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The Role of EEG Biofeedback Training Preceding an Automated Monitoring Task

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THE ROLE OF EEG BIOFEEDBACK TRAINING
PRECEDING AN AUTOMATED MONITORING TASK

by

Matthew B. Hilscher

A Thesis Submitted to the
Department of Human Factors & Systems
In Partial Fulfillment of the Requirement for the Degree of
Master of Science in Human Factors & Systems
Embry-Riddle Aeronautical University
Daytona Beach, Florida
Spring 2001
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PRECEDES AN AUTOMATED MONITORING TASK

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Matthew B. Hilscher

This thesis was prepared under the direction of the candidate's thesis committee chair, Dennis A Vincenzi, Ph. D., Department of Human Factors & Systems, and has been approved by the members of the thesis committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors & Systems.

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ABSTRACT

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Title: The Role of EEG Biofeedback Training Preceding an Automated Monitoring Task
Institution: Embry-Riddle Aeronautical University
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Discussions are taking place in aviation circles to revamp and revolutionize air traffic management under the term “free-flight”. The plans for a new system would incorporate, to a high degree, automation technologies that may have important human factors implications. One such concern speaks to quality of mental involvement as authority roles change. This modification of cerebral involvement may have an affect on performance during critical system failures. The purpose of this research has been to investigate whether specialized EEG biofeedback training might have an ameliorating effect on reducing the vigilance decrement. Partial support was found that evidences utility to this end.
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INTRODUCTION

There are currently discussions in the aviation industry surrounding the advent of building a new Air Traffic Management (ATM) System. The planning of such a system has received international attention from the world community of aviation operators, who are interested in integrating the development of advanced technologies and procedures for future air traffic management. The nature of this evolution is to relax restrictions in air transport operations wherever feasible. This evolving process to reinvent the ATM system has been termed “free-flight”.

The concept of free-flight is intended to provide increased flexibility and efficiency to the National Airspace System (NAS). Free-flight introduces a highly dynamic quality to airspace and traffic flow. Comparatively, today’s traffic conflict points are somewhat predictable, but in free-flight, potential conflicts would continually move. As sited in Fleming and Lane (2000), the research by Coularis and Dorsky (1995) suggest that the drive to eliminate constraints and relaxed restrictions are motivated by studies that suggest a reduction in schedule and route constraints could save the operators as much as 3.5 Billion U.S. dollars annually. Monetary saving aside, this technological evolution in the NAS system would also bring with it new challenges in the area of human performance. As system improvements are developed, human factors issues must be included during the analysis and design phases.
It is a generally agreed, in principle, that safety should not be compromised in the transition to free-flight. A complementary founding principle is that human factors concerns must be raised and addressed from the beginning and throughout the research and development of new technologies, policies and procedures (RTCA, 1995). From an ATC perspective, the dialogue surrounding free-flight has raised a number of human performance problems (including but not limited to workload extremes, passive monitoring demands, and difficulties in reverting to manual control).

There seems to be agreement that in free-flight scenarios the use of automation will be heavily relied upon to facilitate controller performance. Among other functions, automation will augment controllers efforts to keep a mental picture of the traffic at all times. As the RTCA (1995) report outlines, planned technologies will incorporate a high degree of task sharing between human & computer support systems. Predictively, free-flight technology will *automatically* identify conflicts and propose possible solutions to both controller and pilot. An important quality to consider is that human operators (pilots, air traffic controllers, and airline operations personnel) must now *monitor* and *predict* any changes in the distribution of authority and control that might result as a function of the airspace configuration and other operational constraints.

To develop the point, one of the chief concerns integral to the effectiveness of free-flight, is determining to what extent the role of “automation aiding” will play in the future system. Current trends suggest that with continuously increasing levels of automation in the ATC environment, controllers are more apt to engage in “passive monitoring” with subsequent reduction in cognitive attentiveness and efficiency (Thackray & Touchstone, 1989; Hopkin, 1995). As automated technology and systems continue to increase and
become more capable, the human operators role would necessitate that they spend less time actively controlling such systems and more time passively monitoring such systems (Hanson, 1997).

**Statement of the Problem**

The context of this investigation was developed from the concepts expressed in the above introduction; i.e., that development and dependence upon automation may contribute to an increase in vigilance and monitoring requirements for future free-flight scenarios. The purpose of this study is to investigate whether individuals who participate in a brief electroencephalographic (EEG) biofeedback training, would subsequently improve their detection efficiency in a monitoring vigil within an automated system.
REVIEW OF LITERATURE

Context of automation

The past decade has seen the air traffic service provision undergoing major changes as airspace is redesigned and designated and air traffic management systems are being upgraded (Gahan, 1999). These advances in air traffic control operations can be attributed to the capabilities of new hardware and software evolutions; however, it could be argued that the introduction of modern technology with greater levels of automation has also created new knowledge and attentional requirements on the human side. Without careful consideration, the limitations that are imposed by attention can be severe if not properly respected and taken into account in the design of equipment and interfaces (Wickens, 1992b).

A report to the National Aerospace Laboratory NLR by Hilburn, Bakker and Pekela (1997) suggests that an operator’s task is increasingly being shifted from active control to supervisory control by the introduction of automated systems. Humans are no longer continuously controlling a process themselves, they monitor the performance of highly autonomous machine agents. Rather than strategically controlling air traffic, the “controller” of the future might well fill the role of a strategic flow manager, and/or a tactical “separation assurance monitor”, who would intervene only when losses of separation were imminent.
The changes inherent to a free-flight environment, if not properly designed, could very well lead to “automation surprises.” These automation surprises have been observed and reported in various domains (most notably flight deck and operating room automation, e.g. Sarter & Woods, 1994a; Moll van Charante et al., 1993) and have contributed to a considerable number of incidents and accidents.

Clearly, automation in the aviation industry can be a mixed blessing. On the one hand, an examination of air carrier accidents suggests that newer, more highly automated aircraft have had substantially fewer accidents than earlier aircraft (Billings, 1997). By all accounts the influence of automation is thought to be positive. Some of the general benefits include: increased safety, greater reliability, greater economic efficiency, and new levels of comfort.

On the other hand, there are also some serious concerns that are attributable to automated systems. From a human factors perspective, automation brings with it many problems. The human counterpart can experience performance decrements, loss of situational awareness, development of poor mental models, and increased mental workload as a result of over reliance and a lack of understanding of the automation. In effect, the human can be lulled into a false sense of security, the human monitor can begin to exhibit “automation induced complacency” and a loss of situational awareness may result. Wiener (1981) defines complacency as “a psychological state characterized by a low index of suspicion.”

Systems must be designed so that the humans involved in monitoring automated processes maintain an acceptable level of situational awareness. Simply throwing automation at a problem has proven to be an unacceptable solution since
humans are not good monitors of automated systems (RTCA, 1995). There appears to be an optimal level of mental engagement that should be associated with human-machine automation in order to optimize human performance.

With the advent of free-flight on the horizon, there is a very real threat (unless properly designed around) that controllers will become even less involved with operations. Without direct involvement with traffic, controllers, especially younger ones, may never be able to develop the skills (working memory and tenacity) that is required of them. Indeed, by its very nature, automation characteristically does just that; it tends to take humans “out of the loop” and relegates humans to the role of monitoring, thus dulling our attentional vigilance.

**Vigilance**

It has been shown that controllers are more vigilant when they have more to do, compared to when they are undertasked (Sawin & Scerbo, 1994). A significant number of incidents occur in ATC during periods of low traffic levels and limited workload. The investigations of Krol (1971) conclude that air traffic controllers find their workload lighter when they are actively controlling an aircraft. When they merely monitor its track on radar, workload increases. By the very nature of the job requirement, maintaining vigilance for critical events such as loss of aircraft separation, altitude deviations, visual flight rules pop-ups, incorrect pilot readbacks, and other infrequent events is an important component of the air traffic controller’s task. Research in the transportation safety sector strongly suggests that loss of vigilance is a common phenomenon in complex real-world operations (Mackie &
Miller, 1978). From what has already been established, it would appear that free-flight necessitates a greater role of automation and may inadvertently be increasing a controller’s workload by leaving them too little to do. By virtue of their repetitiveness and simplicity, vigilance tasks seem tedious and cognitively undemanding. However, the opposite appears to be true; it is still tedious but can be cognitively more demanding. (Warm, Dember, & Hancock, 1996).

Vigilance research has been defined as the investigation of human behavioral and physiological responses in task settings characterized by the requirement to detect critical events (“signals”, or “targets”). The occurrence of critical events may be rare, but the early detection of which is vital to the effective or safe operation of a system with a human “in the loop”. The topic of vigilance, has had a long research history (see Warm, 1984, for a complete review). Research efforts began during World War II when it was discovered that radar operators, although highly motivated by the importance of their task, detected fewer signals as their watch progressed (i.e. they experienced a vigilance decrement) (Mackworth, 1944). The length of the vigil and total watch period accounted for the performance changes. In follow-up studies, Mackworth’s (1950) research indicated a serious drop in detection efficiency during the first 15-30 minutes of performance. More recently, the research with automated environments indicates that the ability to monitor a highly-automated system declines significantly after approximately about 20 minutes (Parasuraman, Molloy, & Singh, 1993).

Fisk and Scerbo (1987) report that since those early investigations, vigilance has remained a topic of interest to researchers and the experimental paradigms have
expanded to include numerous tasks. Mackie (1987) states that well over a thousand studies have been published demonstrating that vigilance decrements occur as a function of time spent performing various kinds of signal detection tasks or demonstrating that performance is suboptimal throughout a task because of its boring, monotonous character. It has been hard to predict when, and in what situations, a vigilance decrement will occur. There are countless variables that can potentially influence detection efficiency. Some of the factors include but are not limited to: time of day, motivation, type of signal, sleep, display design, and task duration. Warm and Jerison (1984) suggest that the ability to find a unitary “factor” of vigilance has eluded researchers. Despite the enormous attempt by researchers to understand vigilance phenomena, it still remains cryptic. There is justification to reexamine the role of the human in our ability to sustain attention in automated computer-based systems.

It can be said that the types of operational problems such as boredom, that historically gave birth to vigilance research still abound and perhaps are increasing. If the aviation industry stays on the current course, controllers in the near future may well be working in a highly automated free-flight arena, and be called to serve as passive monitors in these complex systems. Thus, if safety is not to be compromised, it appears that researchers need to recognize the behavioral consequences and limitations of human cognitive capabilities in automated systems. With this understanding, future technology can be developed to be more sensitive to those boundaries between attention and inattention.
Attention

It has been found in the literature that different investigators used the concept of attention in dissimilar contexts. The psychological construct of attention can be defined in many different ways depending upon how attention is conceptualized. For this paper, attention will be defined as a cognitive ability that functions as a mechanism for reducing uncertainty and for maintaining cognizant awareness of the immediate surroundings. This directed attention, when maintained for a long period of time, becomes sustained attention (vigilance).

Parasuraman, Molloy, and Singh (1993) found some evidence to suggest that individuals with high self-reported levels of “energetic arousal” exhibited better monitoring of automated systems (at least temporarily). For the person who has a relatively short attention span, there could be an increased danger of them falling off into a “hazardous state of diminished awareness.” This refers to a phenomenological experience such as daydreaming, “spacing out” from boredom, or “tunneling” of attention, as reported in aviation safety reports (Pope and Bogart, 1993).

Like any cognitive ability, individuals differ to the extent that they are able to maintain vigilance. It is also important to recognize that this is a domain in which we can maintain, to a certain degree, a measure of self-regulated control. Individuals have the capacity to improve their proficiency and self-knowledge of sustaining attention (Kaiser & Othmer, 1997).

The question arises whether employing a biofeedback protocol, as part of an advanced training phase, would improve sustained attention to the point where it would positively influence a controller’s task performance during a monitoring vigil.
**Electroencephalogram**

One of the most direct methods by which fatigue, and its counterpart attention, can be studied is through the use of the electroencephalogram (EEG), which records the electrical activity of the brain. By definition, brain waves are categorized by their frequency, which is a measurement of the number of oscillations (or cycles) a wave makes per second, and their amplitude, which is the strength of the signal. While the EEG is understood to be a gross index of behavioral process, certain frequencies, when dominant, tend to be associated with particular states of mind and mental functioning. This information can be interpreted, as providing a physiological component, or “attentional pulse” of the participant under study.

Kamiya (1969) was one of the pioneers who demonstrated that human subjects could exert operant control over their EEG activity. Over time it became evident that specific EEG band widths and protocol regimes could be applied more appropriately to specific applications and problems. For many years now clinical applications have shown efficacious use of the EEG (also know as neurofeedback) to enhance cognitive performance of those suffering from attention deficit disorder (Kaiser & Othmer, 1997). In another context, Sterman et al. (1993) has been able to identify a potential EEG index for workload using spectral analysis of the 8-12 Hz band. More specific to this investigation, the following empirical literature shows evidence of the effective use of EEG protocols to promote effective states of awareness.
Beatty, Greenberg, Deibler, and O'Hanlon (1974) hypothesized that learned regulation of theta activity (4 to 7 Hz) would affect detection performance in a prolonged monitoring task. They proposed that learned suppression of the occipital theta rhythm would maintain efficient detection, whereas increased theta activity would lead to a greater than normal decrement in performance of a monitoring task. The EEG's of 19 undergraduates were recorded from over the left occipital and parietal cortex. Twelve of the individuals were trained to suppress theta and seven to increase the amount of EEG activity in the theta band. The poorest detection performance was that of the group that produced theta during monitoring a radar simulator, whose vigilance performance dropped continuously over the two-hour period. Conversely, the best monitoring performance was shown by the group that was taught to suppress theta activity. In fact, an improvement in detection was observed for the theta-suppressed group in the last segment of the experiment, a period during which the theta-augmented group showed its worst performance. These results demonstrate a significant relationship between operantly regulated cortical activity and behavior in humans.

For this investigation, the above suggests that real performance benefits (monitoring efficiency) may be realized with EEG biofeedback technique for modern ATC operations.

**Biofeedback’s Objective**

The objective of participants who engage in training of this sort, is to divide an individuals attention between the computer feedback and internal feelings and sensations (felt knowledge) while the individual makes an effortful attempt in the
development or fine tuning of a particular cognitive goal. The strategy is for one to observe, and learn with reinforcement, how to maintain the inner sensations and feelings associated with the cognitive objective using the auditory and visual cues that are specific to the frequency and amplitude of interest. EEG biofeedback can best be understood as an instrumental learning process whose end result is the facilitation of voluntary control of EEG activity. For the uninitiated, this process of mastering brain waves naturally takes time, and more acute control is achieved with spaced practice. Paradoxically, in order to “learn” control, participants have to “learn to forget about trying” and “let it occur” (Peper 1972).

As the earlier literature suggested, the suppression or inhibition of low frequency brainwaves (4-8 Hz) are associated with helping to improve concentration and the ability to focus attention. This particular brain wave pattern is naturally produced, and can be modified (inhibited) with concentrated effort using the device. The utility of the feedback is to shape behavior. The mental exercise seeks to train the brain to concentrate more resourcefully, effectively focusing one’s attention, in a unique way, to become more cognizant of mind wandering. The computer and biofeedback device simply act as a coach or mirror, to help the participant bring his/her brain into a particular focused state with use of proper technique. The learning process (called an orientation effect) takes place while in the process of attending to one’s own awareness. This “self-regulated learning” to suppress low amplitude brain wave patterns can take hold in a relatively short amount of time.

Gradients of mastery can be influenced by manipulating a threshold index to achieve peak-performance. Generally speaking, the average individual can learn
relatively quickly through the use of EEG training how to more keenly experience
different states of consciousness. For this experiment, a protocol has been written to
raise greater awareness of "attentional lapses." This transfer of learning would then
be applied to an automated monitoring task that occasionally "failed." If subjects are
able to remain more alert for a significantly longer period of time, detecting failures
more rapidly and accurately, this would offer support for developing a high-end
training protocol to countermeasure the vigilance problem associated with
automation complacency in the ATC environment.

Summary

If the aviation industry predictions are correct, the role of free-flight in the
National Air Space system promises to bring with it higher degrees of automation.
The increase of automation technology in human-machine systems has led to
increased demand for effective monitoring skills, an area in which humans have
typically demonstrated poor performance (Parasuraman, 1987; Parasuraman, Molloy
& Singh, 1993).

The preceding literature has laid the groundwork for research to determine
and justify the experimental employment of a biofeedback-associated "alertness
indicator" (EEG theta protocol), and evaluating if it will have an ameliorating effect
on reducing the vigilance decrement. By introducing this process as an aid for high-
end training with ATC controllers, one may see an improvement in monitoring
effectiveness.
Statement of the Hypothesis

Research exists suggesting that the outgrowth of highly automated ATC systems would relegate the role of controller to one of being a passive monitor consequently engendering cognitive complacency. Based on the knowledge of sustained attention and level of active involvement, the following hypothesis and predictions were postulated:

Hypothesis: It was hypothesized that exposure to 30 minutes of short term EEG biofeedback training would improve cognitive performance for detecting automation failures during a subsequent 30 minute monitoring task.

It was predicted that the effects of a short–term training protocol with EEG biofeedback will significantly improve detection efficiency as defined by: 1) detection rate, 2) error rate, and 3) reaction time, in a one dimensional discrimination activity. Those participants in the treatment condition will show greater detection efficiency on all measures as compared to those in the control group.

Prediction One: It was predicted that detection rate will increase as a function of training.

Prediction Two: It was predicted that the number of errors (false alarms) will decrease as a function of training.

Prediction Three: It was predicted that reaction time will decrease as a function of training.
METHOD

Participants

Participants for this study were obtained from the undergraduate population at Embry-Riddle Aeronautical University. Thirty-seven participants were chosen on the basis of cost, time, and availability. A list of the participants to be used in the study were subjected to a random assignment process. The demographic composition consisted of 11 males and 26 females reporting to be average aged college sophomores. Those randomly selected participants who provided informed consent were assigned to one of two groups.

Apparatus

The principle apparatus used for the treatment condition was a Neurodata EEG Physiograph version 2.0™. This is a physiological monitoring device that assesses and provides feedback of real time electroencephalographic brain wave data.

The software used was Cool Spring Software version 1.53™, A Test Of Visual Field Attention. This application presents a simple visual stimuli (a black ring) in random locations within a visual field. The participant presses a mouse button when a stimulus appears.
Performance measurement. Data collection for the dependent measure, for all participants, was recorded using an adapted version of the Multi-Attribute Test Battery (MAT) developed by Comstock and Arnegard (1992). For research simplicity, the nature of the monitoring task has been simplified to watching four instrument gauges (See Figure 1). This task requires the participant to vigilantly monitor the gauges, to detect when a cursor goes outside a nominal range without an alarm (automation failures).

![Figure 1. Gauges showing an automation failure.](image)

The system monitoring task consists of four vertical gauges with moving pointers and green and red warning lights. The scales for the gauges are marked as indicating the temperature and pressure of two aircraft engines. Occasional “system malfunctions” occur at random intervals, indicated by the pointer on one of the four engine gauges going “off limits”. These system malfunctions are normally detected and reset automatically. The successful identification and correction of the
malfunction is indicated by a red warning light, which is extinguished when the problem is corrected. There are 16 such offsets, per ten minute block. However, from time to time, the automation fails to detect a malfunction. The automation failure rate is constant across time, seven malfunctions per ten minute block. Participants are only responsible for detecting failures.

In addition to the monitoring task, participants in both conditions also attended and manipulated a tracking device that served as a cognitive distracter. No data was recorded for this activity.

**Design**

The purpose of this study was to investigate if there are any performance benefits to be realized by employing EEG biofeedback training prior to monitoring automated gauges for a 30 minute vigil.

The experiment consisted of a one-way between subjects design incorporating a single two level independent variable for group type. The biofeedback treatment condition was the between subjects factor. Three dependent variables exist (1) detection rate (correct detection of automation system failures), (2) false alarm rate (incorrect detection of automation failures), and (3) reaction time (time to detect failures).

The study employed a post-test only parametric design. Scoring for all dependent measures were automatically recorded within the MAT software program; evaluation (scoring) of participants’ monitoring task performance was outside of the experimenter’s influence.
Procedures

After appropriate screening, each participant was randomly assigned to one of two test conditions. Participants in both groups were asked to wear a three-sensored EEG biofeedback device during their respective tasks (See Figure 2). This was done to help mitigate experimental “demand characteristics” that wearing an apparatus may bring about.

The participants assigned to the treatment condition were required to perform a concentration exercise. During the concentration exercise, the participants received real-time EEG biofeedback data, and were guided through an instructional script (see appendix A). This 30 minute cognitive task offered the participant techniques to progressively suppress high theta amplitudes. For each participant assigned to the treatment condition, a physiological threshold index was set specific to that individuals’ 2 minute base-line appraisal prior to the instructional exercise. This personalized threshold line represented their average theta signature while doing light reading. Following this preliminary step, detailed explanations guided the participants to incrementally suppress theta amplitudes below their self-assigned threshold line. The concentration exercise was considered valid if the participant was able to maintain theta suppression for greater than 50% of the time below the threshold line. This insured that participants had learned a nominal level of deliberate/willful theta suppression.

In a similar fashion, the control group also wore the EEG biofeedback device; unbeknownst to them, no EEG data was being collected. They engaged in a comparable scripted concentration exercise, which was not biofeedback related, for precisely the same amount of time (see appendix B). The degree of experimental
manipulation was identical; only the nature of the 30 minute cognitive task was different. Again, the study attempted to determine if there was a statistically significant difference between those participants who received a ½ hour of EEG feedback training, and those engaged in a filler task.

![Figure 2. EEG Device with active sensor on P3 & two linked ear references.](image)

For comparative purposes, other than the contrast in the type of cognitive task, there was no attempt to make the two groups different in any way. After their respective concentration exercises, each participant immediately undertook the automated monitoring task, once a ten minute instructional sample was given from a script (see appendix C). After the running of all subjects, the performance data was subsequently evaluated using inferential statistics.

**Data Collection**

Data collection was taken on three performance measures during the course of this experiment.Parsed from the MAT were: detection rate of automation failures, false alarm rate, and reaction time.
Dependant Variables:

*Detection Rate (Correct detection of automation system failures):*

Detection rate is defined as the number of correct responses made by the participant when monitoring the automated system for automation failures. The system was set at 60% reliability. During the course of any ten minute period, the software causes the engine parameters to deviate out of range 16 times. Setting the system at a reliability of 60% caused the system to automatically reset 9 out of the 16 times that the engine parameters deviated, and required the participant to manually detect and reset the system 7 of the 16 times that the engine parameters deviated.

*False Alarm Rate (Incorrect detection of automation failures):*

False alarm rate is defined as the number of times the participant attempted to manually reset one of the engine parameters when they should not have.

*Reaction Time (Time to detect automation failures):*

Reaction time is defined as the time required for a participant to react to a system malfunction. A maximum of ten seconds is allowed to reset the malfunction. If the participant does not reset the correct engine parameter that malfunctions within ten seconds, the system records the reaction time for that event as 10 seconds and resets the parameter without assistance from the participant.

Independent Variable:

The treatment condition consisted of rewarding the suppression of EEG amplitudes in the 4-8 Hz frequency band (theta waves). The treatment group received three (six minute) training sessions with two (two minute) micro-breaks. Both auditory and visual feedback were provided when participants’ amplitude range
raised above their threshold line. Specifically, a tone went off and the wave signal changed color from purple to yellow when attention started to lapse off task. Upon suppression of theta a reward of silence was given, and the wave remained purple.

The control condition required participants to observe a computer screen for 30 minutes, and immediately identify, with the click of a mouse button, the random appearance of a black ring on a white background. (See Figure 3)

Figure 3. Visual search task showing black ring stimulus and centering cue
RESULTS

Data

The data from three dependent variable measures (detection rate, false alarms, reaction time) were collected for 37 participants, divided between the levels of the independent variable (19 biofeedback and 18 for control). These data groups were summarized (see Table 1), and tested for significance using a one-way analysis of variance (see Table 2).

Detection Rate

The mean detection rate (correct detection of automation failures) for the biofeedback training condition was .87, and for the control group was .88. The means did not differ significantly using an ANOVA, F (1,35) = .135, p = .716. The prediction that biofeedback training would increase the number of automation failures detected was not supported.

False Alarm Rate

The mean rate of false alarms (incorrectly identifying automation failures) for the biofeedback group was 5.3 and for the control group 7.7. These means do not differ significantly using a one-way ANOVA, F(1,35) = .982, p = .329. The prediction that biofeedback training would increase the number of false alarm errors detected was not supported.
Reaction Time

The mean reaction time (time to detect automation failures) for participants who received biofeedback training was 3.0 seconds. The mean time for the control group was 3.42 seconds. Shorter reaction time indicated better performance. These means differed significantly using a one-way ANOVA, $F(1,35)=4.408, p=0.043$, indicating that the mean time to react to automation failures during a 30 minute vigilance task appears to improve with the influence of biofeedback training. An $\eta^2$ of .112 was obtained indicating that 11.2% of the variability in the means was due to the effect of biofeedback training.

The 30 minute session was then broken down into three 10 minute blocks. The first two blocks did not reveal any significant differences. Specifically, it was found that the greatest change in reaction time occurred in the last ten minutes of the task, occurring just when one would expect the vigilant decrement to surface. The biofeedback training group reacted on the average in 2.6 seconds while the control group reacted in 3.39 seconds, for a difference of .79 seconds. These means differed significantly using a one-way ANOVA, $F(1,35)=5.428, p=0.026$. Thus, the prediction that participants’ reaction time would decrease as a function of short term biofeedback can be supported. A graphical depiction points out the trend (See Figure 4)
Table 1. Descriptive Statistics

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<th>Biofeedback</th>
<th>Control</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>DETECTION-RATE</td>
<td>19</td>
<td>18</td>
<td>37</td>
</tr>
<tr>
<td>Mean</td>
<td>.8774</td>
<td>.8889</td>
<td>.8830</td>
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<tr>
<td>Std. Deviation</td>
<td>.09746</td>
<td>.09324</td>
<td>.09428</td>
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<tr>
<td>FALSE ALARM</td>
<td>19</td>
<td>18</td>
<td>37</td>
</tr>
<tr>
<td>Mean</td>
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<td>7.777</td>
<td>6.513</td>
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<tr>
<td>Std. Deviation</td>
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<td>10.03263</td>
<td>7.55212</td>
</tr>
<tr>
<td>REACTION TIME</td>
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<td>18</td>
<td>37</td>
</tr>
<tr>
<td>Mean</td>
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<td>3.422</td>
<td>3.209</td>
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<tr>
<td>Std. Deviation</td>
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<td>.62695</td>
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Table 2. ANOVA

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<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
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<td>.135</td>
<td>.716</td>
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<td>FALSE ALARM</td>
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<td>(1,35)</td>
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<td>.329</td>
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<td>REACTION TIME</td>
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<td>(1,35)</td>
<td>1.583</td>
<td>4.408</td>
<td>.043</td>
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Figure 4. Graph showing Reaction Time break-down into ten minute blocks
DISCUSSION

As the data show, this experiment did not reveal any significant differences for either of the first two predictions. Within the context of the experimental task, little can be inferred with respect to the influence of short term EEG biofeedback and its affect on vigilance for these measures. Both detection rate and false alarm rate, within the parameters of the MAT, did not reveal any significant changes between the groups. Two reasons can be offered to account for this.

First, the outcome may be due to the fact that the monitoring task was only 30 minutes in length. While vigilance tasks with associated decrements can range between 12 minutes and 2 hours, the 30 minute session (an experimental constraint) may not have been an adequate time period for potential differences to emerge that were specific to this measure. The second consideration is that the MAT’s measure for accuracy may have been too coarse of an index for measuring such a subtle cognitive performance change that EEG training may impart. The monitoring task may have been too easy since both groups showed an accuracy rate of approximately 88%. Another consideration is that the behavioral change itself was too faint; that is, the EEG training length may have been insufficient to disclose a robust learning effect. It could be tenuously speculated that there may have been latent effects of the EEG training that cannot be reported because the accuracy measures specific to the
MAT may not have been sensitive enough to tease out the effect. Refinements would aim to lengthen the vigil to a period greater than half an hour, increase EEG training time, and/or employ alternate testing methods to tease out delicate effects.

This study's third prediction was supported by the anticipated results. Statistically, the data revealed that EEG training may contribute to reducing reaction time for detecting automation failures in automated monitoring tasks that are at least 20 minutes in length. The application of .79 seconds may be relevant if a critical situation arose that necessitated adverting two aircraft on a collision course with very high closing rates. Again, if the length of the monitoring task would have been greater than 30 minutes, there may have been even greater differences in reaction time, and one could further speculate as to the durability and sustainability of the biofeedback training.

This finding cautiously suggests that reaction time performance improvements may be realized after approximately 20 minutes if such training was applied to air traffic control environments that required operators to engage in passive monitoring for extended periods of time (greater than 30 minutes) where quick reaction to automation failures is deemed important.

In planning a free-flight ATC system that would feature a high degree of automation, such biofeedback training might offer performance benefits if such systems were to fail. All other things remaining equal, one may expect to find that individuals in passive monitoring scenarios who undertook such preparation would subsequently experience faster reaction times. Accordingly, the creation of a high-end training protocol for controllers, may consider a cognitive module that addresses
the vigilant decrement. This study’s finding may also be applied to the most current evolutions of “adaptive automation” (Scerbo, 2000). This technology looks at employing appropriate EEG power band ratios in a closed-loop system. This could affect changes in the level of automation, as level of alertness fluctuates. Conceivably, greater closed-loop system efficiency may be realized with adaptive automation if optimal reaction times were previously established.

Although this investigation’s finding is in part consistent with earlier efforts, clearly much more research needs to be performed to determine the feasibility of integrating laboratory findings into ATC applications.
CONCLUSION

The results of this study indicated that there are potential performance benefits that might be realized from the implementation of EEG biofeedback training when applied to monitoring tasks that are at least 30 minutes in length. The experimental hypothesis that short term EEG biofeedback training would improve cognitive performance for detecting automation failures during a vigilance task was partially supported. This research fulfilled its intent to determine that self-regulation of attentional mental states, using EEG biofeedback, may have a moderately useful effect (heightening of monitoring skills) on a subsequent automated vigilance task.
REFERENCES


Appendix A

Treatment Condition Script
Overview: (Script to be read out loud)

Thank you for participating in a human factors experiment. Today's meeting should last approximately 1 hour and 15 minutes. The purpose of this research is to determine if different concentration exercises can influence one’s ability to perform multiple monitoring tasks, when a computer automates one of the tasks. The first part of the experiment will take 30 minutes, you will be asked to participate in a concentration exercise that will introduce you to a unique learning strategy. This concentration exercise requires that you self-examine and pay very close attention to the way you stay focused (more clarification later). The second part of the experiment will also take approximately 30 minutes, you will be asked to divide your attention between a tracking task and an automated monitoring task on a computer screen. Finally, we will take a few minutes to debrief, explaining in detail, what the experiment was about. You might consider a restroom break before we begin. As part of the procedure, I would ask you to please take a moment to answer a questionnaire and fill out a participant consent form.

Background:

For the first part of this experiment, you will be requested to learn a skill. This skill is designed to sharpen your ability to focus, and increase your capacity to concentrate for longer periods. In order to do this, the only requirement is that you are willing to put forth the necessary mental/emotional effort into a concentration exercise. The instructions will ask you to progressively reflect on the internal
method (the process) by which you direct your attention. To help us accomplish this, we will be employing a laboratory technique borrowed from the field of behavioral psychology called biofeedback. There are many modalities of biofeedback, but for our investigation, an EEG biofeedback apparatus will serve as a useful human factors tool to facilitate self-understanding.

The experiment consists of (3) six-minute concentration exercises. Each biofeedback exercise is immediately followed by a three-minute break, to discuss what intrapersonal learning took place. This training is a painless, non-invasive procedure. In a short time, you will be able to recognize and change brain wave signals that are self-produced. As a theoretical point, the benefit of a biofeedback device is to coach you, in order to gain more precise control of the body and mind. Some domains are by and large outside of our control, when we are made aware of the mechanisms of control, we can influence them. A highly sensitive computer will monitor your naturally produced brainwave patterns, which are by definition a very weak signal. The signal is amplified, to the point where you will be able to see it and gradually manipulate it. The feedback information is given in the form of both a visual and auditory mode. As a behavioral goal: please keep in mind that the presented information will help you to recognize when your attention span starts to lapse or fade (i.e. daydream). As you concentrate, take note of any cognitive relationships. This is not a relaxation exercise per se, but an opportunity to engage in intense self-observation in order to sharpen and sustain your concentration skills. It is very likely that this experience is unfamiliar to you. Our focus is in understanding the way in which (how) we pay attention. This is a process emphasis,
so it may take a little time for you to get the flow of things, some degree of frustration is to be expected, but you can do no wrong. Please do not worry about trying to achieve a final product.

**Hook-up Permission:**

We will be applying three sensors (like this one). Two reference sensors will be placed behind the ear and the third one will be attached to the top of your head. (Show picture) If this is OK with you we will proceed

In order for us to set up the equipment properly, you will be requested to turn away from the monitor for five minutes and enjoy some leisurely reading. During this time I shall carefully hook-up the sensors so that the computer can be calibrated and take a base line reading. After this is accomplished, you will be asked to face the monitor and be guided through the concentration exercise.

**Explanation & Instructions:**

What you see before you is a representation of your brain’s electrical activity. Brainwaves are categorized by their frequency, which is a measure of the number of oscillations (or cycles) per second and their amplitude, which is the strength of the signal. Today’s objective will be to suppress a particular band (show area of interest), the theta rhythm, which is between 4-8 CPS.
How to interpret the audio and visual feedback:

On this screen, what you see before you is a solid line; this is known as the threshold line. Anytime the wave line (your theta signal) goes above that line, it will change color and make a tone. In a moment I will invite you to sit quietly and play with your thoughts; do what you can to lower the wave. The computer will act as a mirror or coach in your efforts, but you must do the work to produce changes.

As a cautionary note, since we are dealing with a delicate signal, many influencing factors can cause the wave to move unnaturally. In an attempt to limit artifact /noise you will be asked to refrain from clenching your jaw or tightening your neck muscles. Please blink naturally, breathe regularly and easily. Try to limit your body movement. When you adjust your seating the wave tends to spike (an unsettling experience), allow a moment or two for the signal to stabilize before refocusing.

Instructions Strategy:

For the first six-minute trial, the instructions will be intentionally vague. The goal is to lower/suppress the theta wave, do what you can to silence the tone as long as possible. Try to involve yourself fully in the feedback screen as an active participant. Put yourself right ahead of the line, “willing it” to go down. Briefly, experiment with different self-statements and concentration styles (attentional states: narrow focus vs. empty minded-broad focus). You may find, that simply by the way you think about things, you will slowly come to understand that you have some (not perfect) influence over the wave. Find a personal strategy that works for you, try to
shape your thoughts and feelings in a way that lowers the wave, so that it stays deep into the purple region. Again, the tone is something we would like to go away. You may think of “the reward” as being silence; try not to be self-conscious when you hear the tone, I will not be watching over you, but reading quietly in another part of the room. Do you have any questions? Please relax and begin, I will stop the clock when it is time.

First 2-minute microbreak. Questions and technique:

Can you help me understand what you experienced? What was your sense of control? Did you see any relationships between your thoughts and the wave?

Instructions: Please take a deep breath and relax, this time around, I will ask you to ignore all distractions, both external and internal, trust your unconscious mind (not logical) to perceive what needs to be done to reduce the tone. As you begin to make progress (no tone and purple color) a word of caution, we can get excited / cognitively aroused and becoming distracted with our own success, inadvertently making the wave rise. Also, please ask yourself what does this particular state feel like during the extended silence, are you feeling a calm-relaxed alertness? As you are beginning to realize, this task is all about greater mastery of “internal dialogue.” Use your mind and will to reduce wayward distractions, you may try to focus on the absence of thought; the “empty-set”, this is not easy to do, because we are conditioned for lots of stimulus. At times, your mind will wonder, notice what happens to the line. Try to mentally slow-down, focus on just one thing. I will stop the exercise in six minutes.
Second 2-minute microbreak  Questions and technique:

How did this session compare to your first? Was it easy to stay focused? Our goal was to become more cognizant of our own awareness, how did you experience this? Are you beginning to appreciate just how easy it is to become distracted with our own intruding thoughts? See if you can “cognitively gear down” while remaining attentive; think about just one thing, get the wave even lower. (Analogy=swimming efficiency: imagine holding your breath while swimming underwater, you can swim a further distance, if you swim at a slower pace.) If you experience an intruding thought, do not despair, ignore it, and regroup to focus in this new way. Again, be highly alert internally, catch yourself when your mind beings to wander. Minimize distractibility and reduce cognitive arousal. As a final strategy: I would ask you to concentrate on the process. As a cue, “recall the feeling state” -the silence, what worked for you? (If necessary offer the following: ...some people’ self-statements are “be-empty, “zone-out”, “stop thinking”). I will stop the exercise in five minutes.

Session Ends

Over the three concentration segments you may have progressively experience fewer lapses in attention. These exercises have been created to help you appreciate how easily our focus can wonder, even when we want to pay close attention to something. It seems sometimes our mind is not our own. I think you can appreciate, that with more biofeedback practice we could further condition our brain and mind to be relaxed and highly alert; becoming less susceptible to daydreaming and
distractibility. This completes the first part of the experiment. Please relax a few minutes while I set up the next computer program.
Appendix B

Control Group Script
**VISUAL SEARCH SCRIPT** (CONDITION B)

Overview (Script to be read out loud)

Thank you for participating in a human factors experiment. Today’s meeting should last approximately 1 hour and 15 minutes. The purpose of this research is to determine if different concentration exercises can influence your ability to perform multiple monitoring tasks, when a computer automates one of the tasks. The first part of the experiment will take 30 minutes, you will be asked to participate in a concentration exercise. This concentration exercise requires you to rapidly identify a black ring, which appears in random locations on a monitor, (more clarification later). The second part of the experiment will also take approximately 30 minutes, you will be ask to divide your attention between a tracking task and an automated monitoring task on a computer screen. Finally, we will take a few minutes to debrief, explaining in detail, what the experiment was about. You might consider a bathroom break before we begin. As part of the procedure, I would ask you to please take a moment to answer a few screening questions and fill out a participant consent form.

**Instructions:**

You will be asked to sit before this monitor for the next 30 minutes, your only task will be to intensely observe the computer screen, and to click the mouse key as quickly as possible when you see the appearance of a black circle (Show example). The circle will appear at random times in various locations, please remain vigilant for its appearance. At times, your mind may wonder off task (this is
natural), however, try to remain focused and alert by whatever method you know. It is important that you try to do your best until the session ends. Silence is not required; you can ask a question at any time.

**Hook-up permission:**

While you are concentrating for the appearance of the black ring, we would like to collect physiological data about your cognitive arousal level. This data will be transparent to you. In order to set up the instrument, I seek your permission to attach three sensors, one to the top of your head, the other two to the back of your ear (Show example). There is no risk of being shocked, these sensors serve to archive biological data on a remote computer. If this is OK with you, we will proceed.

During your concentration task, I will not be watching over you, but reading quietly in another part of the room. Do you have any questions? Please relax, and begin, I will stop the clock when it is time.

**Session Ends:**

Congratulations, this concludes the first part of the study, please take a couple of moments to relax and stretch and let me ask you about your experience. How difficult was it for you to stay alert, did you daydream? Did you learn anything from the experience? In a moment we will begin the second part of the experiment, please relax while I set up the computer program.
Appendix C
Monitoring Task Script
**Monitoring Task Instructions** (BEHAVIORAL MEASURE)

The second part of the experiment will last approximately 40 minutes. The purpose of this module is to investigate how well people can perform multiple tasks simultaneously when a computer automates some of the tasks. The tasks that you will be asked to perform will be computerized simulations of the sort that aircraft pilots might be required to perform. The computer will display two windows on the monitor. Each window represents a different kind of task, as indicated by the following headings: System Monitoring, Tracking (Point to windows).

**System-Monitoring:**

The system-monitoring task is displayed in the upper left hand window as you see here. The display consists of four dials that represent the temperature and pressure gauges associated with each of two aircraft engines. You will monitor the four dials for any abnormally large fluctuations by the dial pointers. The dial pointers are yellow triangles that normally fluctuate slightly, but remain fairly close to the centerline. The normal range is defined as the area between one mark above and one mark below the center mark (show). Occasionally, a pointer will drift beyond one of these marks. When this happens you are to respond by pressing either, the key labeled: (Show) T1 (temperature of engine 1), P1 (pressure of engine 1), T2 (temperature of engine 2), P2 (pressure of engine 2). Whenever you correctly reset an out-of-range dial, that dial will return to the center position, remain there for
a few seconds, and then continue to fluctuate. You do not need to worry about the green “OK” light and the “warning” light at this point in the experiment.

**Tracking:**

The tracking task is displayed in the upper middle window of the screen. In this task, you will be required to use the mouse to keep “the aircraft” centered in the tracking window. This simulates the action of a pilot staying on a computer-generated course.

Your task is to keep the aircraft, designated by the green circle, within the dotted rectangular box in the center of the tracking window. If you wish to move to a different location on the screen, you must move the mouse in an identical direction on the mouse pad. The aircraft has a tendency to drift away from the center. Your goal will be to try to keep the aircraft in the center rectangular box for as long as possible.

**Objective:**

It is very important to remember that the two tasks are of equal importance, so you should give *equal attention* to each task. Take the next ten minutes to practice the two tasks. Familiarize yourself with each goal. Please feel free to ask any questions.

**2-Minute Break:** Please relax a moment while I reset the computer.

In this 30-minute session, the *monitoring task* will be automated. When the automation routine detects engine trouble, a red warning light will appear first, and
the problem of the out-of-range dial will be subsequently fixed. You should not reset any gauge in this red *automated* condition.

However, you should keep an eye on the monitoring task because the automation may not be 100% reliable or accurate. If there is engine trouble (yellow pointer goes out of the nominal range) and the preceding red warning light does not go on, then you should fix the offending engine parameter as quickly possible by pressing the corresponding key. The automation system may fail to detect and repair an errant instrument, so you must be vigilant to watch for such events. Do you have any questions?

Again, the two tasks are of equal importance so you should give equal attention to each task.

Lastly, if there is anything that you learned from your participation in the first part of the experiment (about staying alert) you can apply that knowledge here. Relax, do your best, I will stop the clock when it is time.
Date __________________

The purpose of this study is to assess if different concentration exercises influence monitoring performance.

When I, __________________________ sign this statement, I am giving my informed consent to the following basic considerations:

I understand clearly the procedures to be done, including any that might be experimental. Approximately 1:15 minute concentration exercises

I understand clearly any discomforts and/or risks that might be associated with this research project; feeling more tired.

I understand any benefits anticipated from this research project; learning

I have been informed about other suitable procedures that would be of advantage to me.

I understand that provisions have been made to protect my privacy and to maintain the confidentiality of data acquired through this research project

The project director has offered to answer my questions about the procedures. He can be contacted for further information about this research project at 226-6741, advisors name Dennis Vincenzi 226-7035.

I understand clearly that I may withdraw at any time from this research project without penalty or loss of benefits to which I am otherwise entitled.

I am not involved in any agreement for this project, whether written or oral, which includes language that clears the institution from alleged fault or guilt. I have not waived or released the institution or its representatives from liability for negligence, if any, which may arise in the conduct of the research project.

I understand that if I am injured as a result of biomedical and behavioral research procedures, medical treatment is available for such injury, in an amount not to exceed $500. I also understand that no monetary compensation is available for wages lost because of such injury. Further information can be obtained by contacting the Vice President for Research and Special Projects, Embry-Riddle Aeronautical University (904) 226-6190. I the person signing below, understand the above explanations. On this basis, I consent to participate voluntarily in the “Feedback Training for a Semi-Automated Vigilant Task”

Signature of person giving consent____________________________________

Signature of principal investigator____________________________________
The purpose of this study is to determine whether short-term biofeedback training affects performance on semi-automated simulated flight tasks. The effects of biofeedback training in previous studies have indicated that suppression of theta activity enhances monitoring efficiency. It is our belief that such training may teach people who may be relegated to a passive monitoring role in automated systems (i.e. future air traffic controllers), would be able to sustain their attention with fewer performance decrements.

If you have further questions after you leave, you can contact me at Embry-Riddle Aeronautical University, Human Factors Lab (904) 226-7926 or 253-7682. mhilscher@hotmail.com Thank you for your participation in this experiment.
Screening Questions

Instructions: Please circle the response that best applies

1. Have you ever participated in biofeedback training for Attention Deficit Disorder?
   
   Yes                      No

2. Could you please rate your energy level at this very moment:

   Exhausted    Somewhat Tired    Average Energy    Energetic    Hyper

3. In your lifetime have you ever had an epileptic seizure?

   Yes                      No

4. Please read vision chart

Initial  __________