Complexity Methods for Behavioural Science

Cross-Recurrence Quantification Analysis and other flavours of RP's

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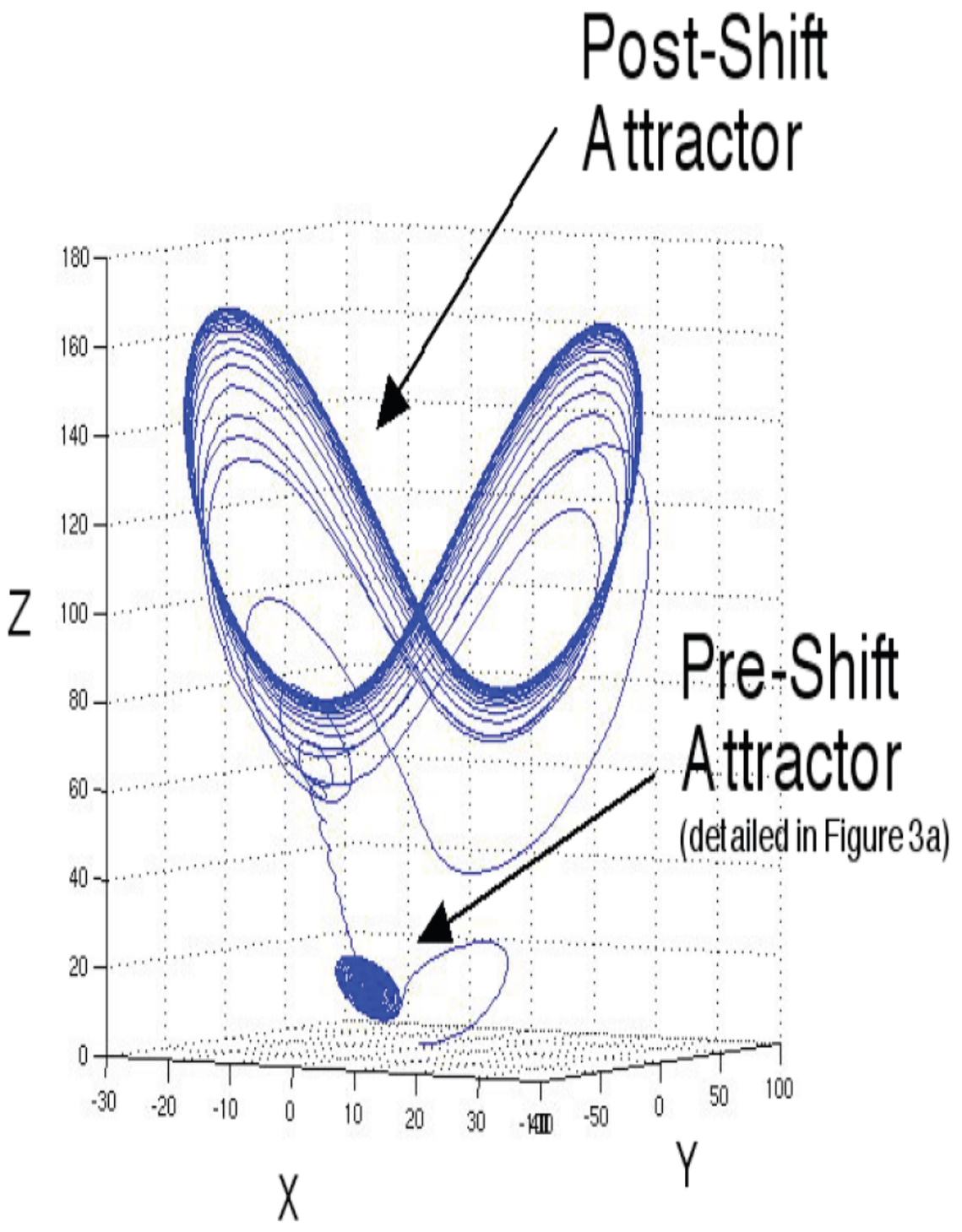
1. If we can reconstruct the state space of a complex dynamical system from one observable dimension....

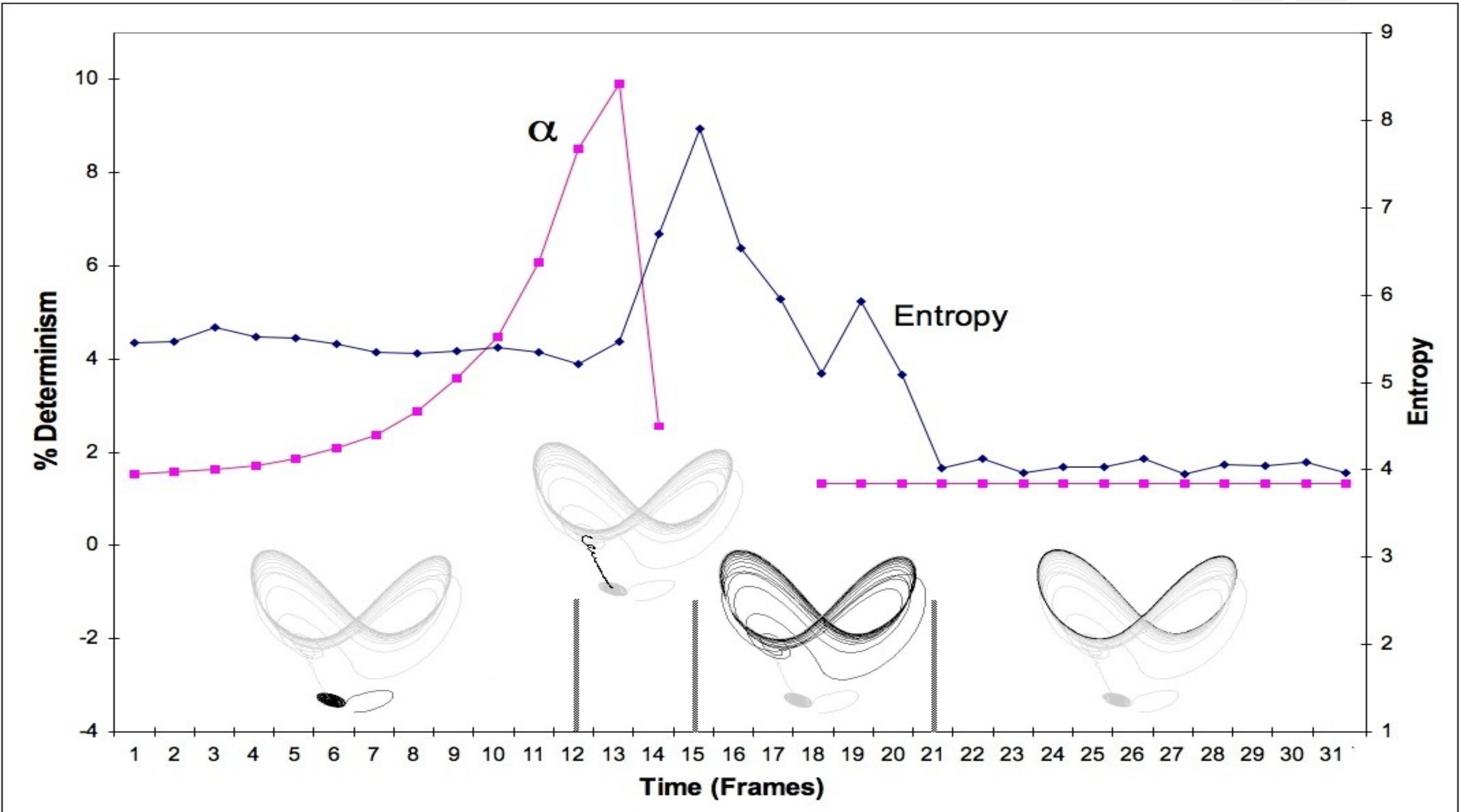
2. If we can quantify the attractor dynamics in this state space...

3. Direct measurements of physical observables in humans should tell us something about the the dynamics of the unobservable cognitive system

4. Could we predict insight in problem solving from a phase transition in phase space reconstructed from hand movements?



Lorenz system – Transitions in phase space



Insight as a phase transition

- Stephen, D.G., Dixon, J.A., & Isenhower, R.W. (2009). Dynamics of representational change: Entropy, action, and cognition. JEP: HPP.

Gear Domain

- Gear systems problems
- Solve problem any way they wish
- Code strategies
  - Force-tracing
- Gear system does not move

- Force-tracing actions create information about the system
- Discovery of Alternation

Insight as a phase transition

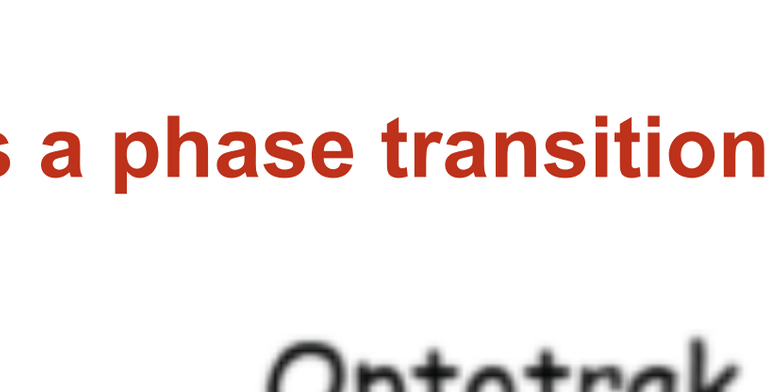
Optotrak

100 Hz sampling rate, 4 markers Velcro-ed to forefinger

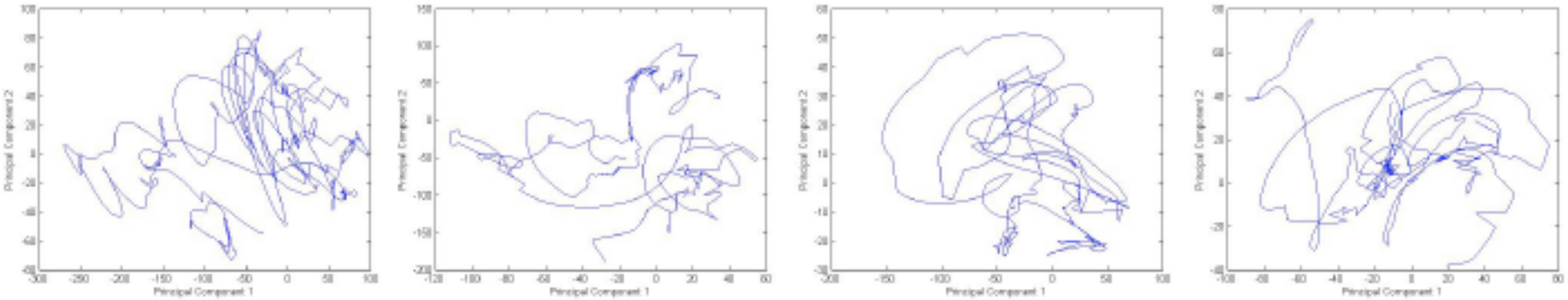
Markers emit infrared light

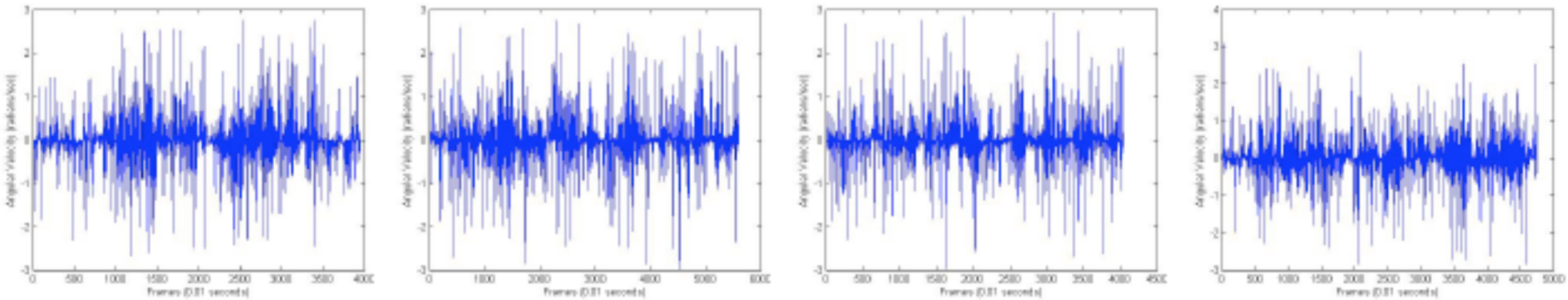
2 markers for left camera

2 markers for right camera

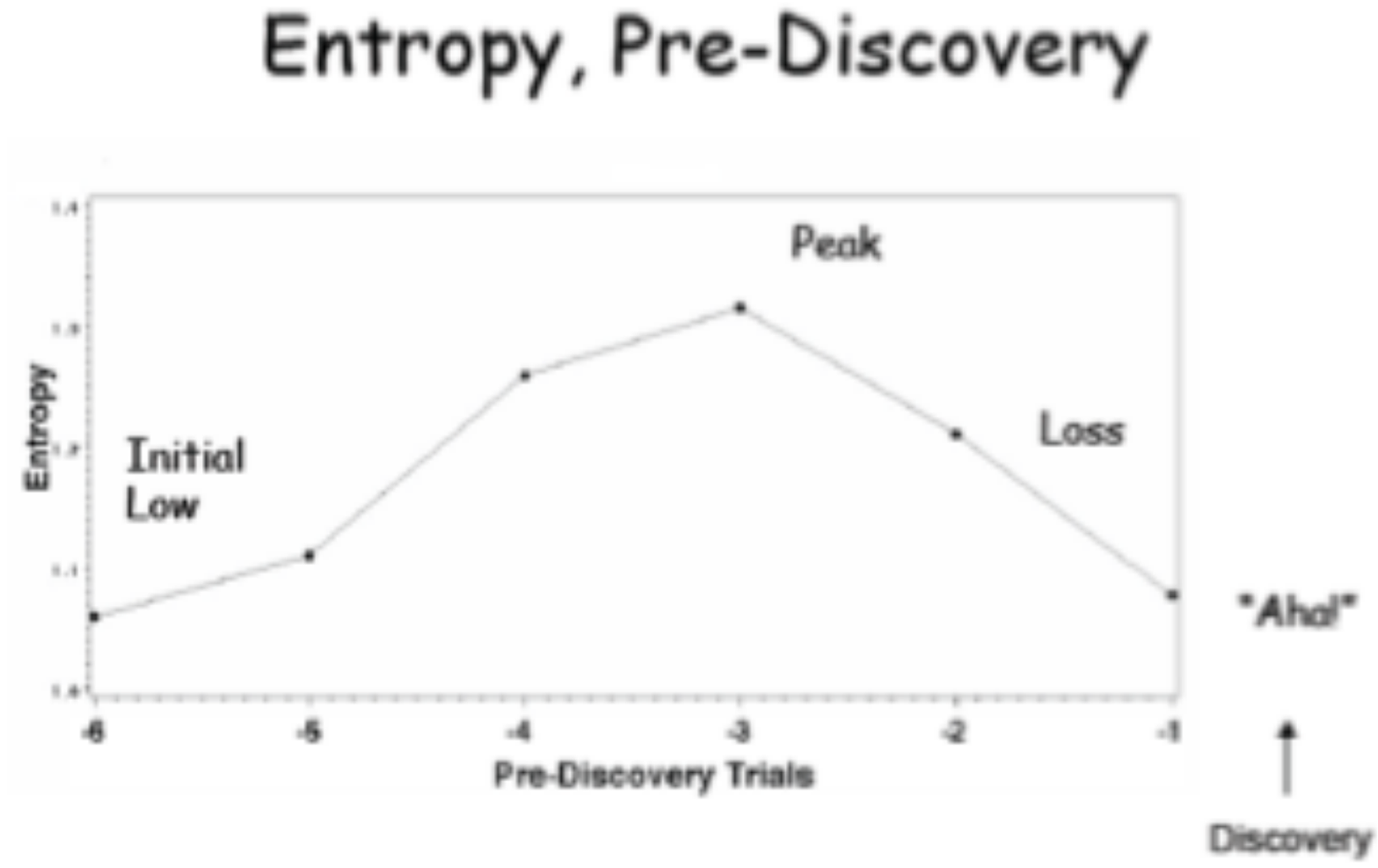


Angular velocity of finger movements

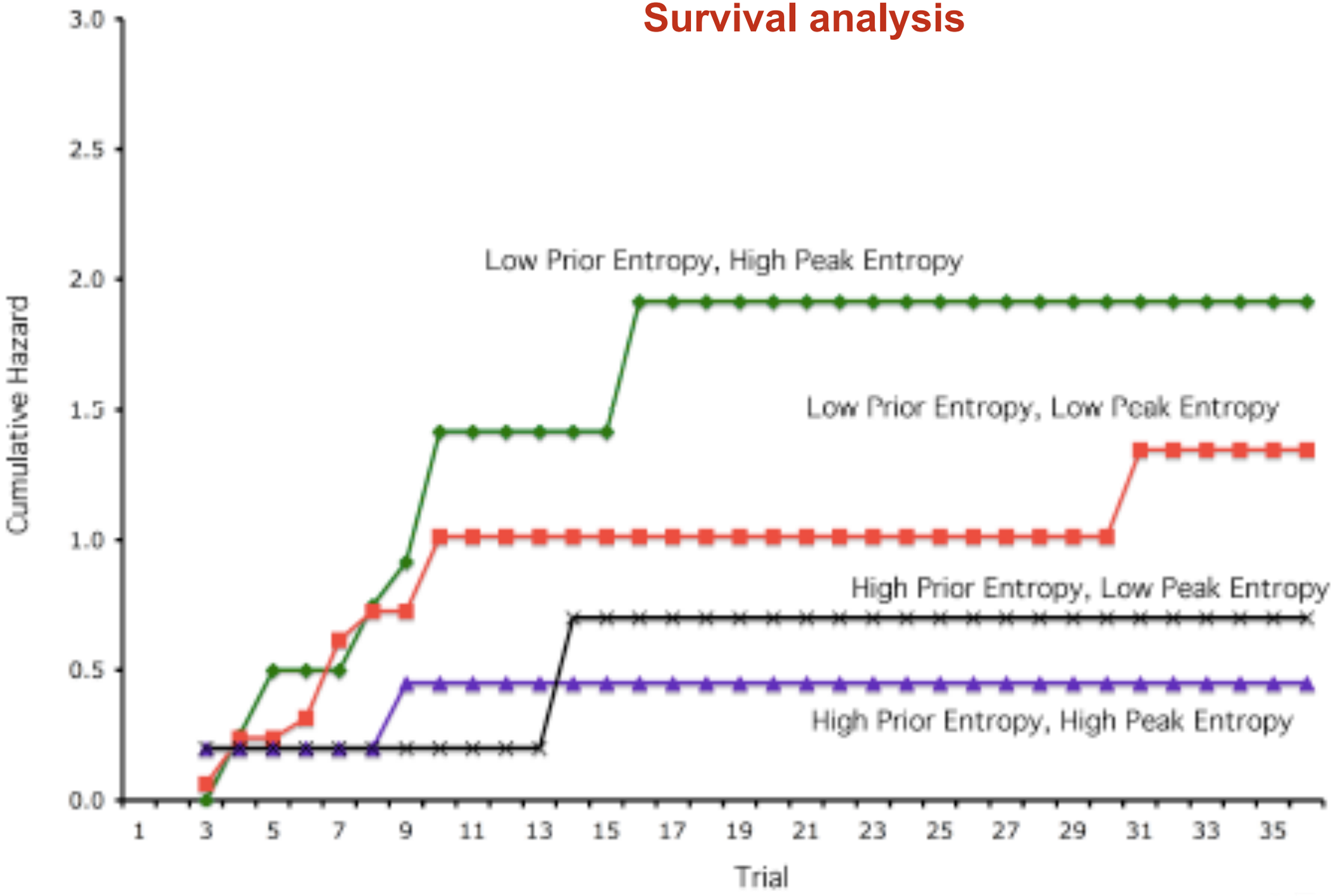




Insight as a phase transition



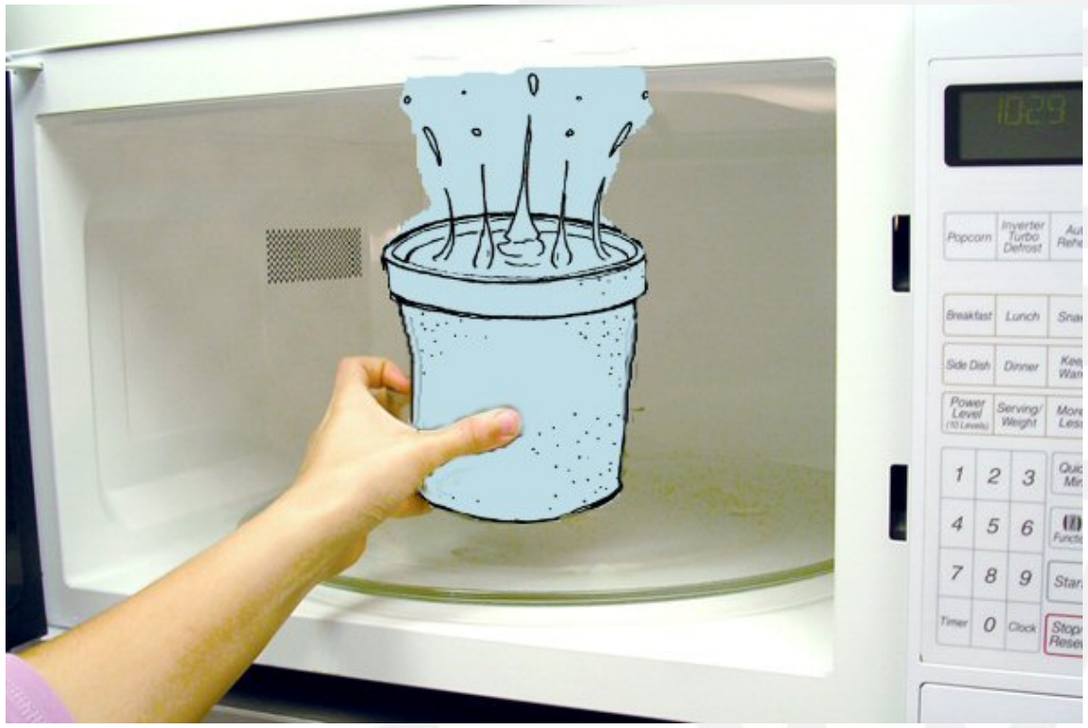
Survival analysis

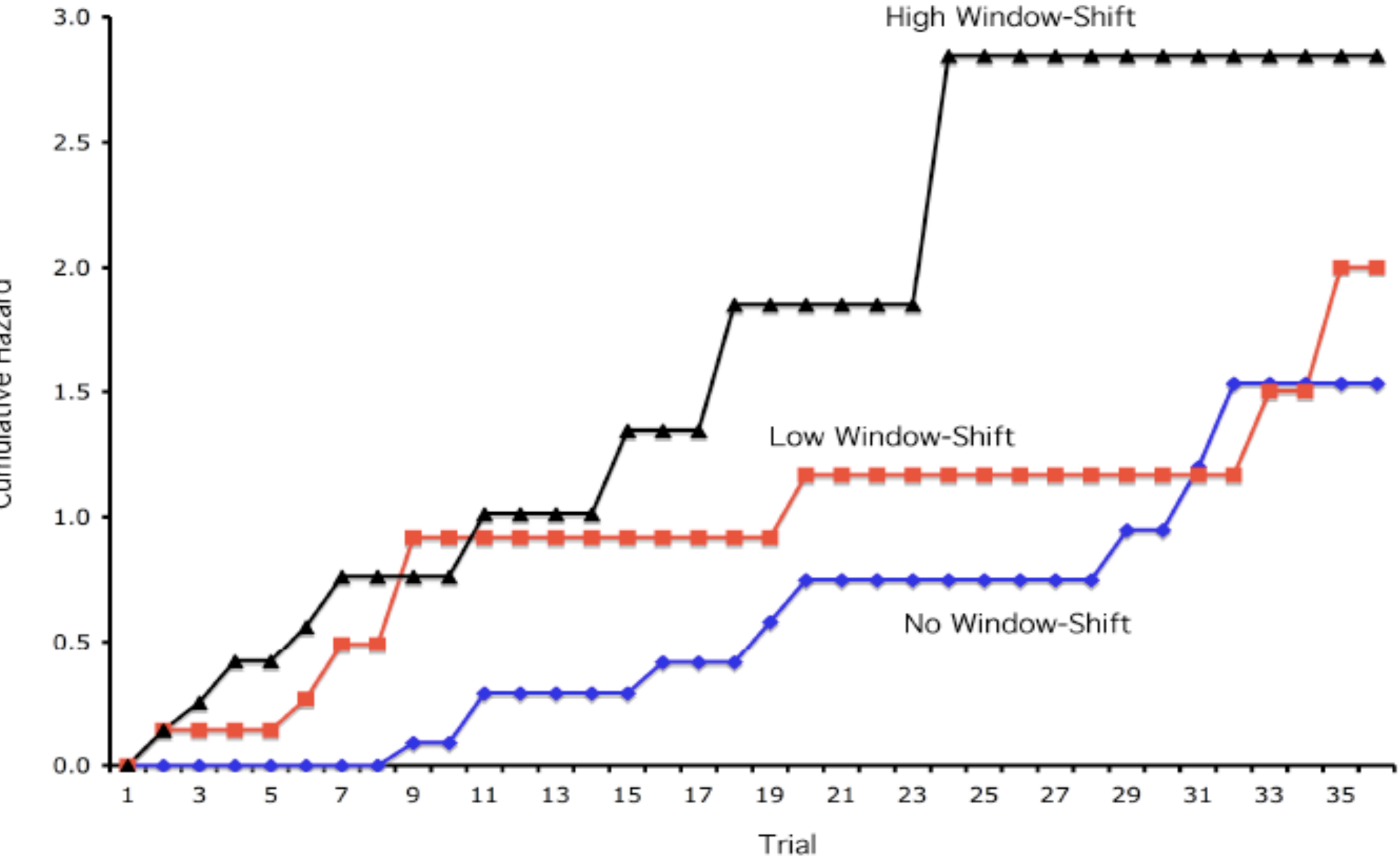


1. Assumption: Noise / Entropy drives the structural change

1. Hypothesis: Increase noise, this will lead to an earlier discovery of the rule

1. Additional condition: increase noise by making the gear problems shift position on the screen




High Window-Shift
Low Window-Shift
No Window-Shift
Cumulative Hazard
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
Trial

Cross Recurrence Analysis

- Instead of analysing if a system re-visits locations in reconstructed phase space: Analyse if two systems share locations in phase space

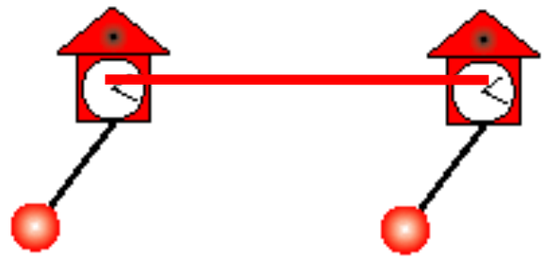
- Cross recurrence analysis tells you something about synchronization or coupling of systems in time.

- Same strategy as autorecurrence: Reconstruct phase space and see if points between two trajectories are adjecent

Synchronisation: Huygens' Clocks

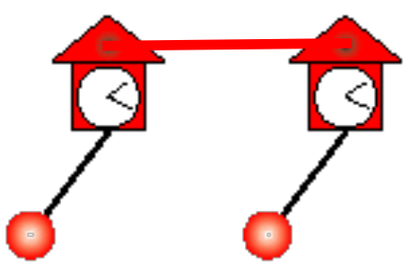
Synchronisation is a science in itself…

For now just note that synchronisation occurs in systems which are coupled in some way

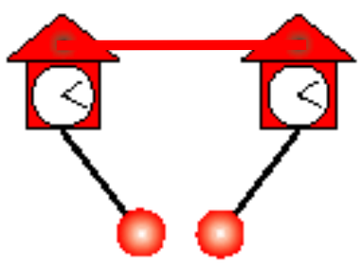


1629-1695

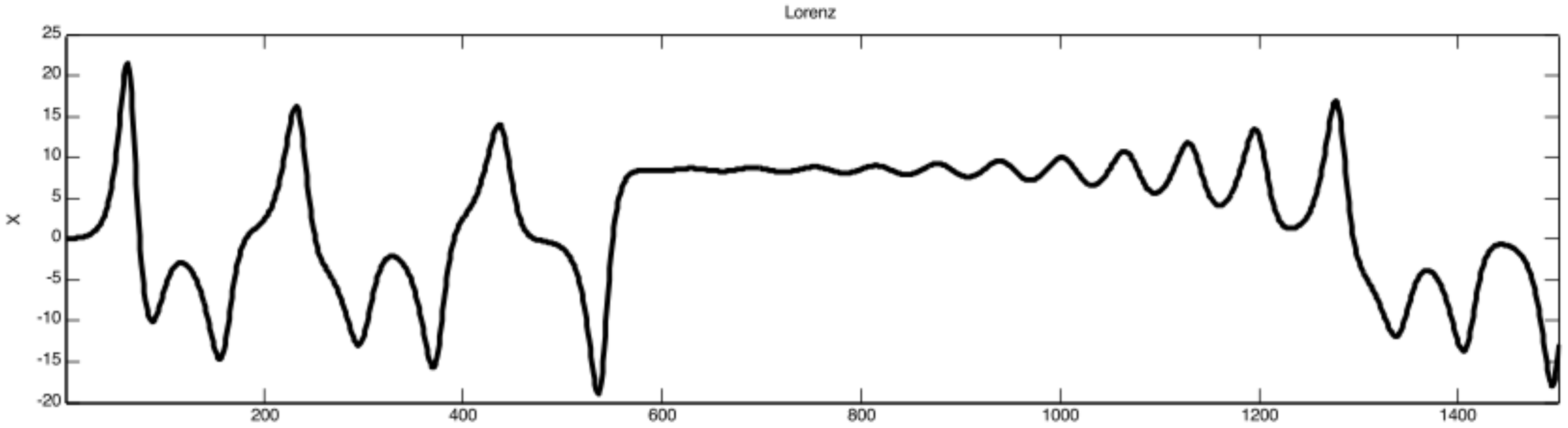
In-Phase

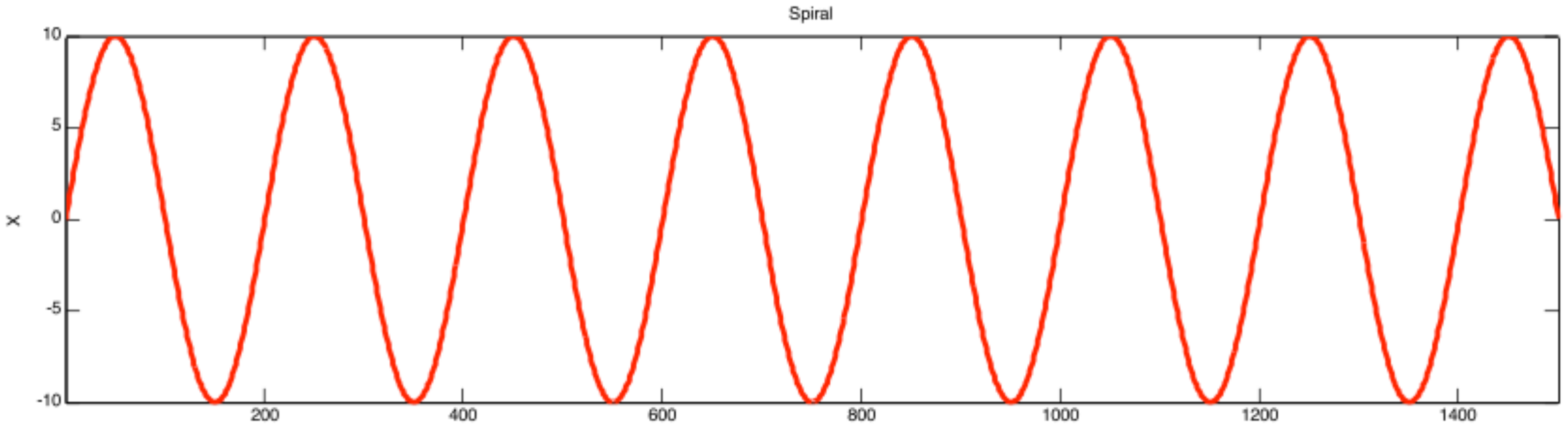


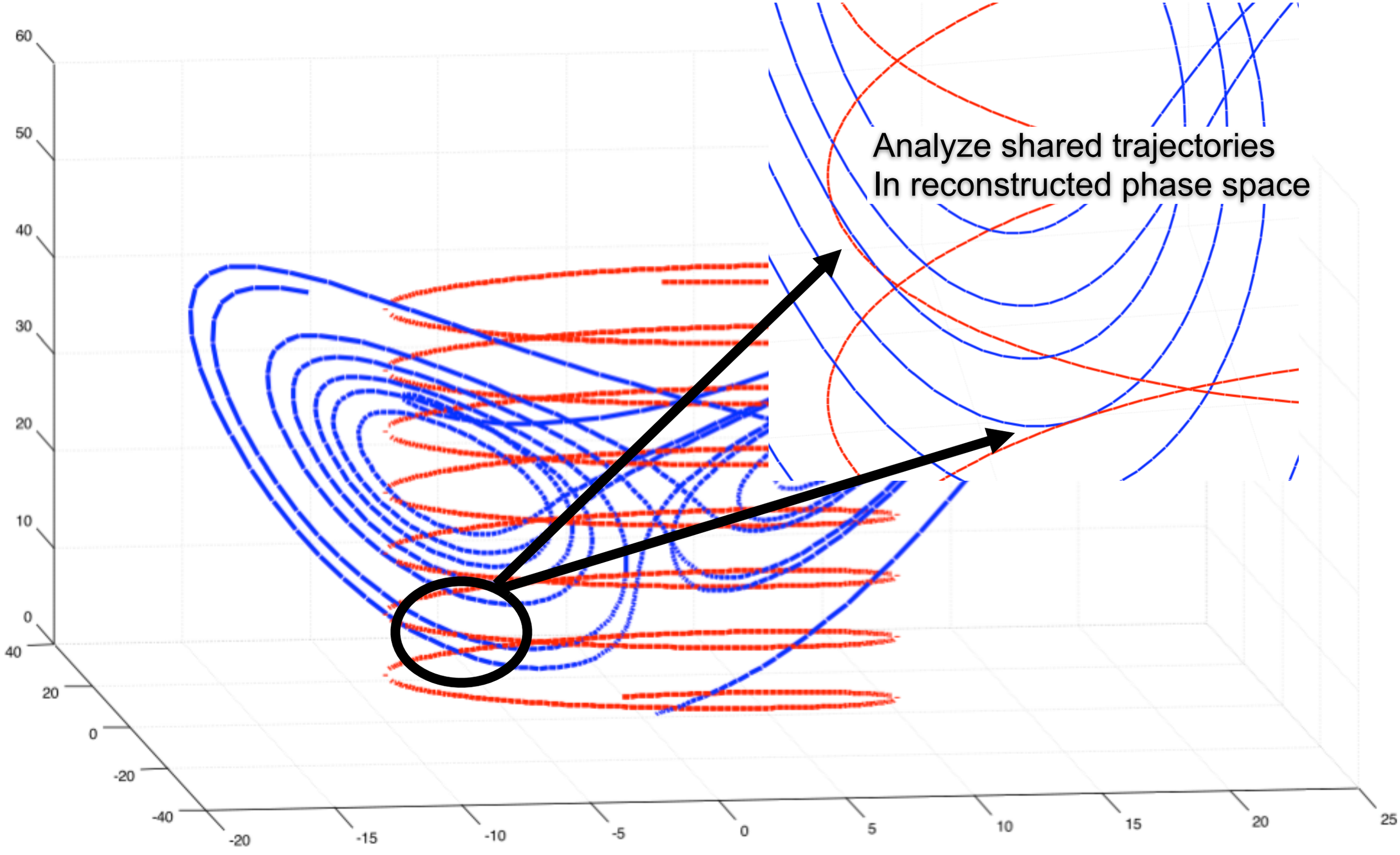
Anti-Phase



Time Series of X – Lorenz and Spiral

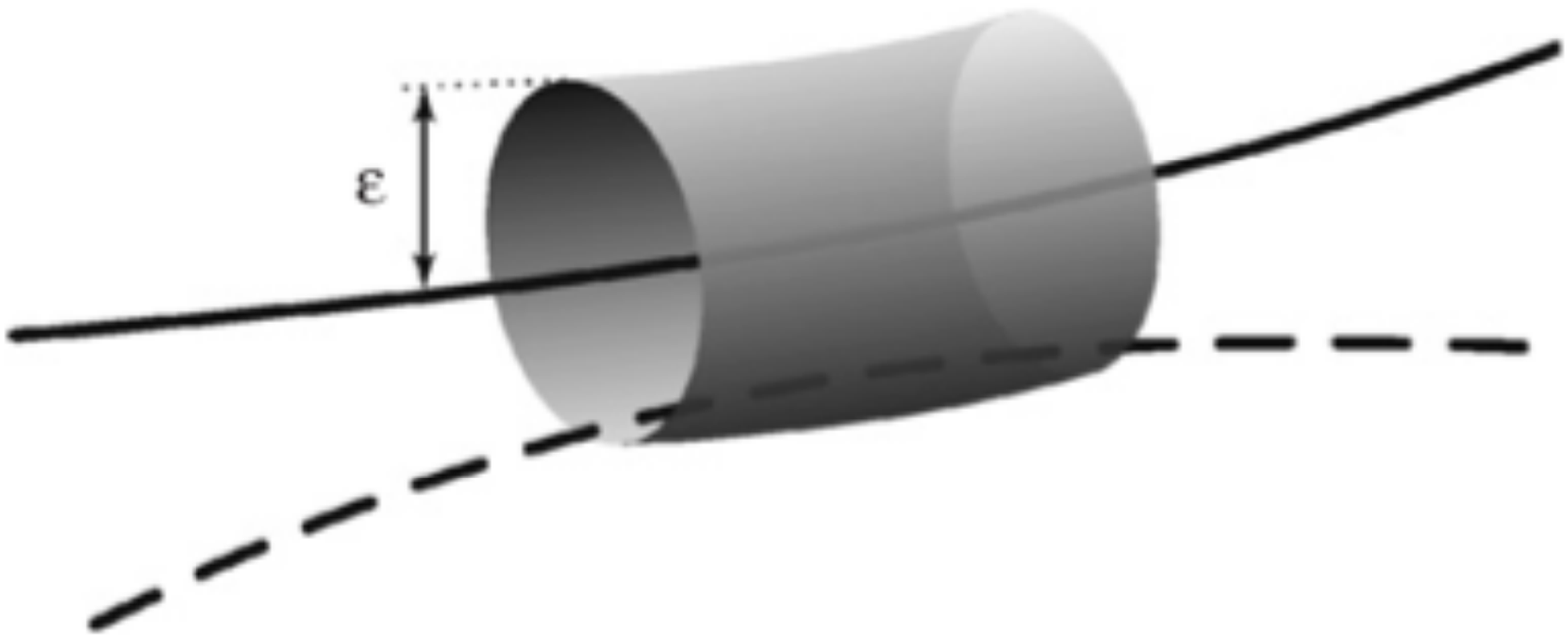




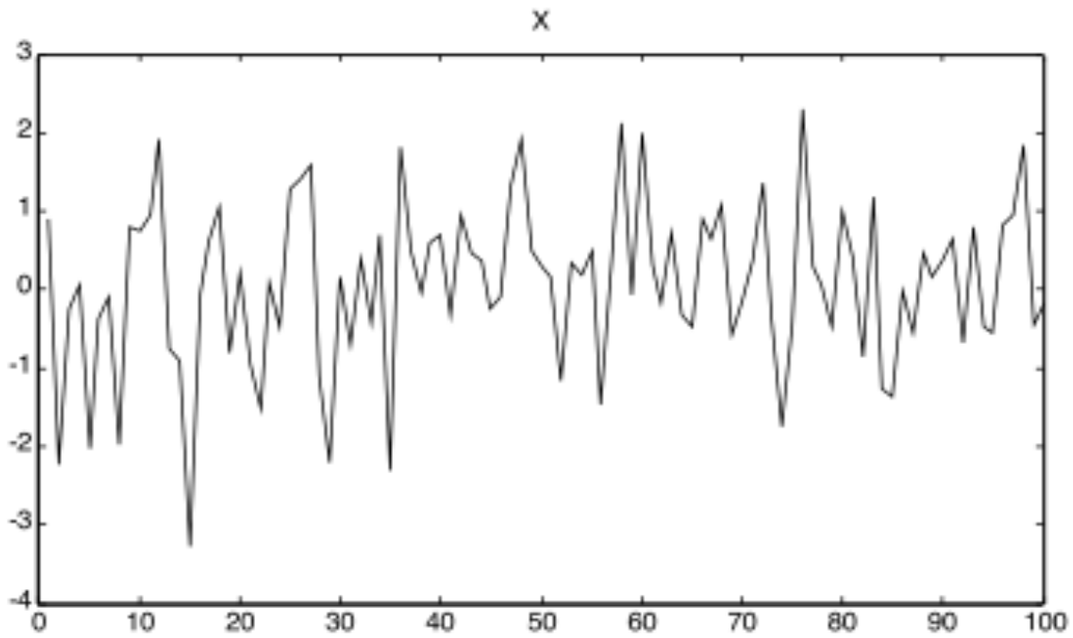

Analyze shared trajectories
In reconstructed phase space
60
50
40
30
20
10
0
40
20
0
-20
-40
-20
-15
-10
-5
0
5
10
15
20
25

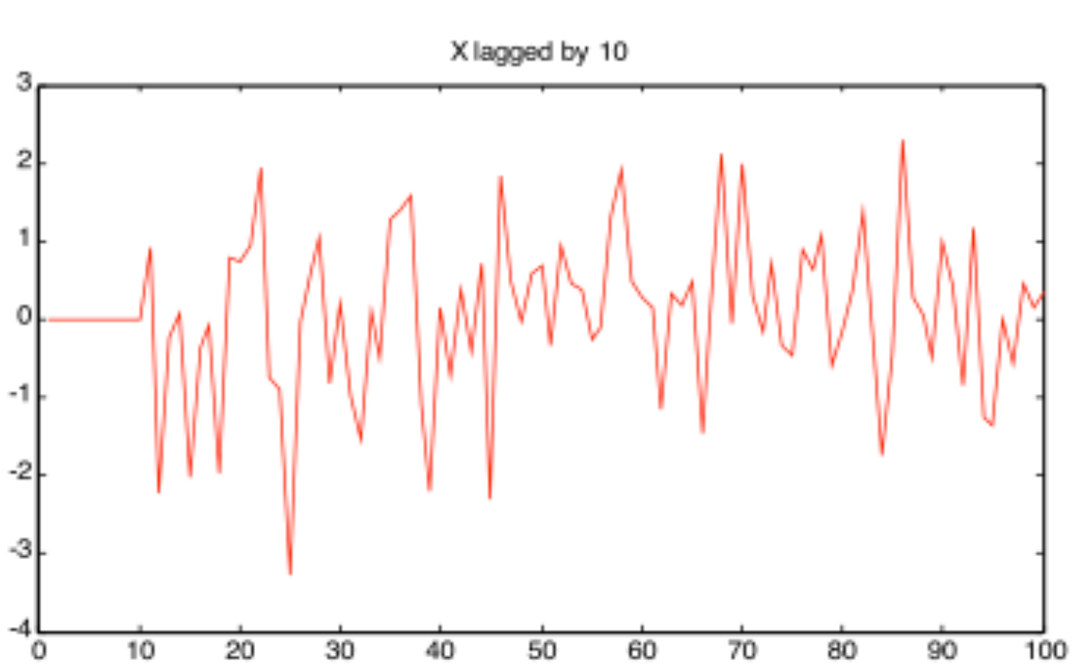
Within radius / threshold = shared trajectory

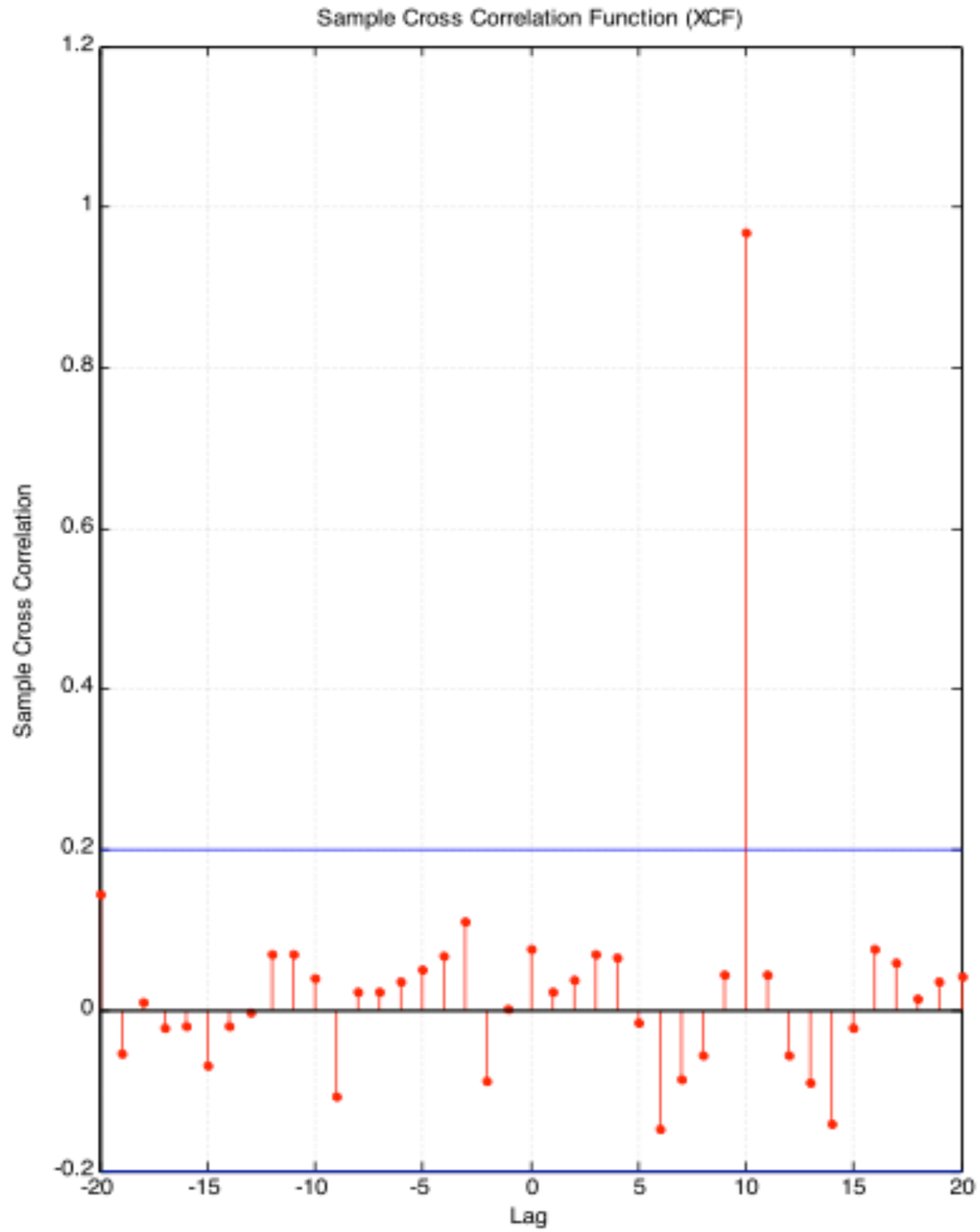
N. Marwan et al. / Physics Reports 438 (2007) 237–329



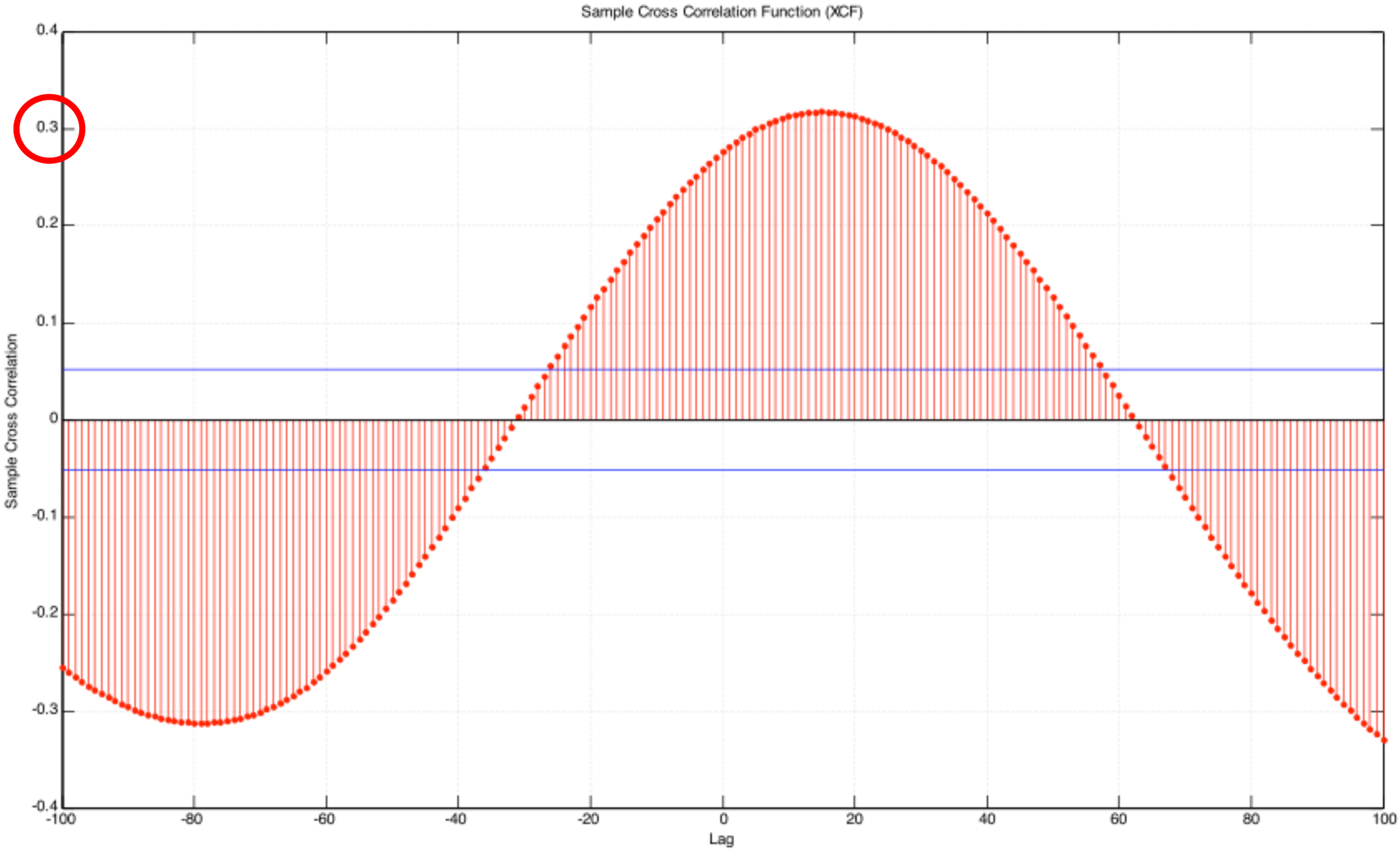
Intuitive notion of synchronisation – Cross Correlation



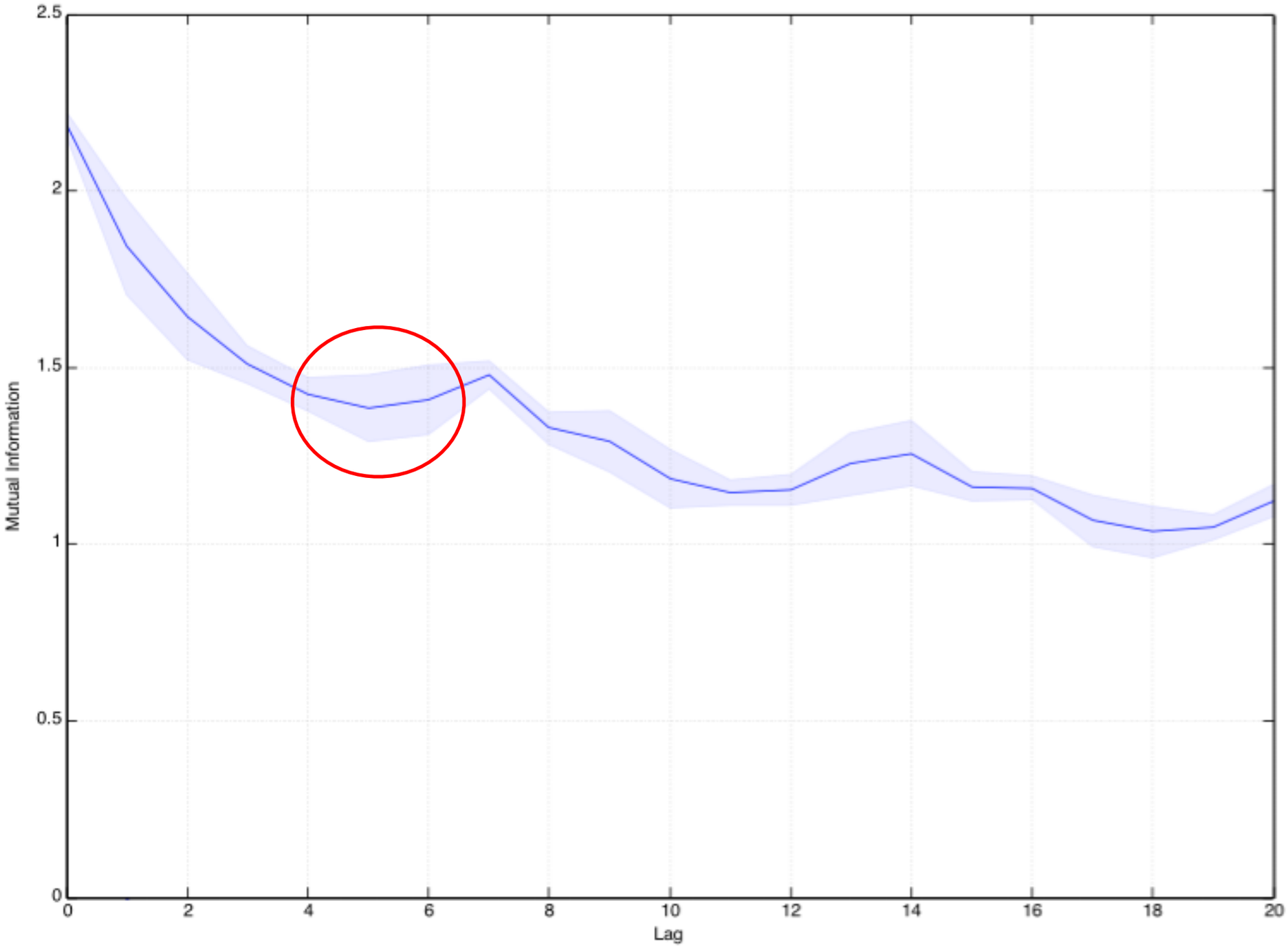


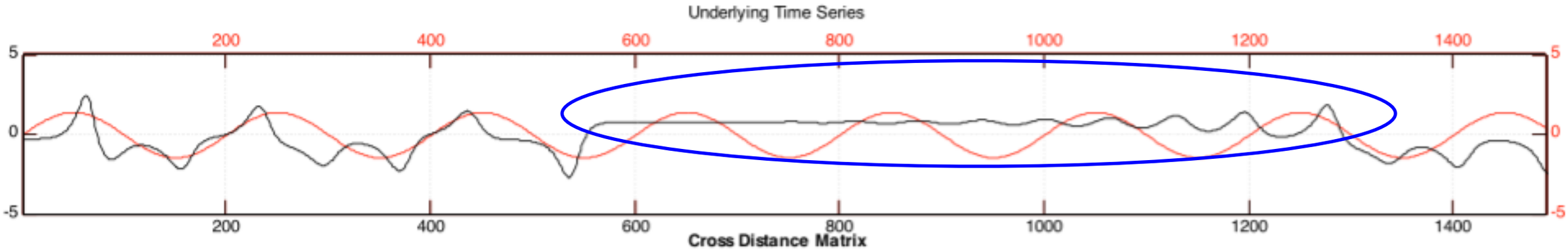


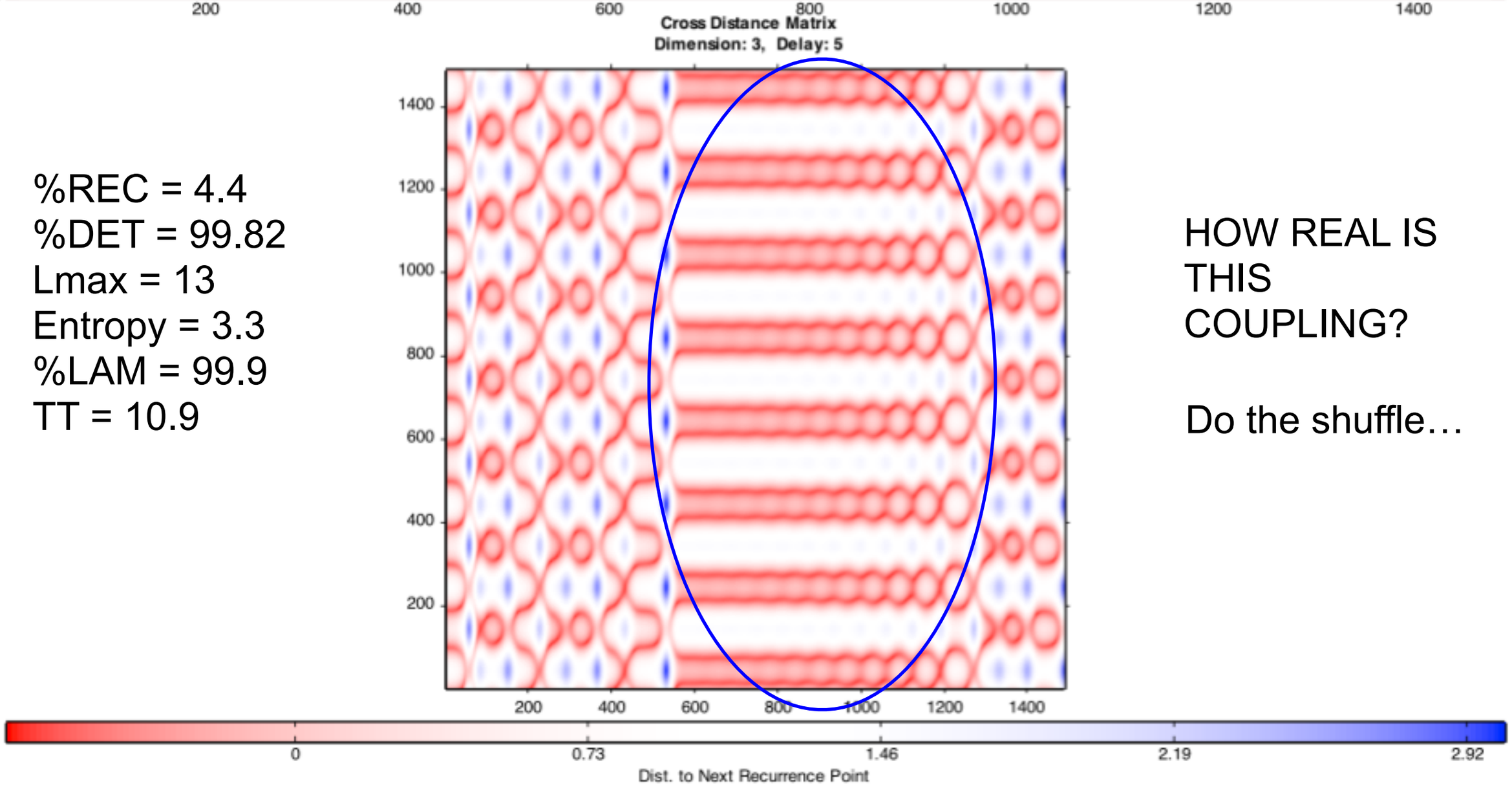
Intuitive notion of synchronisation – Cross Correlation



Lorenz and Spiral – Mutual Information



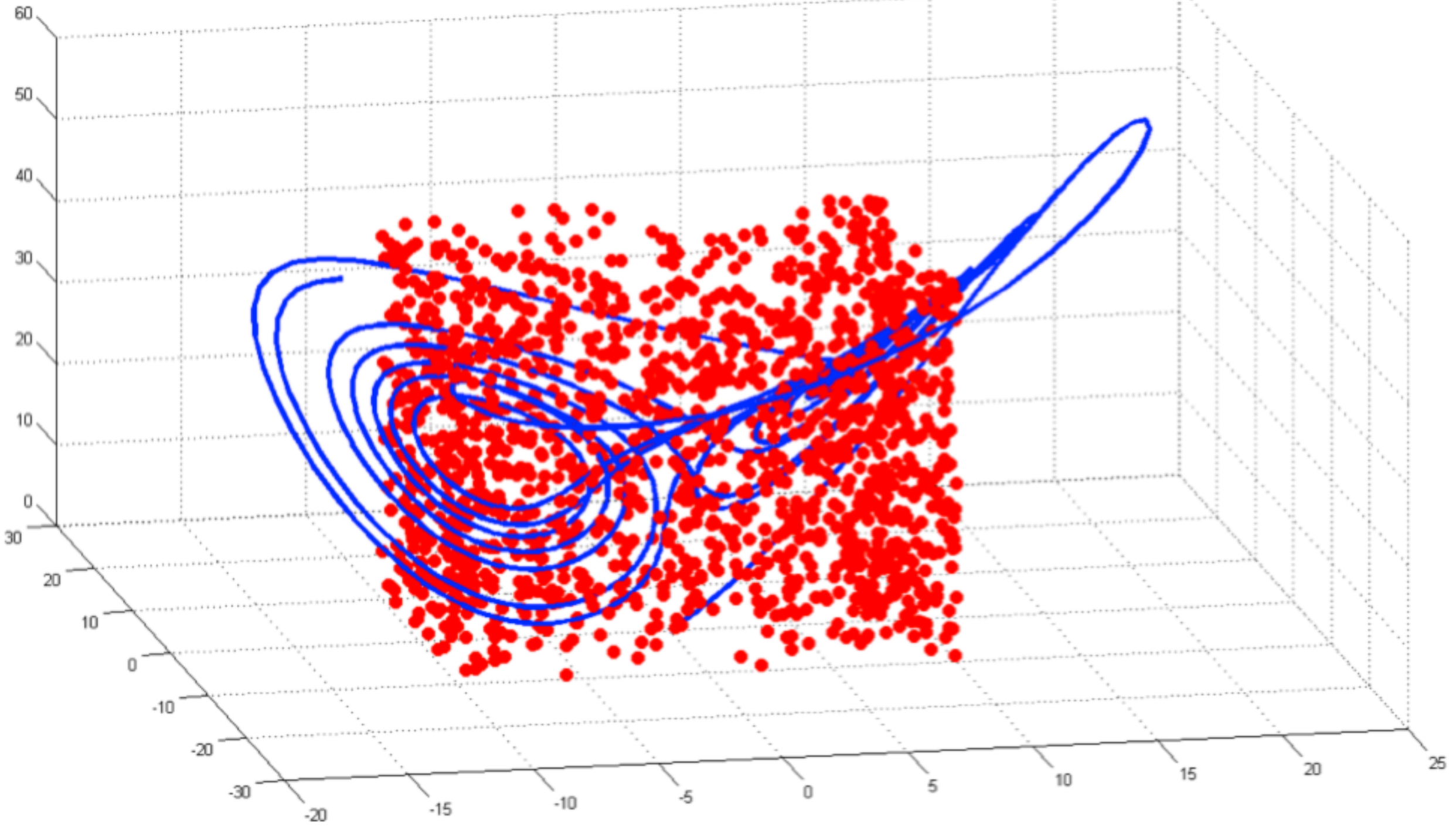


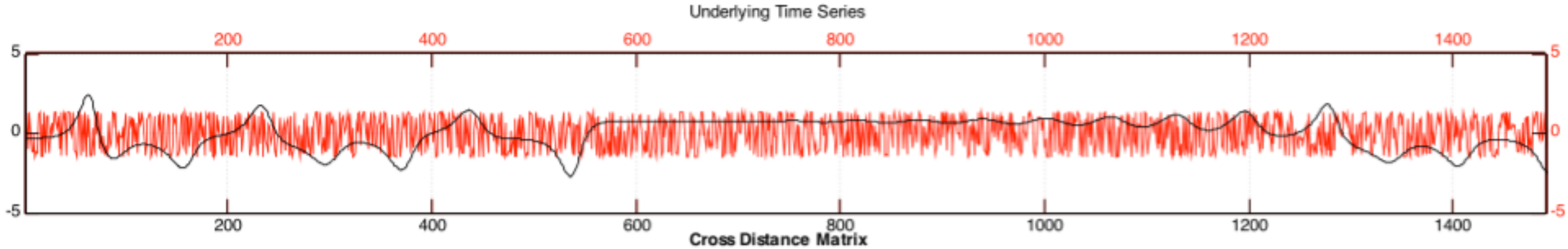


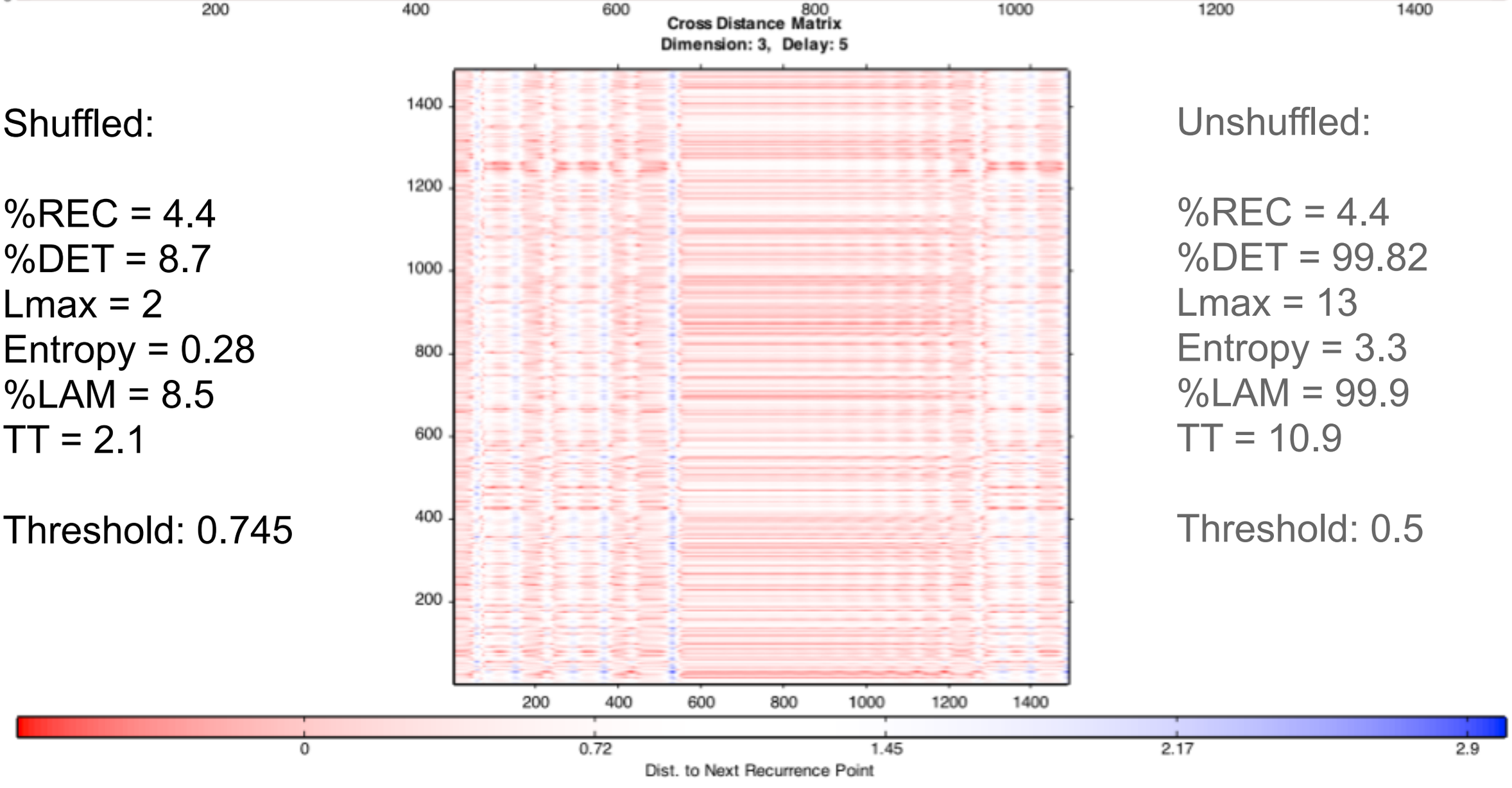
%REC = 4.4
%DET = 99.82
Lmax = 13
Entropy = 3.3
%LAM = 99.9
TT = 10.9

HOW REAL IS THIS COUPLING?

Do the shuffle…


60
50
40
30
20
10
0
30
20
10
0
-10
-20
-30
-20
-15
-10
-5
0
5
10
15
20
25





Shuffled:

%REC = 4.4
%DET = 8.7
Lmax = 2
Entropy = 0.28
%LAM = 8.5
TT = 2.1

Threshold: 0.745

Unshuffled:

%REC = 4.4
%DET = 99.82
Lmax = 13
Entropy = 3.3
%LAM = 99.9
TT = 10.9

Threshold: 0.5

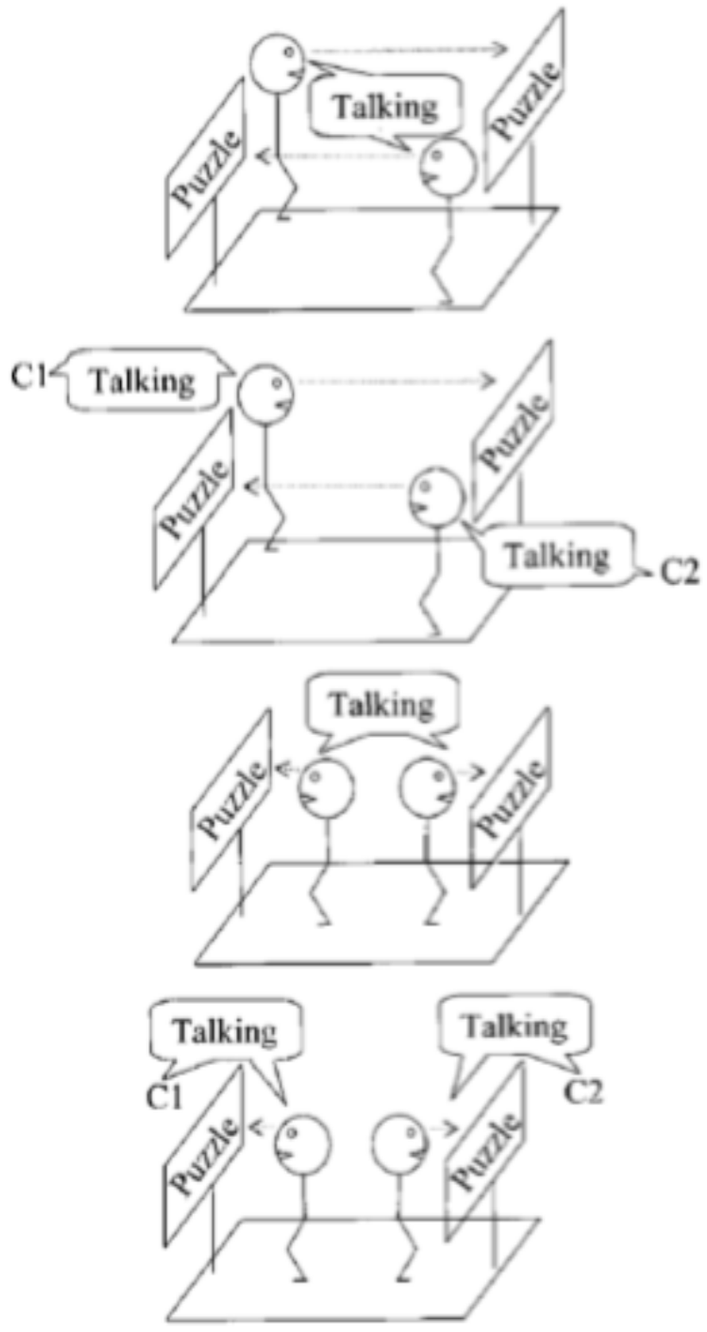
Some Applications

- Coupling of postural sway through communication
- Coupling of language development between infant and caretaker
- Coupling of eye movements to communication

Coupling of postural sway through communication

- Postural sway measured by force plate

- Level of direct communication manipulated by talking directly or to confederate / visibility



Shockley, K., Santana, M-V., Fowler, C. (2003). Mutual Interpersonal Postural Constraints Are Involved in Cooperative Conversation. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 326-323.

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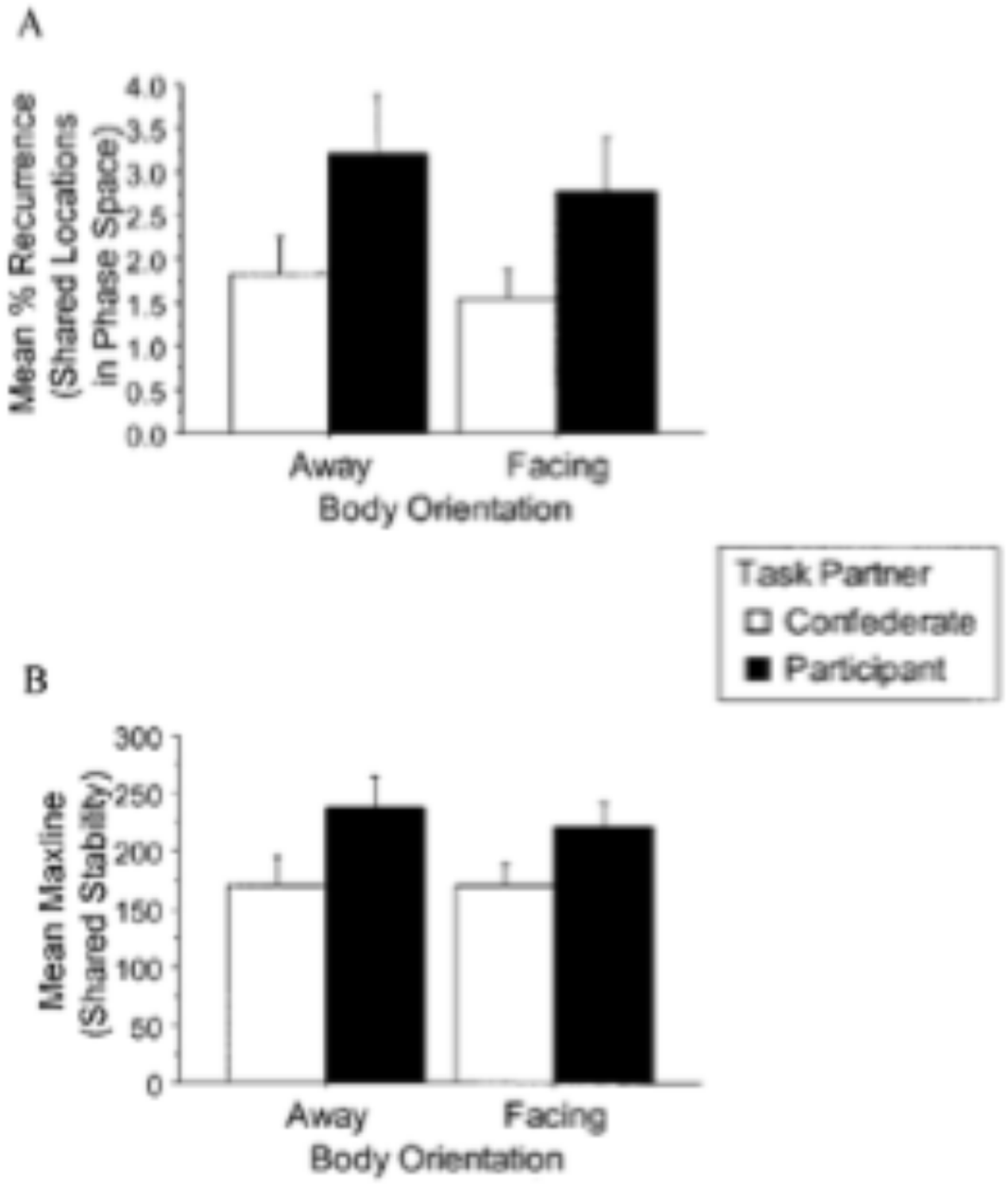
Coupling of postural sway through communication

Speech can be a “coupling tool” for coordination of previously autonomous bodies

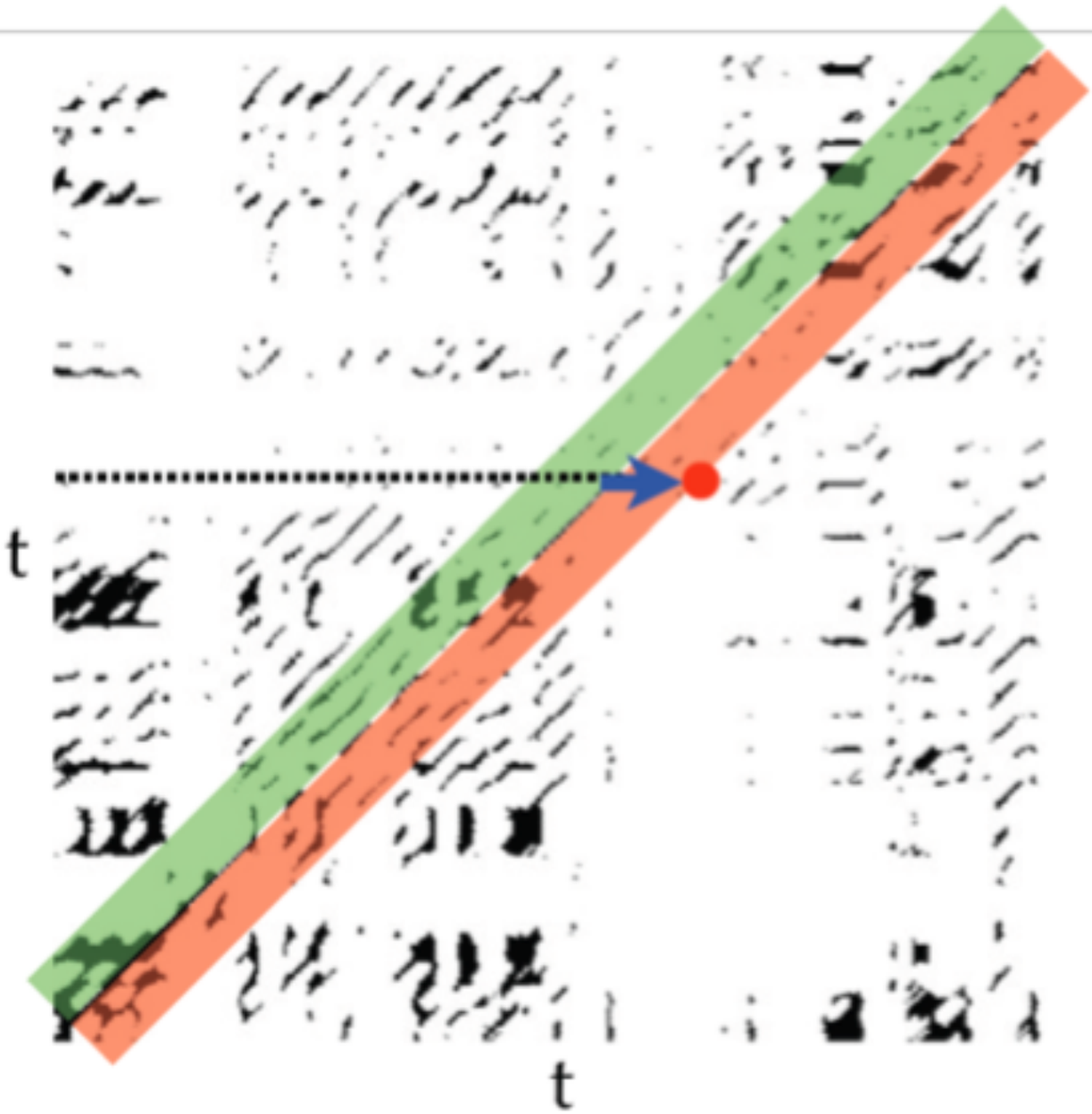


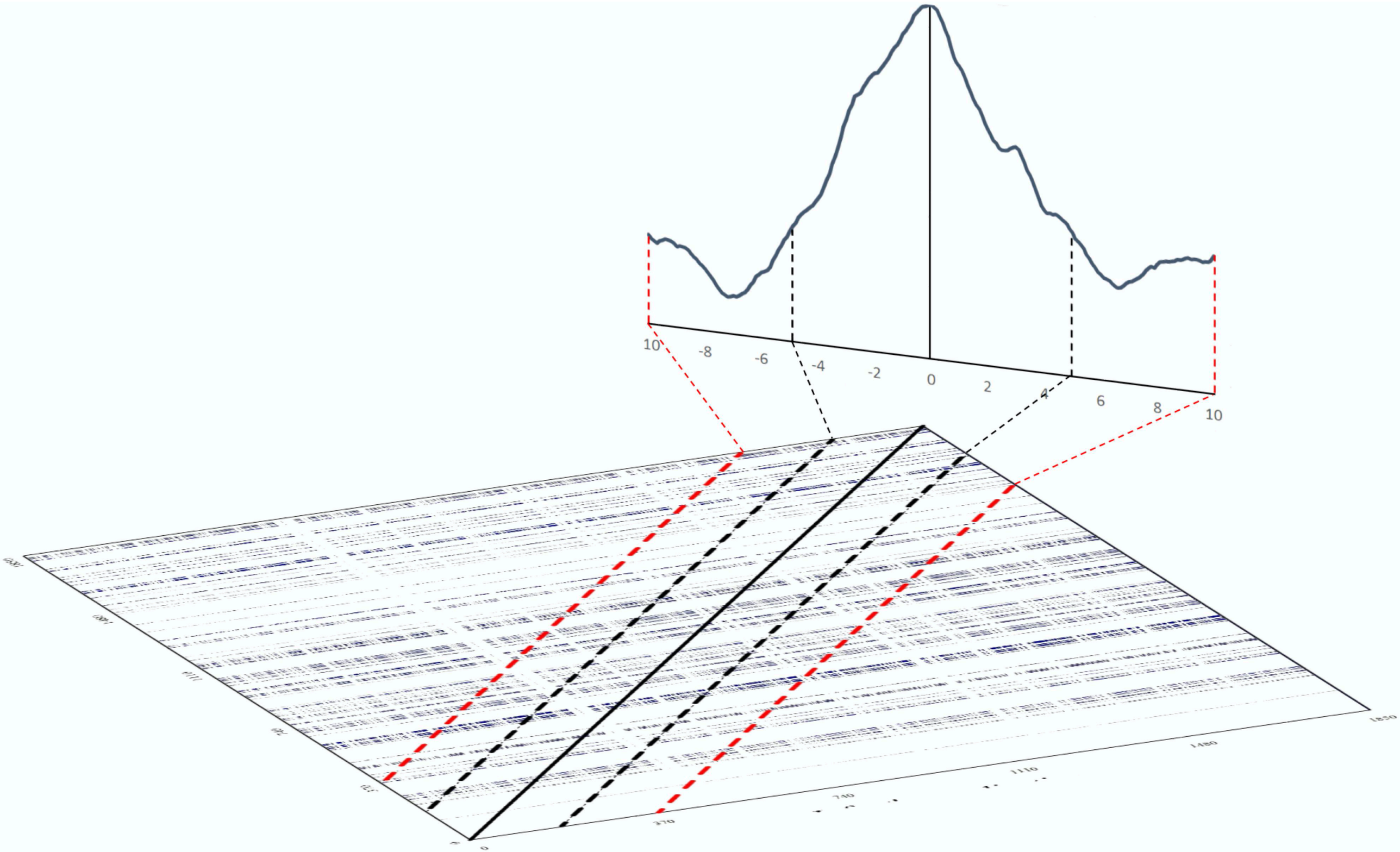
Shockley, K., Santana, M-V., Fowler, C. (2003). Mutual Interpersonal Postural Constraints Are Involved in Cooperative Conversation. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 326-323.

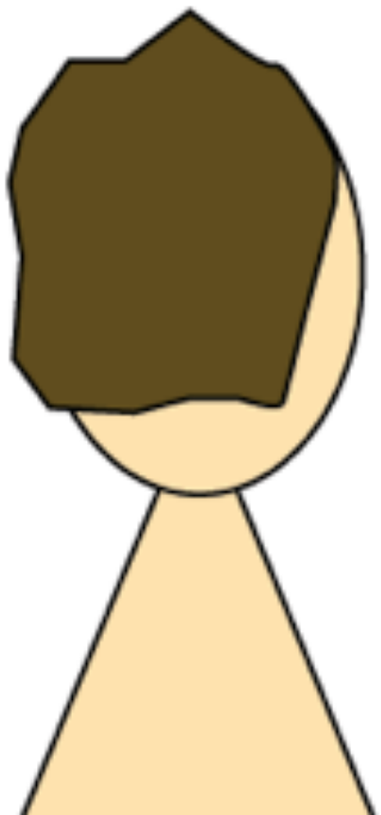
Who leads?

Time Series
On Y-axis
leads at red dot:

The category- / word- / syntactic- / pattern first occurred there,
in the X-axis series
it occurred later




10
-8
-6
-4
-2
0
2
4
6
8
10
0
370
740
1110
1480
1850

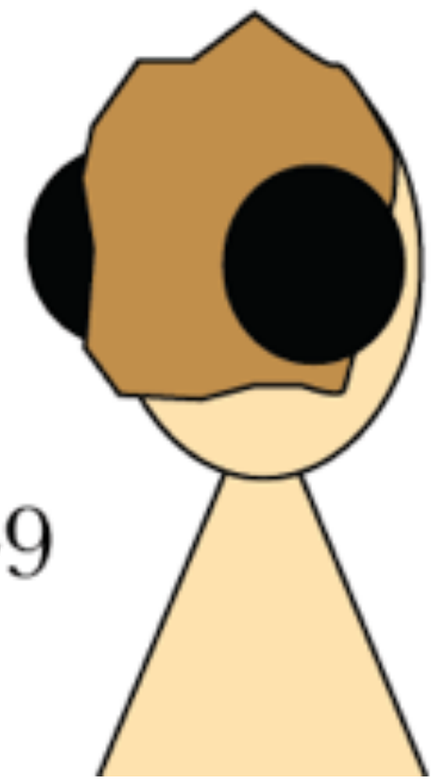


N = 4

eye movement patterns...

1, 2, 2, 2, 2, 4, 4, 5, ...

“blah blah blah...”



eye movement patterns...
1, 1, 1, 2, 2, 2, 2, 4, ...

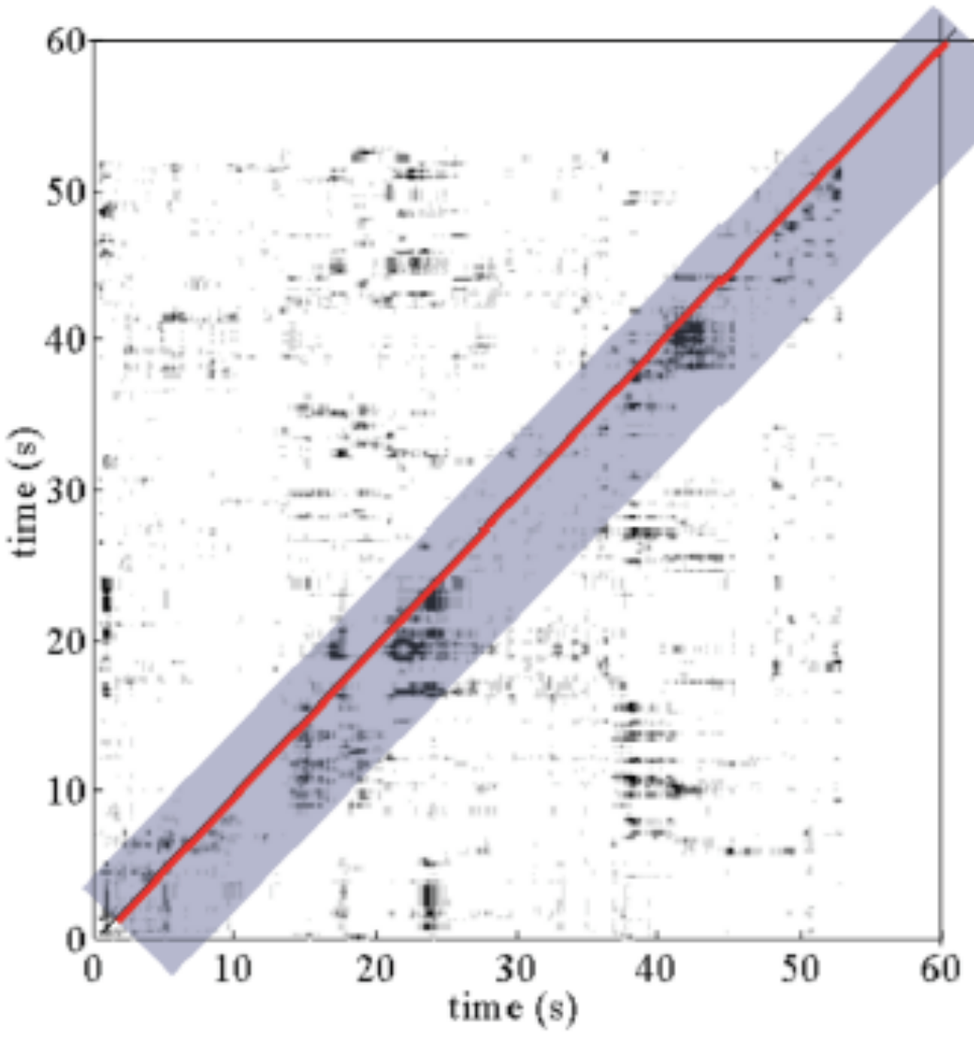
“blah blah blah...”

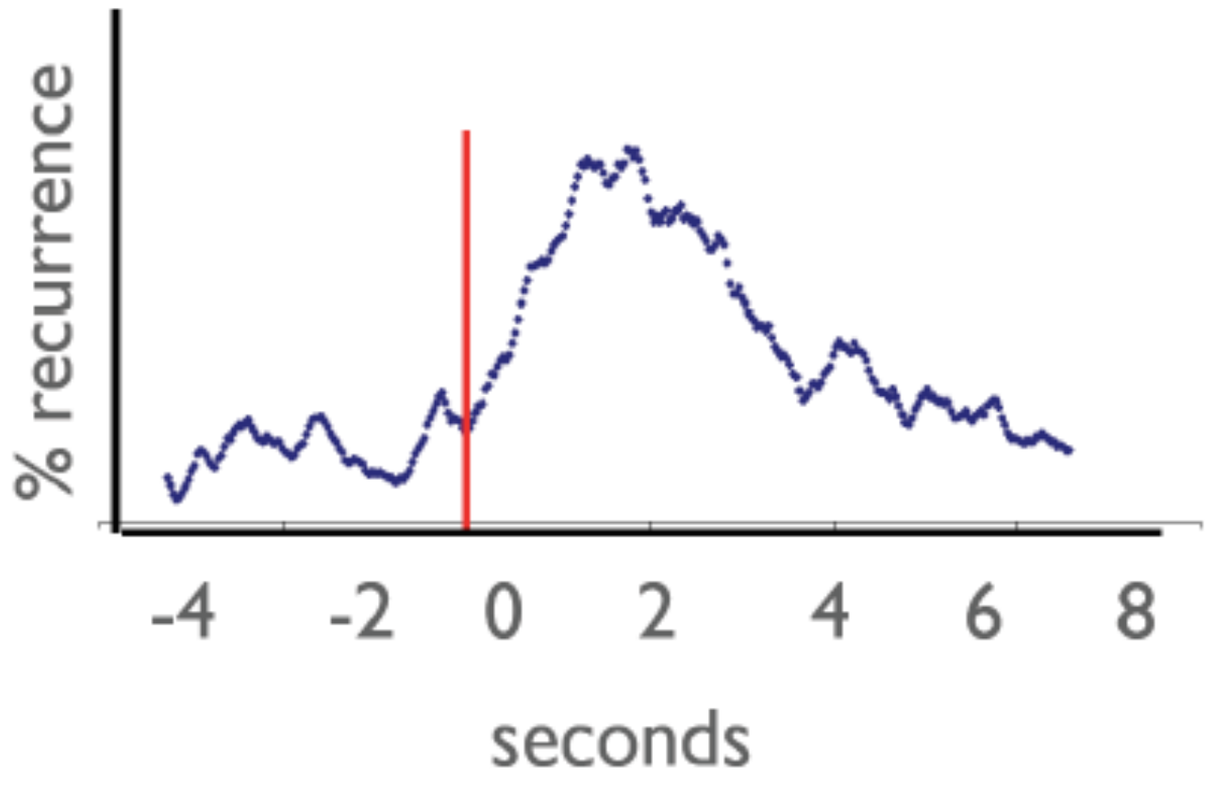
N = 49

Coupling of eye movements to communication

Richardson, D.C., Dale, R., Kirkham, N.Z. (2007). The art of conversation is coordination. *Psychological Science, 18*, 407-413.

Speaker





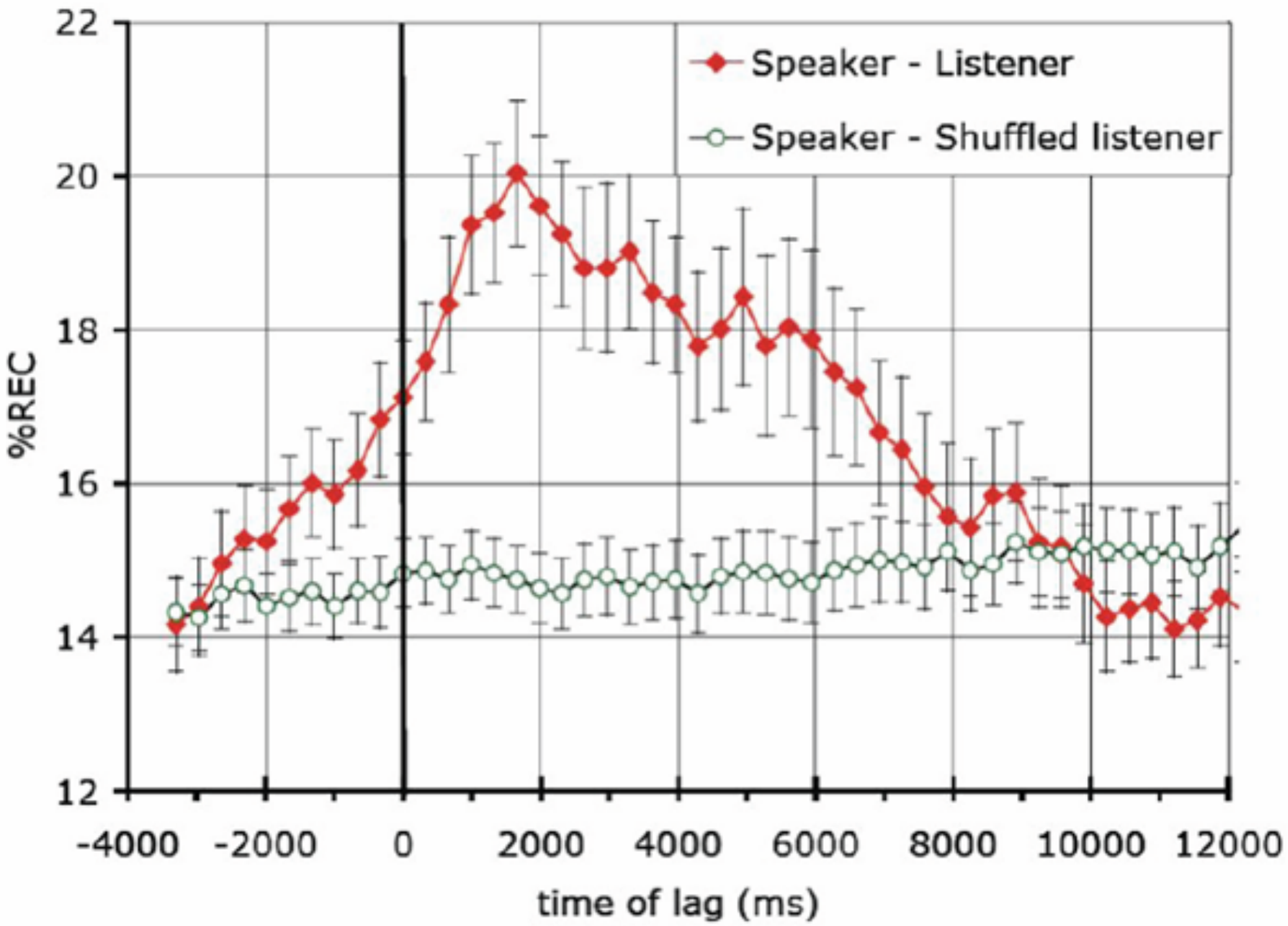
Listener

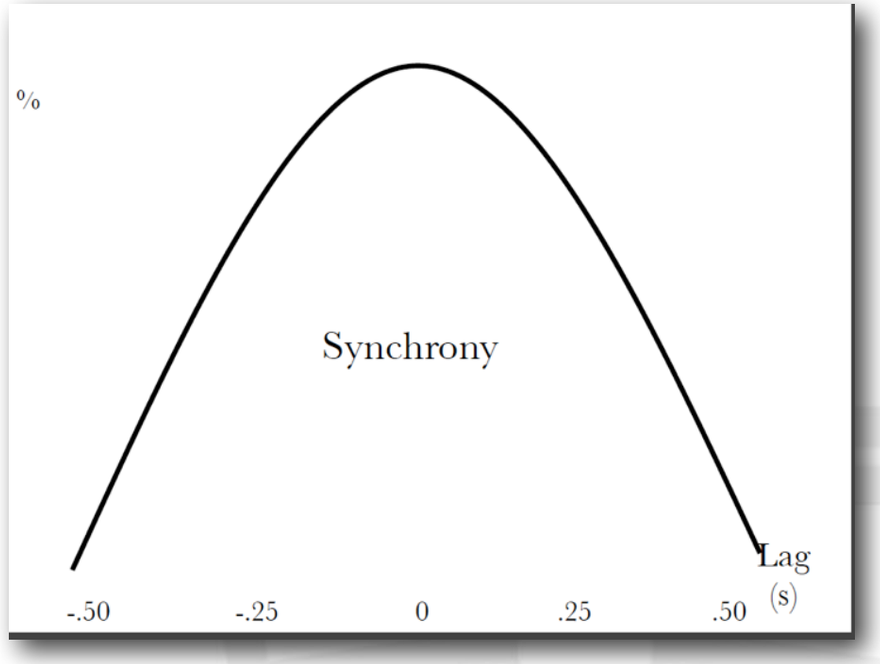
Richardson & Dale, 2005

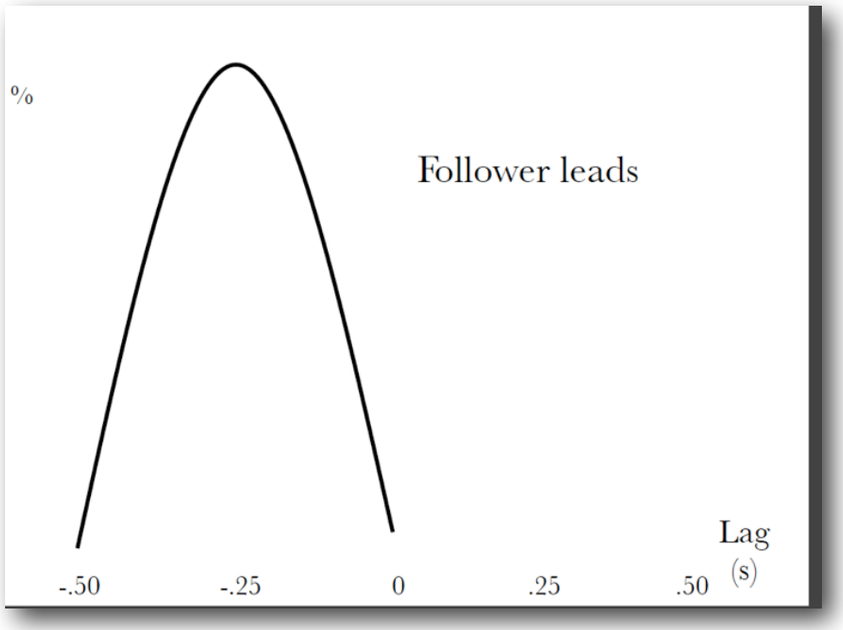
Coupling of eye movements to communication

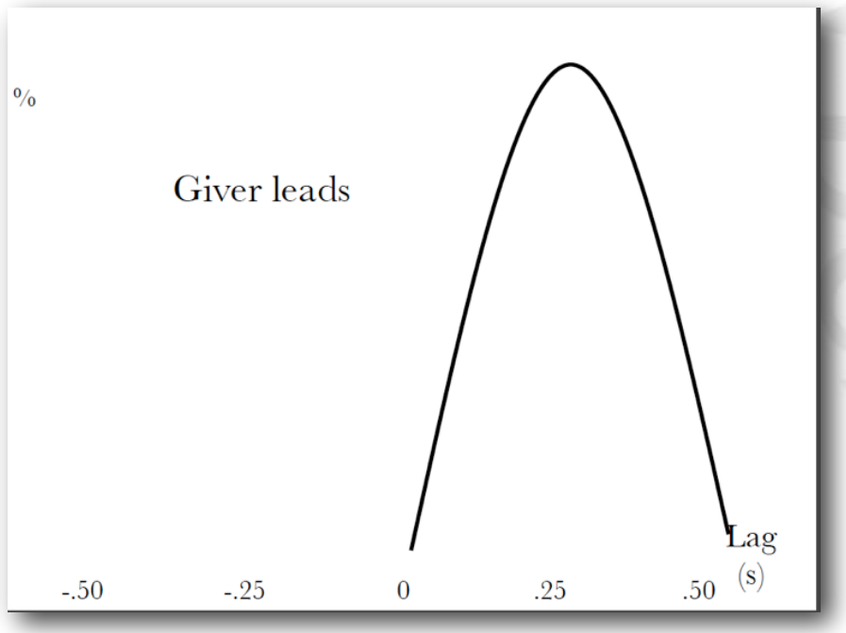
Richardson, D.C., Dale, R., Kirkham, N.Z. (2007). The art of conversation is coordination. *Psychological Science, 18*, 407-413.

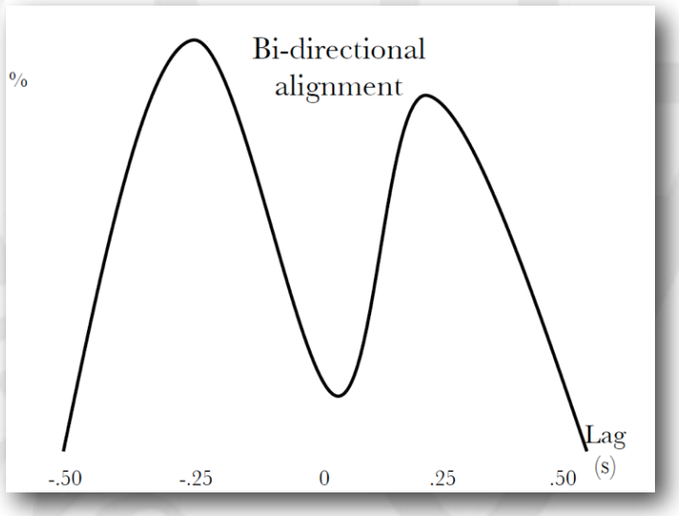
Listeners eye movements are coupled and lagging depending on level of interaction in conversation



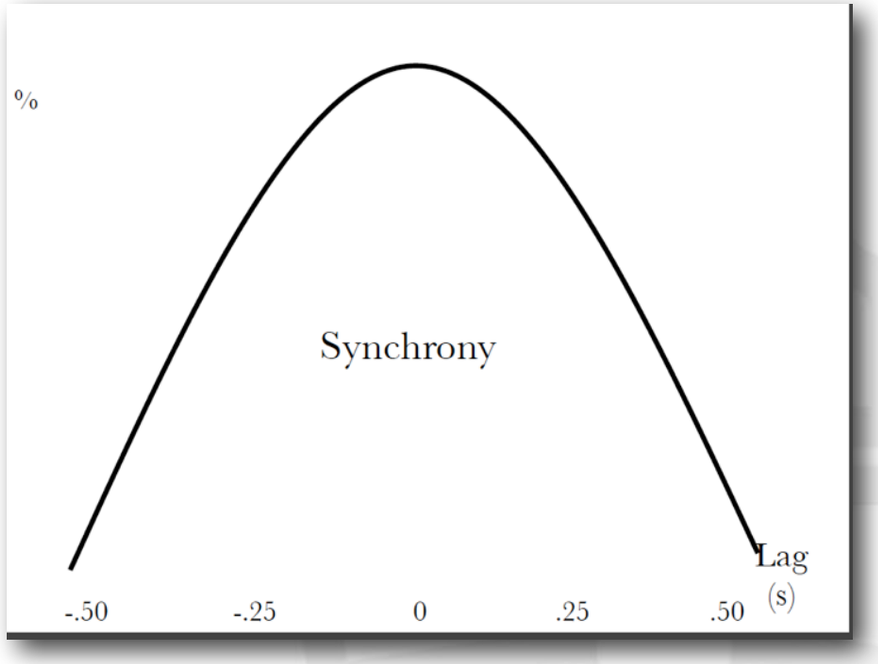


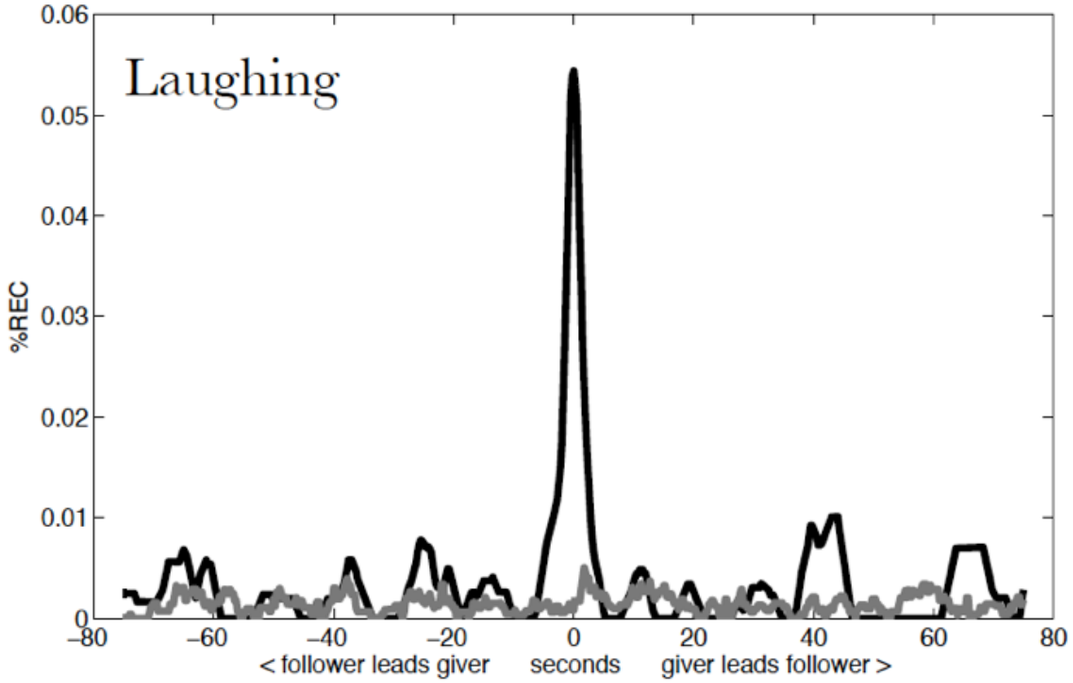






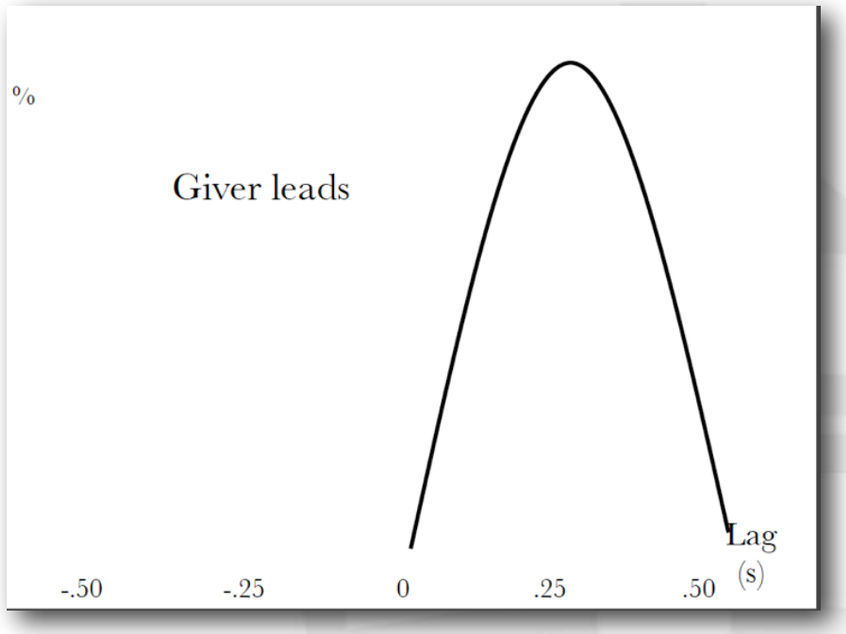
Louwerse, M. M., Dale, R., Bard, E. G., & Jeuniaux, P. (2012). Behavior matching in multimodal communication is synchronized. *Cognitive science*, *36*(8), 1404–26. doi:10.1111/j.1551-6709.2012.01269.x

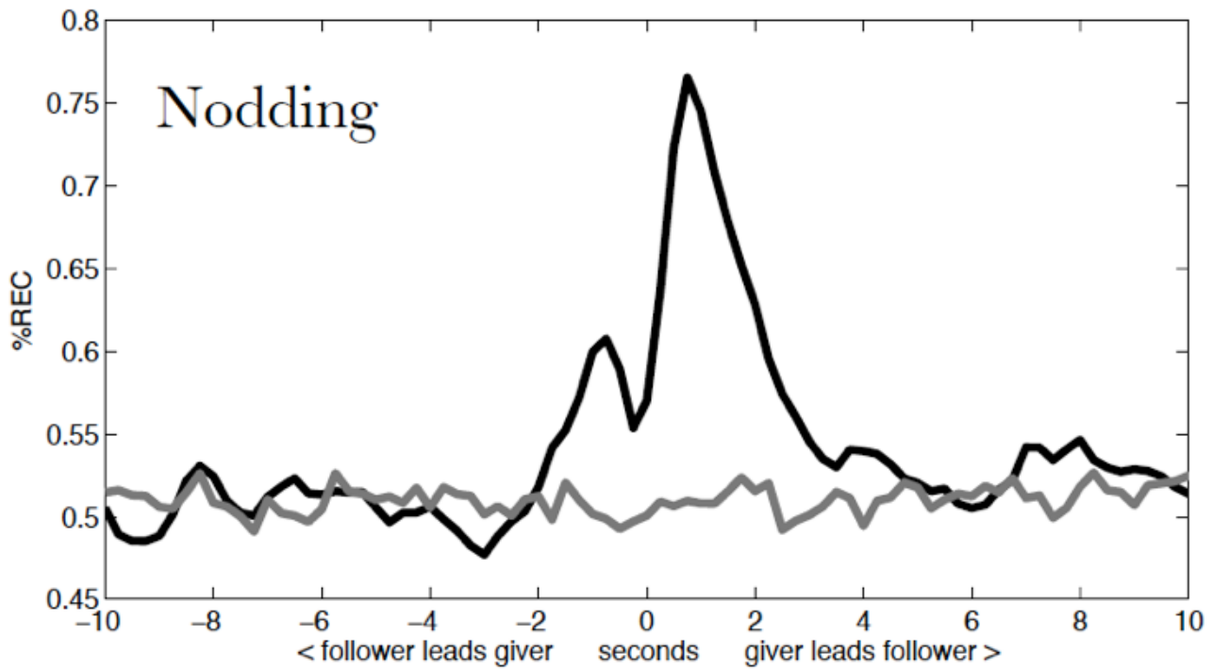




Louwerse, Dale, et al., in prep

Louwerse, M. M., Dale, R., Bard, E. G., & Jeuniaux, P. (2012). Behavior matching in multimodal communication is synchronized. *Cognitive science*, *36*(8), 1404–26. doi:10.1111/j.1551-6709.2012.01269.x





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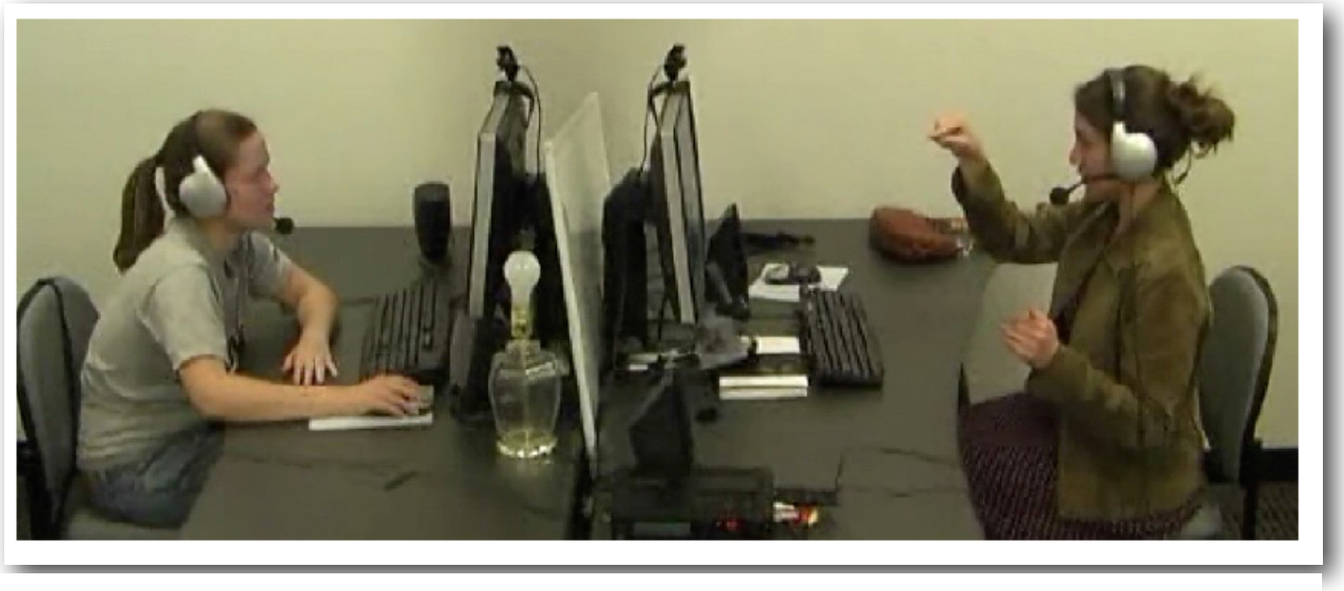

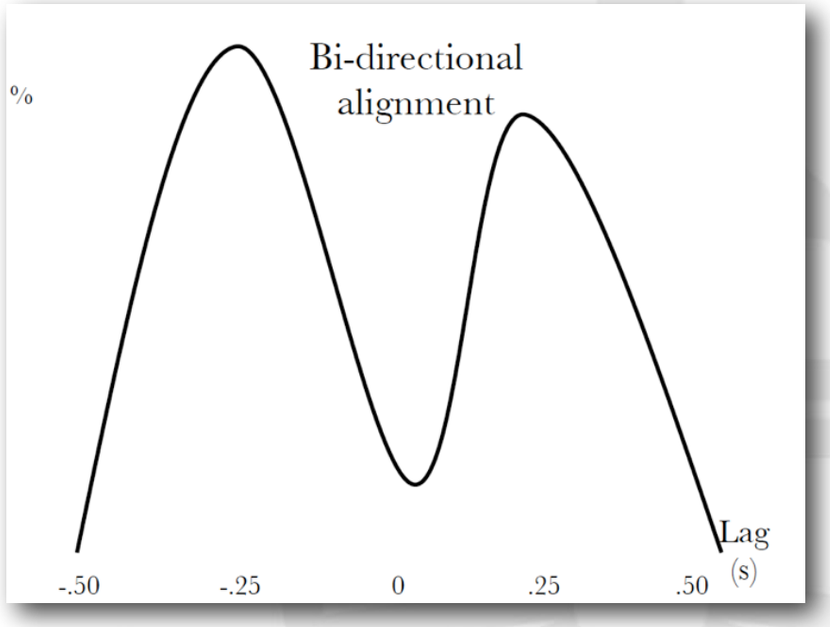

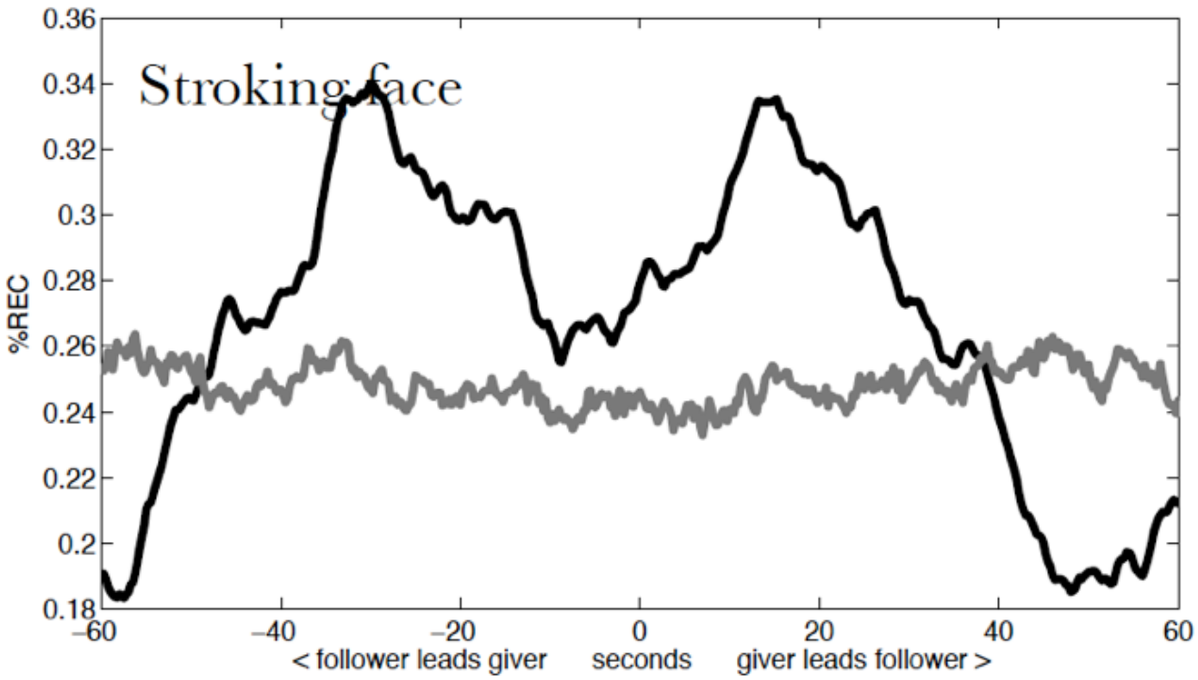

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Rescaling *before* Reconstruction

- You could also rescale the time series *before* you do the reconstruction:

- **Max distance** -> unit scale $\mathbf{X}_{\mathbf{unit}} = (\mathbf{X}\text{-}\min(\mathbf{X})) / (\max(\mathbf{X})\text{-}\min(\mathbf{X}))$

  Scale of 0-1 (in package *casnet* you can use the **elascer** function)

- **Mean distance** -> z-score $\mathbf{X}_{\mathbf{z}} = (\mathbf{X}\text{-}\text{mean}(\mathbf{X})) / \text{std}(\mathbf{X})$

  Z-score scale (in package *casnet* you can use the **ts_standardise** function with: **adjustN = FALSE**)

Research question

- **Motor coordination + Cooperation + Learning / Problem solving**

- Does the coordination of postural sway differ between typically developing children and children with a neurodevelopmental disorder, when they perform a cooperative task?

- And if so, how do they differ?

- And… why?

Participants

Typically developing children

- 183 dyads
  - M_{age} = 10;8 years
  - *SD* = 1;00
  - range: 8-13
  - 95 boys and 88 girls

- Dyad composition
- Recruitment of participants

Children with a neurodevelopmental disorder

- 106 dyads
  - M_{age} = 10;10
  - *SD* = 1;3
  - range: 8 – 13
  - 74 boys and 32 girls.

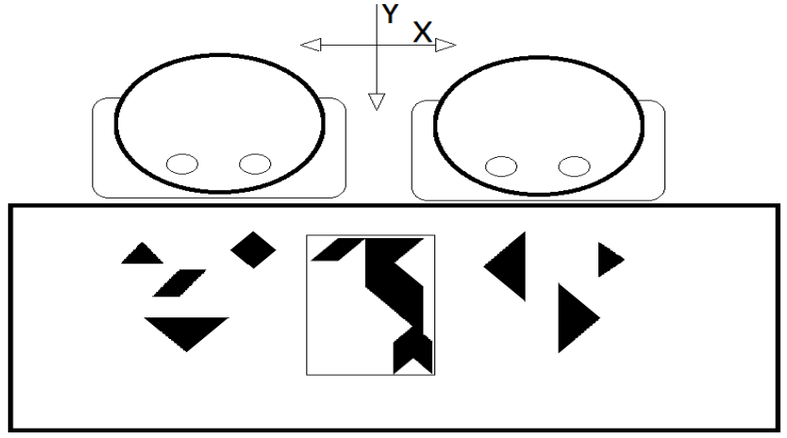
Materials and Procedure

Tangram task

- Three sets of 18 puzzles
- Printed on A4 paper
- Pretest, coop, posttest

Two Nintendo Wii Balance Boards

- Simultaneously recorded postural sway
- Sampling rate 100Hz
- Records x- and y-coordinates



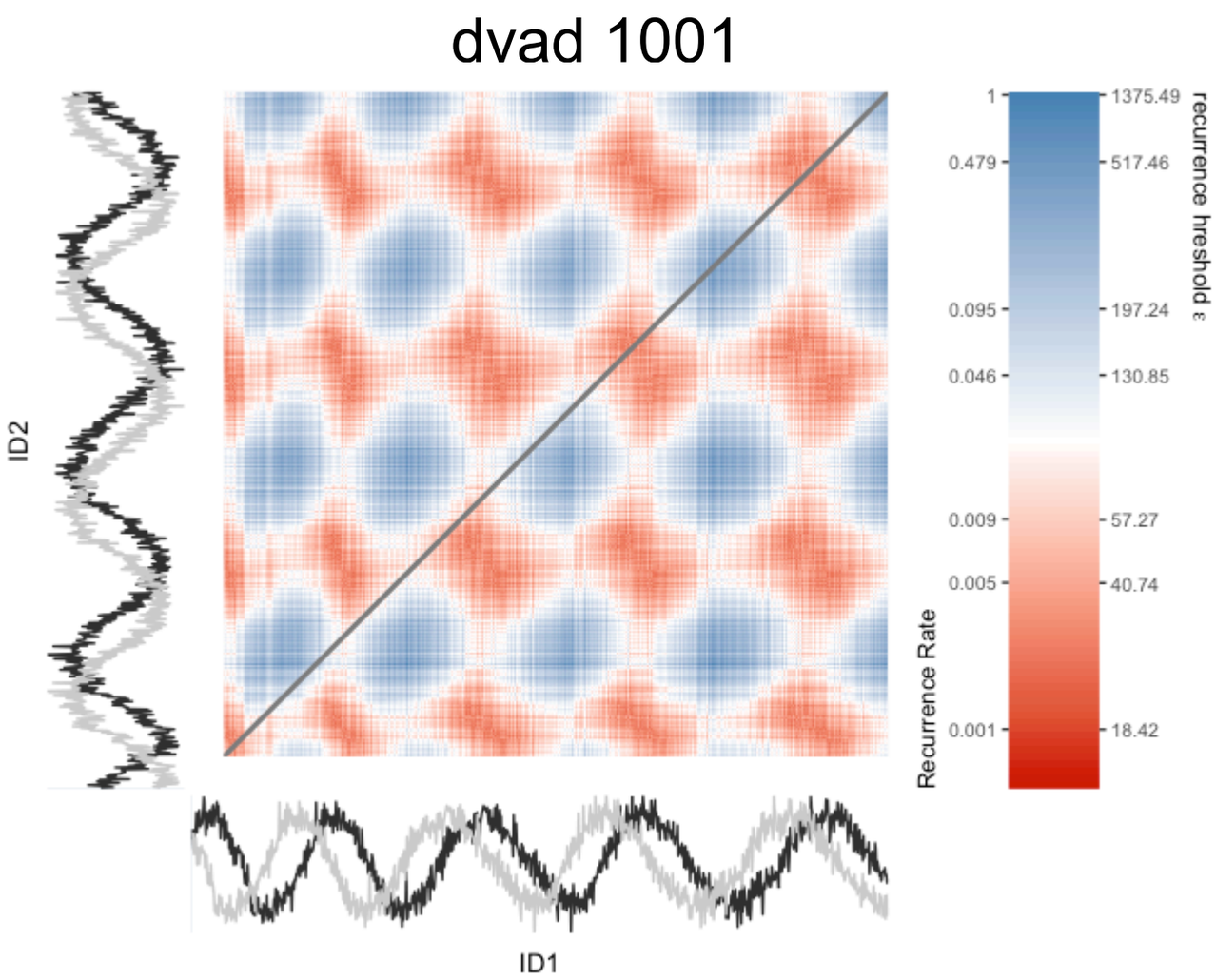
Data Preparation

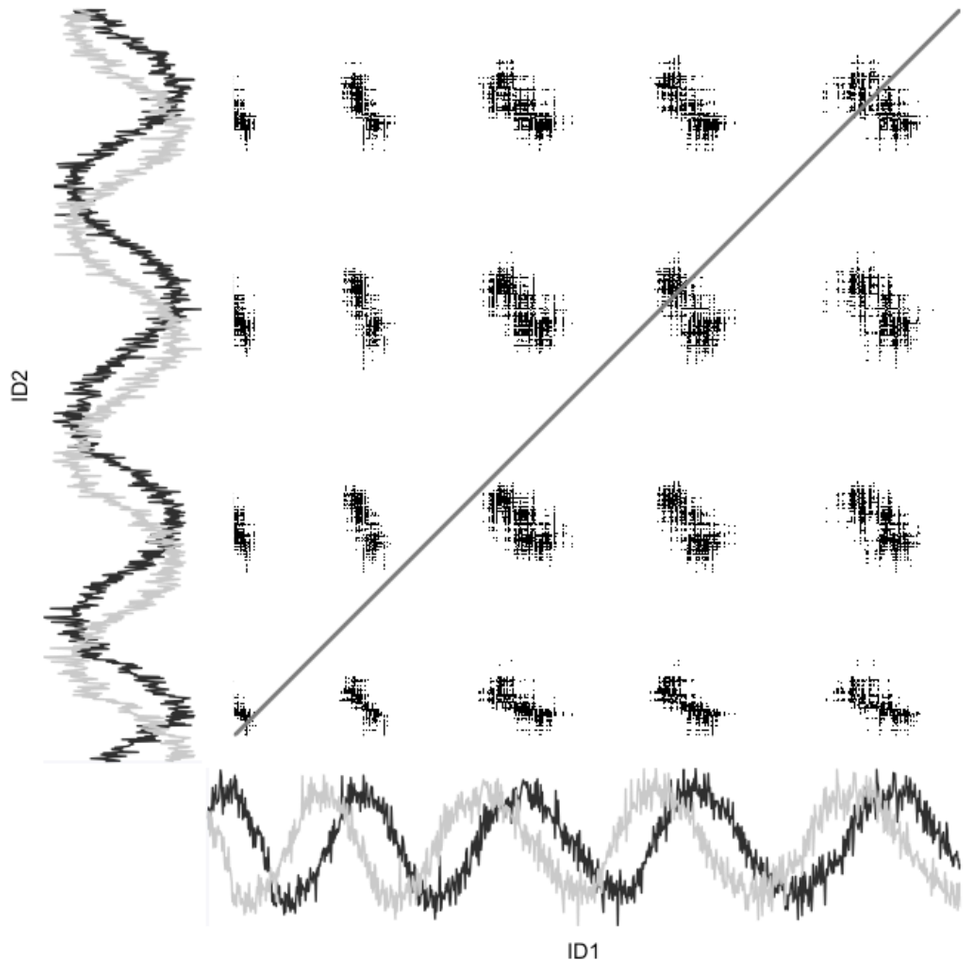
- Data reduction
  - 100Hz → 5Hz
  - Time series of approximately 3,000 data points per dyad

- Displacement scores
  - $\text{Displ}_t = \sqrt{(X_{(t+1)} - X_t)^2 + (Y_{t+1} - Y_t)^2}$

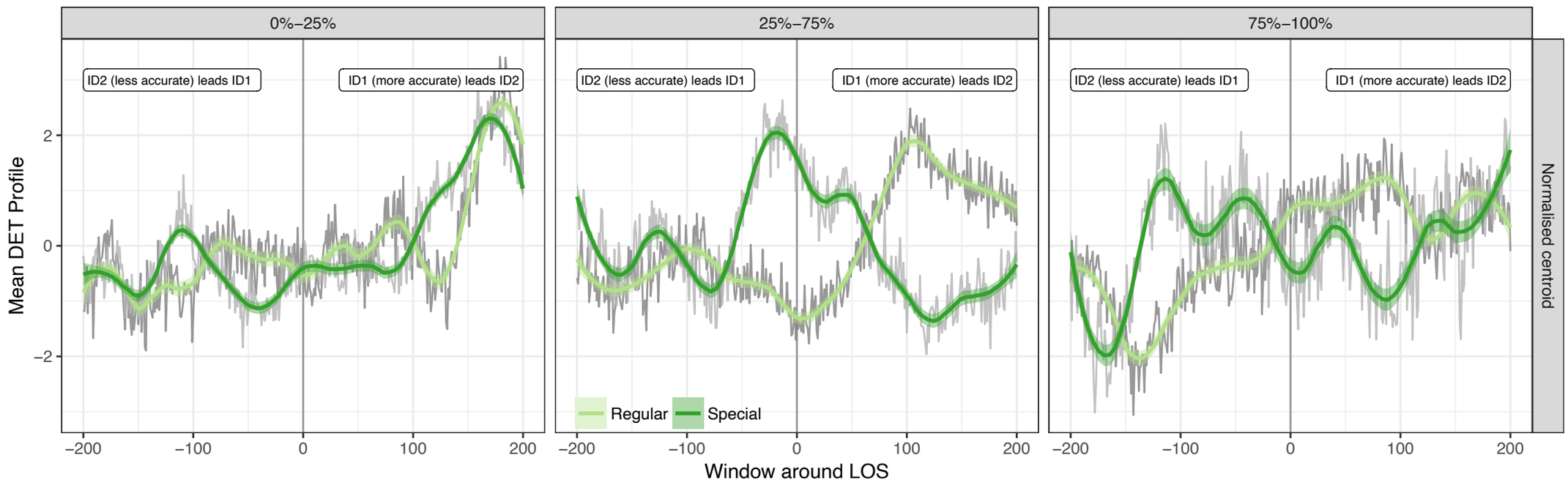
- In a previous study we showed that measures obtained from surrogate and randomized timeseries differ significantly from the observed timeseries (Vink, Wijnants, Cillessen, & Bosman, 2017).

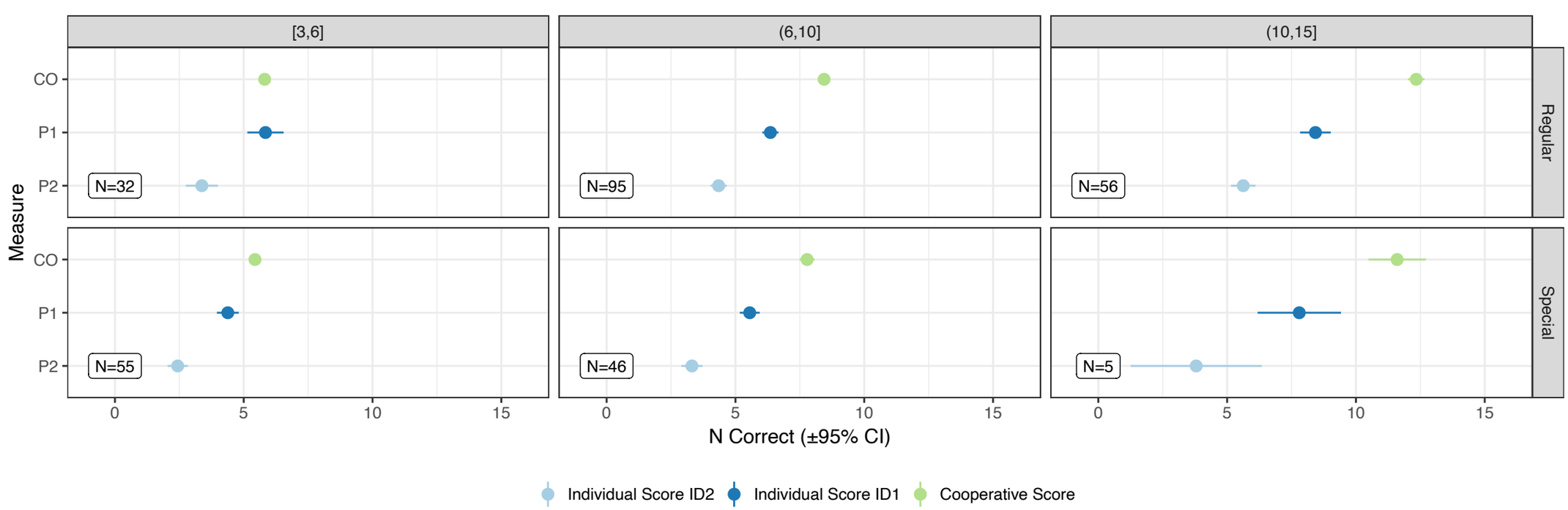
Cross Recurrence Quantification Analysis





PRE–MEASURE ACCURACY ID1 (left) > ID2 (right) [panels: percentile correct puzzles]

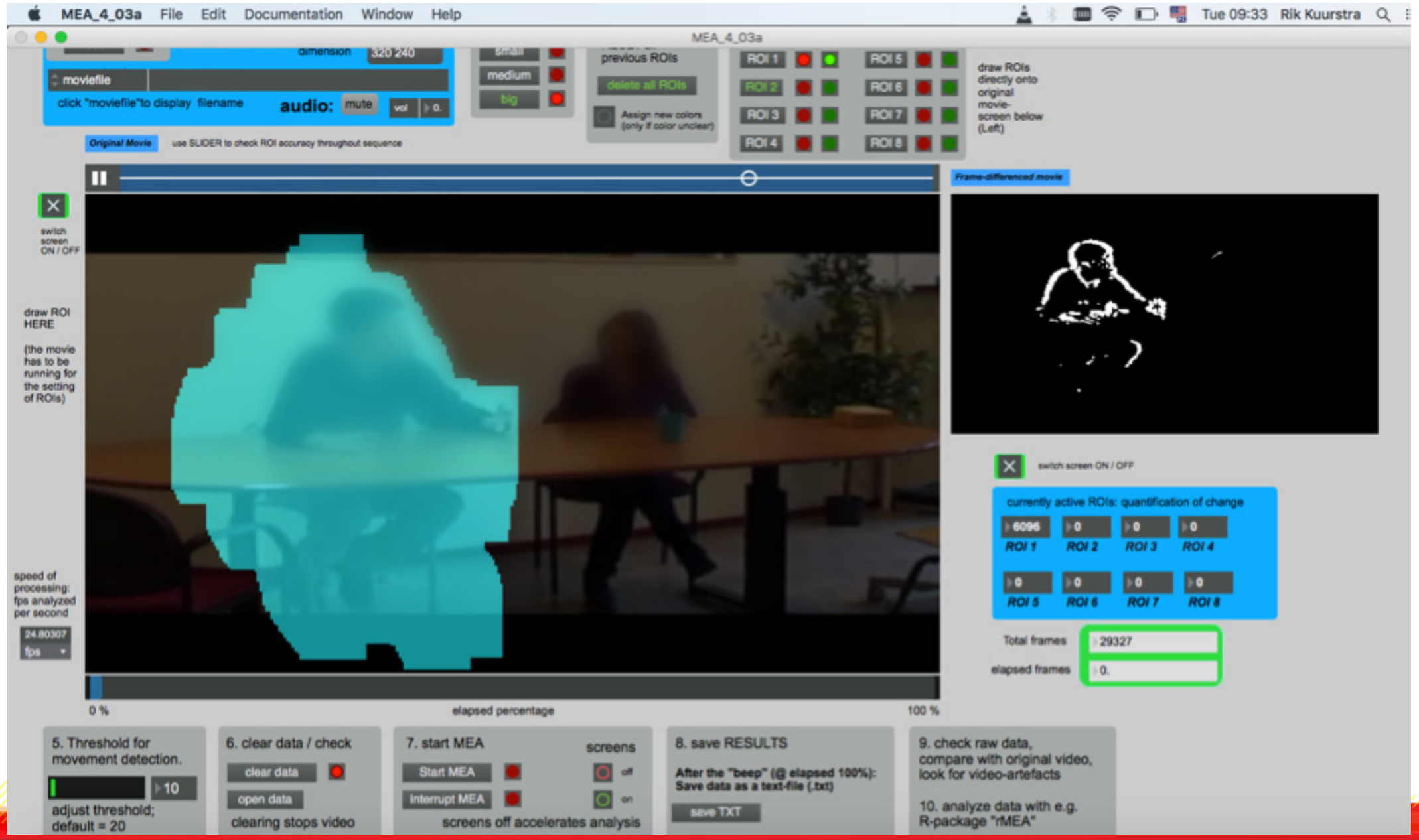




To summarize

- Children with a neurodevelopmental disorder and potentially comorbid postural sway disturbances performed less than their typically developing peers.
- However, their movement process (i.e., interpersonal synchronization/ coordination) was similar.
- In addition, less disorder in synchrony predicted better task performance
  - This supports the view that in less restricted tasks where there is multifinality (i.e., more than one way of solving the problem):

    “diversification of action is likely to occur, and complementary forms of interaction will in many cases supersede synchronous kinds of interaction” (Wallot, Mitkidis, McGraw, & Roepstroff, 2016, p. 3).


MEA_4_03a File Edit Documentation Window Help
Tue 09:33 Rik Kuurstra
MEA_4_03a
moviefile
click "moviefile"to display filename
audio:
mute
vol
0.
dimension
320 240
small
medium
big
previous ROIs
delete all ROIs
Assign new colors (only if color unclear)
ROI 1
ROI 2
ROI 3
ROI 4
ROI 5
ROI 6
ROI 7
ROI 8
draw ROIs directly onto original movie-screen below (Left)
Original Movie
use SLIDER to check ROI accuracy throughout sequence
Frame-differenced movie
switch screen ON / OFF
draw ROI HERE
(the movie has to be running for the setting of ROIs)
switch screen ON / OFF
currently active ROIs: quantification of change
6096
0
ROI 1
ROI 2
ROI 3
ROI 4
ROI 5
ROI 6
ROI 7
ROI 8
Total frames
29327
elapsed frames
0.
speed of processing: fps analyzed per second
24.80307
fps
0 %
elapsed percentage
100 %
5. Threshold for movement detection.
10
adjust threshold; default = 20
6. clear data / check
clear data
open data
clearing stops video
7. start MEA
screens
Start MEA
Interrupt MEA
off
on
screens off accelerates analysis
8. save RESULTS
After the "beep" (@ elapsed 100%): Save data as a text-file (.txt)
save TXT
9. check raw data, compare with original video, look for video-artefacts
10. analyze data with e.g. R-package "rMEA"