PROPOSING A WORKER’S MENTAL HEALTH ASSESSMENT USING BIO-SIGNALS

Cost-Effectiveness Analysis of the proposed FFD evaluation method

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Abstract

Existing Fitness-For Duty (FFD) programs predominantly focus on assessing a worker’s drug and alcohol use and fatigue management. However, there are a number of important psychological parameters that can affect a worker’s performance and attitude. For example, a growing number of workers who experienced the Fukushima accident have suffered from depression and anxiety about the future and have exhibited a loss of motivation. The concern is, these psychological manifestations may contribute to human error or may develop into a factor to promote an insider threat. FFD programs are key to the effective operation of NPPs. Thus, the objective of this study is to suggest incorporating a new mental health assessment, based on human bio-signals, into FFD programs. Based on a literature review, this study investigated a variety of human reliability programs currently incorporated into FFD programs to identify their benefits and limitations. To overcome the identified limitations, a new mental health-check-up program using bio-signals is proposed based on the results of our previous research. Using Multi-Criteria Decision Making (MCDM) and a Cost-Effectiveness analysis, the feasibility of implementing proposed additions to the mental health check-up program were investigated. This program will be helpful in assessing the day-to-day reliability of the nuclear workforce and useful to improving the nuclear safety and security culture.

1. INTRODUCTION

In the US Nuclear Regulatory Commission’s (NRC’s) regulation 10 CFR part 26, the importance of a Fitness-For-Duty (FFD) program is highlighted [1]. Nuclear facility workers have to perform their tasks safely and securely. In order to do this, nuclear industries are required to assess a worker’s physical, physiological and psychological ability. To comply with this NRC regulation, nuclear industries implemented a drug and alcohol test and fatigue management (through reporting an employee’s working hours) program [2]. However, current FFD programs are limited to self-evaluation or interview with a manager with long delay time in reporting drug and alcohol testing, and with no reliable tool to measure actual fatigue. To address these limitations, our previous research [3-5] developed a classification model for identifying potentially unfit workers (Alcohol-use, Sleep-deprivation, High stress, Depression and Anxiety) based on bio-signals. In this study, we investigated the feasibility of implementing our proposed FFD evaluation model based on a cost-effectiveness analysis.

2. CURRENT FFD PROGRAMS AND THEIR LIMITATIONS

Many industries as well as nuclear facilities generally require FFD programs in order to ensure safety in the workplace or in facility operations. Most FFD workplace programs focus on Drug & Alcohol testing (D&A), whereas some medical programs or organizations in the U.S. such as, NASA and the U.S. Air force, additionally include fatigue management in their FFD programs. As the consequences of human error in military and hospital situations could lead to the loss of civilian/patient life, these developments seem reasonable. In addition to fatigue management, a psychological evaluation is also used in high reliability industries. In the case of law enforcement (police officers), psychological evaluation is an important portion of their FFD management since they deal with the negative aspects of human nature. Police officers undergo psychological evaluations using both questionnaires
and consulting with a psychiatrist. However, these programs are vulnerable to manipulation by the person completing the self-evaluation.

Despite their good intentions, the FFD programs implemented by industry still have limitations as mentioned in the introduction. To overcome these limitations, developing a program based on an objective technology, that will measure physiological and psychologically fitness/unfitness for duty is desirable. In addition, the technology should provide the benefits of simple measurement, low-cost, and provide an integrated diagnosis of their fitness/unfitness status. Our past studies focused on measuring bio-signals to detect a worker’s mental status. Bio-signals can be obtained from the response of two nerve systems: 1) Central Nerve System (Electroencephalogram (EEG)) and 2) Autonomic Nerve System (Electrocardiogram (ECG), Galvanic Skin Response (GSR), respiration and so on). EEG is the most commonly used clinical measurement data for diagnosing epilepsy, and brain death. According to recent studies [6-8], an EEG may be helpful in the diagnosis of various neuropsychiatric disorders with functional abnormalities in the brain. In addition, stress induces an imbalance in the autonomic nerve system. Thus, ECG, GSR, PPG, and respiration are appropriate signals for analysis when the program objective is detecting a worker’s stress, depression, and anxiety status.

As early as World War II, an EEG screening system was applied by the U.S Air Force and Navy to predict epilepsy of pilot applicants [9]. Since then, bio-signal technology has made rapid progress to be developed into high function wearable devices which can measure a subject’s stress and fatigue using EEG signals. In the EEG area, there is an ample opportunity to support a relationship between bio-signals and a worker’s fitness for duty. As psychological distress, and stress and fatigue management are key issues for improving job performance, thus, we proposed a new integrated FFD measurement program based on these bio-signals.

3. PRELIMINARY RESULTS FROM OUR FORMER STUDIES [3-5]

A total of 124 subjects, from 20 to 29 years of age, participated in the experiments. Bio-signal data from 114 subjects were used for training a classification model and validating the model. After developing the model, 10 subjects (whose fitness status was blinded), were also studied to determine the reliability of the model to predict their fitness-status. All 124 subjects were in generally good health, took no medications, and had normal sleep habits. This study categorized the subjects into Normal group (A: 36 subjects), Alcohol-use group (B: 21 subjects), Sleep-deprived group (C: 11 subjects), Heavy chronic stress group (D: 26 subjects), Depression group (E: 10 subjects), and Anxiety group (F: 10 subjects).

These groups’ bio-signals were recorded during the steady states (Eye closed and Eye open). We collected the data of EEG, ECG, GSR, Respiration, Blood Volume Pulse (BVP), and dynamic changes in blood pressure (BPHEG). EEG raw data were subjected to a Fast Fourier Transform (FFT) algorithm to calculate the absolute (µV2) power and relative (%) power and the FFT Power Ratio (Arb). A total 76 EEG indicators were developed from this frequency analysis. For developing ECG indicators, RR intervals (RRI) were extracted from the ECG recordings. In addition to beat-to-beat analysis (time domain), a frequency domain analysis was performed to calculate the power spectrum density. Thus, we developed a total of 64 ECG indicators including the cases of eye open and eye closed. Additionally, GSR, Respiration, BVP and BPHEG indicators (total 8 indicators) were identified for measuring a worker’s FFD status.

From the work we identified 148 independent variables/features. These variables were calculated using both frequency and time domain analyses. The dependent variable is a subject’s FFD status (A: Normal, B: Alcohol-use, C: Sleep-deprived, D: High/heavy stress, E: Moderate Depression, and F: Moderate Anxiety). Using these datasets (the 148 features and an FFD status for each of the 114 subjects), we trained a classification model. The classification accuracy of the model was validated by analyzing a subset of the data, not used in the original classification model training. While many classification models were initially developed, the classification accuracy value allowed us to choose the best model. As indicated in Table 1, the classification accuracy of the two models selected was 98.9% and 99.4%.

Our former studies also calculated the prediction rate and validation accuracy. To further verify this model’s classification performance, ten new subjects were tested to determine their physiological and psychological status. However, unlike the original test subjects, these students were blind tested without gathering any prior FFD information. The model calculated y-fitting values (predicted values). After the blind test, a different researcher analyzed the ten subjects’ self-evaluation measurements. These data were compared the prediction values, from our suggested algorithm, to the collected actual values (self-evaluation results). The
prediction rate was 76.8% using the Support Vector Machine (SVM) and 96.32% using the Ensemble Bagged Trees method. The validation accuracy, based on this new test set was almost 100%. This indicates our classification model’s performance is reliable.

Table 1. CLASSIFICATION AND PREDICTION RATE

<table>
<thead>
<tr>
<th>Model</th>
<th>Classification Accuracies</th>
<th>Validation accuracy (new test)</th>
<th>Prediction rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic SVM</td>
<td>98.9%</td>
<td>95.26%</td>
<td>76.84%</td>
</tr>
<tr>
<td>Fine KNN</td>
<td>97.8%</td>
<td>100%</td>
<td>65.26%</td>
</tr>
<tr>
<td>Ensemble Bagged Trees</td>
<td>99.4%</td>
<td>100%</td>
<td>96.32%</td>
</tr>
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</table>

4. COST-EFFECTIVENESS ANALYSIS

To apply the proposed bio-signal based mental health evaluation method, a cost-benefit assessment was made to compare the existing FFD technologies to the new FFD evaluation method. This study used a Cost-Effectiveness Analysis (CEA) that compares the relative costs and outcomes (effectiveness) of different courses of action [10]. We constructed a decision tree to evaluate the costs and effectiveness of the new FFD evaluation method using bio-signals compared to conventional technologies for the purpose of Drug & Alcohol Testing (D&A). A lack of fatigue and stress management data forced our study to focus on D&A data. To compare the effectiveness, two existing D&A methods were used i.e., Blood and Urine tests. The CEA analysis was performed using TreeAge Pro software. Our decision tree model allowed us to examine the relationships among the variables and determine to the effectiveness of performing FFD bio-signals monitoring (Fig.1 decision tree and analysis results).

The costs from each approach and the outcomes were estimated by using a Multi-Criteria Decision Making (MCDM) analysis [11]. In this estimation, the multi-attributes of the methods such as level of invasiveness, detection periods, and risk of false positive were considered. Values ranging from 1 to 5 were assigned based on the examination of the expected consequences of the decision in the given strategy. These values came from the published literature [12]. Depending on the effects of each category, most of the values were assigned as High (1~2 score) or Low (5 score). The values were a little different for each category. For example, as detection period is shortened, the effectiveness of the selected test is improved. Thus, in the detection period category, the blood test, urine test, and bio-signal evaluation were assigned the scores of 3, 1, and 5 respectively. By using the assigned values, an aggregate score for each technology was calculated. When a technology was successful the aggregate score was used to represent its total effectiveness. However, when a technology was not successful in detecting a worker’s FFD, only the half of the value for the total effectiveness was used. The results are shown in Figure 1 as the cost effectiveness graph (right). The figure highlights the effectiveness of the newly proposed FFD evaluation technology and identifies it as the best option compared to other existing technologies. To overcome issues from subjective assessment, we applied the Monte Carlo simulation (sample number: 100,000) for the sensitivity analysis. When bio-signal option’s cost and effectiveness set up normal distribution, the best preference among three options is the new FFD program.

Fig.1. Decision Tree and Cost-Effectiveness Results. This analysis aims to evaluate three different FFD evaluation technologies.
5. CONCLUSION

This paper compared the cost-effectiveness of a new mental assessment method based on the use of bio-signals, to the existing FFD methods. Data for 148 independent variables (76 EEG indicators, 64 ECG indicators, 2 BVP, 2 GSR, 2 Respiration and 2 BPHEG) and dependent variables (subject’s fitness status: normal, alcohol-use, sleep-deprived, heavy stress, moderate depression and anxiety) were collected and analysed. These results showed that the bio-signal data to represent the resting states (Eye closed and Eye Open) have a statistically significant difference between the unfit-for-duty subjects and healthy workers. The newly developed classification model was also found to be reliable when identifying a worker’s fitness status. Based on a cost-effectiveness analysis, the proposed FFD evaluation method was found to be the best option compared to other existing approaches. These results indicate the possibility of using the new FFD assessment method for mental assessment programs in nuclear power plants as well as in other high reliability industries, such as aerospace, military and transportation industries.

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REFERENCES