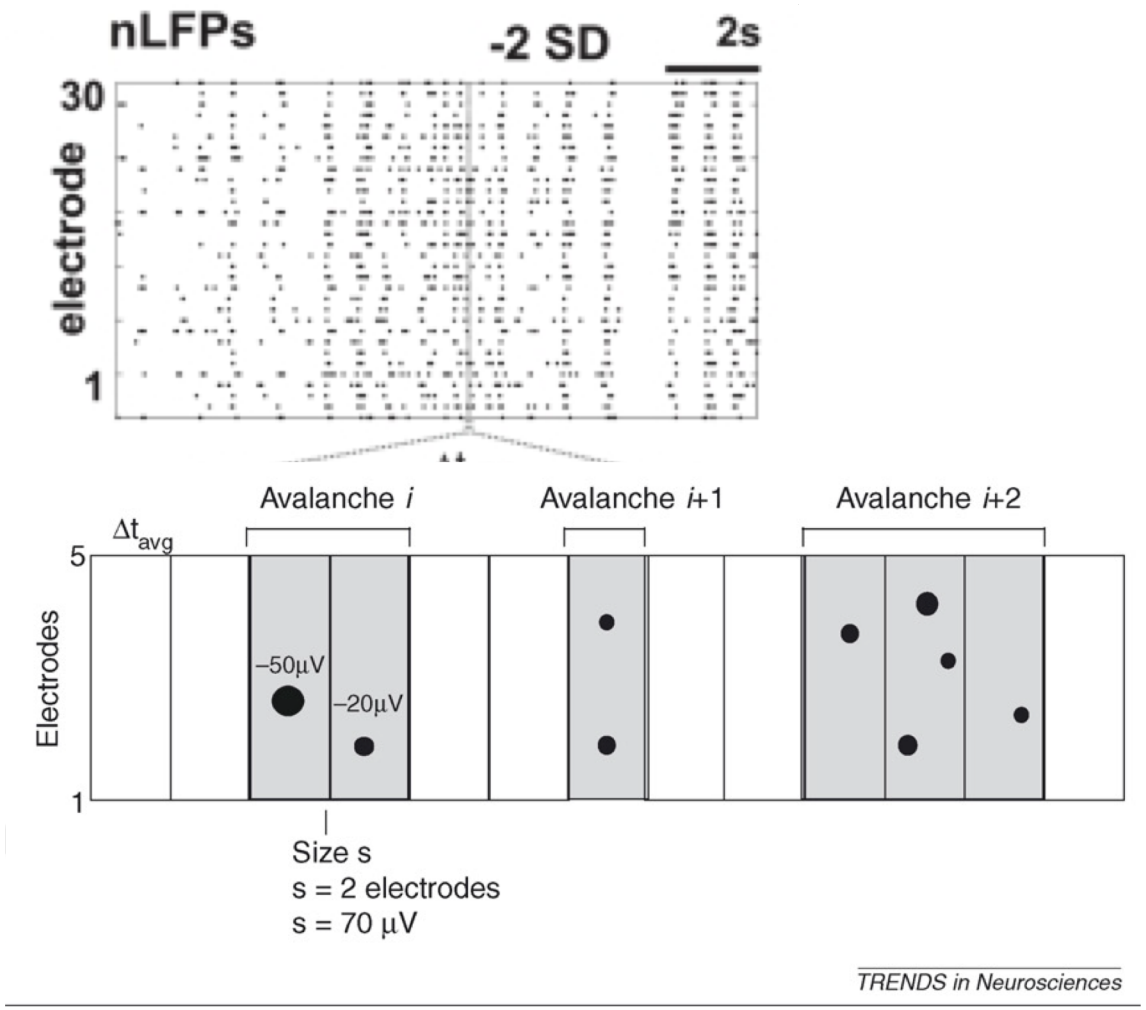




Beggs and Plenz , J Neurosci 2003
Plenz and Thiagarajan, TINS 2007

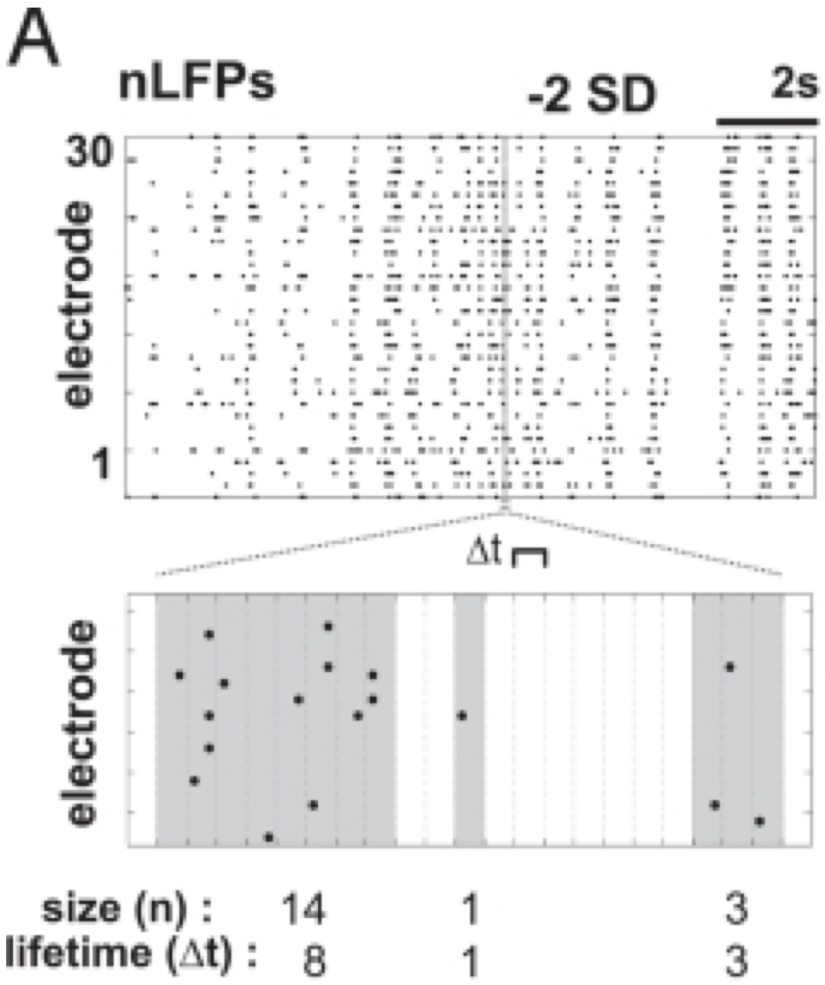
Aggregating negative deflections in the LFP into clusters based on time intervals.

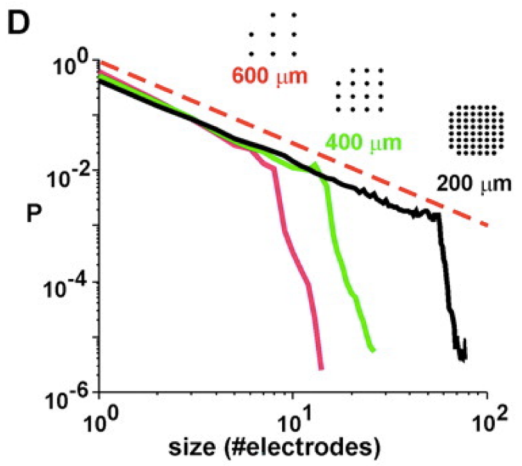


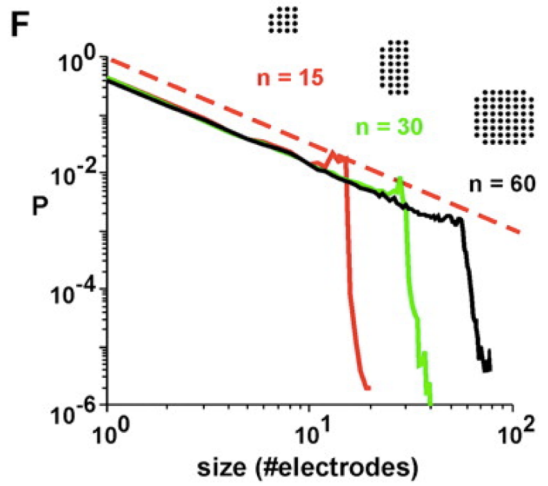


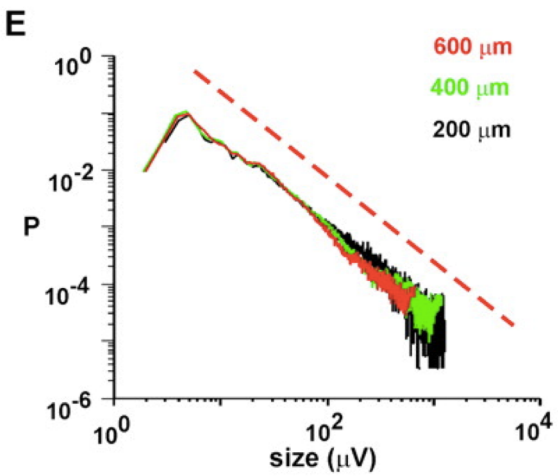
Beggs and Plenz , J Neurosci 2003
Plenz and Thiagarajan, TINS 2008

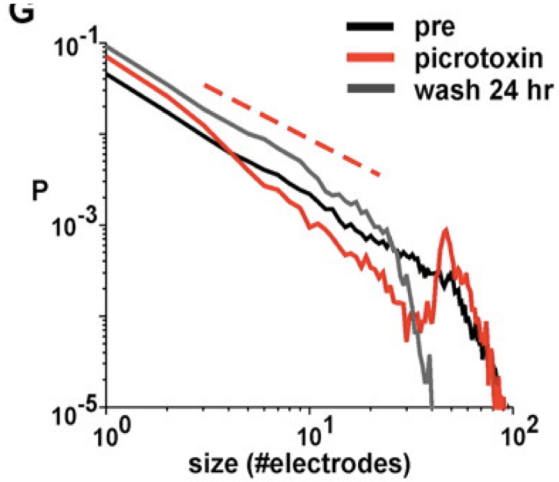
Cluster size distribution described by power law $P(s) \propto s^{\alpha}$
No characteristic scale: depends on the size of the system





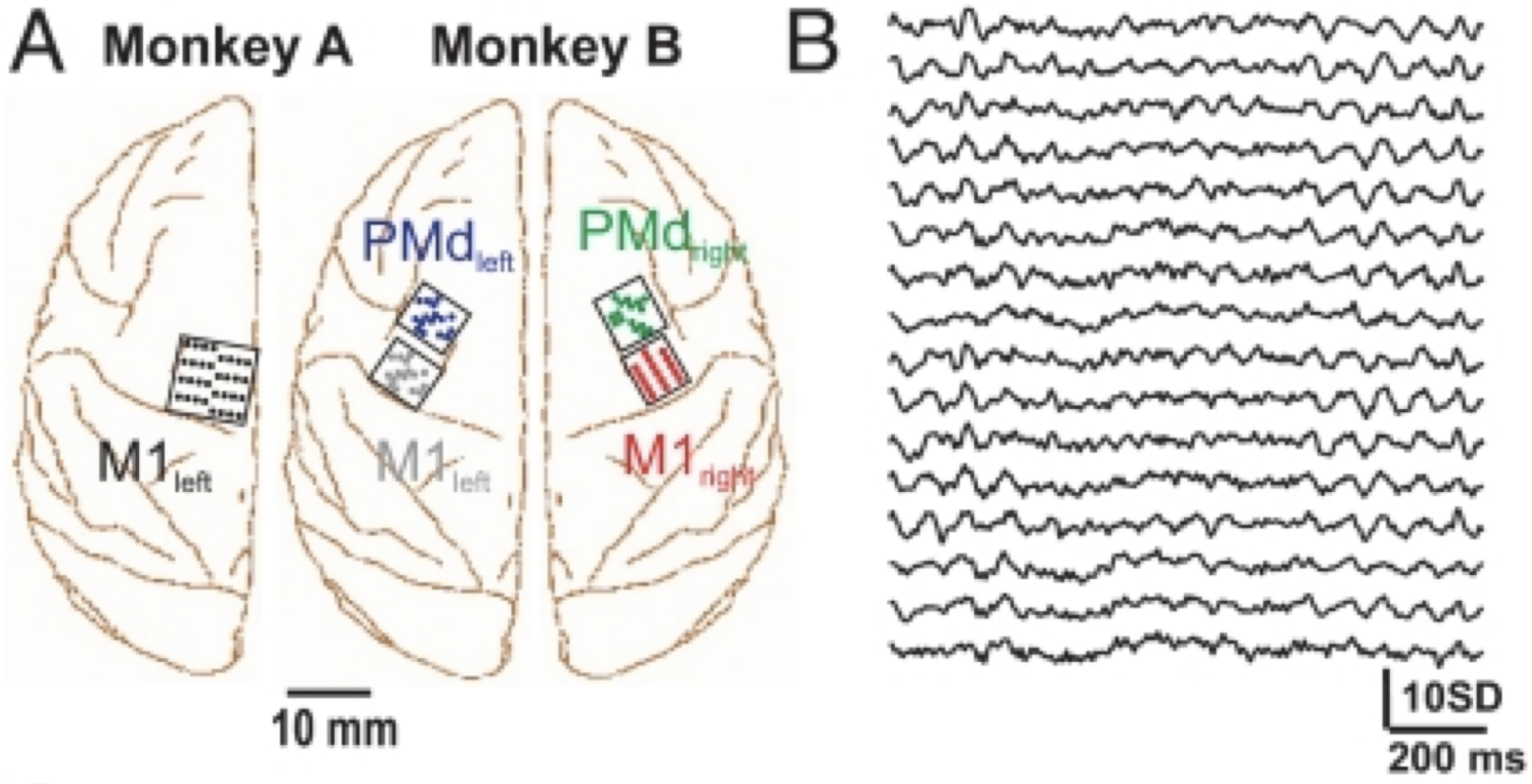






Important Parameter Choices
nLFP threshold (z) , Δt

Dominant negative deflections less obvious in in vivo recordings in monkeys compared to organotypic cultures and slices (previous slides).



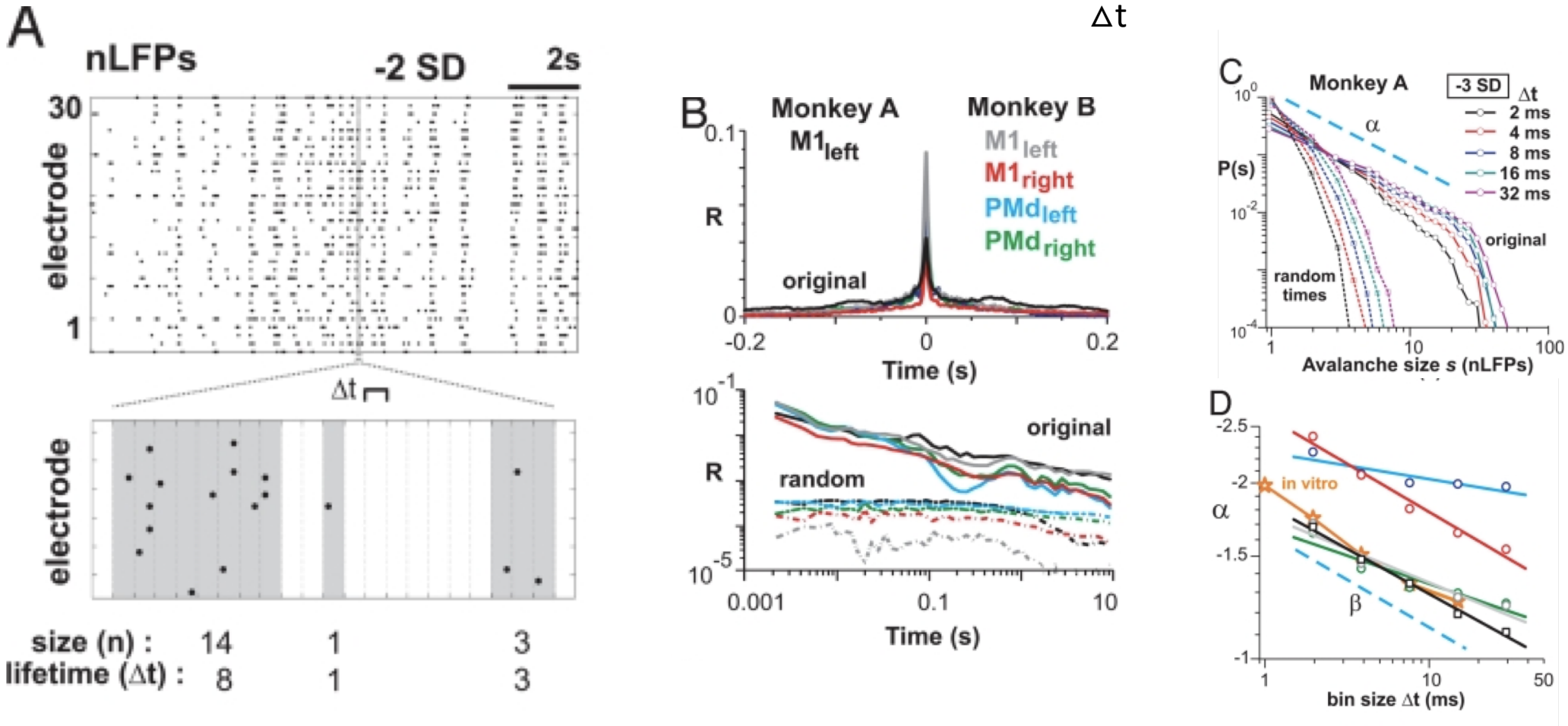
Petermann et al., PNAS 2009

Avalanches still exist in monkeys with different relationship between power law exponent and Δt

Parameter Choices

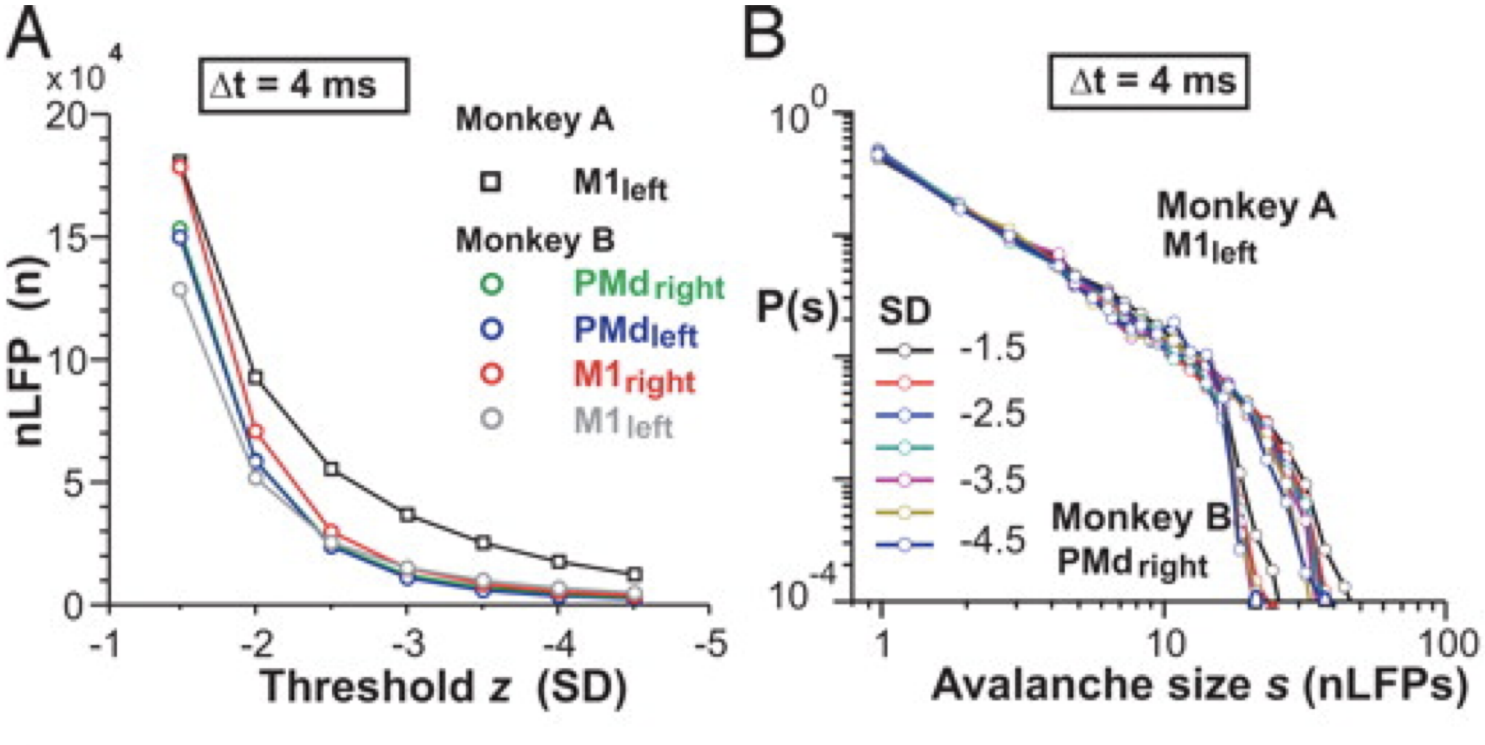
nLFP threshold

Δt

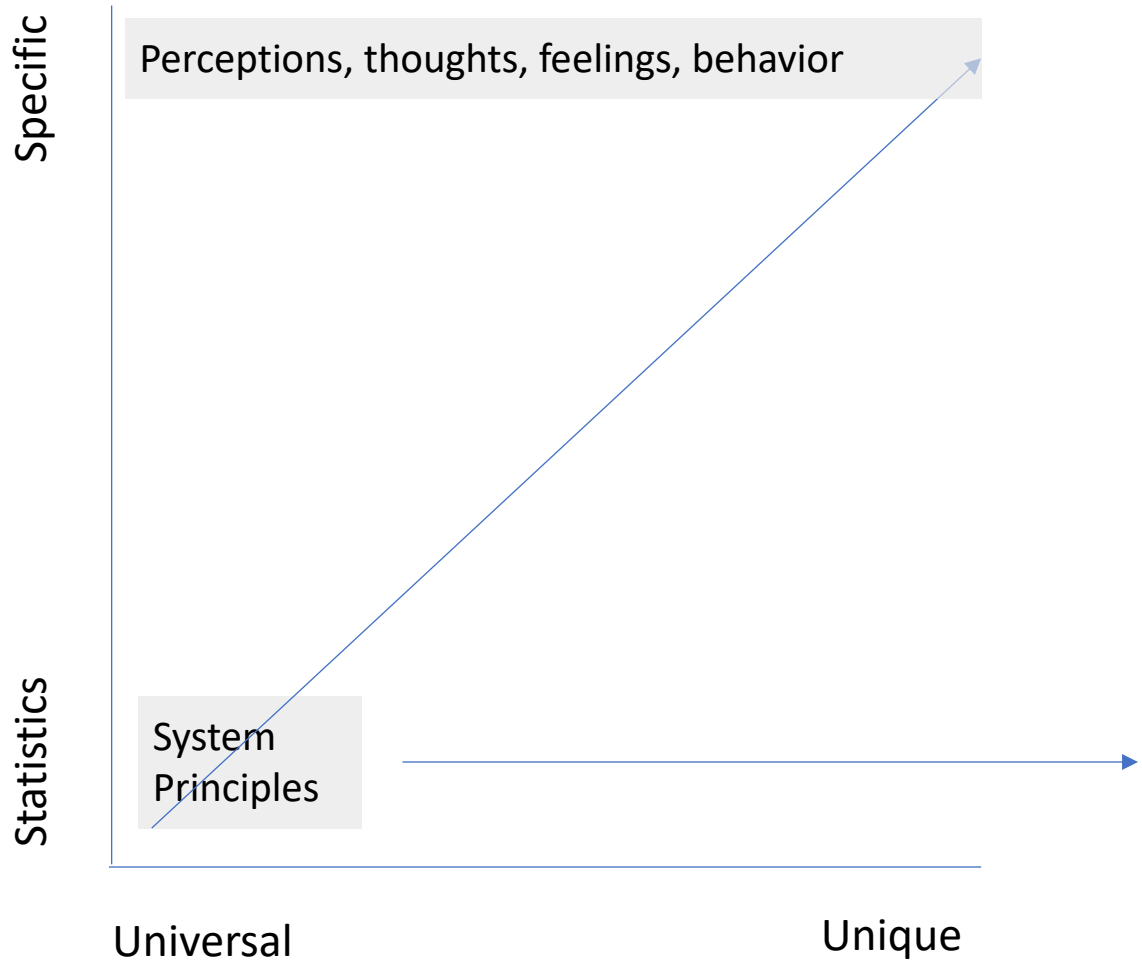


Petermann et al., PNAS 2009

Power law exponent is independent of nLFP threshold (scale free on multiple dimensions)



Petermann et al., PNAS 2009



Avalanches:

Macro Statistical Feature

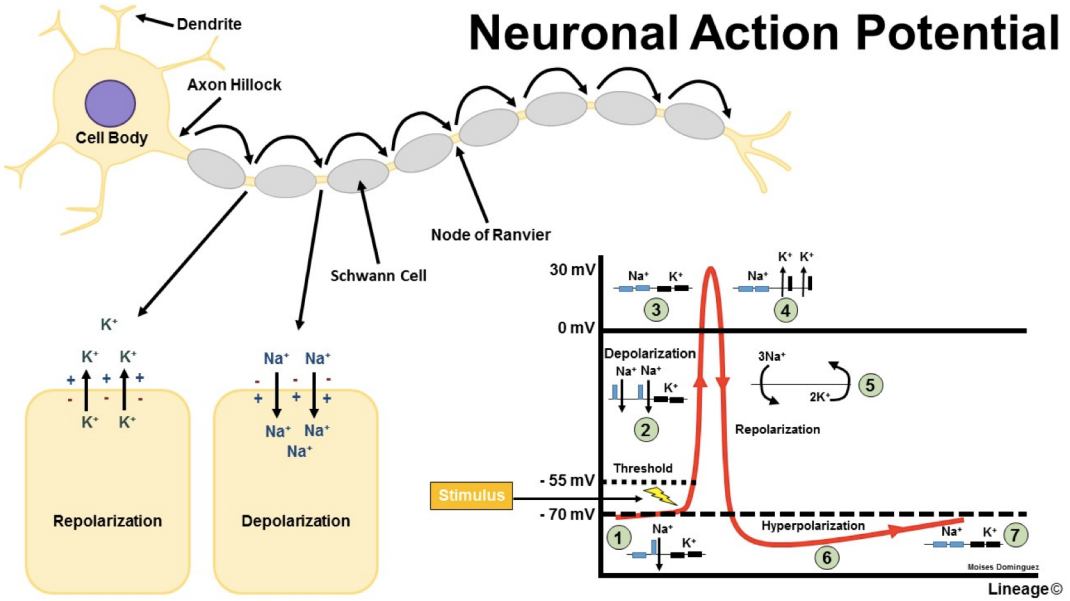
- Invariant in space and time
- Conserved across species
- Intrinsic to the tissue
- Depends on balance of excitation and inhibition

Some key questions

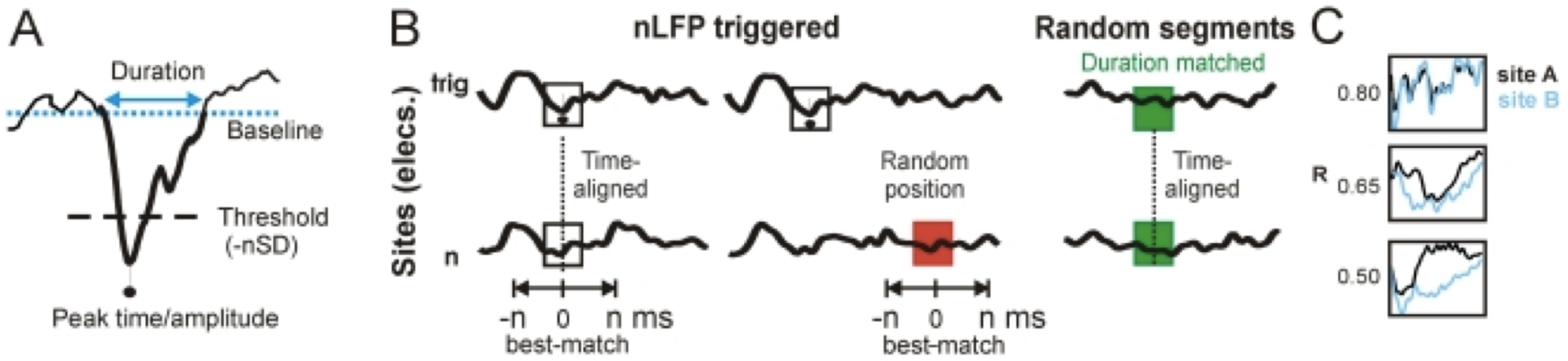
Are nLFPs in any individual avalanche always on contiguous electrodes? **No!**

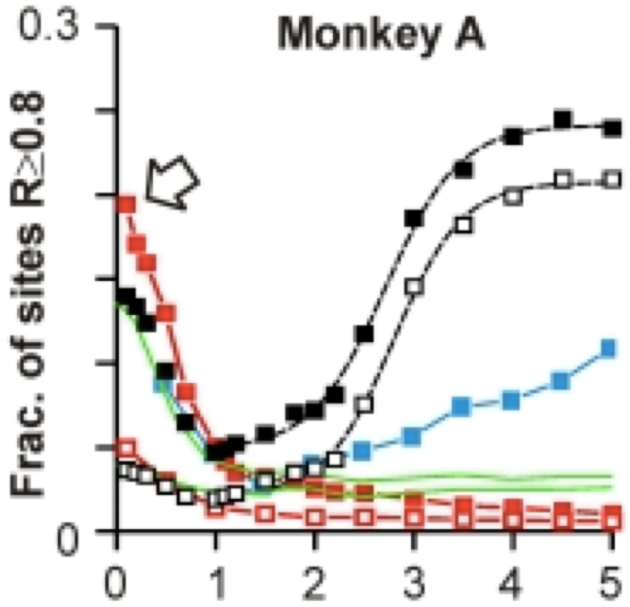
Avalanches only consider peaks of the nLFPs what are the characteristics of these negative deflections? **First quick glance: Duration of 100 – 300 ms – time scale of perception!**

Is there an active propagation process?



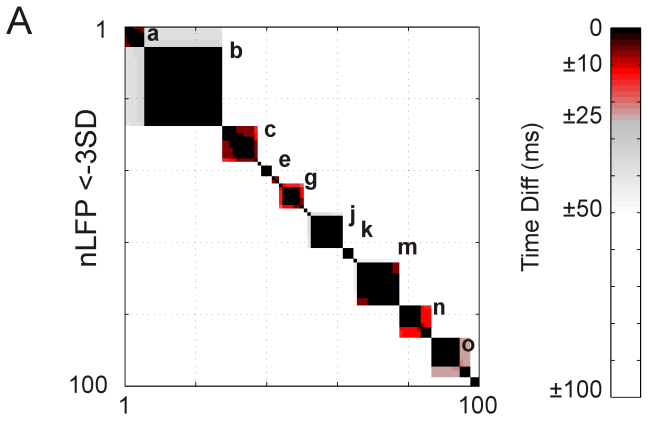
Coherence Potentials: Network level action potentials

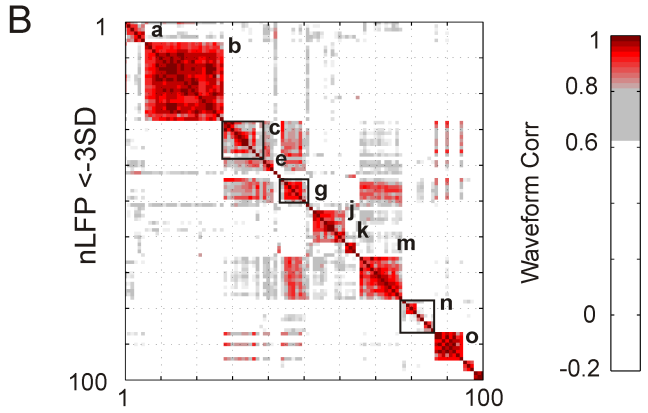


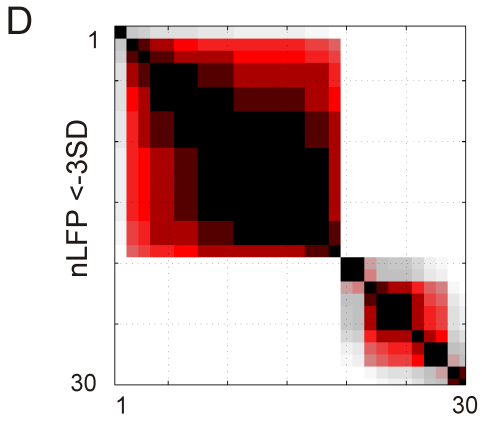


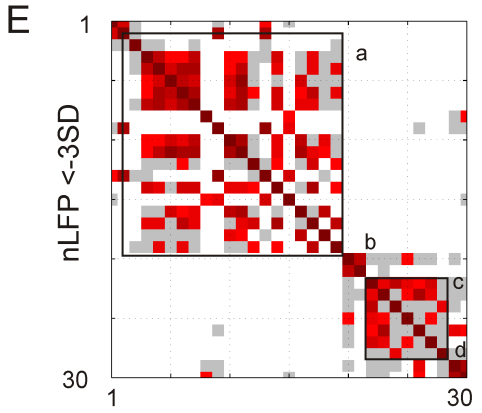
Thiagarajan and Plenz, PLOS Biology, 2010

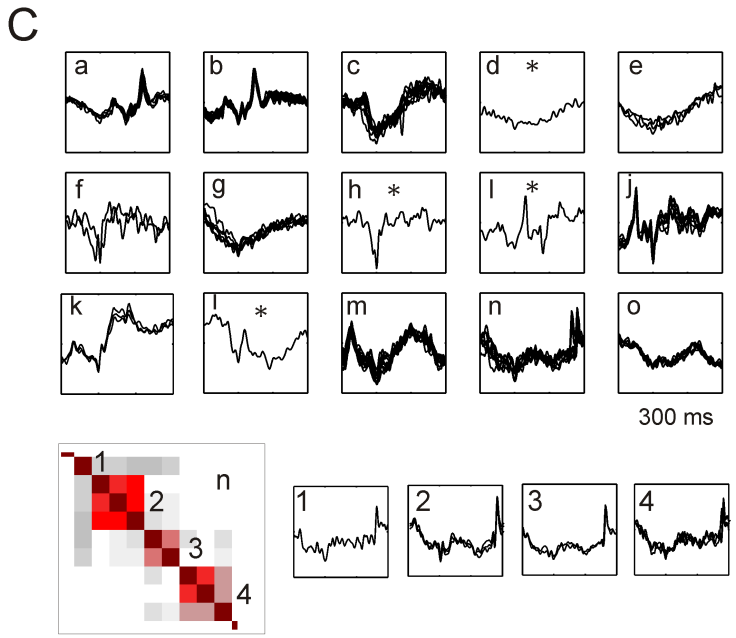
Coherence Potentials

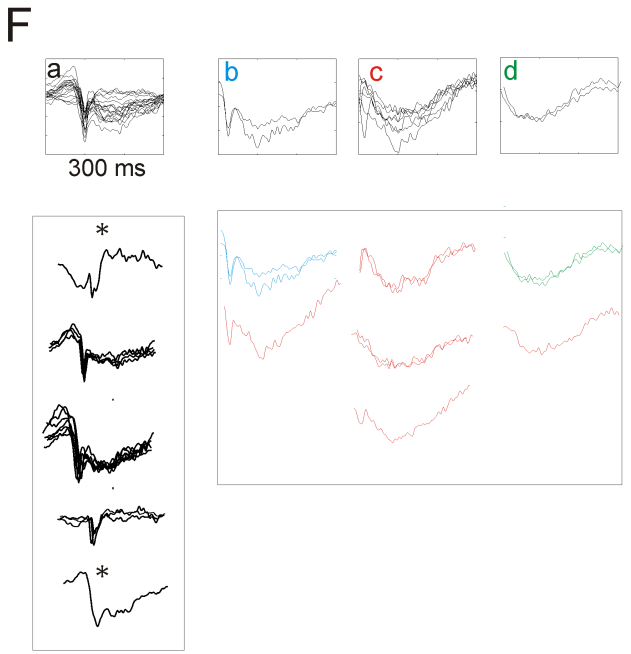


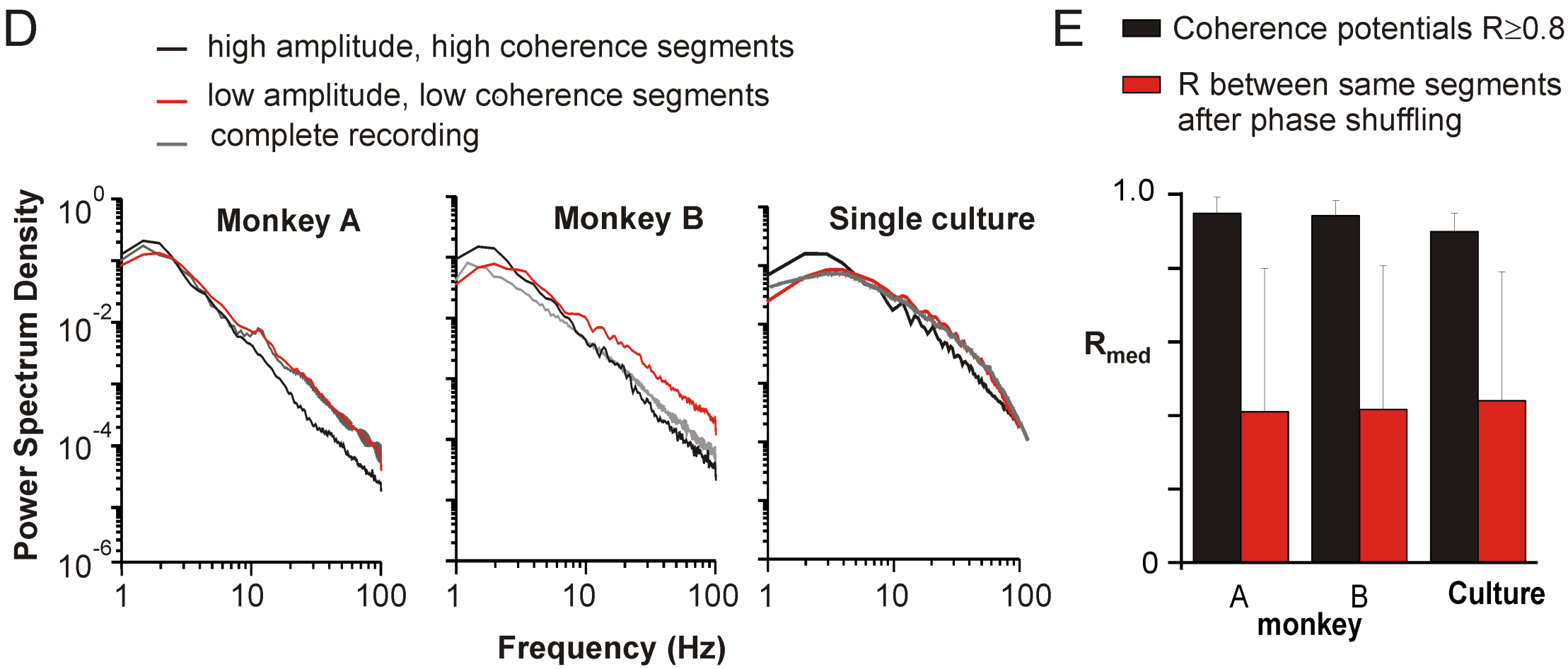




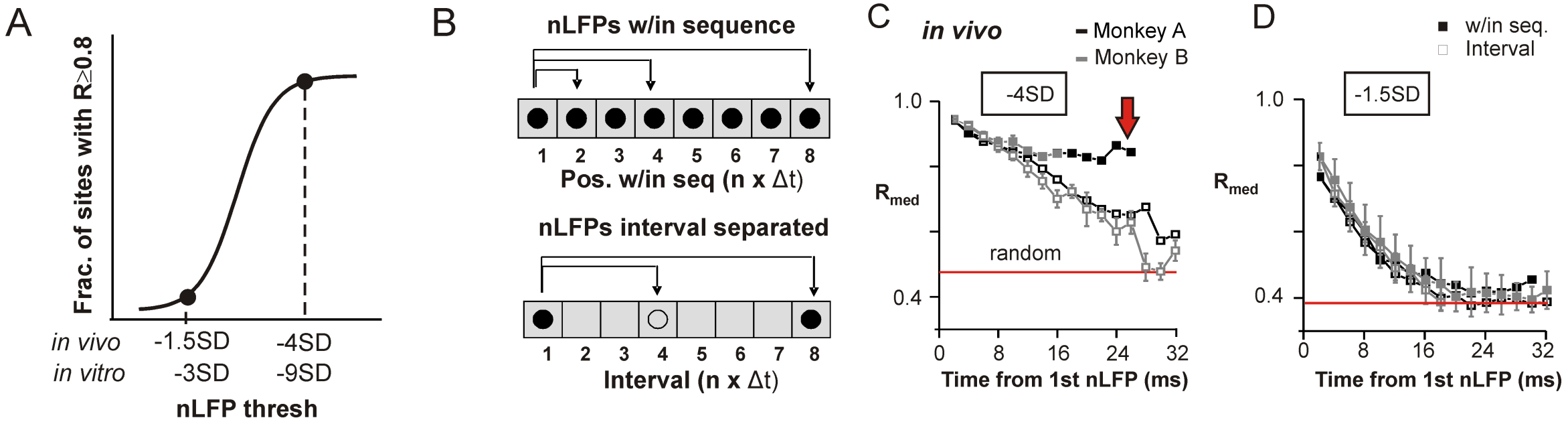




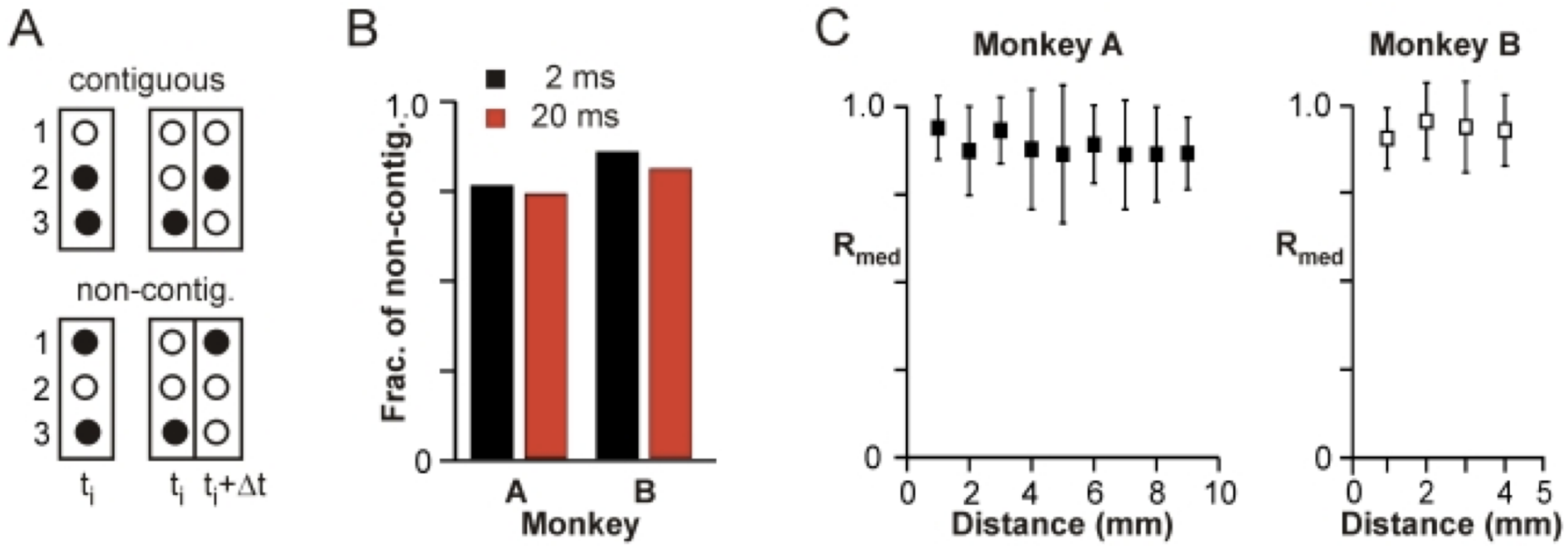


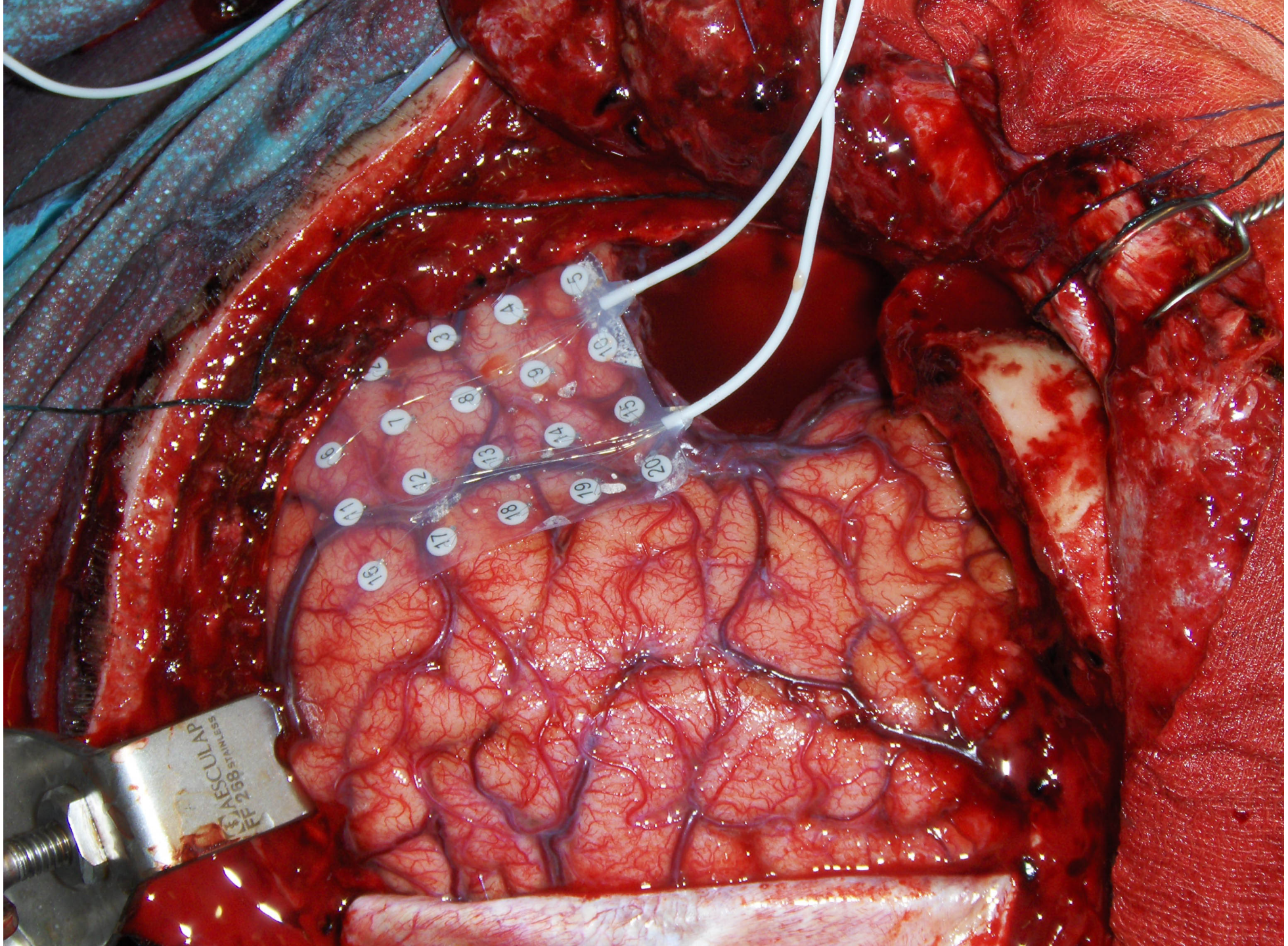

D
high amplitude, high coherence segments
low amplitude, low coherence segments
complete recording
Power Spectrum Density
Monkey A
Monkey B
Single culture
Frequency (Hz)
E
Coherence potentials R≥0.8
R between same segments after phase shuffling
R_med
monkey
A
B
Culture

Coherence potentials don’t decay in time

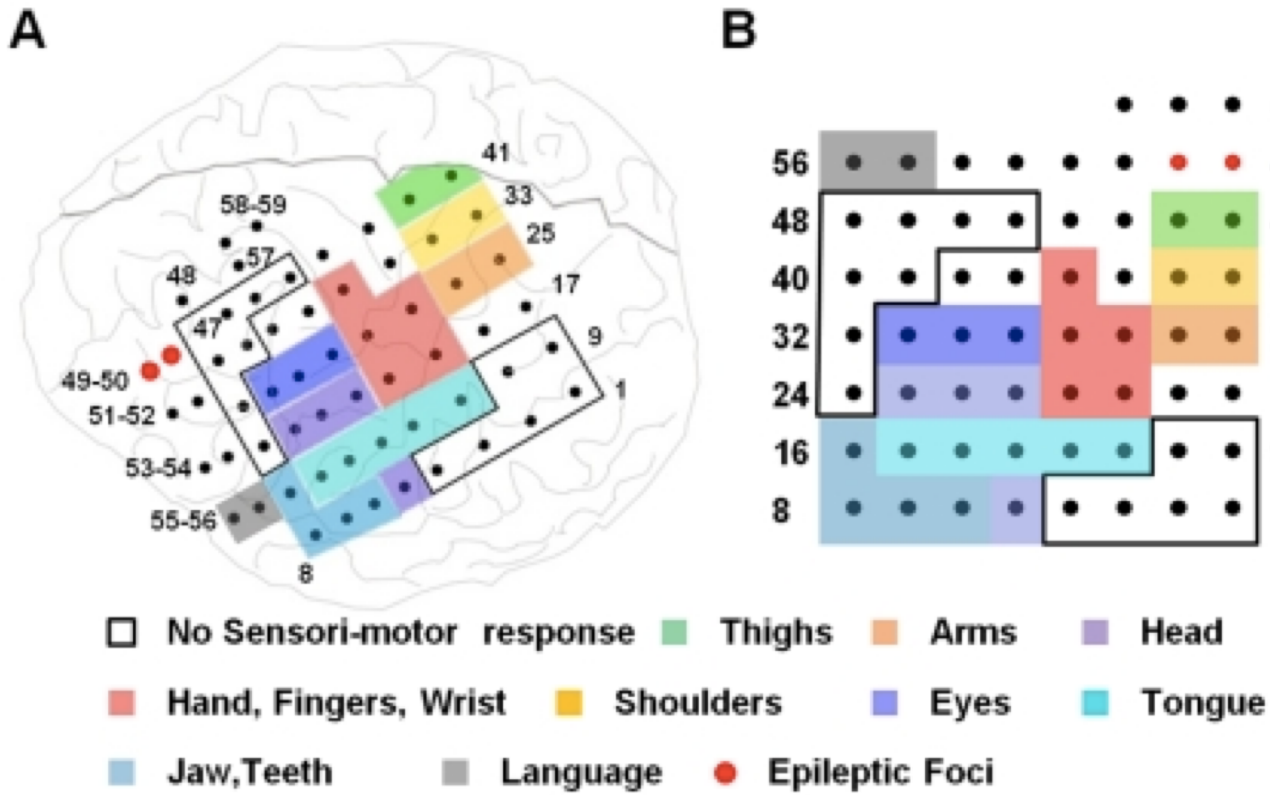


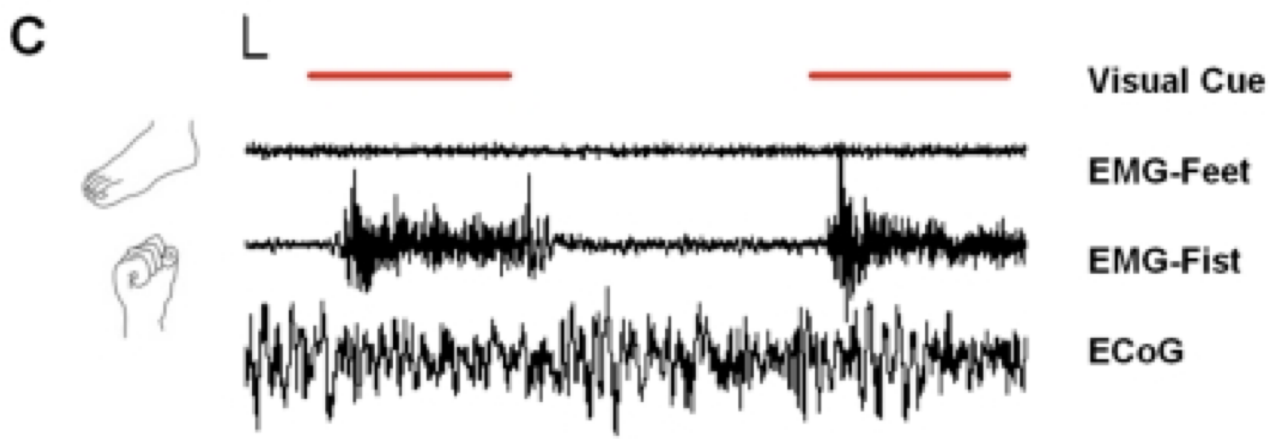
Coherence potentials don’t decay in space





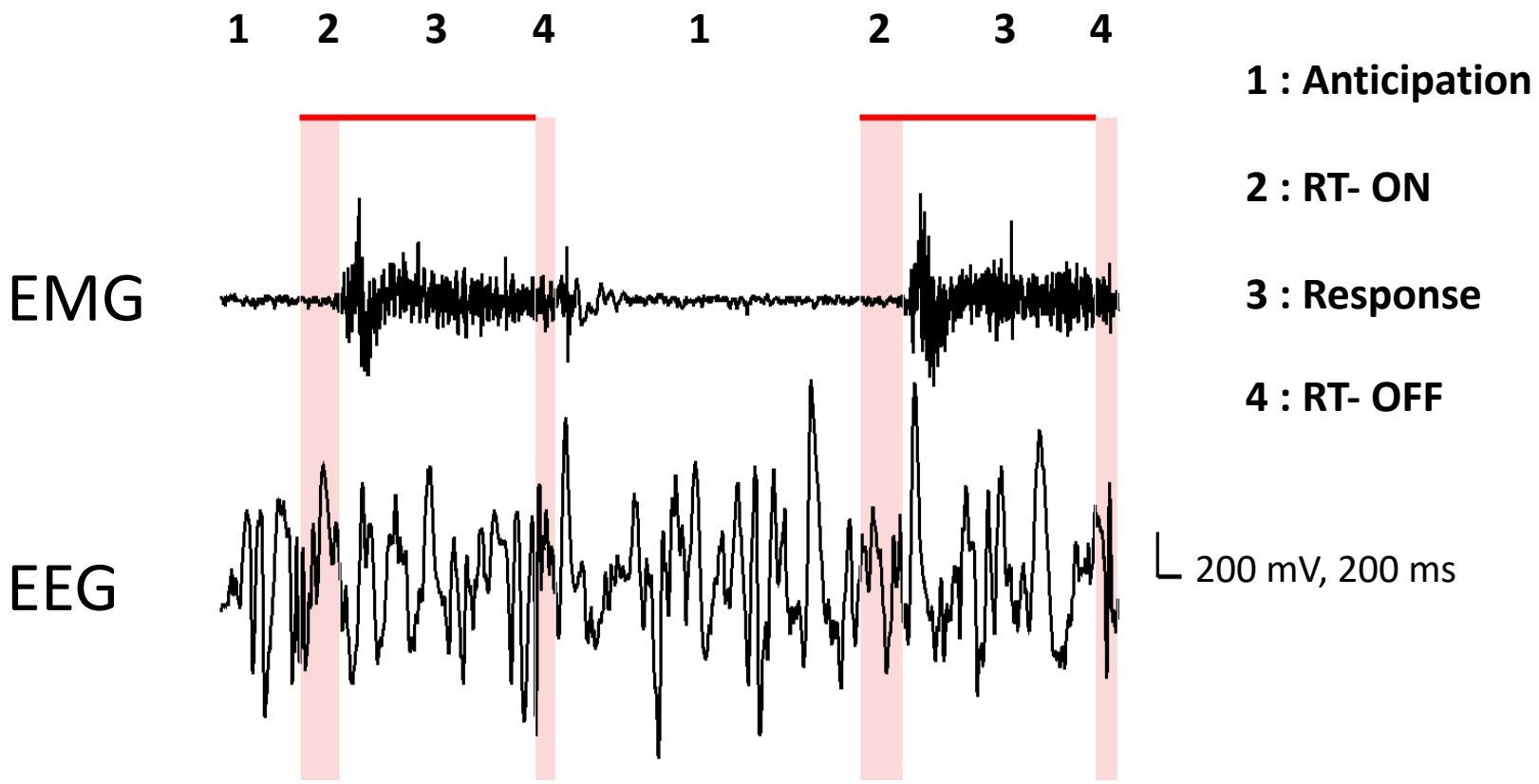
Human ECOG recordings



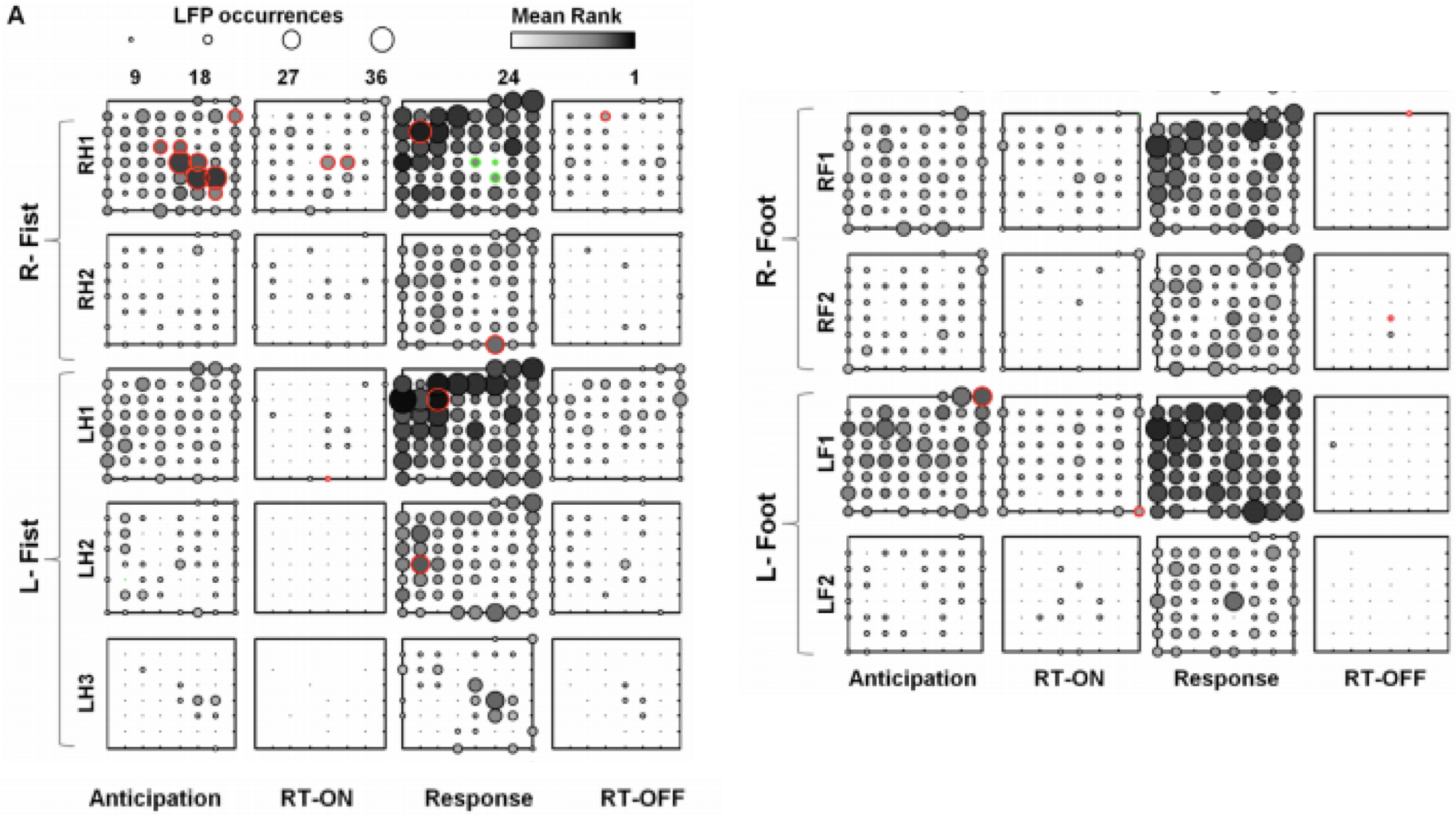


Parameshwaran and Thiagarajan, PLOS One 2012

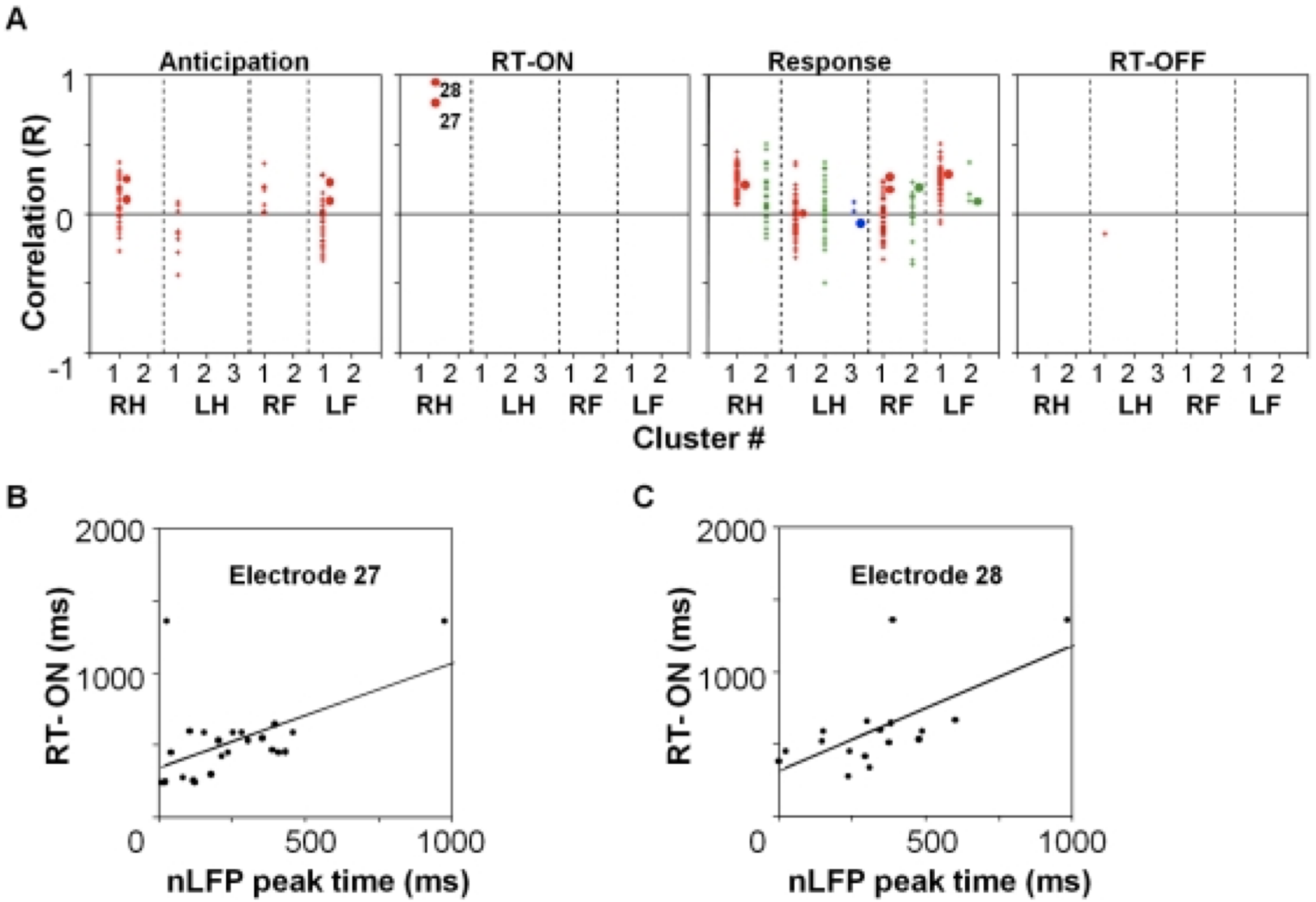
Trial with random intervals



Is there a waveform pattern that spans all the trials for a particular task ?
9/150 patterns were ‘trial spanning’


A
LFP occurrences
Mean Rank
9
18
27
36
24
1
R- Fist
RH1
RH2
L- Fist
LH1
LH2
LH3
R- Foot
RF1
RF2
L- Foot
LF1
LF2
Anticipation
RT-ON
Response
RT-OFF

Some inkling of relation to behavior



Summary

1. Avalanche behavior is a statistical principle that is invariant to scale of measurement and arises across species

2. Coherence Potentials are a fine scale feature of avalanches and represent an active propagation of complex waveforms without distortion of structure.

3. Coherence Potentials are evident in LFP recordings as well as ECOG

4. Specific Coherence Potentials are related to specific tasks and predict onset of motor behavior

Phase information matters →
time domain features should be preserved


THANK YOU