Idiographic, Cross-task Architectural Parameter Variation as Compu-Cognomic Data

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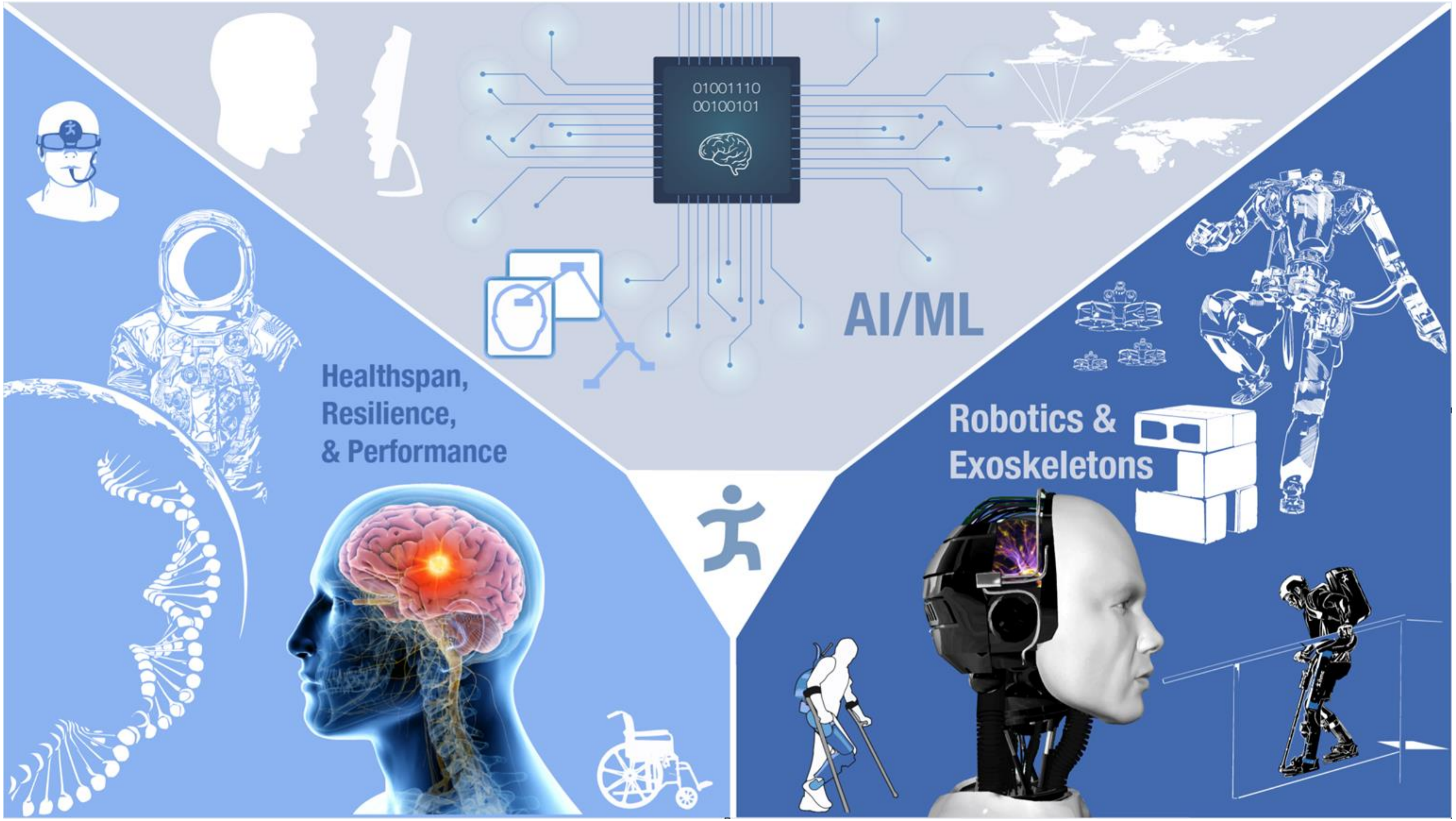
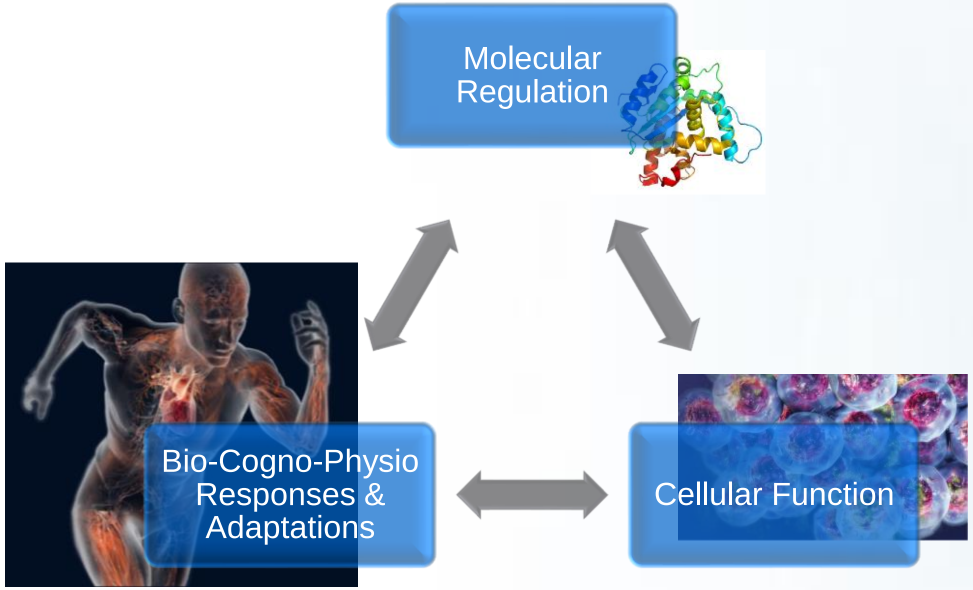
Presentation at ACT-R Workshop 23 July 2024

Human-Centered Science and Technology

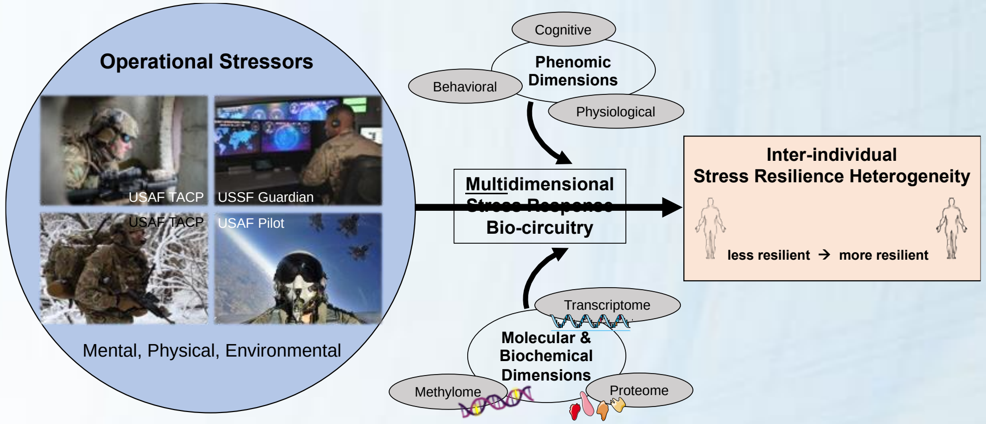


Healthspan, Resilience & Performance



Understanding HRP from ***molecule*** *to* ***whole human***

SENSE



AUGMENT

ASSESS

Biospecimen and Performance Data Sources

Project	Study Identifier (Acronym)	Cohort	Stressors	Stress Duration
ROPER (Retrospective Studies)	**NCT02057094** (SERE)	N = 71 all males	MARSOC SERE school: mental, physical, environmental	18 days
	NCT02731066 (HIGH)	N = 23 all males	Simulated SUSOPS with energy deficit at sustained high altitude: mental, physical, environmental	21 days
	NCT02734238 (OPS)	N = 50 all males	Sea level training with energy deficit: mental, physical	28 days
	NCT04120363 (OPS II)	N = 32 all males	Simulated multi-stressor SUSOPS: mental, physical	21 days
	PEERLESS (TACP TOPT)	N = 74 all males	TACP TOPT selection course: mental, physical, environmental	5 days
A2PEX (Studies in Progress)	**Sleep Deprivation** (Sleep Dep)	N* = 30	Sleep deprivation: mental, physical	27 hours
	Cognitive Fatigue (Cog Fatigue)	N* = 30	Cognitive fatigue: mental	14 hours
	Physical Fatigue (Phys Fatigue)	N* = 30 DoD-affiliated personnel	Physical fatigue: mental, physical	5 days

*N** - expected number of participants

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Suite of Cognitive Tasks in ROPER & A2PEX

		Procedural			Working Memory			Visual/Spatial		Reasoning/Decision Making				Multimodal/Multitasking			
	Study	**PVT/ SRT**	**PRO RT**	**Go/ No-Go**	**N-Back**	**Code-Digit Sub**	**Match to Sample**	**Scanning Visual Vigilance**	**Neuro-tracker/ VisTrack**	**Grammatical Reasoning**	**Math Processing**	**Balloon Analog Risk Task**	**Ultimatum Game**	**AF-MATB**	**CA2PES**	**VirTra**	**SP-VISTa**
ROPER	**SERE**	x								x							
	HIGH	x			x		x	x		x		x	x				
	OPS	x			x		x	x		x		x	x				
	OPS II	x			x		x	x				x	x				
	TOPT	x	x	x		x	x		x		x					x	
A2PEX	**Sleep Deprivation**	x		x	x				x		x			x	x		x
	Cognitive Fatigue	x		x	x				x		x			x	x		x
	Physical Fatigue	x		x	x												x

Unique Modeling Opportunities

- Idiographic, Cross-task Parameterization Variation
  - Many participants performing multiple tasks across multiple days while stressed
- Parameter Optimization methodology
  - Must develop efficient methods for exploration of very large parameter space
- ACT-R models as a source for the Compu-Cognome
  - Architectural parameterization provides a way to identify cognitive markers of resilience (or any phenotype of interest)

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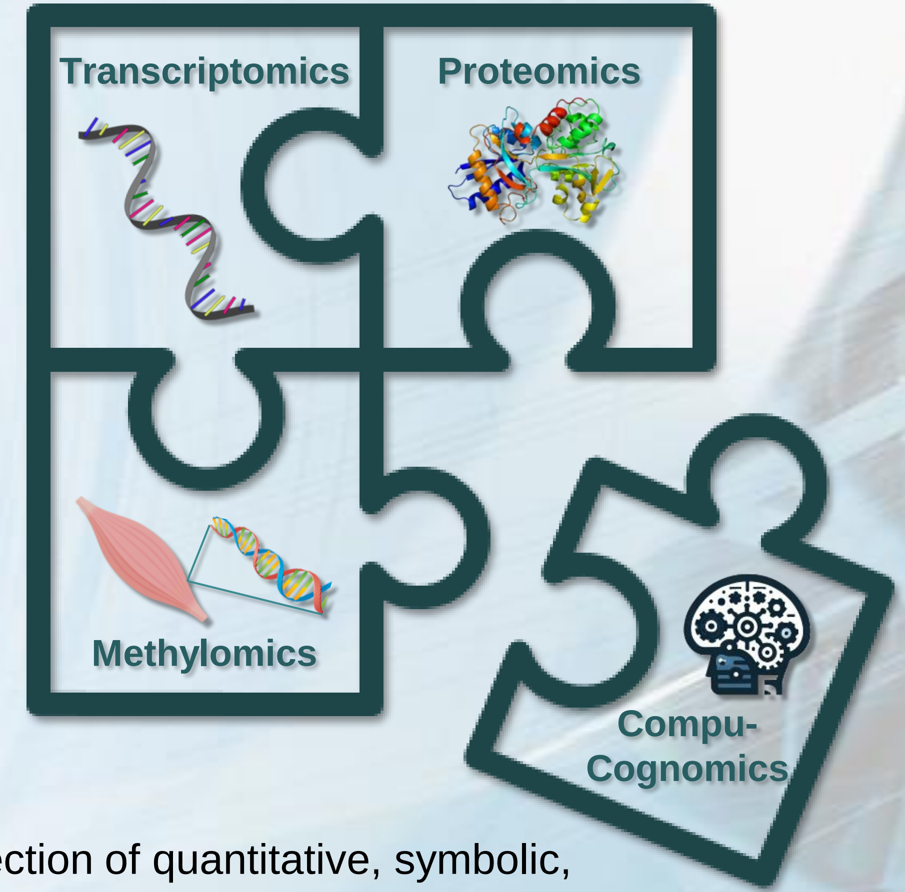
Compu-Cognomics as a Piece of the Multi-Omics Methodology

- The suffix –*ome* refers to a *totality* or *collective*
- Compu-Cognome serves as additional data sources for multi-omic analyses
- Unique scientific opportunity to build an analytical bridge from "molecules to minds"
  - From traditional multi-omic data to observable behavior (the phenome)
  - Through the explanatory mechanisms available in the Compu-Cognome of cognitive architectural theory



Compu-Cognome (*n*) – collection of quantitative, symbolic, and neurofunctional mechanisms that explain and predict variation in cognitive performance.

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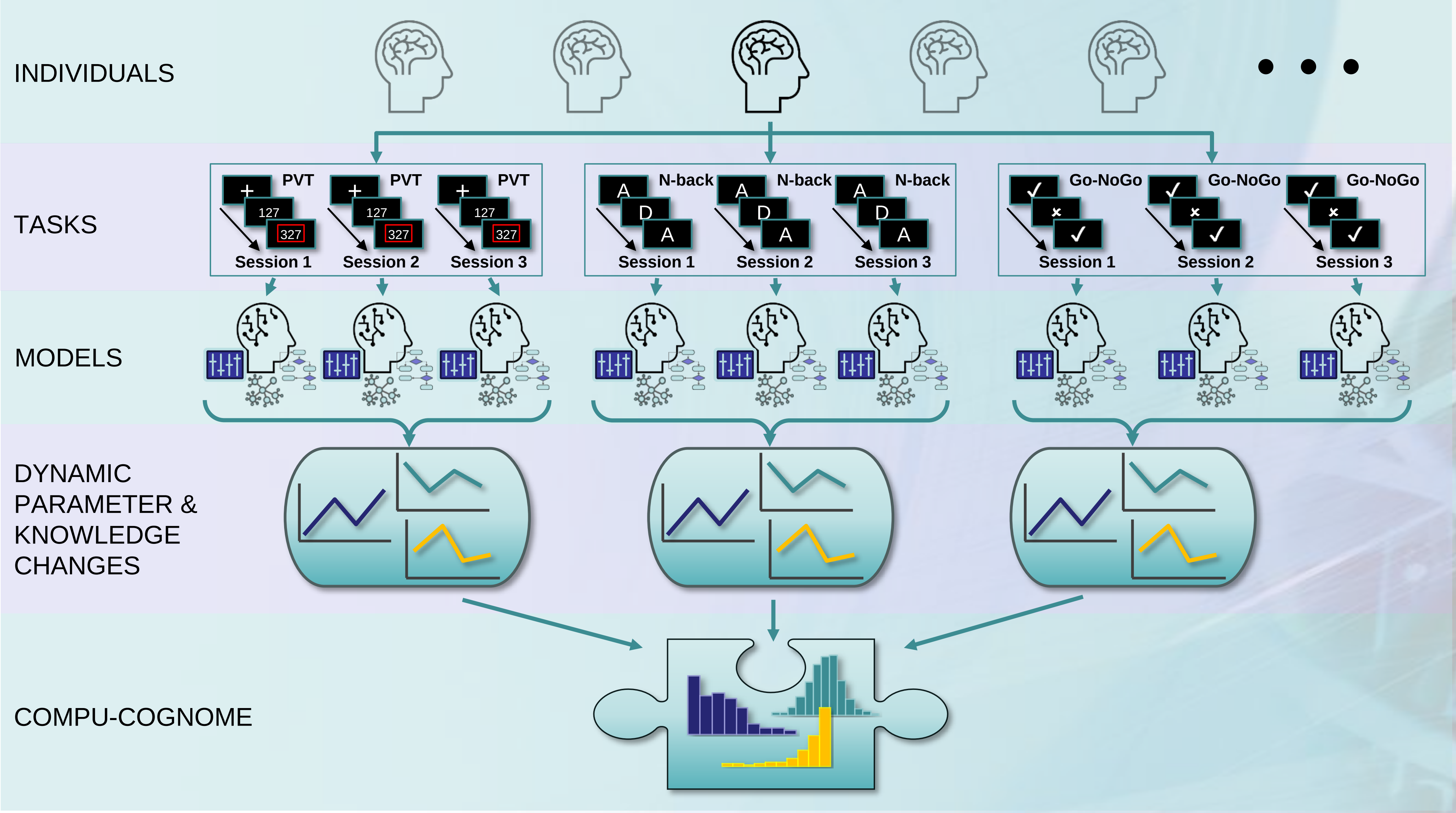
Constructing a Compu-Cognome



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Architectural Parameters Across Tasks (partial example)

- Unique opportunity in ROPER/A2PEX to gain a better understanding of the space of architectural parameters and their relationship to performance across a range of tasks

Mechanism	Parameter	Meaning	TASKS (example subset)		
			PVT	N-Back	Go/No-Go
Declarative Memory	:ans	activation noise (s)		x	
	:bll	activation decay (d)		x	
	:mp	mismatch penalty (similarity weighting; P)		x	
	:lf	latency factor (retrieval time; F)		x	
Procedural Memory	:dat	default action time (cognitive cycle time)	x	x	x
	:egs	expected gain noise added to utility	x	x	x
	:ut	utility threshold	x	x	x
	:iu	initial utility value	x	x	x
	:p	production value (cost)			x
	:ppm	production partial matching	x		
Goal/Intention	:g	goal value (cost)			x
	:ga	spreading activation value from goal buffer		x	
	:imaginal-activation	spreading activation value from imaginal buffer		x	
Fatigue	:utmc	utility threshold minute constant	x	x	x
	:utbmc	utility threshold biomath model constant	x	x	x
	:fpdec	fatigue procedural decrement	x	x	x
	:fpmc	fatigue procedural minute constant	x	x	x
	:fpbmc	fatigue procedural biomath model constant	x	x	x

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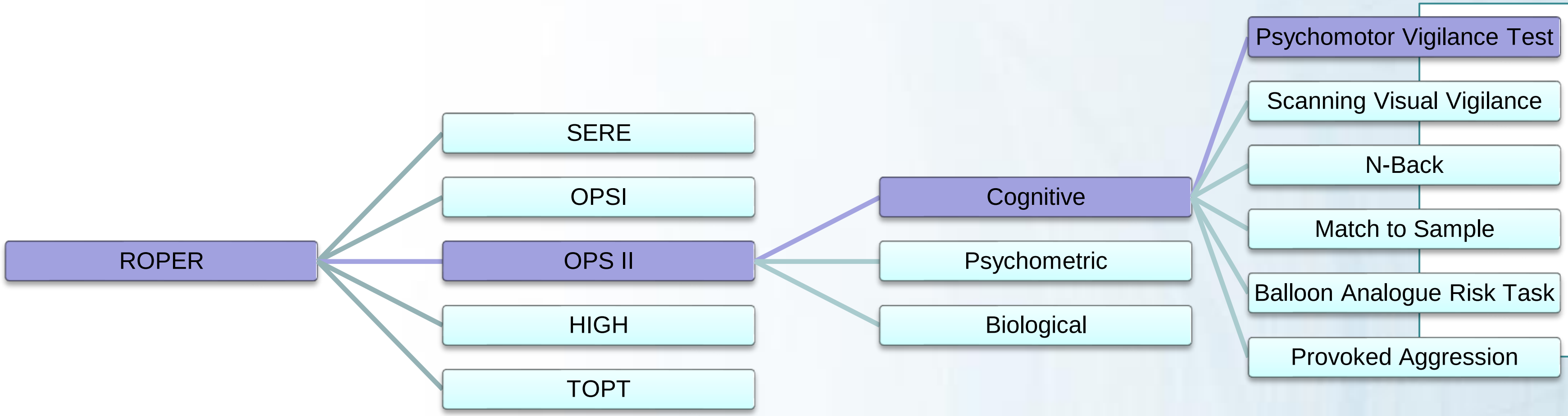
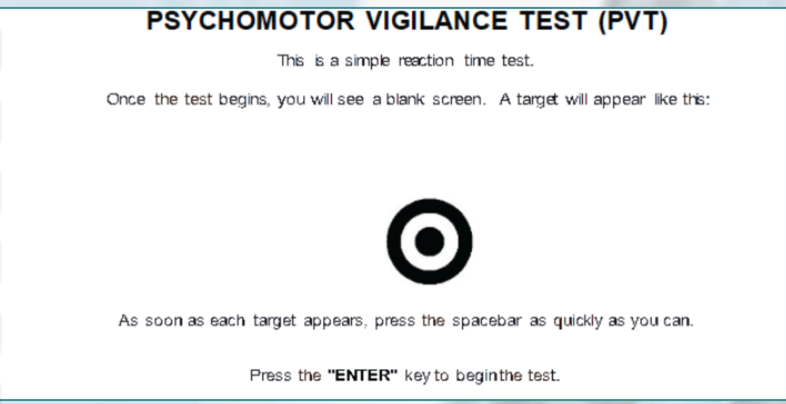
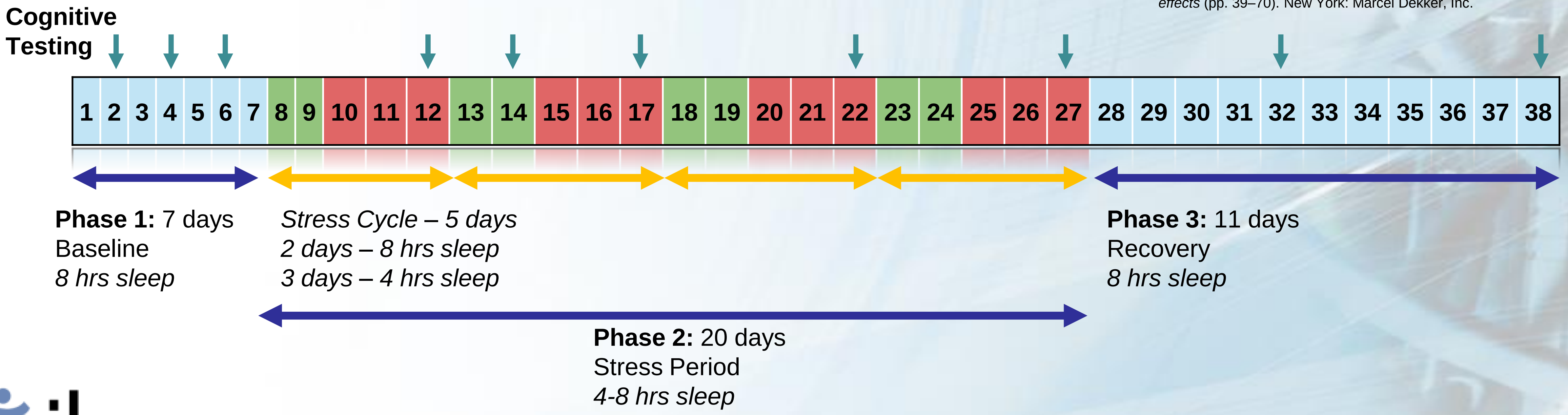
OPS-II PVT – Preliminary Analyses





Dorrian, J., Rogers, N. L., & Dinges, D. F. (2005). Psychomotor vigilance performance: Neurocognitive assay sensitive to sleep loss. In C. A. Kushida (Ed.), *Sleep deprivation: Clinical issues, pharmacology and sleep loss effects* (pp. 39–70). New York: Marcel Dekker, Inc.



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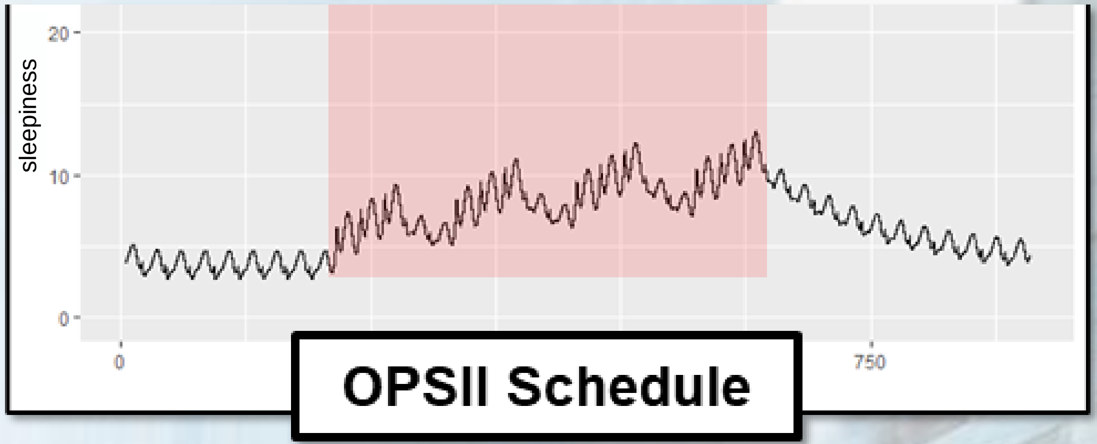
PVT Model & Fatigue Module

- PVT Model
  - 3 Production Rules
    - **Wait** – explicitly waits during the delay
    - **Attend** – shifts attention to the stimulus
    - **Respond** – executes a key press once the stimulus has been attended
- Fatigue Module
  - Introduces *microlapses* – requires rescheduling of conflict resolution
  - Utility and Utility Threshold attenuated by biomathematical model of alertness[1] based on given sleep schedule

$$FP = :fp\text{–}percent * (1 - :fpbmc * biomath\text{–}prediction) * (1 + time\text{–}on\text{–}task)^{:fpmc}$$

$$Utility = alertUtility * FP$$

$$UT = :ut * (1 - :utbmc * biomath\text{–}prediction) * (1 + time\text{–}on\text{–}task)^{:utmc}$$



Gunzelmann et al. (2009) model accounted very well for sleep deprivation effects on PVT performance.[2]

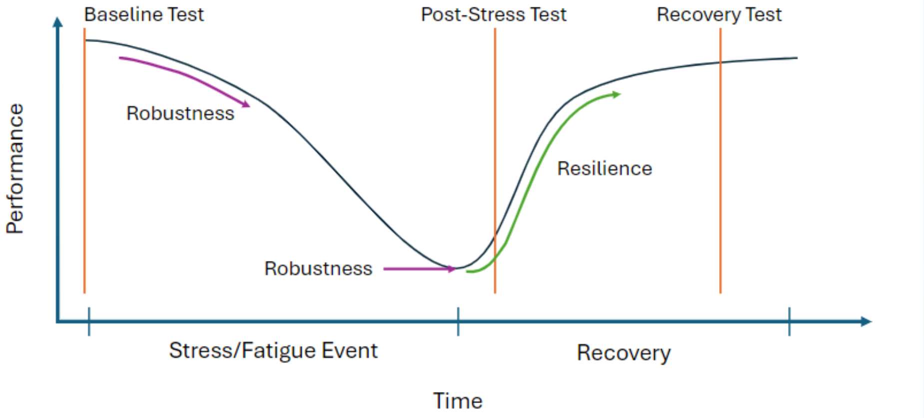
PVT and Fatigue Module Acknowledgements:
Glenn Gunzelmann, Rick Moore, Tim Halverson, Bella Veksler, Kevin Gluck, Michael Krusmark, Taylor Curley, and Dan Bothell

[1]McCauley, P., Kalachev, L. V, Mollicone, D. J., Banks, S., Dinges, D. F., & Van Dongen, H. P. a. (2013). Dynamic circadian modulation in a biomathematical model for the effects of sleep and sleep loss on waking neurobehavioral performance. *Sleep*, 36(12), 1987–97.

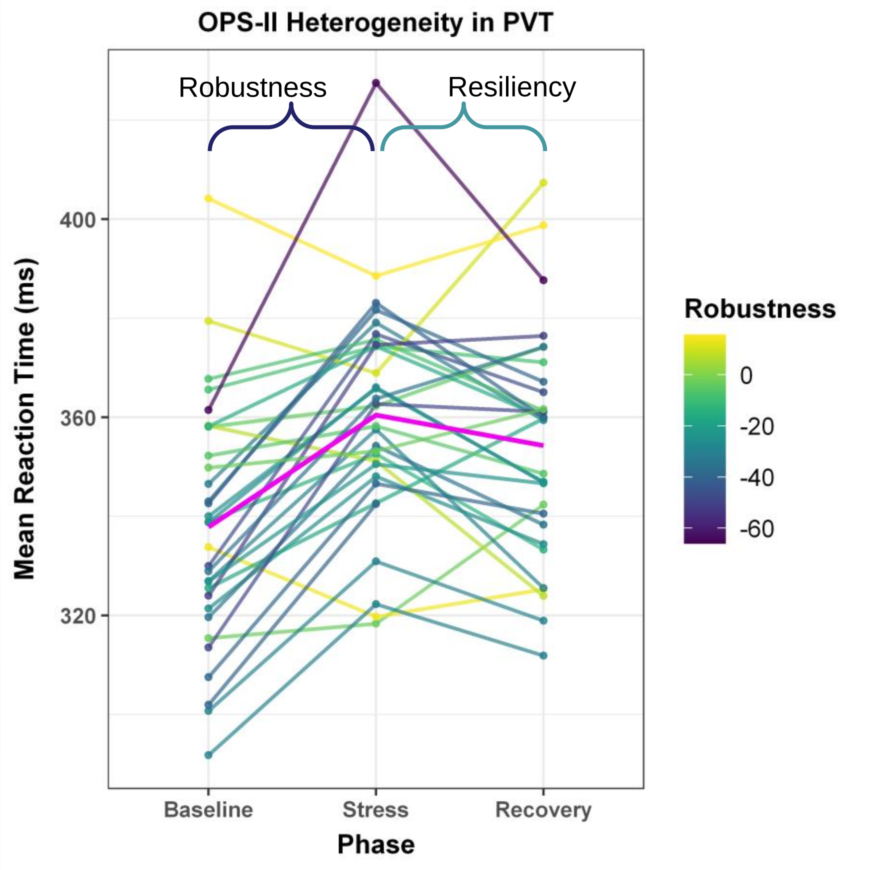
[2]Gunzelmann, G., Gross, J. B., Gluck, K. A., & Dinges, D. F. (2009). Sleep deprivation and sustained attention performance: Integrating mathematical and cognitive modeling. *Cognitive Science, 33*(5), 880-910.

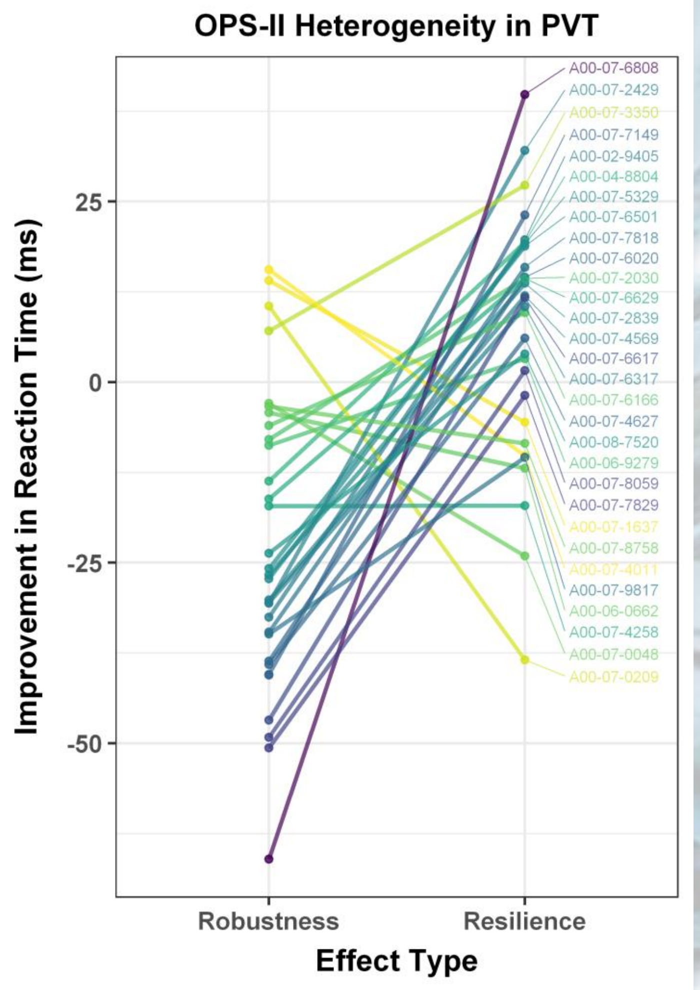
Heterogeneity in robustness and resilience to stress

- Avg performance degrades from Baseline to Stress and rebounds during Recovery
- Extreme heterogeneity at the individual level



- Robustness: ability to maintain performance level
- Resilience: ability to recover to baseline





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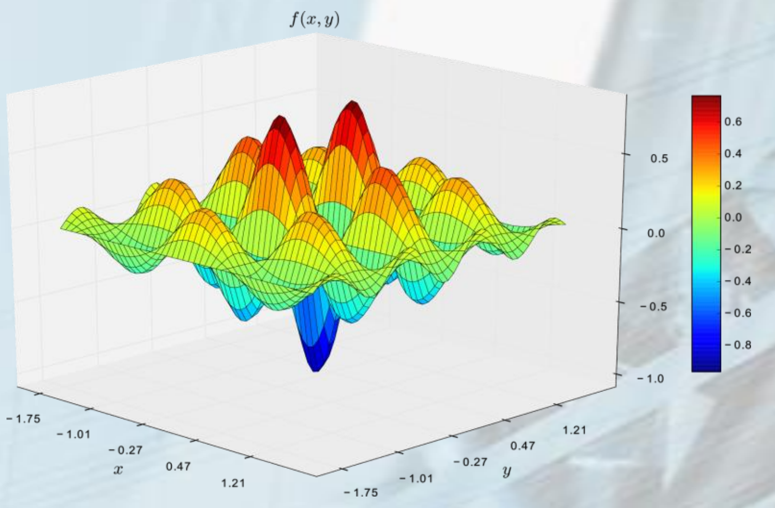
Parameter Optimization for Modeling Individual Performance Over Time

- Simulated Annealing
  - random search optimization method with systematic component for searching for the global optimum
    - Speed vs Completeness in search space
      - Escapes local minima (with enough iterations)
    - Handles complex parameter spaces well
    - optimSA package in R can only specify one objective function



- Objective Function
  - RMSE between distributions of RTs for Humans vs Model
  - Also explored squared Pearson Correlation Coefficient (r^2)

- Initial Param Opt with 4 Edge-case Participants
  - Very low temp and few iterations
    - only ~150 samples per participant (7hr to solution)

		Resilience	
		Best	Worst
Robustness	Best	A00-07-3350	A00-07-0209
	Worst	A00-07-2429	A00-07-7829

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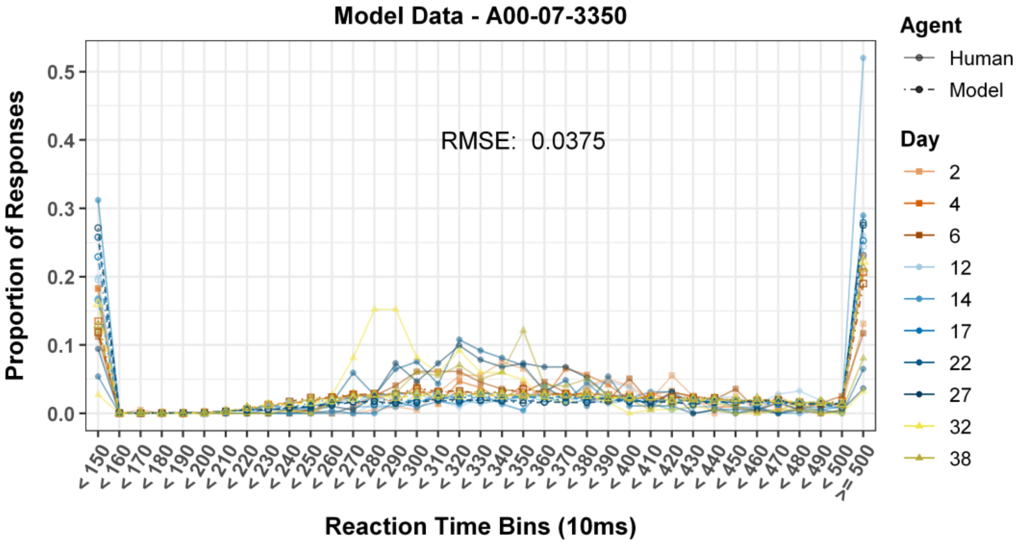
Identifying Parameters to Characterize Individuals

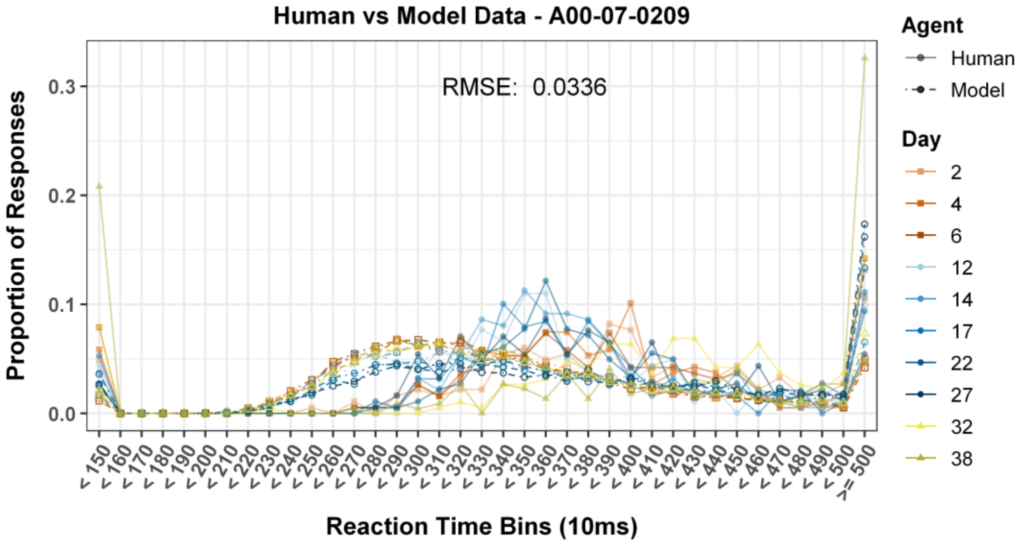
Best ← **Resilience** → **Worst**

Best ↑ **Robustness** ↓ **Worst**

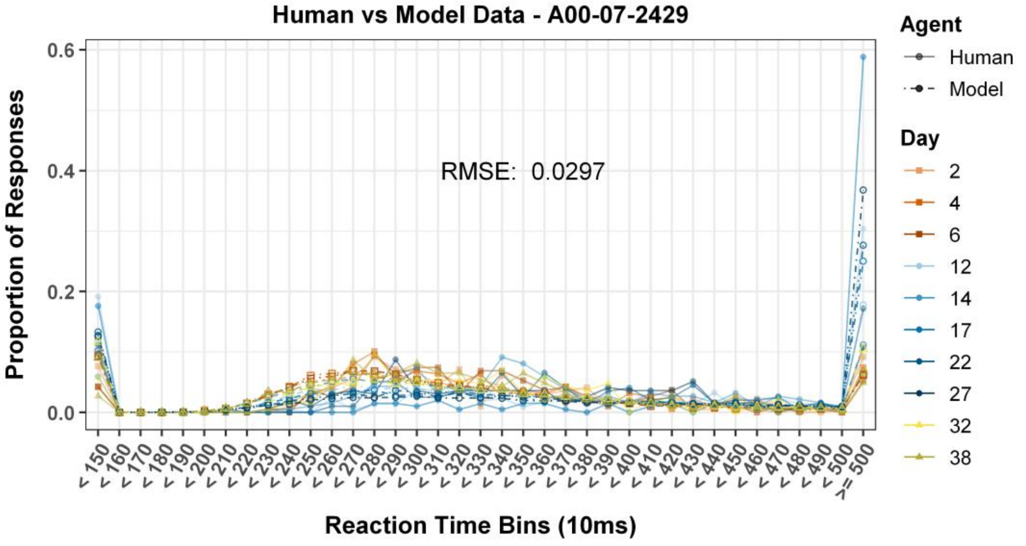
Param	Best Val
:dat	0.05
:egs	0.36
:ut	2.26
:iu	2.2
:utmc	0.0
:utbmc	0.02
:fpdec	1.0
:fpmc	-0.03
:fpbmc	0.03



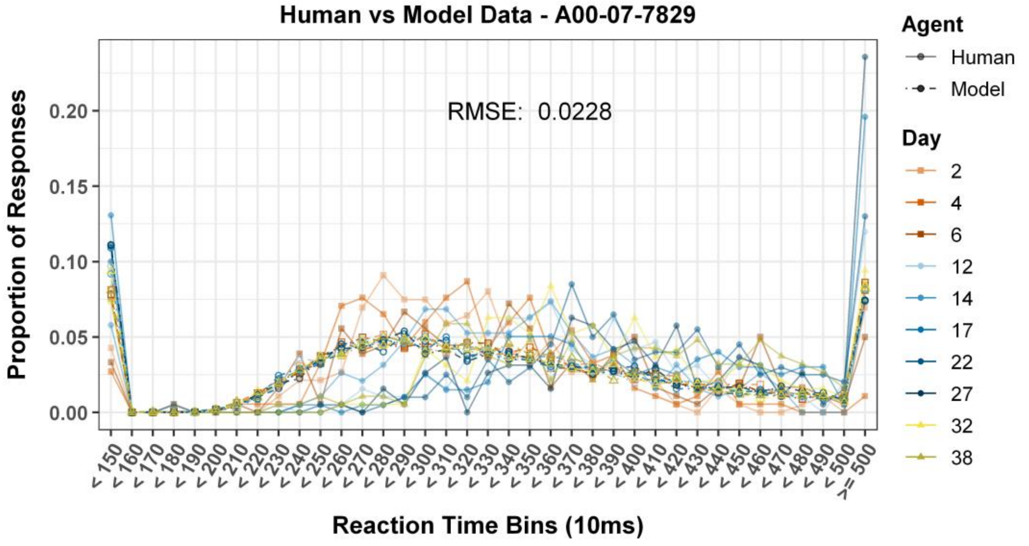
Param	Best Val
:dat	0.06
:egs	0.27
:ut	2.15
:iu	2.73
:utmc	-0.01
:utbmc	0.01
:fpdec	1.0
:fpmc	-0.07
:fpbmc	0.02



Param	Best Val
:dat	0.05
:egs	0.33
:ut	2.23
:iu	2.73
:utmc	-0.1
:utbmc	0.0
:fpdec	0.96
:fpmc	-0.1
:fpbmc	0.02



Param	Best Val
:dat	0.05
:egs	0.38
:ut	2.46
:iu	2.46
:utmc	0.0
:utbmc	0.01
:fpdec	1.0
:fpmc	-0.01
:fpbmc	0.01



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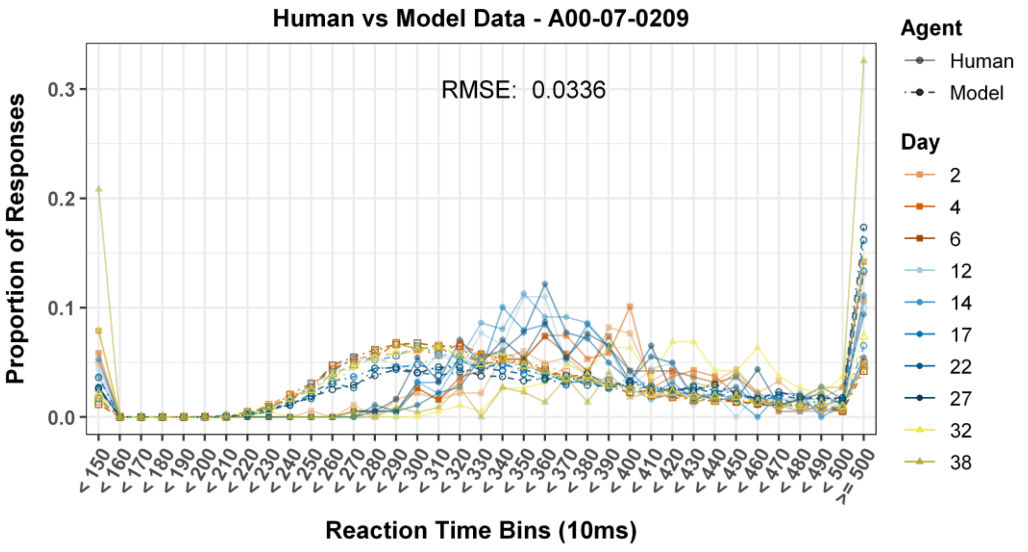
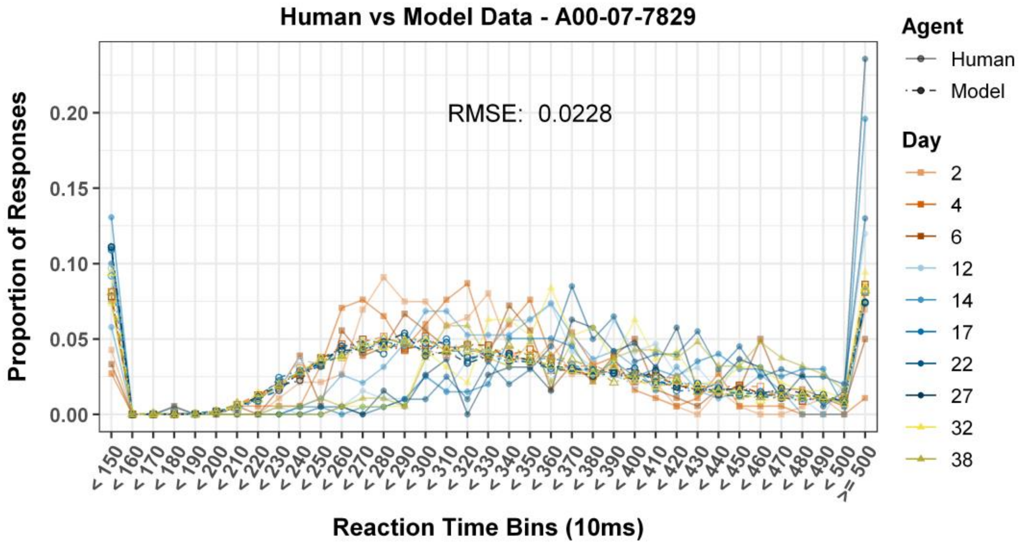
r^2 better at fitting longitudinal patterns

RMSE

Param	Best Val
:dat	0.06
:egs	0.27
:ut	2.15
:iu	2.73
:utmc	-0.01
:utbmc	0.01
:fpdec	1.0
:fpmc	-0.07
:fpbmc	0.02

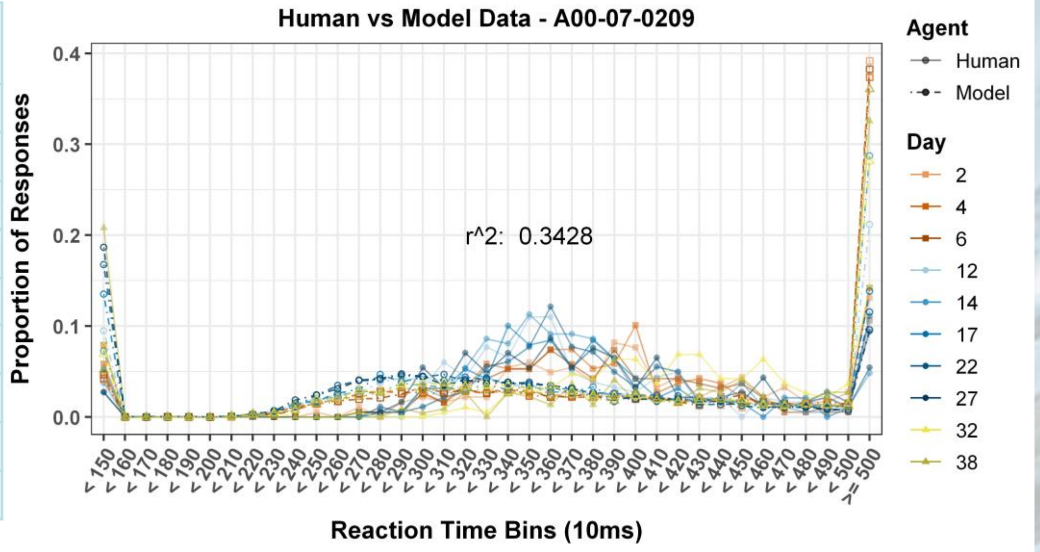


Param	Best Val
:dat	0.05
:egs	0.38
:ut	2.46
:iu	2.46
:utmc	0.0
:utbmc	0.01
:fpdec	1.0
:fpmc	-0.01
:fpbmc	0.01

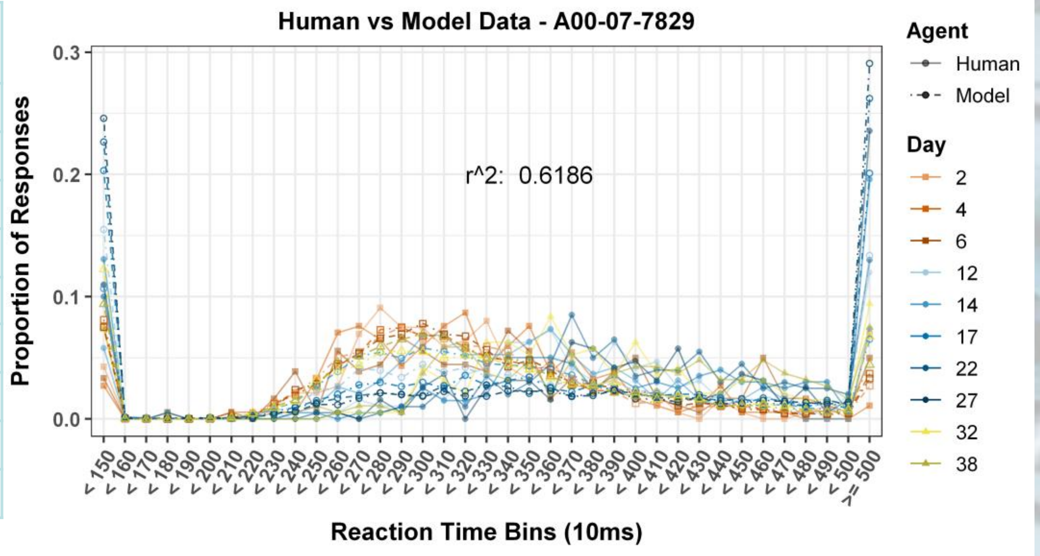


r^2

Param	Best Val
:dat	0.06
:egs	0.26
:ut	2.03
:iu	**2.02**
:utmc	-0.01
:utbmc	**0.03**
:fpdec	**0.97**
:fpmc	-0.07
:fpbmc	0.02



Param	Best Val
:dat	0.06
:egs	0.36
:ut	2.27
:iu	**2.94**
:utmc	**-0.02**
:utbmc	0.02
:fpdec	**0.97**
:fpmc	0.0
:fpbmc	**0.04**



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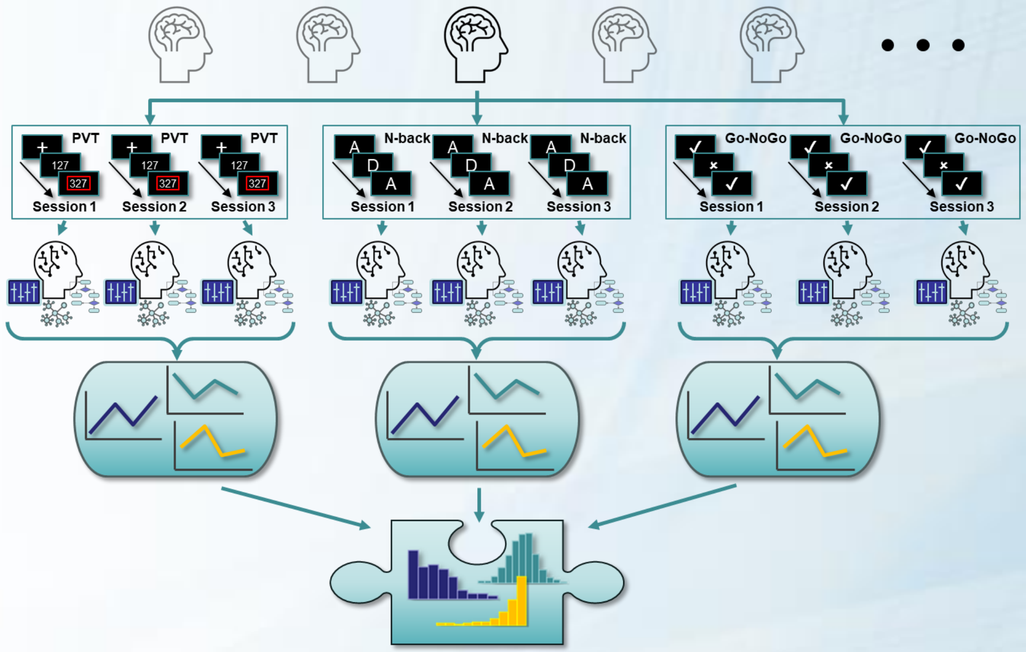
What's Next?

- Expand set of models
  - Acquired models of N-back and Go/No-Go. Can we find any more?
  - Will create our own models of other tasks.
- Scale up parameter optimization methods to model individual heterogeneity in stress response
  - Multiple studies X many participants X multiple tasks X multiple days



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Modeling Approach Considerations

- Modeling individual tasks separately does not inherently account for intra-individual architectural constraints
  - Theoretically, same architectural parameters for explaining performance in one task should also explain performance in another task
- Modeling multiple tasks performed by the same model is desirable
  - Cognitive Supermodels[1] (Salvucci, ACT-R Workshop 2010)
  - Primitive Operations[2] (Taatgen, ACT-R Workshop 2017)

[1]Salvucci D. D. (2013). Integration and reuse in cognitive skill acquisition. Cognitive science, 37(5), 829–860. https://doi.org/10.1111/cogs.12032
[2]Taatgen, N. A. (2013). The nature and transfer of cognitive skills. Psychological Review, 120(3), 439–471.

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Decisions for Scaling up Parameter Optimization

- Programming language:
  - R – fits within current data pipeline, many parameter optimization packages available
  - Python – newer and more advanced parameter optimization packages available
  - LISP – fits current modeling language; potentially computationally faster; need to code our own algorithm = more overhead
- Optimization Method:
  - Multitude of possibilities to choose from! (brute-force; random; SA; Genetic; Bayesian; etc.)
  - Important needs:
    - Computational efficiency
    - Parallelization (may need high performance computing center/cluster)
    - Systematic search
    - Multiple Objective Functions?
- Objective Functions:
  - RMSE/D – Root Mean Squared Error/Deviation
  - r^2 – squared Pearson correlation coefficient
  - R^2 – Coefficient of Determination
  - Maximum Likelihood Estimation (Stocco et al., *in prep*; Fisher, Houpt, & Gunzelmann, 2022)
  - Multiple Objective Functions?
- Data interpolation could help reduce model run time (Moore & Gunzelmann, 2014)

Stocco, A., Mitsopoulos, K., Yang, Y. C., Hake, H. S., Haile, T., Leonard, B., & Gluck, K. (*in prep*). Fitting, Evaluating, and Comparing Cognitive Architecture Models Using Likelihood Measures: A Tutorial With Examples in ACT-R.

Fisher, C. R., Houpt, J. W., & Gunzelmann, G. (2022). Fundamental tools for developing likelihood functions within ACT-R. *Journal of mathematical Psychology, 107*, 1-17.

Moore, R. L. & Gunzelmann, G. (2014). An interpolation approach for fitting computationally intensive models. *Cognitive Systems Research*, 29-30, 53-65.

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Acknowledgments

AIR FORCE RESEARCH LABORATORY

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AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

PENNINGTON BIOMEDICAL RESEARCH CENTER
LSU

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U.S. Army Research Institute of Environmental Medicine

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Thank You!

Questions?

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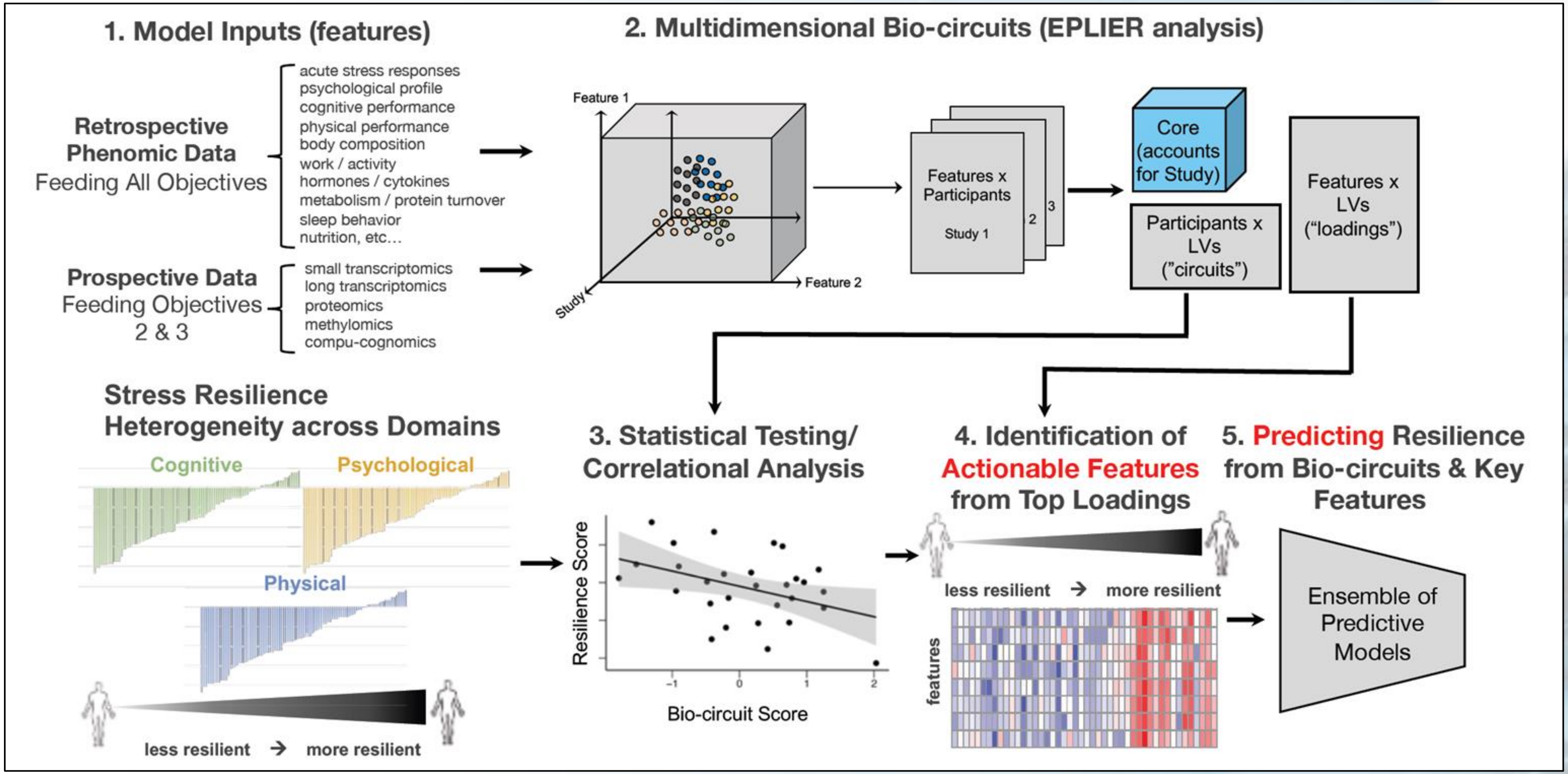
BACKUP

Resilience to Optimize PERformance (ROPER)

What are the fundamental bases of stress response heterogeneity?



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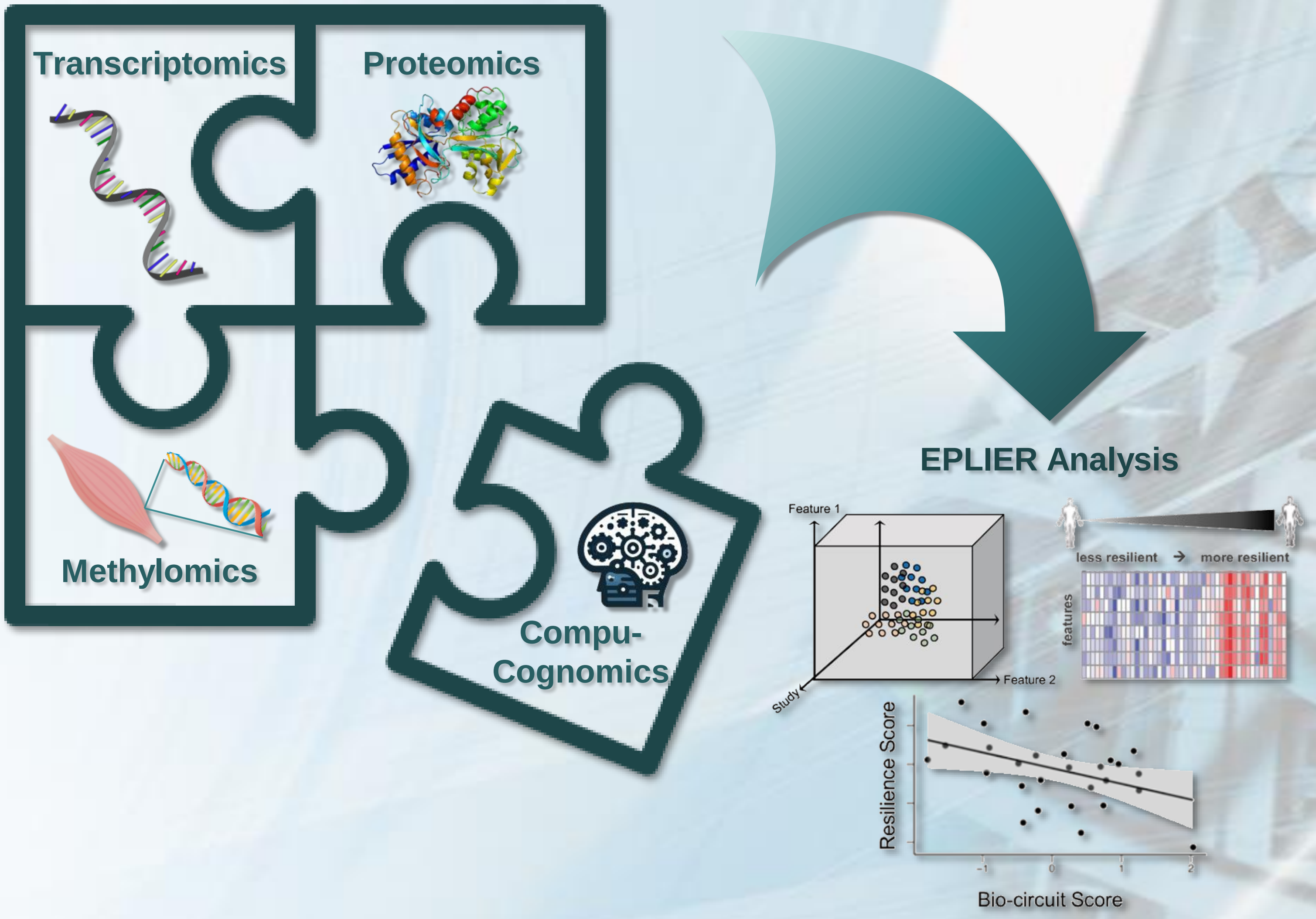

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Research that makes a difference...

that makes a difference