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**Pilot Biofeedback Training in the Cognitive Awareness Training Study (CATS)**

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## PILOT BIOFEEDBACK TRAINING IN THE COGNITIVE AWARENESS TRAINING STUDY (CATS)

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### ABSTRACT

One of the ongoing problems that pilots face today is a diminished state of awareness such as boredom, sleepiness, or fatigue during cruise conditions that could result in various pilot errors. This study utilized a cognitive training exercise to sharpen the pilot's awareness during simulated flight thereby providing them with a means to overcome these diminished states of awareness. This study utilizes psychophysiological methods in an attempt to assess a pilot's state of awareness more directly. In turn, the pilots will be able to train themselves to recognize these states of awareness and be more mentally sharp during mundane tasks such as those experienced in cruise conditions. The use of these measurement tools may be beneficial for researchers working within the NASA Aviation Safety Program. This paper will provide the reader with some background information concerning the motivation for the study, a brief description of the experimental setup and design matrix, the dependent and independent variables that were employed, and some preliminary findings based on some of the subjective and objective data that was collected. These preliminary findings are of part of an ongoing study being conducted at the NASA Langley Research Center in Hampton, Virginia.

### INTRODUCTION

What is biofeedback training? Several definitions of biofeedback training have been developed over the years, but there are two distinct ones that help to more clearly outline its true meaning. The first one provided by John Andreassi reads as thus, biofeedback training is "a means providing immediate information regarding physiological processes about which the individual would normally be unaware."<sup>1</sup> The other one that further helps to support this is stated by Douglas Bernstein, *et al.* Bernstein states that biofeedback training is "a special method in which a measuring device tracks and gives information about biological processes like blood pressure; still, the processes themselves remain out of conscious awareness."<sup>2</sup>

Since the 1960s, biofeedback has been used to help patients treat and/or overcome specific ailments such as bronchial asthma, drug and alcohol abuse, anxiety, tension and migraine headaches, cardiac arrhythmias, essential hypertension, Raynaud's disease/syndrome, and others. But not only does biofeedback training treat physiological ailments, but it can also be employed to

deal with psychological disorders such as post-traumatic stress disorder, depression, anxiety, and the like.

The question that begs to be asked is if it is possible to apply similar and/or new techniques to people who experience normal changes in their states of awareness due to boredom, sleepiness, or fatigue brought about by tasks that seem to be more of a mundane monitoring nature. An example of this would be a pilot flying in cruise condition with autopilot fully engaged. In this task scenario, the pilot's main functions are to monitor traffic and weather and to oversee the controls system operation that the autopilot has taken over. But due to the fact that these tasks are not as mentally engaging as tasks during takeoff or landing, a pilot may experience diminished states of awareness such as the aforementioned states of boredom, sleepiness, or fatigue. These states could in turn impair the pilot's ability to effectively monitor and maintain the airplane's state. Lapses in effective monitoring may result in instances of pilot error which could lead to aircraft incidences such as Controlled Flight Into Terrain (CFIT), mid-air collisions, flying into hazardous weather conditions, misinterpretation of aircraft control information, or misinterpretation of aircraft failures and/or alarms.

One goal in the study of aviation safety is to try and reduce and possibly eliminate errors caused by poor judgments of the pilot. There are different means currently being employed to help reduce the fatigue and workload of the pilot such as changing some of symbology and visual stimuli that the pilot sees in the flight displays and various other displays on the control panel itself. But of particular interest is the ability to detect these states of awareness so that these cues in the control panel can actually help to reengage the pilot and train them to be more mentally sharp and prepared. This study helps to promote this ideal by utilizing cognitive training exercises that are invoked the moment the data acquisition system recognizes that the pilot is experiencing the aforementioned states of awareness. This study actually is comprised of three phases. The first phase that has been conducted recently is the subject of this paper.

In phase I, a simple flight scenario was developed using Microsoft® flight simulator 2000 where several test subjects demonstrated takeoff, cruise, and aircraft anomaly identification. A more detailed description of the experiment is described in the method section below. Reaction time, proper anomaly identification, EEG, and heart rate were the main variables studied in this experiment. The goal is to see if the cognitive exercise has a positive influence on the awareness and the performance of the test subjects. If it does, then the second phase of the study will commence. Therefore, the hypothesis in phase I is that by utilizing these cognitive exercises during cruise flight, the pilot will be more mentally sharp as inferred from a more active EEG signal and will react faster to problems faced in the operations of the flight simulator and also resolve the problems quicker as well. The brain wave patterns will also show a more active state of awareness.

In phase II of the study, test subjects will utilize this same training exercise before flying the test scenario and see if there are any long-term effects of the training. In the third phase of the study, a psychophysiological data acquisition system will be utilized to measure various indices such as EEG or heart rate real-time to determine when the pilot has indeed begun to experience these diminished states of awareness. Once the system has recognized these diminished states of awareness, the computer will first put the simulated aircraft into autopilot and then invoke this cognitive training exercise by itself to help the test subjects to overcome these previously mentioned states of awareness. Then, the acquisition system will return the pilot back to his normal flight duties. The system will also be tested to help accommodate instances where the test subject has encountered high workload

environments and has showed signs of high mental stress. It will then provide some means to take over some of the duties of the flight automatically to help offload and prioritize the tasks for the test subject so that it can reduce and/or manage their level of stress. Once the system detects that the workload has decreased, then the tasks will be returned to the test subject. Again, the goal of this study is to help provide for a new means to deal with these diminished states of awareness that are often experienced by commercial and general aviation pilots.

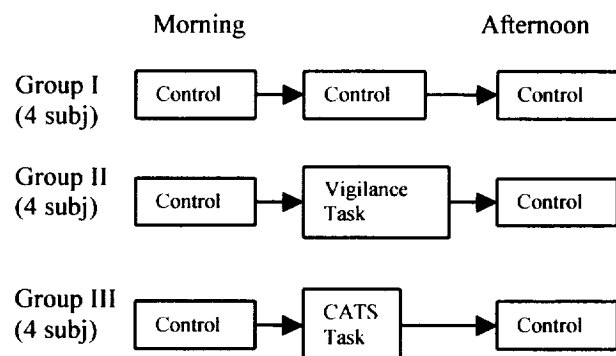
## **METHOD**

### **Subjects**

Subjects that were used in phase I of CATS consisted of 12 males whose age range was from 22 to 64 years old. They also possessed 4 to more than 20 years of computer experience using Macintosh®, Microsoft®, and/or UNIX® systems. Their level of education ranged from an Associate of Science Degree to a Ph.D. The attempt was to find test subjects that had some experience using Microsoft® Flight Simulator, but due to the lack of participation from the initial call for test subjects, it was necessary to elicit test subjects who had no experience with this particular software to meet the desired total number of test subjects. As for experience dealing with physiological monitoring, almost 60% of the test subjects have had some experience being monitored, mostly by heart rate sensors.

### **Experiment Design and Test Matrix**

The experimental design and test matrix is shown in Figure 1:



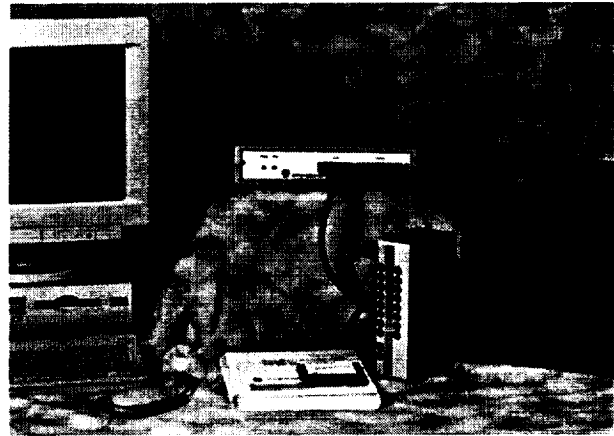
**Figure 1. Experimental design and test matrix.**

The test subjects were broken into three groups using a mixed-subjects approach. The three groups as shown in

Figure 1 consist of a control group (N=4), a vigilance group (N=4), and an experimental group (N=4). Each group experienced three experimental sessions in which a flying scenario was invoked that included a different aircraft anomaly per session that was preset within the software. The anomalies included failures first, in the altimeter, second, in the attitude indicator (artificial horizon), and lastly, in the vertical speed indicator. Each test subject was required to identify the anomaly when it occurred through a verbal response while at the same time press a button to help time sync the response with the physiological data. They were also given various pre-recorded Air Traffic Control (ATC) commands that provided them altitude and heading information. Prior to the study, the test subjects were given several background questionnaires, which included a biographical questionnaire, Levenson's Locus of Control Scale<sup>3</sup>, Proneness to Boredom Scale<sup>4</sup>, and the Epworth Sleepiness Scale<sup>5</sup>. The data collected from these questionnaires were analyzed prior to the study to help determine a fair and proper distribution of the test subjects amongst the three groups. All the data were then standardized (z scores) to provide equal weight amongst all the scores except that a weighting factor was then added to the flight simulator score experience to enhance its importance in the final score determination. The scores were then tallied into a zsum value. These zsum values for each test subject ranged from -.37 to .81. The test subjects were then assigned sequentially to each group starting with the control group then to the vigilance group then finally to the experimental group using the lowest score first and then building up to the highest score. Again, this procedure was to ensure an even distribution of test subject personalities, abilities, and experience amongst all three groups.

### **Equipment Description**

The Microsoft<sup>®</sup> Flight Simulator 2000 Professional Edition was used for all flight scenarios. A physiological electrically isolated data acquisition system known as the MP100<sup>™</sup> as shown below developed by BIOPAC Systems, Inc. was used to measure Electroencephalograph (EEG) and Electrocardiogram (ECG) data.



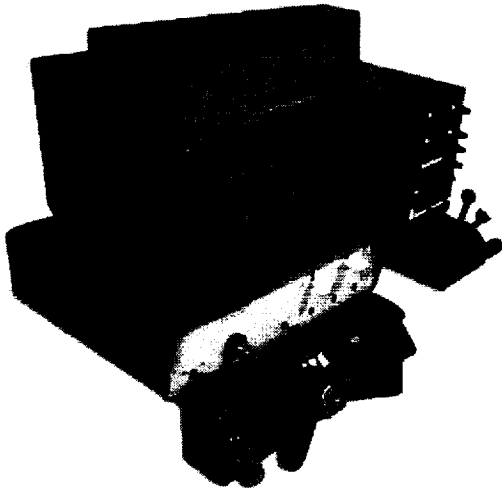
**Figure 2. MP100<sup>™</sup> data acquisition system.**

An EEG cap as shown below, developed by Physiometrix, Inc. was used to measure EEG data.



**Figure 3. Physiometrix<sup>™</sup> neuromonitoring system.**

Also, various heart rate electrodes and data acquisition software were employed as well. The external "out the window" view was projected on to a screen and a smaller monitor was used to provide the control panel indicators and dials. As for the controls, an aviation training device developed by FlightLink<sup>™</sup> was used to provide directional control of the simulated aircraft. A sample of this device is provided below.



**Figure 4. FlightLink™ Aviation Training Device.**

The aircraft used in the simulation was a Cessna 182S and the flying conditions were pure VFR (Visual Flight Rules) with no winds or clouds.

#### **Procedure**

After the proper assignment of test subjects was determined, the test subjects were given assigned dates and times to appear for the simulator. All test subjects were given a 1 hour demonstration of the simulator prior to their assigned test day and a brief description of what was expected of them, but all questions relating to experiment purposes and hypotheses were deferred to the end of their test day. All test subjects were also asked to avoid all caffeine products their assigned day to avoid adding any additional stimulus to their physiological state. The first session on the assigned test day consisted of a short pre-flight briefing, psychophysiological prepping and application, pre-flight questionnaires to provide a subjective means to determine current state of awareness (includes the Stanford Sleepiness Scale<sup>6</sup>, the Terri Dorothy Fatigue Scale<sup>7</sup> (reprinted and modified with permission of the author Terri Dorothy), and the Cox and Mckay Stress Arousal Checklist<sup>8</sup>), takeoff from a pre-determined simulated airport, instructions from ATC to determine required altitude and heading, cruise flight for approximately 24 minutes, then a final heading and direction change with the first anomaly invoked at the 26 minute timeframe, and then once the test subject identified the anomaly, the simulation was paused so that the test subject could fill out the same awareness questionnaires again to determine, subjectively, the test subject's current state of awareness. As for the specific timeframe, it was based on efforts to ensure that vigilance decrement<sup>9</sup> had occurred with the test

subjects. After completing the questionnaires, the test subjects were then given an opportunity to experience a landing scenario whose sole purpose was to provide statistical psychophysiological data for other baseline research efforts and was not specifically intended for this experiment. After the test subjects completed the landing scenario, they were then given a 10-minute break.

Upon returning from their break, the test subjects started the same flight scenario again except that two of the groups, the vigilance and the experimental, were also afforded the use of a laptop computer for purposes to be described in further detail below. The control group flew the exact same scenario as before except that the second anomaly was invoked at the 26-minute interval. The difference with the control group and the other two groups was that the vigilance and the experimental groups were given an intervention during flight at the 18-minute time interval and were required to perform their specific tasks for 5 minutes. At the end of the 5 minutes, these test subjects then reengaged the flight scenario and the same anomaly that the control group received at the 26-minute time interval was then invoked and these two groups were asked to properly identify the anomaly as before. Again pre-test and post-test questionnaires were given to each test subject to subjectively determine current state of awareness. The tasks that were given to the vigilance group and the experimental group were vastly different. The experimental group was given a software program known as Captain's Log™ (©1996 Joseph A. Sandford, Ph.D. All Rights Reserved). The original intent of the software is that it was developed as a cognitive training system to help those suffering with Attention Deficit Hyperactivity Disorder (ADHD) and people who have suffered brain maladies such as stroke to perform various exercises that help retrain and refocus their mental abilities. The hope of this experiment was that this same software could be used to help stimulate the test subject's cognitive thinking abilities to sharpen their respective mental state of awareness. The vigilance group was given a mundane and non-stimulating computer vigilance task developed by Dr. Mark Scerbo from Old Dominion University. The purpose of having the vigilance group is to remove any novelty effects that the Captain's Log™ software might produce. That is, the vigilance group is introduced to show that there is hopefully, no effect of stimulation on the test subject due to having a "new" computer task to perform. The hopes are that the Captain's Log™ software in it of itself will produce the necessary cognitive brain stimulation necessary to sharpen the experimental group's state of awareness. After the test subjects completed their respective sessions, the EEG cap and heart rate electrodes were removed from the

test subjects and then they were excused for a long lunch break. Again, before the test subjects left the lab, they were instructed to avoid any caffeine products so that no external psychophysiological stimulation was given to them.

Upon the test subject's return, the EEG cap and heart rate electrodes were reapplied and the test subject returned to the simulator. This last session was utilized as a repeat control as a comparison for the first session and to see if there were any carryover effects for the experimental group. The flight scenario was exactly the same as the first session except that a different anomaly was introduced. Again, the test subjects were administered pre-test and post-test questionnaires to gauge their relative state of awareness. At the end of this final session, the psychophysiological sensors were completely removed from the test subjects and any excess prepping gel or sensor residue was removed. The test subjects were then provided with a complete description of the experiment in the debriefing session. They were given information on the driving factors that helped to produce the experimental hypotheses along with a description of what was being observed during each session. After this download of information regarding the experiment was given, the test subjects then completed a debriefing questionnaire. The questionnaire helped to validate the scenarios and sensations experienced by the test subjects along with providing the experimenter with useful information regarding the sensor applications and other environmental lab concerns. The test subjects were then given an opportunity to provide for any useful suggestions, comments, concerns, and/or questions that they might have.

## **Variables Measured**

### **Independent Variables**

- CATS Intervention
- No Intervention
- Vigilance Task

### **Dependent Variables**

- Reaction time to anomalies
- Correct identification of anomalies
- Background questionnaires
  - Proneness to Boredom Scale
  - Levenson's Locus of Control Scale
  - Epworth Sleepiness Scale
  - Subjective scales

- Stanford Sleepiness Scale
- Terri Dorothy's Fatigue Scale
- Cox and McKay Stress Arousal Checklist

- EEG data
- ECG data
- Reaction time to ATC commands
- Correct compliance to ATC instructions

## **RESULTS**

The subjective data was analyzed using SPSS<sup>®</sup> for Windows<sup>™</sup>. The general linear model for repeated measures and the one-way Analysis of Variance (ANOVA) were employed to analyze the data. Currently, the psychophysiological data is still being analyzed. As for the subjective questionnaires, no significant differences were found in the analyses. The only measure of significance that was seen in the analysis occurred in the anomaly reaction time for the different sessions across the groups. A trend leading to a potential significance in the data was observed. According to the analysis, the response time was near significance between groups I and III ( $F(2,9)=4.157$ ,  $p = .053$ ). When looking at the Tukey and Duncan Post Hoc Tests, significant differences were found between Groups I and Group III for the reaction time response measure. This may indicate that the experimental Group III experienced some effects of the CATS intervention over the control Group I which had no intervention.

## **CONCLUSIONS**

Several factors contributed to the lack of significant results in the data analyzed to date. One in particular was the observation that there were several test subjects who had little or no experience flying the simulator, and they spent a good portion of their time trying to learn how to use the controls and the simulator program. Therefore, their level of engagement and awareness were relatively high throughout the duration of the experiment. This higher level of engagement helped to skew the data. Also, the sample size was probably not large enough to overcome subject to subject variability. But the fact that there is a trend in the reaction time data shows that the results are promising even for a small sample size. It is highly recommended that a further study be conducted with a larger number of test subjects. Also, it is suggested that each test subject be given at least an hour of practice prior to the study to

help avoid the learning curve effects on their respective states of awareness. Upon completion of the psychophysiological analysis, more can be said about the physiological state of the subjects.

### **ACKNOWLEDGEMENTS**

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