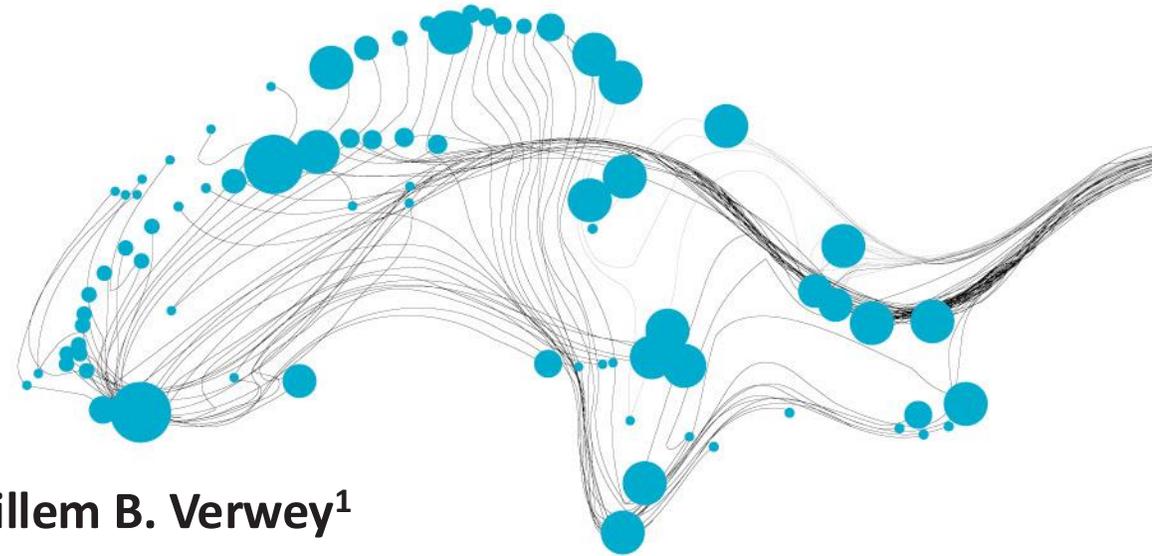
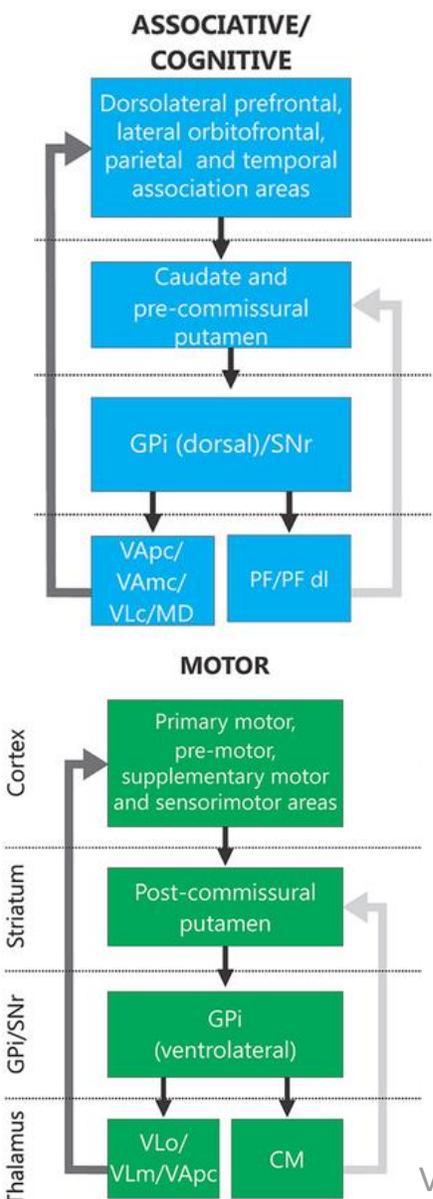


# Insights to hierarchical processing from centre of mass fractal dynamics during motor learning



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# Testing the TLS predictions: Is Variability Noise or Signal?



Verwey, 2025

## Aims:

Can we measure a bodily 'signature' of the TLS as a learner shifts from 'Cognitive' to 'Autonomous' control?

Simultaneous cortical control suggest variability & adjustments

## Predictions:

1. Fractals (i.e. self-similarity/ scale-invariant dynamics) will showcase in motor performance.
2. If the motor system is becoming increasingly automated – does motor preparation therefore become more prominent?

Gorsu et al. 2025

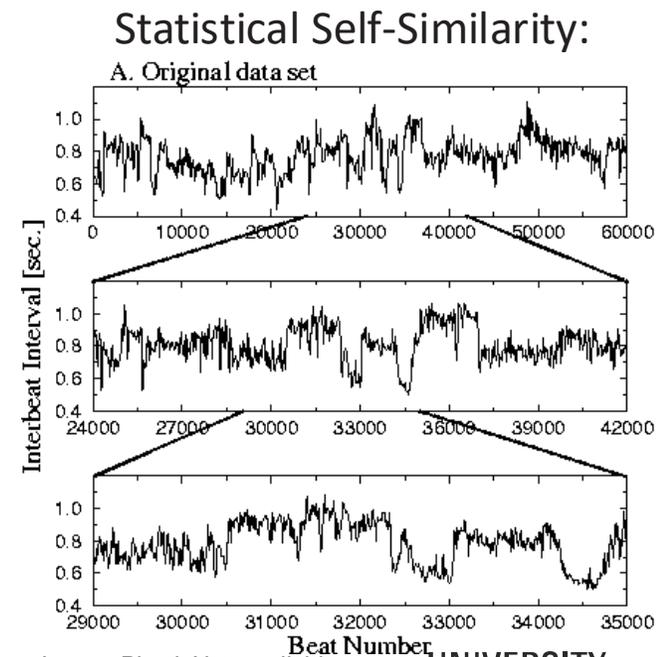


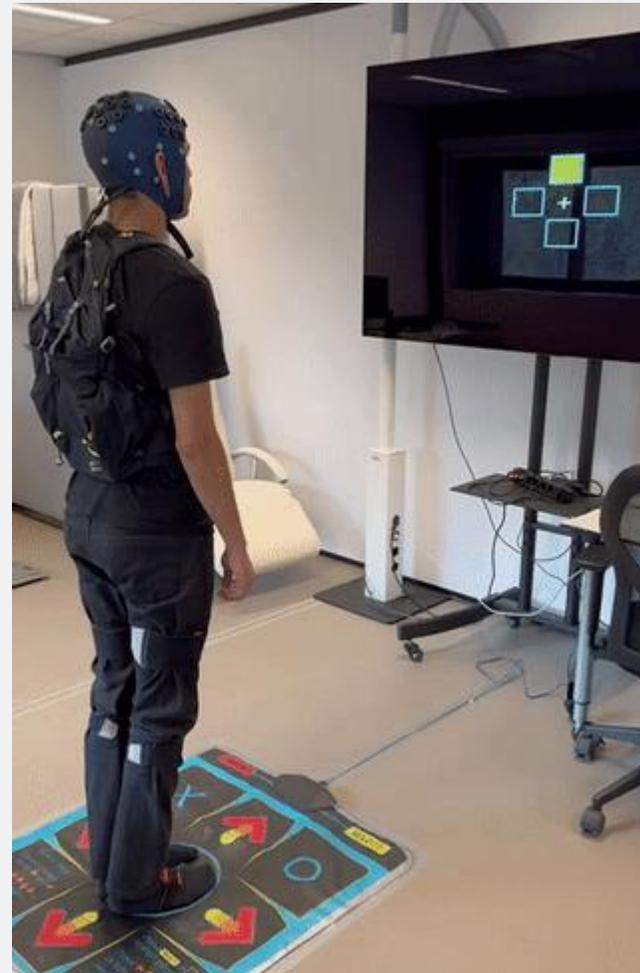
Image: PhysioNet, available at <https://archive.physionet.org/tutorials/0rnc/vvca/film/#SECTION00022000000000000000>



# Dance-DSP task: A window to motor dynamics



1<sup>st</sup> Block



8<sup>th</sup> Block

## Participants

22 participants (16 female), avg. age 20.6 yrs  $\pm$  2.5, healthy with no neurological/psychological issues.

**Behavioural:** Log mean step-time per sequence (*LogMeanRT*) & *Accuracy* (1/0)

**Kinematics:** Centre of mass (*CoM*) acceleration via Xsens IMUs

x, y, z axes – summarised as vector magnitude (*V<sub>m</sub>*)

$$CoM_{acc,mag}(t) = \sqrt{CoM_{acc,x}(t)^2 + CoM_{acc,y}(t)^2 + CoM_{acc,z}(t)^2}$$

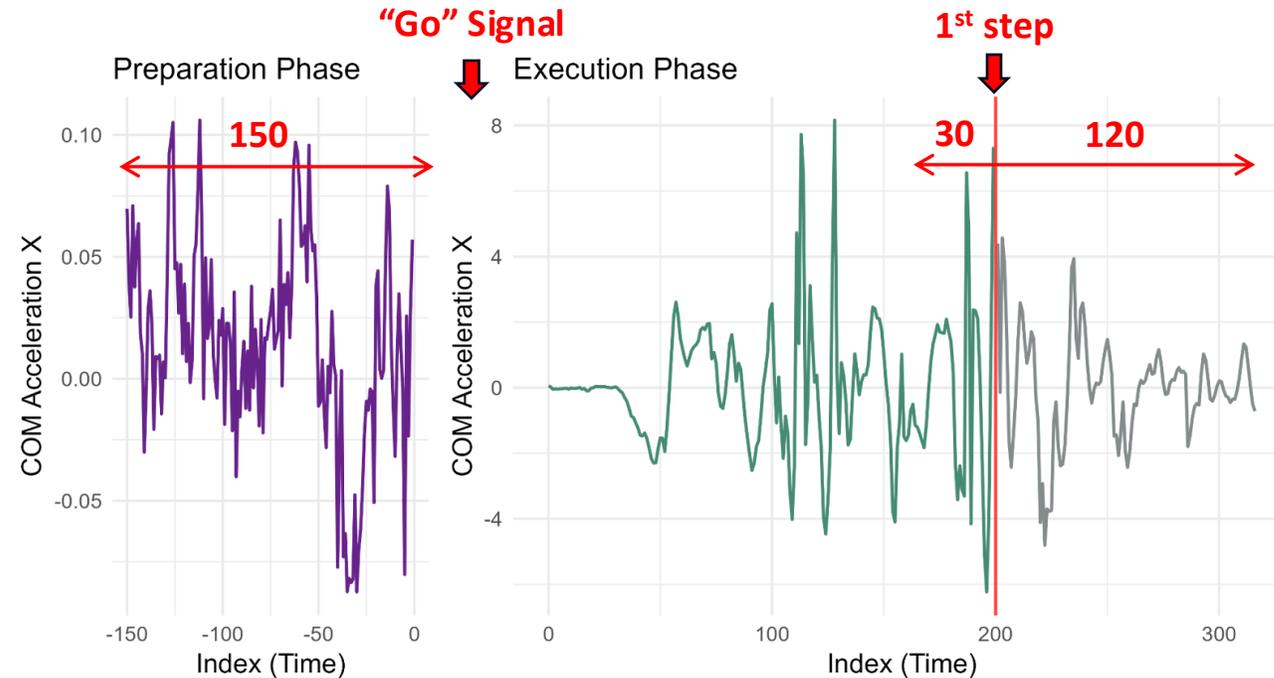
# Fractal Extraction

## Hurst–Kolmogorov (HK) Exponent

Mangalam & Likens 2025

Hpreparation (Readiness of the neuromuscular system): 150 sample epoch of Vm (100Hz)

Hexecution (Efficiency of the motor-output): 150 sample step-aligned epoch of Vm (100Hz)



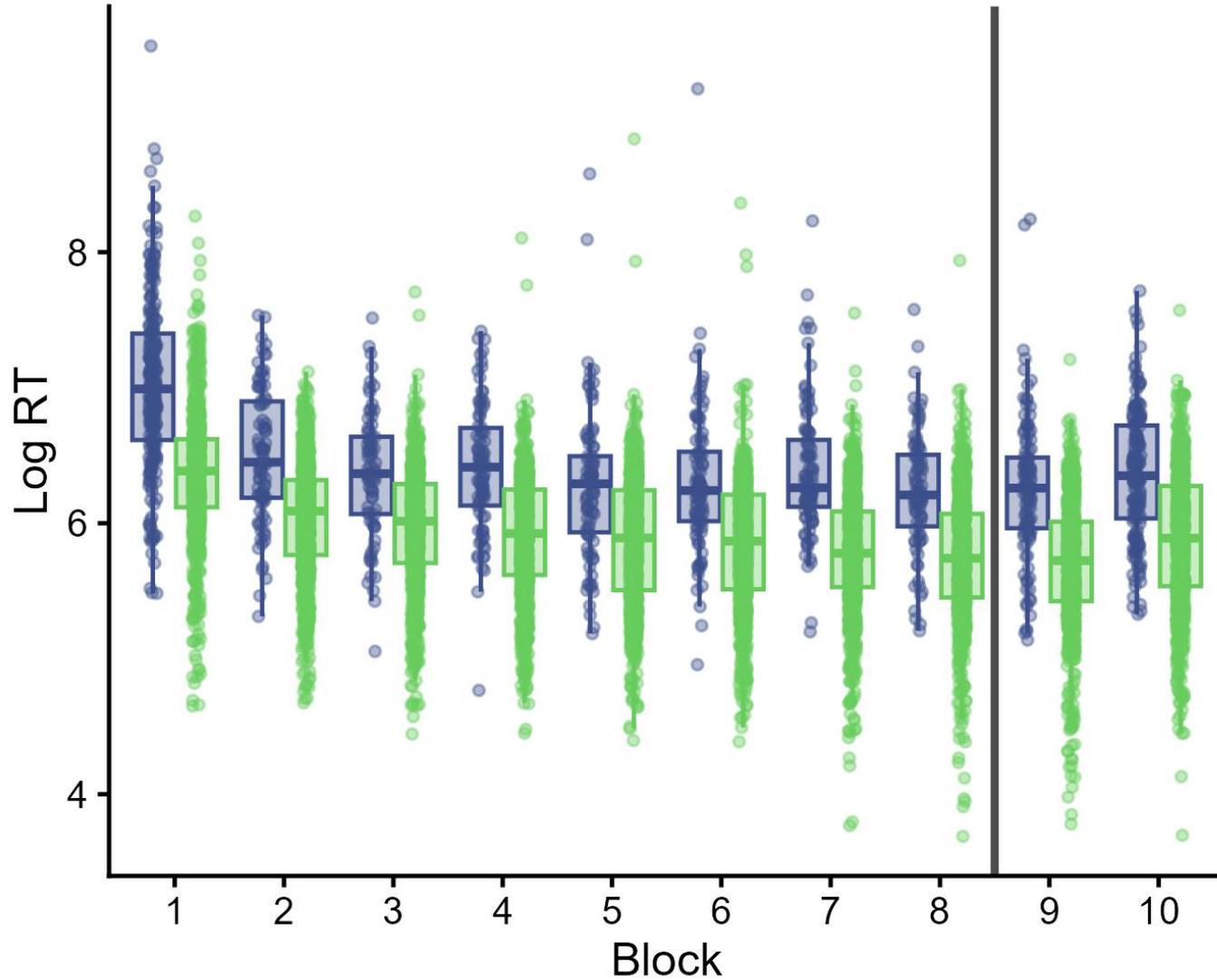
HK is a Bayesian approach to Hurst values for a given dataset.

Motor system random (0.5), or if it has structured, persistent dynamics ( $>0.5$ ).

$$\rho_k = \frac{|k+1|^{2H} - 2|k|^{2H} + |k-1|^{2H}}{2} \approx \frac{H(2H-1)}{k^{2-2H}}, \quad k = 0, 1, \dots$$

# Behavioural learning results

Trial-wise Log RT across blocks



Accuracy

Inaccurate

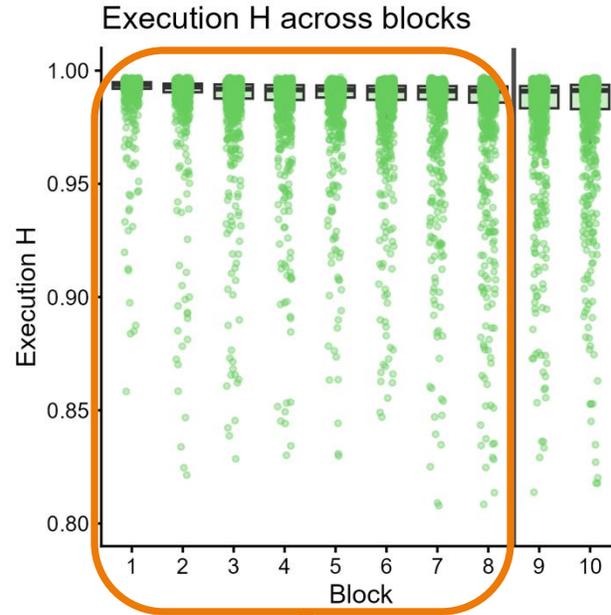
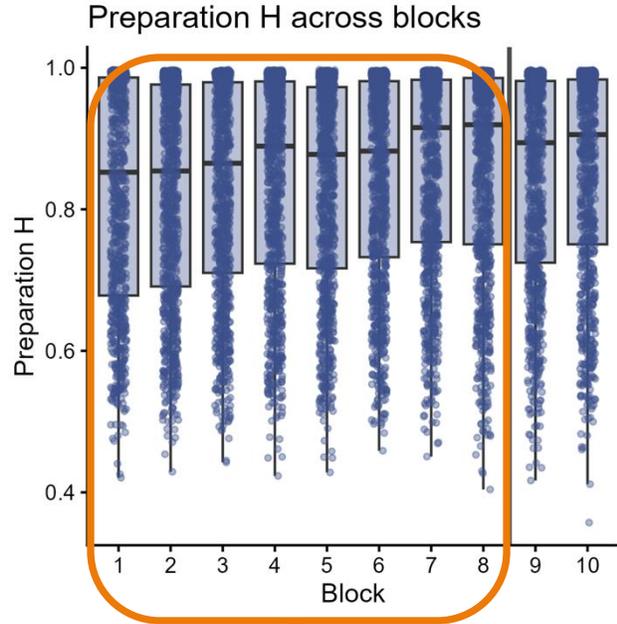
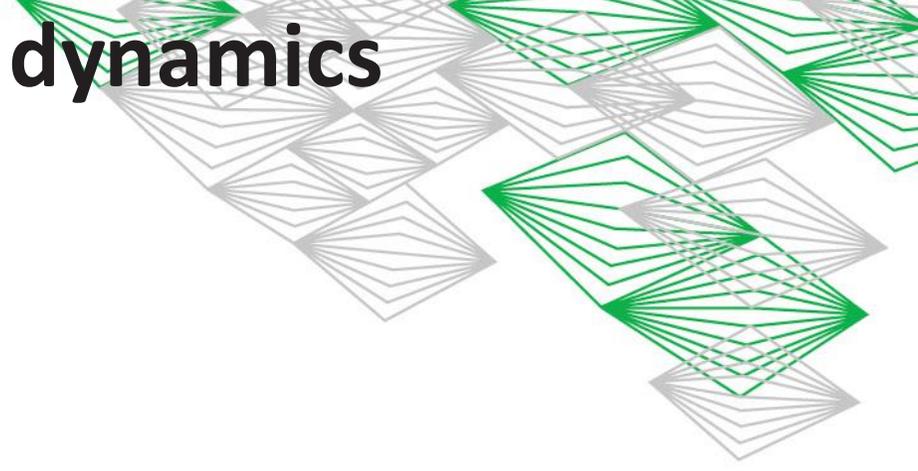
Accurate

No speed accuracy trade-off

RT reductions across most blocks

Retained only accurate trials for H (~10% removal)

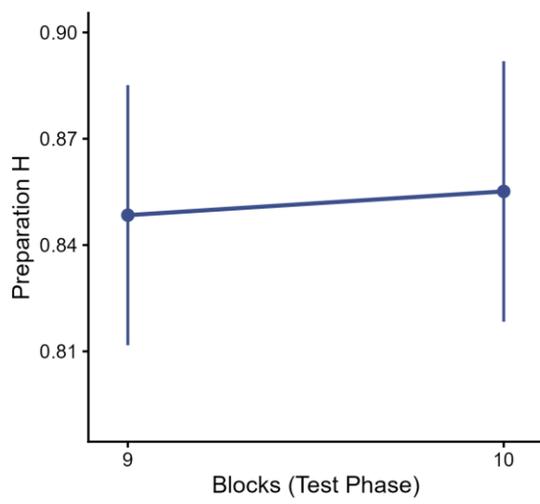
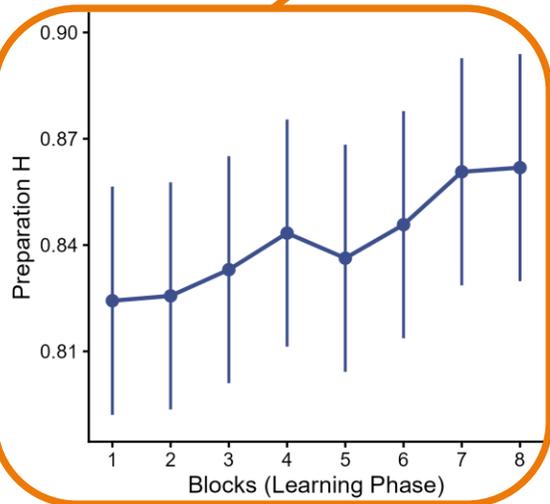
# Learning facilitates divergence in fractal dynamics



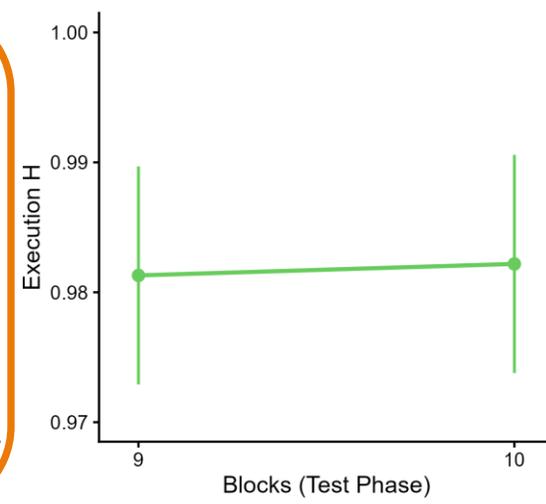
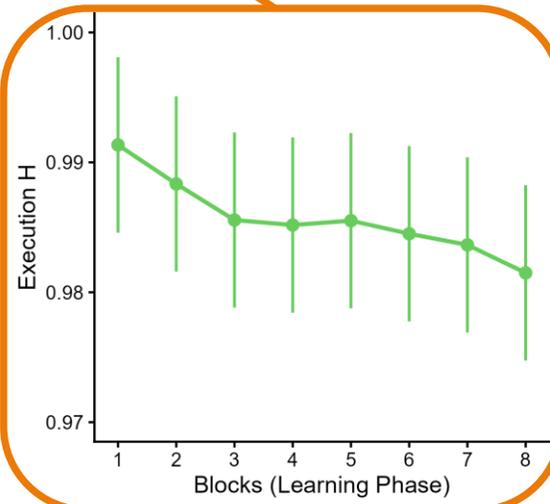
Preparation becomes increasingly more cognitively and controlled ( $H \uparrow$ )

Execution becomes more automated & efficient ( $H \downarrow$ )

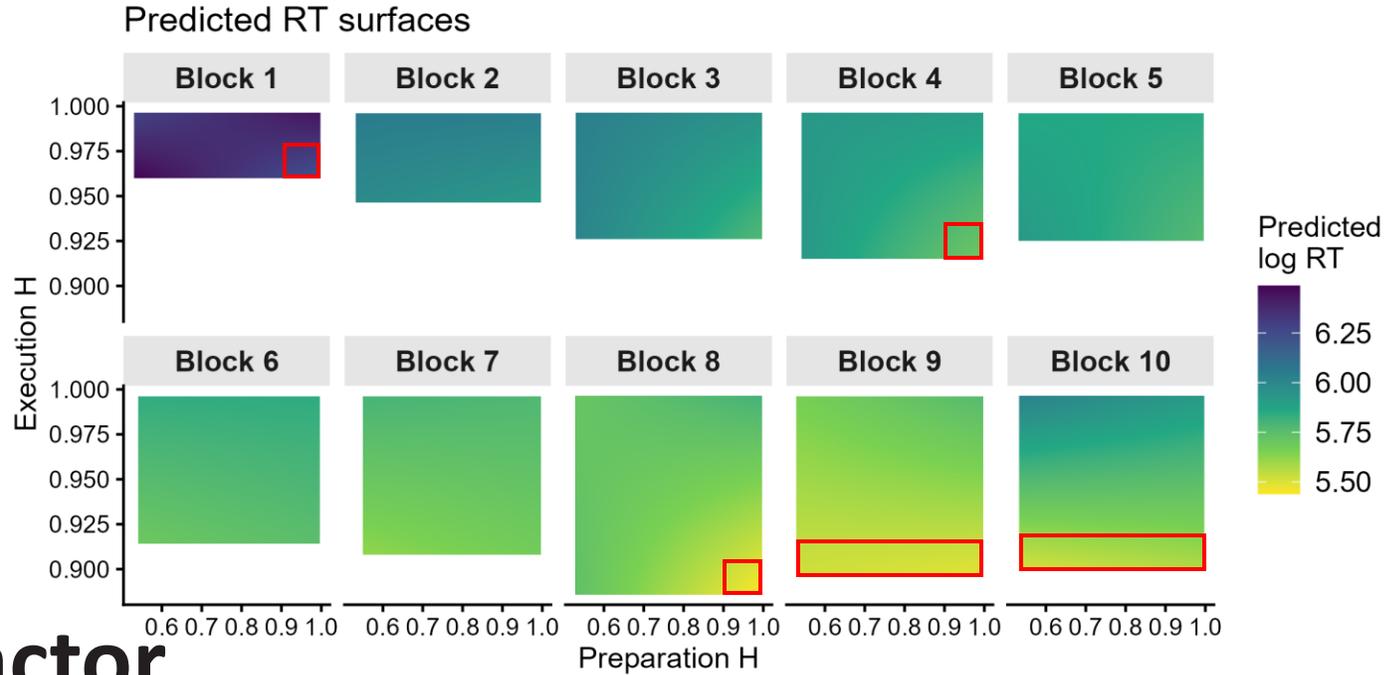
Predicted Preparation Hurst exponents across Blocks



Predicted Execution Hurst exponents across Blocks



# Readiness-Efficiency Coupling



The fastest, accurate trials happen only when Preparation H is  $\uparrow$  and when Execution H is  $\downarrow$

Coupling is 'reset' when performing Unfamiliar sequences.

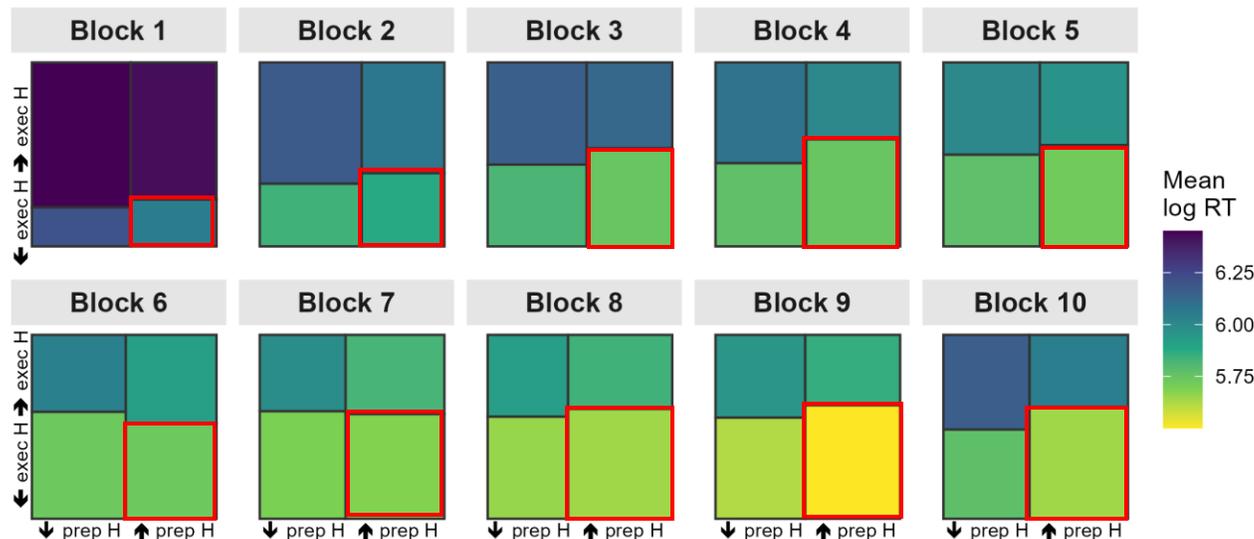
Scale invariance in action

The motor system is fine-tuning and over time, the system is actively pulled into the High-Prep/Low-Exec H states.

In Dynamical Systems this is an Attractor State.



## Attractor states



# Conclusion

1. In healthy – Learning creates fractal dissociation: The brain optimizes by  $\uparrow$  cognitive planning (prefrontal/parietal network), while allowing the body to flexibly and efficiently move (sensorimotor/striatal network).
2. In pathology – e.g. Parkinson's: Loss of automaticity may manifest as a rigid fractal signature — Execution H fails to  $\downarrow$  reflecting compensatory cortical override of striatal deficits.
3. For Interference – High Execution H = Vulnerable, learners using up excess resources. Any multitasking interference (talking, walking, obstacles) will crash their performance.
4. Low H Execution = Robust. If learners achieve Low H (automaticity), the motor channel is protected from cognitive interference.



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Students:

Emma Wiechmann, Victoria Lakomski, Johannes Pannermayr, Marcel Hildebrandt

Raoul for initial discussions and ideas!

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