Investigation of Relation between Operator's Mental Workload and Information Flow in Accident Diagnosis Tasks of Nuclear Power Plant

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1. Introduction

In the main control room (MCR) of a nuclear power plant (NPP), there are lots of dynamic information sources for MCR operators' situation awareness. As the human-machine interface in MCR is advanced, operator's information acquisition, information gathering and decision-making is becoming an important part to maintain the effective and safe operation of NPPs [1]. Diagnostic task in complex and huge systems like NPP is the most difficult and mental effort-demanding for operators.

This research investigates the relation between operator's mental workload and information flow in accident diagnosis tasks. The amount of information flow is quantified, using information flow model and Conant's model, a kind of information theory [2]. For the mental workload measure, eye blink rate, blink duration, fixation time, number of fixation, and gaze direction are measured during accident diagnosis tasks. Subjective methods such as NASA-Task Load Index (NASA-TLX) and Modified Cooper-Harper (MCH) method are also used in the experiment.

It is shown that the operator's mental workload has significant relation to information flow of diagnosis task. It makes possible to predict the mental workload through the quantity of the information flow of a system.

2. Mental workload and information flow of diagnosis tasks

Using a stage model qualitatively and information theory quantitatively, the cognitive information flow of diagnosis task can be quantified. The amount of information flow can be used to predict a diagnosis time to completion and the operator's workload of diagnosis tasks.

The objective of this research is to investigate the relation between the information flow of diagnosis tasks and operator's mental workload which is measured by subjective and physiological methods.

2.1 Physiological measures: eye movement parameters

Eye movement parameters have been used to monitor the operator's mental workload for the evaluation of human-machine interfaces, especially in the field of aviation as well as automobile industry. Differently from other techniques, mental workload measures using eye tracking system have the advantages of being continuous and non-intrusive to the primary responsibilities of the operators [3]. Under high workload during a diagnosis task, operators have to give more mental effort in order to maintain an adequate level of performance.

It is known that the higher the mental workload is in diagnosis task, the longer the proportion of the fixation duration is for instrument or alarm-list observation [4]. Operator's reduced blinks help to maintain continuous visual input when high levels of visual attention are required, because visual input is disabled during eye closure. Table 1 shows the characteristics of eye movement and measures related to each eye movement for mental workload.

Table 1. Characteristics of eye movement and measures related to each eye movement for mental workload

	Measures	Characteristics
Blink	- Blinks per minute - Blink duration - Blink interval time	- Easy to collect and analyze the data - Revealing task complexity
Fixation	- Fixation time - Number of fixations - Fixation fraction (%)	- Excellent tool to track the operator's cognitive process (e.g. scanning route or pattern) - Showing the difficulty of information extractions, difficulty level of task - Finding out the critical instrument
Gaze direction	- Horizontal/Vertical gaze direction - Horizontal/Vertical gaze variability	- Easy to collect and analyze the data - Showing the important component to specific task

2.2 Subjective measures

Among lots of methods to measure the human mental workload, subjective rating techniques such as NASA-TLX and MCH are most widely known and accepted methods to measure operator's mental workload because of their high face fidelity, operator acceptance, ease of use, high transferability. The subjective methods have some shortcomings such as susceptibility to operator's memory problems, bias, experience and degree of familiarity with certain task as well. In these subjective methods, operators would rate the level of mental effort that they felt, immediately or retrospectively after the task done.

2.3 Information flow of accident diagnosis tasks

In the information flow model, four stages of information processing are considered: perception, identification, diagnosis, and planning. To quantify the information flow, a stage model of diagnosis task should be qualitatively developed to be appropriate to NPPs [5]. Based on that information flow model, the amount of information flow could be calculated by using Conant's model, a kind of information theory especially for hierarchical systems.

3. Experiments

Experiments set the goal at investigating the relation between operator's mental workload and information flow in accident diagnosis tasks. 8 accident cases were considered and given to the subjects.

3.1 Experimental design

The subjects were trained to use the PC-based FISA-2 simulator. Their eye movement information was continuously recorded during the experiments through eye tracking system, faceLAB™. Figure 1 shows the testbed for experiment.

Figure 1. Testbed for experiment

3.2 Measures

Subjects were requested to rate their mental workload using NASA-TLX and MCH method after each diagnosis task. NASA-TLX is pair-wise comparison test and multidimensional rating technique providing an overall workload score based on a weighted average of ratings on six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration. MCH is unidimensional rating method with 10-point scale. For the eye movement parameters, subjects' blink rate, average blink duration, fixation time, number of fixations, gaze direction data were recorded through the eye tracker.

3.3 Tasks and results

Each subject were asked to identify 8 accident cases; 1) Steam Generator Tube Rupture (SGTR), 2) Loss of Coolant Accident (LOCA), 3) Steam Line Break (SLB), 4) Feed Line Break (FLB), 5) Main Steam Isolation Valve Failure, 6) Reactor Coolant Pump Trip, 7) Pressurizer Spray Valve Failure, and 8) Pressurizer Spray Valve Failure with Pressurizer Heater Failure. The information flow (bits) of each accident diagnosis task was quantified and the information flow rate (bits/s) of each diagnosis task could be manipulated in FISA-2 simulator by means of simulation time.

Information flow of 8 accident cases was calculated and compared with the results of NASA-TLX and MCH rating and the eye movement data. Results showed that there was a significant relation between information flow rate of diagnosis task and operator's mental workload.

4. Conclusion

The relation between information flow and operator's mental workload in accident diagnosis tasks was investigated in this work. Information flow was quantified based on a stage model and Conant's model. Mental workload was measured through subjective and physiological measure. NASA-TLX and MCH was used for subjective measure and each subject's blink and fixation data were logged and analyzed for physiological measure.

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