Neuroergonomics

Analyzing Brain Function to Enhance Human Performance in Complex Systems

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Presented at the 26th Army Science Conference, Orlando, FL, December 2, 2008
### Neuroergonomics - Analyzing Brain Function to Enhance Human Performance in Complex Systems

#### Abstract

See also ADM002187, Proceedings of the Army Science Conference (26th) Held in Orlando, Florida on 1-4 December 2008, The original document contains color images.
Why Neuroergonomics?

- To design effective human-machine systems, we must
  - Understand mind in relation to work and technology—ergonomics
  - Mind cannot be understood without studying the brain—neuroscience
  - Hence study brain and mind in complex work domains—Neuroergonomics

- Neuroergonomics can provide for more effective and natural interaction between humans and technology

Oxford University Press, 2008
Two Examples of Neuroergonomics

• Neuroimaging and adaptive automation
  ➢ Enhancing performance of operators supervising multiple unmanned vehicles

• Molecular genetics and proteomics
  ➢ Identifying rapid decision makers in command and control
Example 1:
Neuroimaging and Adaptive Automation

Enhancing performance of operators supervising multiple unmanned vehicles
Robotic Evolution Overview*

Teleoperation will decrease

Robot autonomy will increase

Shared supervisory control will accelerate transition

* 2005 Joint Robotics Program Master Plan
Soldier-Robot Teaming

- Unmanned vehicles being introduced in Army systems to:
  - extend manned capabilities
  - provide tactical flexibility
  - act as “force multipliers”

- Goal: Enhance Soldier-system performance while optimizing workload

- Approach: Use **adaptive automation** to provide support to Soldier when and where needed
Adaptive Automation

An approach to automation in which the “division of labor” between human and machine is flexible and context-dependent.
Triggers for Adaptive Automation

• Critical events
• Mission phase
• Operator performance
• User modeling
• Operator neurocognitive states (attention, workload, situation awareness, fatigue etc.)

Simulation Integration Lab (SIL)

- Reconnaissance, Surveillance, and Target Acquisition (RSTA)
  - With and without Automatic Target Recognition (ATR) support
- Monitor UAV and UGV assets
- Secondary change detection task

Change Detection Task: Icon on Situation Map Moves
Testing the Efficacy of Adaptive Automation

- Manual: no support
- Static automation: Automatic Target Recognition (ATR) in middle of simulated reconnaissance mission
- Adaptive automation: Automatic Target Recognition (ATR) in middle of simulated mission
  - *if and only if* subject’s change detection performance up to that point in time is less than a threshold

![Diagram of manual, static, and adaptive automation](image-url)
Effects of Adaptive Automation on Situation Awareness (SA) and Workload

![Bar chart showing the effects of manual, static, and adaptive automation on SA and mental workload.](chart.png)
Attention Enhances the P1 and N1 Event-Related Brain Potential Components

ERPs and Attention

Brain Topography of Attention Effect

Fu, Greenwood, & Parasuraman (2005), Human Brain Mapping
Event-Related Brain Potentials (ERPs) to Attended and Unattended Probes

Change detection probe: Sine wave grating

Wavelet analysis

Attended Probe

Unattended Probe

ERP to Probe Event

C1

N1

P1

Time (milliseconds)
Effect of Adaptive Automation on the P1 Brain Potential Attention Effect

- **O_L Electrode Site**
- **O_R Electrode Site**

<table>
<thead>
<tr>
<th>Automation Condition</th>
<th>Manual</th>
<th>Static</th>
<th>Adaptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 Difference Wave (µV)</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Example 1: Conclusions

• Adaptive automation triggered by operator change detection performance enhances human performance in multiple UAV/UGV supervision—increased SA and reduced workload

• Brain measures of attention (P1 and N1 components of the ERP) provide converging neural evidence for the efficacy of adaptive automation

• A neuroergonomic approach to adaptive automation can lead to improved human-machine synergy

➢ Licklider’s (1960) vision of human-computer *symbiosis*?
Example 2:
Molecular Genetics and Proteomics

Identifying rapid decision makers in command and control
Identifying Sources of Individual Differences

• Individual differences reflect
  ➢ Development
  ➢ Experience
  ➢ Training
  ➢ Genetic factors (natural variation)

• Can molecular genetics help in understanding
  ➢ Normal variation in cognition?
  ➢ Exceptional individuals (“cognitive superstars”)?
Effects of Working Memory Load on Prefrontal Cortex Activation

Jiang, Haxby, Martin, Ungerleider, & Parasuraman (2000). Science
Prefrontal Cortex Activation and Working Memory Load

Can this broad range of individual differences at high load be explained?

Subject 7: The Odd Man Out
Genes, DNA, and SNPs

- Human genome: ~ 20-25,000 genes
  ~ 3 billion DNA base pairs (bp)

- The DNA alphabet
  - thymine (T)
  - adenine (A)
  - guanine (G)
  - cytosine (C)

- DNA base pairs can have different forms (alleles)

- Allelic variation often due to substitution of one amino acid for another—single nucleotide polymorphisms (SNPs)
  
  e.g. 
  ..........ACA\text{T}AGA.......... vs.
  ..........ACA\text{C}AGA.......... 

- 1 SNP for every 1000 bp in unrelated individuals
Candidate SNP Approach

Top-Down

Cognitive Function
Regional Brain Network
Neurophysiology of Brain Area
Neurotransmitter Innervation

Neurotransmitter Modulation
Protein Regulation
Neurotransmitter SNP
SNP
SNP Databases (e.g., http://www.ncbi.nlm.nih.gov/SNP/)

Bottom-Up
Gene SNPs Associated with Cognition

- Dopaminergic/Noradrenergic Genes
  - DRD 4
  - DAT 1
  - COMT
  - DBH
- Nicotinic Cholinergic Genes
  - CHRNA4
  - CHRNA7
- Muscarinic Cholinergic Genes
  - CHRM2
- Genes Affecting Neuron Health and Plasticity
  - BDNF
  - APOE-e4

Working Memory and Complex Decision Making

• Important moderating factor in many different cognitive functions—decision making, problem solving, language processing, mathematical cognition, etc.
• The dopamine beta hydroxylase (DBH) gene product converts dopamine to norepinephrine in the brain
• DBH modulation may be selective for prefrontal cortex dependent functions, such as working memory and executive function
• Do individuals with DBH gene variants
  ➢ Have high working memory capacity?
  ➢ Exhibit higher decision accuracy under time pressure?
The DBH Gene and its SNPs

-1021 C/T SNP

-1021 C/T SNP

CC
CT
TT

Genotypes

-1021 C/T SNP

Exonic regions. Width of boxes indicate length of exons (not to scale)

Untranslated region (part of an exon)

Intronic regions

5' → 3' Direction of gene transcription

"-" indicates that the SNP is 1021 bases upstream of the transcription start site (base + 1)

SNP is 444 bases downstream of the transcription start site (excluding intron length)
Working Memory Task

- **Fixation**: 1000 ms
- **1-3 Target locations**: 500 ms
- **Delay**: 3000 ms
- **Same or Different?**
- **Target**: 2000 ms
Effects of T Allele Dose of DBH -1021 C/T SN on Spatial Working Memory

Memory Load (Number of Target Dots)

Genotype

- CC
- CT
- TT

T Allele Dose

- 0
- 1
- 2
• What is the mechanism by which DBH is linked to working memory?
• Is DBH a “functional” SNP?
• Genes are only of interest if they are expressed and influence proteins, particularly in the brain
• Cognitive proteomics: linking gene-controlled proteins to function
Effects of DβH on Synaptic Dopamine (DA) and Norepinephrine (NE)

- A. High DβH Level: NE receptors active
- B. Low DβH Level: DA receptors active
Effects of T Allele Dose of DBH -1021 C/T SNP on Plasma Dopamine β Hydroxylase Levels

Low DβH level associated with high working memory
Decision Making in Command and Control

Decision making task performed both with and without automated support
DβH Enzyme Levels and Decision Time

95% reduction in decision time

Manual
Automation

High DβH enzyme activity
Low DβH enzyme activity
Subject 7: A “Cognitive Superstar”

- Has very high verbal and spatial working memory—4 standard deviations above average
- Can maintain attention at 100% accuracy for 2 hours
- Shows reduced prefrontal fMRI activation and no increase with load in a working memory task
- What are S7’s DBH genotypes?
- S7 has the T/T genotype in the -1021 C/T SNP associated with high working memory and low DβH enzyme level
- Has lowest blood DβH enzyme level among 650 subjects tested to date
What Else Do We Know About S7?

• Age 26, Male Graduate Student
• High-average but not superior IQ
• Good but not exceptional grades
• Normal MRI (volumetric analysis of specific cortical regions not done)
• NOT an avid video game player (cf. Daphne Bavalier studies on attentional capacity)
Example 2: Conclusions

- DBH—a dopaminergic/noradrenergic gene expressed strongly in prefrontal cortex—associated with normal individual differences in working memory (verbal and spatial)
- Plasma DβH levels inversely correlated with working memory and decision making performance
- Molecular genetics provides a new approach to understanding
  - individual differences in cognition
  - exceptional cognitive performance
Ongoing Research

• **Gene-gene interactions**
  - Effects of cholinergic (CHRNA4) and neurotrophic (Alzheimer risk) genes (APOE) on attention
  - Interactive effects of nicotinic (CHRNA4) and muscarinic (CHRM2) genes on attention

• **Gene-environment interactions**
  - Effects of COMT and DBH and variable-priority training on dual-task performance
  - Moderating influence of COMT and BDNF genes on effects of aerobic exercise on executive attention in older adults
Ongoing Research

- Spatial working memory in normal and DBH --1021T/C knockout mice
- RNA interference studies in rat model of aging (Fischer 344 strain, Bizon group)
Neuroergonomics: Conclusions

• Neuroscience is not a panacea to the challenges facing the Army
  ➢ but appropriately applied neuroscience
  ➢ that goes beyond the bench to examine complex cognitive functions of humans performing real work in real settings—Neuroergonomics
  ➢ can yield great benefits in enhancing soldier and system performance

• Two examples of successful neuroergonomics research
  ➢ Neuroimaging and adaptive automation
  ➢ Molecular genetics and proteomics

• Neuroergonomics can lead to more effective and natural interaction between humans and technology