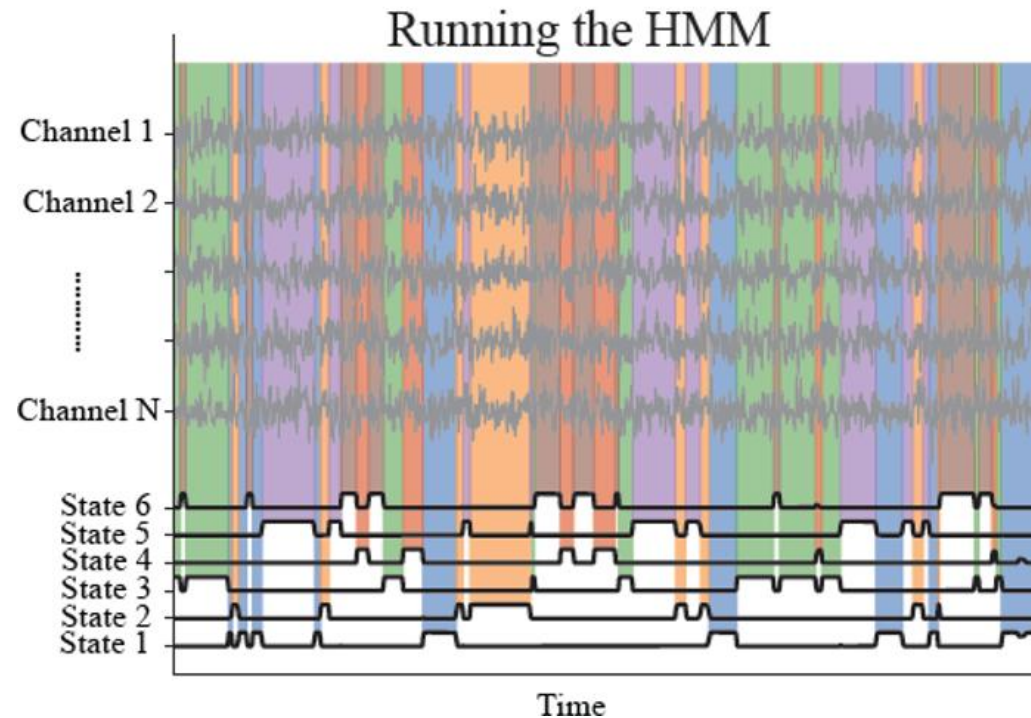


Statistical Inference on Brain Dynamics

Nick Yao Larsen
Postdoc

How do brain states relate to behavior?

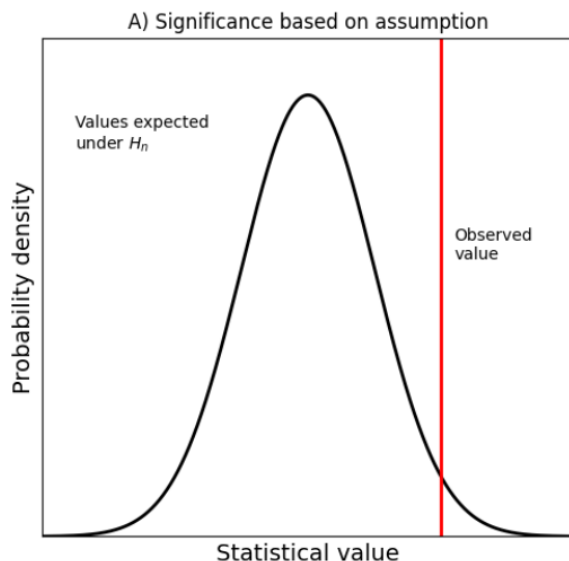
- HMM decodes brain activity into dynamic state time courses
- We want to know: do these brain states relate to task behaviour or physiology?
- Brain activity fluctuates over time, across individuals and sessions
- We need statistical tools capable of taking that into account



Parametric vs Non-parametric

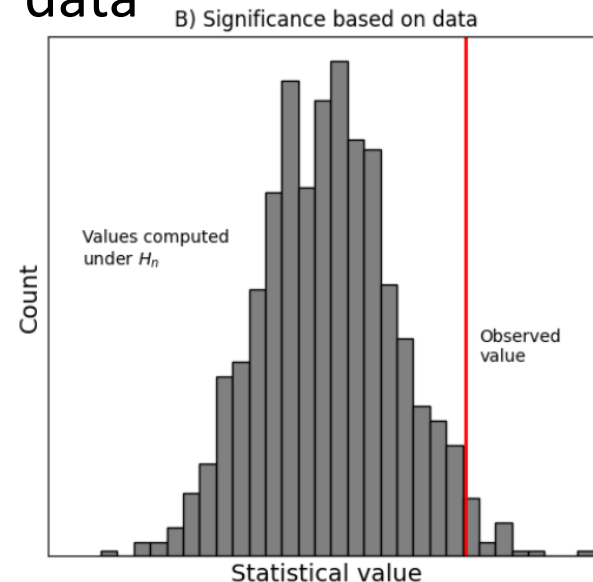
Parametric statistics

- Assume the data follows a known distribution (often Gaussian)
- Expect the variability to stay constant across measurements
- Assume each observation is independent from the rest



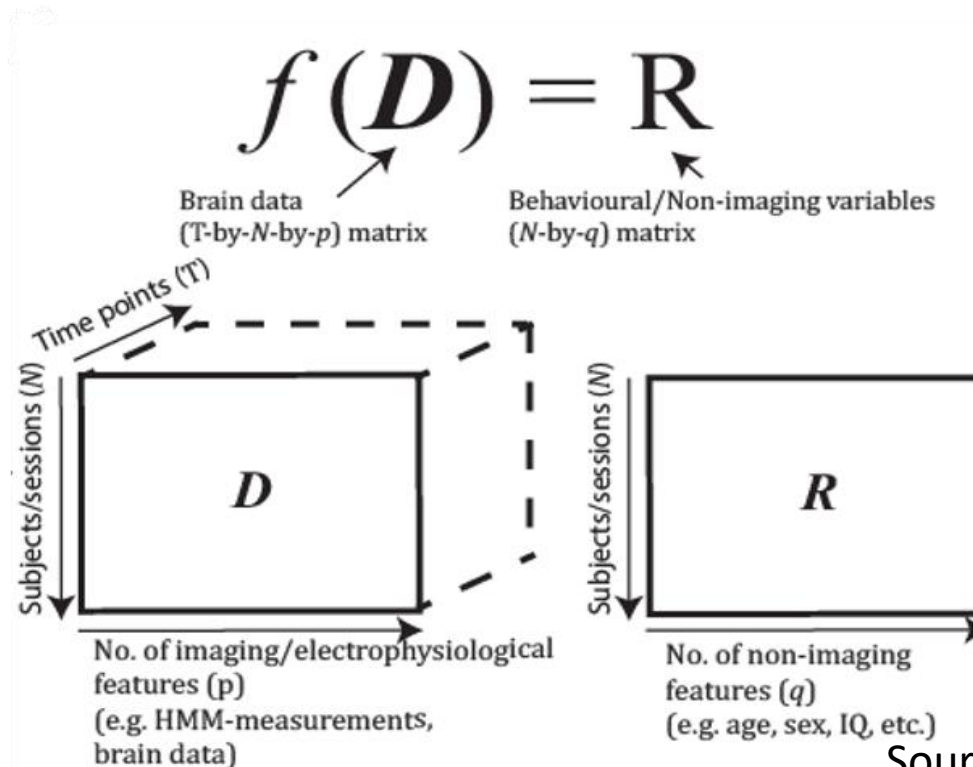
Non-Parametric statistics

- Don't rely on a specific shape or distribution of the data
- Build a null distribution directly from your data (no formulas needed)
- Common choice for high-dimensional or time-varying brain data



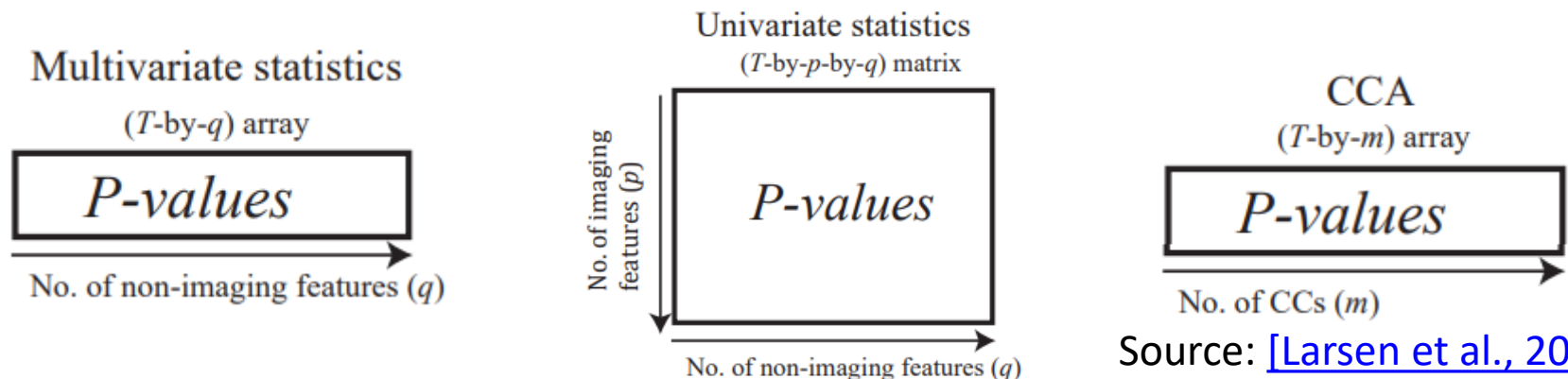
Linking brain activity to behaviour

- **D**: Brain-derived variable (independent/predictor)
- **R**: Behavioural or physiological variable (dependent/outcome)
- Goal: Test if **D** is associated with **R**, using different study designs



What we test

- **Many-to-one (Multivariate):**
Test whether multiple brain features together relate to one outcome (e.g. do all state time courses together relate to age?)
- **One-to-one (Univariate):**
Test one brain feature at a time against one outcome (e.g. does State 1 relate to age?)
- **Many-to-many (Canonical Correlation Analysis):**
Link multiple brain features to multiple behavioural variables (e.g. how do brain states relate to a profile of cognitive traits?)



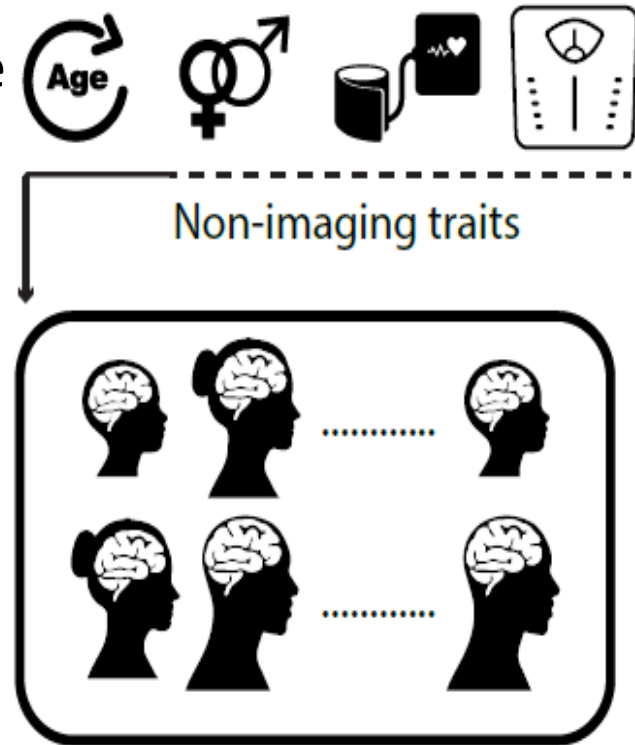
Overview of 4 types of tests

- Across-Subjects
- Across-Trials
- Across-Sessions
- Across-State-Visits

Overview of 4 types of tests

Notebook: [Across-Subjects Notebook](#)

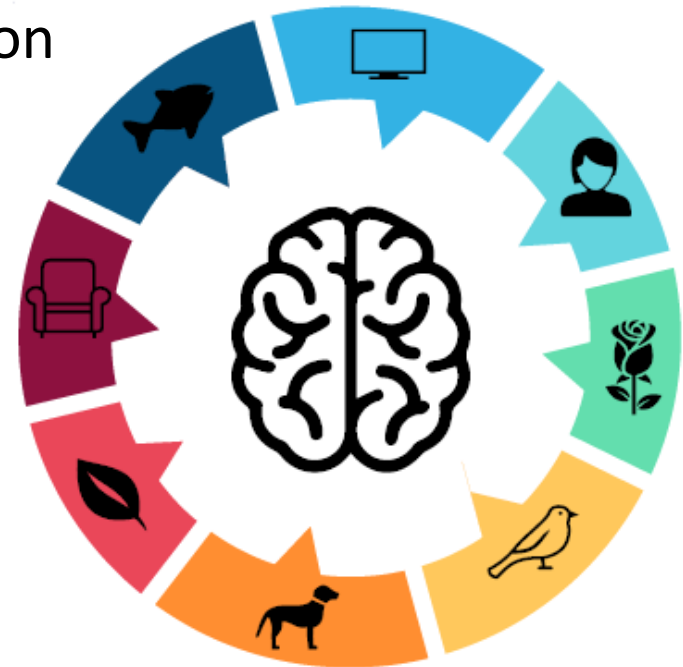
- Across-Subjects
 - **Ask:** Are differences in brain features associated with behavioural traits, like age, diagnosis, or cognitive scores?
 - Take summary measure per person
 - Suitable for testing across people



Overview of 4 types of tests

Notebook: [Across-Trials Notebook](#)

- Across-Trials
 - **Ask:** Does brain activity change depending on what condition or stimulus is presented on a trial?
 - Treat each trial as its own observation
 - Suitable for stimulus-response or task designs

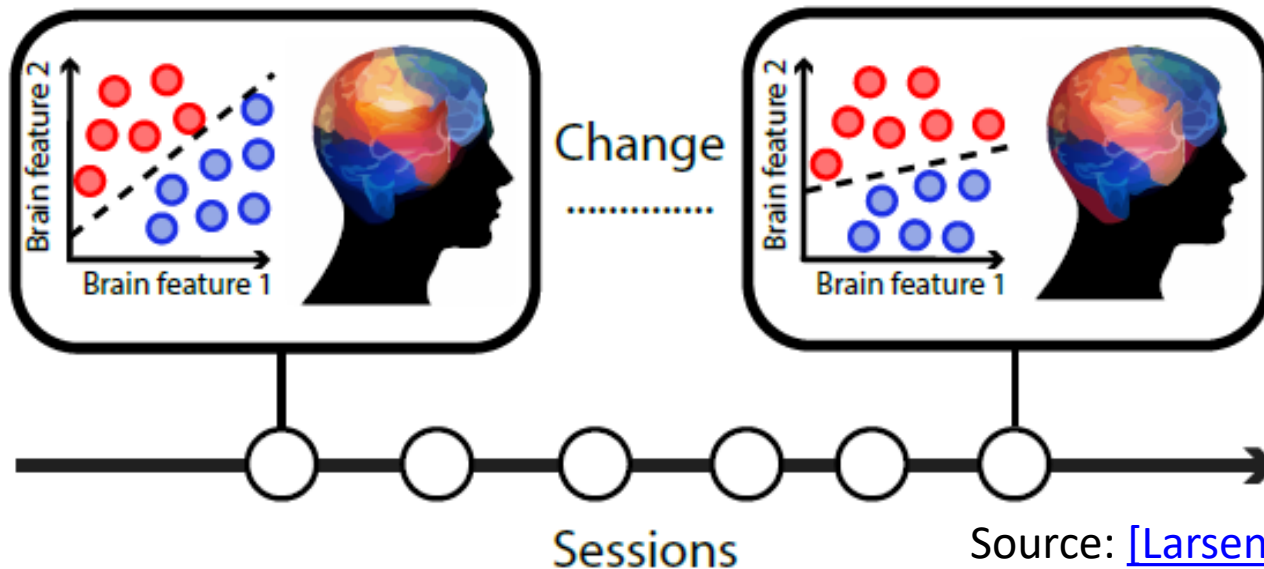


Source: [\[Larsen et al., 2025\]](#) arxiv

Overview of 4 types of tests

Notebook: [Across-Sessions Notebook](#)

- Across-sessions
 - **Ask:** Do brain dynamics change across sessions for the same individual?
 - Treat session of measurements as its own observation
 - Suitable when you want to track changes over time

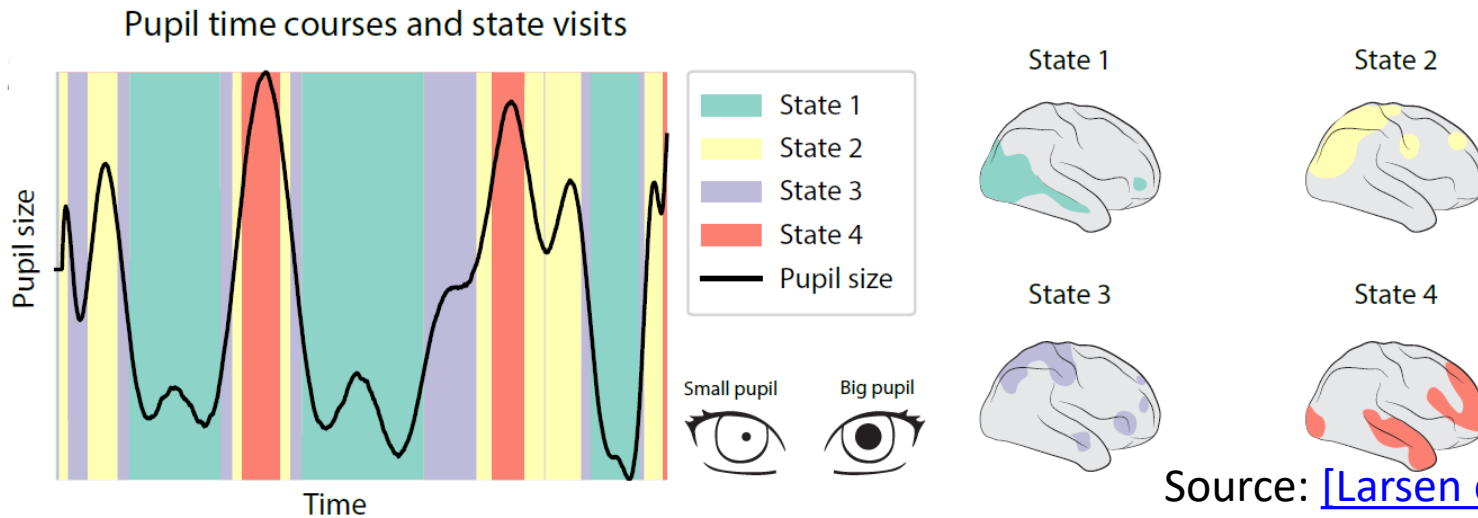


Source: [\[Larsen et al., 2025\]](#) arxiv

Overview of 4 types of tests

Notebook: [Across-State-Visits Notebook](#)

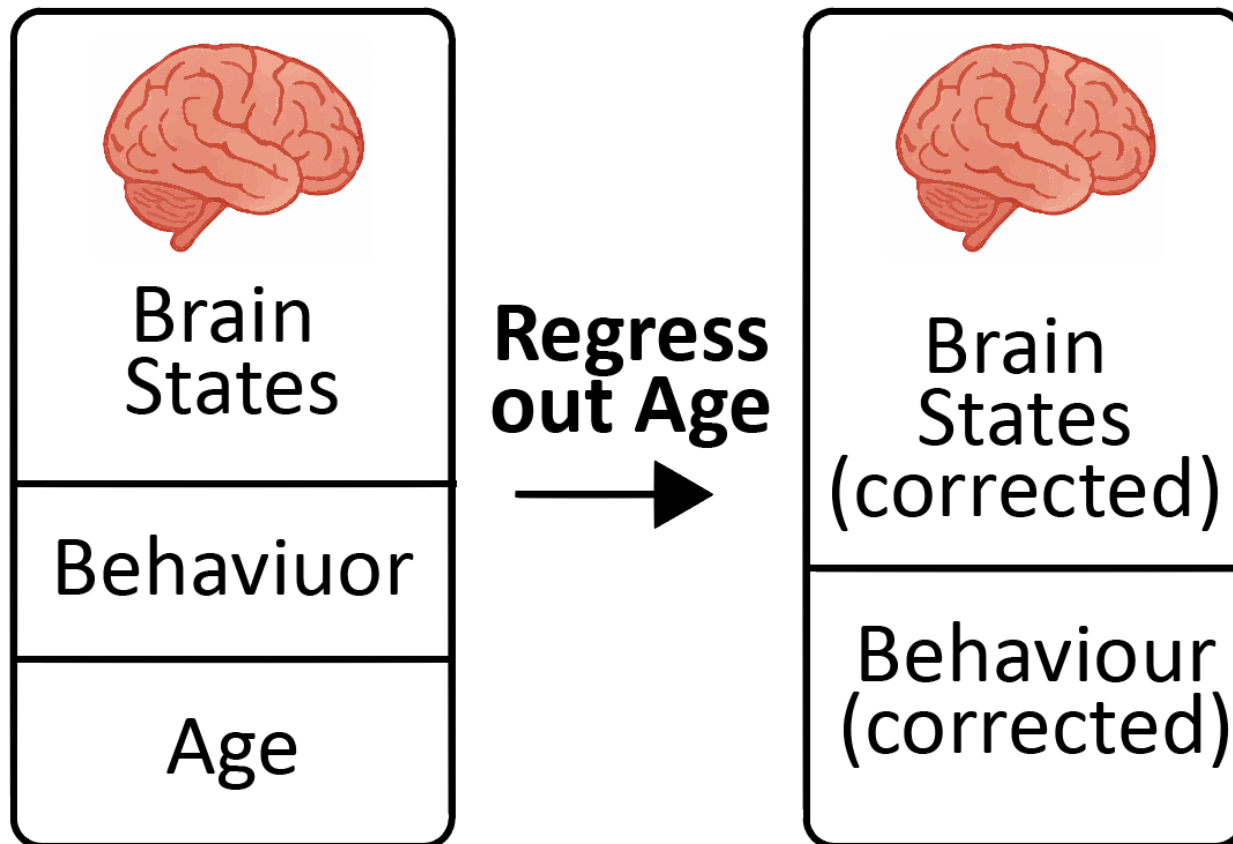
- Across-state-visits
 - **Ask:** Is another signal (e.g. pupil size, heart rate), behaving differently depending on which brain state the person is in?
 - Decode brain activity into state visits (Viterbi path)
 - Suitable when another signal is recorded at the same time



Source: [Larsen et al., 2025](#) arxiv

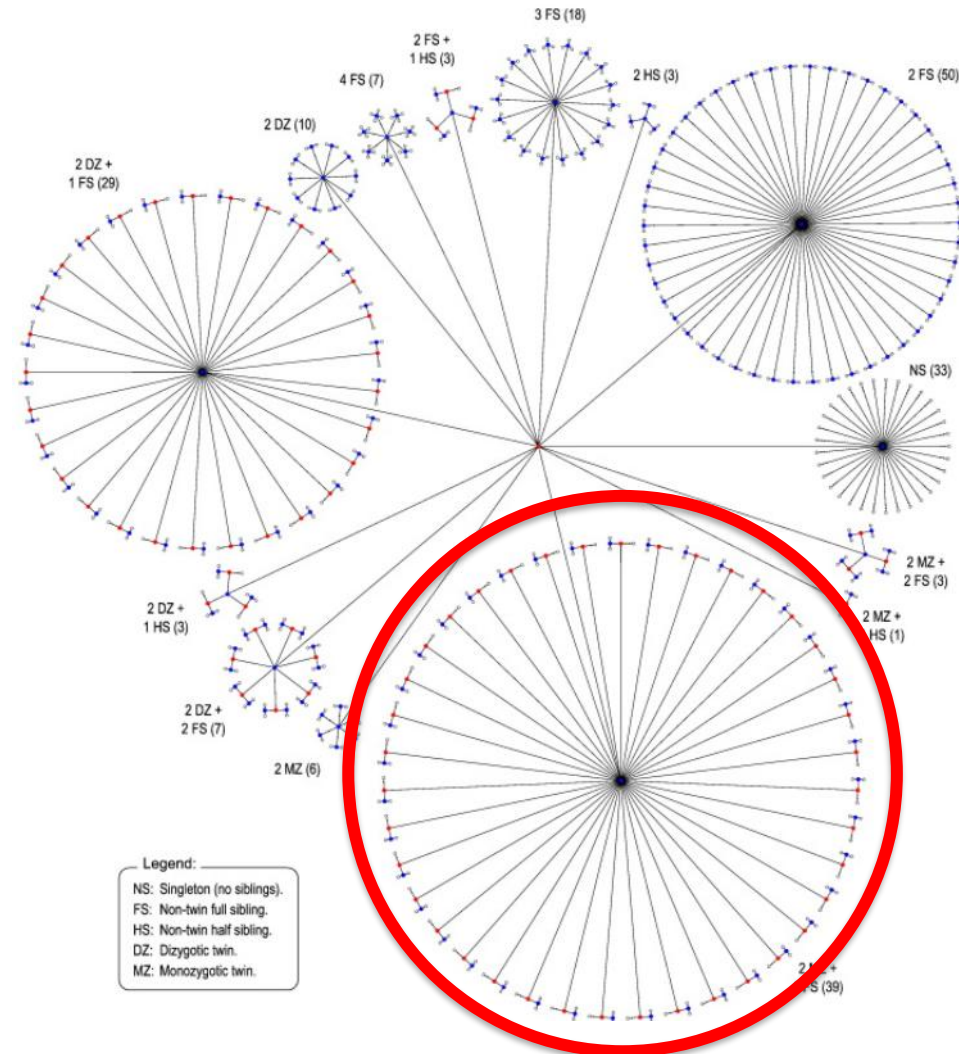
Handling confounds

- Control for age, motion, etc.



Hierarchical data structures

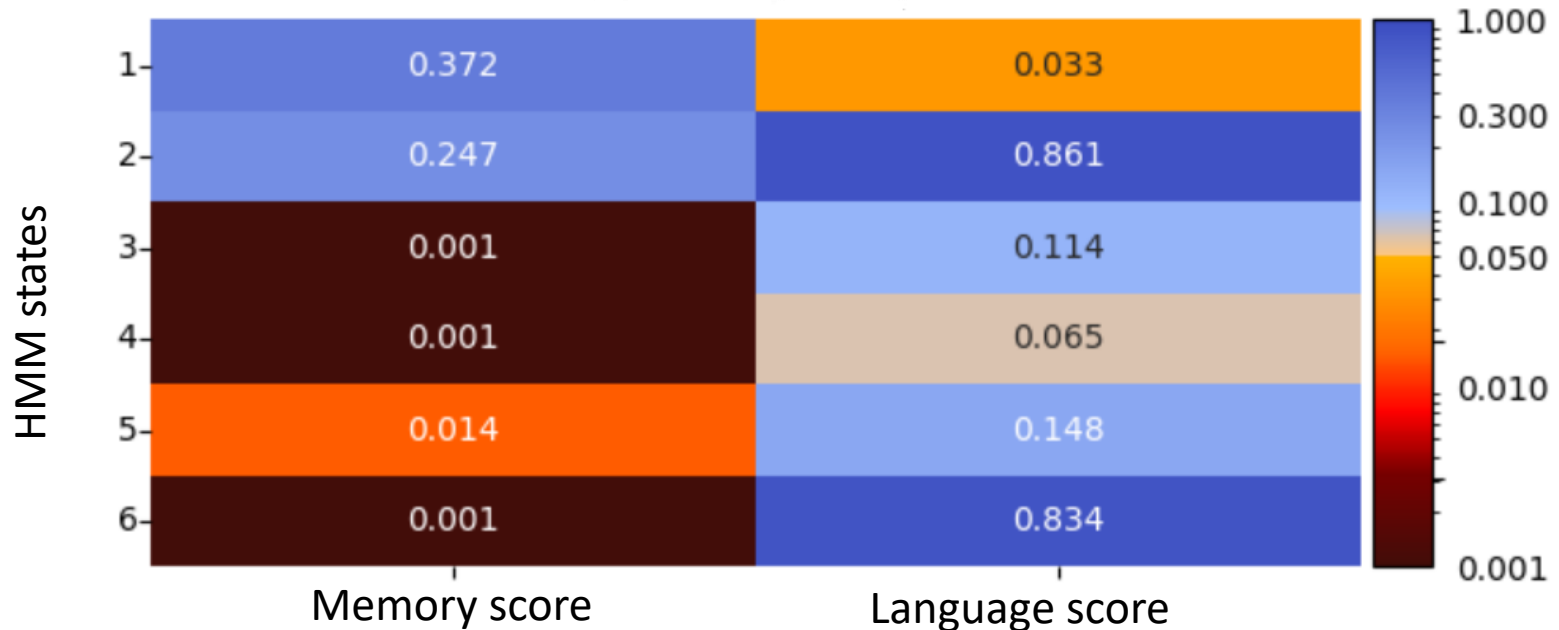
- Accounts for related data (e.g. twins, families, repeated sessions)
- [PALM](#) is supported, with simpler built-in options available



Multiple testing correction

- Many comparisons inflate false positives
- Corrections methods available in GLHMM
 - **Classical methods:** Bonferroni, Benjamini–Hochberg (FDR) etc.
 - **Max-T correction:** Controls family-wise error across tests
 - **Cluster-based correction:** Groups neighbouring effects (e.g. space/time/frequency) to reduce false positives

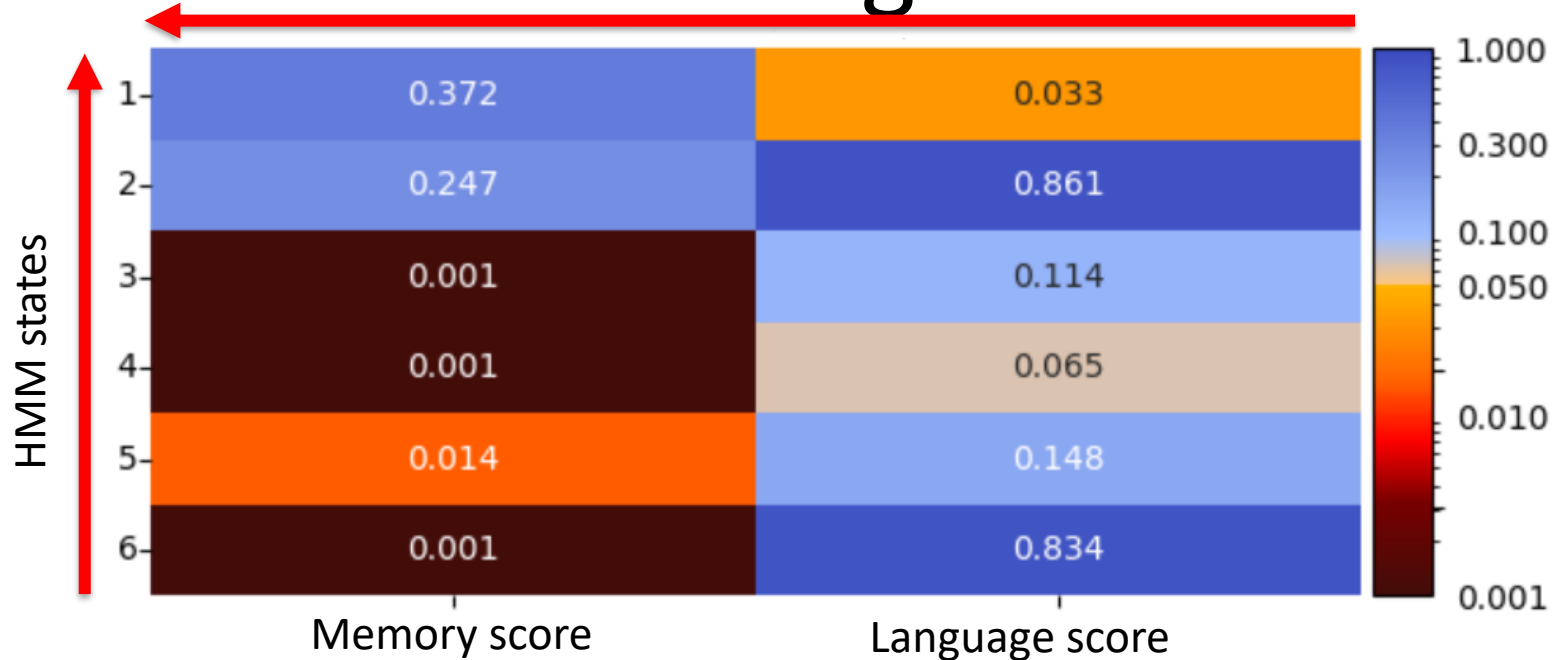
Combining tests



- Running tests across many states and traits gives a matrix of p-values
- This can be useful, but also hard to interpret all at once
- Sometimes we want a summary:

Is there any relationship between these brain states and the behavioural traits overall?

Combining tests

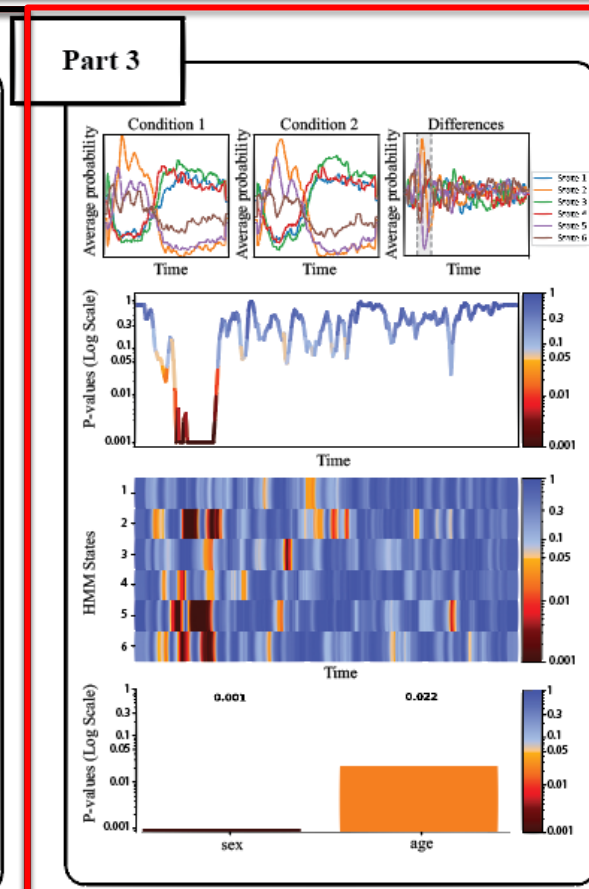
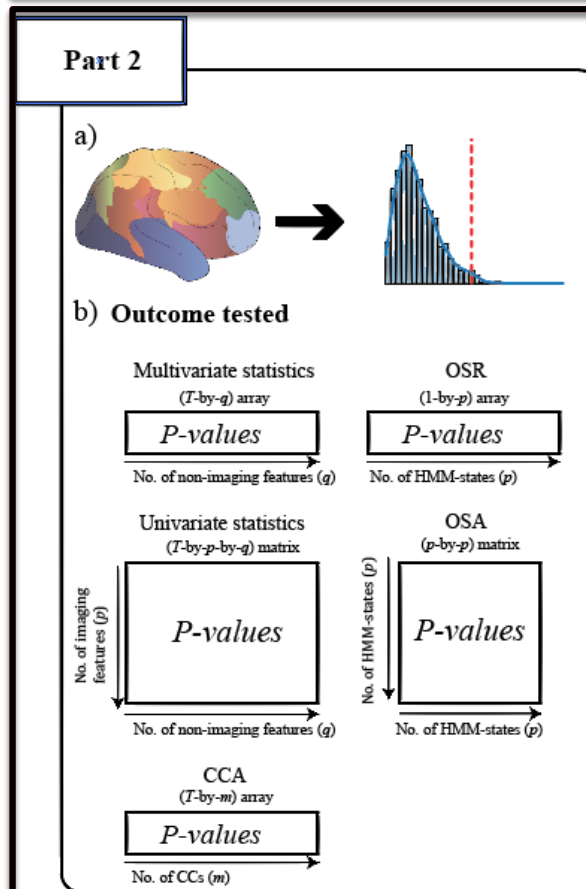
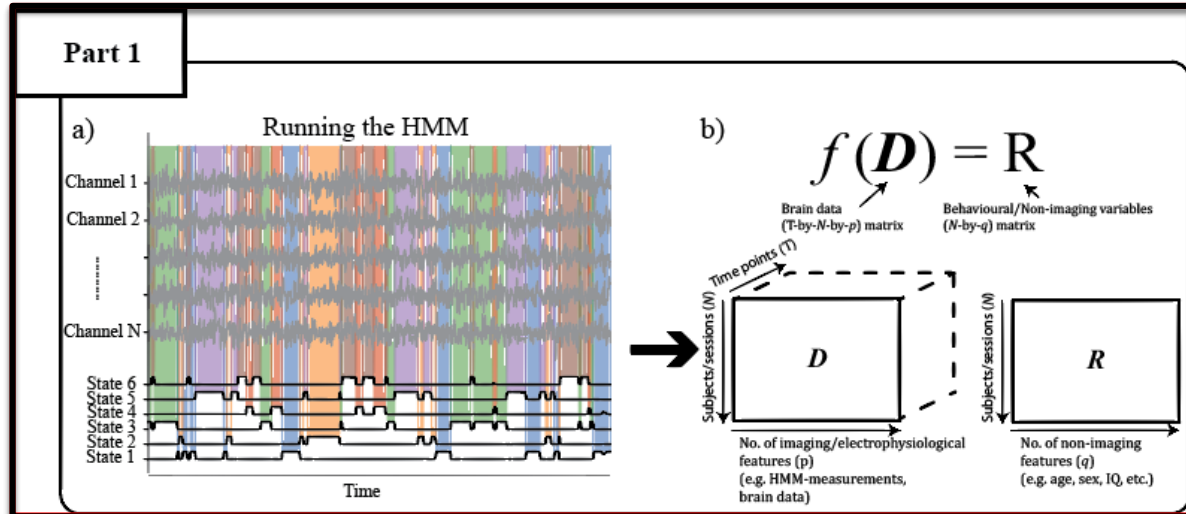


NPC (Non-Parametric Combination) summarises multiple p-values

- **Across rows** (*'across_rows'*) → One p-value per non-imaging trait
- **Across columns** (*'across_columns'*) → One p-value per brain state
- **All entries** (*'True'*) → One overall p-value
- Helps answer: which non-imaging trait matter? which state? is there a global effect?

Visual Summary of Framework

Source: [\[Larsen et al., 2025\]](#) arxiv



Final Words + Resources

- GLHMM toolbox and tutorials available
 - [1. Across-Subjects Notebook](#)
 - [2. Across-Trials Notebook](#)
 - [3. Across-Sessions Notebook](#)
 - [4. Across-State-Visits Notebook](#)
- Ready to apply to your own dynamic brain data