Neuroergonomics

Analyzing Brain Function to Enhance Human Performance in Complex Systems

Raja Parasuraman
George Mason University

Presented at the 26th Army Science Conference, Orlando, FL, December 2, 2008

Arch Lab GEORGE MASON UNIVERSITY

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **DEC 2008**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Neuroergonomics - Analyzing Brain Function to Enhance Human Performance in Complex Systems**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **George Mason University**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
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.

14. ABSTRACT

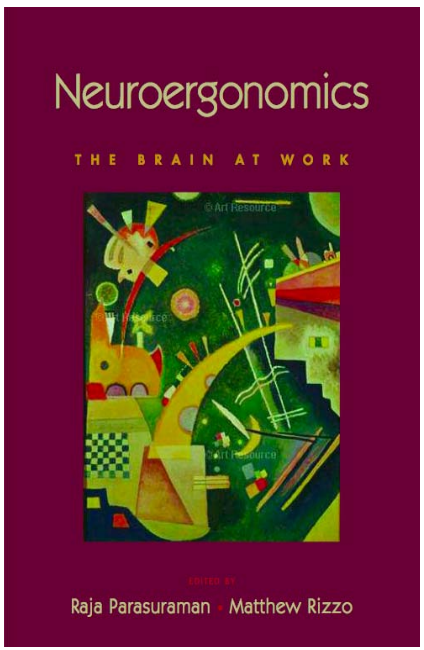
15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**37**	

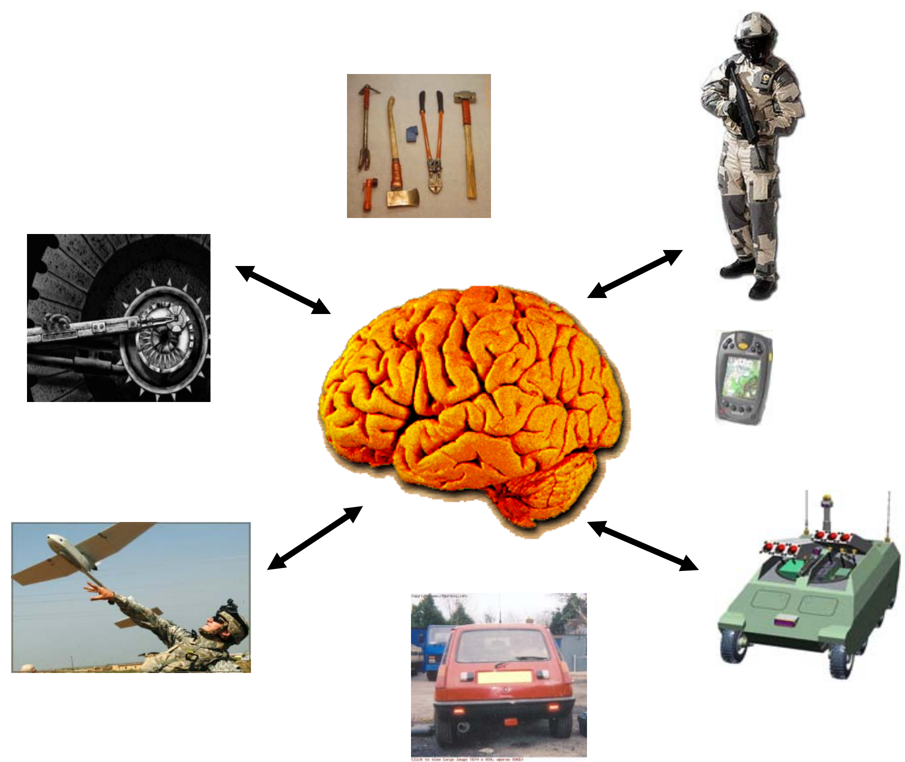
Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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

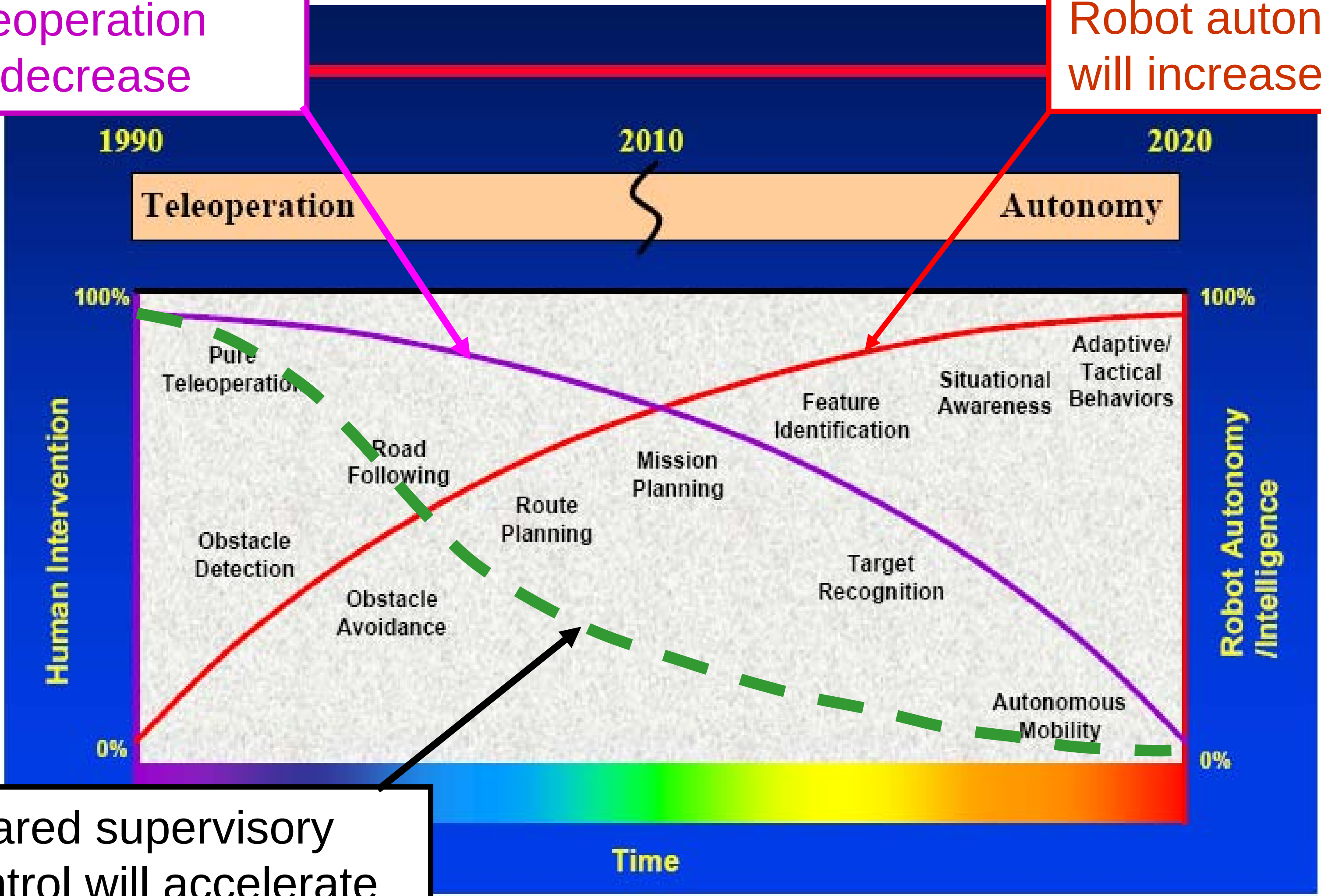
Example 1:
Neuroimaging and Adaptive Automation

Enhancing performance of operators supervising multiple unmanned vehicles

Robotic Evolution Overview*

Teleoperation will decrease

Robot autonomy will increase

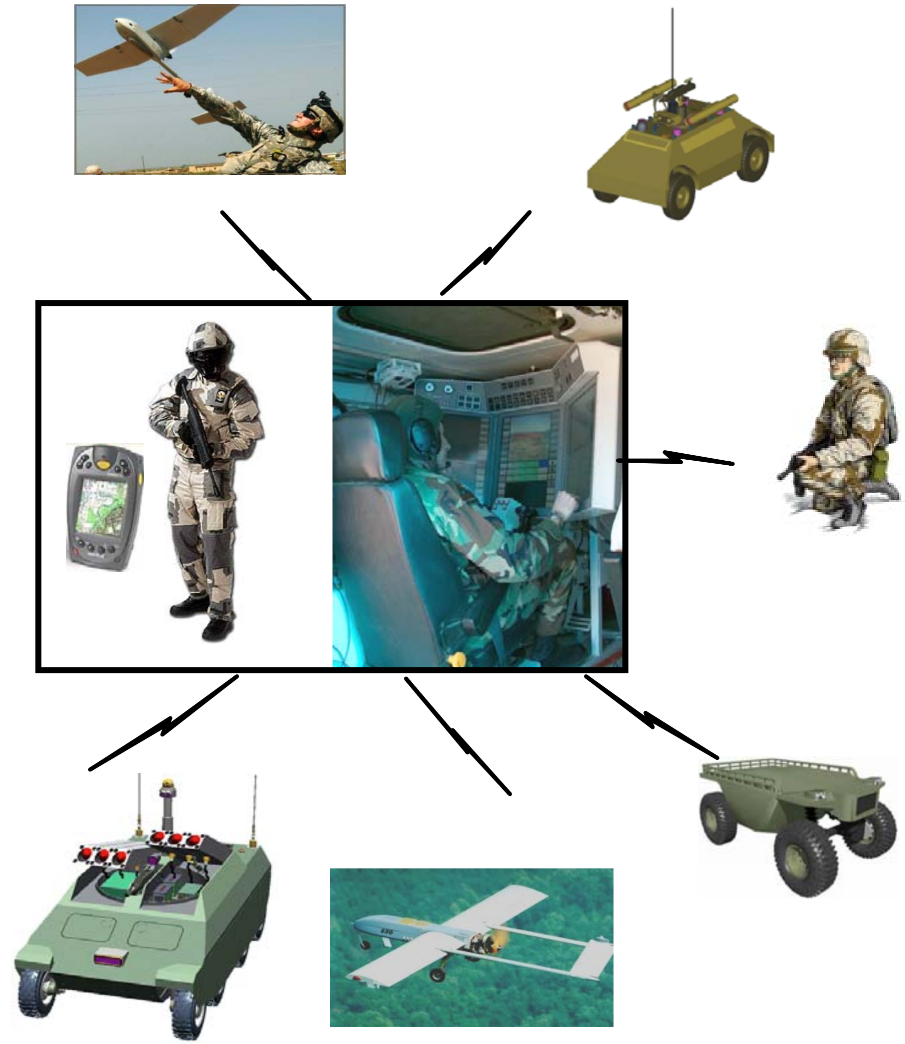


Shared supervisory control will accelerate transition

* 2005 Joint Robotics Program Master Plan

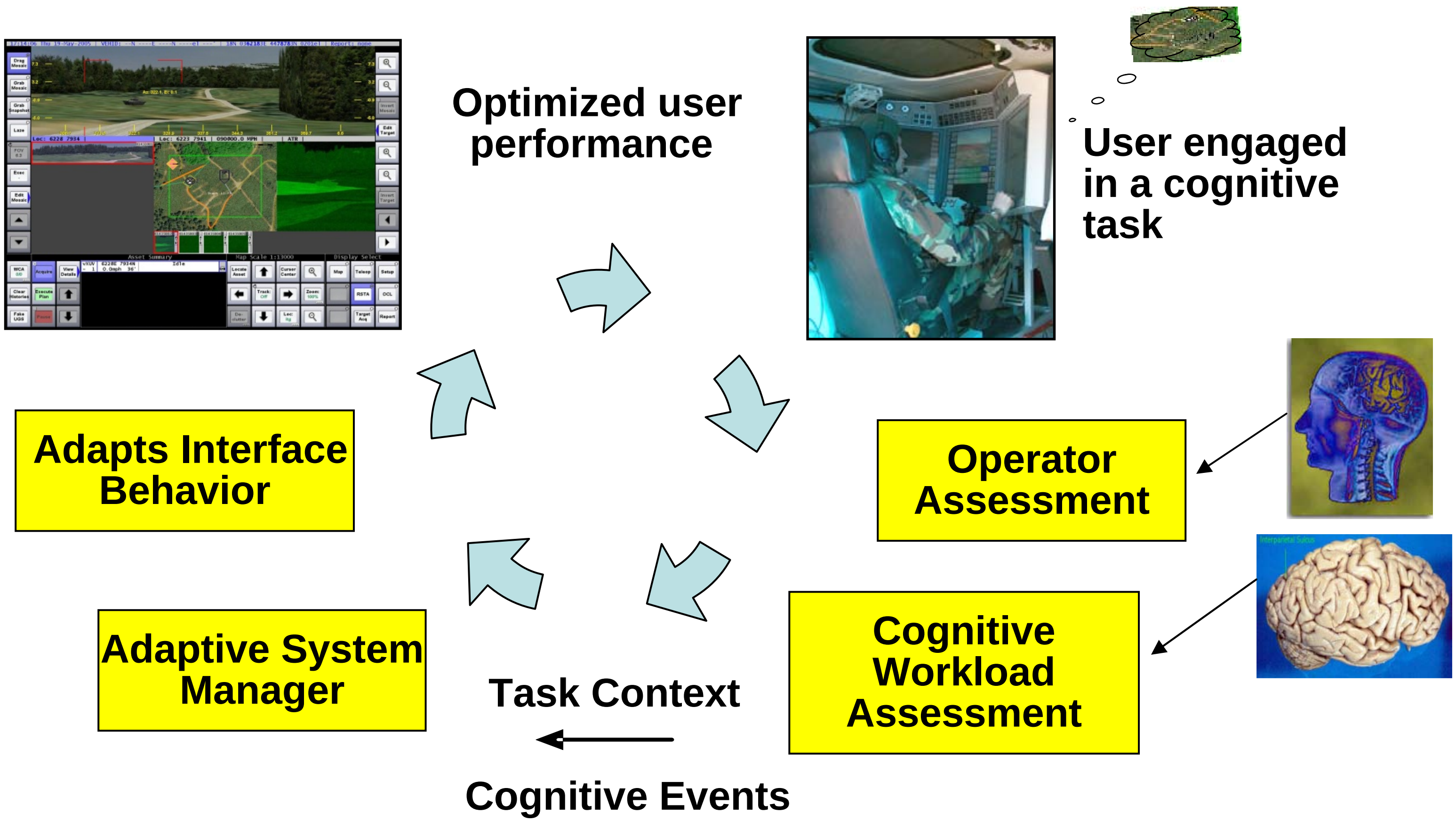
Soldier-Robot Teaming

- 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



Arch Lab

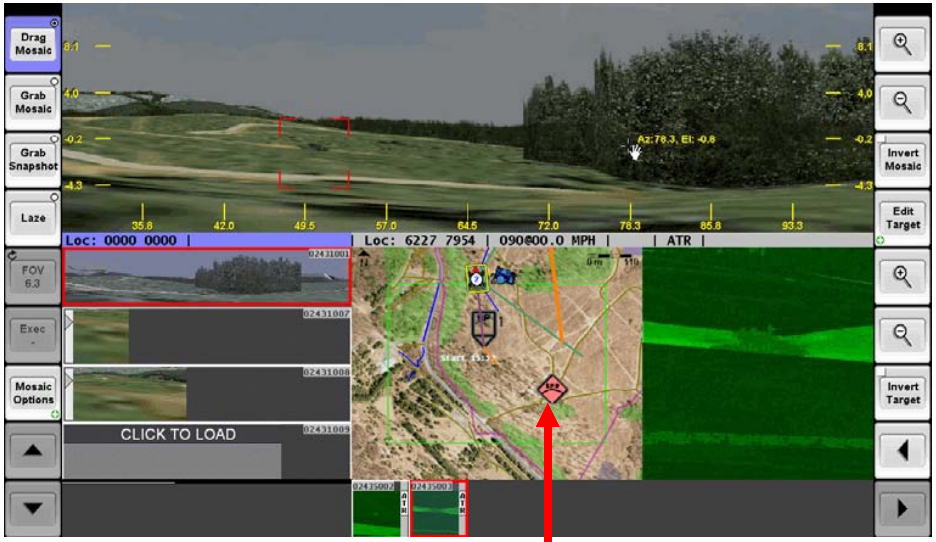
Triggers for Adaptive Automation

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

Parasuraman (2000), *Ergonomics*.




Simulation Integration Lab (SIL)



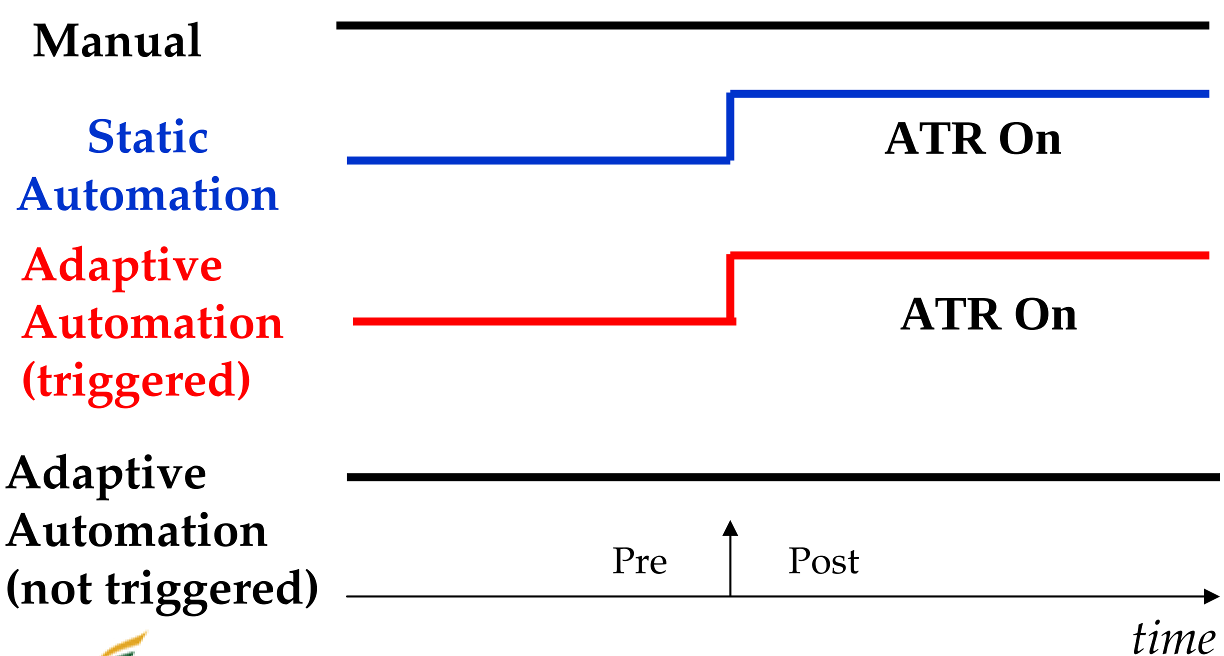
- Reconnaissance, Surveillance, and Target Acquisition (RSTA)
  - ➢ With and without Automatic Target Recognition (ATR) support
- Monitor UAV and UGV assets
- Secondary change detection task

Change Detection Task: Icon on Situation Map Moves

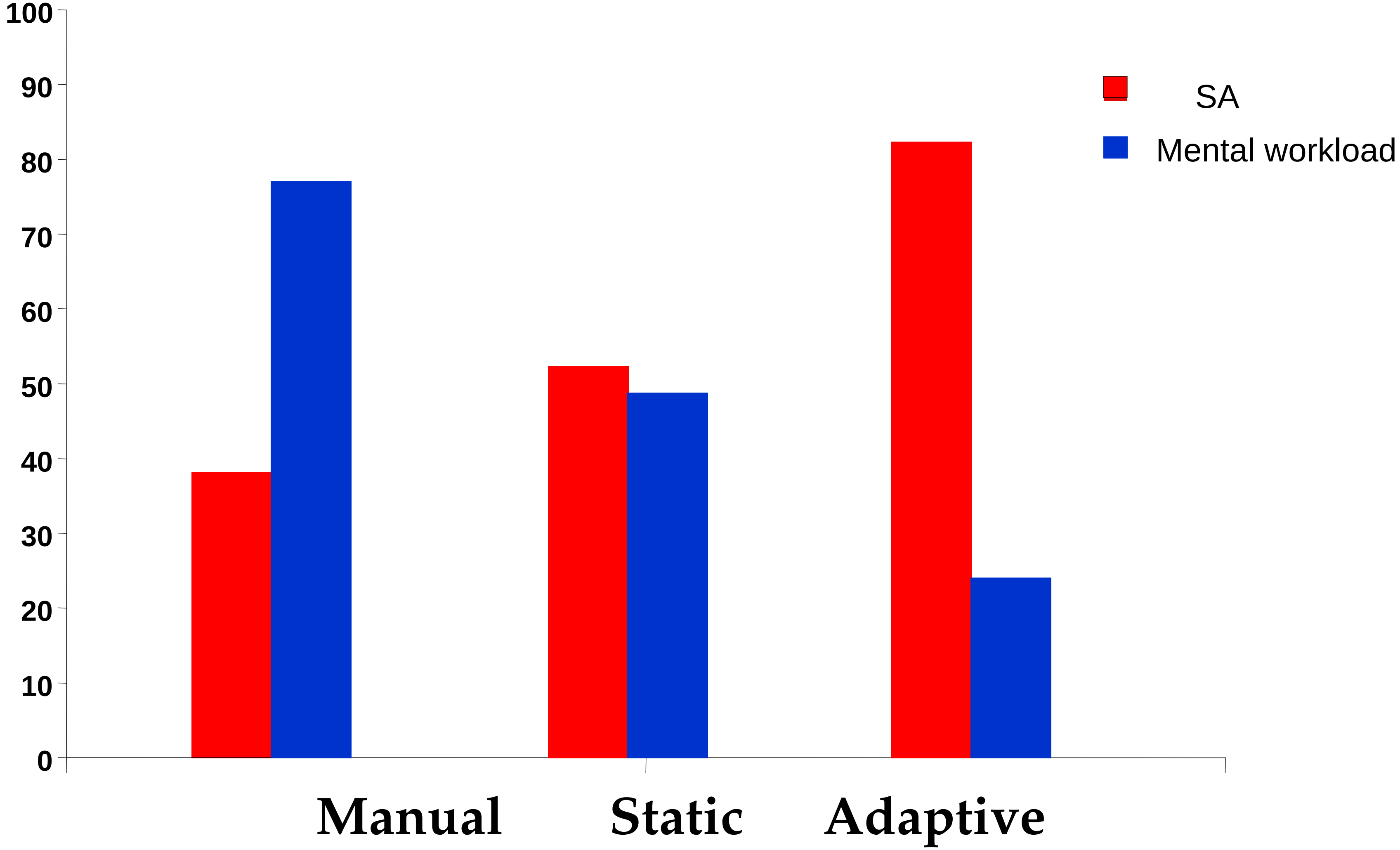
Arch Lab   GEORGE MASON UNIVERSITY

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**

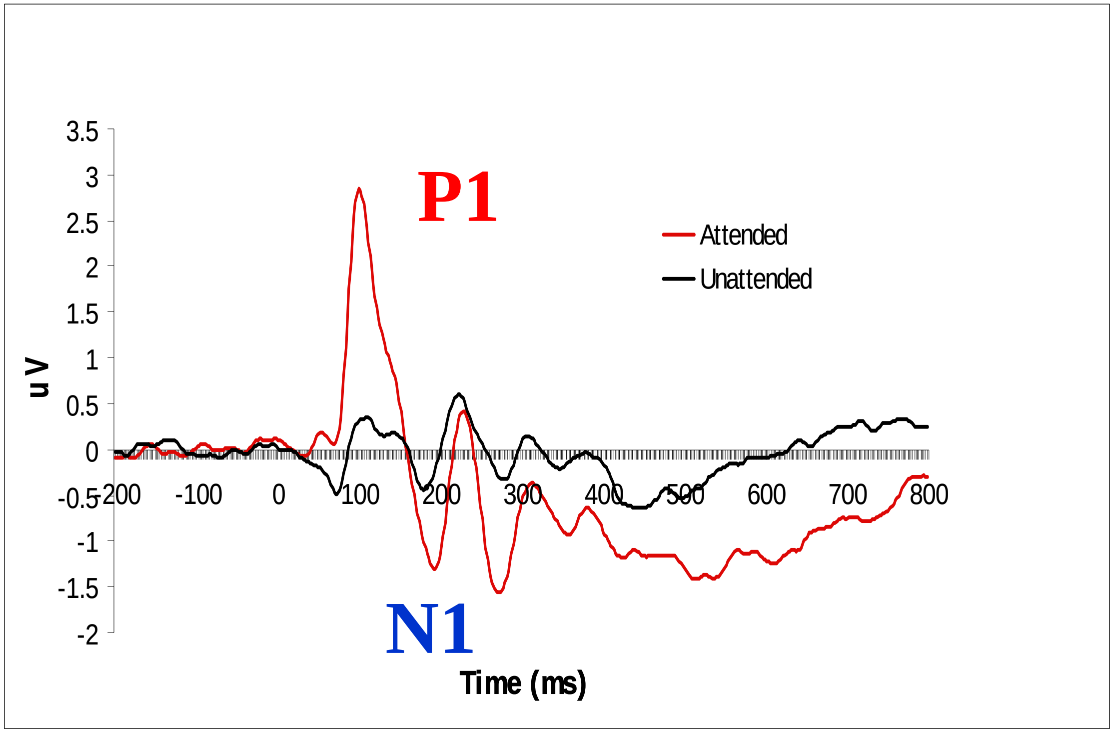


Effects of Adaptive Automation on Situation Awareness (SA) and Workload

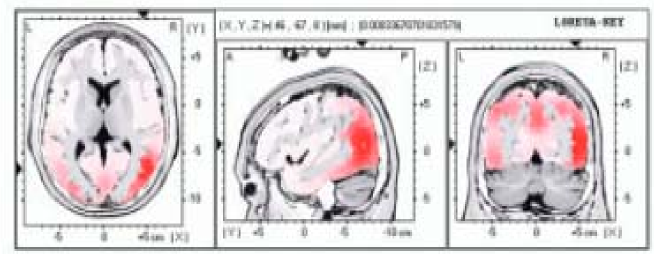


Attention Enhances the P1and N1 Event-Related Brain Potential Components

ERPs and Attention

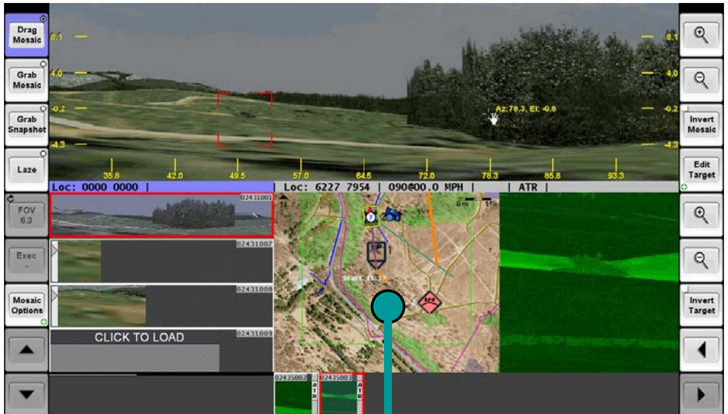


Brain Topography of Attention Effect



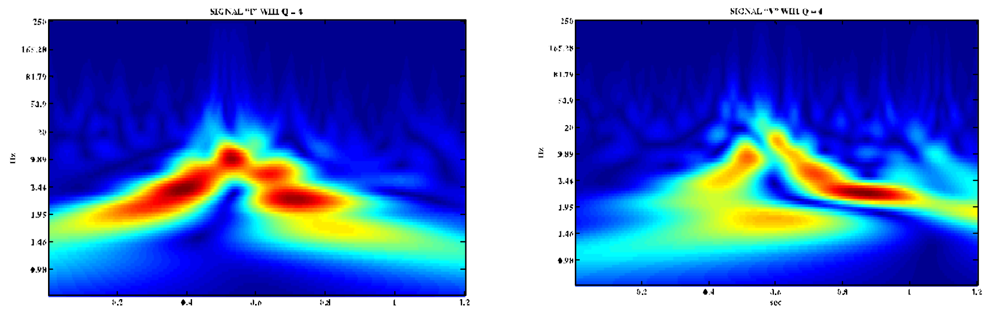
Fu, Greenwood, & Parasuraman (2005), *Human Brain Mapping*

Event-Related Brain Potentials (ERPs) to Attended and Unattended Probes



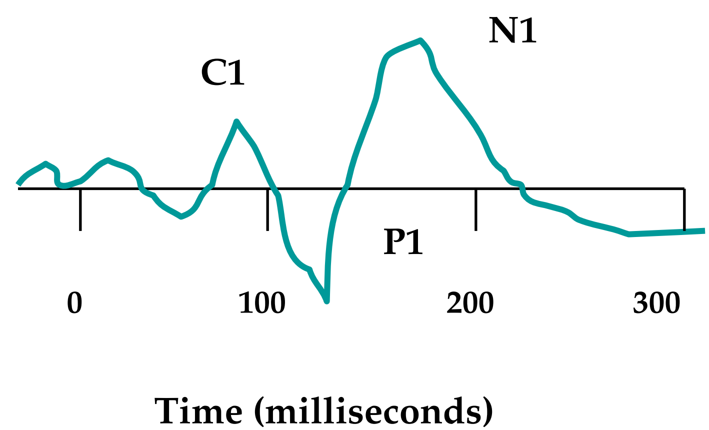
Change detection probe:
Sine wave grating

Wavelet analysis



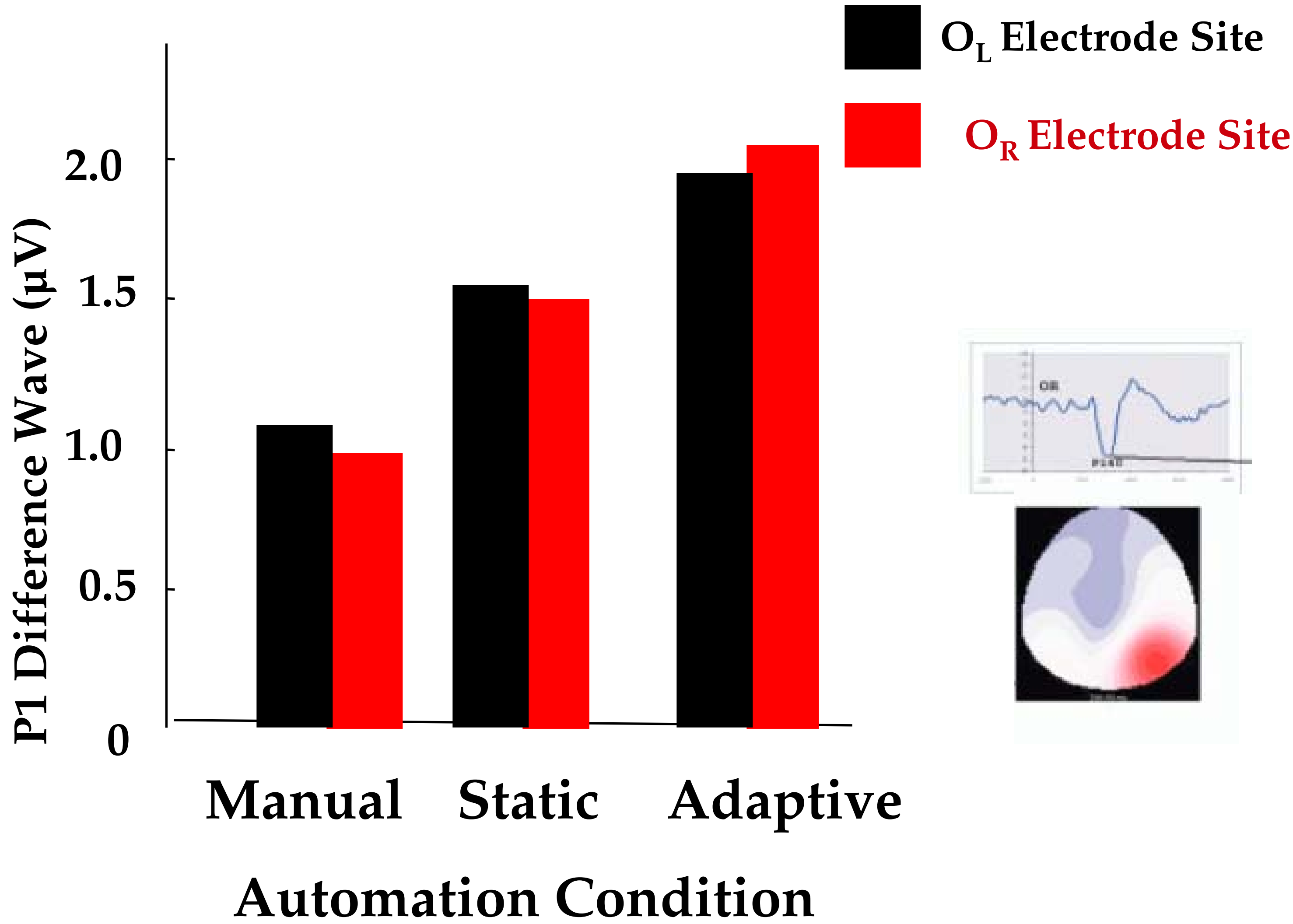
Attended Probe   Unattended Probe

ERP to Probe Event



Arch Lab George Mason University

Effect of Adaptive Automation on the P1 Brain Potential Attention Effect



Arch Lab

GEORGE MASON UNIVERSITY

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

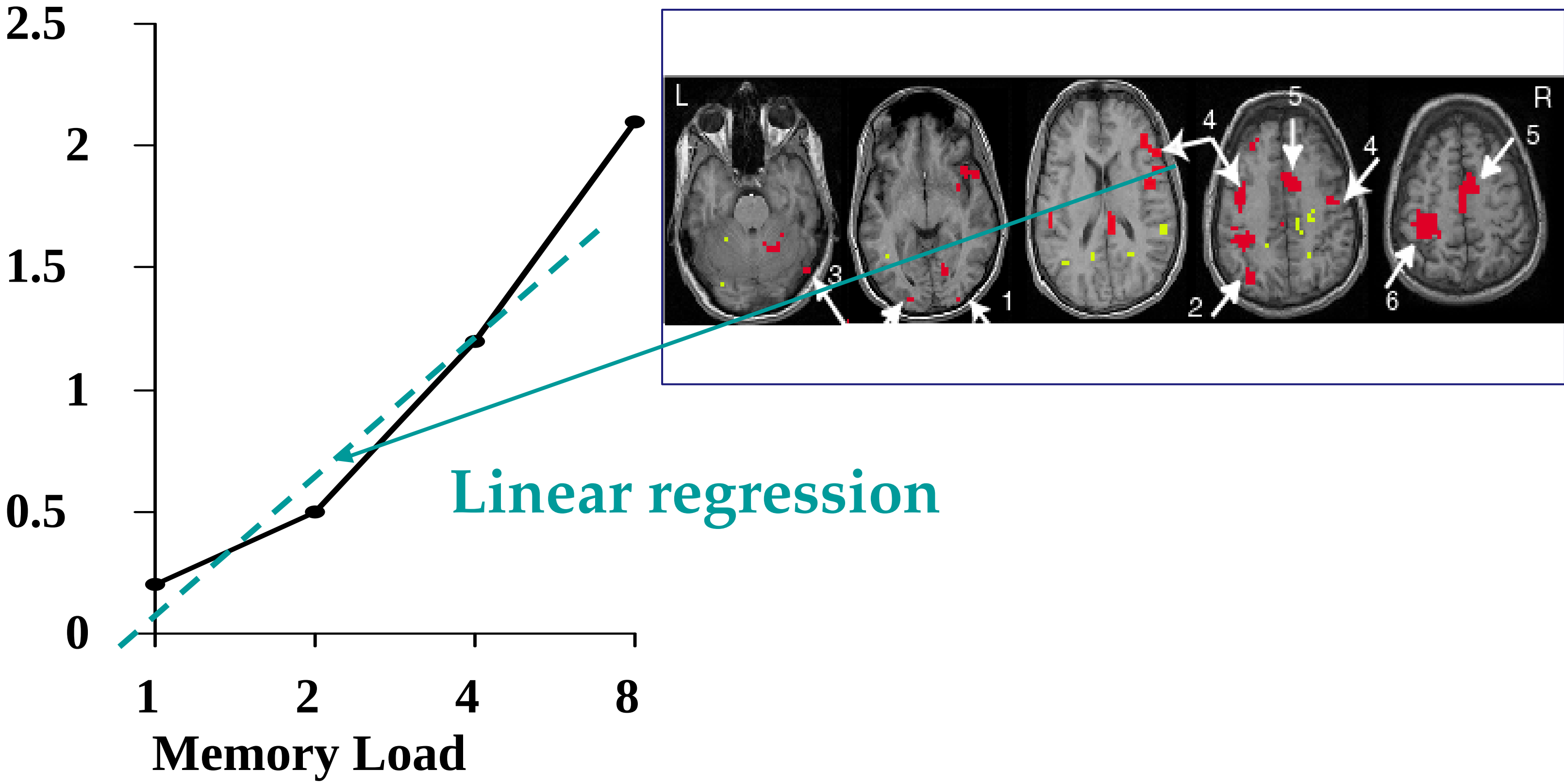
Identifying rapid decision makers in command and control

Identifying Sources of Individual Differences

- **Individual differences reflect**
  - **Development**
  - **Experience**
  - **Training**
  - **Genetic factors (natural variation)**

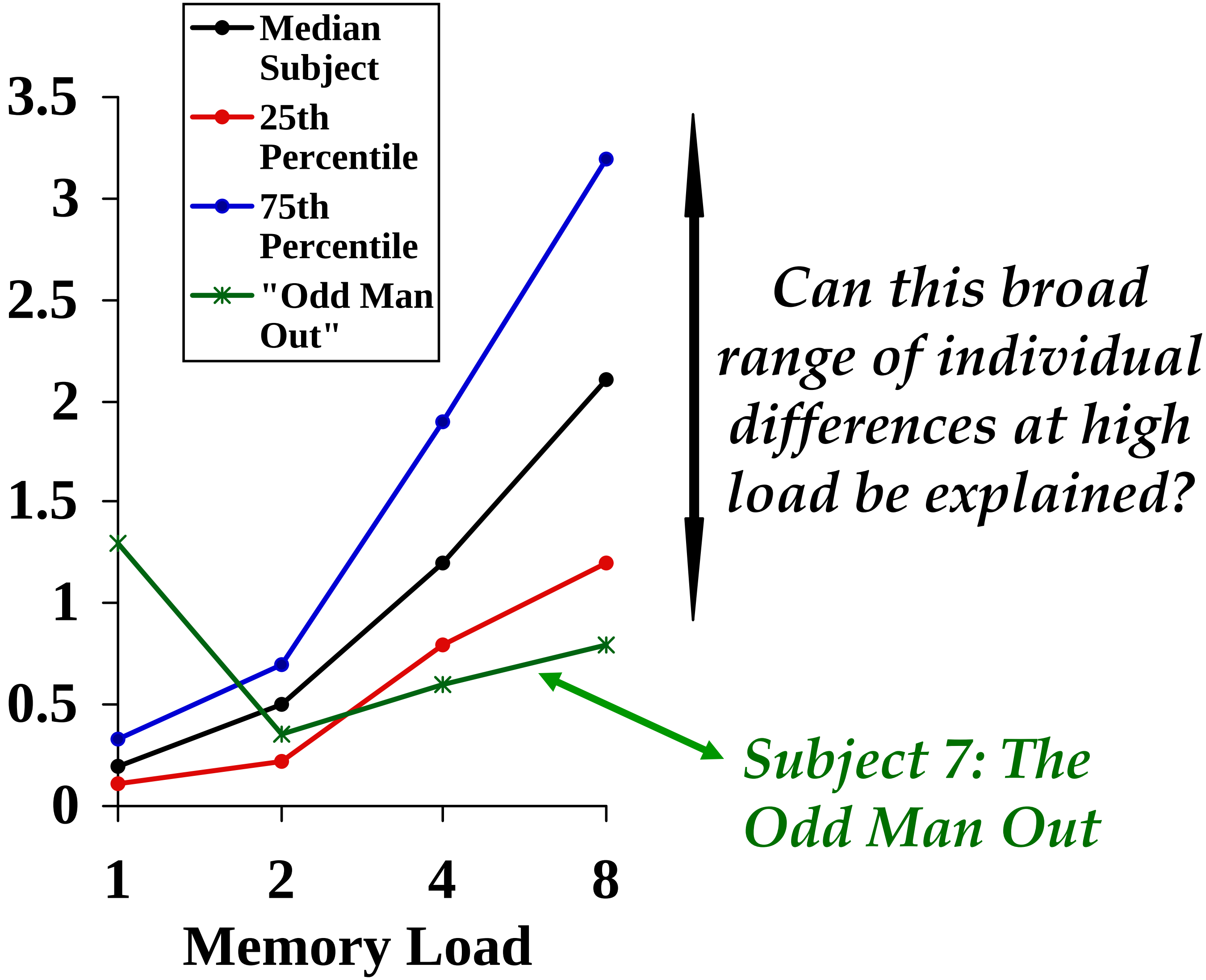
- **Can molecular genetics help in understanding**
  - **Normal variation in cognition?**
  - **Exceptional individuals ("cognitive superstars")?**

Effects of Working Memory Load on Prefrontal Cortex Activation



Jiang, Haxby, Martin, Ungerleider, & Parasuraman (2000). *Science*

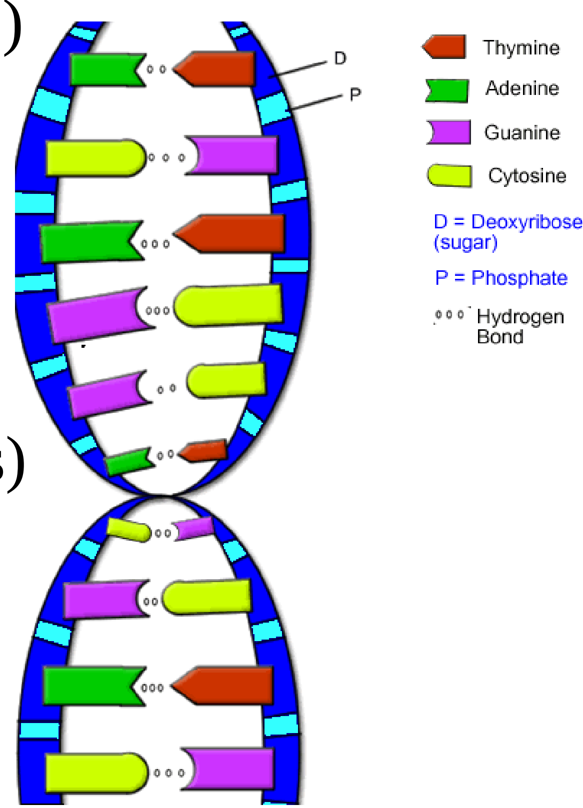
Prefrontal Cortex Activation and Working Memory Load



Arch Lab

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**T**AGA………. vs.
……….ACA**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

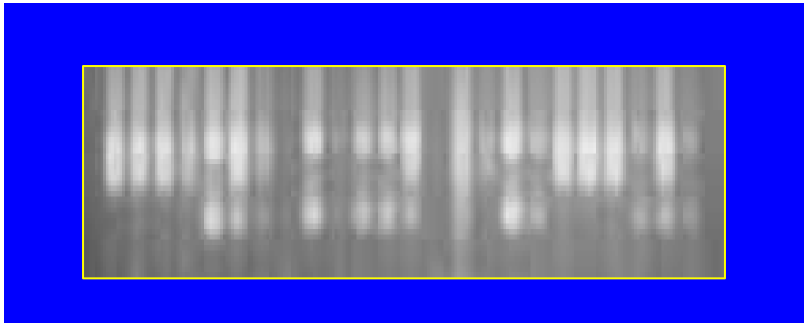
Arch Lab

GEORGE MASON UNIVERSITY

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

Greenwood & Parasuraman (2003). *Cognitive Neuroscience Reviews.*

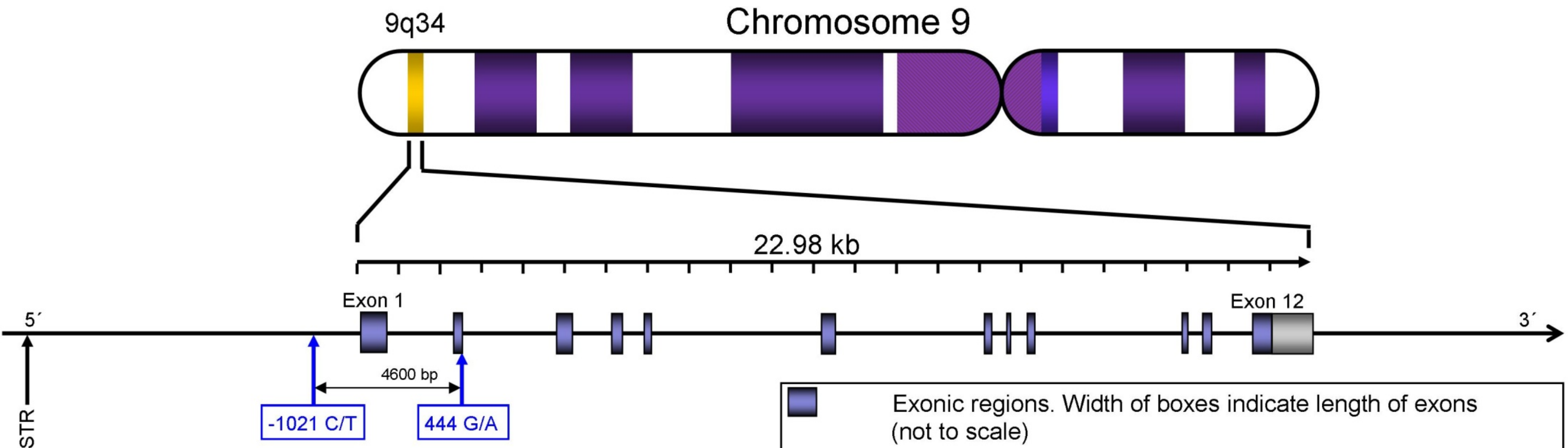


Arch Lab GEORGE MASON UNIVERSITY

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

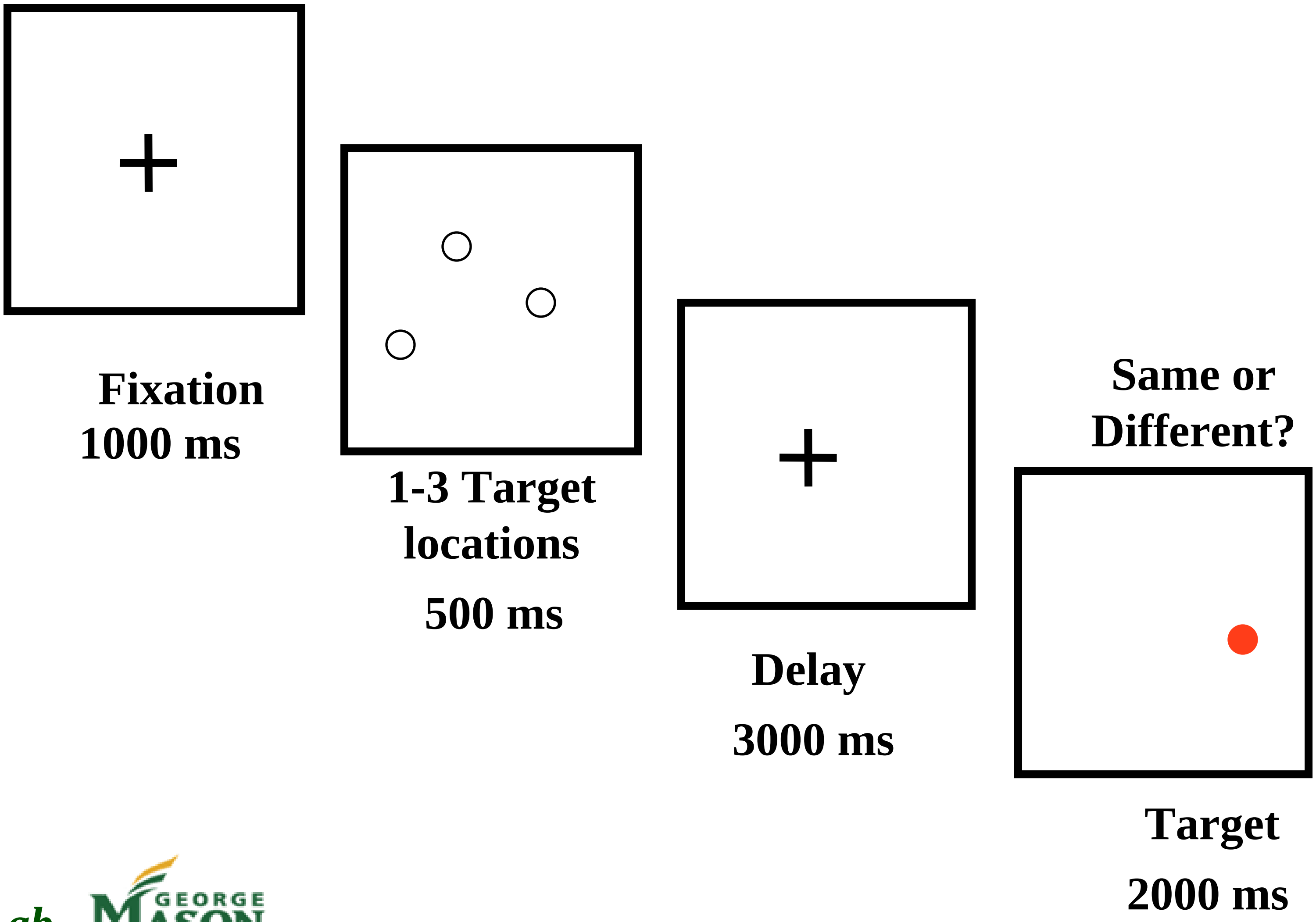


-1021 C/T	444 G/A	
C (10-fold)	G (Glu) (2-fold)	High DBH activity
T	A (Glu)	Low DBH activity

- 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
- -1021 C/T: "-" indicates that the SNP is 1021 bases upstream of the transcription start site (base + 1)
- 444 G/A: SNP is 444 bases downstream of the transcription start site (excluding intron length)

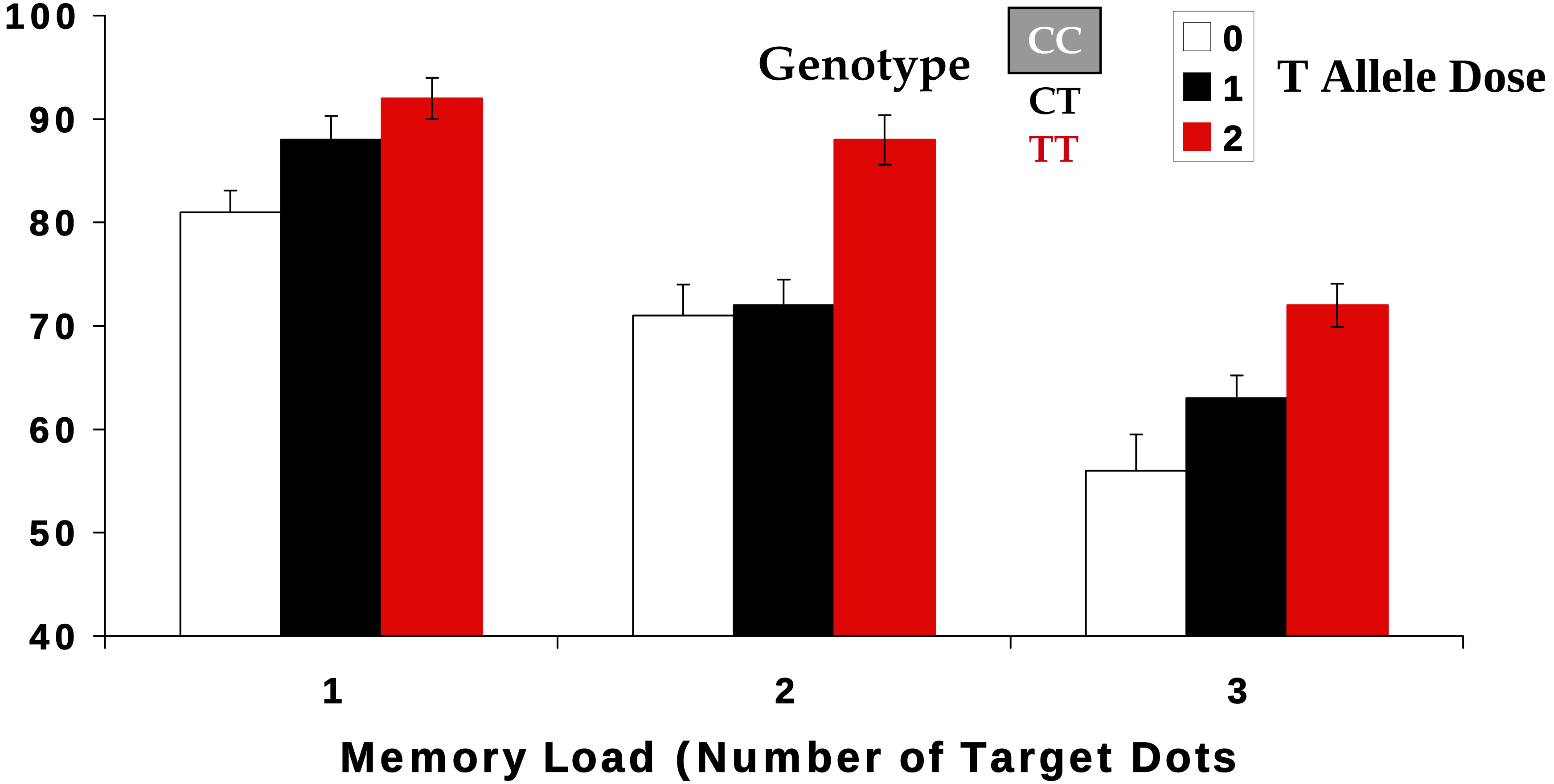
-1021 C/T SNP — **Genotypes**:
- **CC**
- **CT**
- **TT**

Working Memory Task



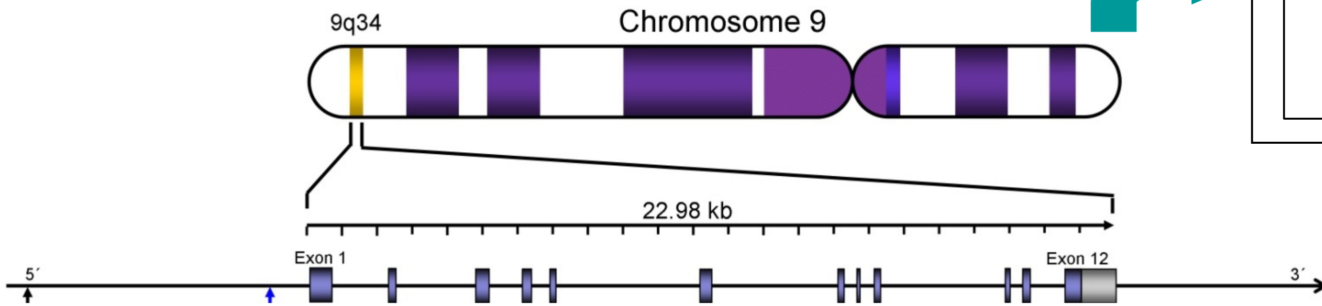
Arch Lab

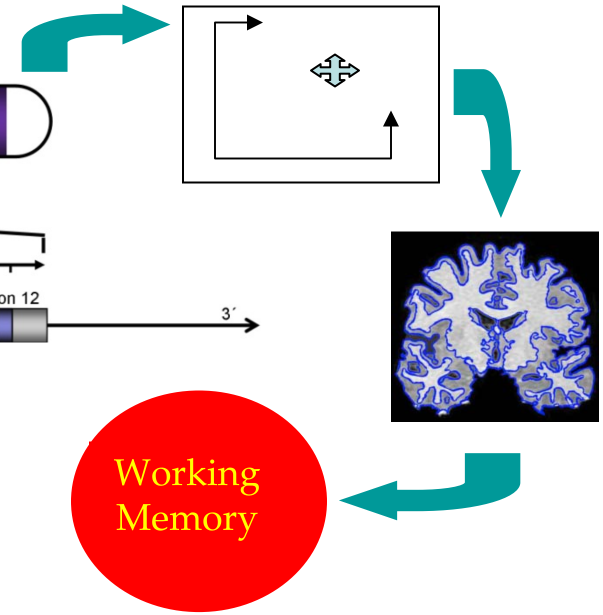
Effects of T Allele Dose of DBH -1021 C/T SN
on Spatial Working Memory



Arch Lab

GEORGE MASON UNIVERSITY

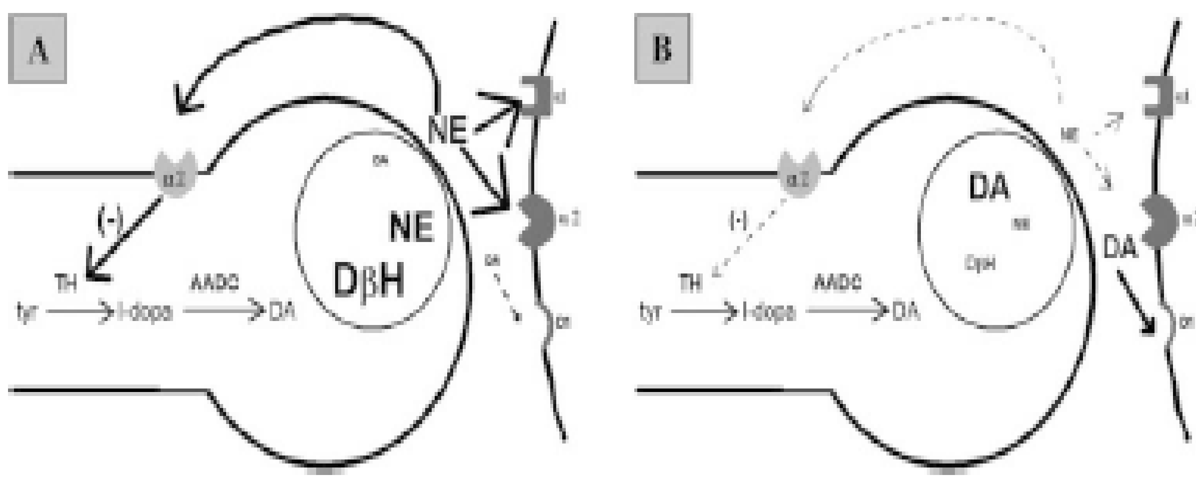




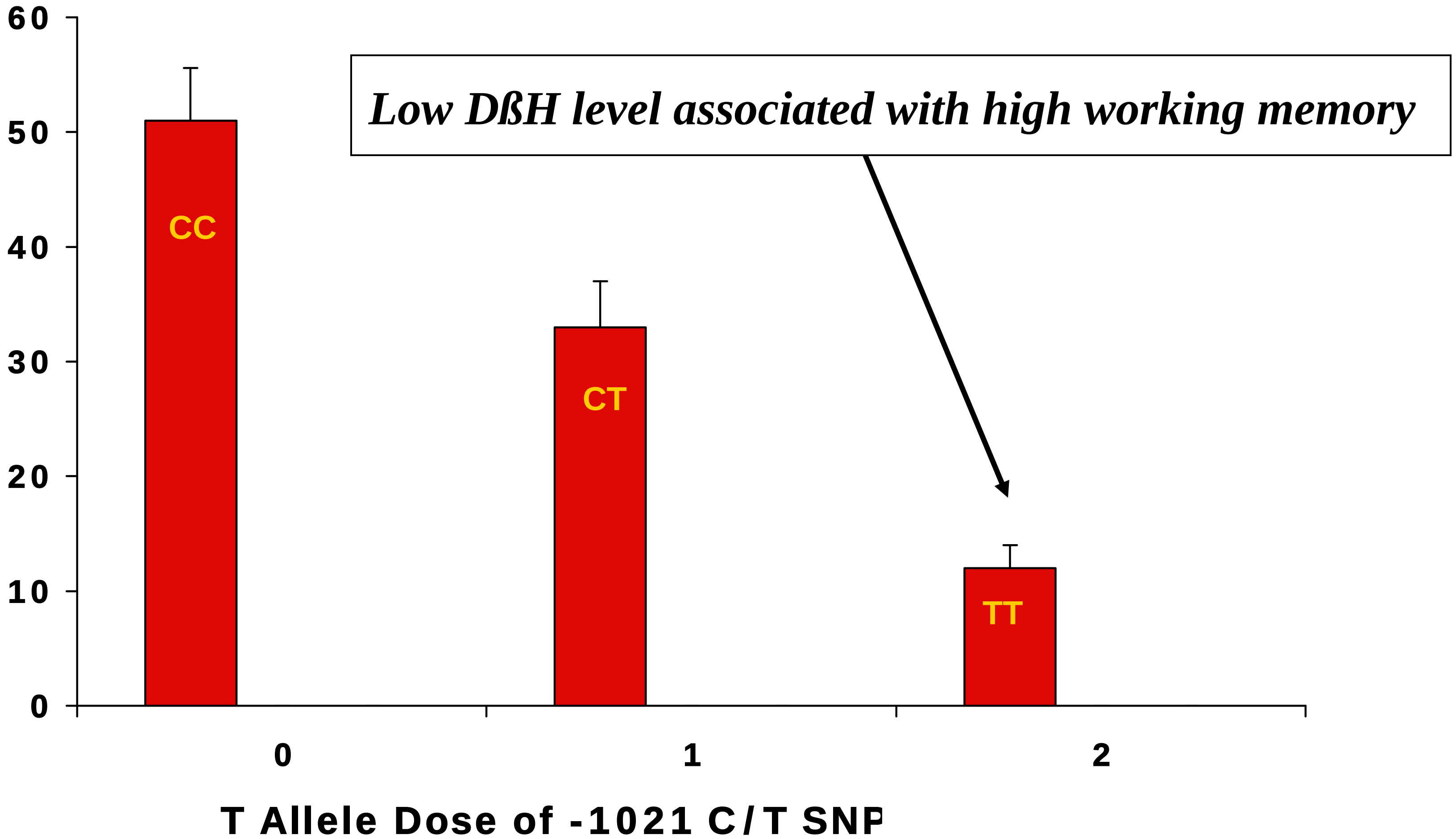
- **What is the mechanism by which DBH is linked to working memory?**
- **Is DBH a "functional" SNP?**
- **Genes are only of interest if they are *expressed* and influence proteins, particularly in the brain**
- **Cognitive proteomics: linking gene-controlled proteins to function**

Effects of DßH on Synaptic Dopamine (DA) and Norepinephrine (NE)

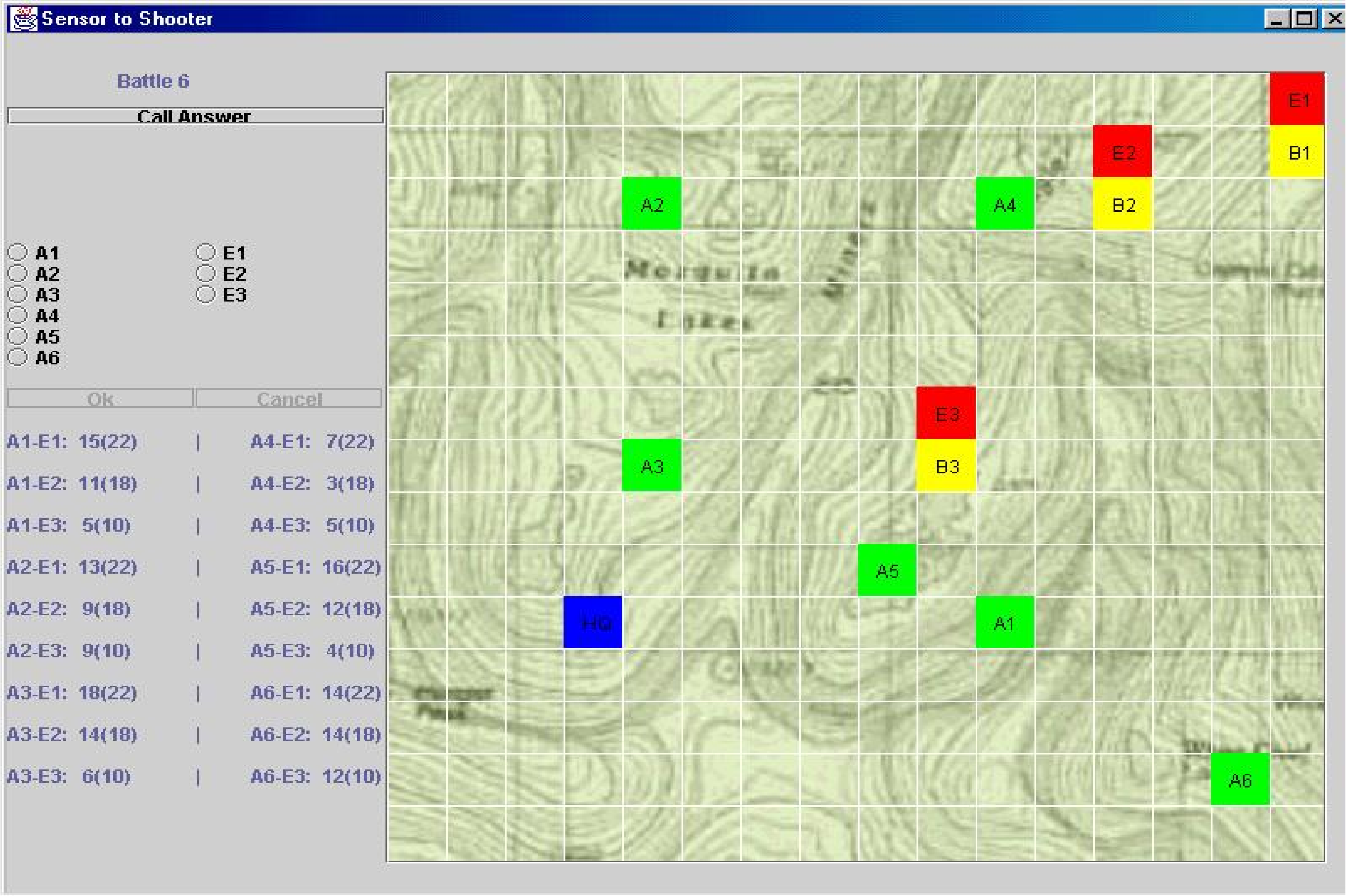
- A. High DßH Level: NE receptors active
- B. Low DßH Level: DA receptors active



Effects of T Allele Dose of DBH -1021 C/T SNP on Plasma Dopamine ß Hydroxylase Levels

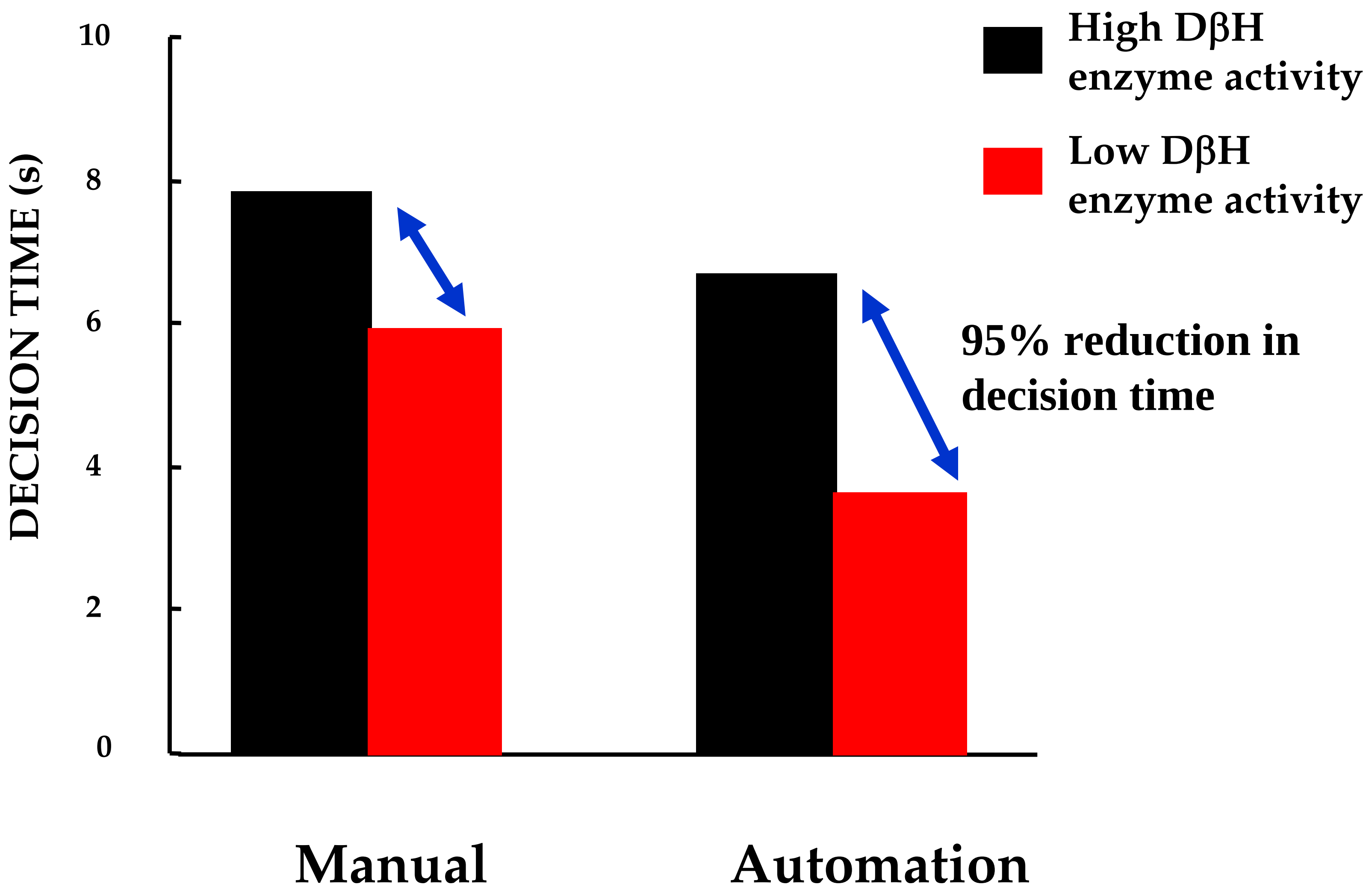


Decision Making in Command and Control



Decision making task performed both with and without automated support

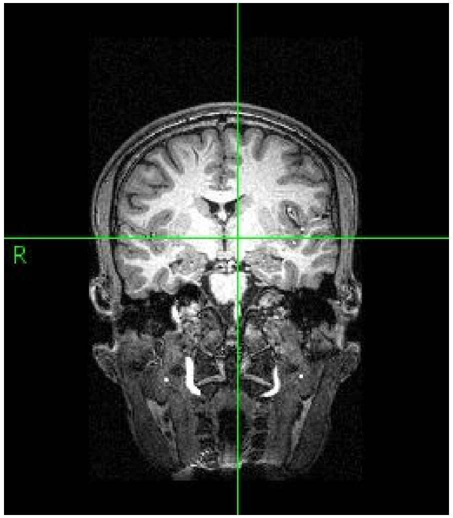
DβH Enzyme Levels and Decision Time



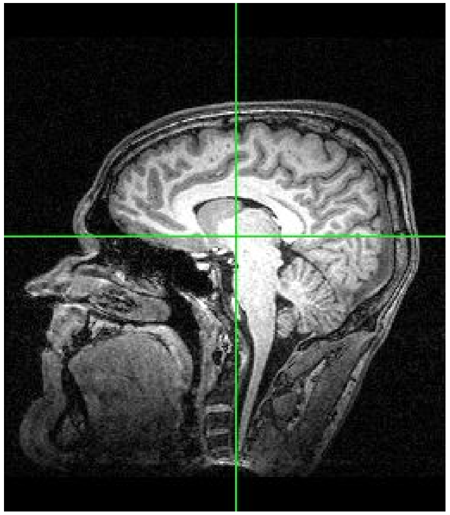
Subject 7: A "Cognitive Superstar"

- 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 DßH enzyme level
- Has lowest blood DßH 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

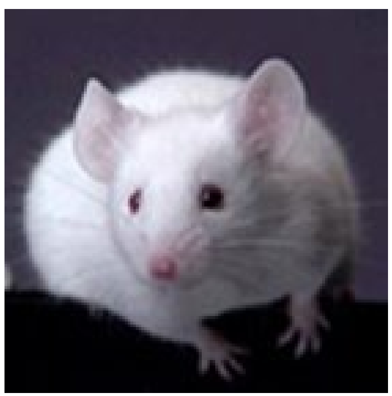
- DBH—a dopaminergic/noradrenergic gene expressed strongly in prefrontal cortex—associated with normal individual differences in working memory (verbal and spatial)
- Plasma DßH levels inversely correlated with working memory and decision making performance
- Molecular genetics provides a new approach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

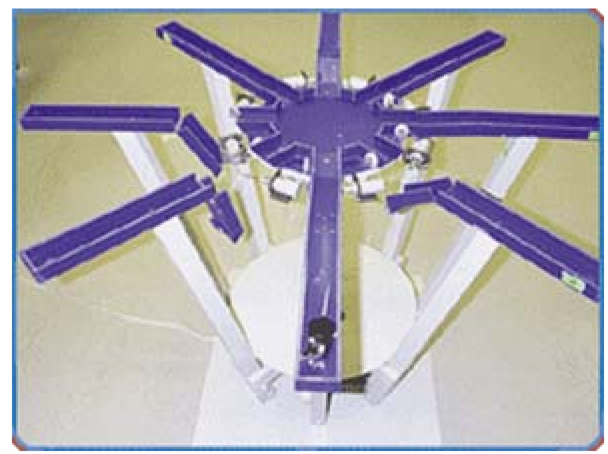
Ongoing Research

- **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