The Interplay of Biocybernetic Adaptation and Biofeedback Training

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“It is accurate to say that biofeedback is the grandparent of all physiological computing technology. It was the biofeedback approach that first used technology to create a closed-loop design to teach human participants the necessary skills for autonomic self-regulation.”
Computer automation of biofeedback training

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An Early Marriage of Biofeedback and Computers in an automated shaping paradigm
Background of Crew State research at NASA Langley Research Center
Human Error in Aviation Incidents and Accidents

• A primary goal of NASA’s Aeronautics research focus is to improve the National Airspace System which already has an exceptionally high level of safety.

• ~70% of incidents and accidents are attributed to human error
Use of Automation in Aviation and Hazardous States of Awareness (HSAs)

• Plays a significant role in the cockpit
  – enables humans to perform beyond normal abilities (longer shifts, improved control, etc.)
• Can lead to suboptimal psychological states
  – complacency
  – boredom
  – diminished alertness
  – compromised vigilance
  – lapsing attention
  – preoccupation
  – absorption
Identification of hazardous awareness states in monitoring environments

Pope, Alan T.; Bogart, Edward H.

SAE PAPER 921136; SAE, International Conference on Environmental Systems, Seattle, WA, United States, July 13-16, 1992

A state identification procedure and a model for predicting aerospace crew/system combinations that interact to produce hazardous states are described. This procedure in conjunction with the model provide a capability for evaluating the design of advanced flight deck automation concepts based on the pilot's ability to maintain effective states of awareness. The model describes individual and situational factors that affect the likelihood that persons in operational settings will experience hazardous states of awareness.

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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
Brainwave Correlates of Hazardous States In Advanced Concepts Flight Simulator
A Model of Crew at Risk for Experiencing Hazardous States of Awareness


Inspiration for Biocybernetic Adaptation research at NASA Langley Research Center
Biocybernetic system evaluates indices of operator engagement in automated task

Alan T. Pope, Edward H. Bogart, Debbie S. Bartolome

Accepted 3 November 1994

Negative Loss of Engagement Triggers Increased Task Demand (i.e., Manual)

Positive Loss of Engagement Triggers Decreased Task Demand (i.e., Automatic)

“performance equilibrium” Hettinger et al. (2003)

Figure 2. Expected behavior of effective engagement index under negative and positive contingencies.
Adapting Automation based upon EEG Measures of Task Engagement
Adapting Automation based upon EEG Measures of Task Engagement
Adaptive Automation for Mitigation of Hazardous States of Awareness

Chad L. Stephens, Mark W. Scerbo and Alan T. Pope

Recent studies employing the LaRC-developed Engagement Index
Spinoffs
Physiological modulation concept based on biocybernetic adaptation
Physiological Modulation

Physiological Modulation in the sense used here refers to an ongoing process (e.g., a manual task, as in a video game) that is being changed or shifted by an external influence (a physiological signal).

Analogous to:

- In electronics and telecommunications, modulation is the process of varying one or more properties of a periodic waveform, called the carrier signal, with a modulating signal that typically contains information to be transmitted.

Amplitude and Frequency modulation

- In music, modulation is most commonly the act or process of changing from one key (tonic, or tonal center) to another.

Musical modulation

Brain Computer Interface (BCI) compared to Physiologically Modulated Control (PMC)

Have you ever noticed that “The Force” in Star Wars is used in two different ways?

In raising the Starfighter from the swamp, “The Force” is used alone - not to enhance manual skill.

In Luke’s training with a light saber, “The Force” is used to enhance manual skill.

A similar difference distinguishes the Physiologically Modulated Control method from the conventional Brain Computer Interface method.
A key characteristic of this design is the distinction between direct control and modulation of control.

This distinction parallels the distinction made by Fairclough between intentional brain-computer interface operation and the biocybernetic adaptation paradigm that is based on spontaneous operator functional state.

Physiological modulation is an example of “BCIs as intelligent sensors” that synergistically integrates BCI sensors with the manual mode of control input.
Dr. James A. Naismith invented basketball, little knowing that he would not only fill that hour with a more enjoyable activity, but he would also create one of the twentieth century's most popular sports.

The invention of basketball serves as a model for using games to promote adherence to an exercise regimen (like biofeedback training).

Seminary students at the International Young Men's Christian Association Training School in 1891 were required to exercise for one hour per day. While students played football in the fall and baseball in the spring, they had no winter sport and had to resort to one hour per day of calisthenics, which was extremely unpopular.
Split Screen:

Left: Simulated physiological signal crossing reference levels.

Middle: Videogame Controller

Right: Real-time combined effect of physiological signal level and hand control.

Introduced in:
Early embodiment of the physiological modulation concept: Extended Attention Span Training (EAST)
The number and agility of enemy X-Wing fighters is inversely proportional to an EEG bandpower ratio.

A horizontal bar graph displays the magnitude of the ratio (“The Force”).

Player steers and fires weapons using a joystick.

Introduced in:

The Videogame Neurofeedback Loop

Gran Turismo™ Game

Sony Playstation

Gran Turismo is a trademark of Sony Computer Entertainment, Inc.
Eastern Virginia Medical School
Videogame Neurofeedback Research
Videogame Modulation by EEG

Beta/(Theta + Alpha)

Adjustable Offset for Shaping

Accelerator (X) Button Pressed

Full Racing Speed

Barely Moving

SMR

Adjustable Threshold for Shaping

Vibration Signal

Loss of Steering

10 seconds

Accelerator (X) Button Pressed

Accelerator (X) Button Pressed

Videogame Modulation by EEG
PARENT POST-TREATMENT SATISFACTION SURVEY

Satisfaction with results

How much their children enjoyed coming for treatment

N.S.  p<.03
CHILDREN’S POST-TREATMENT SATISFACTION SURVEY

Satisfaction with results

How much they enjoyed coming for treatment

p=.03

N.S.
POST-TREATMENT SATISFACTION SURVEY

ESTIMATES OF HOW MUCH (0-100%) ADHD PROBLEMS HAVE IMPROVED FOLLOWING TREATMENT

Parent Ratings

Children’s Ratings

N.S.

p<.07
Summary of Findings in EVMS study

- Both the videogame and standard neurofeedback groups improved significantly on most main ADHD outcome measures. No significant difference in treatment change was seen in group comparisons.
- Parents’ subjective appraisal of treatment effect on ADHD was more positive for the videogame group.
- The videogame treatment was rated significantly more enjoyable by both parents and children.
- Trends on pre-post QEEG change maps indicate that the videogame training may have advantages in creating more quantitative EEG effect in the therapeutic direction.
Conclusions of EVMS study

- The videogame biofeedback technology, as implemented in the NASA prototype tested, produces equivalent results to standard neurofeedback in effects on ADHD problems.
- Both the videogame and standard neurofeedback improve the functioning of children with ADHD substantially above the benefits of medication.
- The videogame technology provides advantages over standard neurofeedback treatment in terms of enjoyability for the children and positive parent perception, and possibly has stronger quantitative post-treatment effects on EEG.
Advantages of videogame biofeedback

- Inherently motivating, keeps trainees on task continually
- Blends sophisticated neurofeedback (or biofeedback) training into popular entertainment in such subtle ways that none of the entertainment value is lost and EEG biofeedback is no longer a chore but a treat
- Allows individuals to select the games that they like best, making sure that the games stay current and are suitable for each person’s gender and developmental level
- Can be used largely without clinician involvement or effort – making group treatment or properly arranged home use easy
- Is inexpensive technology, as game software does not have to be written for EEG biofeedback
From flight simulation to brain stimulation: The S.M.A.R.T. BrainGames system uses electroencephalogram neurofeedback to make a video game respond to the activity of the player’s body and brain.

Compatible with off-the-shelf Sony PlayStation® video games, the interactive, at-home video training tool fully preserves high-tech entertainment value, unlike previous biofeedback methods that had a propensity to be too repetitive and simplistic.

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Zeroing Out Negative Effects (ZONE)

- Technology for training psychophysiological skills conducive to optimal performance through perturbation of training tasks, environments and devices
• The ZONE technology (U.S. patent number 8628333) 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
An embodiment of U.S. patent number 8628333

Biofeedback Training for Optimal Athletic Performance
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
Some game consequences reward the player for achieving a psychophysiological goal by diminishing an undesirable effect in the game (analogous to negative reinforcement). These are analogous to the “unnecessary obstacles we volunteer to tackle” that McGonigal identifies in video games. “We set these unnecessary obstacles for ourselves because overcoming them is fun. It creates a positive kind of stress, called eustress, which is actually good for us. It gives us a sense of achievement, makes us more ambitious and more likely to succeed.” [Jane McGonigal, “Reality is Broken: Why Games Make Us Better And How They Can Change The World”]

Other game consequences reward the player for achieving a psychophysiological goal by producing a desirable effect (analogous to positive reinforcement) such as additional scoring opportunities. That is, some modulation effects enable superimposed disadvantages in a digital game or simulation to be reduced by physiological modulation, whereas others enable advantages to be effected by physiological modulation.
Wii Games used in NASA LaRC MindShift prototypes

- Link’s Crossbow Training
- Iron Man
- Trauma Center New Blood
EEG-based MindShift FPS
Edison Nation

Google + Hangout Live

NASA Langley MindShift-Edison Nation Challenge Q&A

Hosted by:
NASA Langley Research Center
738 have them in circles

Add to circles
Modulated robot (protects itself and others from an inattentive operator)

- Enables practicing bidirectional self-regulation (slowing & speeding robot to maneuver)
- Supports self-regulation competitive robot games
Physiological User Interface For A Multi-User Virtual Environment (MUVE)

Pope & Palsson (2011)
SpyNet COTS physiological modulation game, “Wavelengths”

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RESTORE:
[A] mission task simulations (instrument functionality feedback)
[B] recreational activities encouraging recurrent practice for honing effective physiological responses
[C] monitoring and assessing physiological responses to task challenges
• How does it fit within the NASA mission?

  – “Congress declares that the general welfare of the US requires that the unique competence of NASA in science and engineering systems be directed to assisting in bioengineering research, development, and demonstration programs designed to alleviate and minimize the effects of disability.” The National Aeronautics and Space Act, Sec. 20102. (f)

  – Projected as a pilot training technology to be researched under Committee on Aviation Safety Technology (CAST) Safety Enhancement (SE) 211 work in Crew State Monitoring (CSM) element
Spin-Back to Core Research

Commercial Aviation Safety Team (CAST) mandate to study Training for Attention Management

“Training-based mitigations - self-diagnosis methods for flight crew members to recognize and recover from channelized attention, confirmation bias, startle/surprise, and diverted attention”

Analogous to training to recognize symptoms of hypoxia
NASA LaRC Core Research

ARMD AvSP Crew State Monitoring
LaRC Cockpit Motion Facility Research Flight Deck

ARMD ASP Cognitive State Assessment
LaRC Human and Autonomous Vehicle Systems Lab
Spin-Back to Core Research

• Commercial Aviation Safety Team (CAST) mandate to study Training for Attention Management

• “Training-based mitigations - self-diagnosis methods for flight crew members to recognize and recover from channelized attention, confirmation bias, startle/surprise, and diverted attention”

• Analogous to training to recognize symptoms of hypoxia
• What if we could accomplish a goal of improving pilot’s attentional and stress self-management by subtly conditioning their attentional and stress self-management skills during simulator training?

• Trainee pilots would experience a flight scenario where environmental conditions are modulated by their self-management of their attentional resources. For example, simulated turbulence or buffet would be programmed to be proportional in amplitude to a brain/physiological measure of inattention. Or ambient lighting or temperature would similarly be adjusted.

• While dealing with operational challenges in the simulation, subject pilots would experience a diminution of adverse environmental conditions as their attention management skill improved.
Spin-Back to Core Research

• That self-regulation skill can be learned in the context of games and simulations requires an appreciation that the learning that takes place when interacting with games involves psychophysiological conditioning as well as instructional and/or entertainment content delivery.

• Individuals may also hold beliefs that militate against acceptance of the possibility of learned self-regulation, similar to the concept of “theories of intelligence” that identifies impediments to academic achievement (Dweck).

• An individual’s “theory of self-regulation” would refer to an individual’s attribution of their self-regulation ability to either a fixed state (I can or I cannot self-regulate my attention, arousal, etc.) as opposed to an incremental change view such that self-regulation skill can be developed through practice with feedback.
References


For coverage of our core research:

Adaptive Automation for Mitigation of Hazardous States of Awareness  
Chapter 26 in *The Handbook of Operator Fatigue*  
edited by Matthews, Desmond, Neubauer, and Hancock, Ashgate 2012.

For coverage of our biofeedback work:

Pope, A.T., Stephens, C.L., and Gilleade, K. M.  
Biocybernetic Adaptation as Biofeedback Training Method  
Chapter 5 in *Advances in Physiological Computing*  