Linking brain structure and behavioral variability in dynamic structural equation models

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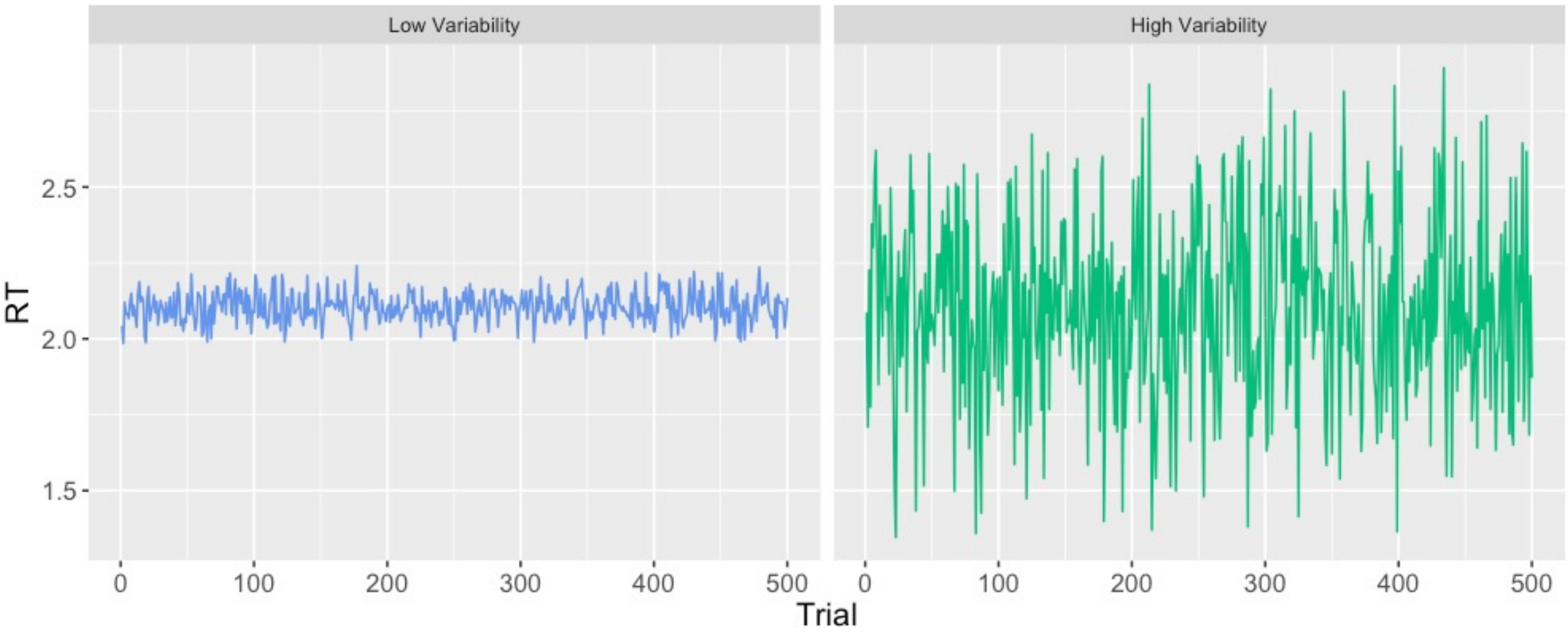
Variability in Performance

- Majority of research to date focuses characterizing and predicting the mean of behavior and cognition
  - Group or individual means
  - Change in means over time

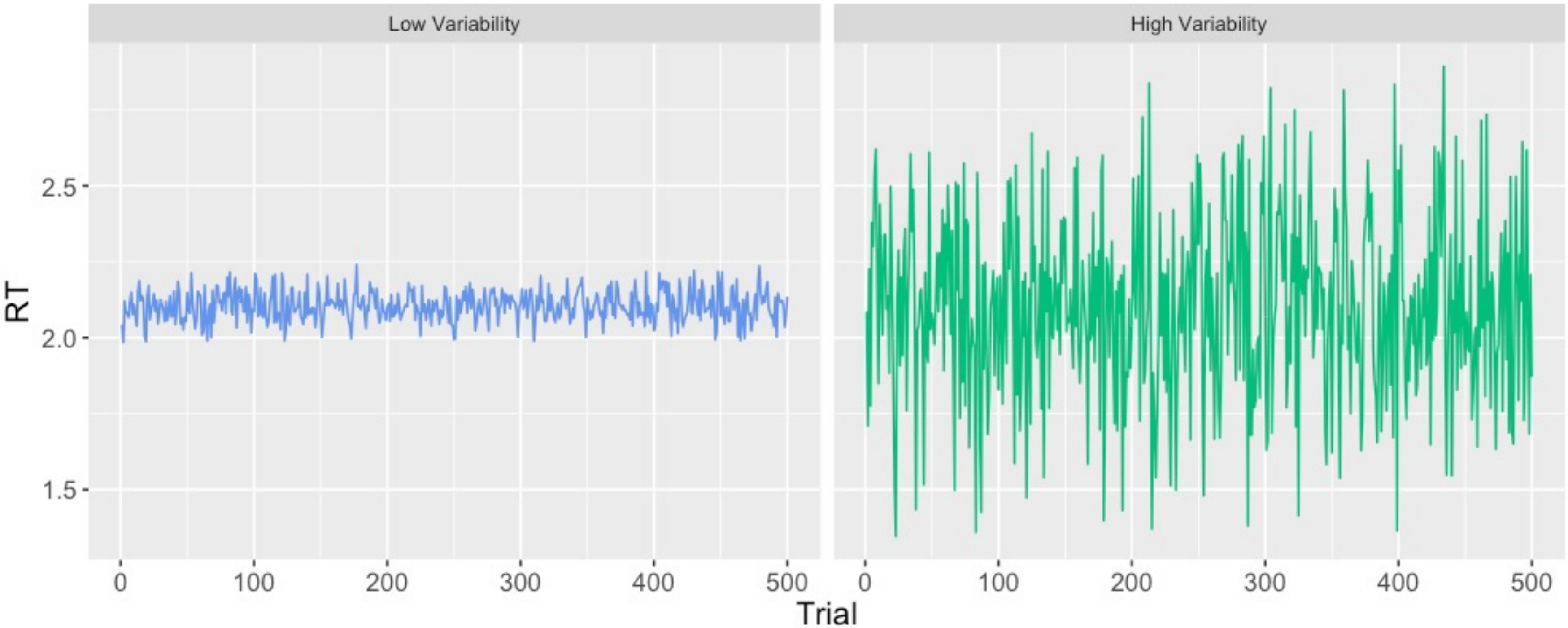
- However, a sole focus on modeling mean levels can miss another important source of individual differences in behavioral and cognitive performance: variability
  - Until recently, methodological tools have not been available to predict variability directly

Variability in Performance



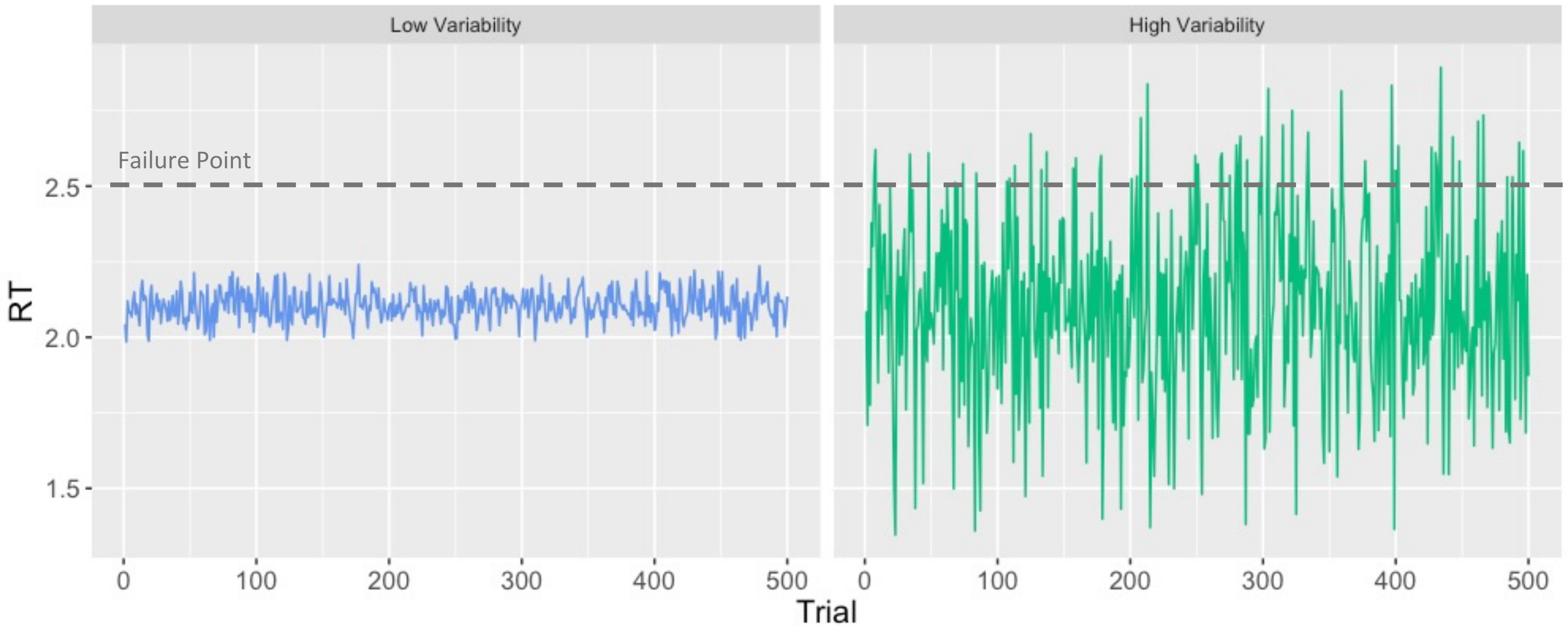
Variability in Performance

- Intrinsic mechanism differences



Variability in Performance

- How performance interacts with external factors



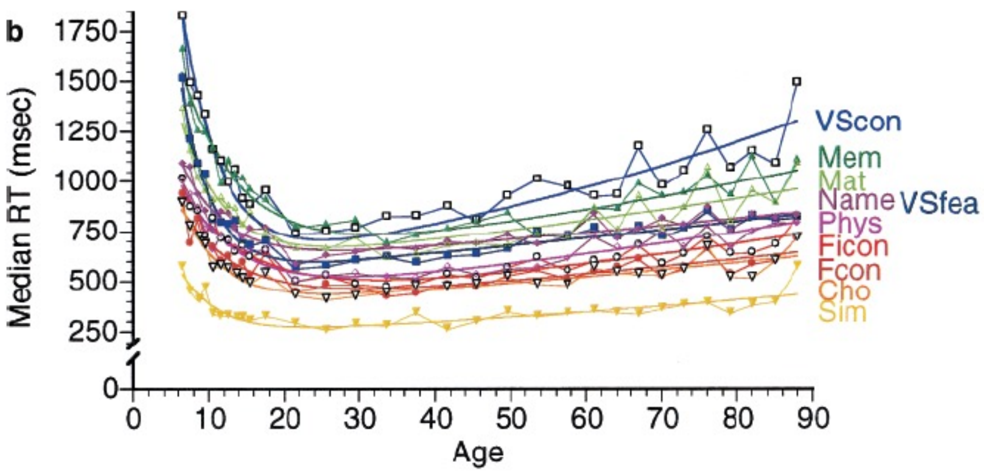
Variability in Performance

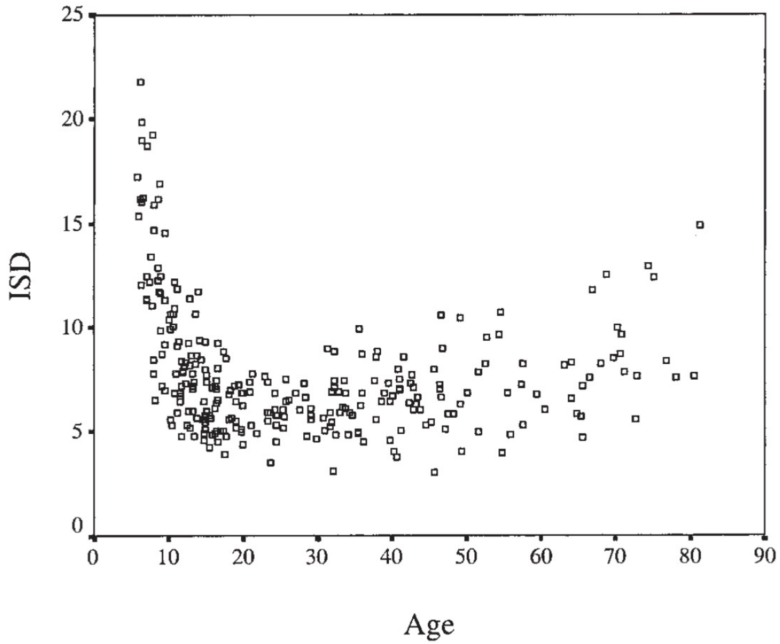
- Similar means do not necessarily reflect similar profiles of repeated performance
  - Consistent versus inconsistent performance

- Understanding potential causes of consistent vs. inconsistent performance can help build a better causal model of behavior
  - e.g., limits on response time versus attentional processes
  - e.g., reliability of the mean

Variability and Development

- Across the adult lifespan, reaction time (RT) displays a ”Nike swoosh” effects
  - Sharp improvements in early decades followed by protracted slowing over aging



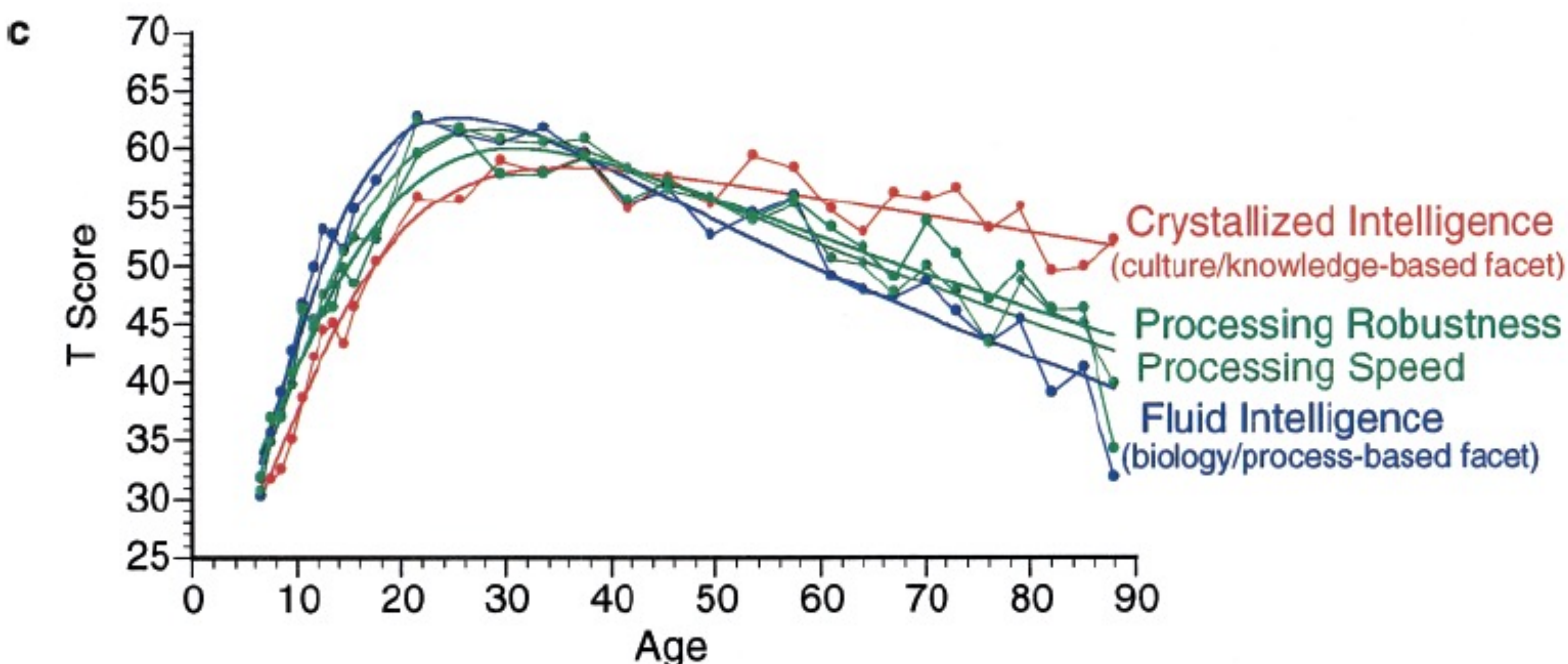


Li et al. (2004), *Psych Science*

Williams et al. (2005), *Neuropsychology*

Variability and Development

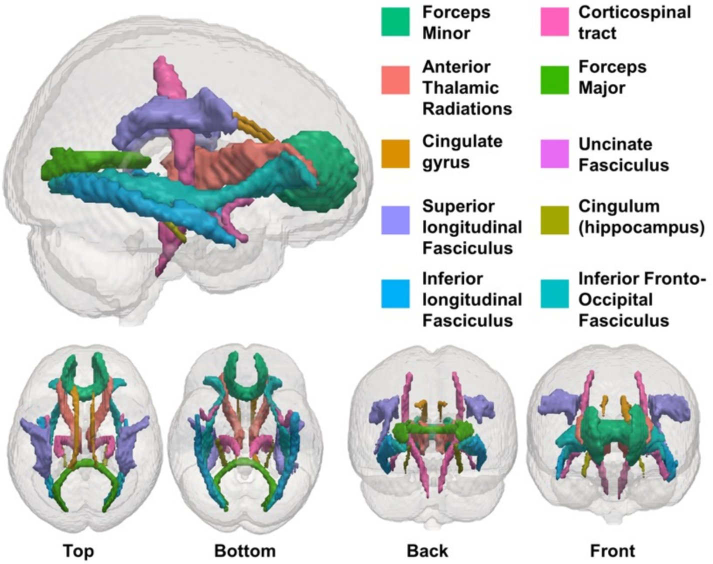
- Across the adult lifespan, reaction time (RT) displays a "Nike swoosh" effects
  - Sharp improvements in early decades followed by protracted slowing over aging
  - Inverse pattern in cognitive abilities



Li et al. (2004), *Psych Science*

Variability and the Brain: White Matter

- White matter tracts transmit signals between brain regions via insulated (i.e., myelinated) fibers
  - Impairments in this insulation might lead to inconsistent (i.e., variable) signal propagation (Kail, 1997)
    - Lower signal-to-noise system



Variability and White Matter

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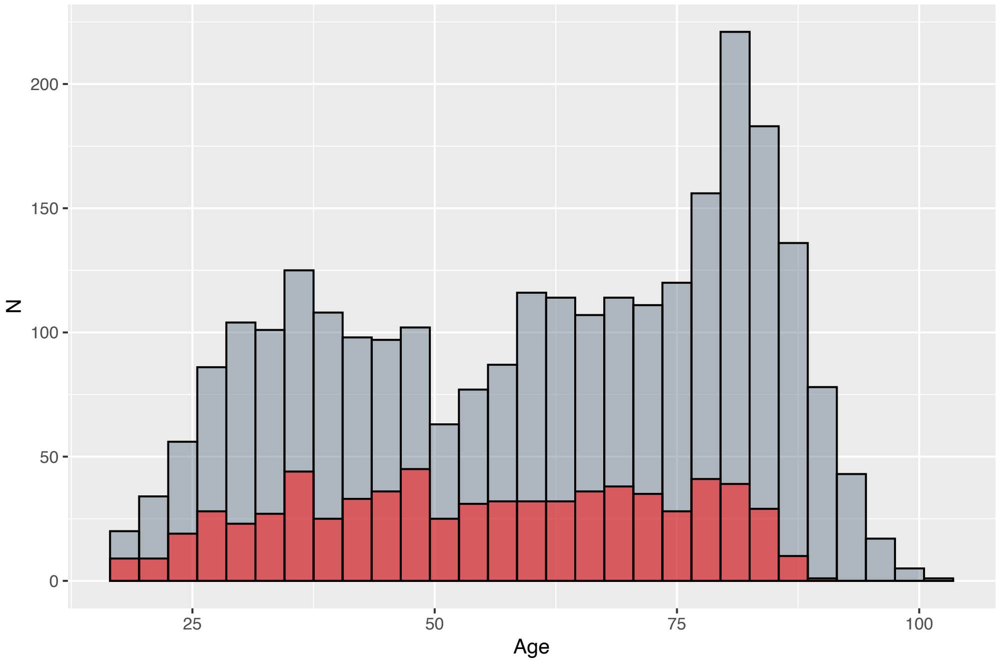
- Prior work (Fjell et al., 2011; Tamnes et al., 2012; Kievit et al., 2014; 2016) showed that higher fractional anisotropy (FA) in white matter related to faster processing speed and better cognitive performance
  - In clinical samples, white matter injury leads to more variable performance (Britton et al., 1991; Sorg et al., 2021)

Limitations of Work Thus Far

- Most work done in small samples or in clinical populations
- Observed measures of variability (iSD and iCV)
  - Often confounded with mean performance (esp. with floor effects in RT data)
  - Can be inflated by unmodeled components of performance (e.g., trends, autoregression; de Haan-Rietdijk et al., 2016)
  - Treated as fixed and known vs. estimates
  - Want to be able to simultaneously model the mean and variability of performance, as well as predictors of each

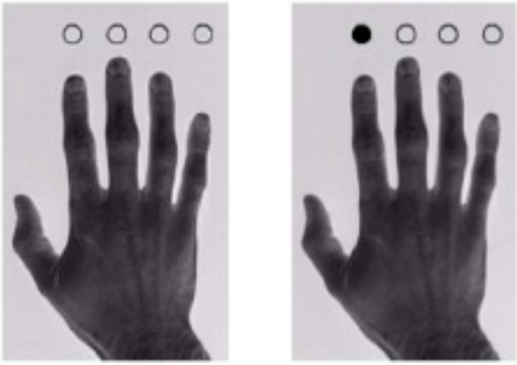
Current Work

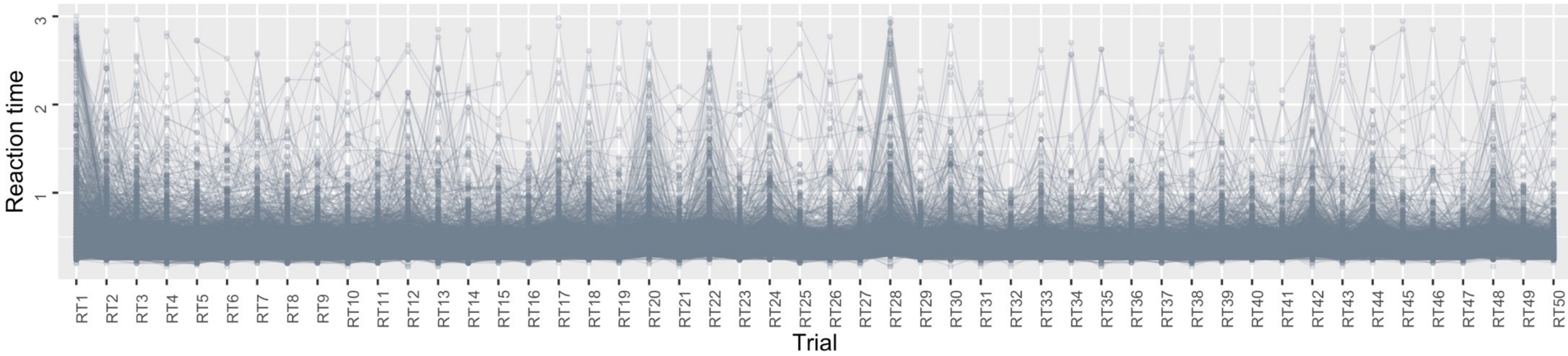
- Cambridge Centre for Ageing and Neuroscience (Cam-CAN) dataset
  - N=2681 (708 neuroimaging; red); ages 18-102



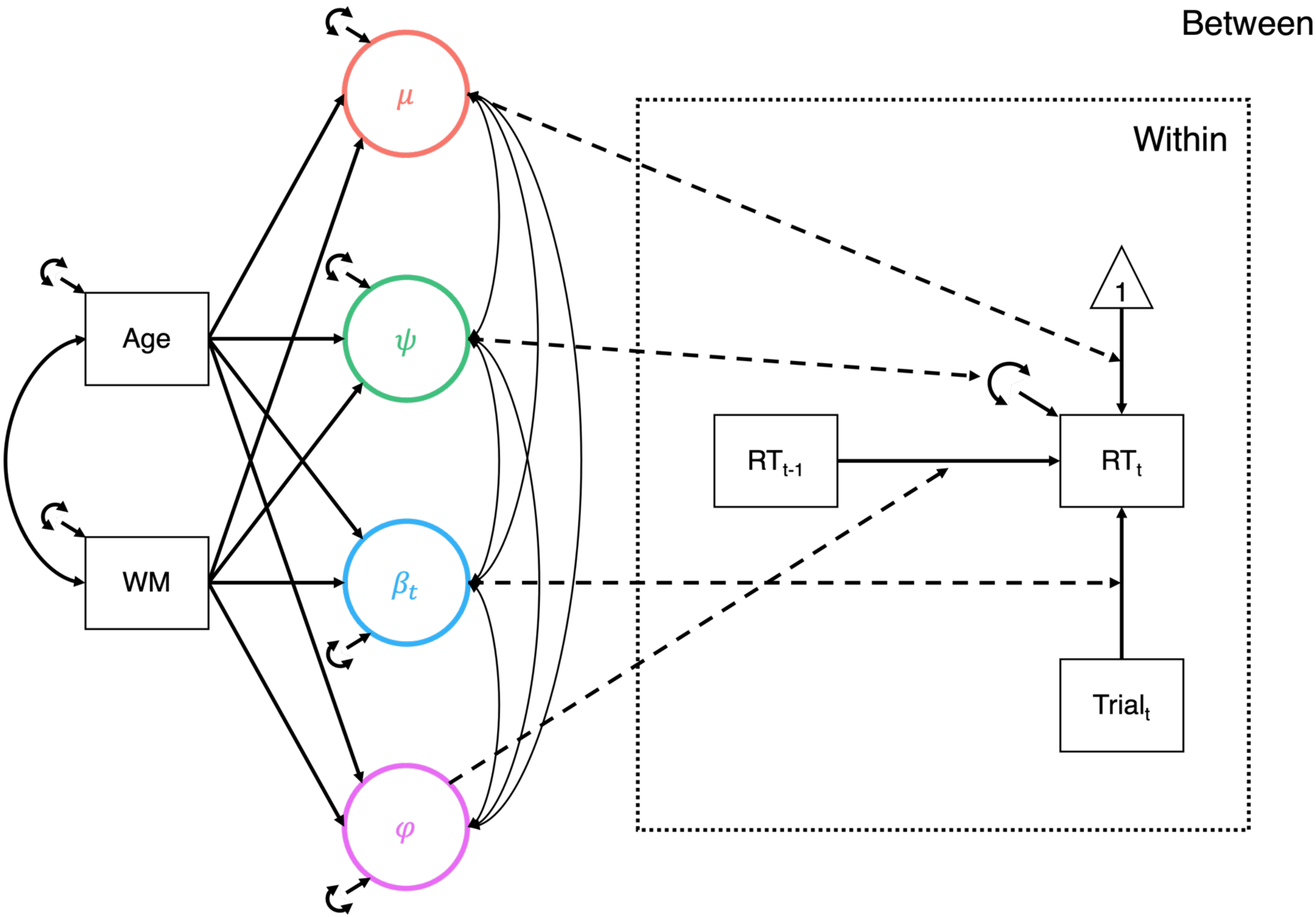
Current Work: Data

- Cambridge Centre for Ageing and Neuroscience (Cam-CAN) dataset
  - N=2681 (708 neuroimaging); ages 18-102
- Simple RT task
  - 50 trials





Current Work: DSEM Model



Current Work: DSEM Model

Level 1:

$$\log\left(RT_{t,i}\right) = \mu_i + \varphi_i RT_{t-1,i} + \beta_{ti} Trial_{t,i} + \varepsilon_{t,i}$$

$$\varepsilon_{t,i} \sim N\left(0, \psi_i\right)$$

Level 2:

$$\mu_i = \gamma_{00} + \gamma_{01} WM_i + \gamma_{02} Age_i + u_{0i}$$

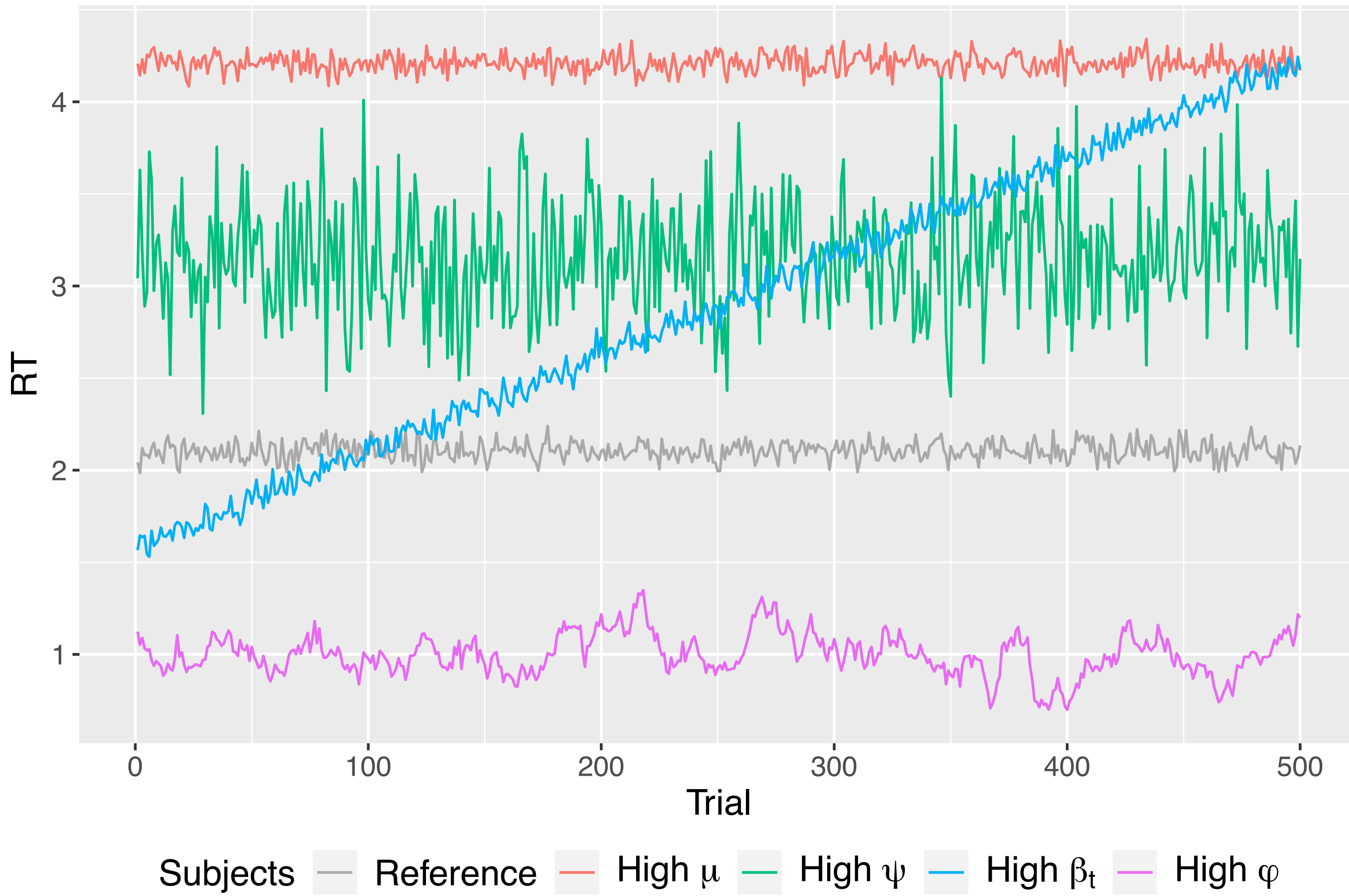
$$\varphi_i = \gamma_{10} + \gamma_{11} WM_i + \gamma_{12} Age_i + u_{1i}$$

$$\beta_{ti} = \gamma_{20} + \gamma_{21} WM_i + \gamma_{22} Age_i + u_{2i}$$

$$\psi_i = exp\left(\omega_0 + \omega_1 WM_i + \omega_2 Age_i + u_{4i}\right)$$

$$\boldsymbol{u}_i \sim MVN\left(\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \tau_{\mu} & & & \\ \tau_{21} & \tau_{\varphi} & & \\ \tau_{31} & \tau_{32} & \tau_{\beta_t} & \\ \tau_{41} & \tau_{42} & \tau_{43} & \tau_{\psi} \end{bmatrix}\right)$$

Current Work: DSEM Model



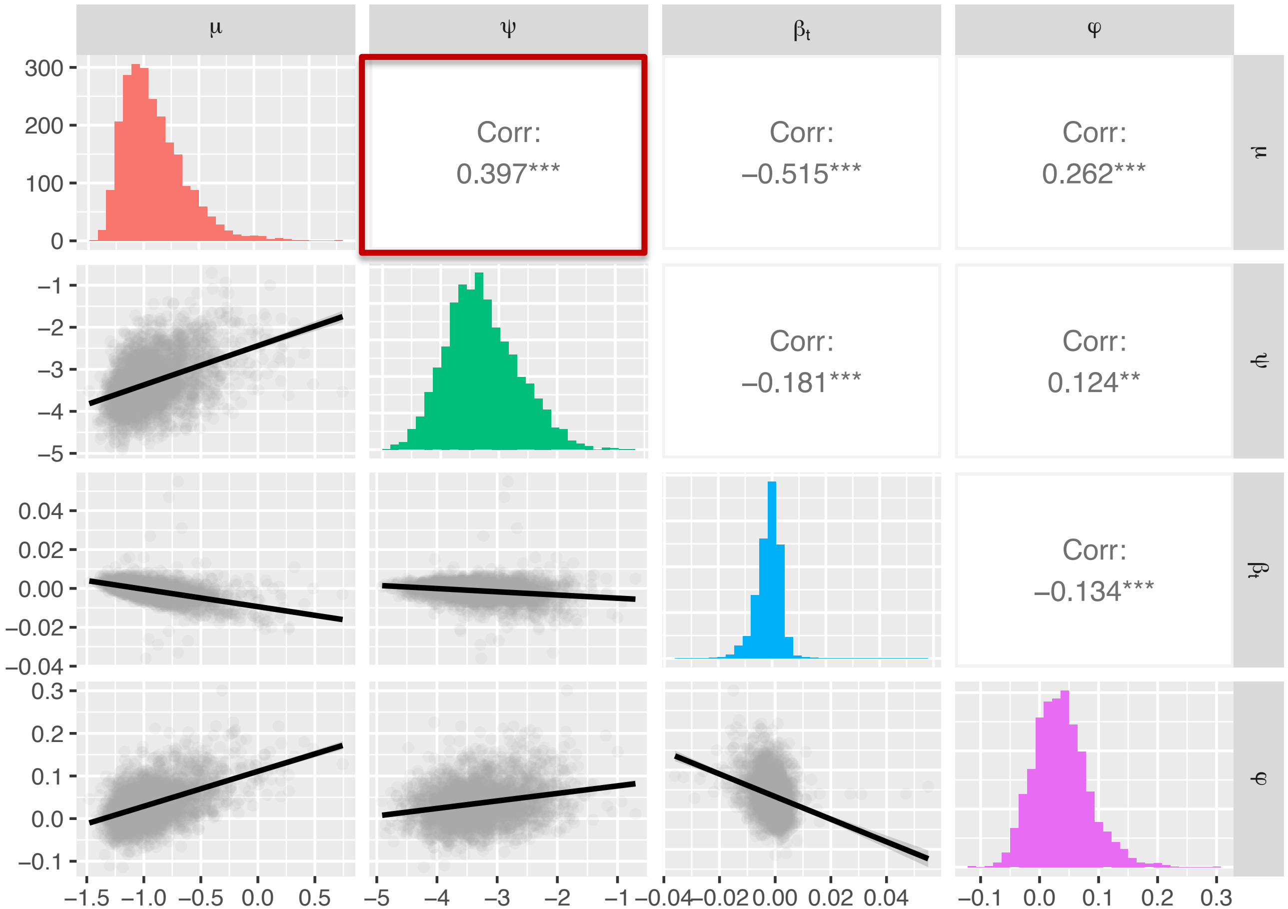
Current Work: Results

- Model comparisons based on DIC favored random effects for all 4 components of performance

- Unconditional Model
  - Significant (between-person) variance in both mean level and (within-person) variability in performance
    - As well as in the trend and autoregressive terms

Current Work: Results

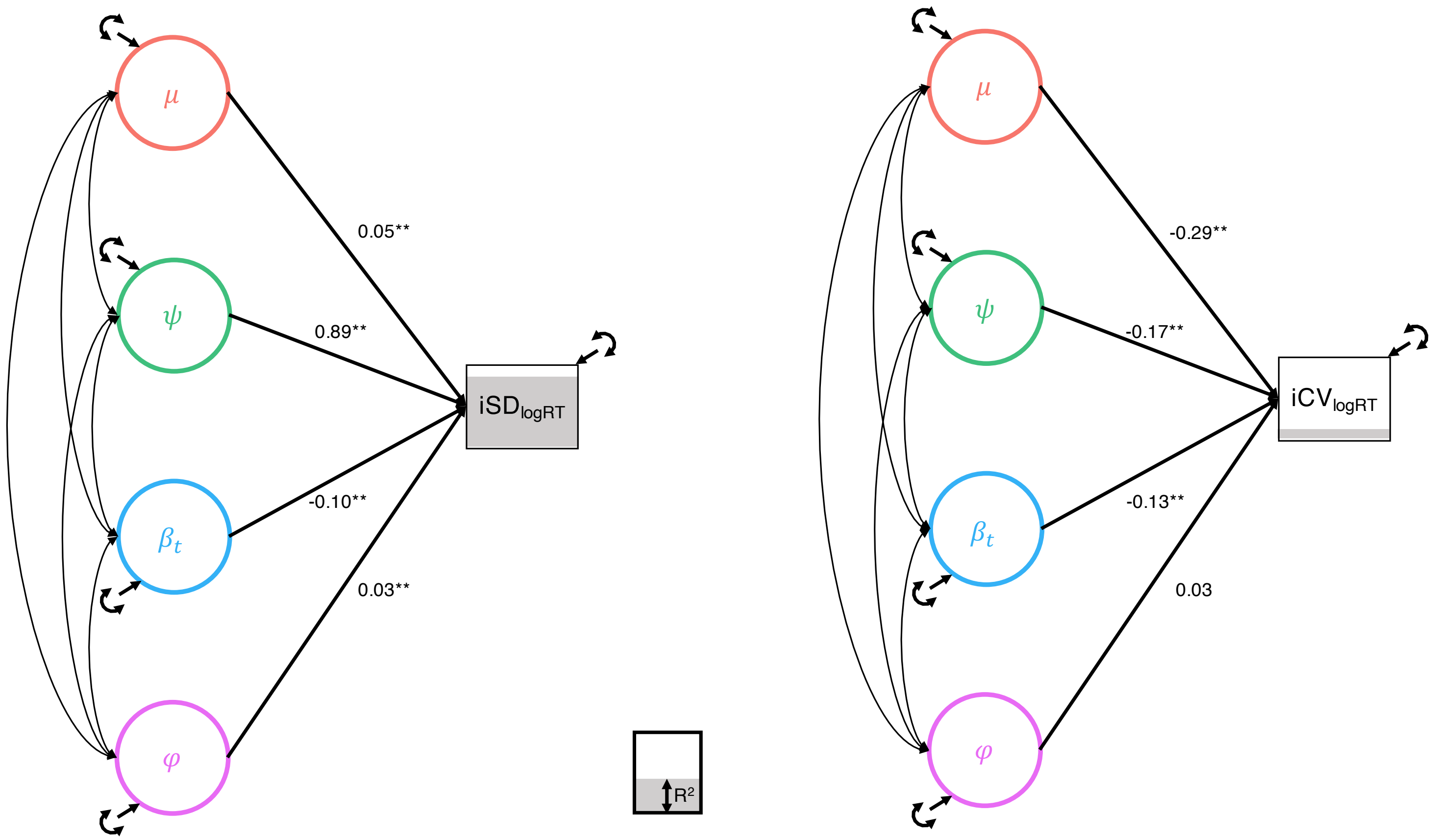
- Mean level (μ), variability (ψ), and autoregression (φ) positively correlated
  - All negatively correlated with the trend (β_t)



- correlation between computed mean and variability (r = .666) higher than model-based estimate

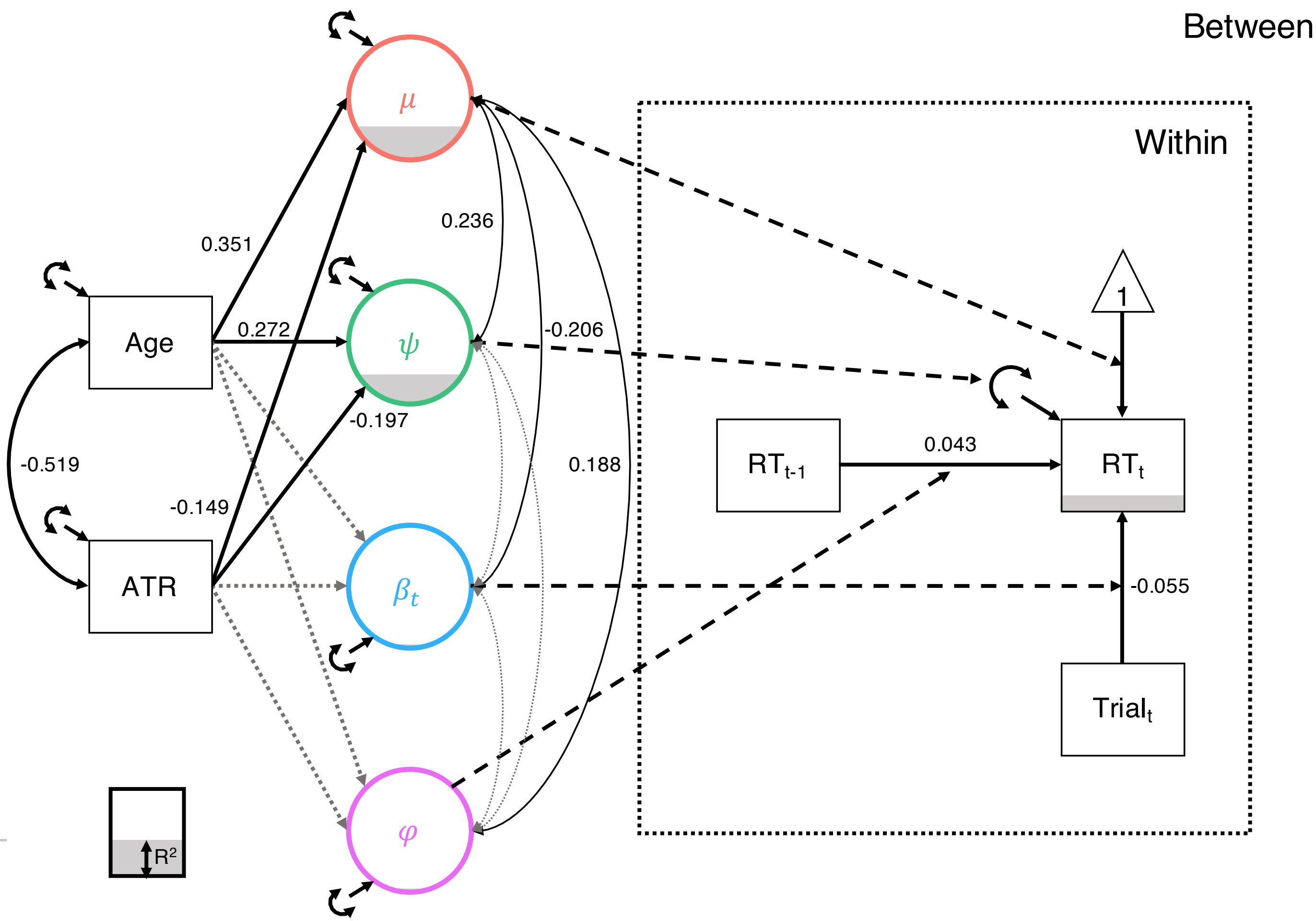
Current Work: Results

- Computed measures are confounded



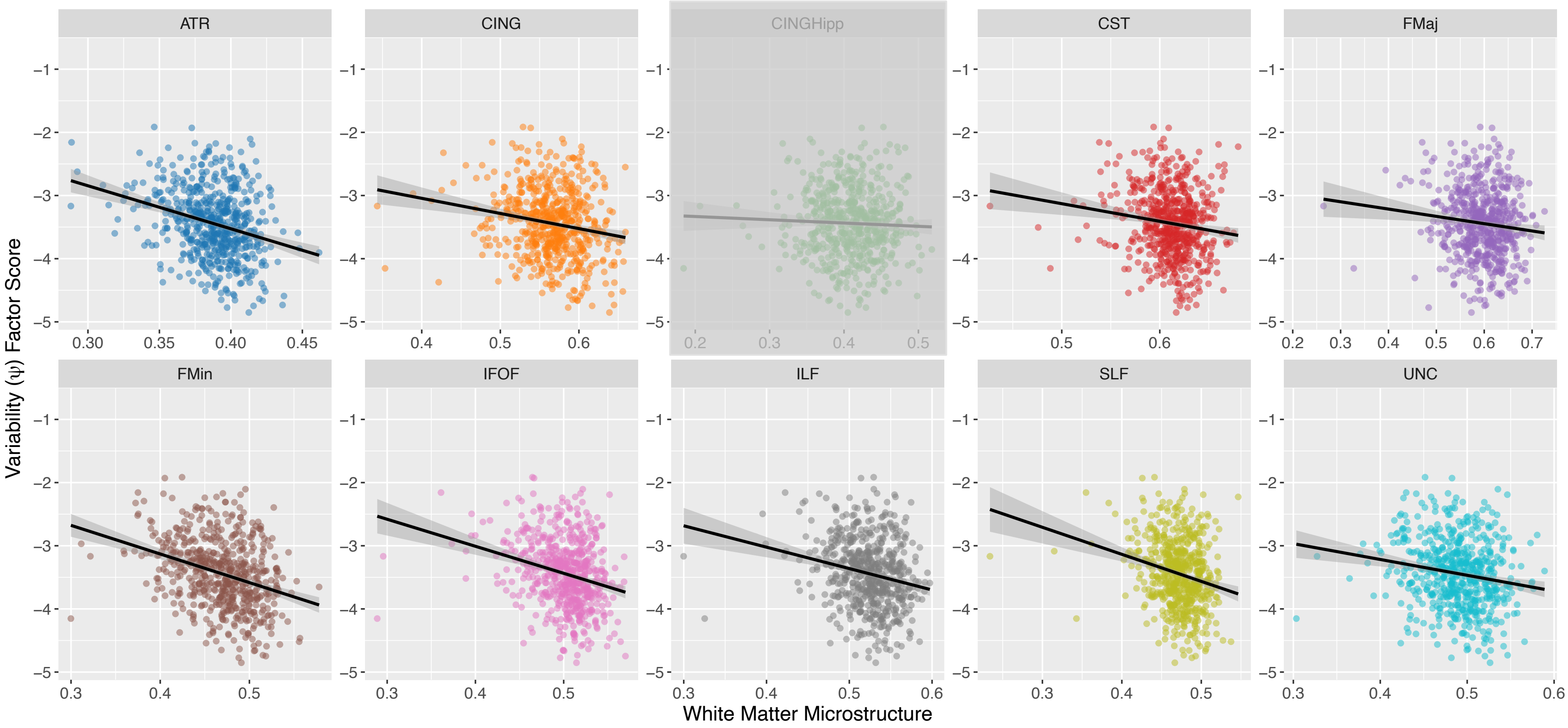
Current Work: Results

- In the conditional model, advanced age and reduced WM predicted poorer performance



Current Work: Results

- Poorer WM integrity predicted increased variability



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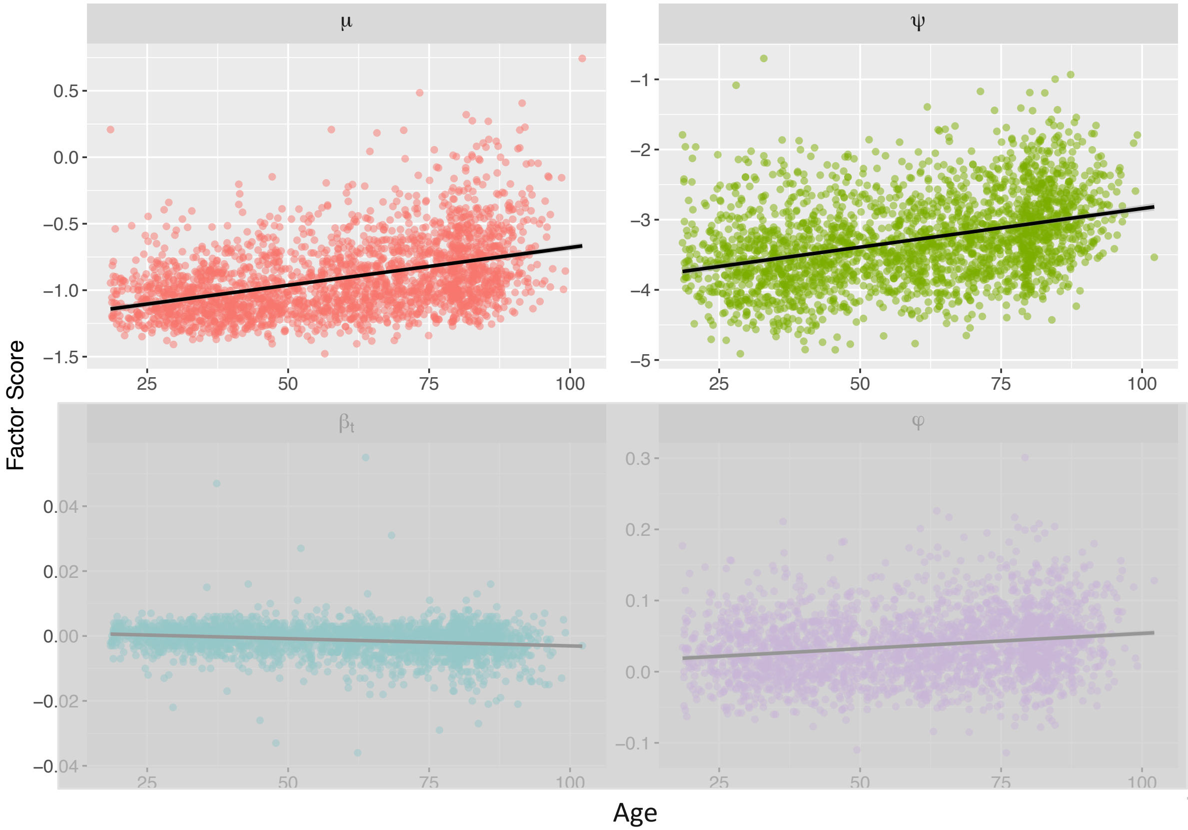

Current Work: Conclusions

- Found broad support for a neural noise hypothesis of behavioral variability
  - Lower WM tract FA predicted slower and more variable performance
  - WM effects held controlling for age

- Were able to model both mean and variance simultaneously without convergence issues despite relatively high correlation
  - Additional information from modeling the trend and autoregression terms
  - Provides an exciting tool for future investigations of individual differences

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