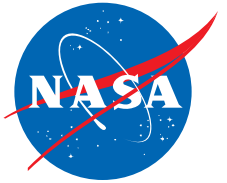


Combining Engineering and Psychology in New Ways

Alan T. Pope & Chad L. Stephens
NASA Langley Research Center

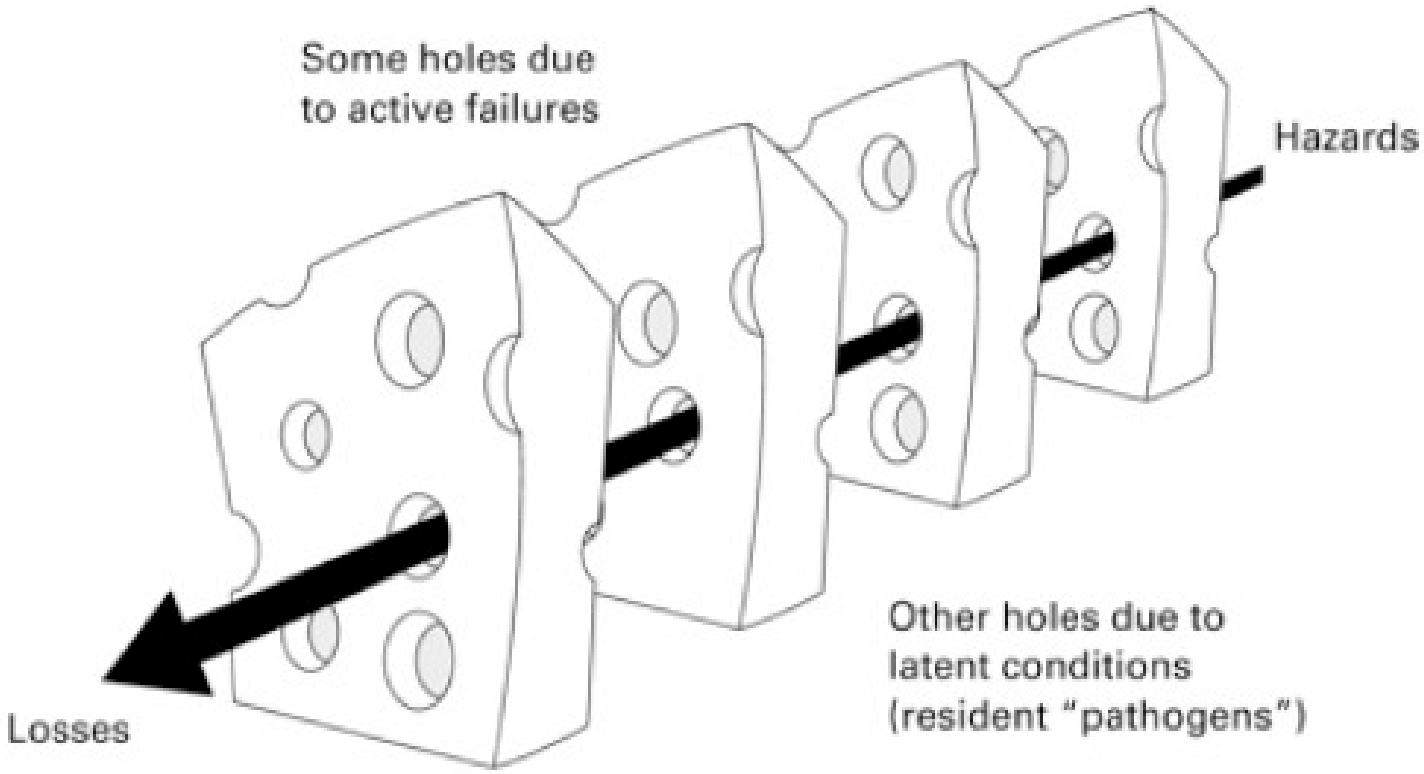
Human Error

- A primary goal of NASA and FAA is to improve an industry with an exceptionally high level of safety.

- ≈70% of incidents and accidents are attributed to pilot error
  - military and civilian aviation

The Swiss Cheese Model:

Understanding system failures



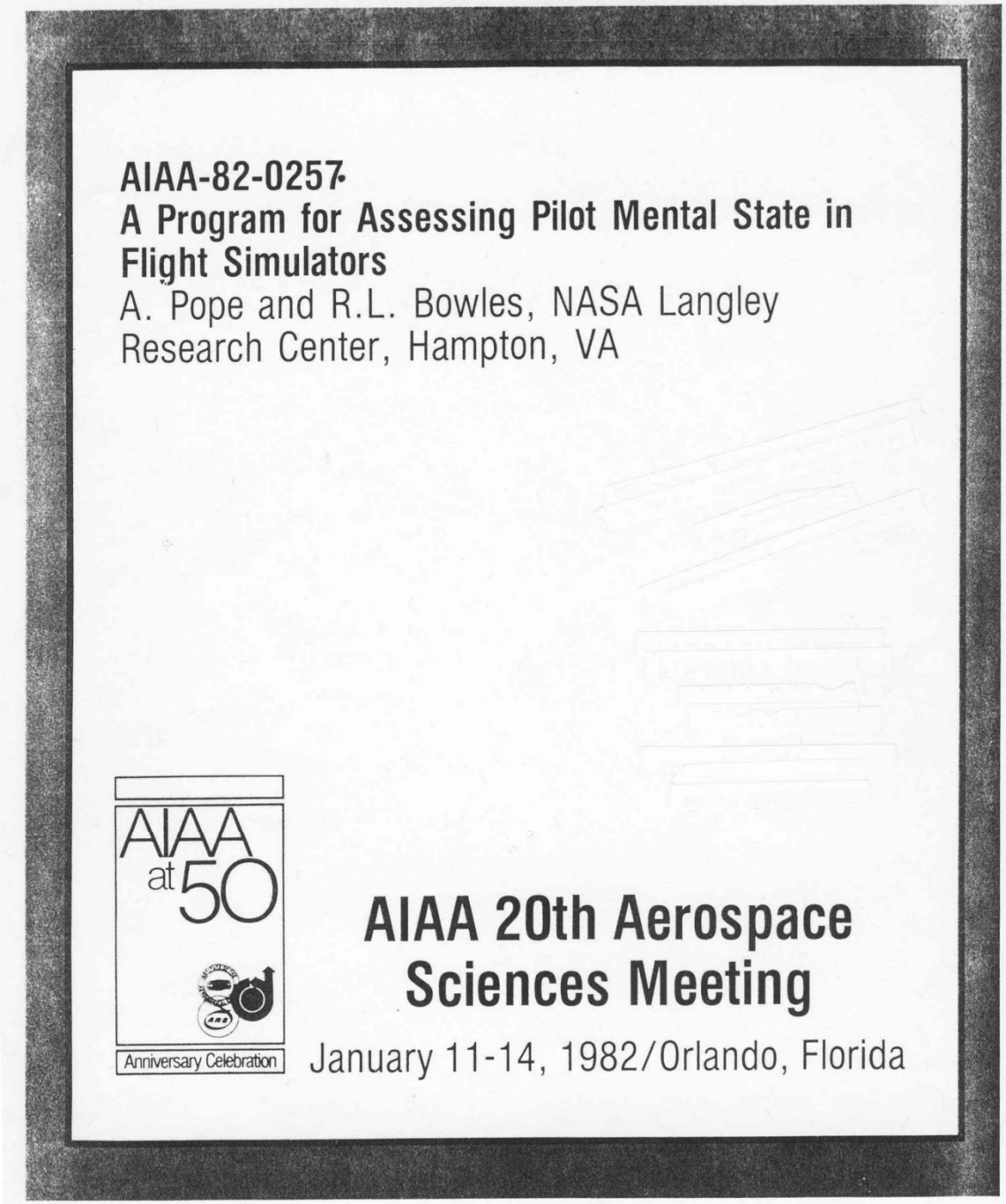
Successive layers of defences, barriers and safeguards

Problem of Interest

- ‘Pilot error’ can be deceiving
- What about all 85k safe flights which occur everyday?
- Conceptualize: number of accidents attributed to human error as an area in which to improve safety in aviation and other human systems
- How can science bolster the “last line of defense”?
  - Identify/Optimize “functional state”
    - monitoring & using the physiological and psychological state during which performance is maximum

Beyond Automation: Augmented Cognition

- Automation plays a significant role in the cockpit
- Adaptive Automation is a better solution
  - "closes the loop"
  - attempts to prevent hazardous states of awareness: absorption, inattention
  - capable of incorporating subjective and objective measures of operator state to adjust flight tasks



AIAA-82-0257

A Program for Assessing Pilot Mental State in Flight Simulators

A. Pope and R.L. Bowles, NASA Langley Research Center, Hampton, VA

AIAA at 50

Anniversary Celebration

AIAA 20th Aerospace Sciences Meeting

January 11-14, 1982/Orlando, Florida

The Aviation Safety Reporting System (ASRS) database reveals that civil transport flight crew members often relate their mistakes to experiencing certain states of awareness:

- Crew members report becoming "**complacent**" and succumbing to "**boredom**."
- **Diminished alertness, compromised vigilance, and lapsing attention**, frequently ***not*** associated with fatigue.
- Attributed to conditions of **quietness, droning noise and motion, monotony, repetition, and familiarity**.
- Crews report being **excessively absorbed or dangerously preoccupied** prior to an error incident.
- Crews occasionally lapse into awareness states that are **incompatible** with the demands of the tasks of monitoring and managing the progress of highly complex systems.

The idea of Hazardous States of Awareness, such as underload, complacency and absorption, which interfere with effective performance,
and
the construct of "task engagement"
were introduced
along with
a predictive model and quantitative methods
for measuring the constructs.

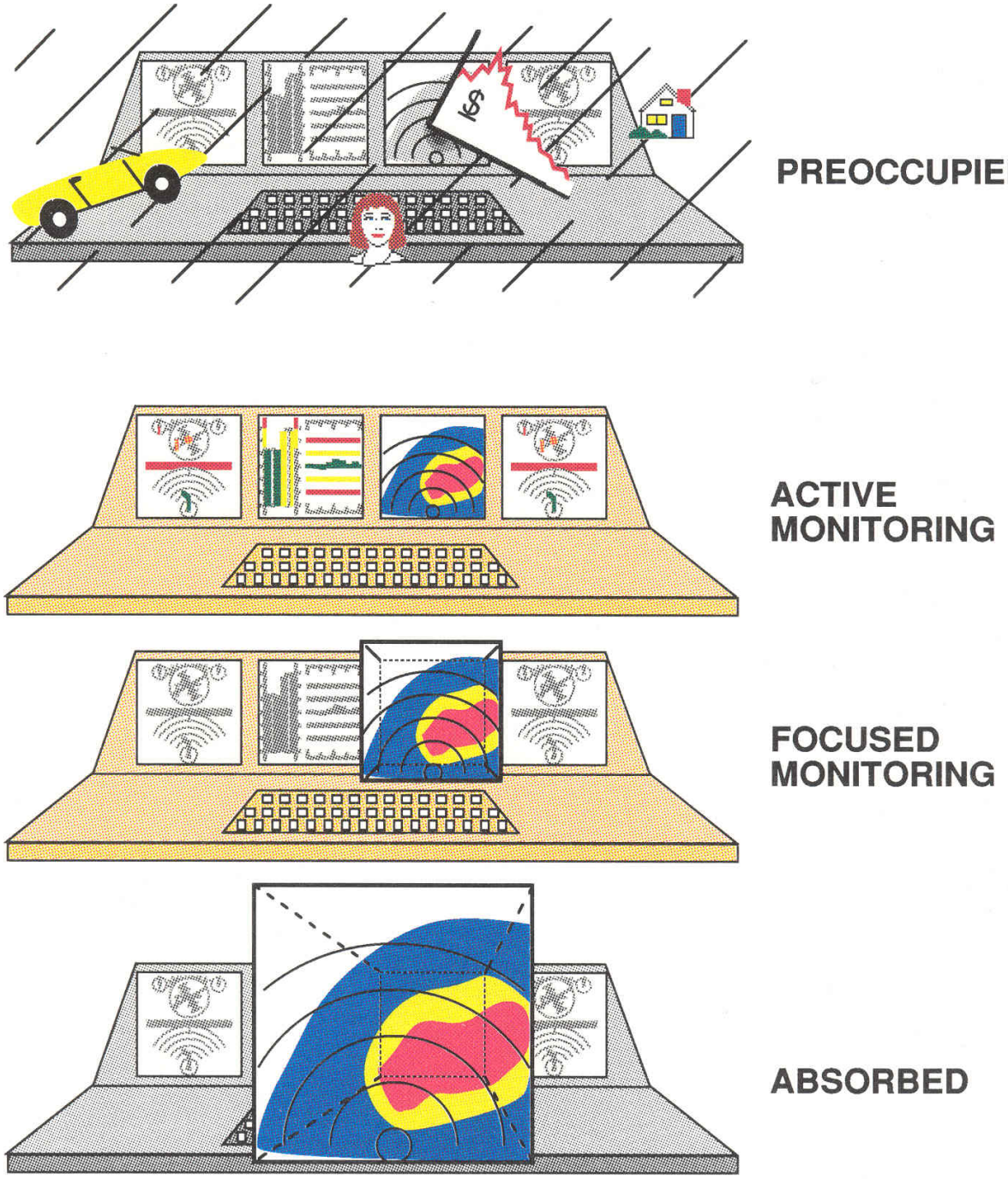


Figure 1. Characterizing Hazardous States of Awareness

A focus of this work was the determination of brainwave correlates of HSAs that are experienced by crew in highly complex technology environments (e.g., modern aircraft flight decks), in order to identify contributing factors and countermeasures to these mental hazards.

Brainwave Correlates of Hazardous States In Advanced Concepts Flight Simulator

National Aeronautics and Space Administration Hazardous States

Computer Classification of Mental States for One Subject Using EEG Power Spectra

Mental State	n	Classification (%) as: I	II	III	IV	V
Initial Discriminant (Test)						
I Eyes Open	40	95.0	0.0	2.5	0.0	2.5
II Eyes Closed	28	3.6	96.4	0.0	0.0	0.0
III Vigilant	40	0.0	0.0	100.0	0.0	0.0
IV Absorbed	37	5.4	0.0	0.0	89.2	5.4
V Preoccupied	40	0.0	0.0	0.0	2.5	97.5
Subsequent Identification (Retest)						
I Eyes Open	33	69.9	2.7	5.5	4.1	17.8
II Eyes Closed	40	1.5	98.5	0.0	0.0	0.0
III Vigilant	39	6.3	0.0	92.4	0.0	1.3
IV Absorbed	40	3.9	0.0	6.5	62.3	27.3
V Preoccupied	40	0.0	23.8	6.3	2.5	67.5

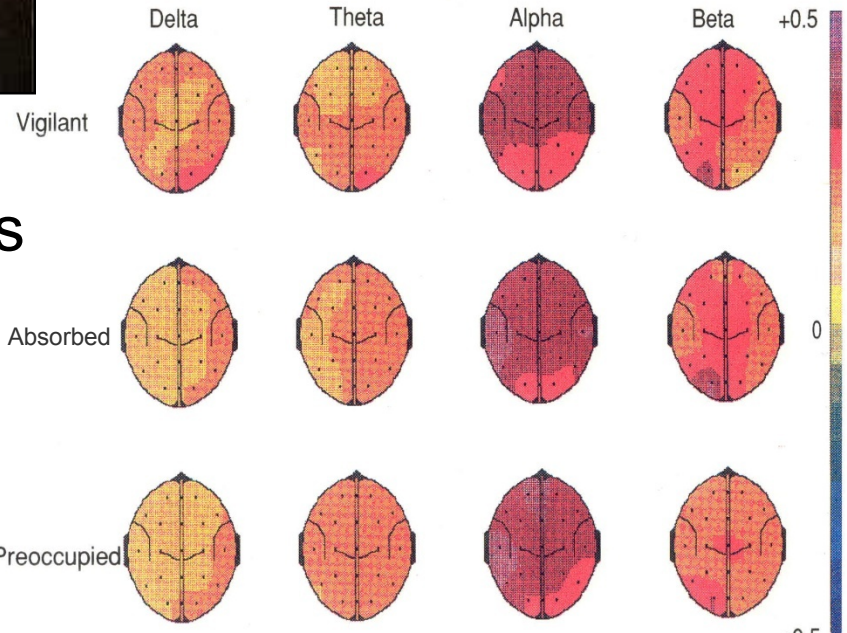
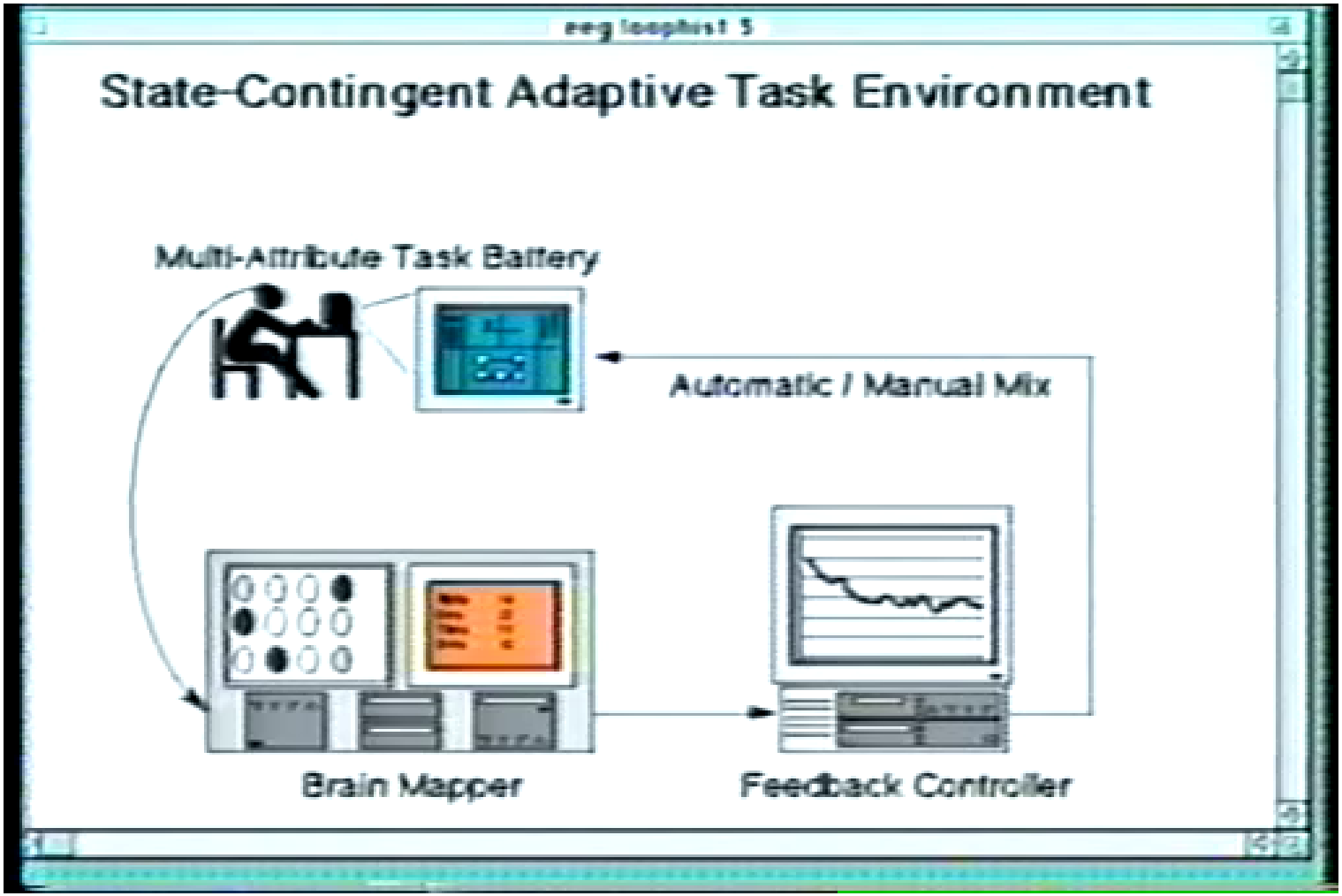
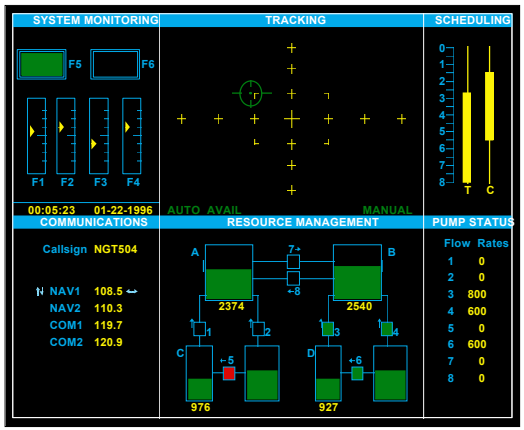


Figure 1.- Brainmaps of three mental states.

This research led to the first method of physiologically-driven adaptive automation in the field of human factors, using a "closed-loop" research paradigm that first assessed an index of task engagement and then adjusted the level of automation based on the index.



Multi-Attribute Task Battery Display

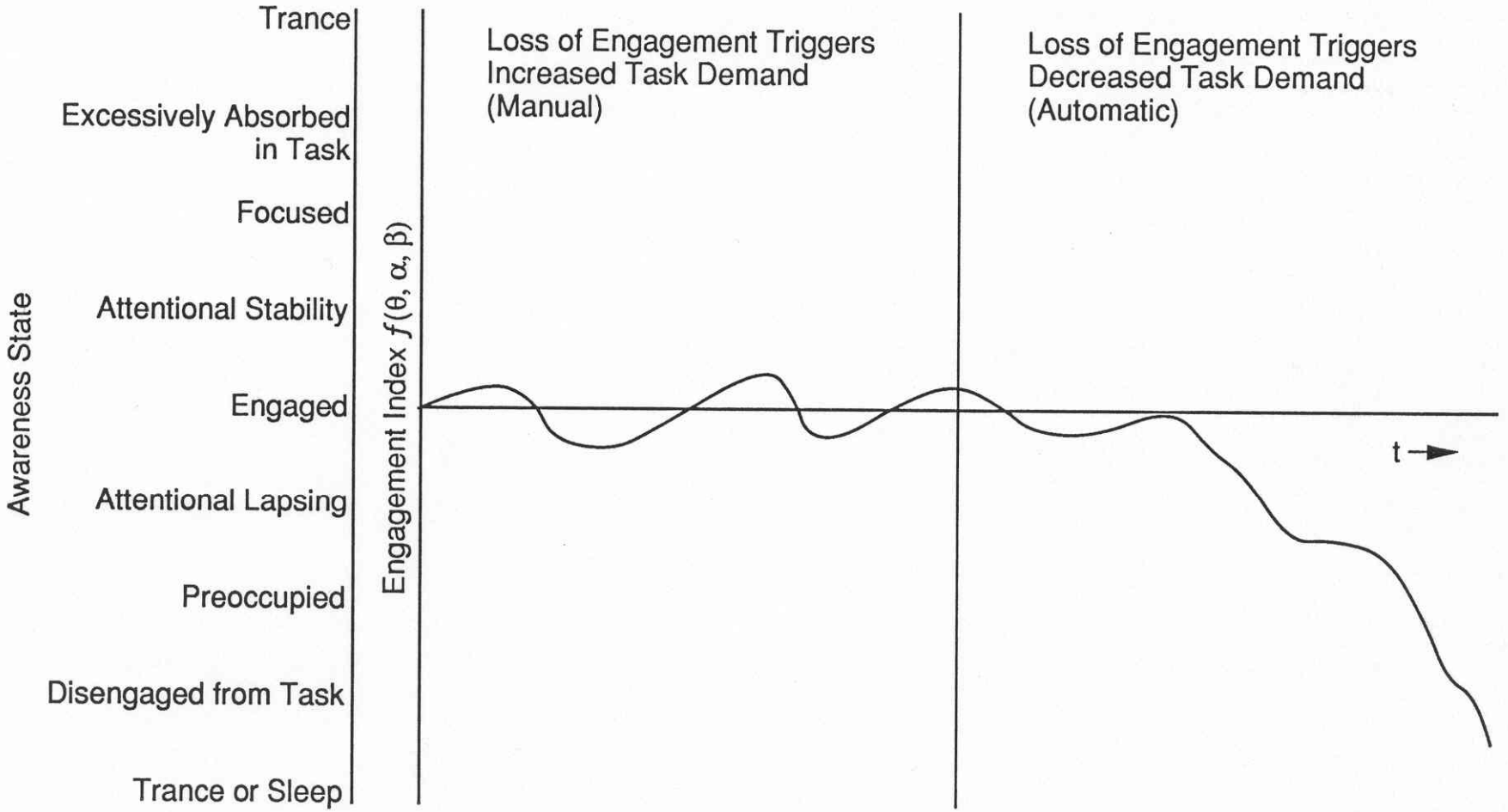


Biocybernetic system:

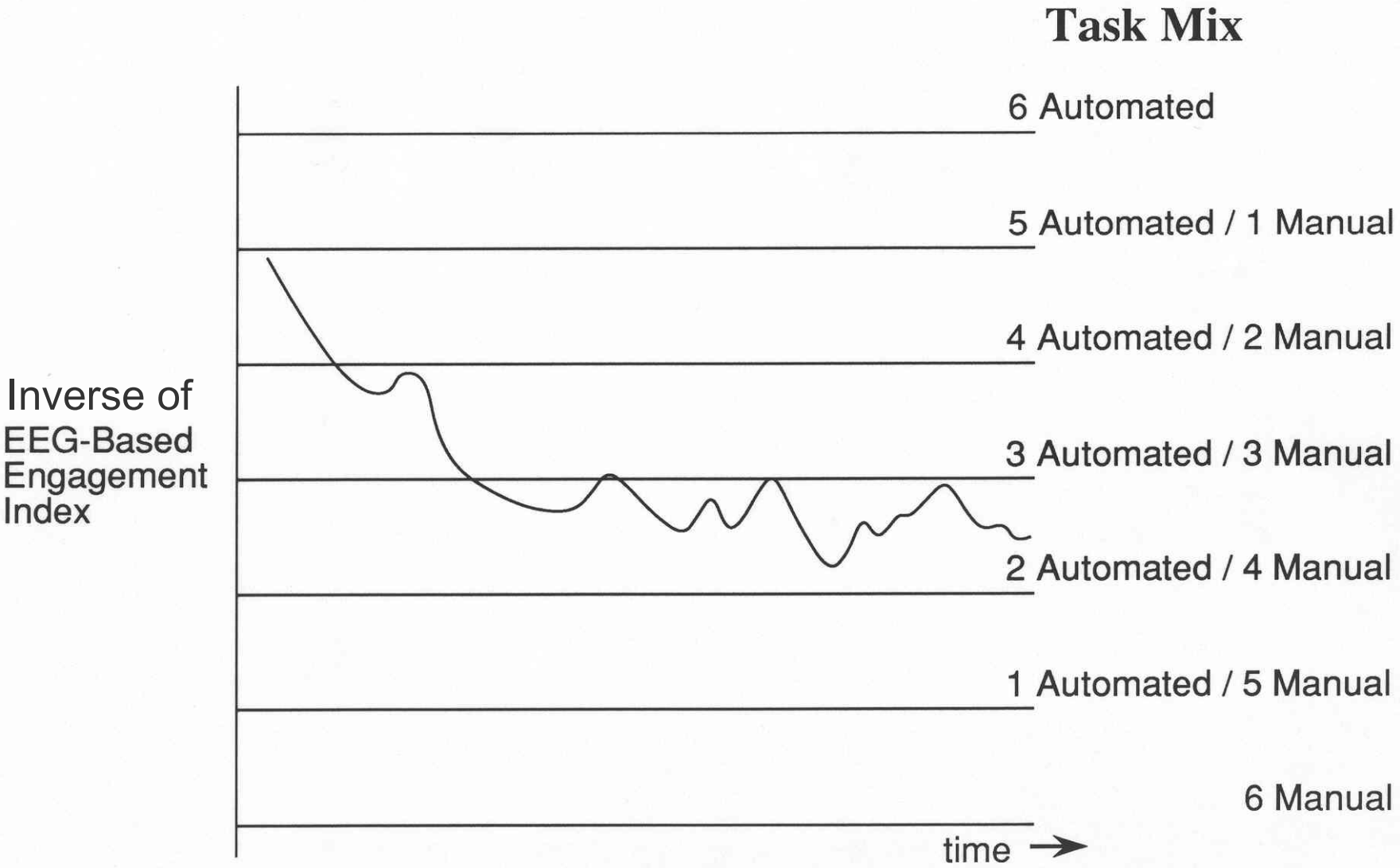
1) Evaluates indices of operator engagement in automated task;

2) Adjusts level of automation based on best index.

State-Contingent Mode-Control Environment for Evaluating an Index Function



State-Contingent Mode-Control Environment for Automation Assessment



The Adaptive System seeks the mix of human/automation task allocation that results in stable oscillation of the engagement index.

NASA Flight Simulators incorporating

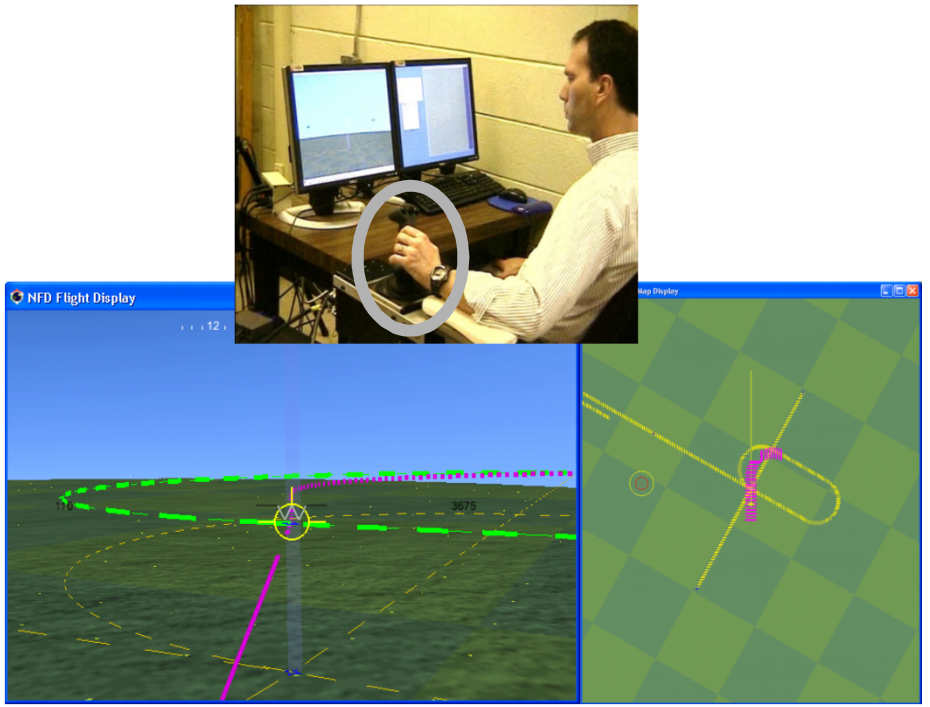
Biocybernetic Technologies

Adapting Automation based upon EEG Measures of Task Engagement

Naturalistic Flight Deck

Current state of the art:
Separate interface for
each automation level
Three ways to move the aircraft

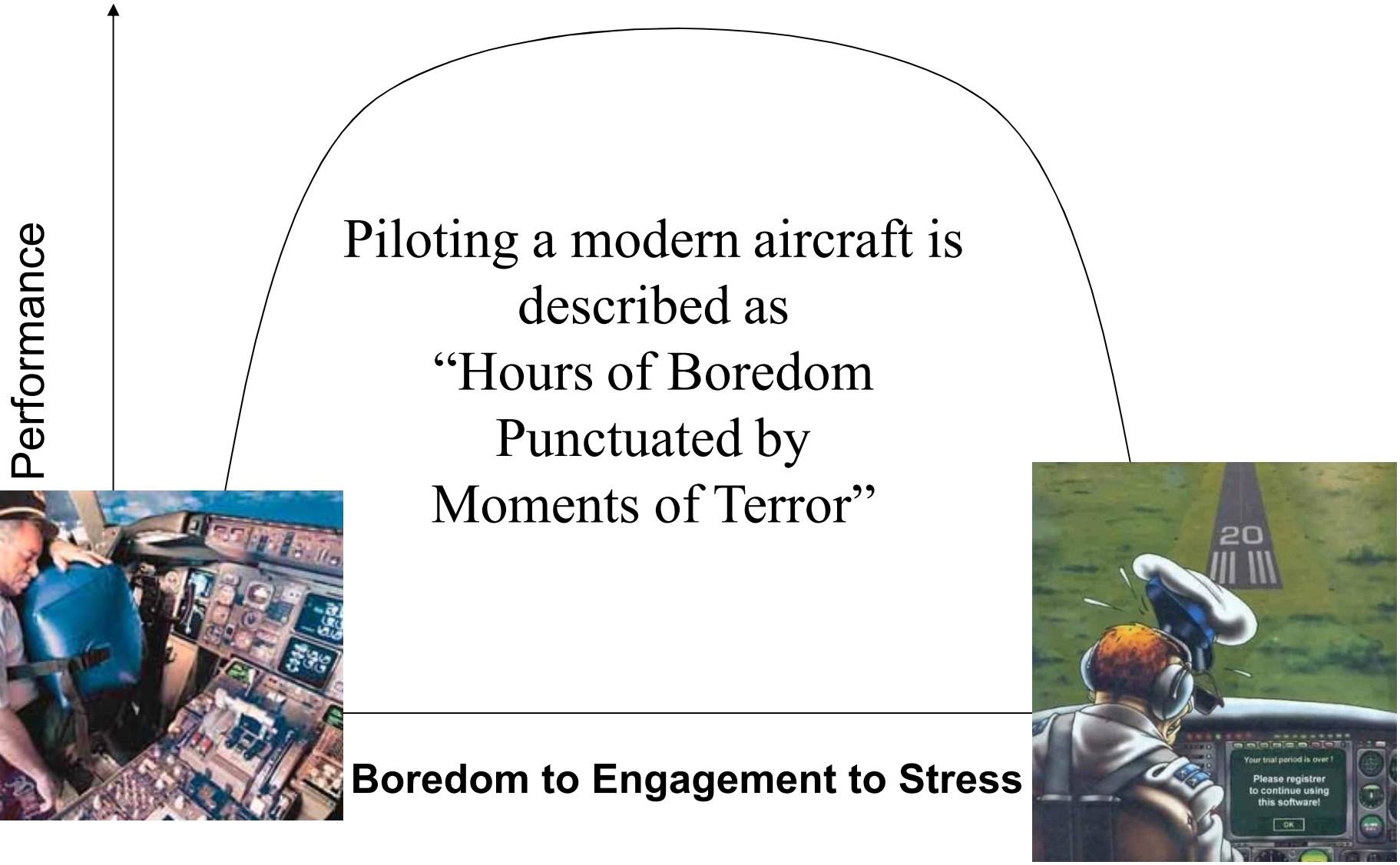
H-inspired:
Single interface allows efficient
management of all levels
One way to move the aircraft



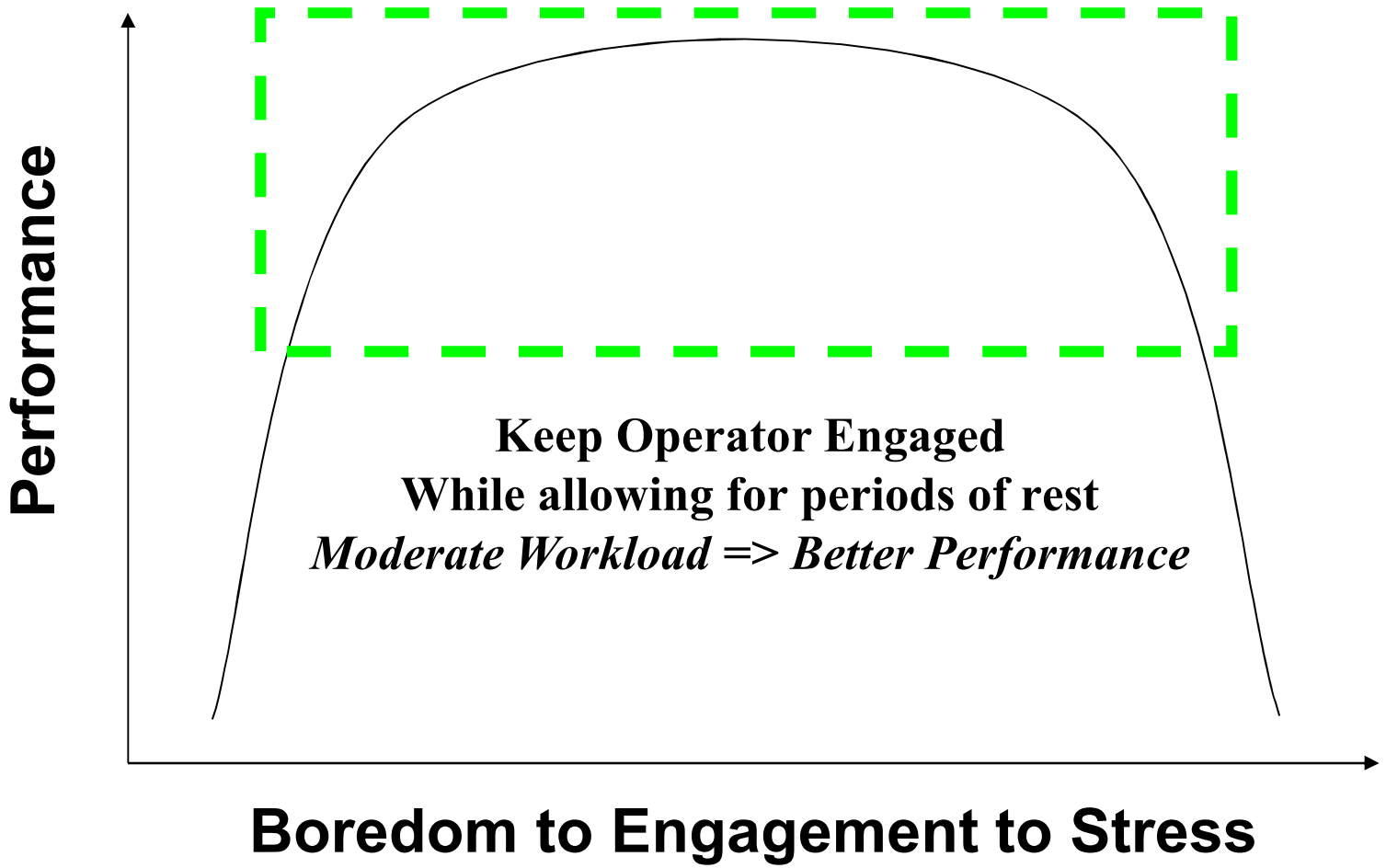
Workload Moderation

- User initiates significant flight behaviors (e.g., turns, takeoffs, altitude changes) at or near the the time of execution (i.e., no lengthy preprogrammed route executions)
- Behaviors are simple to initiate
  - Automation recognizes and supports contextual appropriate options
  - H-mode handles inner-loop control
- Automation provides robust task management alerting
  - Monitors human performance for errors
  - Alerts when tasks are imminent or missed
- Automation performs normal user roles if the user is either unable or is performing a rare task such as troubleshooting or acting as back-up for a failed system
  - H-mode goes ‘to the nearest stable’ if user is incapacitated

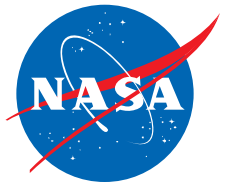
Modern Flight Deck Automation



NFD Goal


Performance
Keep Operator Engaged
While allowing for periods of rest
Moderate Workload => Better Performance
Boredom to Engagement to Stress

Affective State Control Metaphor (ASCM) Study



Psychology at NASA?

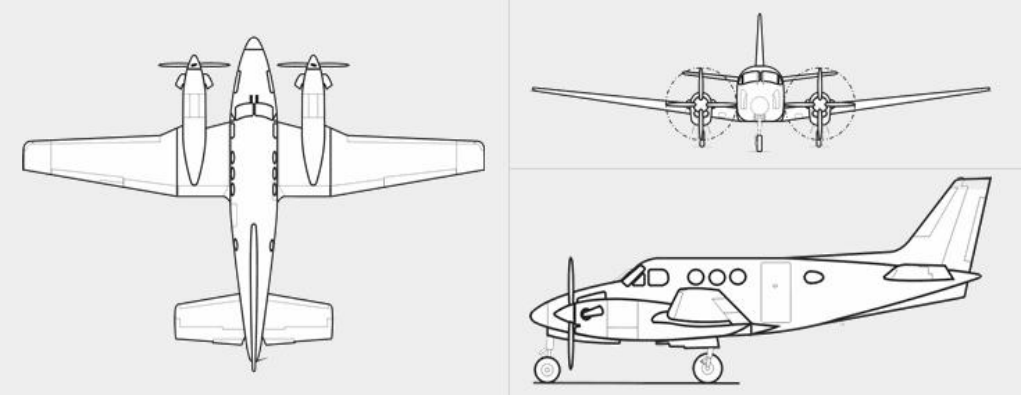
Human Factors

Alan Pope, M.S. EE, Ph.D. trained as a clinical psychologist

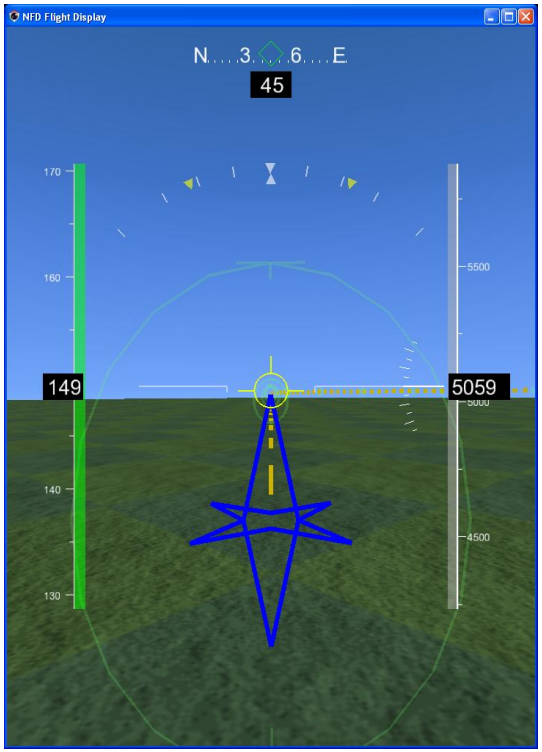
Engagement Index derived from EEG

Naturalistic Flight Deck

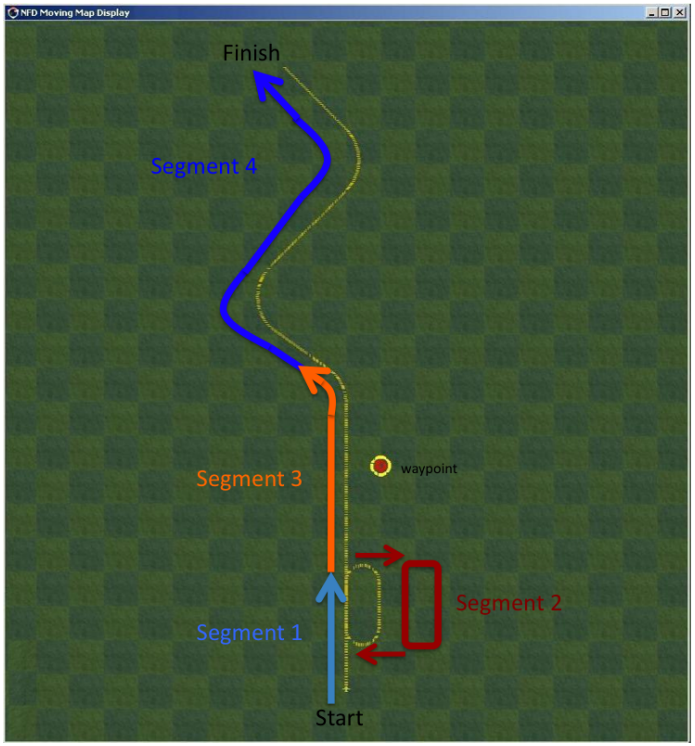
Simulated Beechcraft King Air C90GTi



Primary Flight Display



Moving Map Display



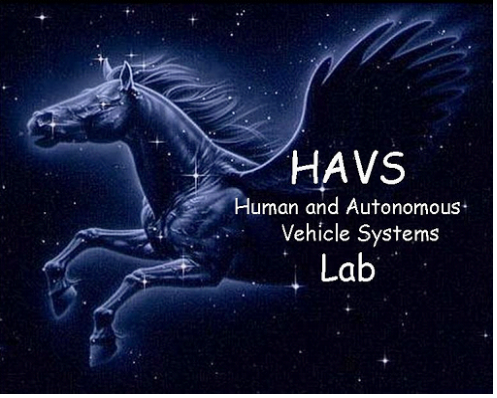
Hypotheses

- Based on previous research it is hypothesized that basic emotional states, both discrete and dimensional, will be distinguishable via patterns of physiology.

  Disrete Emotions
  - Christie & Friedman (2004), Kriebig et al (2007), Nyklicek, Thayer & Van Doornen (1997), Rainville et al (2005), Stephens, Christie & Friedman (in prep)

  Dimensional Emotion Model
  - Winton, Putnam & Krauss (1984), Putnam & Krauss (1991).

- Previous Research in Applied Situations
  - MIT Media Lab - Affective Computing
    - Picard, Vyzas & Healey (2001) Toward Machine Emotional Intelligence: Analysis of Affective Physiological State. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 23, 1175-1191.
  - Psychometrix Associates, INC
    - Hudlicka & McNeese (2002) Assessment of User Affective and Belief State for Interface Adaptation: Application to an Air Force Pilot Task. *User Modeling and User-Adapted Interaction* 12, 1-47.



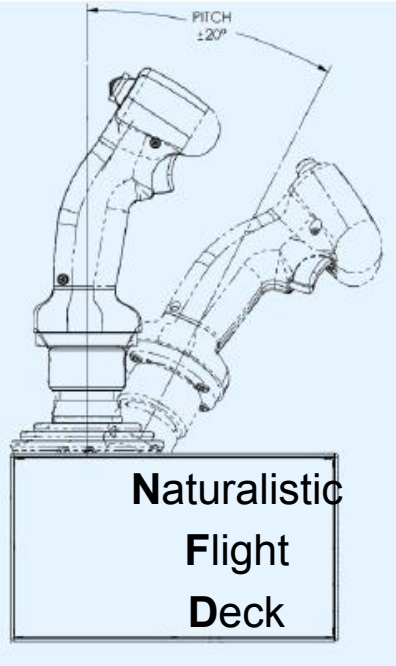
Method

Sample

- ~20 non-pilots (13 men, 7 women)
  - non-smokers, self-report no history of: cardiovascular disorder, neurological disorder, depression, alexithymia

Apparatus

- Naturalistic Flight Deck (simulator)
- Psychophysiological recording
  - gtec gMobiLab
  - Applied Science Lab – Eye Tracker
  - Colin 7000 NIBP



Method

Independent Variables:

- Two vehicle control conditions are presented using a computer based medium fidelity static flight simulation with side-stick controls.
- The two control conditions can be described as car-like and plane-like with differences in how the position of the control inceptor translates commands to the simulated aircraft.

Dependent Variables:

- Physiology (gtec bMobiLab)
  - electrocardiogram (ECG)
  - impedance cardiogram (ICG)
  - Colin - blood pressure (BP) sphygmomanometer/tonogram
  - electroencephalogram (EEG)
  - pulse plethysmogram (PPG)
  - galvanic skin response (GSR)
  - ASL - pupillometer (PO)
- Self-Report
  - Discrete and dimensional affective state
- Performance
  - Side-stick Control - deviation from flight path (Euclidean distance) during each of four flight path segments.

Laboratory Flight Simulator

Experiment protocol

- Informed Consent
- Physiological Equipment Connection
- Flight Sim Training
  - Practice with Plane-like and Car-like controls
- Flight Sim – Plane-like and Car-like controls
  - 4 path segments each followed by Affect Self-Report
- Debriefing

- Session lasts approximately 2.5 hours

A Study of Affective State, Derived from Physiology, in a Computer Based Flight Simulator

Student Name - University

Chad L. Stephens - Virginia Polytechnic Institute & State University

Mentor Names - Directorate

Alan Pope, Paul Schutte & Ralph Williams - Research & Technology Directorate

Project Summary

Emotion is a dominant motivational force in daily life and in moment to moment decisions. The Integrated Intelligent Flight Deck (IIFD) Project is one of four projects in the NASA Aviation Safety Program with a vision for future flight deck systems which sense operator awareness, engagement and affective state to mitigate hazards. The purpose of the current project is to verify the possibility of assessing emotional state while subjects operate a computer based flight simulator equipped with a sidestick control. Empirical evidence from this project will contribute to NASA's Aviation Safety Program through the IIFD Project specifically the Robust Automation and Human Systems (RAHS) element including the goals of operators late sensing technologies and methodologies for in situ operators late classification. The implications for this line of research include a better understanding of the experience of emotions, decreased pilot error, and increased flight safety.

Introduction

- The Robust Automation/Human Systems (RAHS) Element focuses on the development of a flight deck system capable of detecting unsafe operator behaviors or conditions
- In addition to the development of fail-safe methods for dynamically changing information presentation and operator/automation function allocations in the presence of detected hazards.
- This future flight deck system is aware of the vehicle, operator, and airspace system state and responds appropriately.
- The system senses internal and external hazards, evaluates them, and provides information to facilitate timely and appropriate responses to mitigate hazards.
- The current project exemplifies operator state sensing technologies, methodologies, and operator trait characterization studies conducted to help achieve this mission.

Goals

- Integrate physiological recording equipment into a cohesive portable system
- Demonstrate capability of recording physiology *in situ*
  - Note technological problems e.g. interference
  - Note subject discomfort e.g. negative feedback
- Establish data reduction/analysis protocol
- Test hypothesis regarding emotion state characterization

Non-NASA Sources

Guenter Edlinger & Gunther Krausz,
g.tec medical engineering GmbH
GUGER TECHNOLOGIES OEG

Phillip Cusimano, Aleksandar Dimov & Taj Hudson
BIOPAC Systems, Inc.

Lloyd Smith
Cortech Solutions, Inc.

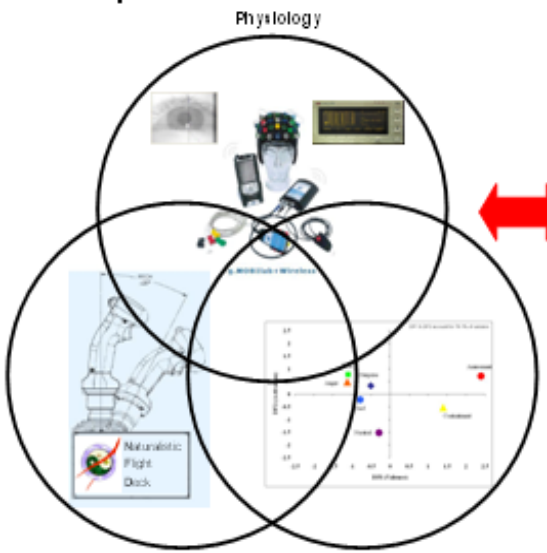
ANSLAB (Autonomic Nervous System Laboratory)
University of Basel, Switzerland

NASA Missions

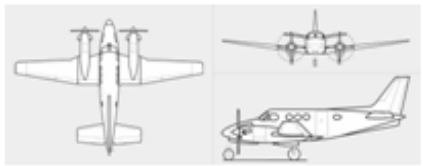
NASA Aeronautics Research Mission Directorate > **Aviation Safety Program**
> **Integrated Intelligent Flight Deck (IIFD) Project** > Robust Automation/Human Systems (RAHS) Element
> **Affective State Control Metaphor (ASCM) Study**

Method

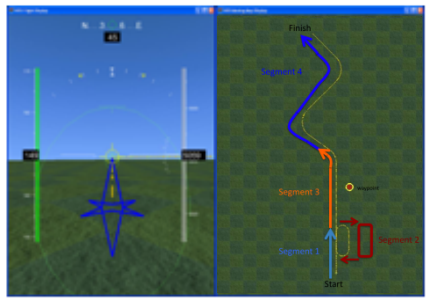
Operator State Assessment



Naturalistic Flight Deck



Simulated Beechcraft King Air C90GTi



Primary Flight Display Moving Map Display

Proposed Analytic Strategy

- **Raw physiological data will be reduced to variables indicative of cognitive awareness/engagement and stress/emotion state.**
- **Pattern Classification Analysis of Autonomic Nervous System (ANS) variables and Affective Self-Report (ASR) variables will be performed by combining subject responses with data previously collected from subjects during experimentally induced emotional state (Figures 1 & 2).**

Figure 1

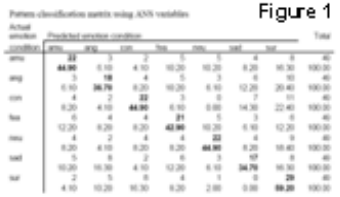
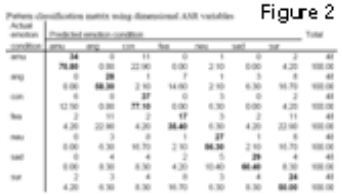


Figure 2



Results

Goals Accomplished:

- gtec gMobiLab optimized and consolidated into a cohesive portable system
- *In situ* physiology recording successfully accomplished
  - adequate signal-to-noise ratio obtained
  - subject discomfort minimized

Remaining Goals:

- Establish data reduction/analysis protocol
- Test hypothesis regarding emotion state characterization

Conclusions/ Future Research

- The current project demonstrates the uses of operator state sensing technologies and methodologies supporting achievement of this mission directorate.
- The planned operator trait characterization whether successful or insufficient will inform the development of the future flight deck.
- Future research can build on the knowledge gain during this project to detect and mitigate hazards related to operator cognitive and affective state.

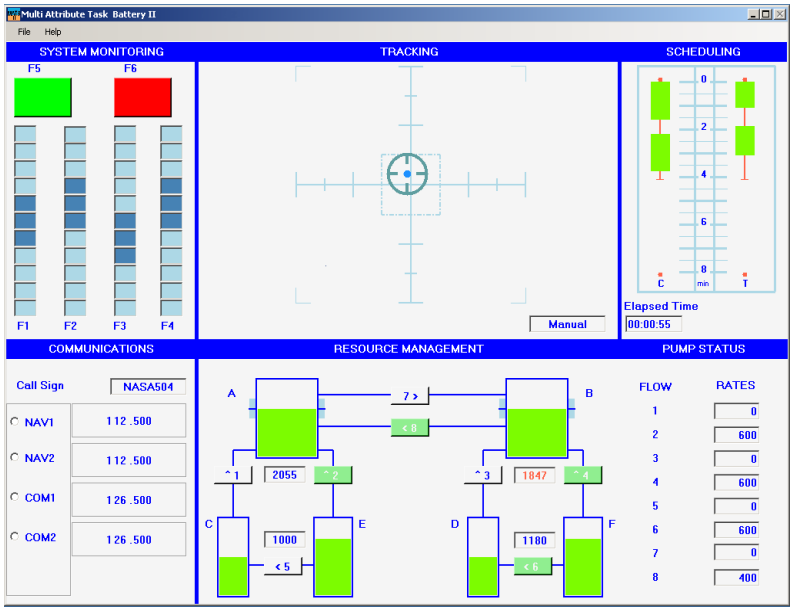
Acknowledgements

Alan Pope for his guidance and electronics expertise. Paul Schutte for his assistance with and ideas for the project. Ralph Williams with out whom this project would have never gotten off the simulated ground. Kara Latorella, Dan Burdette, Ray Comstock, Kyle Ellis and Daniel Mills for their wealth of knowledge and support.

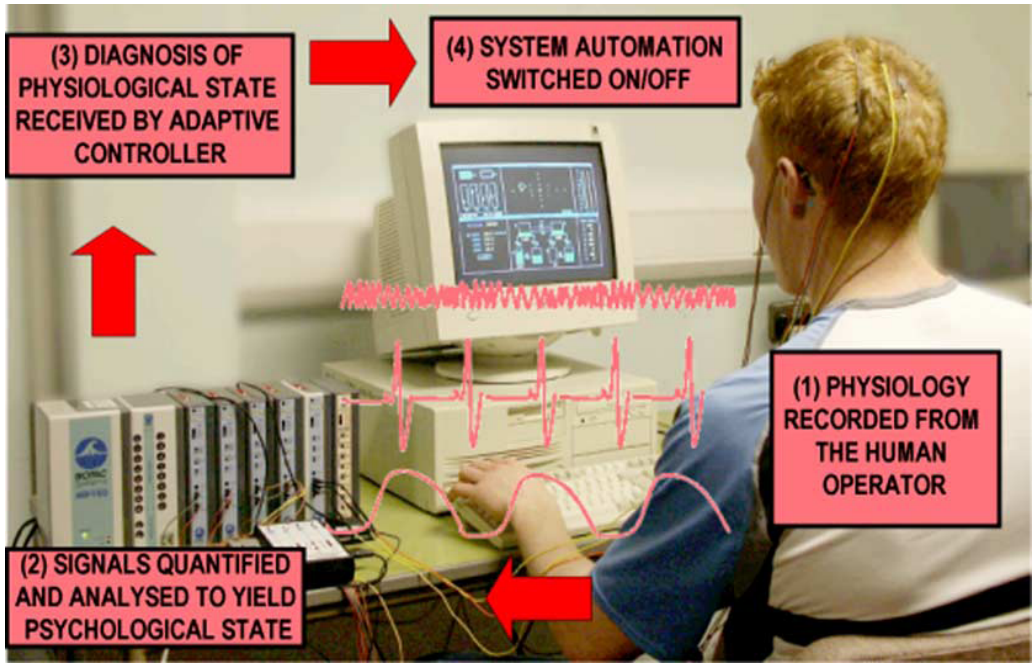
- The NASA Graduate Student Researchers Program (GSRP) is a 12 month fellowship for graduate study leading to masters or doctoral degrees in the fields of science related to NASA research and development.
- The GSRP will support approximately 180 graduate students annually.
- Mentoring and internships at NASA Centers are important aspects of the GSRP Fellowship.

EEG & ECG-derived Indices of Engagement *(Pope & Stephens, LaRC)*

- "Workload–Workload–Workload"
- Underload is a problem too
  - *(c.f., Comstock, Harris, Pope, 1988)*
- EEG-based engagement index (EI) reflects underload conditions
  - *(Pope, Bogart, Bartolome, 1995)*



NASA Multi-Attribute Task Battery - II
(Santiago-Espada & Comstock, LaRC)

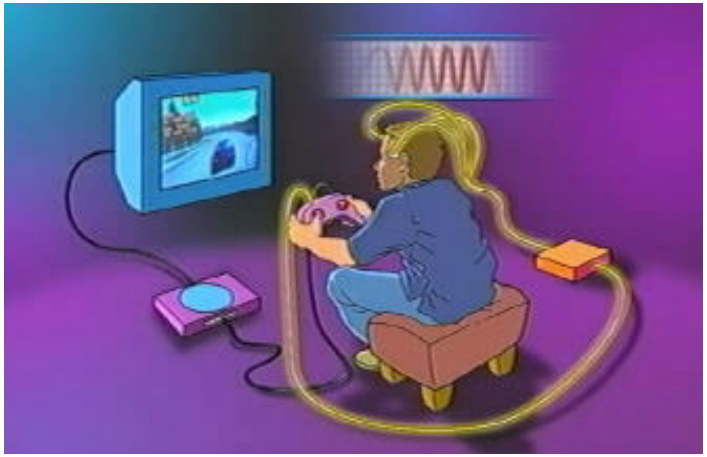


Study 1
- Better Engagement Index
  = f(EEG, ECG), for overload also
- Open-loop automation modulation

Study 2
- Closed-loop automation modulation based on Study 1 Engagement Index

NASA Spin-off Technology

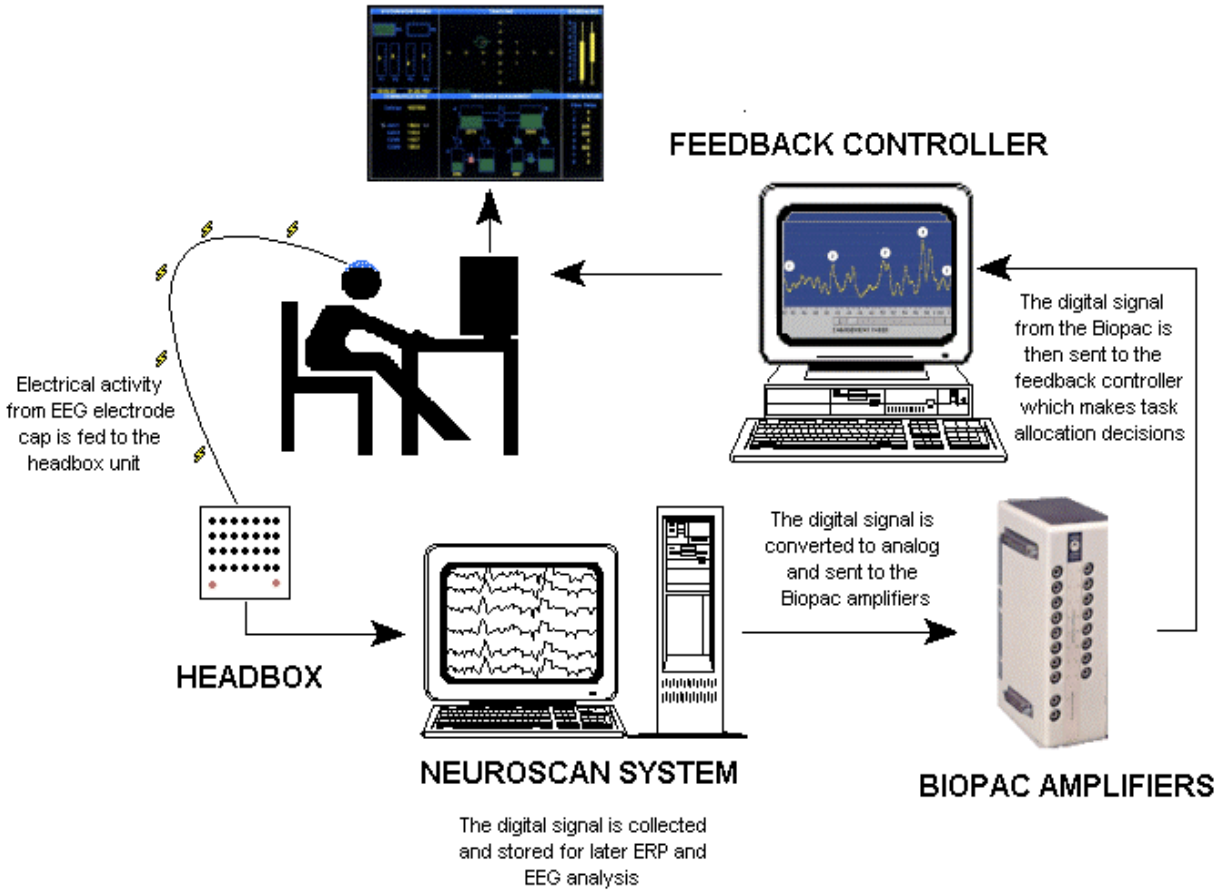
What have you done for me lately?



This biocybernetic adaptive task methodology was spun off
to form the basis for
physiologically-modulated simulation training technologies,
one embodiment of which is a patented videogame neurofeedback invention
for
amelioration of Attention Deficit Hyperactivity Disorder (ADHD) and stress.

Past Research

- The most recently developed human performance enhancement technology is based upon the LaRC biocybernetic flight deck adaptive automation research of the 1990s.

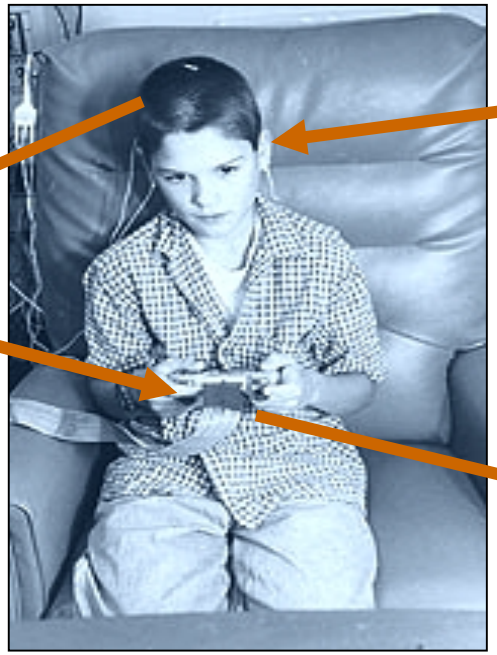


Our technology is not direct control, but interface enhancement

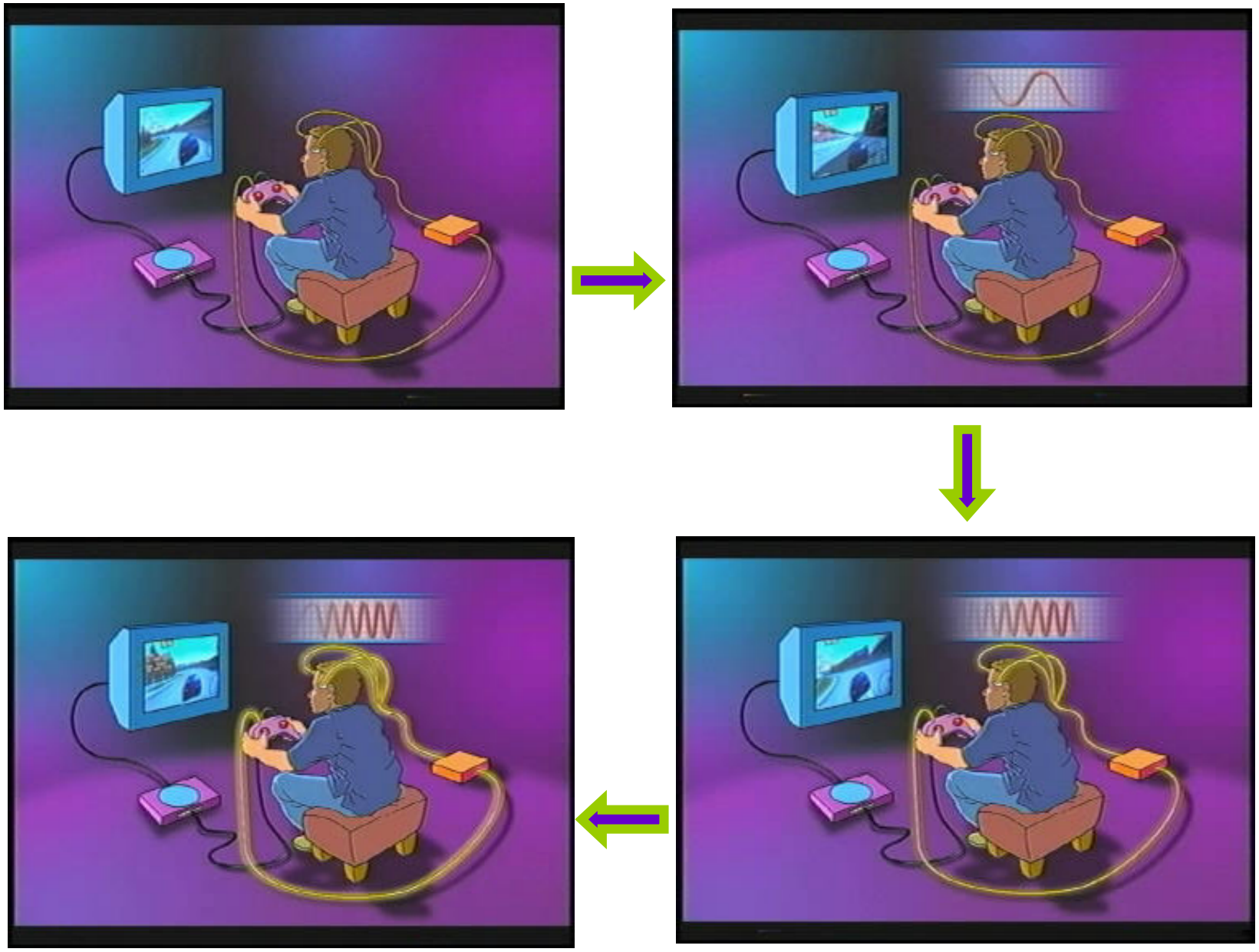
Eastern Virginia Medical School
Videogame Neurofeedback Research

"Video games have actually gotten a bad rap," says Alan Pope, a researcher and clinical psychologist at the NASA Langley Research Center in Hampton, Va. "Games up the stakes as you go along, and you're happy about it. That's a positive thing." – *Business Week, December 1996*

The Videogame Neurofeedback Loop



NASA Concept

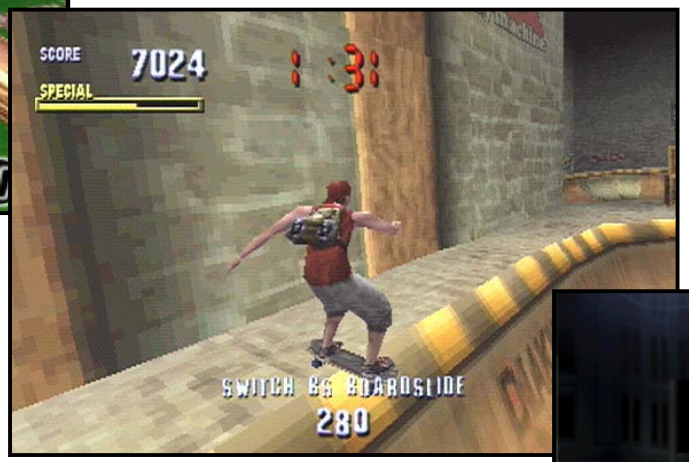


S.M.A.R.T. BrainGames

Truly interactive, fun, self-motivating training.

Spyro the Dragon

New training displays ~ (off-the-shelf video games) can be purchased for $5-$10.



Tony Hawk

Issues of frustration, stress, and performance anxiety become more pronounced during game play. Training can focus on decreasing these issues as they emerge, leading to real world gains.

Gran Turismo

Zeroing Out Negative Effects (ZONE)

Technology for training psychophysiological skills conducive to optimal performance through perturbation of training tasks, environments and devices

ZONE

- The ZONE technology (U.S. published patent application number 20060057549) is a training method for improving performers' responses to stress, anxiety and loss of concentration.

- The technology informs and/or rewards the trainee for successful attainment of an optimal target state of psychophysiological functioning through real-time changes in the task equipment.

- These information and reward consequences can take various forms, including improved configuration of the task environment (e.g., change of putting surface from moving to still).

ZONE

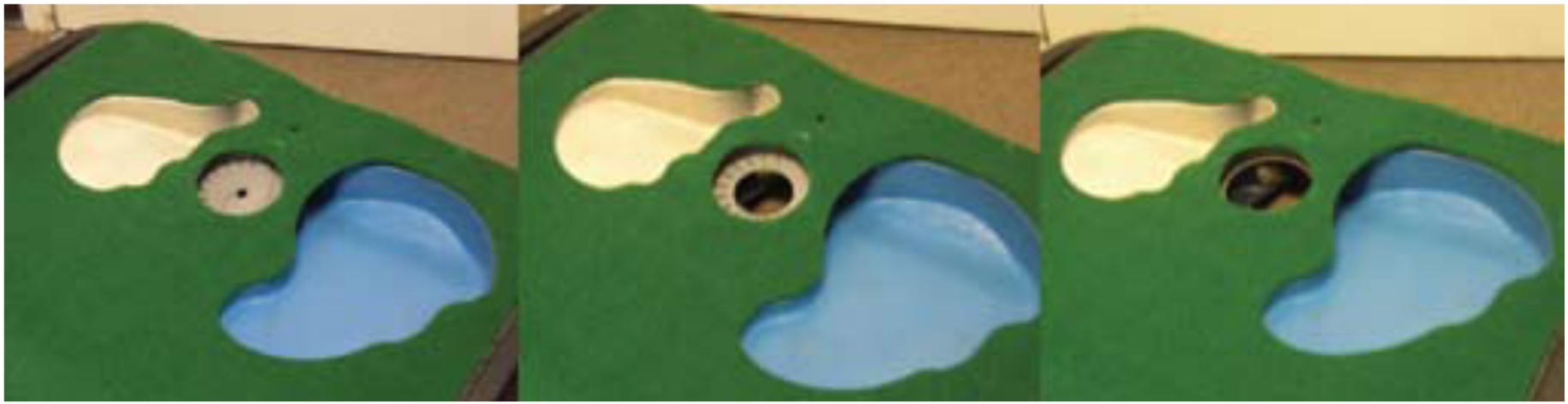
- ZONE is based upon the concept of “Instrument Functionality Feedback” (“IFF”), a biofeedback method originated at LaRC for physiological training of pilots in flight simulators.
- The concept is embodied in the LaRC videogame biofeedback technology (U. S. Patent No. 6,450,820) as well as in a pilot training technology studied at LaRC called “Stress Counterresponse Training.”
- IFF simply means that trainees receive feedback of how their physiology is functioning through changes in the functionality of the equipment that they are operating rather than through graphs and other signal displays, which is the way biofeedback is usually presented.

ZONE

- Research by Dan Landers and Debbie Crews of Arizona State showed that, in the few seconds prior to successfully performing a discrete sport movement, skillful athletes exhibit a particular brain signal reflecting an optimal mental state.

- This finding won the first prize in the Golf Magazine 2001 "Science in Golf " competition and was demonstrated on the PBS program “Scientific American Frontiers”, March 19, 2002 (http://www.pbs.org/saf/1206/segments/1206-2.htm).

ZONE



Increasing Concentration

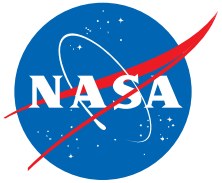
Effect of concentration brainwaves on putting hole size in ZONE training setting

Psychophysiological Modulation of Gameplay

+

Wii can do it!

State of the Art
Gaming and Simulation



Nintendo®

SONY®

Microsoft®

intel

UBISOFT

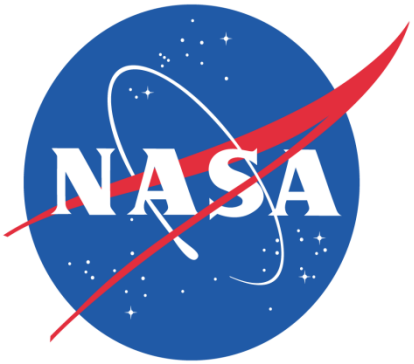
MATTEL®

VIRTUALHEROES®

NeuroSky®
Brain-Computer Interface Technologies

Emotiv Systems®

uncle Milton®



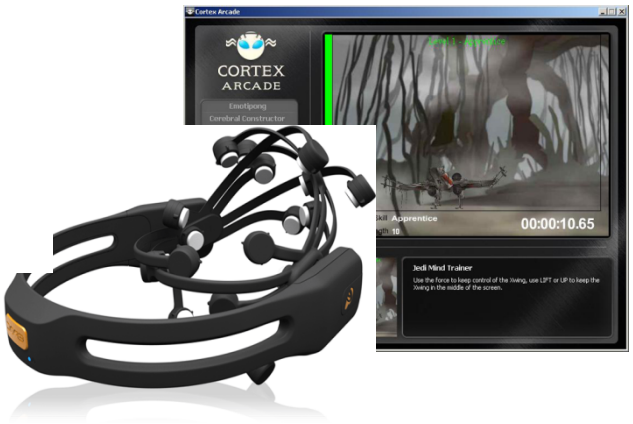
OCZ Technology®

Immersive Experiences

Direct Control via Physiology

Emotiv

Brain Computer Interface Technology



OCZ Technology

Neural Impulse Actuator

Nintendo

Vitality Sensor

Neurosky Inc.

Apple

App Store

Google

Current Bio/Neurofeedback Game Technology

SmartBrain Technologies

BrainMaster Technologies, Inc.

Thought Technology Ltd.

Popular Video Game Systems

Being Enhanced By Psychophysiological Modulation

Nintendo

Sony

Microsoft

Novel Concepts for Videogames

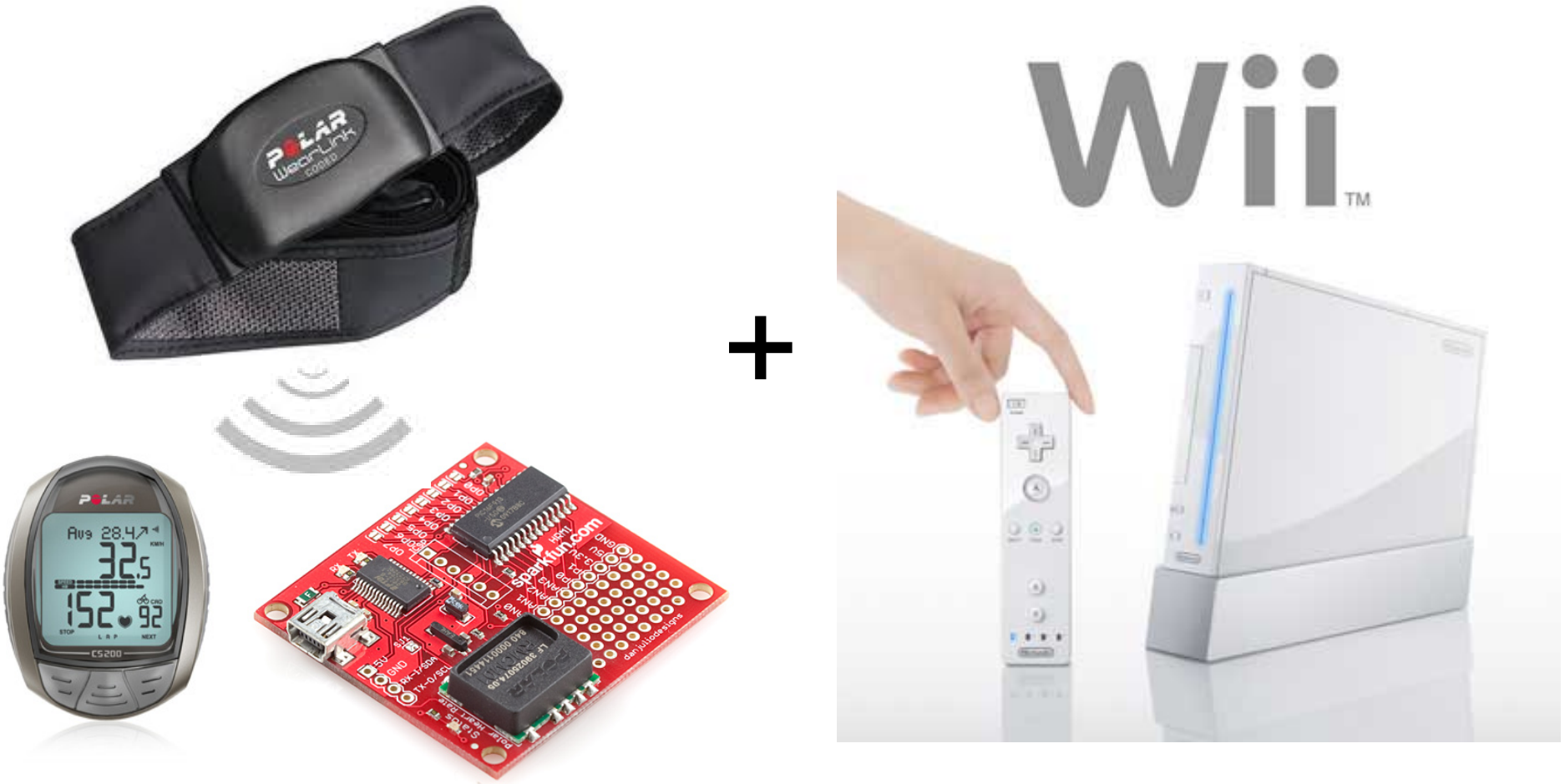
- Enhancing the challenge of gameplay
  - Attenuation (joystick, button & motion-control dampening)
  - Disruption (cursor movement modulation)

- Outside (overt) – Wii motion-control, MS Kinect

vs.

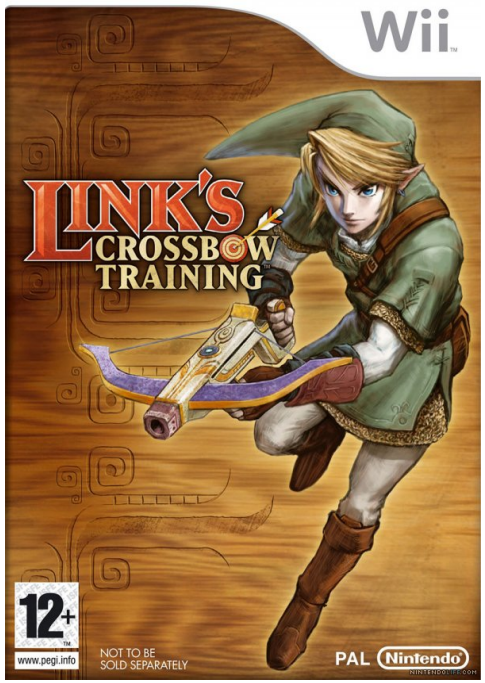
- Inside (covert) Body Behaviors - MindShift

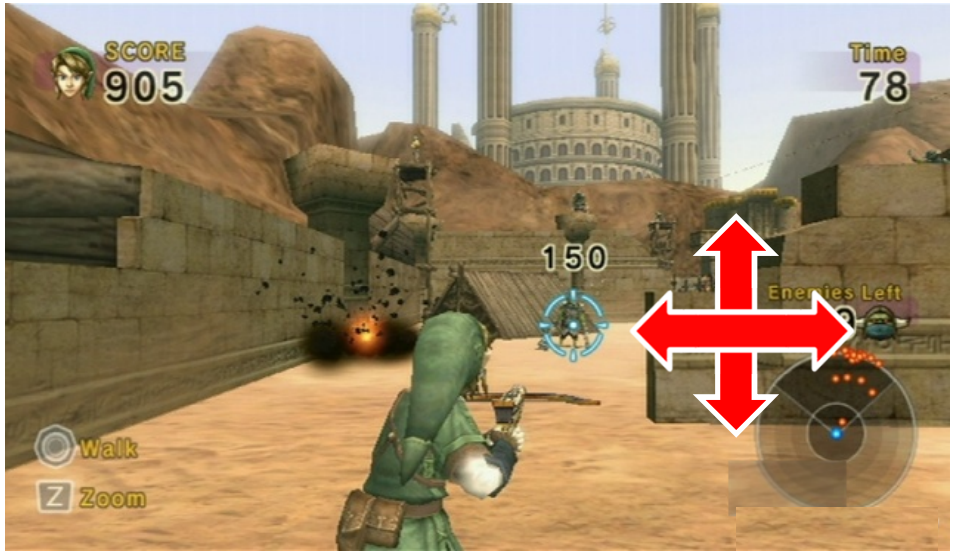
Psychophysiological Modulation of Gameplay

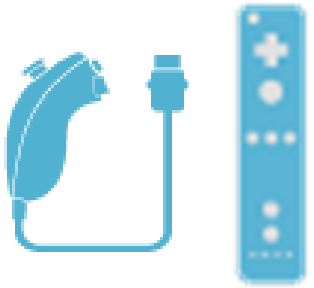


Wii can do it!

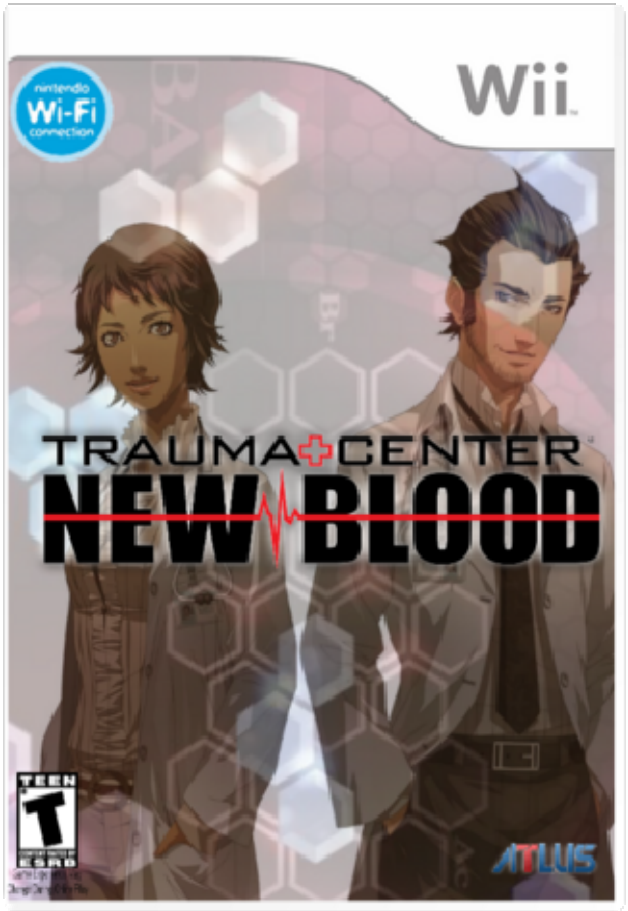
FPS – crosshairs Position *and* POV modulation

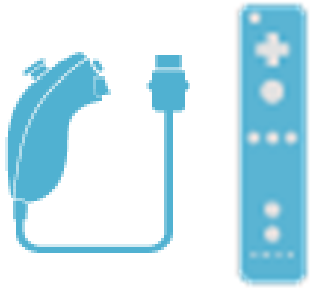




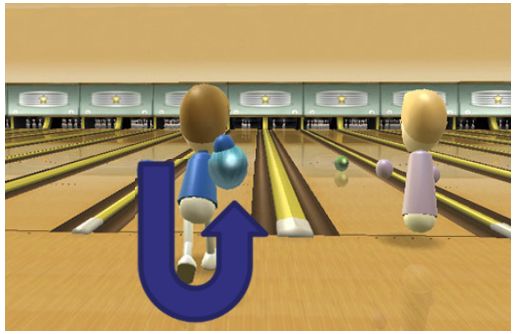


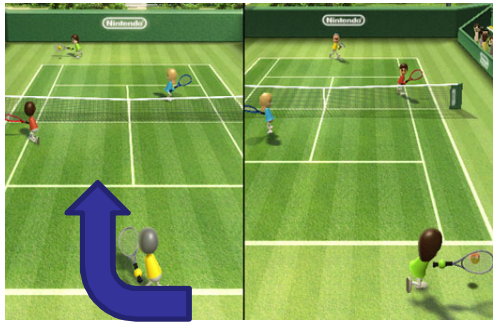
Medical Simulation – cursor position modulation



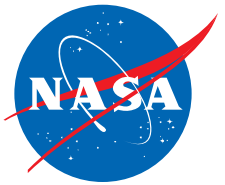


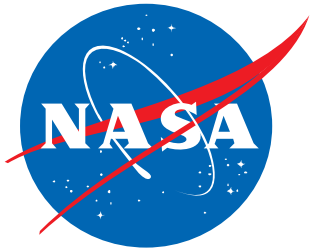
Sports – swing strength modulation





Racing – steering attenuation





Closed-loop Operator State Modulation

Task Engagement Training
Psychophysiological self-regulation helps pilots interact with automation through the enhancement of cognitive resource management skills.

Neurofeedback Videogame for ADHD
Currently being employed in the treatment of ADHD in a network of clinical settings (www.smartbraingames.com).

Mental State Skill Training for Sports
Zeroing Out Negative Effects (ZONE) technology (USPTO Published Patent Application 20060057549)

Stress Counter-response Training
Integrates the requirement to maintain physiological control to the functionality of a simulator, training pilots to maintain physiological equilibrium suited for optimal cognitive and motor performance under emergency events in an airplane cockpit.

Recreation-Embedded State Tuning for Optimal Readiness and Effectiveness
Aims to help crews with the psychological toll of long-duration space flight by training protocols that improve self-regulation of cognitive states.

ZONE

The technology offers wide-ranging applications, including:

- Improving skill-based performance
- Sports psychology – golf, tennis, baseball, football, hockey, basketball, lacrosse
- Marksmanship training – improving aim and concentration
- Video gaming – mental game technology leveraging motion sensor controllers

ZONE

Benefits

- Improves responses to stress, anxiety, and loss of concentration during performance

- Appeals to users by embedding biofeedback training in actual task required to perform better

- User simultaneously masters muscle skill and optimal mental state for executing in real situations