Use Of Neurofeedback To Achieve Human Performance Enhancement In The Nuclear Power Industry

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Abstract

The nuclear industry has spent many millions of dollars to provide training to personnel to operate our nuclear facilities.

However, even with excellent training programs, candidates often fail examinations. For many, the debilitating effects of performance anxiety are contributing factors.

Neurofeedback technology instantly presents psychophysiological feedback to the trainee while the trainee is performing a training task. This feedback can teach the trainee to effectively cope with environmental and psychological stressors.

We hypothesize that NF training can help NPPs resolve staffing and training challenges while yielding a high ROI by ultimately improving success rates for Certification training candidates.

INTRODUCTION:

In the pursuit of optimal success in selection and qualification of individuals to operate our nuclear facilities, the nuclear industry has never ceased to observe, learn, and integrate new technologies, processes, and approaches into its training methodologies.

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To that end we have introduced full scope simulators, desktop simulators, time management training, stress management training, in efforts to help our trainees to develop the skills and abilities to be successful in both our training programs, and more importantly, when they take on the responsibility for a Nuclear reactor.

Neurofeedback ("NF") is a promising technology for improving nuclear operator performance during training and station operation. Neurofeedback brainwave monitoring combined with interactive 3D desktop simulation can teach users to maintain an attentive, relaxed state during highly stressful training for improved performance in testing and control room environments. Training candidates learn to control cognitive, affective, and psychomotor domains through direct feedback of their individual psychophysiological parameters. This training could assist the trainee not only to be successful in their training programs, but to be more aware, attentive, able to multi-task, and able to recognize and handle both external and internal stressors more effectively.

NF utilizes electroencephalograph (EEG) equipment to measure electrical activity in the brain commonly referred to as brain waves. Scientists studying the brain have found that it continuously produces four distinct speeds or frequencies of brain waves. Although these different brain waves are produced simultaneously and in combination, a person's state of consciousness depends on the dominant (strongest) frequency band at each time. During sleep, the brain produces dominant slow *delta* waves. During daydreaming or in the twilight of sleep, the brain produces dominant *theta* waves that are slow but a bit faster than delta. When the brain is calm and mentally unfocused (e.g., when a person relaxes with the eyes closed), the still faster *alpha* waves are dominant. Finally, when people work on mentally demanding tasks such as concentrate on schoolwork in an alert and focused manner, the *beta* waves that are the fastest of these four classes of brainwaves are most dominant.

NF is not nascent technology. It has been researched and used for over 30 years. In the 1970s, NF research focused on the treatment of epilepsy. When clients were taught to relax and produce specific brain wave activity, the basis of all clinical NF training, occurrence of seizures was reduced [1]. Shortly thereafter, researchers discovered that NF might help reduce the symptoms associated with hyperactivity [2] and later with Attention Deficit Hyperactivity Disorder or ADHD [3].

Recently, NASA conducted NF research in an effort to help prevent accidents among astronauts and pilots during flight by increasing performance through enhanced attention. NASA identified that accident frequency increases for pilots and astronauts during 'Hazardous States of Awareness' [4,5]. Hazardous States of Awareness (HSA) include both periods of low stimulation (hypoarousal) and periods of over-stimulation (hyperarousal), which can occur during periods of high stress. NASA now incorporates their research findings into flight simulator training. As pilots and astronauts work on the flight simulator, brainwave activity is monitored. When the brainwave activity indicates that a pilot or astronaut has diminished attention, auditory or visual cues prompt the astronaut back to an attentive state. This is further evidence of the efficacy of feedback based training.

To initiate their research, NASA attempted to evaluate crew engagement utilizing NF as an assessment technology. NF assessment increased NASA's knowledge base regarding crew engagement and provided insight into adaptive task allocation. This forced them to evaluate adaptive task allocation design options for reduced automation-related complacency. Automation-related complacency is also a problem inherent in the nuclear power industry. Subsequent evaluations of adaptive task allocations design options prompted the development of a new taxonomy of HSA as it related to automation–related complacency as measured by NF. Once implemented, new candidate measurement techniques and assessments could be performed through these established psychophysiological correlates. These correlates consisted of psychological constructs including situational awareness and shared problem models - all of which are highly relevant to the nuclear power field.

The particular application of NF developed for human performance enhancement in the nuclear power industry is based conceptually on the aforementioned technology and procedures developed by NASA. Comparable to those pilots and astronauts in simulator training, training candidates in the nuclear power industry often experience a high level of stress during classroom and simulator testing or unit transients (hyperarousal). Additionally, one problem inherent in the nuclear power industry is automation–related complacency (hypoarousal). Training and assessment in the nuclear power industry also relates highly to the same psychophysiological correlates mentioned in NASA's research. Therefore, given the training and performance similarities between astronauts and nuclear training candidates, it is hypothesized that NF training could be beneficial in improving the success rates of Certified training candidates.

The method of NF developed specifically for the nuclear power industry integrates 3D computer simulator operation [Figure 1] with cognitive skill training and behavioral shaping. Both theoretical analysis [6] and empirical data [7] have indicated that neuro adaptive training interfaces can be highly efficacious. This is facilitated through the use of deliberate practice in the NF training protocol. Deliberate practice includes strategic analysis of operator performance on cognitive, affective, and psychomotor domains. Analyses performed by trainers will enable effective goal setting for each individual training candidate in an effort to produce optimal outcomes in each of the domains.

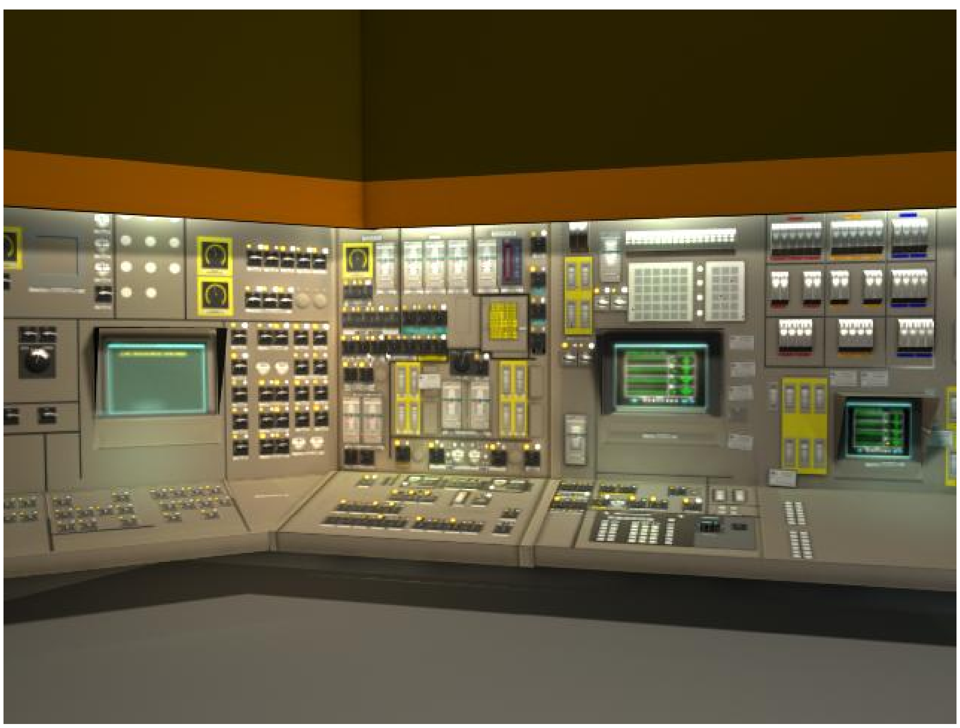

Figure (1) 3D neurofeedback training environment.

The cognitive domain involves knowledge acquisition and the development of intellectual skills. This encompasses the recall or recognition of specific facts, procedural patterns, and concepts that are of utmost importance to the training candidates in order to effectively manage their duties and to pass rigorous examination.

The affective domain encompasses the method in which we emotionally process such constructs as feelings, values, and attitudes. Our priority is with two major subcategories within the affective domain: receiving and responding. Receiving is related to the training candidate's willingness and ability to attend to (receive) particular stimuli which may include simulator work, note taking, classroom activities, etc. Pragmatically, from a teacher/training candidate paradigm, the affective domain concerns getting, holding, and directing the training candidate's attention. Responding refers to active participation of the training candidate. NF will be utilized to engage the training candidate to be actively attending to various training stimuli, particularly simulator training during both hypoarousal and hyperarousal states.

The psychomotor domain encompasses actual physical movement and coordination. These skills are developed by repetitive practice. For our requirements, this domain is primarily related to actual physical movement in relation to work with the simulator or actual control panels. Physical movement is integrally related to both the cognitive and affective domains in that it greatly diminishes if either the cognitive or affective domains are disrupted by states of hypo and hyper arousals. Physical movement is necessary for the training candidates who must utilize both care and precision when manipulating detents in various analog instruments.

Subclasses within the psychomotor domain include imitation, manipulation, precision, articulation, and naturalization. Due to the advanced skill levels of the training candidates and the physical requirements inherent in the simulator, our focus will be on Articulation and Naturalization.

Articulation can be defined as optimal psychomotor skill development; skills are so well developed that the training candidate can modify movement patterns to meet a problem situation, which is a necessary skill for training candidates. Obviously, this requires that the training candidate be highly engaged and able to receive even under hypo or hyper arousal states. The goal of the NF training is to teach the training candidate to be in a state of flow or Naturalization where response is fluid regardless of hypo or hyper arousals. NF training far exceeds classroom and simple simulator training. Since our proprietary form of NF training necessitates psychophysiological engagement, it operantly conditions training candidates to optimally perform to manipulate materials out of knowledge, skills, and abilities developed even during periods of duress such as a unit transient, or automation – related complacency.

While all of these domains appear to be distinctly separate, they are closely linked. This is perhaps epitomized when training candidates, who are well trained and knowledgeable (cognitive domain), cannot pass examination due to a lack of control over their affective domain. This, in turn, may even affect the psychomotor domain by producing hand tremors and even inhibiting peripheral vision to instrument displays [8].

Our use of NF is unique in that it can teach the training candidate to be relaxed and optimally effective in cognitive, affective, and psychomotor domains, even under states of hypo or hyper arousal, by means of active engagement. The system operantly conditions the training candidate to be actively engaged under two simulated conditions: hypoarousal and hyperarousal. This conditioning is performed through actual feedback of real-time physiological brainwave parameters while training candidates manipulate a 3D realistic computer simulation of the nuclear facility. The training candidates can activate and control the simulator only when they are actively engaged. Furthermore, the training candidates can only be actively engaged when physiological parameters are within calm-yet-alert states. The NF component enables the training candidates to see their physiological state on screen and therefore can be taught to control it under conditions of hyperarousal or hypoarousal. Thus, the training candidate is effectively working in all three domains while learning to concurrently control physiological parameters to maintain peak performance even under stressor caused duress (unit transients), fatigue, or inactivity (automation – related complacency).

To obtain long-term effects, training candidates must consistently participate in 40-60 hours of training, which can be integrated with standard operator training activities. Results become permanent such that users develop the ability to identify periods of distraction and low concentration and take corrective measures [9].

In addition to the hours spent on NF training, the candidates will also partake in a Mental Strategies for Successful Testing program. The aim of this program is to educate training candidates on the mental skills required for successful performance. Once learned, these skills are easily implemented into their daily work routines. This program is designed to work in concert with NF as well as to facilitate the efficacy of NF training. The Certification training candidates will be required to work on specific mental skills shown in research to optimize performance. These skills include:

1. Focus and attention: This construct is important in the testing environment, particularly when reading the manual and scanning the panel.
2. Arousal control: Each individual has an optimal level of functioning. It is important to help the training candidates find their level and then implement strategies to get to that level prior to testing (i.e., psyching up or calming down).
3. Positivity: This is most important in the weeks and days leading up to the testing. Having a positive attitude will allow for a more rewarding learning and testing experience.
4. Confidence: Training candidates need to feel confident in their abilities to complete the test. Confidence will be important in the days and minutes leading up to the test.
5. Goals: Training candidates need to recognize that in order to get from A to B there must be a plan. Setting goals is one means by which success can be attained in the testing environment.

By combining this educational program with the NF training, the Certification training candidates will have a greater opportunity for success, specifically in highly stressful environments such as those encountered during control room alarms and testing situations. Furthermore, automation–related complacency should be minimized to produce optimal training candidate performance.

Applications for this technology are outlined below:

2. Improved training performance:

2.1. INITIAL TRAINING SELECTION: identification of training candidates with high potentials in simulator and classroom environments. **Measure**: brainwave activity versus results achieved from current processes and historical data.
2.2. WRITTEN EXAMINATIONS: enhance performance on written exams. Through enhanced focus and attention as well as more effective time management (garnered through the use of goal setting), training candidates are better able to succeed on their written examination. **Measure**: pre and post NF training exam scores.
2.3. SIMULATOR TRAINING: enhance performance on simulator events. **Measure:** number of errors committed pre and post NF training.
2.4. RECERTIFICATION TESTING: for future consideration

3. Improved station performance:

3.1. HUMAN PERFORMANCE ERRORS DURING 'HAZARDOUS STATES OF AWARENESS': reduce human performance errors during circadian troughs and periods or low stimulus/activity. **Measure**: Event Free Day Resets, survey incumbents
3.2. HUMAN PERFORMANCE ERRORS DURING PERIODS OF OVER STIMULATION: reduce human performance errors during periods of high sensory input/overstimulation. **Measure**: extrapolation of simulator data (from item 3 above), survey incumbents
3.3. HUMAN PERFORMANCE ERRORS COMMITTED BY FIELD OPERATORS: reduce errors committed by field staff performing sequential operations per procedures. **Measure**: field simulator Job Performance Measure errors, work protection errors.
3.4. IMPROVED COGNITIVE FUNCTION AND DECISION MAKING BY KEY MANAGEMENT STAFF: improve strategic decision making capability of senior staff. **Measure**: survey participants on their perception of pre and post NF training.

4. Scope:

The scope of this pilot program is to explore the potential for NF combined with a "Mental Strategies for Successful Testing" program for improving Operator performance in the initial simulator training setting as evidenced by qualitative and quantitative measures including improved First Time Through (FTT) Rate from which Return on Investment (ROI) can be calculated.

5. Background :

In 2005, the World Association of Nuclear Operations identified a growing problem of Weaknesses in Operator Fundamentals which has been captured in Significant Operating Experience Report (SOER 3-05). Numerous events have occurred worldwide involving breakdown in fundamental operator behaviors where shift operating crews did not mitigate the effects of operational transients. In some events, the operating crews did not effectively monitor changes in reactor power or take prompt actions to place the reactor in a safe condition. The most common behavioral shortfalls noted in these events are included instances where personnel lost focus on monitoring important system parameters, or did not work as a team to make conservative decisions to place the plant in a safe condition. As a result, Ontario Power Generation, Bruce Power, and other utilities embarked on a quest to develop and implement measures to address these findings.

In July 2005, Ontario Power Generation and Freer Logic of North Carolina demonstrated the use of NF at the Pickering Learning Center. The presentation was well-received and paved the way for a partnership which has resulted in the development of a proof of concept simulation which integrates the existing 2-dimensional desktop simulator with a 3-dimensional virtual reality simulation which is integrated with a NF module through a laptop computer.

In June 2005, Dr. Krista Chandler, a professor and consultant of sport psychology from the University of Windsor introduced a program entitled, “Mental Strategies for Successful Testing” at the Bruce Power Workshop for Recertification. This program addressed goals and roles for authorized staff as well as strategies for arousal control, developing confidence, and positive thinking.

6. METHODOLOGY:

6.1. Conceptualization Phase for NF use in nuclear operations.
6.2. Present NF concept at Ontario Power Generation (July 2005)
6.3. Introduce “Mental Strategies for Successful Testing” at Bruce Power and Ontario Power Generation.
6.4. Develop 3D VR interface of Darlington Control Room panel integrated with NF module.
6.5. Establish protocol for integrating 3D VR interface and NF module with Darlington simulator database through use of fetch routines.
6.6. Create scenario from Darlington Abnormal Incident Manual to use in proof of concept demonstration.
6.7. Finalize proof of concept for presentation at Ontario Power Generation.
6.8. Following successful proof of concept demonstration, Ontario Power Generation to engage in contract to provide seed money to complete series of fetch routines to allow simulator to run in 3D VR environment.
6.9. Complete linkages to simulator database.
6.10. Initiate pilot project to nominally include 5 initial training candidates to engage in NF activities.
6.11. Establish baseline measures for target audience.

6.12. Integrate 40 to 60 hours of coaching and NF to enhance focus and attention and subsequently human performance in the simulator.
6.13. Introduce training candidates to various mental strategies (Mental Strategies for Successful Testing) to be used in conjunction with NF training.
6.14. Measure results.
6.15. Interview participants and their trainers.
6.16. Based on results, expand program to include all initial authorization training candidates.
6.17. Measure impact on First Time Through Rate (FTT).
6.18. Correlate results against cost of training and historical average pass rates.
6.19. Calculate Return on Investment for program using Jack Phillips Methodology.

7. Conclusion:

By aiding Certified Operators and Shift Managers in Training to maintain focus and minimize internal (anxiety and competing thoughts) and external distractions, it is anticipated that success rates in training can be elevated and Forced Loss Rate (FLR) can be reduced by enhancing operator responses to transients, thus yielding strategic and economic benefits. These benefits can be quantified through application of a Return on Investment (ROI) study which identifies tangible and intangible benefits of the program.

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