

EEG Biofeedback Aboard the Mars Desert Research Station: Implications for Long Term Space Flight

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BACKGROUND

Over the last 80 years or so science has met with great success in measuring brain waves and associating them with various states of consciousness. However many states of consciousness tend to defy categorization from an EEG standpoint. (EEG stands for electroencephalograph). But the basic brainwave states and their associated EEG frequencies are as follows: High Beta (18-30 Hz) associated with intense focus and hyperarousal, Low Beta (12-18Hz) associated with external attentiveness and moderate arousal, Alpha (8-12 Hz) associated with relaxation and passive attention, Theta (4-8 Hz) associated with deep relaxation and inward focus and Delta (0.5-3 Hz) associated with sleep. Brain waves are reflected micro changes in electrical potential (measured at the scalp's surface). They represent synchronous firings of neurons located in specific areas of the cortex. Although the EEG contains no useful information about the specific "content" of cognitive processes or of thoughts in general, it does manifest changes in the state of physiological arousal, of attentive focus, and even of mood. Over the past 30 years or so, researchers have demonstrated that teaching a person to deliberately alter their EEG, through such techniques as operant conditioning via EEG biofeedback, can be very effective in treating problems involving dysregulation in the dimensions of arousal, attention and affect.

A number of studies have demonstrated the effectiveness of EEG biofeedback in treating hyperactivity, Attention Deficit Disorder and specific learning disabilities (Lubar, 1984, Shouse, 1979, Tansey, 1990, Kaiser & Othmer, 2000). Initially these positive effects were observed as being incidental to the treatment of epilepsy using sensorimotor rhythm (SMR) reinforcement (Serman, 1972, 78 and Lubar, Bahler, 1976). (SMR is the brainwave activity that appears over the sensory motor cortex when a person is in a state of relaxed attentiveness). The simultaneous resolution of these symptoms is not too surprising in that they all share similar EEG abnormalities. These abnormalities are: a relative profusion of low frequency activity (beyond age appropriate norms) and a relative insufficiency of midrange activity. Shouse and Lubar conducted the first systematic study of EEG biofeedback and its effectiveness with hyperactivity in a population without a history of epilepsy (Shouse, Lubar, 1976). The training was shown to be more effective than stimulant medication alone. It was also observed that favorable personality changes occurred along with the resolution of the primary symptoms. These changes included decreases in depression, and increases in self esteem and social appropriateness. Subsequently, EEG biofeedback has demonstrated its effectiveness in treating such conditions as anxiety, PTSD, insomnia PMS and alcoholism.

In the 1990s, psychologist Barry Serman of the Sepulveda Veterans Administration and the UCLA School of Medicine, became involved in a NASA sponsored project measuring the brain wave activity of high performance jet pilots engaged in a variety of tasks for the purpose of identifying the brain wave correlates of peak performance under various operational conditions. A number of tests were performed to measure response capability under a wide range of task loading (from boring vigilance tasks to those of increasing complexity and potential task overload). Basically, pilots were presented with a relatively easy task or situation that would slowly progress in difficulty beyond human ability to respond appropriately. What Serman discovered was that pilots who were able to maintain their alpha activity during flight simulation demonstrated more accuracy in task performance than those whose alpha activity decreased (Serman 1994).

Additionally, he found that during a manageable and periodic challenge the brainwave activity (in parietal sites) exhibited a consistent cycling between resting state alpha (the attentive readiness state) and an alpha-desynchronized, elevated low beta state when engaged in responding. They would then move back into the alpha state following withdrawal of the challenging stimuli. This resting state alpha proved absolutely necessary for the maintenance of optimum performance. This alpha activity is referred to as Post Reinforcement Synchrony (PRS), in that it represented a momentary respite, or pleasure response, following successful completion of a challenge. (Such a challenge has historically been presented in an operant conditioning paradigm, in which the PRS was first identified- hence the reference to reinforcement.) As tasks became increasingly complex, the pilots required longer periods of alpha synchrony before being able to respond to a challenging situation. Further, as the tasks came closer together in time, hence allowing for no alpha respite between challenges, performance fell off. After dealing with these demanding situations for an extended period of time, the pilots brainwave activity began to exhibit higher and higher amounts of theta activity - associated, in this case, with nonfunctionality and burnout. Thus the ability to punctuate stressful periods of high arousal with an alpha reward appears to be necessary in order to maintain adequate performance and avoid burn out. Although the theta state, with its internal focus, can be replenishing for the hyperaroused brain, it can become a dangerous sanctuary in situations that demand continuous external attention and focus.

Subsequent research has demonstrated that EEG biofeedback training can enhance midline parietal alpha activity thus enhancing the brain's resistance to fatigue through increasing cortical flexibility (Putman, 2000). Serman's work on peak performance imply a basic training protocol which would: 1.) Expand and strengthen flexibility by training the capacity to alter the thalamic arousal and attention set point to fit the circumstances 2.) Aid the smooth transitioning between states and maintain the appropriate state when under challenge 3.) Specifically reinforce the alpha-low beta cycle, especially the ability to enter the "readiness" of resting state alpha.(Campbell, 1995).

EEG TRAINING ABOARD THE MDRS

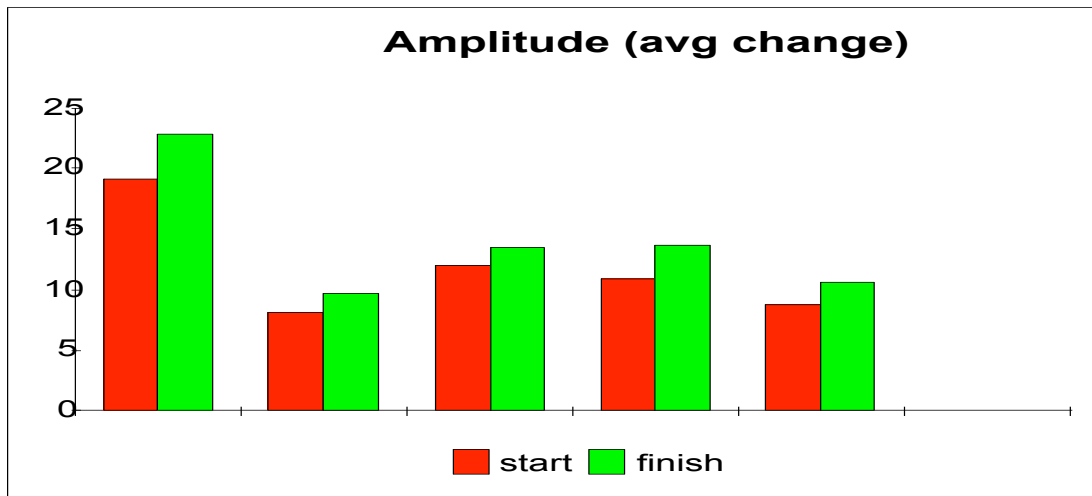
All members of the MDRS crew 2 participated in the experiment with each member experiencing between one and three training sessions lasting 21 minutes each. The training took place within fairly narrow time constraints due to the fact that the training, by necessity, imposed on crew time. All of us were busy with EVAs, habitat maintenance, report writing and individual scientific endeavors. That aside, one of the biggest problems with training inside the hab was the rather “rich” electromagnetic environment which tended to introduce signal artifact into the EEG record. Although the metal scaffolding of the hab structure provided some protection from the gas generator which was located approximately 50 meters from the module, inside appliances created enough EM noise to impact EEG recordings. The electric water heater and the incinolet were in fairly close proximity to my stateroom where the neurofeedback was being performed and as such, caused bursts of 60 Hz artifact. The incinolet was a particularly strong EM field generator (my room was directly over the bathroom).

Neurocybernetics instrumentation was used which employs a differential amplifier with signal gain set to 10,000. This system uses digital filtering for signal processing. Instrument impedance for each of the 2 signal inputs was set at one million meg-ohms. Sampling rate was 160 samples per second. The raw EEG trace and the three filtered wave forms were displayed in a continuous scrolling fashion for monitoring by the therapist. Upon digital filtering, the signal was then sent to a second computer where it was correspondingly mapped into different features of a video game for viewing by the subject. The second screen displayed variations on a Box lights-like game (appropriately named “Space race”) wherein each filtered trace was represented by a box or jet-like image. Size or movement of each of the 3 images varied in direct proportion to the amplitude generated in each frequency band. When threshold criterion was met in all three bands simultaneously and sustained for more than 0.5 seconds, the subject would hear a tone. The neurofeedback software was loaded into 2 Laptop computers (both 486 Compaqs with a Windows 98 operating system in the feedback computer).

The reward frequency was 12-15 Hz with simultaneous inhibition of 4-7 Hz and 22-30 Hz activity. The EEG training protocol was the same for each individual. The active sensor was located at C4 according to the International 10-20 system. (C4 is the central right side of the sensory motor cortex). The reference sensor was placed on the right earlobe with the ground on the left. This training protocol configuration was selected due to its reliability in producing positive effects on attentional ability, mood and arousal (Kaiser & Othmer 2000).

Average reward frequency amplitude changes (in microVolts) over the course of the training sessions for 5 of the 6 participants are shown in figure 1. The 6th subject’s record was unfortunately not useable due to artifact.

Fig. 1



There was a clear trend toward increased activity in the reward frequency band for each of the subjects. Average amplitude increase for the group was 2.26 microVolts over the course of the session. Consistent increases were not noted in either of the inhibit bands. Nearly all found the training to be a pleasant experience and at least mildly relaxing. Most reported that they experienced no noticeable changes in their level of arousal or functioning during the following day although one member noted a slight improvement in quality of sleep. This is not too surprising. Historically, EEG biofeedback has been used to deal with existing pathology (people who feel great generally don't show up at our clinic) and thus it is difficult to assess its preventative capabilities -particularly within a short time window with a relatively small number of training sessions. MDRS participants are generally highly motivated individuals who are without significant pathology.

EEG BIOFEEDBACK AND ITS EFFECT ON IMPROVING SUSTAINED ATTENTION

The following are some of the results from a (soon to be published) study on Attention Deficits Disorder performed at the EEG Institute in Encino, California, utilizing a dual site training montage. The group was comprised of 34 males and females age range 7-62 years -being treated for a variety of disorders. Changes in attentional ability were measured by a continuous performance test (the TOVA -Test of Variables of Attention). What is unique about this study is that only those persons who were treated with bipolar montages (mostly interhemispheric) were examined. Approximately half of the persons included had scores in the normal range upon initial evaluation by the TOVA. Participants were medication free during administration of the test.

The TOVA is a computerized test that involves a flash presentation of one of 2 visual patterns -one designated as the "target" and the other as the "non-target". The subject was instructed to press a microswitch when presented with the target and to

refrain from pressing when viewing the non-target. The purpose of this test is to measure impulse control and sustained attention capability (Greenberg, 2000). The duration of the test was 22.5 minutes. Response time and response variability were also measured. The TOVA was administered prior to training and every 20-25 sessions thereafter. A diagnosis of ADD by the TOVA involves meeting a standard score threshold criterion based on an age related normed database. The emphasis was on observing the changes occurring within each scale particularly Impulsivity and Inattention. In adopting this approach we were able to monitor shifts in different dimensions of functioning. Scores were in standard score with one standard deviation equal to fifteen points either above or below the mean.

Fig.2

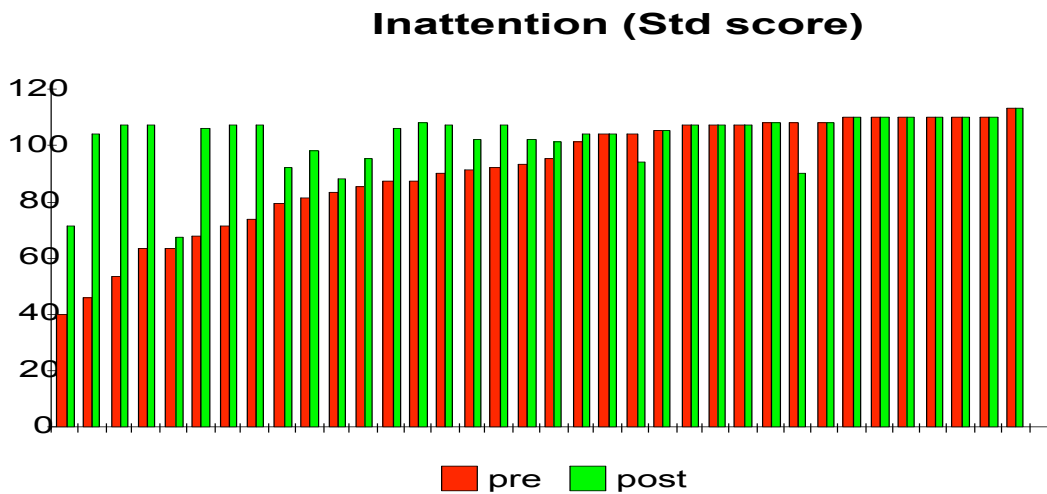


Figure 2 indicates a trend toward normalization of attentional deficits with the most severely impaired individuals showing the greatest degree of improvement following 20 sessions of EEG training. A standard score below 85 (one standard deviation) is considered in the below normal range. This amounted to about half of the persons in the above sample. For those scoring <85 on the Inattention scale, the improvement was the most substantial: (Mean std pre score = 69; post = 98, $p < .05$).

Fig.3

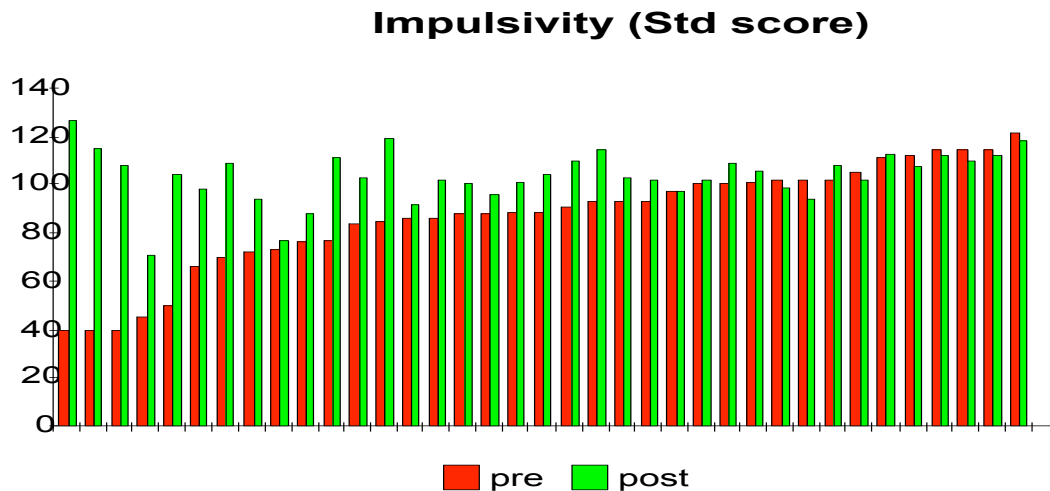


Figure 3 also reflects a trend towards normalization for improving impulse control with the most severely impaired persons making the greatest gains upon TOVA retest following 20 sessions of EEG training. As with Inattention, those whose initial scoring was poorest on the Impulsivity scale showed the greatest degree of improvement. (Mean std pre score < 85 = 63.4; post = 100.4, $p < .05$).

IMPLICATIONS FOR LONG TERM SPACE MISSIONS

Our journey outward will be fraught with unforeseen difficulties and challenges. Science certainly indicates that a depressed or exhausted brain tends to fair less well than a brain that is not. Antarctic and seagoing expeditions provide evidence that conditions of isolation, confinement, unremitting danger, separation from family, lack of privacy and boredom will inevitably take their toll on mood and task performance as well as relationships between crewmembers. Fortunately the level of technology that humans had to manage early last century was comparatively simple and thus the consequences of acts of inattention and absent mindedness were generally non lethal. However, with the dawning of long term space flight, we have raised the level of technological complexity which, in turn, requires more sophisticated and vigilant -management strategies. We raise the stakes considerably as we move out into the space environment as events aboard MIR have indicated. Reports from polar regions, under the sea and orbit strongly suggest that intellectual tasks become more difficult in such places than in normal environments. After several months in Antarctica, 32 out of 35 participants experienced absent mindedness and wandering attention. In a few cases, their behavior could be described as a fugue state -where a person wanders away from his quarters and “comes to” far away, without any memory of how he got there (Harrison, 2001).

Addressing the multidimensional problems that will emerge will certainly call upon all health science disciplines. Any long term journey in the space environment is going to be difficult on every level. When a group of people are confined in a relatively small space for long periods of time with the threat of death a constant companion, there

will always be a price to be paid both psychologically and physically. This will occur no matter how careful the selection process, extensive the training or well engineered the spacecraft. The idea therefore is to prevent these inevitable deleterious effects from overriding a human's capability to manage a situation. Neuroregulatory training strategies are certainly not (in themselves) a complete solution to the problem. But they will likely help to maintain the required flexibility to make a significant difference in maintaining performance if the research here on terra firma are any indication.

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