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

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Human-Centered Science and Technology

Healthspan, Resilience, & Performance

AI/ML

Robotics & Exoskeletons
Healthspan, Resilience & Performance

Molecular Regulation

Bio-Cogno-Physio Responses & Adaptations

Cellular Function

Improving HRP under stress & in extreme environments

Understanding HRP from molecule to whole human
Operational Stressors
Mental, Physical, Environmental

Multidimensional disease response
Bio-circuitry

Inter-individual Stress Resilience Heterogeneity

less resilient → more resilient

SENSE

ASSESS

AUGMENT
## Biospecimen and Performance Data Sources

<table>
<thead>
<tr>
<th>Project</th>
<th>Study Identifier (Acronym)</th>
<th>Cohort</th>
<th>Stressors</th>
<th>Stress Duration</th>
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</thead>
<tbody>
<tr>
<td><strong>ROPER</strong> (Retrospective Studies)</td>
<td>NCT02057094 (SERE)</td>
<td>N = 71 all males</td>
<td>MARSOC SERE school: mental, physical, environmental</td>
<td>18 days</td>
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<tr>
<td></td>
<td>NCT02731066 (HIGH)</td>
<td>N = 23 all males</td>
<td>Simulated SUSOPS with energy deficit at sustained high altitude: mental, physical, environmental</td>
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<tr>
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<td>NCT04120363 (OPS II)</td>
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<td>Simulated multi-stressor SUSOPS: mental, physical</td>
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<tr>
<td></td>
<td>PEERLESS (TACP TOPT)</td>
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<td>TACP TOPT selection course: mental, physical, environmental</td>
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<tr>
<td><strong>A2PEX</strong> (Studies in Progress)</td>
<td>Sleep Deprivation (Sleep Dep)</td>
<td>N* = 30</td>
<td>Sleep deprivation: mental, physical</td>
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<td></td>
<td>Cognitive Fatigue (Cog Fatigue)</td>
<td>N* = 30</td>
<td>Cognitive fatigue: mental</td>
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<tr>
<td></td>
<td>Physical Fatigue (Phys Fatigue)</td>
<td>N* = 30</td>
<td>DoD-affiliated personnel Physical fatigue: mental, physical</td>
<td>5 days</td>
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</tbody>
</table>

N* - expected number of participants
## Suite of Cognitive Tasks in ROPER & A2PEX

<table>
<thead>
<tr>
<th>Study</th>
<th>Procedural</th>
<th>Working Memory</th>
<th>Visual/Spatial</th>
<th>Reasoning/Decision Making</th>
<th>Multimodal/Multitasking</th>
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<tbody>
<tr>
<td><strong>ROPER</strong></td>
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<td>SERE</td>
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<td>Physical Fatigue</td>
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### Procedural Tasks
- PVT/SRT
- PRO RT
- Go/No-Go

### Working Memory Tasks
- N-Back
- Code-Digit Sub
- Match to Sample

### Visual/Spatial Tasks
- Scanning
- Visual Vigilance
- Neurotracker/VisTrack

### Reasoning/Decision Making Tasks
- Grammatical Reasoning
- Math Processing
- Balloon Analog Risk Task
- Ultimatum Game

### Multimodal/Multitasking Tasks
- AF-MATB
- CA2PES
- VirTra
- SP-VISTA
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)
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.
Constructing a Compu-Cognome

**INDIVIDUALS**

**TASKS**
- PVT
- N-back
- Go-NoGo

**MODELS**

**DYNAMIC PARAMETER & KNOWLEDGE CHANGES**

**COMPU-COGNOME**
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 |
<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Declarative Memory</strong></td>
<td>:ans activation noise (s)</td>
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<td></td>
<td>:bl activation decay (d)</td>
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<td></td>
<td>:mp mismatch penalty (similarity weighting; P)</td>
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<td>:lf latency factor (retrieval time; F)</td>
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<tr>
<td><strong>Procedural Memory</strong></td>
<td>:dat default action time (cognitive cycle time)</td>
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<td>:egs expected gain noise added to utility</td>
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<td>:ut utility threshold</td>
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<td>:iu initial utility value</td>
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<td></td>
<td>:p production value (cost)</td>
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<td>:ppm production partial matching</td>
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<tr>
<td><strong>Goal/Intention</strong></td>
<td>:g goal value (cost)</td>
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<td></td>
<td>:ga spreading activation value from goal buffer</td>
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<tr>
<td></td>
<td>:imaginal-activation spreading activation value from imaginal buffer</td>
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<tr>
<td><strong>Fatigue</strong></td>
<td>:utmc utility threshold minute constant</td>
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<tr>
<td></td>
<td>:utbmc utility threshold biomath model constant</td>
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<td></td>
<td>:fpdec fatigue procedural decrement</td>
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<td>:fpmc fatigue procedural minute constant</td>
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<td>:fbmc fatigue procedural biomath model constant</td>
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<table>
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<th>TASKS (example subset)</th>
<th>PVT</th>
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<th>Go/No-Go</th>
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OPS-II PVT – Preliminary Analyses

**Phase 1:** 7 days
- Baseline
- 8 hrs sleep

**Phase 2:** Stress Cycle – 5 days
- 2 days – 8 hrs sleep
- 3 days – 4 hrs sleep

**Phase 3:** 11 days
- Recovery
- 8 hrs sleep

**Psychomotor Vigilance Test (PVT)**

- Once the test begins, you will see a blank screen. A target will appear like this:
- As soon as each target appears, press the spacebar as quickly as you can.
- Press the "ENTER" key to begin the test.

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

\[
FP = \text{:fp–percent} \times (1 - \text{fp\_bmc} \times \text{biomath–prediction}) \times (1 + \text{time–on–task}) \times \text{fp\_mc} \\
\]

\[
\text{Utility} = \text{alert\_utility} \times FP \\
\text{UT} = \text{:ut} \times (1 - \text{ut\_bmc} \times \text{biomath–prediction}) \times (1 + \text{time–on–task}) \times \text{ut\_mc} \\
\]

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 Curiley, and Dan Bothell


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
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)

<table>
<thead>
<tr>
<th>Robustness</th>
<th>Best</th>
<th>Worst</th>
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<td>Worst</td>
<td>A00-07-2429</td>
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Identifying Parameters to Characterize Individuals

<table>
<thead>
<tr>
<th>Param</th>
<th>Best Val</th>
<th>Resilience</th>
<th>Best Val</th>
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<th>Best Val</th>
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Model Data - A00-07-3350

Human vs Model Data - A00-07-2429

RMSE: 0.0375

RMSE: 0.0297

Human vs Model Data - A00-07-2009

Human vs Model Data - A00-07-7829

RMSE: 0.0336

RMSE: 0.0228

Reaction Time Bins (10ms)
**r²** better at fitting longitudinal patterns

**RMSE**

<table>
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<th>Best Val</th>
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**r²**

<table>
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**Human vs Model Data - A00-07-0209**

**Human vs Model Data - A00-07-0209**

**Human vs Model Data - A00-07-7829**

**Human vs Model Data - A00-07-7829**
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

...
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*)

---


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)**

---


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  – Architectural parameterization provides a way to identify cognitive markers of resilience (or any phenotype of interest)
Acknowledgments
Thank You!

Questions?

Contact: ecranford@ihmc.org
BACKUP
Resilience to Optimize PERformance (ROPER)

What are the fundamental bases of stress response heterogeneity?
Compu-Cognomics as a Piece of the Multi-Omics Methodology

- Compu-Cognome serves as additional data sources for multi-omic analyses
- Unique scientific opportunity to build an analytical bridge from “molecules to minds”
  - Phenomic and multiomic data to observable behavior
  - Through the explanatory mechanisms available in the Compu-Cognome of cognitive architectural theory

Transcriptomics  Proteomics

Methyonomics

Compu-Cognomics

EPLIER Analysis
Research that makes a difference... 

*that makes a difference*