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Experimental investigation between attentional-resource effectiveness and perception and diagnosis in nuclear power plants

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HIGHLIGHTS

- Effectiveness in information searching is measured by two eye-tracking measures.
- The relationship between the effectiveness and perception and diagnosis is addressed.
- An experimental study is conducted to investigate the relationship.
- The experimental results show close correlation.
- The eye-tracking measures as inferential measures for perception and diagnosis.

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ABSTRACT

Eye-tracking-based measures of attentional-resource effectiveness in information searching such as FIR (fixation to importance ratio) and SAE (selective attention effectiveness) have been developed based on cost-benefit principles. The relationship between the eye-tracking-based measures and perception and diagnosis of operators during operating tasks in main control rooms (MCRs) of nuclear power plants (NPPs) is investigated with experimental studies. The FIR and the SAE, which represent how effectively an operator attends to important information sources, are used as measures of the effectiveness in information searching. Perception failure rate (PFR) and diagnosis score (DS) are used as measures of perception and diagnosis, respectively. Experimental results show that the FIR and the SAE correlate closely with the PFR and the DS, respectively. It is concluded that the FIR and the SAE can be used as inferential measures of perception and diagnosis for human factors in NPP MCRs.

1. Introduction

As the design of instrumentation and control (I&C) systems for various plant systems including nuclear power plants (NPPs) is rapidly moving toward fully digitalized I&C (Yoshikawa, 2005; Lee and Seong, 2007), the role of the operators in advanced NPPs shifts from a manual controller to a supervisor or a decision-maker (Sheridan, 1992) and the operator tasks have been more cognitive works. Generally, operator tasks in NPPs are performed through a series of cognitive activities such as monitoring the environment, detecting changes in the environment, understanding and assessing situations, decision-making, planning responses, and implementing responses (Barriere et al, 2000). Perception is frequently considered a crucial key to detect some problems (Adams et al., 1995; Durso and Gronlund, 1999; Klein, 2000). As shown in the TMI accident, correct diagnosis is one of the most critical contributions to safe operation in NPPs as well (Kemeny, 1979). Operators in NPPs selectively attend to important information sources to effectively understand current status (Mumaw et al., 2000). Selective attention to important information sources is continued while maintaining current knowledge on NPP systems as well. Self-rating techniques based on questionnaires are widely used for the evaluation of cognitive activities such as situation awareness, workload, and so on. In self-rating techniques, generally subjective evaluation coupled with the self-rating is made and it is not possible to evaluate continuously. The eye tracking measures are known as being objective and can provide continuous information on activities of subjects. These days developed are eye tracking systems

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Nomenclature and abbreviations

ACR	advanced control room
AHP	analytic hierarchy process
AIR	Attentional-resource to the Importance of the information sources Ratio
AOI	area of interest
APR-1400	advanced power reactor 1400
CI	consistency index
CR	consistency ratio
DEMIS	difficulty evaluation method in information searching
DS	diagnosis score
ETS	eye tracking system
FF	feed flow
FIR	fixation to importance ratio
FLB	feed line break
FWIV	feed water isolation valve
GUI	graphic user interface
HES	high expertise subject
HMI	human–machine interface
HUPESS	HUman Performance Evaluation Support System
I&C	instrumentation and control
IE	informational expectancy
IV	informational value
L	level
LES	low expertise subject
LOCA	loss of coolant accident
MCR	main control room
MMS	mental model score
MSIV	main steam isolation valve
NPP	nuclear power plant
OCT	optimal control theory
P	pressure
PFR	perception failure ratio
PRZ	pressurizer
RCP	reactor coolant pump
RI	random index
S/G	steam generator
SA	situation awareness
SAE	selective attention effectiveness
SF	steam flow
SGTR (A)	loop-A steam generator tube rupture
SLB (B)	loop-B steam line break
SME	subject matter expert
T	temperature
TBN	turbine
1A	experiment-1 after training
1B	experiment-1 before training
2A	experiment-2 after training
2B	experiment-2 before training

which have capability to measure a subject' eye movement without direct contact. Hence the measurement of the eye movement is not intrusive to the operators' activities. In the majority of cases, the primary means of information input to the operator are through the visual channel. An analysis of the manner in which the operator's eyes move and fixate gives an implication on operator's information processing. The authors have developed measures of attentional resource effectiveness in information searching such as FIR (fixation to importance ratio) and SAE (selective attention effectiveness) for use in human factors studies, which represent how effectively an operator attends to important information sources (Ha and Seong, 2010). The FIR is the ratio of attentional resources (i.e., the number and the duration of eye fixations) spent on an information source to the importance of the information source. The SAE incorporates the FIRs for all information sources. The FIR and the SAE have been used as performance measures in a HMI (human–machine interface) evaluation method named "DEMIS (difficulty evaluation method in information searching) as well (Ha and Seong, 2009b).

In this study, the relationship between the FIR and the SAE and perception and diagnosis is investigated with experimental studies to demonstrate the applicability of the FIR and the SAE as inferential measures of perception and diagnosis. Perception failure rate (PFR) and diagnosis score (DS) are defined and used as measures of perception and diagnosis. A subject's perceptions on important information sources and diagnosis results were asked in a debriefing after each experiment. Finally statistical analyses between the FIR and the SAE and perception and diagnosis are performed to see the relationship.

2. Attentional-resource effectiveness, perception and diagnosis

2.1. Theoretical and empirical background

Operators in NPPs continuously monitor the status of the plant system during normal operation. When they detect symptomatic events representing abnormal situations, they actively search for relevant information to correctly understand the situation. Stages of information processing depend on mental or cognitive resources, a sort of pool of attention or mental effort that is of limited availability and can be allocated to processes as required (Wickens et al., 2004). With regard to attentional resources, there are two aspects of attention: selecting information sources for further information processing and dividing attention between tasks. Attention is typically driven by four factors: salience, expectancy, value, and effort (Wickens and Hollands, 2000). Salience refers to stimulus in the environment such as alarms, alerts, or some remarkable indication representing deviation from the normal situation. Expectancy shifts attention to specific sources which are most likely to provide information. Frequency of looking at or attending to an information source is modified by how valuable it is to look at. Attention may be inhibited if it is effortful compared to its value. Perception or understanding is accomplished by three simultaneous processes: bottom-up processing, top-down processing, and unitization (or matching) of the two processes. Bottom-up processing is derived by stimulus or salient information sources through sensing mechanisms. After detecting a stimulus, the information is matched to a mental model that is established based on knowledge and experience. Expectancy derived from the mental model leads to effective selection of information sources, which is top-down processing. The series of bottom-up processing, top-down processing, and unitization is the process of perception or understanding.

The first studies on information searching (or visual sampling) behavior have been done for flight maneuver tasks by Jones et al. (1949), Milton et al. (1949) and Fitts et al. (1950). They suggested that dwell time was a function of the difficulty of reading an instrument and of interpreting the data from it. The difference in the relative fixation frequencies was more than ten to one, and it was concluded that this was due to their relative importance (Fitts et al., 1950). The first theoretical model of the visual sampling was made by Senders (1955, 1964). Senders focused on the optimum sampling of dynamic instruments as a function of the bandwidth (event rate) of signals, employing optimal sampling theory. Senders' original scanning model was subsequently elaborated by others (Carbonell, 1966; Carbonell et al., 1968; Smallwood, 1967; Baron and Kleinman, 1969; Baron et al., 1970; Kleinman et al., 1970; Kleinman and Curry, 1977; Levison, 1971; Wewerinke, 1981; Stein