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The Relationship between Human Operators' Psycho-physiological Condition and Human Errors in Nuclear Power Plants

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1. Introduction

The safe operation of nuclear power plants (NPPs) is substantially dependent on the performance of the human operators who operate the systems [1]. In this environment, human errors caused by inappropriate performance of operator have been considered to be critical since it may lead serious problems in the safety-critical plants. In order to provide meaningful insights to prevent human errors and enhance the human performance, operators' physiological conditions such as stress and workload have been investigated.

Physiological measurements were considered as reliable tools to assess the stress and workload. T. Q. Tran et al. and J.B. Brooking et al pointed out that operators' workload can be assessed using eye tracking, galvanic skin response, electroencephalograms (EEGs), heart rate, respiration and other measurements [2-3].

The purpose of this study is to investigate the effect of the human operators' tense level and knowledge level to the number of human errors. For this study, the experiments were conducted in the mimic of the main control rooms (MCR) in NPP. It utilized the compact nuclear simulator (CNS) which is modeled based on the three loop Pressurized Water Reactor, 993MWe, Kori unit 3&4 in Korea [4] and the subjects were asked to follow the tasks described in the emergency operating procedures (EOP). During the simulation, three kinds of physiological measurement were utilized; Electrocardiogram (ECG), EEG and nose temperature. Also, subjects were divided into three groups based on their knowledge of the plant operation.

2. Experiment

The experiments were performed with 21 graduate students majoring in nuclear engineering at Korea Advanced Institute of Science and Technology (KAIST) in Korea and Khalifa University of Science, Technology and Research (KUSTAR) in U.A.E. Subjects are divided in three groups- Level 1 (13 subjects), Level 2 (5), and Level 3 (3, higher knowledge group) based on their knowledge of the plant operation. Before the experiments, the subjects were trained for two hours in order to be accustomed to operate the plant simulator and EOP of the given accident. After training, each subject was asked to follow EOP to mitigate the accident as a reactor operator (RO). During the experiment, video physiological data were collected. Duration of each unit task and timing of errors are recorded by experiment conductors.

Steam generator tube rupture (SGTR) scenario was selected as the malfunction of nuclear simulator. The tasks in the EOP of SGTR were analyzed to identify the possible human errors during the experiments by using systematic human error reduction and prediction approach (SHERPA) [5]. Some of error modes were modified for the simplicity of analysis scheme to consider the nature of EOP (execution and check tasks) and the operation scheme of CNS (selection task). Thus, we consider the action errors, the checking errors, and the selection errors.

3. Analysis of Psycho-physiological Condition

3.1 Human error probability

By using human error modes, the human errors during experiments were analyzed. Total number of human errors is 119 and the average number of errors of each subject is 5.92 over total 39 tasks. Among 119 human errors, Level 1 made 93 (average 6.6), Level 2 made 18 (average 3.6), and Level 3 made 8 (average 2.7) errors.

3.2 ECG recordings

ECG detects the electric excitation of hearts as voltage between two electrodes equipped on the surface of human body [6]. In order to observe the trend of human errors along the tense level, the mean values of both activities of PSNS and SNS during the experiment were calculated.

The map of PSNS and SNS activity is shown in Figure I. Subjects in the Level 1 tends to have lower SNS activity and higher PSNS activity which indicates relatively lower tense level. Also, the effect of tense level with knowledge to the number of human errors is analyzed. For all subject, the number of human errors was positively related to PSNS activity (R^2=0.431).

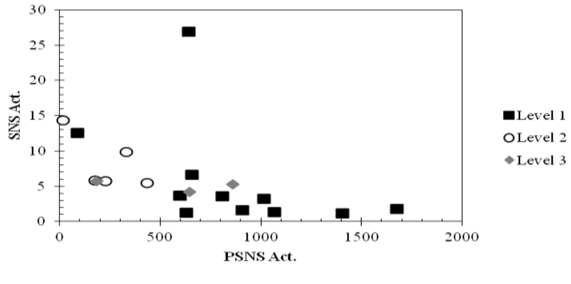

Figure I. The map of SNS activity and PSNS activity

3.3 EEG recordings

EEG measures the current that flow during synaptic excitations of the dendrites of many pyramidal neurons in the cerebral cortex which is the dominant part of the central nervous system [7]. Since EEG beta power is related to human's tense (alertness) condition [8], beta power ratio was mainly investigated in this study.

As a result, subjects who are tense tend to make fewer human errors as shown in Figure II. In addition, subjects who have higher knowledge have tendency to be located in upper left position whereas subjects in Level 1 are evenly distributed. It indicates subjects in Level 3 are much tense and make fewer human errors. Beta power ratio of subjects was negatively related to the number of errors (R^2=0.342) for all subjects.

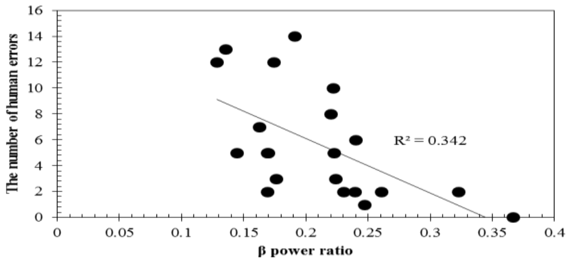

Figure II. The map of SNS activity and PSNS activity

3.4 Nose temperature recordings

When human is tense, the nose temperature begins to drop down since it may induce peripheral metabolic response which is mediated primarily by the sympathetic nerve system [9]. In order to measure the tense level using thermal camera, two factors were analyzed: The portion of below the mean value and The standard deviation. Since nose temperature drops when human is tense, if the portion below the mean value through time scale is high, the subject is considered to be tense for longtime during the experiment. In addition, if standard deviation is high, there may be big difference between min-max peak during the experiments and it indicates that there are big distinguishable periods of different physiological conditions: The period when subject is relatively tense and The other when subject is relatively relaxed.

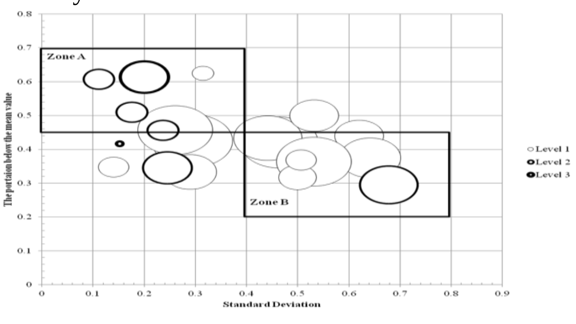

Figure III. The map of standard deviation and the portion below the mean value

As shown in Figure III, the subjects who are tense make fewer human errors. The size of circle is associated with the number of errors. The bigger circles indicate the more human errors. In order to see the difference more clearly, we divided the area into two zones; Zone A and B. The subjects of zone A are relatively tense consistently during the experiments while the subjects of zone B are relatively relaxed and their tense level is not consistent. In addition, subjects who have higher knowledge have tendency to be located in zone A.

4. Summary and Conclusion

The result shows that subjects who are tense make fewer errors. In addition, subjects who are in higher knowledge level tend to be tense and make fewer errors. For the ECG data, subjects who make fewer human errors tend to be located in higher tense level area of high SNS activity and low PSNS activity. The results of EEG data are also similar to ECG result. Beta power ratio of subjects who make fewer errors was higher. Since beta power ratio is related to the stress due to tension, it indicates subjects who are tense tend to make fewer errors. Also, subjects with higher knowledge level have tendency to be relatively tense. These trends were also observed with nose temperature data. Subjects who make less human errors have tendency to be tense consistently while subjects who make more number of human errors are relaxed and their tense level jumps during experiment.

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