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Method to Investigate Cognitive Aging Effects in Nuclear Operations Using the Rancor Microworld Simulator

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ABSTRACT

Many nuclear power plant (NPP) operators are close to, or at, retirement age. Since NPP operators are responsible for tasks that engage different and complex cognitive abilities, human factors researchers recently called for an examination of cognitive aging effects and potential interactions with modernized control rooms. One way control rooms are being modernized is by replacing paper-based procedures with computer-based procedures (CBPs). This paper outlines a method for testing the preference and usability of three types of CBPs as a function of age in simulated NPP operations. We will use the Rancor Microworld Simulator, which mimics an NPP control room and allows novices to learn to perform operator tasks quickly. The experiment will have two independent variables: age (young and old) and CBP type (Type 1, 2, and 3). The three types of CBPs vary in levels of embedded instrumentation and controls. We will recruit adults aged 18–25 years (younger group) and ≥60 years (old group) from the general population. The dependent variables will be preference and usability metrics via survey and simulator logs. All participants will perform two scenario types (start-up and loss-of-feedwater operations) and will be randomly assigned to one type of CBP to guide them through the scenario. We will use analyses of variance to determine whether there is a main effect of age and any age × CBP type interactions on the preference and usability dependent variables.

Keywords: Cognitive aging, procedures, Rancor Microworld

1. INTRODUCTION

There are currently 56 million adults aged 65 years and older in the United States [1], and by 2040, that number will increase to 80 million [2]. Various factors have contributed to longer life expectancies, including lower rates of child mortality, modern medicine, and improved healthcare [3]. Due to individuals living longer, more older adults continue to be a part of the workforce beyond the traditional retirement age [4]. For instance, the nuclear energy industry presently has an aging workforce, with many operators in nuclear power plants (NPPs) close to, or at retirement age [5]. It is important to acknowledge that age-related changes in cognitive function can impact performance in the workplace [6]. For example, in a study examining flight simulator performance of pilots between the ages of 40 and 69 over a 3-year period, overall performance declined. However, pilots who had more years of experience and were older had better performance scores than pilots who were younger and had less experience [7]. A recent paper [8] argued that cognitive aging effects in nuclear operations warranted investigation. This was the first in a planned

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series of three articles. While there have been many investigations into how cognitive aging affects performance in sociotechnical industries, such as aviation [9], only recently has there been a push to study aging in the nuclear power industry. The present paper, the second of a series, proposes a method for investigating cognitive aging effects in nuclear operations.

As individuals age, they experience changes in cognitive abilities that are often associated with age-related brain changes [10]. Certain areas in the brain are more heavily impacted by age, such as the prefrontal cortex, which result in a change in executive functions [11]. Executive function refers to an array of higher-order cognitive abilities, such as working memory, attention, and fluid problem-solving [12]. Most types of executive functions decline in older adulthood. These age-related changes in cognitive function can impact an NPP operator's ability to carry out certain tasks. For instance, operators monitor systems, detect issues, diagnose issues, plan responses to those issues, make decisions, and problem-solve [13]. These tasks require operators to focus and shift their attention, ignore task-unrelated thoughts, evaluate information, and plan and decide how to respond to a particular situation.

Despite older adults experiencing a decrease in some fluid cognitive abilities, such as executive functions, other skills improve. For instance, older adults are less likely to experience mind-wandering thoughts than younger adults when completing a task [14]. Mind-wandering refers to the phenomenon in which an individual becomes distracted by stimuli or information unrelated to the task the individual is undertaking. Lower susceptibility to mind-wandering is advantageous in the workplace, especially in an NPP setting, where older adult operators may be more capable of ignoring distracting stimuli, allowing them to focus on a task, compared to younger adult operators. Moreover, verbal fluency, reasoned thought, and rational decision-making all tend to improve with age [15]. Due to age-related changes in these skills, there are differences in how younger and older adults arrive at decisions. For example, older adults tend to look for and need less information when making a decision than younger adults [16]. It is also plausible that the number of years working in nuclear operations impacts how decisions are approached. This is just one example of how age-related changes in cognitive abilities may impact how younger and older operators carry out tasks.

It is also important to consider whether younger and older adult operators interact with modernized NPP control rooms in the same way. For example, control room digital upgrades can include integrating information automation, which refers to a machine's ability to collect and communicate information to an individual [17]. This form of automation updates NPP operators on the plant status by consolidating information on plant parameters. Using automation can lower the number of human errors by lessening the mental workload, which is important because mental workload can directly impact operator performance [18]. One way that this type of automation can be incorporated into NPPs is via computer-based procedures (CBPs) [19]. The industry has traditionally used paper-based procedures to guide operators through a particular plant task or scenario; operators are expected to follow the procedure precisely and not deviate from its instructions. With the introduction of CBPs, the level of information automation embedded within the procedure can vary [17].

The present paper documents a method to investigate cognitive aging and age × information automation interaction effects (operationalized as three different types of CBPs) in nuclear power operations. We will use the Rancor Microworld Simulator, which can replicate NPP control room environments in a simplified fashion, allowing younger and older novices to be quickly trained to perform basic operator tasks [20]. Taken together, the methodology described here melds basic and applied science in that a rigorous experimental design is applied to an industry-specific problem space using individuals from the general population.

2. METHOD

2.1. Participants

Younger adults (18–25 years old) and older adults ($\geq$60 years old) will be eligible to volunteer for the study. We will recruit young adults via university-based networks and older adults via a database originating from Dr. Anna Hall's Laboratory of Aging Science and Health. This database is comprised of older adults who have previously participated, or indicated willingness to participate, in Dr. Hall's aging research studies. We will test up to 70 individuals, with the goal of a total sample size of 60 participants with 30 in each age group. Participants will be matched for educational level and exposure to the nuclear power industry across age groups.

2.2. Types of Computer-Based Procedures

CBPs guide the participant through their assigned tasks [19]. According to the Institute of Electrical and Electronics Engineers, CBPs can be grouped into three categories, with varying levels of digitalization [21]: Type 1 CBPs only display the instructions, Type 2 shows the instructions along with plant indicators, and Type 3 has embedded soft controls alongside the instructions [22]. Type 1 can best be thought of as a simple digital replica of a paper-based procedure, with Types 2 and 3 containing increasing amounts of information automation respectively. Figure 1 shows the different types of CBP display screens in Rancor. Put simply, participants will complete each scenario using CBPs that contain either no, some, or more information automation. Note that the soft controls in Type 3 CBPs are not considered control automation, since they do not typically perform a series of steps. Rather, they bring the necessary controls for manual operation into the procedures, thereby consolidating information and automating locating the controls.

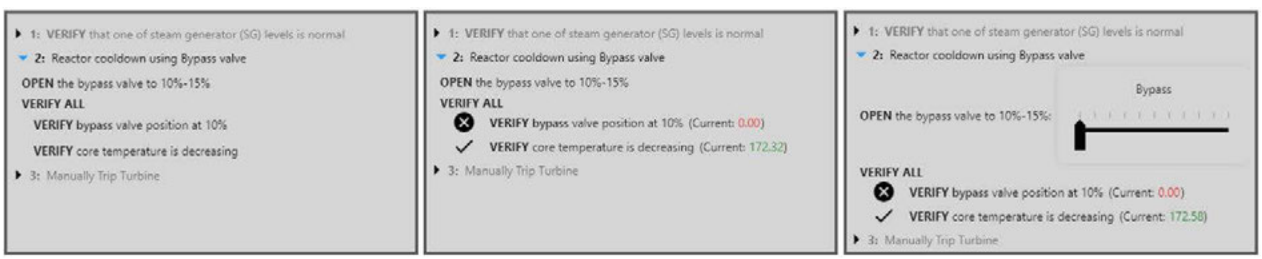

Figure 1. Type 1 (left), Type 2 (center), and Type 3 (right) CBPs in Rancor.

2.3. Types of Scenarios

Participants will each complete two different scenarios: normal or non-event (start-up) and abnormal event (loss of feedwater) operations. A non-event scenario is one that reflects normal working operations in NPPs, such as start-up. An event scenario refers to a situation in which an issue within the plant arises, requiring an NPP operator to perform a series of actions to address the problem. The failure of feedwater pumps is labeled as an event scenario because this situation does not usually occur in daily operations. Due to the emergency nature of event scenarios, participants may experience more pressure when completing them than non-event scenarios [23].

The start-up scenario requires participants to use a start-up procedure, and to complete this scenario, the participant must not trip the reactor. For the failed feedwater pumps scenario, participants will carry out a fault diagnosis and then follow a procedure that shuts down the nuclear reactor. To complete this scenario, participants will need to enter and complete the rapid shutdown procedure accurately and within the time limit. Using two different scenarios will increase reliability and ecological validity.

2.4. Experimental Design

The proposed experiment will use a mixed design to compare the performance of younger and older adults using three different CBPs, which have various levels of embedded information automation. There are two independent variables: age (young, old) and CBP type (Type 1, 2, 3). The dependent variable is human performance, which will be assessed through mental workload, situation awareness, and measures taken from the Rancor simulator logs (generated revenue, time in scenario with reactor core temperature within range, executed actions, and completion time). We will also assess user impressions and usability of the CBPs as a function of age via surveys.

2.5. Rancor Microworld Simulator

Rancor is a simulation program that mimics the environment and operations performed in an NPP [20]. It allows participants to quickly learn how to perform tasks that NPP operators carry out in everyday operations and emergency situations. The Rancor interface consists of three panels: the piping and instrumentation diagram (P&ID), the overview window, and the control window (Figure 2). The P&ID provides the participant with information regarding the reactor, coolant pumps, steam generator, and turbine (i.e., the plant state). The overview window displays information regarding system parameters, including the temperature of the core reactor and the level of reactivity and pressure in the turbines. There is also an alarm panel that notifies the participant when there is a plant upset (e.g., high radiation levels). The control window allows the participant to control the plant through the touch screen. In the present version of Rancor, the control window contains the CBPs.

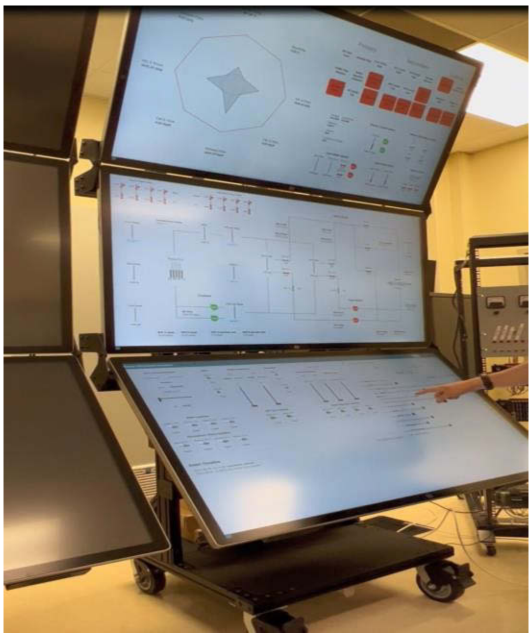

Figure 2. The Rancor interface with overview window (top), P&ID window (middle), and control window (bottom).

2.6. Measures

2.6.1. Demographics

A short demographic survey will be given to all participants asking for their age, gender, field of study, highest level of education, and amount of prior experience in nuclear operations. If the participant reports that they have experience in the field, they will be asked to report for how long.

2.6.2. Rancor simulator logs

Rancor collects various types of data, such as the actions executed in each step of a procedure and values from plant parameters. For this study, we will use simulator logs to assess 1) generated revenue, 2) time in scenario with reactor core temperature within a particular range, 3) executed actions, and 4) completion time. Generated revenue is the difference between the revenue produced at the start and end of a scenario. To calculate the time (in seconds) in each scenario where the core temperature was between 400 and 650°, we will take the sum of the time in each step. We will calculate the average number of actions executed in each scenario as well as the mean time it took participants to finish a scenario.

2.6.3. Mental workload

We will use the National Aeronautics and Space Administration Task Load Index (NASA-TLX) to measure the subjective mental workload after completing each scenario. This questionnaire consists of six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration level [24]. Participants will rate how they felt completing the task on a 10-point scale, ranging from low to high. An average of the six dimensions provides an overall mental workload score. A higher score is indicative of a higher mental workload. The NASA-TLX has demonstrated adequate psychometric properties [25].

2.6.4. Situational awareness

We will use the situation awareness rating technique (SART) [26] to assess subjective situational awareness after completing each scenario. The 3D-SART consists of three items: attentional resources demand (D), attentional resources supply (S), and situation understanding (U). On a seven-point scale, ranging from low to high, participants will rate each item. A higher overall score is indicative of a higher level of situational awareness (SA). The following formula is used to calculate the overall score:

$$SA = U - (D - S) \tag{1}$$

2.6.5. Post-scenario survey

Participants will fill out a survey after they complete each scenario. Using a 10-point Likert scale, they will rate the degree to which they agree with four statements: the training was effective in helping them complete tasks, practicing in Rancor helped them to perform the scenarios successfully, the procedures helped them complete the tasks, and the CBPs were easy to use. Participants will have the option to provide the reasoning behind their choice and any additional comments.

2.6.6. Post-study survey

At the end of the study, participants will be asked to answer three usability questions. They will be instructed to rate each statement on a 10-point Likert scale ranging from highly disagree to highly agree. The questions will reflect participant perceptions of 1) how informative the study was, 2) whether Rancor features were easy to use, and 3) whether the participants thought the CBPs were helpful. Participants will also be asked six free-response questions regarding what they would change or improve about the study, simulator, and procedures.

2.7. Experimental Procedure

Once individuals have provided consent and filled out the brief demographics questionnaire, they will watch a video explaining how nuclear energy is generated and introducing the Rancor interface and procedures within nuclear operations. The video will then walk the participants through the start-up procedure. Participants will have 15 minutes to practice executing the start-up procedure using Rancor. Once this training section is over, participants will watch another section of the video that explains how to perform the loss-of-feedwater scenario in Rancor. Participants will have another 15 minutes to practice performing this scenario. During the training phase, participants can ask the research assistant for help should they run into any issues or become stuck on a particular step of the procedure. Once all participants have completed training, they will go on to the experimental portion of the study. Since all participants will be performing both the start-up and feedwater scenarios using only one type of CBP, the order in which they do so will be counterbalanced. After each participant completes a scenario, they will complete the NASA-TLX and 3D-SART, as well as the post-scenario survey. After the participant completes the second scenario, they will fill out the post-study survey. We will then thank participants for their contributions and debrief them on the study's purpose. It is expected that each participant will complete the study in 90 minutes.

2.8. Planned Analysis and Expected Results

The data will be subjected to 2 × 3 analyses of variance to determine whether main effects of age and age × CBP type interactions exist. Age has two levels (younger and older adults), and CBP type has three levels (Type 1, 2, 3) in the analyses. The dependent variables are usability (from the Rancor simulator logs as well as mental workload and situational awareness from the survey) and preference (from the survey data). We hypothesize that there will be meaningful differences in performance across CBP type as a function of age and that there will be significant differences in levels of mental workload, situational awareness, and usability metrics across procedure type based on age.

3. CONCLUSIONS

While there have been investigations into cognitive aging effects in sociotechnical industries, such as aviation, there has been scant aging research in nuclear operations. Due to the aging workforce in the nuclear energy industry, it is crucial to empirically investigate how changes in cognitive abilities that stem from aging can impact operator performance and to understand whether there are age differences in the usability of the different types of CBPs. For instance, it may be the case that there are differences in user impressions and performances of CBP type between younger and older adults. As the world grows increasingly older, age-differentiated design is gaining traction in sociotechnical systems. The present paper proposes a sound method for assessing cognitive aging effects across different types of CBPs. This paper is the second in a planned series; the third paper will be the findings from the experiment. Those results can give us a better understanding of how information automation impacts the ways in which operators interact and engage with procedures. Should meaningful differences be found as a function of age, this study will pave the way for age-differentiated design considerations for modernized NPP operations.

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