Dynamics of complex systems

Lecture 5: Long-range correlations and scaling (cnt.)

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change perspective

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High variability

Low variability

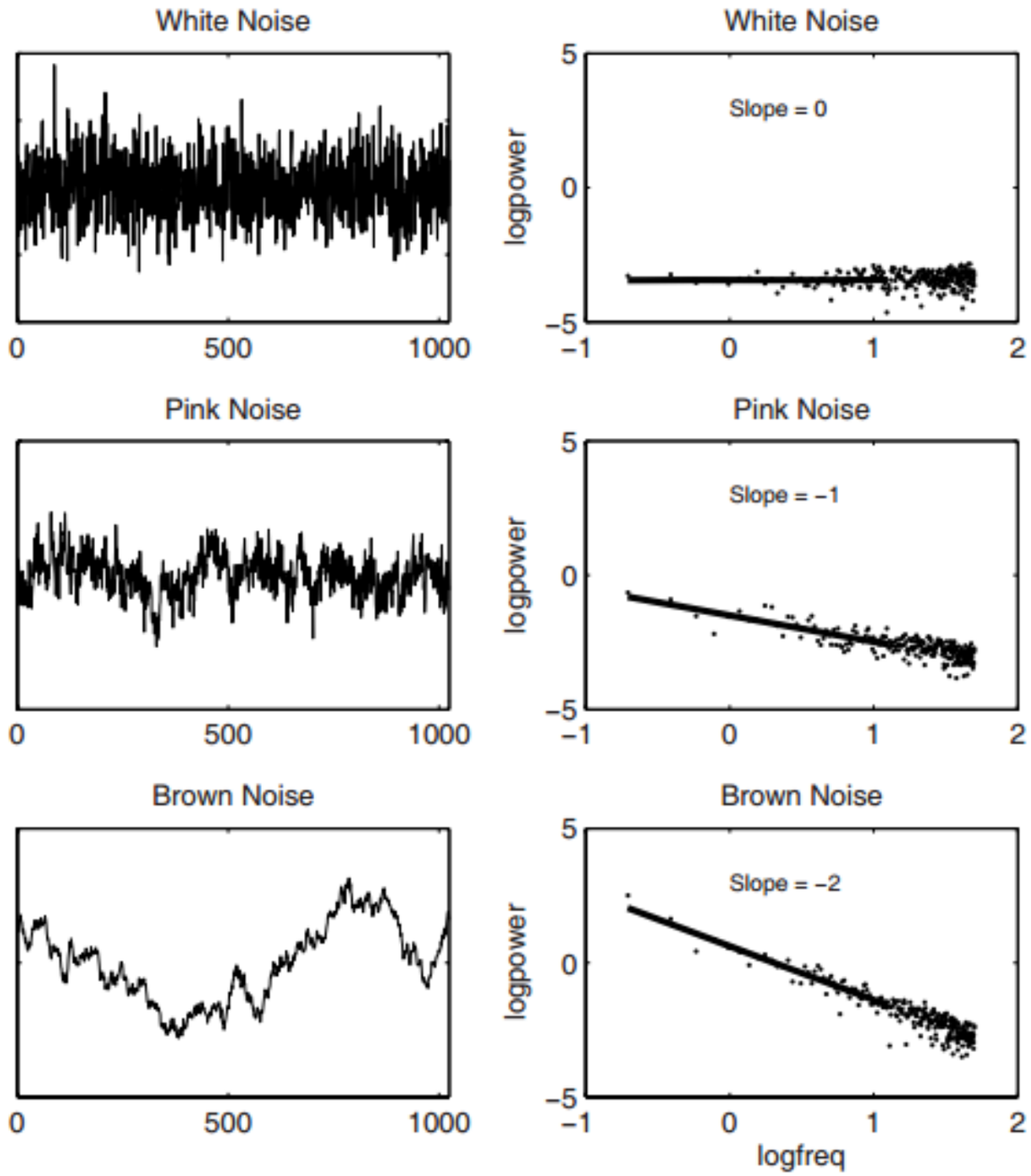


FIGURE 3 | Three different classes of temporal variability, white noise (upper left panel), 1/*f* scaling (middle left panel), and Brownian noise (lower left panel), and their respective power spectra are shown in the respective panels at the right.

Fractal physiology

- A healthy heart fluctuates as 1/*f* noise

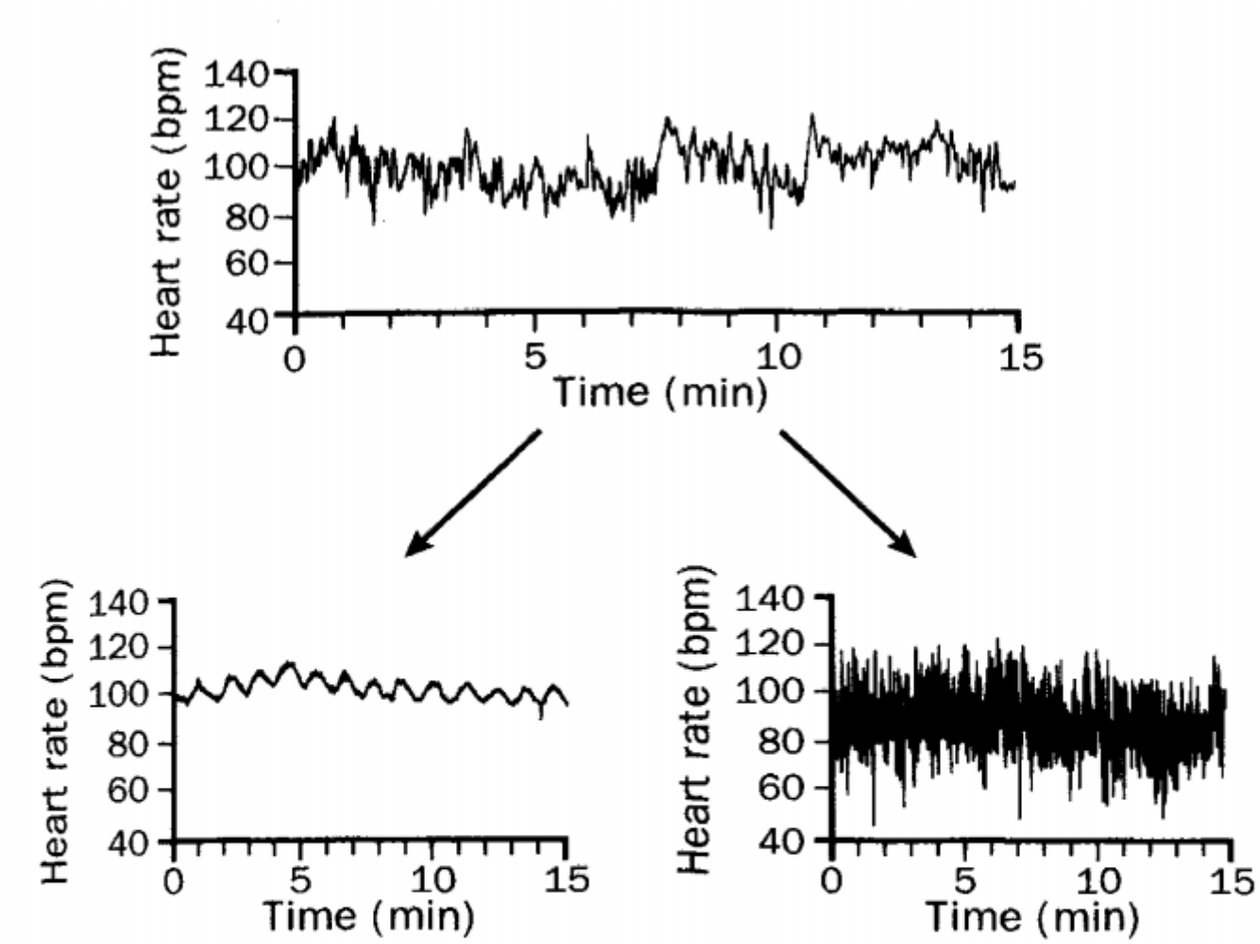


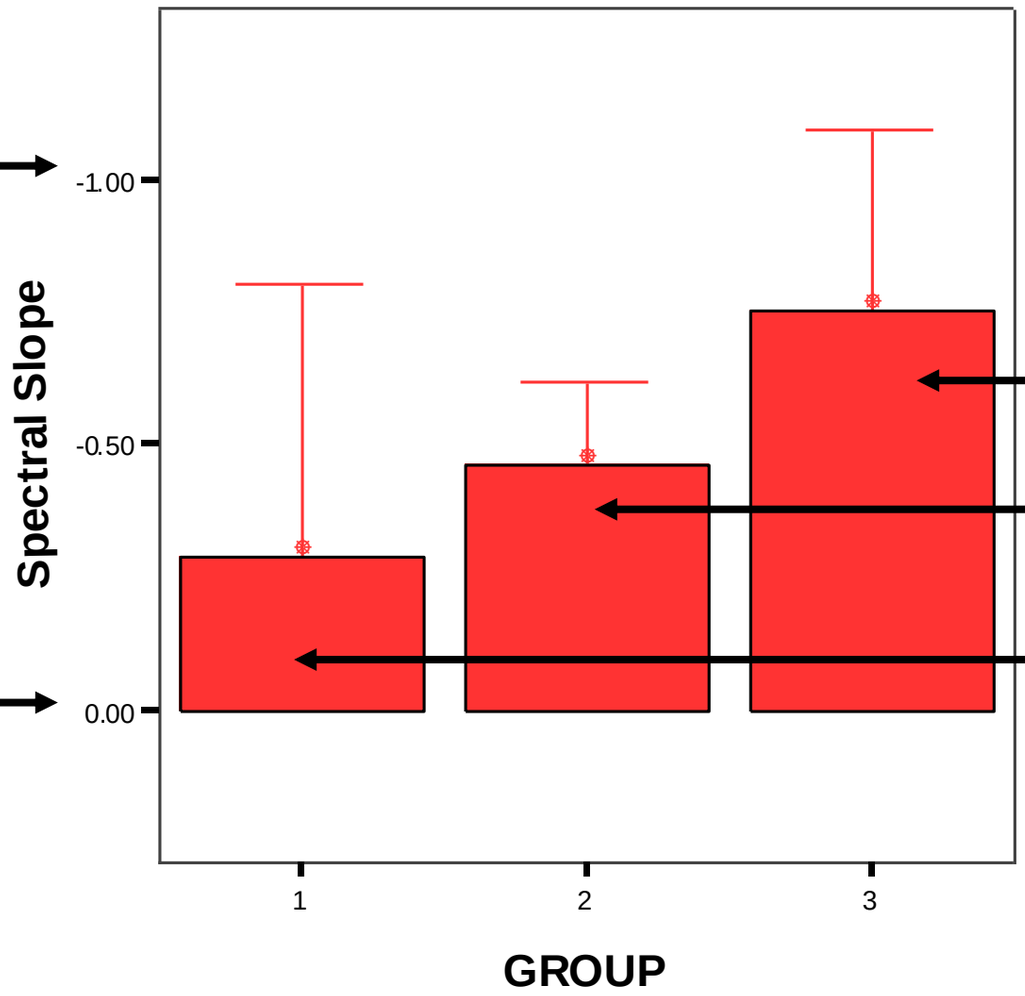
Figure 2: **Healthy dynamics (top), showing multiscale, long-range order; pathological breakdown of fractal dynamics, leading to single-scale (bottom left) or uncorrelated randomness (bottom right)**

Top heart-rate time-series is from a healthy individual; bottom left is from patient with heart failure, and bottom right from patient with atrial fibrillation.

Gait intervals

1/f noise

white noise

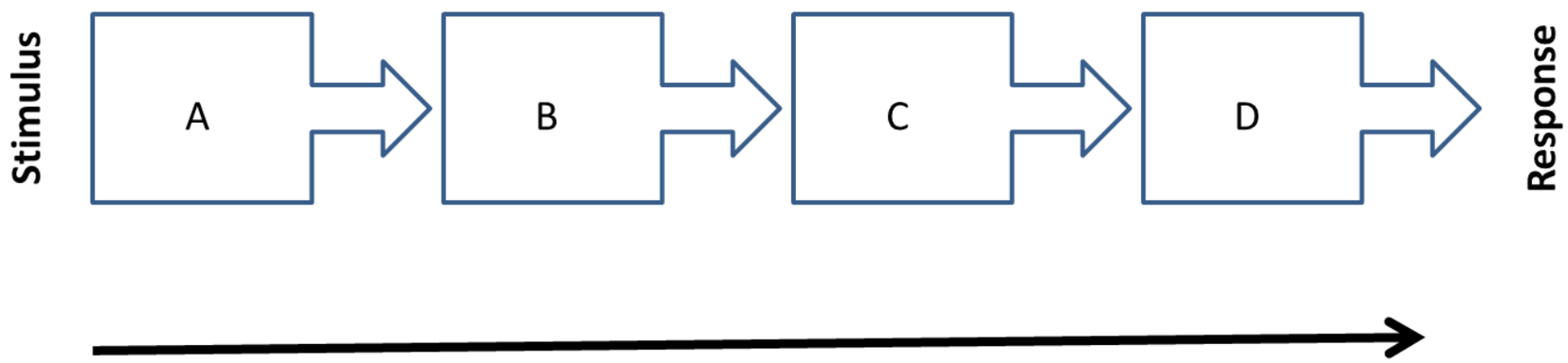


Young adults

Elderly adults

Elderly adults with Parkinson's Disease

(Hausdorff, 2007)



A + B + C + D = RT

E.g., 84ms + 46ms + 128ms + 304ms = 562ms

???

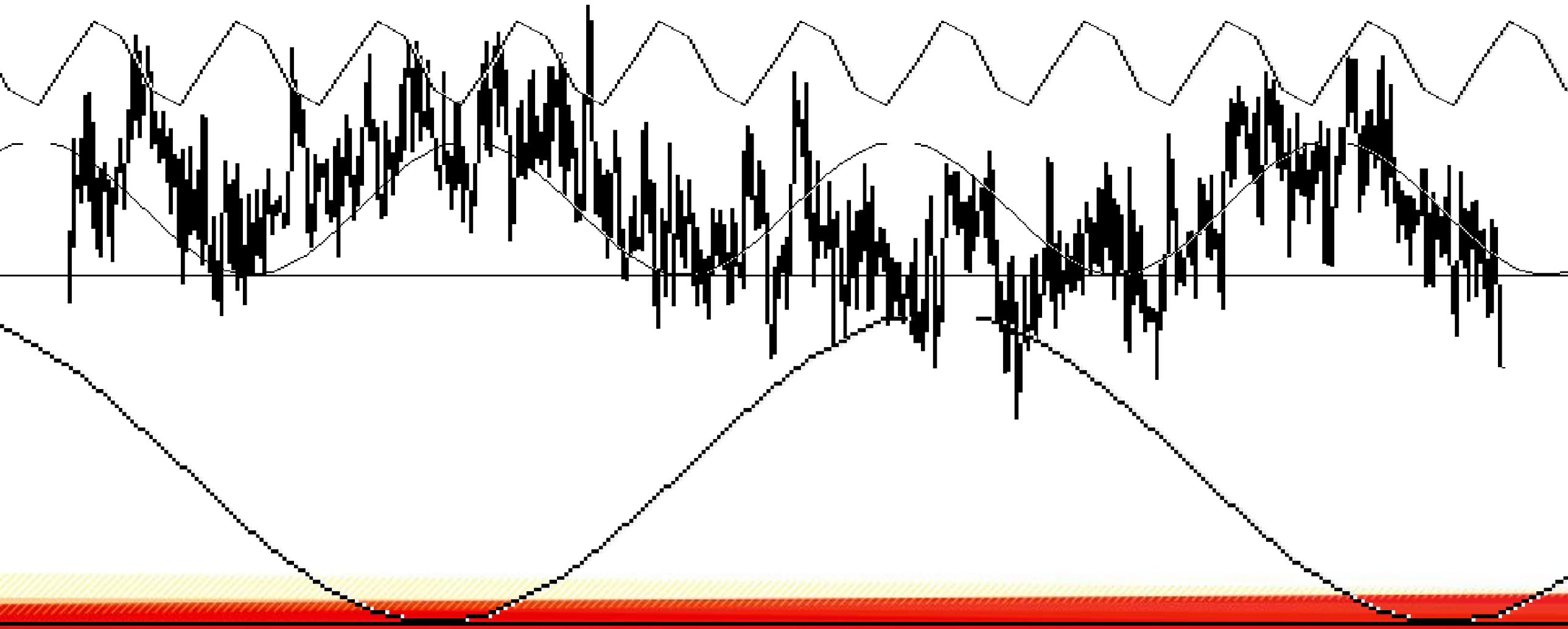
1/*f* Noise in Human Cognition

D. L. Gilden,* T. Thornton, M. W. Mallon

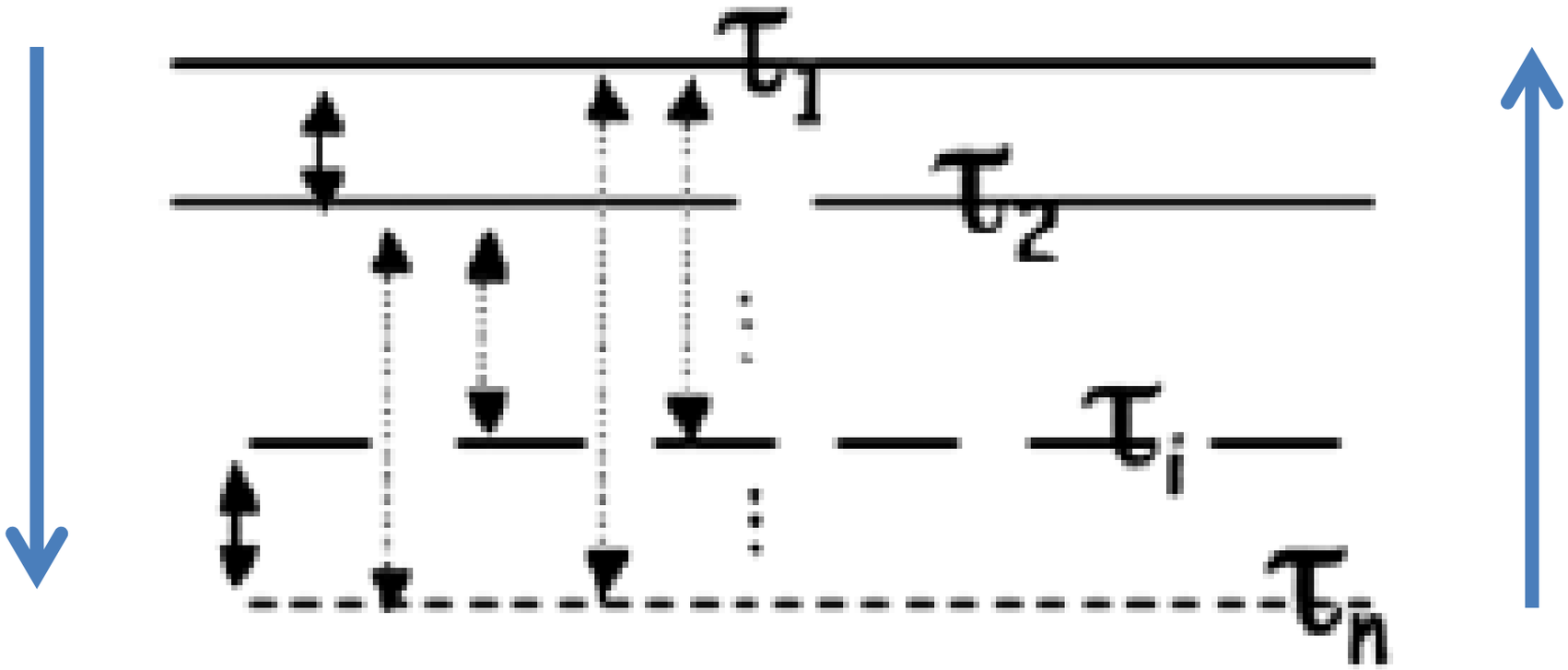
When a person attempts to produce from memory a given spatial or temporal interval, there is inevitably some error associated with the estimate. The time course of this error was measured in a series of experiments where subjects repeatedly attempted to replicate given target intervals. Sequences of the errors in both spatial and temporal replications were found to fluctuate as 1/*f* noises. 1/*f* noise is encountered in a wide variety of physical systems and is theorized to be a characteristic signature of complexity.

Interaction-dominant dynamics

X = structure



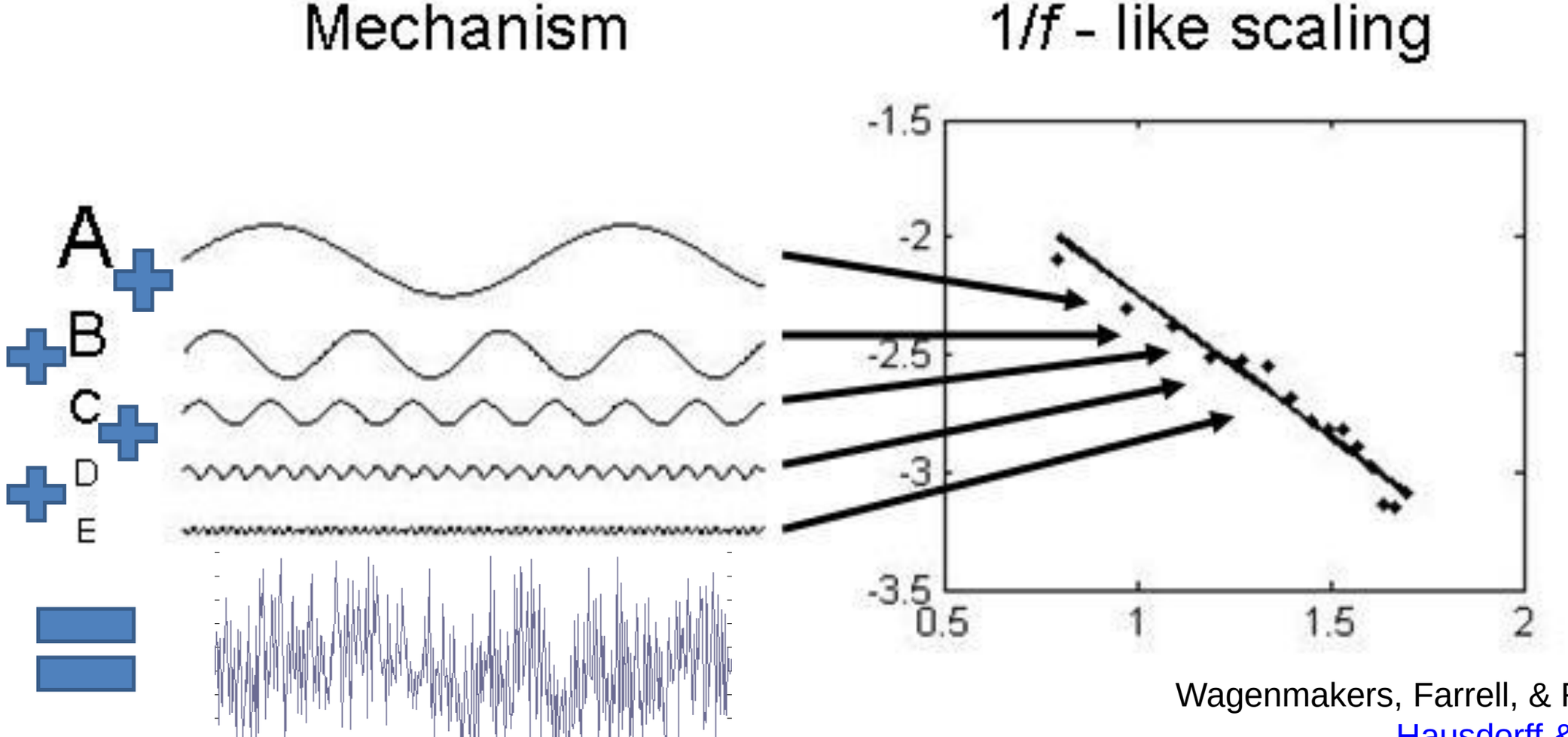
A hallmark of complexity



Changes on multiple time scales are coupled to changes on other timescales

Multiscaled Randomness

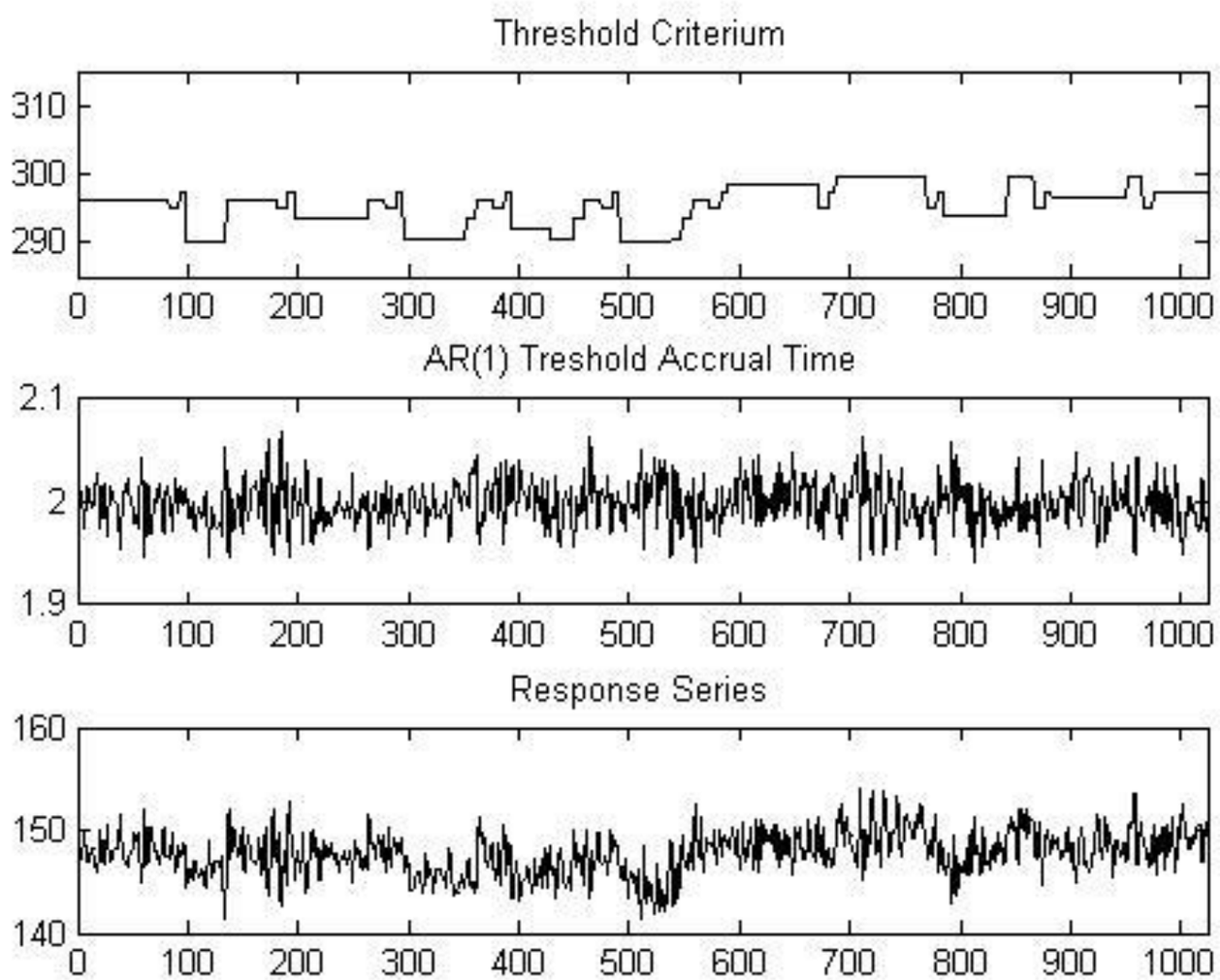
- Three random processes can together mimic a 1/f noise signal
  - If one assumes a slow, an intermediate, and a fast process
- Mostly post-hoc however:
  - conscious, preconscious, and unconscious processes (Ward, 2002)
  - neural, behavioral and cognitive events (Pressing, 1999)
  - planning and control (Valdez & Amazeen, 2008)
  - automatic, conscious, and sustained attention (Wagenmakers et al., 2004).



Wagenmakers, Farrell, & Ratcliff (2004)
Hausdorff & Peng (1996)

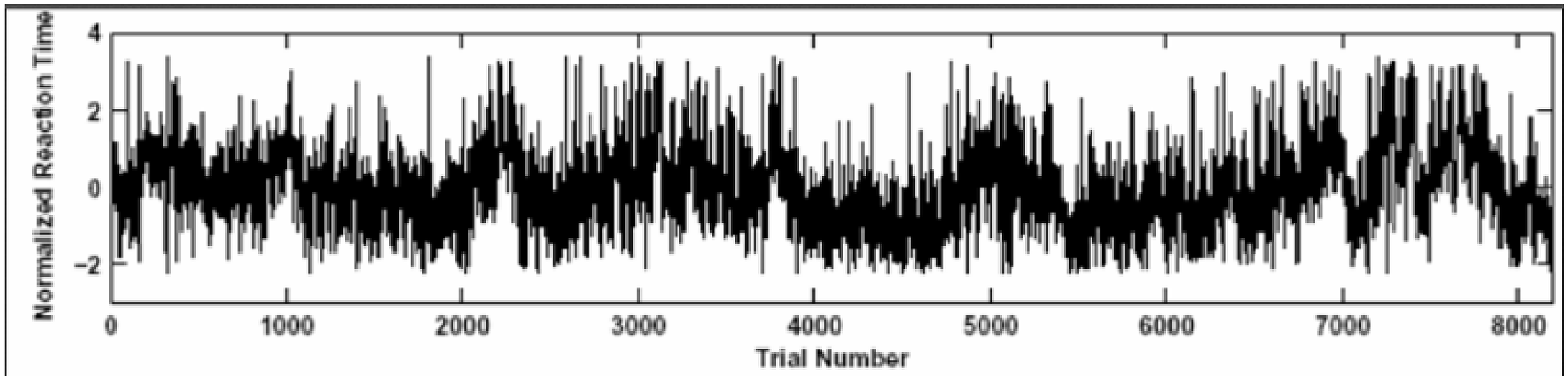
Regime switching

- Shifts in strategy or attention can under limited conditions mimic a 1/f noise signal
  - If one assumes discrete transitions from one mode of operation (i.e., a specific mean or variance) to the next
  - are associated with particular threshold levels that determine the criterion amount of accumulation of information required for a response

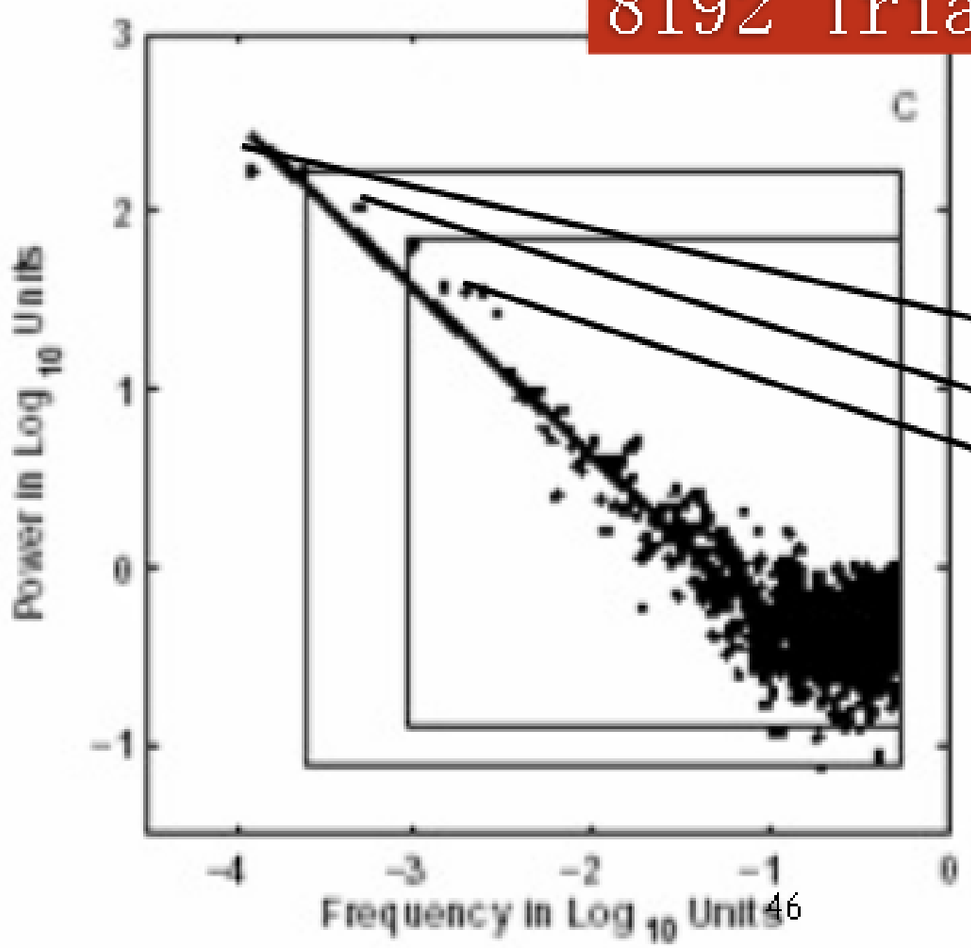


Wagenmakers, Farrell, & Ratcliff (2004)

change perspective

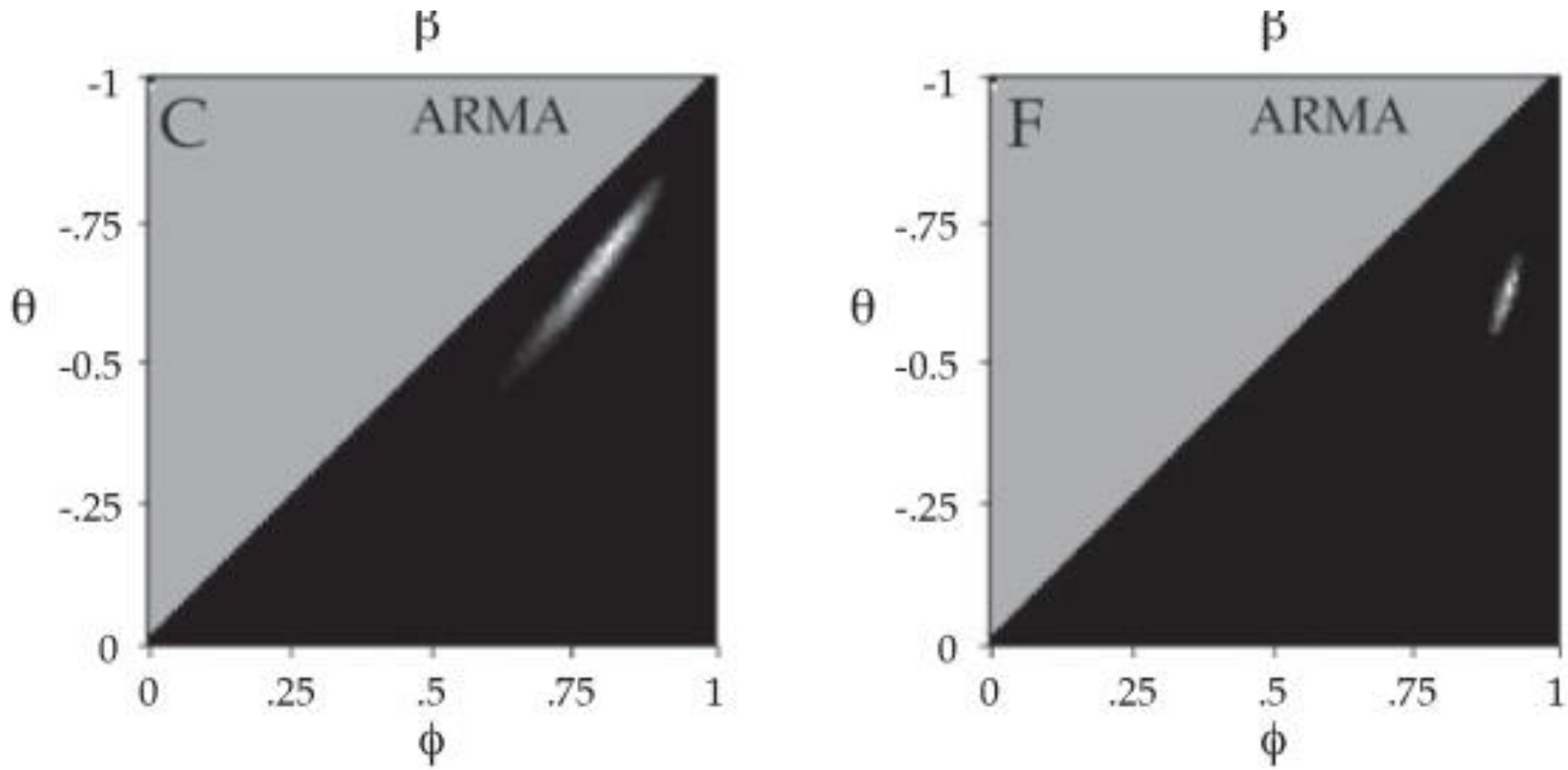


8192 Trials (3 HOURS)



More data points = more components

- Component-dominant approaches could emulate 1/*f* noise
  - Within narrow parameter bounds
  - Other complexity measures (RQA, entropy,…)?
  - Consistent changes with experimental manipulations?



Task constraints

Variable cues add perturbations to task performance

No correlation between fractal streams

More streams of 1/f noise = more components

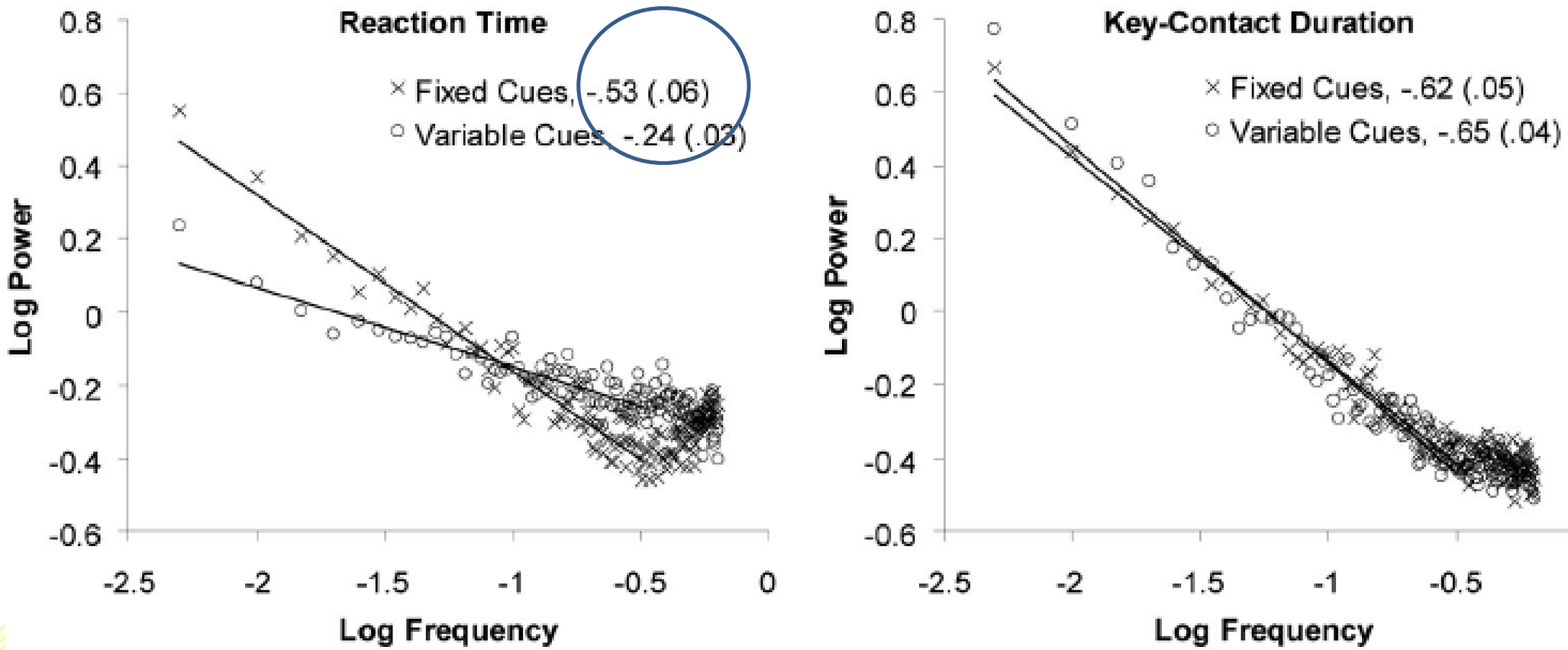
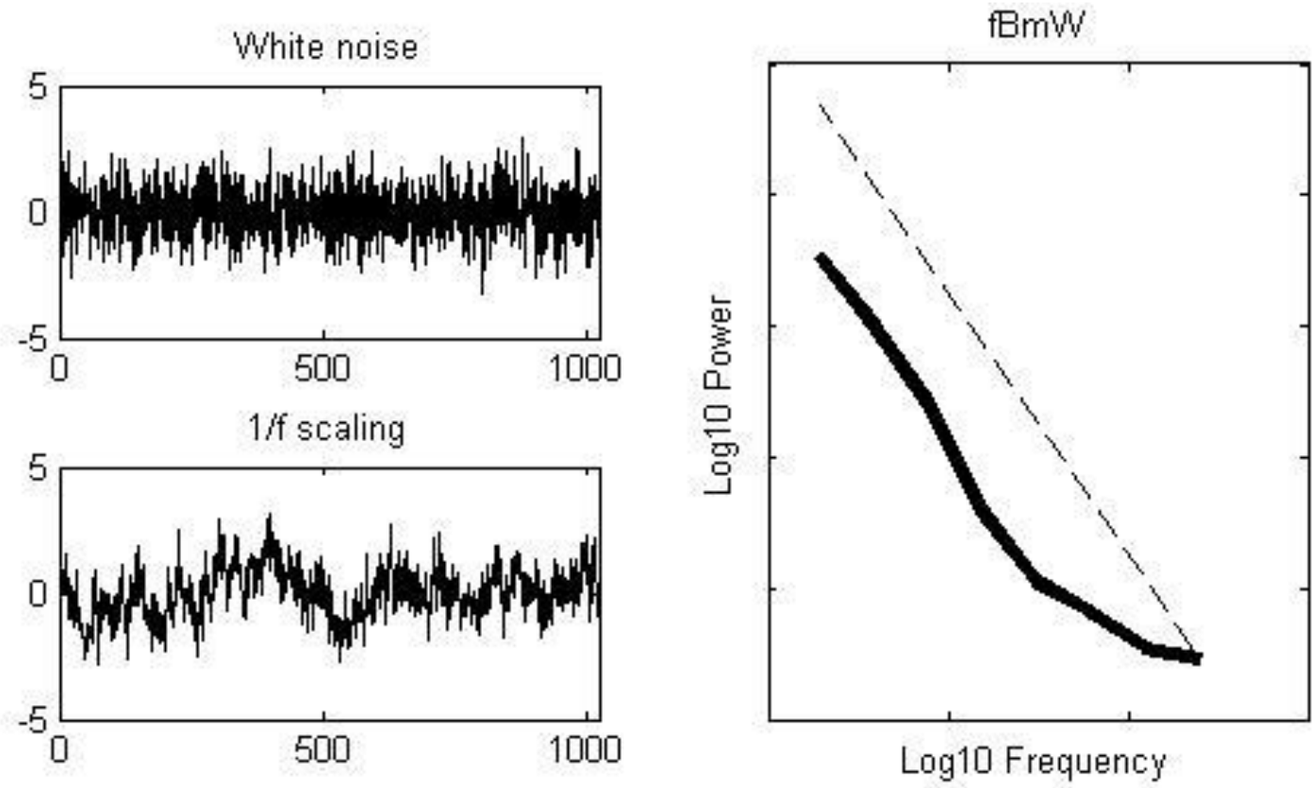


Figure 2. Spectral plots for reaction times (left) and key-contact durations (right) from Experiment 1, each plotted separately for blocks of fixed versus variable release–cue intervals. Average slopes of regression lines are shown with their respective standard errors.

ch

Kello et al. (2007)

- $RT_n = (1/f^{\alpha})_n + \beta\ N(0,1)$
  - 1/f noise part is associated with elementary cognitive processes
  - The random part is attributed to motor delay
  - β is a free parameter that determines the contribution of the random part of the model



change perspective

Gilden (2001)

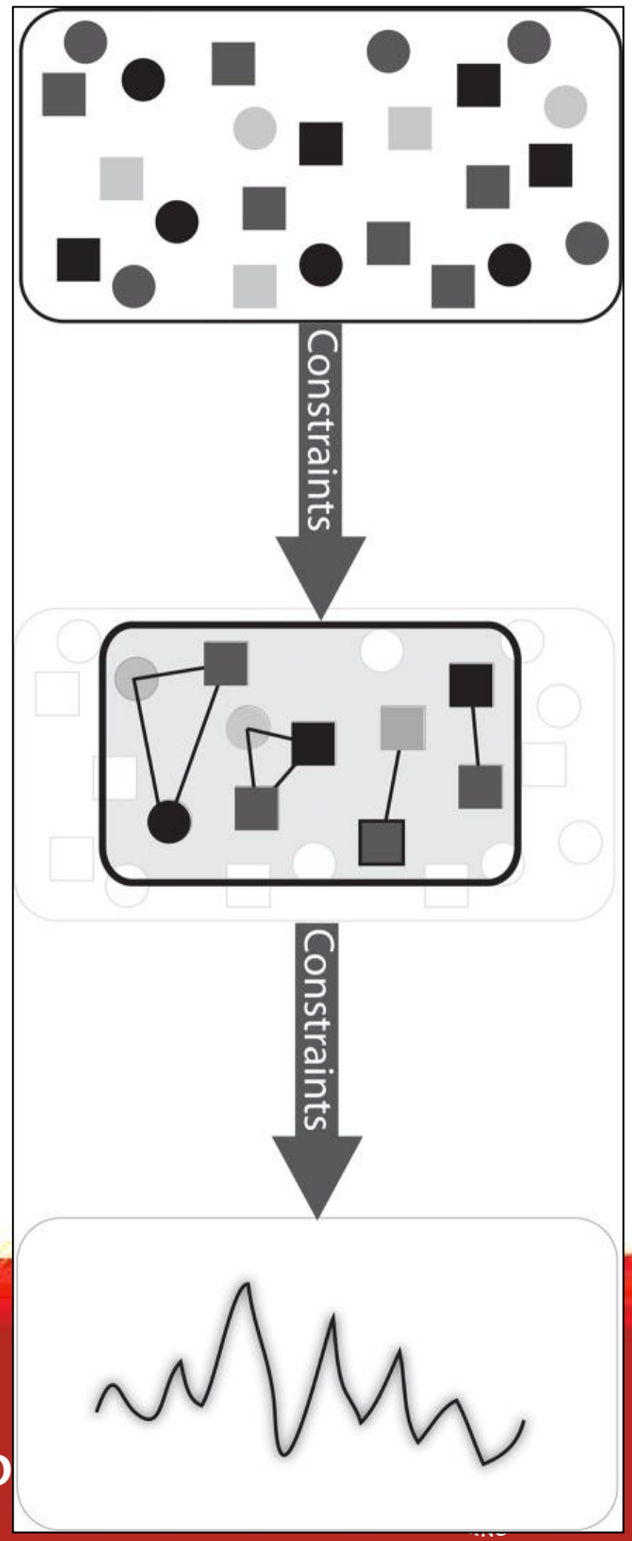
Domain-specific modelling

- Plug-in fractality

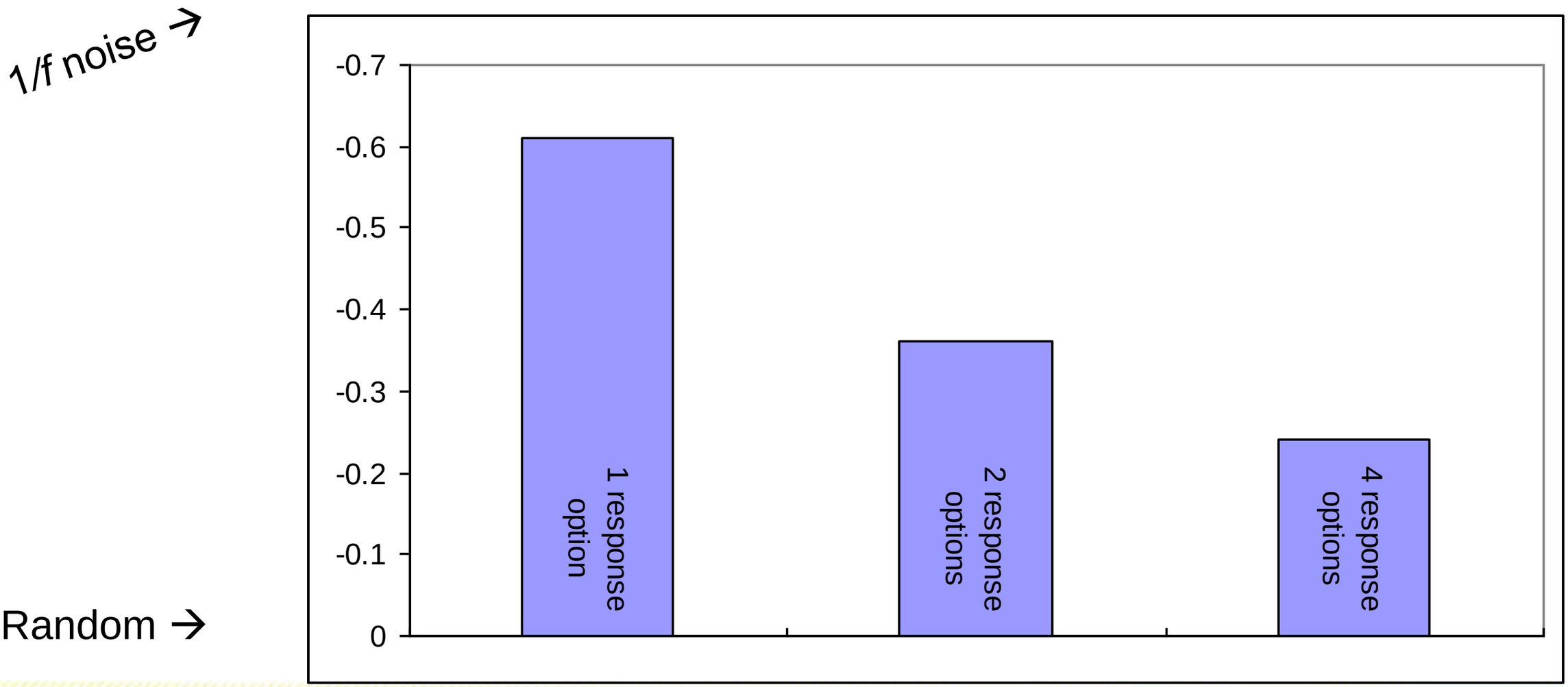
- E.g. finger tapping
- W-K model:
  - Tapping interval = internal clock + motor delay
  - $I_i = C_i + M_i - M_{i-1}$
- Delignières et al. (2008) provided C with fractal properties, thereby accounting for empirical 1/f patterns in tapping intervals
- Diniz et al. (2011): a discussion
- 2012: Délignières: ‘mathematical curiosities’

Interaction-dominance

- Interaction dominance
- 1/f scaling reveals coordination of a task performance
  - Reducing dimensionality
    - High-dimensional DOF
    - Component interactions
    - More orderly, lower-dimensional behaviors
  - Through self-organization
  - To control human performance



External perturbations add extraneous random variation to the measured performances: Number of response options

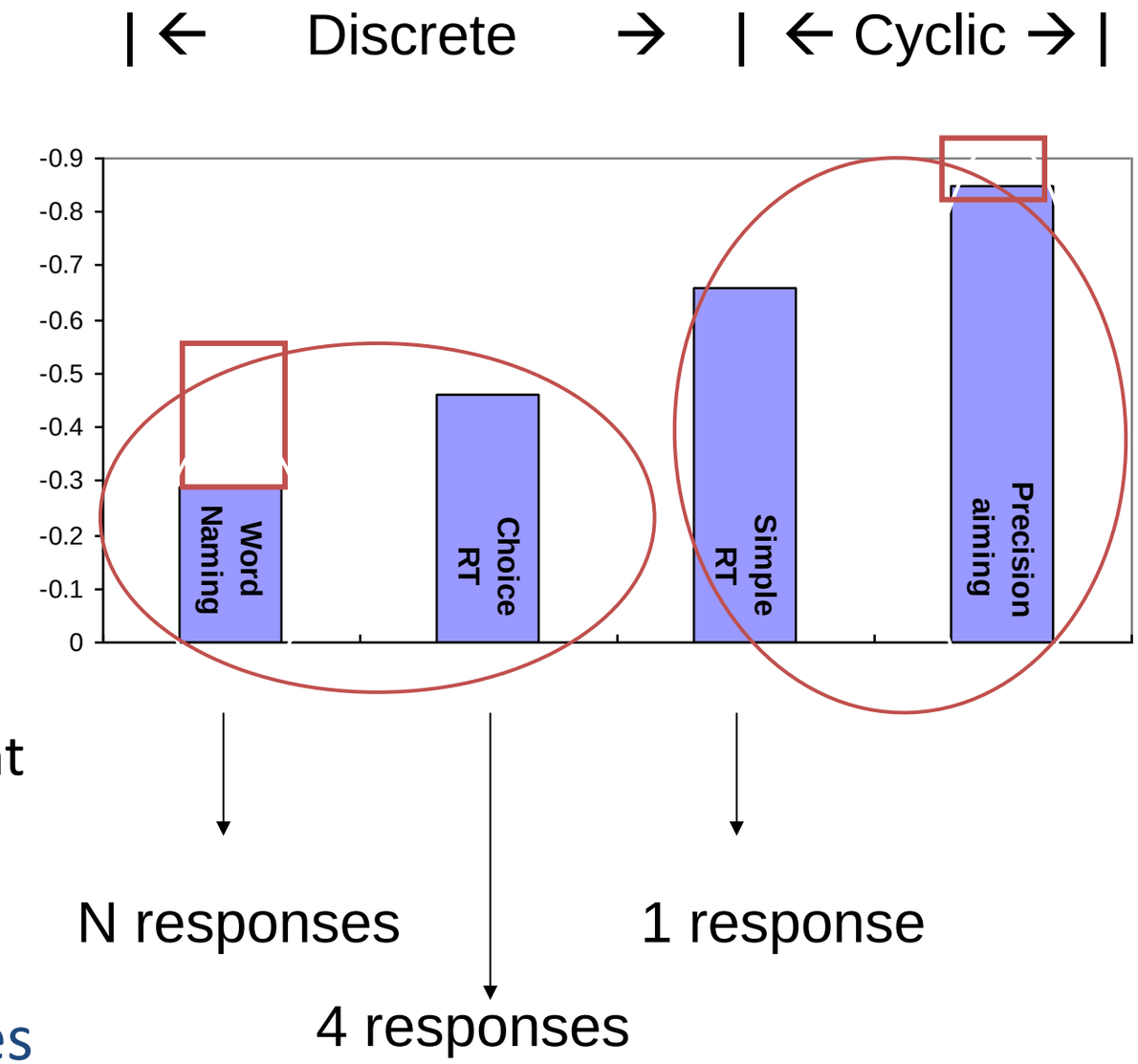


Ward and Richard (2001)

Task constraints

- **Simple RT, Precision aiming:**
  - Each trial is identical:
    same SIGNAL to respond and same RESPONSE
  - EXTERNAL sources of variation in Response Time are minimized
- ➔ Variation must largely reflect INTERNAL sources

- **Choice RT, Word-naming**
  - Experimental trials differ:
    A different SIGNAL to respond and a different RESPONSE
  - EXTERNAL sources of variation in Response Time are introduced to the measured values
- ➔ Variation must reflect INTERNAL sources to a lesser extent



Data from: Van Orden, Holden, & Turvey, 2003; Kello, Beltz, Van Orden, & Turvey, 2007; Wijnants et al., 2009

Task constraints

External perturbations add extraneous random variation to the measured performances: Accuracy feedback

change perspective

Kuznetsov & Wallot (2011)

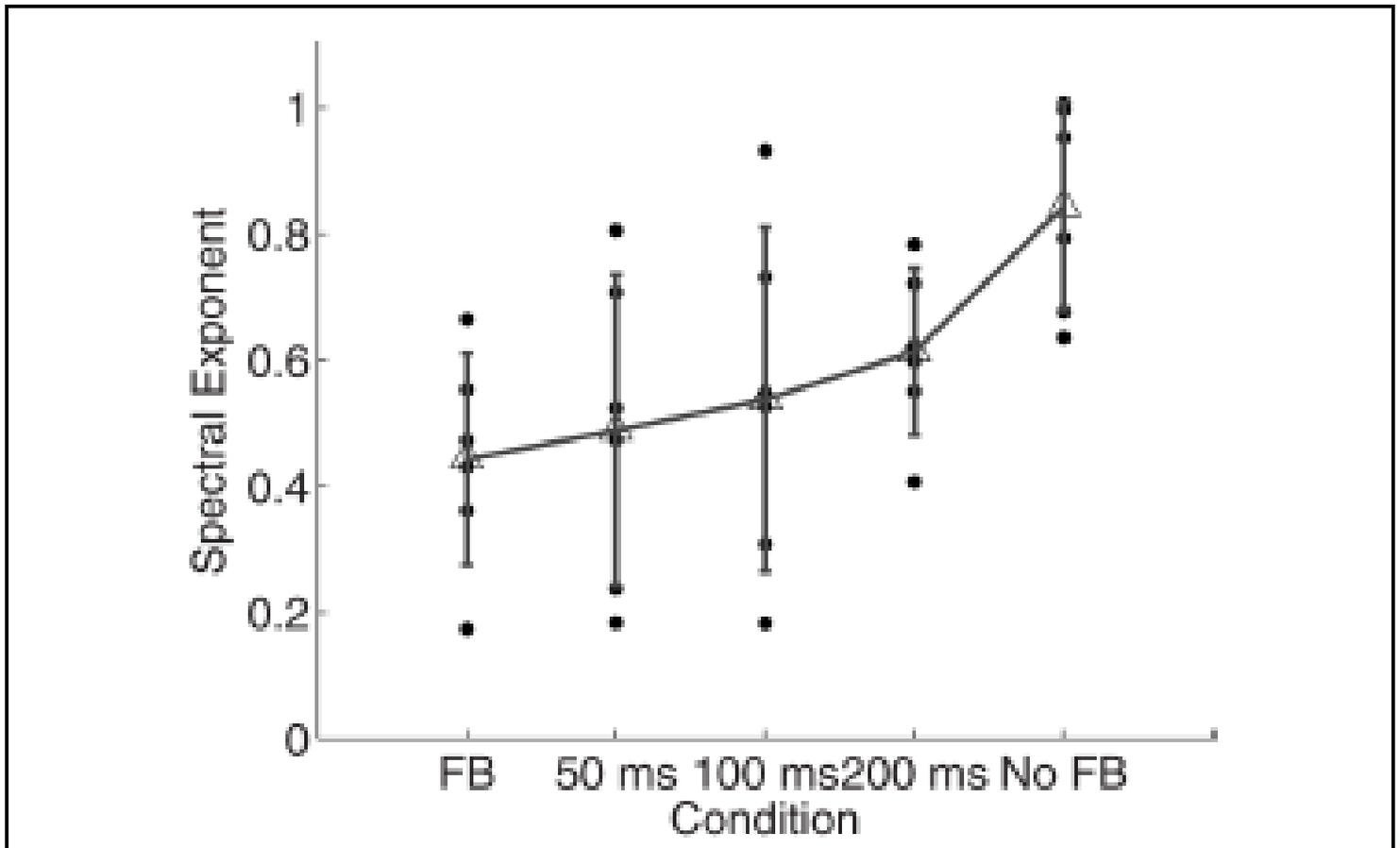
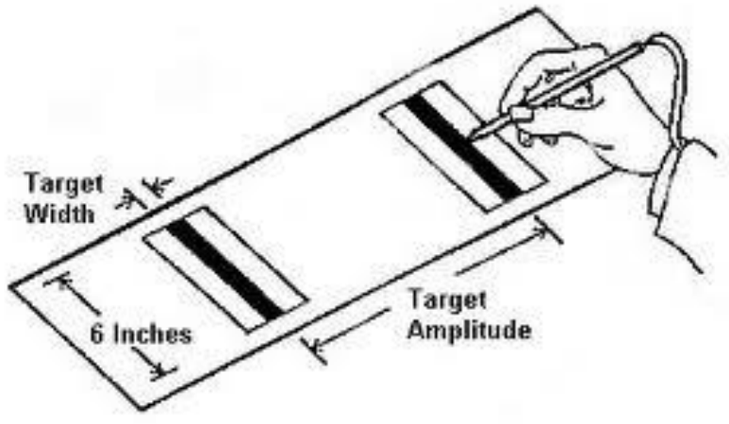
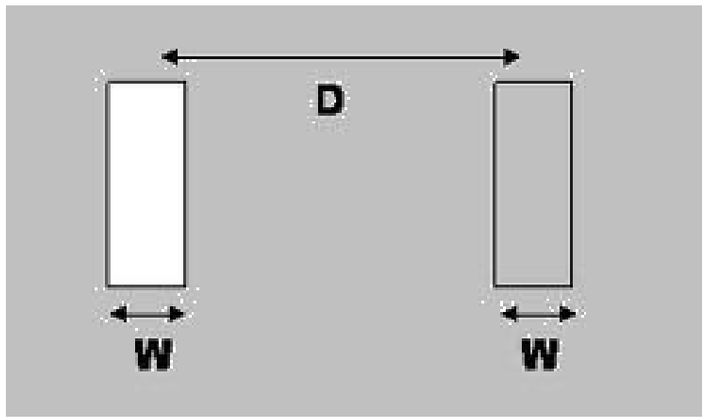
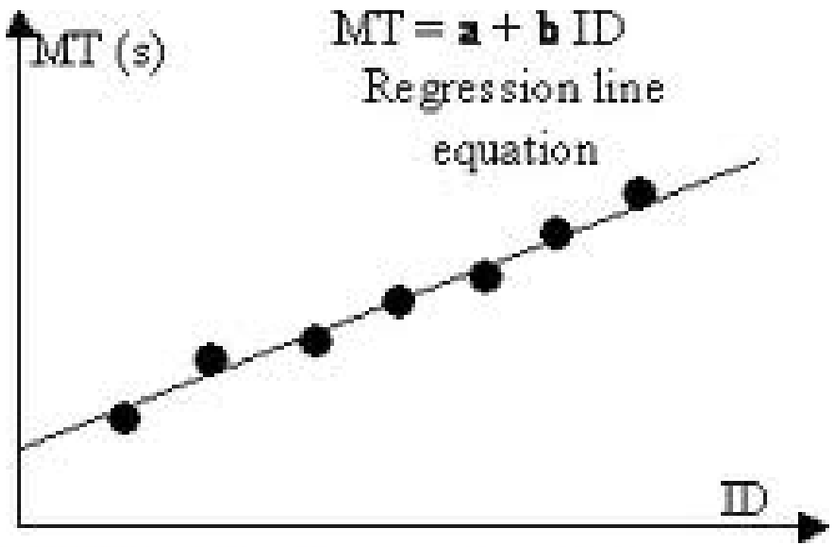


FIGURE 3 | Spectral exponents of the time estimates. Spectral exponents α closer to 0 imply presence of white noise whereas values closer to 1 suggest pink noise. Individual points represent observations from individual participants. Error bars plot within-condition SD.

Fitts task



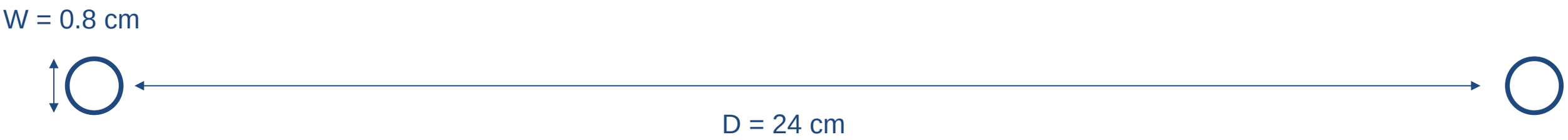




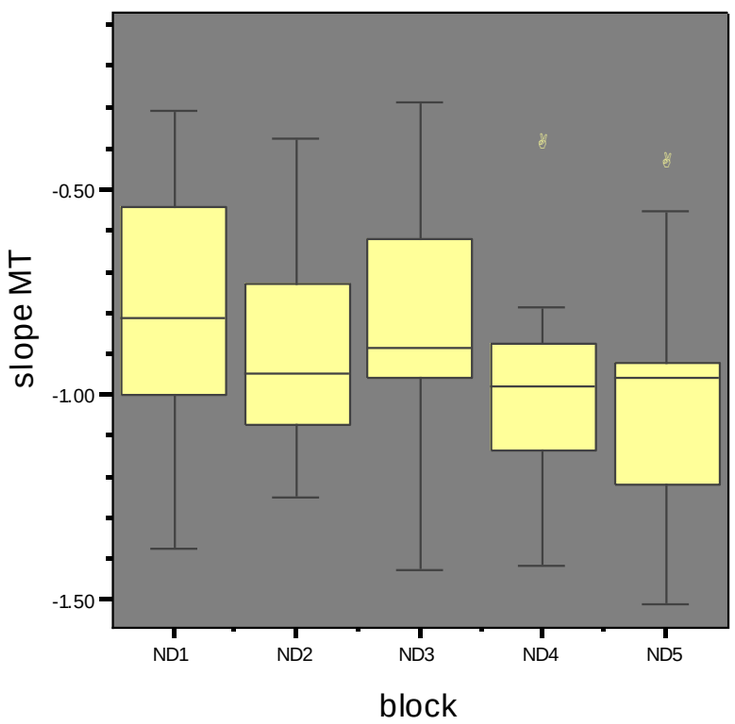
$$T = a + b \log_2\left(2\frac{D}{W}\right)$$

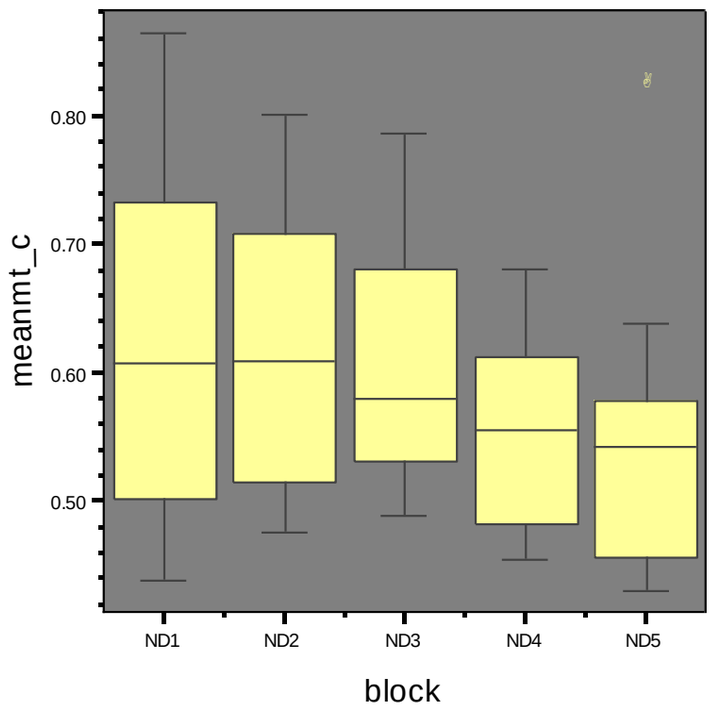
Time — Distance — Coefficients — Width

Motor Learning



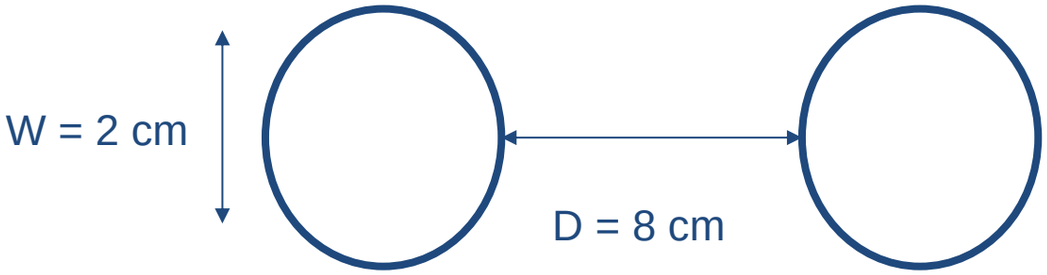
- 5 blocks x 1100 trials
- Non-dominant hand



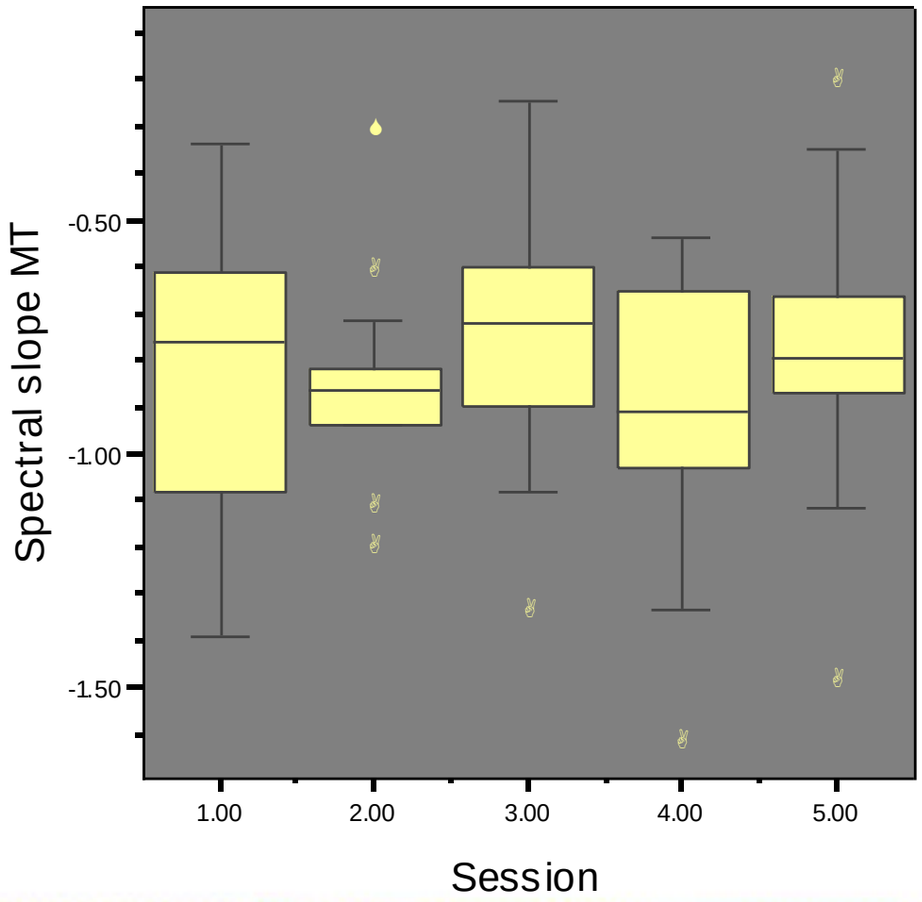


(Wijnants, Bosman, Hasselman, Cox, & Van Orden, 2009)

No Motor Learning



- 5 blocks x 1100 trials
- Non-dominant hand



Speed-Accuracy Trade Off

- Not very accurate
  - *r* = -.77**

- Recruits slow-timescale dynamics of the fractal pattern to the measurement of speed (Movement Time)
  - *r* = .62*
  - Faster participants show more 1/f scaling in their MT dynamics

- Does not recruit slow-timescale dynamics of the fractal pattern to the measurement of accuracy (Line Length)
  - *r* = -.58*
  - Faster participants show reduced 1/f scaling in their LL dynamics

Wijnants et al. (2012)

- Not very fast
  - r = -.77**

- Recruits slow-timescale dynamics of the fractal pattern to the measurement of accuracy (Line Length)
  - r = .45*
  - More accurate participants show more 1/f scaling in their LL dynamics

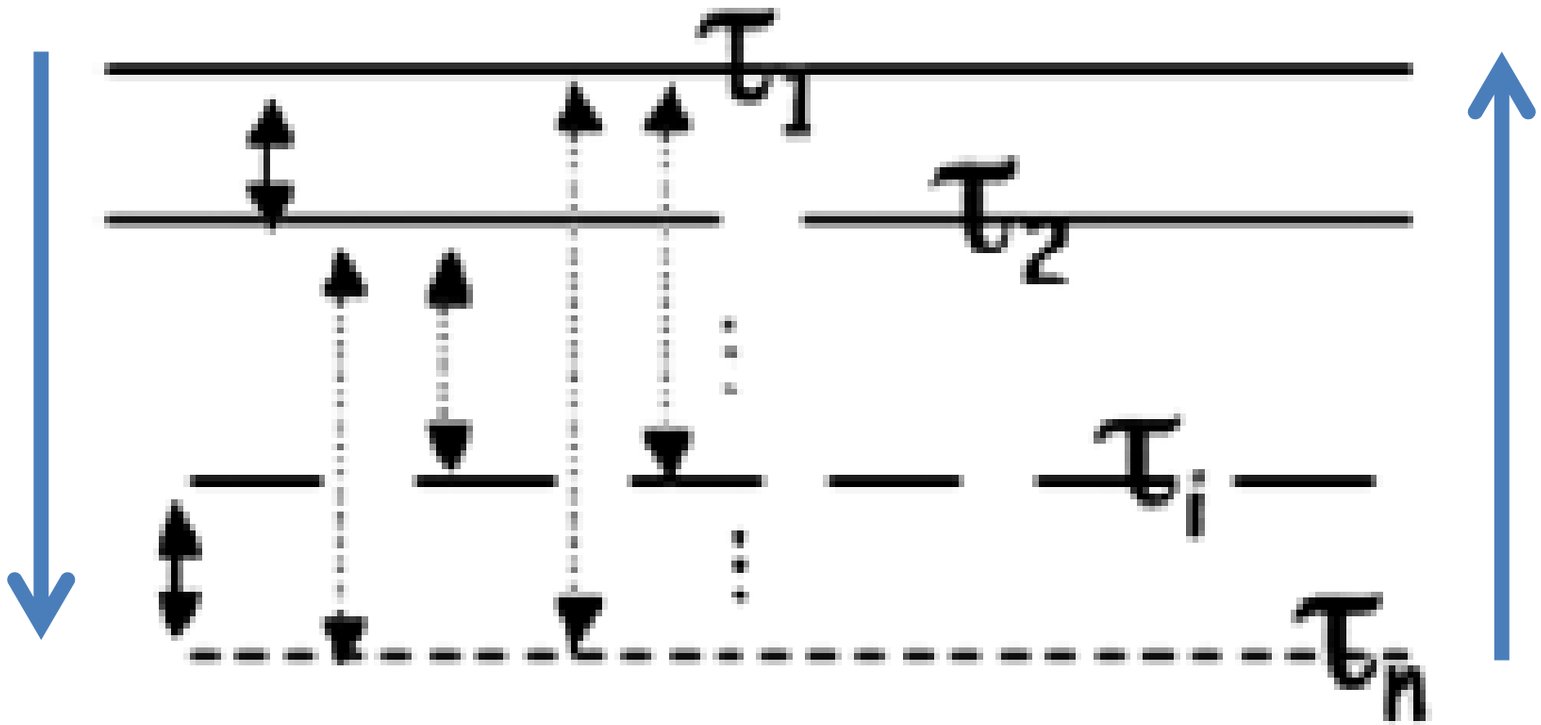
- Does not recruit slow-timescale dynamics of the fractal pattern to the measurement of speed (Movement Time)
  - r = -.71*
  - Accurate participants show reduced 1/f scaling in their MT dynamics

submitted)

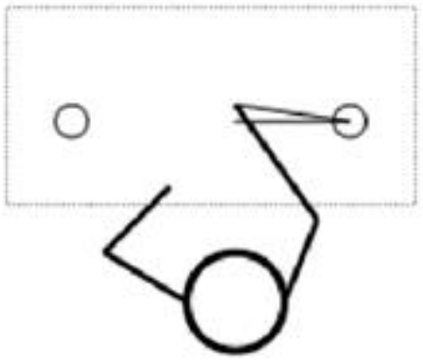
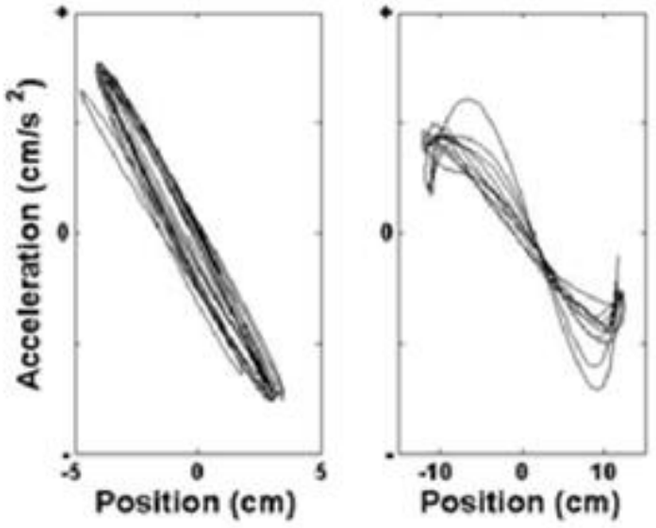
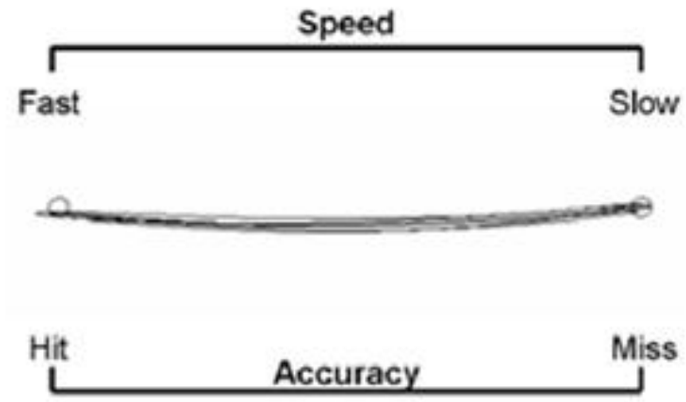
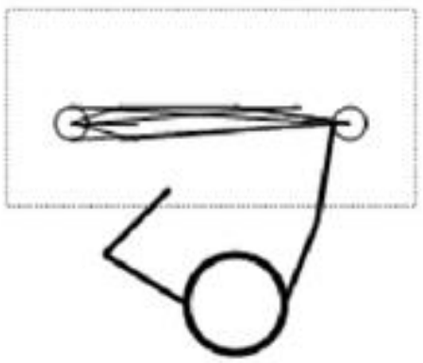
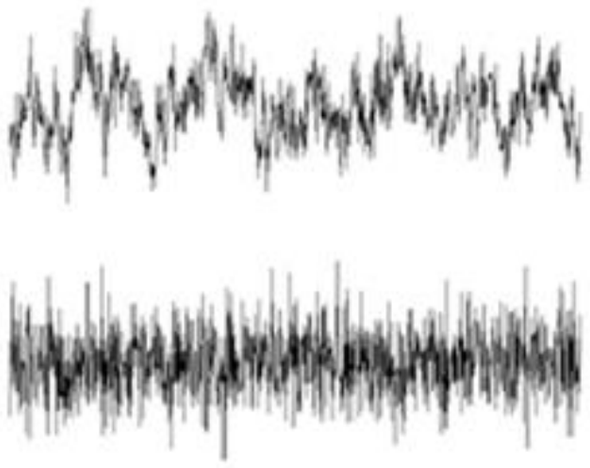
		Harmonicity	Movement time	Accuracy
Difficult condition	FD MT	−0.61**	0.52*	0.70**
	SampEn MT	−0.66**	0.45*	0.74**
	FD MA	0.50*	−0.45*	−0.48*
	SampEn MA	0.75**	−0.64**	−0.74**
Easy condition	FD MT	−0.13	0.00	0.15
	SampEn MT	−0.12	0.03	0.05
	FD MA	−0.31	0.33	0.30
	SampEn MA	0.03	−0.08	0.33

$^{**}p < 0.01$, $^{*}p < 0.05$, one-tailed.

Speed-Accuracy Trade-Off



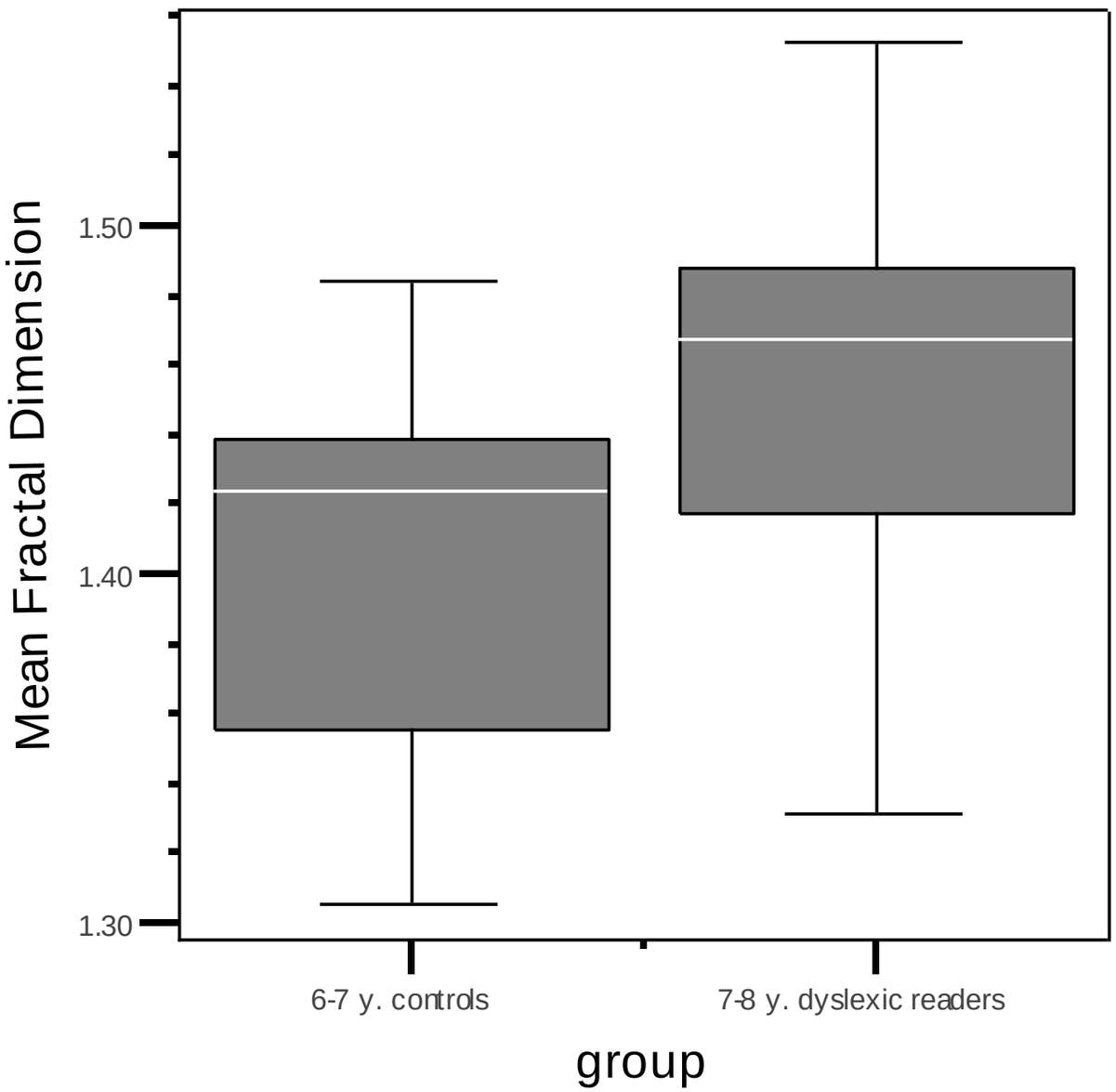
Wijnants et al. (2012)

Timescale	Dependent Measure	Constraint
 Within a trial		Energy Minimization
Single trial		Task compliance
 Over trials		Interaction-dominant dynamics

Word-naming

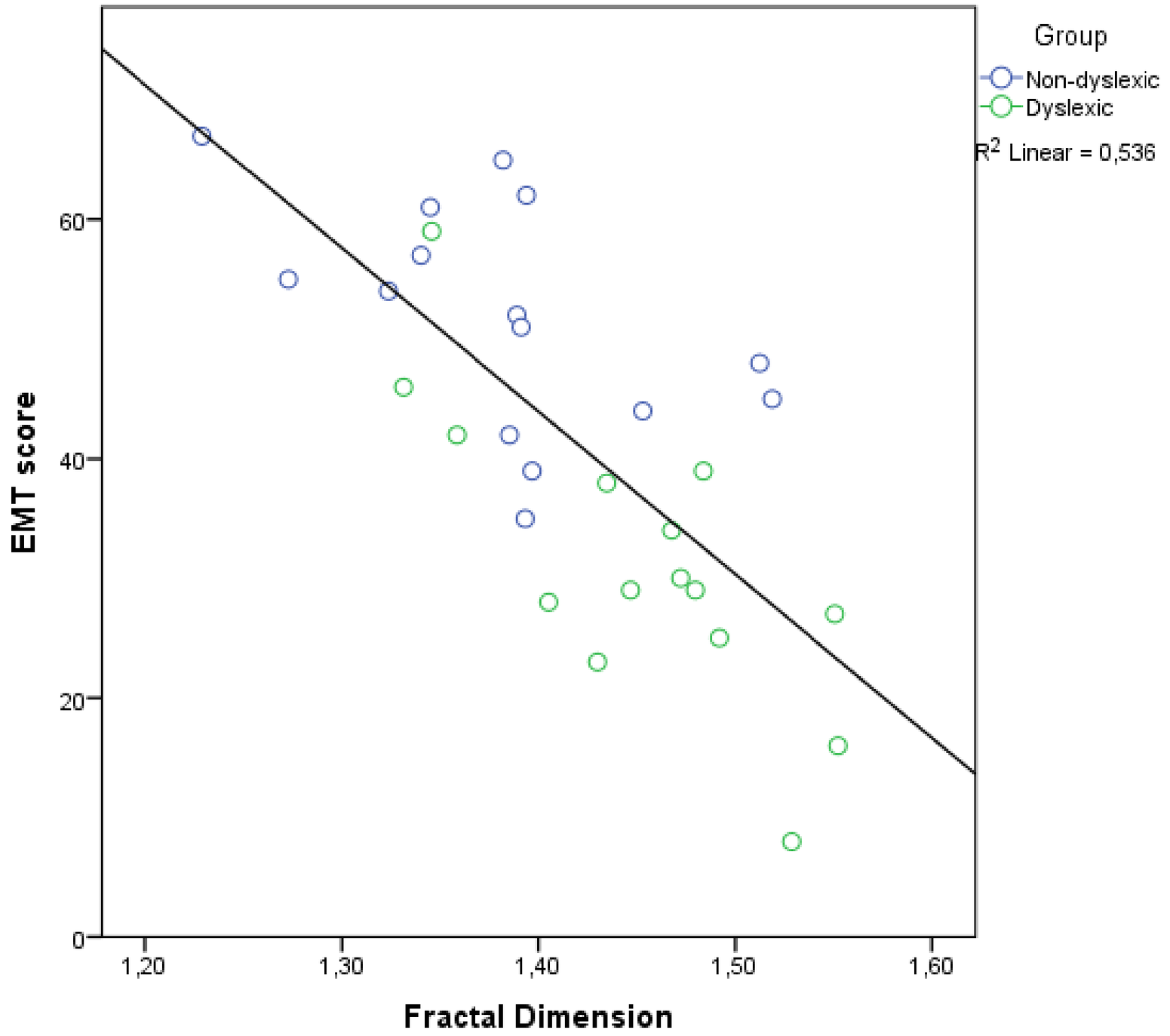
- 7-8 year old Dyslexic Readers
- 6-7 year old Controls
- 1 Block of 550 Word Stimuli

- ➔ Dyslexic Readers Show Reduced 1/f Noise



Word-naming

- Oral reading fluency is regarded as the sole best indicator of reading problems (Fuchs, Fuchs, Hosp, & Jenkins, 2001)



Modular or interactive dynamics?

- These results follow naturally from predictions of an interaction-dominant approach
  - 1/f noise is ubiquitous in human performance
  - 1/f noise is obscured when sources of external variation are increased
  - More stable and coordinated behaviors reveal a clearer 1/f noise signature
  - 1/f noise should be accompanied by additional evidence for emergence and self-organization
  - Indefinite numbers of 1/f signals exist in any behavior

- Component-dominant approaches should post-hoc explain:
  - New components for longer data series
  - New components for every independent stream of 1/f
  - Consistent changes in 1/f scaling with changes in task performance (at multiple levels of analysis)