Structured Reconfiguration of Human Performance Under Workload: Evidence for Heterogeneous Degradation Mechanisms

Yuehai Yu[1], Megan Sax van der Weyden[2], Mohammad Fili[1], Lizhi Wang[3], Craig Yu[1], Guiping Hu[1], Joel Martin[2], Sherry Wang

[1] Department of Systems Engineering and Operations Research, George Mason University, Fairfax, VA, USA
[2] Sports Medicine Assessment, Research & Testing (SMART) Laboratory, George Mason University, Fairfax, VA, USA
[3] Department of Computer Science, George Mason University, Fairfax, VA, USA

Introduction

Operational workload can affect thinking and physical performance in different ways. Slower responses or missed signals may appear before a large decline is visible in average performance.

Purpose

Determine whether prolonged workload causes one overall decline or different changes in thinking, physical output, and body responses.

Materials & Methods

- 12 participants (9 men, 3 women; age 31.3 ± 10.1 years) completed march-only (STP), thinking-task-only (STC), and combined loaded-march plus thinking-task (DT) conditions.
- STP and DT included a 60-minute loaded march at 4.8 km/h with a 30-kg rucksack; DT added Friend-or-Foe target detection.
- Response speed, working memory, jump performance, body-response measures, and perceived workload were recorded before, midway, and after each condition.
- Mixed-effects models compared conditions and stages. The 90th/95th percentiles, signal-detection measures, and correlations tested slow responses, missed signals, and body–performance links.

Results

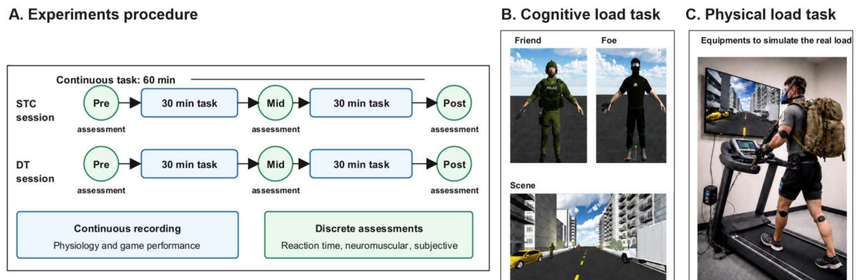
- DT produced more unusually slow responses than STC.
- At the end of DT, participants were less able to distinguish targets and were more likely to miss important signals.
- Jump height and power did not decline under DT; several measures increased relative to STC.
- Individuals followed different patterns, and links between body responses and performance depended on the task.

Conclusions

- **Thinking and response readiness can begin to decline while physical capability appears preserved.**
- **Monitoring should combine response speed, missed signals, physical performance, body-response measures, and each person's baseline.**

BLUF: When participants performed a cognitive task during a prolonged loaded march, they had more unusually slow responses and were more likely to miss important signals. At the same time, their physical performance did not decline and, in some cases, improved. A service member may therefore still appear physically capable while their ability to respond quickly and correctly is beginning to suffer.

Procedures



How We Tested the Question

1 Mixed-effects models

Compared each participant with themselves across the three conditions and three time points.

2 Response-time percentiles

The 90th and 95th percentiles represent the slowest 10% and 5% of responses, which averages can hide.

3 Signal-detection analysis

Measured Friend-or-Foe discrimination and response bias to explain why signals were missed.

4 Correlations by task and person

Tested whether body-response measures tracked performance differently across tasks and individuals.

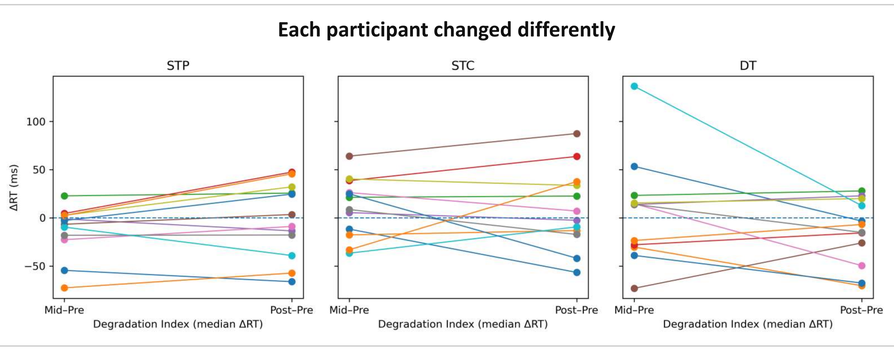
Effect Sizes at Session End

Standardized effect size (Cohen's dz): DT vs. STC

Response-time effects above zero = slower; discrimination/accuracy below zero = worse; jump effects above zero = greater output.

Results

Each participant changed differently



Mixed-effects model

Reaction time differed by condition (bootstrap p = 0.004).
Average accuracy changed little, so slower responses were the clearer warning sign.

Unusually slow responses

End of DT:
90th percentile = 681 ms
95th percentile = 715 ms
End of STC:
90th percentile = 598 ms

Target detection at session end

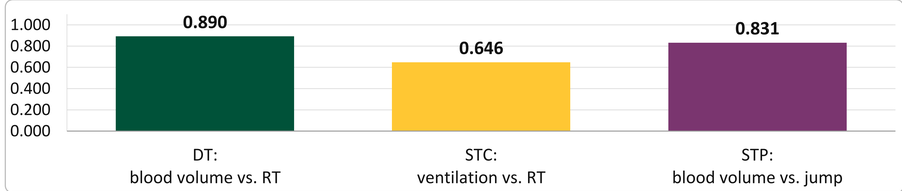
DT vs. STC:
Discrimination (d') = −0.594 (p = 0.030)
Missed-signal risk = +0.034 (p = 0.040)
Response bias did not differ

Physical output was preserved

DT vs. STC:
Working-memory response was 56.8 ms slower
Jump height increased 2.1 cm
Peak power increased 326.8 W
Jump rebound ability increased 0.023

Body Signals Meant Different Things in Different Tasks

Absolute Pearson correlation (|r|; 0 = none, 1 = strong)



All correlations were negative (p < 0.05); n = 10–11 per comparison. RT = reaction time.

The useful body signal depended on task and person; no single sensor worked for everyone.