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Title: Comparative Evaluation of Augmented Reality-based Assistance for Procedural Tasks: A Simulated Control Room Study

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ABSTRACT

This research explores the design, implementation, and evaluation of a prototype augmented reality application that assists operators in performing procedural tasks in control room settings. Our prototype uses a tablet display to supplement an operator's natural view of existing control panel elements with sequences of interactive visual and attention guiding cues. An experiment, conducted using a nuclear power plant simulator, examined university students completing both standard and emergency operating procedures. The augmented reality condition was compared against two other conditions – a paper-based procedure condition using paper manuals and a computer-based procedure condition using digital procedures presented on a desktop display. The results demonstrated that the augmented reality based procedure system had benefits in terms of reduced mental workload in comparison to the other two conditions. Regarding task completion time, accuracy, and situation awareness, the augmented reality condition had no significant difference when compared against the computer-based procedure condition but performed better than the paper-based procedure condition. It was also found that the augmented reality condition resulted in fewer intra-team inquiry communication exchanges in comparison to both paper-based and computer-based conditions. The augmented reality condition, however, yielded poorer memory retention score when assessed against the other two conditions. These results improved the understanding of augmented reality assistance systems for control room operations. We also discussed the implications of this study and directions for future research.

Keywords: augmented reality, procedural task assistance, nuclear power plant operations, simulated control room, operator performance, human factors methods

1 INTRODUCTION

Over the years, both automated and non-automated forms of procedural task assistance methods have been introduced to support personnel with operational duties especially in safety critical environments. In the current study, we present and evaluate a laboratory proof-of-concept system for discovering the benefits of Augmented Reality (AR) technology in assisting operators with Main Control Room (MCR) operations using a Nuclear Power Plant (NPP) simulator.

Task operating procedures are a set of rule-based activities implemented in accordance with predetermined specifications to achieve anticipated results. Since operators are a source of human error during plant operations, proper implementation of procedures is needed to minimize the risk of human error and enhance overall plant safety. In high reliability organizations such as NPP, procedures have been established for most events that an operator could potentially experience. The goal is to develop procedures as very reliable and safe approaches to address any imminent situation in the control room. It is important to note that procedures should not only consider the confines and characteristics of a plant but also consider the cognitive and motor limitations of operators. Training and assistance technology can be used to improve operators' capability. In the current study, we focus on assistance methods that can help operators better perform operating procedures. Previous studies have shown the benefits of AR-based procedural assistance in a wide range of domains such as maintenance, entertainment, and training (Van Krevelen & Poelman, 2010). In the current study, we demonstrate a procedural task guidance system that utilizes AR cues to render task operating assistance on a handheld tablet device. The hypothesis is that AR guidance could improve overall operator performance. We test this hypothesis in a simulated task environment that requires subjects to implement operating procedures using a procedural aid.

In the following sections, we introduce the theoretical foundation of the topic and describe the unique benefits of utilizing AR for procedural support. We also demonstrate the design and implementation of a prototype AR application. Our contributions include an empirical experiment, conducted to examine and compare our proposed Augmented Reality Based Procedure (ABP) system against two existing methods, including both Computer Based Procedure (CBP) and Paper Based Procedure (PBP) systems. The goal is to quantitatively evaluate the ABP prototype in terms of important human factor measures that include task completion time, accuracy of procedure implementation, mental workload, memory retention, situation awareness, and inquiry communication. The explanation and significance of these measures is presented in Section 4.1 in detail.

2 BACKGROUND & RELATED WORK

In NPPs, operators access the majority of plant information and issue control actions from MCRs. The design of displays and informational aids used in MCR settings have been the focus of many human factors studies in the past (Carvalho, dos Santos, Gomes, Borges, & Guerlain, 2008; E. M. Roth, Mumaw, Vicente, & Burns, 1997). A typical team in a control room includes three major roles: a reactor operator, an assistant reactor operator, and a shift supervisor. Together, they are responsible for assessing various situations and implementing procedures in order to maintain safe and effective operations.

The processes in NPPs are very delicate as plant operations are characterized as “99 % boredom and 1 % panic” (Carvalho, dos Santos, Gomes, & Borges, 2008). The “99 % boredom” refers to Standard Operating Procedures (SOPs) that requires uninterrupted monitoring, and the “1 % panic” refers to emergency situations that requires effective adherence to Emergency Operating Procedures (EOPs) or practical problem-solving ability. Procedural issues have been cited approximately 69% of the times to be a contributing factor for events leading to unsafe conditions in NPPs (Paradies, Unger, & Ramey-Smith, 1991; West, Eckenrode, & Goodman, 1991).

Traditionally, PBPs use printed manuals and checklists to assist operators accomplish their tasks. A major drawback of PBPs is that operators have to spend a considerable amount of time searching, understanding, and navigating within procedure manuals (Converse & others, 1995; Foerdestroemmen & Haugset, 1991; E. Roth & O’Hara, 2002). Maintaining awareness during task execution becomes challenging for operators as PBPs contribute to increased mental workload and fatigue (O’Hara, Higgins,

& Stubler, 2000). Researchers have been contemplating on phasing out PBPs in NPP facilities and introducing electronic and automated procedures as a replacement (Fink, Killian, Hanes, & Naser, 2009).

With recent advances in technology, many new systems and devices have been developed to assist human operators implement procedural tasks (Ockerman & Pritchett, 2000). Operators can harness the power and memory of digital devices (e.g., mobile and wearable) to experience richer instructional content and pre-processed information. An early form of procedural assistance included electronic procedures which were essentially digital presentation of PBPs on visual display units with a possibility of added functions such as hyperlinks and navigation (Yang, Yang, Cheng, Jou, & Chiou, 2012). CBPs were later introduced with several additional functionalities such as automatic processing of step logic, automatic checking of preconditions, and display of alerts and warnings (Fink et al., 2009; O'Hara et al., 2000). Although automated procedures have been in the realm of industrial research for a while (Lipner & Kerch, 199; R eynes & Beltranda, 1990), their implementation in real NPP settings have been rare mainly due to obstacles such as expensive upgrade of manual control panel hardware, training employees, and developing new security and safety protocols. Due to these issues, upgrades to MCRs in safety critical industries, such as NPPs, have been slow (Niwa, Hollnagel, & Green, 1996).

Although traditional NPPs have been modernized to some extent, the use of CBPs is still not widely adopted despite a clear operational benefit from human factors standpoint. Previous research has mostly proven the efficacy of CBP for newly developed NPPs that function on integrated systems. Implementing CBPs for second generation NPPs with less integrated systems presents many unaddressed challenges. For instance, the majority of the NPPs in United States were commissioned when the main instrument and control unit were hard-wired analogue panels (R. Boring & Joe, 2014; LeBlanc, Joe, Rice, Ulrich, & Boring, 2015). Introducing CBPs in such plants require a massive overhaul of displays, sensors and other components. Most plants cannot afford the shutdown required for such an extensive overhaul since plants can lose over a million dollars in revenue from just a single day of outage (R. L. Boring, Agarwal, Joe, & Persensky, 2012; Lew, Boring, & Ulrich, 2018). The current process of modernization usually occurs at a very slow pace with one or two components being digitized resulting in control rooms consisting of both analogue and digital systems that function collectively (Lew, Ulrich, & Boring, 2017). Researchers have also expressed concerns about overhauling current MCRs with advance stage CBP systems, such as the risk of reduced situation awareness and automation induced errors (O'Hara, Higgins, Stibler, & Kramer, 2000). We do not claim that ABP is the perfect solution, but it is worth studying for its potential benefits.

Recent developments in display devices, visual tracking techniques, sensor systems, and image processing algorithms have evolved AR research as a multidisciplinary field of research. AR can overlay instructional content virtually onto user's view of the environment, combining real and virtual elements interactively (Azuma et al., 2001; S. J. Henderson, 2011). AR technology has been actively explored as an effective and intuitive medium for instructional support in different domains. AR interfaces were found to significantly reduce head and eye movement and therefore lead to more "eye-on-the-workspace" (Haines, Fischer, & Price, 1980; S. Henderson & Feiner, 2011). AR interfaces could reduce information searching time because AR is effective in guiding users towards possible stimuli's in the task environment (Neumann & Majoros, 1998). AR-based support is also believed to reduce attention switching between workspace and instructional content (Neumann & Majoros, 1998). AR applications can be equipped with unique features such as ambient cues and multimodal augmentation (Tang, Owen, Biocca, & Mou, 2003), which can be extremely effective in capturing users' attention. Previous studies have demonstrated the usefulness of AR-based applications for task guidance in different scenarios including assisting workers with maintenance and assembly of equipment (S. J. Henderson & Feiner, 2007), supporting doctors during surgical operations (Schulz, Waldeck, & Mauer, 2012), assisting pilots with cockpit checklists (Elder & Vakaloudis, 2015), supporting field construction workers (Reiners, Stricker, Klinker, & Müller, 1998), and providing movement training to patients suffering from Parkinson's disease (Espay et al., 2010). Despite the established effectiveness of AR-based instructional aids in many domains, existing literature demonstrates that AR interfaces have not yet been adequately explored in efforts to assist operators in performing MCR operations in NPPs.

Procedural tools are crucial for safe and efficient operation of NPPs. Therefore, it is important that adequate emphasis is given to proper human factors evaluation of such applications. The goal of this paper is to quantitatively evaluate the ABP prototype with respect to important human factor measures. Human factor measures applied to evaluate ABP in this paper assess human machine interaction by taking into consideration the major human capabilities and limitations from physical, perceptual and cognitive standpoints. Normally human factors evaluation is applied later in the design lifecycle; however, it is critical to apply such evaluation to prototypes in preliminary stages so that it can help investigators determine further areas of enhancements as well as help understand the theoretical basis behind why a particular procedural aid would render better operator performance. To confirm the efficacy of a particular procedural aid, it is important to comparatively test and evaluate such a modality against traditional solutions since new technologies can also yield unanticipated effects which could potentially degrade human performance.

In NPPs, working memory overload usually results in procedural errors and degraded task performance (Dai, Zhang, Li, Hu, & Zou, 2014). Working memory is essentially a limited capacity memory storage (Baddeley, 1992). Some tasks in NPPs are inherently complex and procedural implementation of such tasks incurs excessive load on working memory. ABP could potentially reduce working memory load because instructions augmented directly on the control panel would require fewer cognitive resources. When using ABP, the users would have the option to offload some of the working memory load to the interface components of procedural aid that could function as external memory. Moreover, human operators have several information processing channels that can be utilized concurrently (Wickens, 2008). If only a single information processing channel is being over utilized then that could also result in excess cognitive load. ABP could accommodate multiple sensory modalities and codes that could potentially improve information processing capacity and as a result enhance operator performance.

We expect that AR-based support, in comparison to existing methods of procedural assistance, would better aid MCR operators in implementing task operating procedures by reducing the workload of attention switching between the instructional medium and the task at hand. When using CBP or PBP, operators face divided attention scenarios as they receive instructions from secondary displays or through paper manuals but are required to implement those instructions at entirely different locations. Undertaking complex and time sensitive tasks in such situations can be difficult for operators. Using AR technology, elements such as attention guidance cues, virtual instructions, context-sensitive description of control panel elements, and procedural instructions can be rendered in the same visual area overlaid on top of existing control panel displays. Therefore, ABP could complement operators cognitive processing during information search, reduce mental workload and improve operator performance.

To evaluate the effectiveness of task assistance systems, human factors studies are needed to measure and quantify performance and workload. Due to the difficulty in testing real NPP control panels with actual operators, many previous studies have used NPP simulators and tested interface design with student population in proof-of-concept work (Huang & Hwang, 2009; Huang et al., 2006; F.-H. Hwang & Hwang, 2003; S.-L. Hwang et al., 2008; Lee, Hwang, & Wang, 2005; Lin, Yenn, & Yang, 2010a; Xu et al., 2008; Yang et al., 2012). Similarly, in the current study, we conduct an experiment using a simulator and test the ABP prototype with university students as a first step in our research project.

3 PROPOSED SYSTEM

In order to design the optimal AR solution, tracking techniques, display device, user interaction and development platform must be decided prior to developing the system architecture. Multiple tracking techniques could be employed to track the 3D position of different control panel elements. Inertial trackers such as gyroscopes, accelerometers and magnetometers can sense velocity and orientation of the rendering device, and as a result can provide rotational tracking in 3D space (Lang, Kusej, Pinz, & Brasseur, 2002). Vision-based tracking techniques can estimate the camera’s position and orientation with respect to the external environment (Azuma et al., 2001). Computer vision-based tracking approaches could be categorized into two classes: marker-based (Kato & Billinghurst, 1999) and markerless tracking (Comport, Marchand, Pressigout, & Chaumette, 2006). The major advantage of employing markerless tracking is that the physical environment is not affected. Markerless tracking includes image-based tracking, feature-based tracking and model-based tracking. Image-based tracking requires naturally found images of artefacts in the task environment to be pre-collected and annotated with relevant virtual information. During real-time implementation, images tracked from camera feed are referenced against the pre-collected sequential database of orthographic images in order to render AR content (Zhou, Duh, & Billinghurst, 2008). For feature-based tracking, natural occurring affordances are scanned to form a map of point cloud features that can be utilized as potential trackables to render AR content (Neumann & You, 1999). Model-based tracking however identifies lines, edges or textures in the environment by referencing it against a stored model of the environment (Zhou et al., 2008). Using markerless tracking techniques for the current project is infeasible because control panel elements look similar in 3D structure and therefore could produce tracking errors during the identification process. Moreover, these approaches are computationally taxing on the device resulting in faster battery depletion and tracking delays. Marker based tracking incorporates the use of specialized markers called fiducials (QR code, barcode etc.) that function as a fixed reference point in the environment. Modern AR systems, however, often employ hybrid approaches in order to reduce occlusion and rendering error (You, Neumann, & Azuma, 1999). Marker-based tracking is accurate and robust especially when used in conjunction with inertial sensors. Therefore, in this study we used hybrid tracking incorporating the use of markers and inertial sensors to display procedural content to users.

Devices for rendering and tracking AR content include handheld devices, head-mounted displays (HMDs) and projectors (Zhou et al., 2008). Since this is a proof of concept, we used the most reliable option that would result in rapid and accurate tracking. Using AR applications on HMDs such as google glass would result in poorer quality of optical tracking and delayed rendering because it has limited processing power and limited battery life. Projection-based AR would require external hardware and would affect collaborative decision making since projectors would be a fixed rendering system whereas other HMDs and hand-held devices are mobile. We therefore chose handheld AR as our display device and selected ipad mini for this experiment due to its features such as light weight, high processing capability and increased screen size compared to cellphones.

Different types of instructional modalities could be used to overlay procedural information in efforts to attract user’s attention. This could include different forms of types of static or dynamic 2D/3D visuals as well as audio and haptics (Zhou et al., 2008). The goal is to use AR cues as a procedural aid rather than an added alarm therefore the use of haptics is discarded. We only employ the use of audio guidance as well as static and dynamic visuals as means to communicate procedural information to the user. Using multimodal cues ensures that the content is perceivable and comprehendible to the user.

The ABP prototype was designed on Zapwork Studio platform (https://zap.works) and developed using an application called Zappar. It is one of the leading platforms for AR application development. There are many advantages of using Zappar such as cross platform device integration, easy software development, and strong online support and Zappar has been used in multiple domains to develop different types of application (Hobin, 2017; Kaenchan, 2018; Mulbjerg, Rollo, Bucher, Smith, & Collins, 2017; Smith & Shanahan, 2017). Zappar provides specialized markers that are used for AR tracking. The data flow diagram (Figure 1) demonstrates the system architecture in detail. All SOPs, EOPs, monitoring information, and control panel manuals were stored in the database management system using MySQL, whereas data conveyed from the management system to the NPP simulator display was undertaken by PHP and XML.

All potential interface components of the simulator were shortlisted as areas where augmented information could be rendered in efforts to assist the operators perform a task. The Zappar studio provided a development platform where procedural instructions in the form of virtual content could be stored in a chronological timeline in the application’s target database. The application would then track user interaction with the simulator and display the relevant virtual content necessary to assist users. The AR application would guide the user through a series of fixed steps while providing feedback if the user would commit an error. The goal was to allow operators to interact effectively with different interface components of the simulator while they perform crucial task operating procedures.

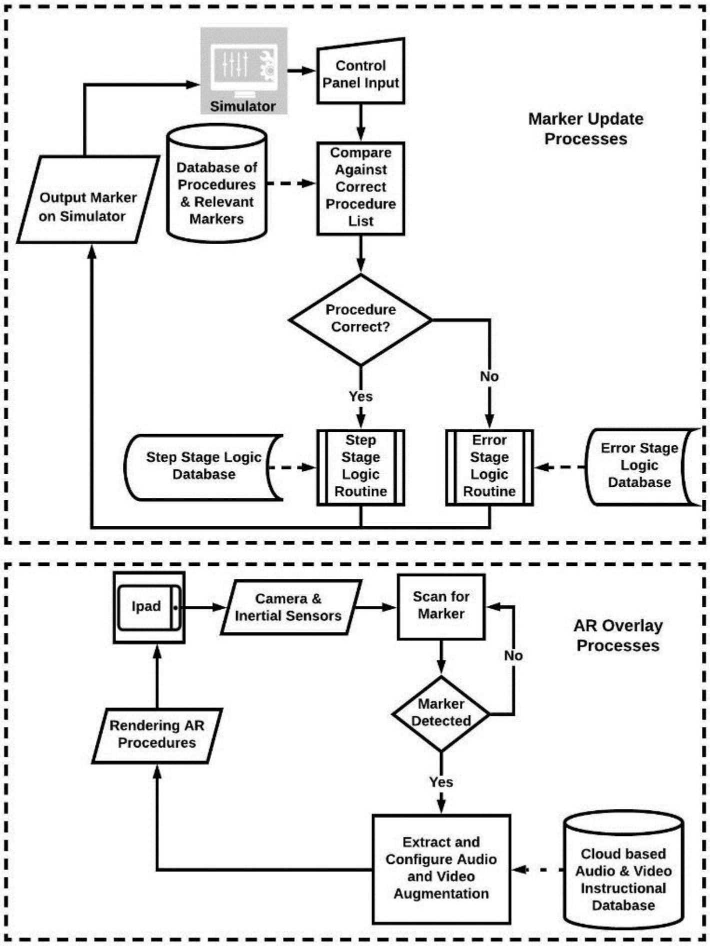

Fig. 1. System architecture describes the functioning of the two major processes of the application that includes the marker update process and the AR instructional overlay process.

There are different kinds of errors carried out by operators in control room settings during human machine interaction. This application does not address rule or knowledge-based mistakes as that requires expert analysis and comprehensive fault detection measures. This application, however, provides feedback to operators on errors such as slips of actions or lapses in memory. Such errors could be committed by operators usually during EOPs when they have inadequate time and are experiencing high cognitive load.

In the current study, the correct procedures are stored as a list in the system. As user interacts with the control panel simulator, user interactions are identified by the simulator and compared with the list of correct procedures. Depending on the correctness of an action, relevant markers (QR codes) are shown on the simulated control panel. The Zapper application will then recognize the markers and display instructions accordingly. For correct actions, the instructions will guide users to the next step. For incorrect actions, the instructions will guide users to rectify the error. Note that the Zapper application does not directly recognize user actions via image recognition. Instead, the function of error detection is programmed in the control panel simulator.

For more implementation details, there are different types of input elements on the control panel interface such as buttons, dials, knobs, switches and sliders. All input elements are denoted by a code which represents the type of the input element (button, dial, switch etc.) and a distinct number that signifies its functionality. For example, a specific button could be categorized as B11 (B representing it's a button and 11 its distinct functionality). For every step, interacted input elements are recorded in two stages: an original stage at the start of a step and a changed stage once the user has interacted with it. For example, a particular step requires the user to move Slider 11 (S11) originally showing a value of 30% to 70% therefore S11.0 would be recorded as an original stage variable with a value of 30% and S11.1 recorded as a changed stage variable with a value of 70%. For other control panel elements these variables could also be nonnumeric such as on/off for switches and buttons.

The system consists of two computational routines which comprise of algorithms that employ conditional logic that facilitates the user to transition to subsequent steps in a procedure (demonstrated in Appendix A). These two routines are categorized as a Step Stage Logic Routine and Error Stage Logic Routine. For every step, user interaction with the control panel interface is recorded as an alphanumeric value labelled as Actual User Interaction (A). This value is compared against Expected User Interaction (E) value in order to determine which marker would be subsequently updated on the control panel interface and what procedural steps would be implemented next. Markers are divided into two categories based on the types of information they augment. This includes markers that deliver information on human error (labelled as EM - Error Markers) and markers which convey regular procedural task implementation information (Labelled as SM – Step Markers).

Many design guidelines were consulted during the design of the AR application (Adams & Pew, 1990; Billinghurst, Grasset, & Looser, 2005; Dünser, Grasset, Seichter, & Billinghurst, 2007; Joe L. Gabbard & Swan II, 2008; Joseph L. Gabbard, Swan, Hix, Kim, & Fitch, 2007; Ganapathy, 2013; Gavish, Gutierrez, Webel, Rodriguez, & Tecchia, 2011; Michael, 2006; Wetzel, McCall, Braun, & Broll, 2008). We made sure that the text added was clear, precise, and easy to read. The visual overlay of virtual components had adequate contrast from the background control panel. The visual instruction rendered were structured and followed a logical pattern. Another key process was confirming that none of the virtual objects obscured any item on the control panel. During the procedure, the areas that needed user input and attention were clearly marked with attention directing graphics and voice augmentation via the AR display so that user attention could easily be directed towards those regions. AR-rendered visual items included text, labels, icons, arrows, and pictures.

The tablet is not just a repository of electronic documents; it can identify the current step and superimpose task relevant instructions and attention guidance cues directly on control panel elements. This application therefore allows operators to view virtual procedures in the natural view of the control panel, combining real and virtual objects interactively, and aligning them with each thus resulting in fewer procedural errors and improved overall performance.

The application is designed to ensure that operators do not switch attention and contexts to comprehend instructional information. The application achieves this by tracking user interaction with the simulator and displaying the relevant virtual content only when needed. Moreover during AR information overlay, the relevant control panel elements that requires user’s response are uniquely annotated to minimize visual search time. Procedural information is delivered by both audio and visual augmentation to improve contextual awareness. The AR application as a result guides the user through a series of fixed steps and also provides feedback if the user commits an error.

There are still several limitations of the current implementation. The major limitation from the tracking standpoint is that physical markers have to be placed on actual control panels that could result in clutter of operator's workspace. Moreover, the application's tracking capacity would be compromised if a marker was accidently moved or concealed during operations. In addition, not employing an HMD implies that users would have to physically point the tablet towards the control panel in order to receive AR information. This might physically exhaust the user if used for a prolonged duration. Regarding error identification, a drawback of the current error tracking approach is that the update of trackable markers and referencing of user actions with tracking data is all occurring at the interface simulator end and not inherent to the ABP aid. This indicates that both the simulator and the procedural aid would have to be individually programmed when adding new procedures or amending previous ones. Lastly, the Zappar application fetches virtual information from a database on the internet which indicates that procedural delivery is reliant on the internet connection and the entire procedural content could be exposed to issues of privacy and security. These limitations are acceptable due to the exploratory nature of the current experiment. Future applications testing with actual power plant interfaces need to address these issues. For example, markerless tracking methods could be implemented and tested on both handheld devices and HMDs.

4 METHOD

4.1 EXPERIMENTAL DESIGN AND MEASURES

The experiment used a within-subject design. The independent variable was the type of procedural methods − ABP, CBP, and PBP. The dependent variables included task completion time, number of errors, mental workload, situation awareness (SA), inquiry communication, and memory retention.

It is important to consider primary performance measures including both efficiency (task completion time) and accuracy (number of errors) when evaluating procedural methods. Prior research has found that CBPs were more accurate and efficient than PBPs (Huang et al., 2007; Huang & Hwang, 2009; F.-H. Hwang & Hwang, 2003; S.-L. Hwang et al., 2008; Lee, Hwang, & Wang, 2005). In the current study, we compared ABP with both CBP and PBP. The amount of time a team took to accomplish a task was recorded by the simulator and designated as task completion time. The errors made by each team while executing the tasks were recorded. The total numbers of errors were counted, including activating wrong buttons, entering incorrect values, step omission, and wrong order of steps.

Mental workload is also an important factor that can be of concern in any human operation (N. P. Moray & Huey, 1988), and it must be considered when evaluating complex task procedures in NPPs as the consequences of excessive workload can lead to catastrophic events. A general definition of mental workload is the ratio of task demands to the capacity of human information processing (Cao & Liu, 2015). Many studies indicate that optimizing the level of mental workload could reduce errors and improve overall plant system safety (N. Moray, Inagaki, & Itoh, 2000; Sebok, 2000). In the current study, mental workload was measured using NASA-TLX questionnaire (Appendix B), which is a subjective, multidimensional assessment tool to rate perceived workload on six different subscales including mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart & Staveland, 1988). Unweighted NASA-TLX was used in this experiment; the overall score therefore was the average of six subscales and was transformed to a range from 0 to 100. Note that the performance subscale was measured inversely with perfect performance associated with lower workload and unsuccessful performance associated with higher workload.

Situation Awareness (SA) has received a considerable amount of attention from the human factors community. The mechanism of SA illustrates how humans perceive and make sense of situations and eventually undertake decision making based on the knowledge of both the internal and external states of the environment. Operators are required to continuously enhance their SA as the situation is always dynamic in NPPs. Past research has also demonstrated that operator SA is a very important factor in NPPs (Ha, Seong, Lee, & Hong, 2007; Hallbert, 1997; Kim, Byun, & Lee, 2011). Studies have illustrated that SA is associated with operator performance (Kim, Park, & Byun, 2009; Lin, Yenn, & Yang, 2010b). The lack of SA can be one of the prime reasons behind human error (Endsley, 1995; Salmon, Stanton, Walker, &

Green, 2006; Sasou & Reason, 1999; Stanton, Chambers, & Piggott, 2001). Measuring SA in the current study can help discover which procedural aid is more viable in supporting operators' acquisition of situational knowledge from the control panel, and Situation Awareness Rating Technique (SART-Appendix C) was employed to measure SA (Selcon, Taylor, & Koritsas, 1991). The SART questionnaire delivers an evaluation of a person's SA from self-rated perspective on attentional demands (D), attentional supply (S), and understanding (U). The rating score is calculated using the formula: Situation Awareness = $U - (D - S)$.

Operators in MCRs utilize intra-team communication to manage control room responsibilities such as monitoring and task implementation activities. According to Lin, Hsieh, Yang, & Huang (2016), communication in an MCR can be defined as the different information exchanges amongst operators. The importance of team communication in assisting operators with procedural tasks has been identified in many studies in the past (Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995; Ford & Schmidt, 2000; Glickman, Zimmer, Montero, Guerette, & Campbell, 1987; Pinto & Pinto, 1991; Scholtes, 1988). In the current study, the number of inquiries that a team exchanged was defined as inquiry communication. During the experiment, the experimenter recorded all the events in which a participant queried their teammate regarding the understanding or implementation of a procedure. This inquiry communication data did not include communication events in which users were merely confirming their actions.

Finally, another important component that must be taken into consideration is memory retention. Higher level of automation and assistance tend to reduce the level of operators' mental processing, which may lead to overreliance on the assistance as well as loss of skills over the long-term. AR assisted support in the past has shown to degrade skill level since augmented cues greatly reduce human cognitive processing and operators are mostly left with final decision making (Rehman & Cao, 2015, 2016). In the current study, because we used student population who can be considered as novice users, their memory of the task procedures would degrade after their participation. To measure memory retention performance, the participants were tested a week after the experiment. During the retention test, participants were provided with an unlabeled control panel diagram and asked to label the specific components with which they interacted during the experiment. Each tested control panel components appeared in only one of the three aid conditions, so we could calculate a retention score for each aid condition. A total of 15 distinct components were asked, with five for each aid condition. The number of correct responses was recorded as the memory retention score.

4.2 PARTICIPANTS

Twenty-four students (13 males and 11 females) from University of Waterloo were recruited to participate in this study and compensated $ 15 for the study. All participants were engineering students who had at least 6 years of experience in using paper and computer for general purpose tasks. All participants reported to be inexperienced with AR based technologies. All reported to have normal or corrected-to-normal visual and auditory acuities. None of the participants had participated in a similar study before, and all participants were interacting with the NPP simulator for the first time. The participants received two training sessions for the experimental task. The interface and control basics were demonstrated to the participants, followed by a practice task. All participants received the same training and practice procedure. The participants were also asked by the experimenter to confirm that they were sufficiently familiar with the system before starting the formal experiment.

4.3 TASKS AND MATERIALS

The team included three major roles, reactor operator, assistant reactor operator, and shift supervisor (Figure 2). Participants were grouped in pairs of two. One participant was assigned as reactor operator, and the other as assistant reactor operator. The experimenter acted as shift supervisor. During the experiment, all task operating procedures were conducted by the participants (reactor operator and assistant reactor operator). The role of the experimenter (shift supervisor) was primarily to oversee the operations conducted by reactor operator and assistant reactor operator. The shift supervisor validated if their implementation of procedures was accurate and also provided assistance if the reactor operator or assistant reactor operator had questions related to the interface elements of the control panel. However, the shift supervisor did not provide any instruction related to the procedural tasks since task implementation was participants responsibility.

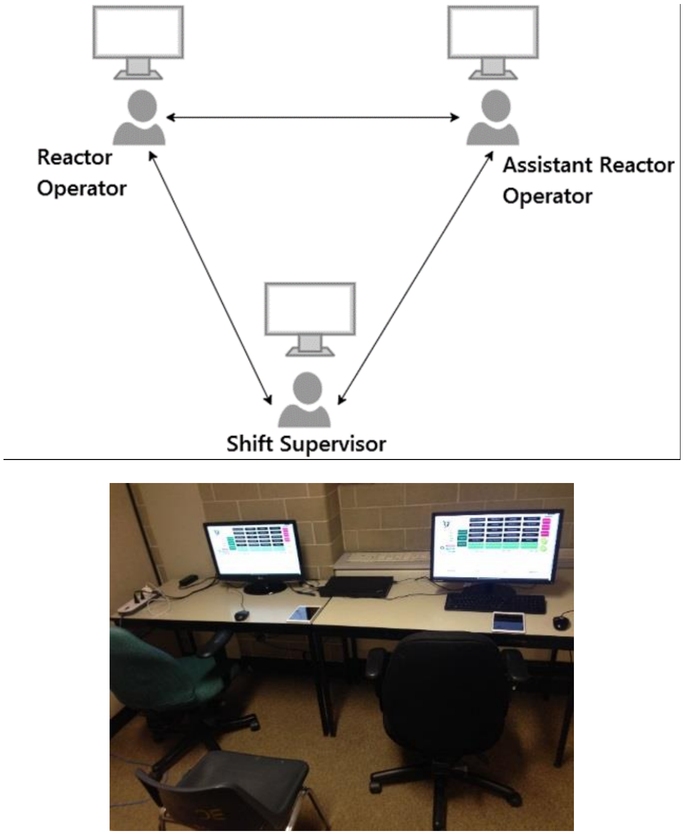

Fig. 2. The personnel setting of the experiment and the operational space of the reactor operator and assistant reactor operator.

The simulator used for this study was a modified version of PCTRAN (Jing-qi, 2007). It was originally developed for training NPP operators in Taiwan and carried the capacity to simulate many different accident scenarios. The simulator displayed all major parameters needed in real-time, such as water levels, pumps, valves, alarms, control rod movements, and coolant fractions. The control panel for each operator was displayed via a monitor (1920 x 1080 pixels) operating on a Lenovo T540P computer with Intel® Core™ i7-4900MQ processor (3.80 GHz). Traditional mouse and keyboards were used as input devices. Our overall goal was not to provide augmented instructions on a screen but on a control panel.

Although the current experiment was conducted on a simulated control panel operated via mouse and keyboard and displayed on a monitor, many NPPs still have a physical control panel encompassing a comparatively wider area and also consisting of physical buttons, knobs and other elements. Only for experimental purposes was our control panel a dual monitor setup. Moreover the whole objective is to validate a technology that can provide digitized instructions on physical control panels so NPPs do not have to bear the cost of revamping the physical panels into computerized displays, which is very expensive and time consuming therefore most NPPs to this date have physical control panels

In the PBP condition, instructions describing operation steps were printed on paper and given to both participants. In the ABP condition, each participant held a tablet (iPad Mini 2) with its camera pointing to the control panel. Instructions were augmented on the tablet screen with arrows pointing to the locations of relevant display and control elements needed in the step (for example, see Figure 3). Audio instructions for a step were played repeatedly until the step was completed. Note that the tablet was only an AR display device, and no control function were implemented on it. Participants still needed to use their mouse to click buttons on the control panel, but they could see the mouse cursor on the tablet screen as a confirmation that they were clicking the desired button.

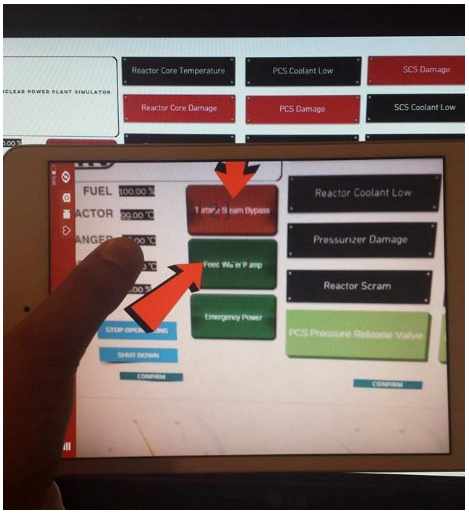

Fig. 3. Augmented arrows pointing towards task-relevant elements, while auditory instructions were played via the speaker; if the camera did not capture the control panel, the tablet screen would add

visual display of the instructions. The image shown on the tablet was the real-time video stream from the tablet's camera, and only the arrows and step indication [2] on the image were augmented.

In the CBP condition, instructions were shown on a supplementary monitor. In order to be comparable to the ABP condition, the CBP showed not only the description of the step, but also contained a picture of the control panel with arrows highlighting target elements (for example, see Figure 4). The difference was that the pictures in the CBP condition were static, whereas the ABP condition overlaid virtual content on live video feed.

[[1] increase SCP and Target Output to 20 % and [2] press confirm]

Fig. 4. Example of CBP used in the current study.

Each participant experienced all three conditions of ABP, CBP, and PBP. In each condition, the operations included both SOP and EOP. The SOP was the same for all three conditions. The SOP included reactor start up, power ramp, monitoring, and shutdown. The EOP used in each condition was one scenario selected from three options, which were all related to the different types of system failures or hazards. The first one was about loss-of-coolant and re-circulation pump trip, the second one was about turbine trip without bypass and loss-of-load, and the third one was about inadvertent rod withdrawal and steam generator tube rupture (Jing-qi, 2007). In order to rule out any potential effects on the dependent variables caused by the three different EOP scenarios, the pairing between procedural methods and EOP scenarios were balanced across subjects using a Latin square design.

Due to the novice nature of the participants, the overall complexity of the tasks was kept within a reasonable level so that participants were able to learn the tasks after a short training of around 30 minutes. Training was provided to the participants before the formal experiment to help participants understand the general functionality of the simulator (e.g., reactor start-up and shutdown).

4.4 PROCEDURE

Participants first read the information letter that described the details of the experiment and signed the consent form. Then they filled a demographic survey questionnaire. Participants were grouped into pairs and were informed with regards to the duties of the reactor operator and assistant reactor operator. Participants were provided with time to practice with the three procedural methods until they felt fully confident to initiate the formal experiment. In the formal experiment, each pair of participants experienced the three conditions (ABP, CBP, and PBP) in an order balanced across subjects. Participants were instructed to collaborate and utilize the procedural methods to implement the task operating instructions. The experimenter (shift supervisor) followed the experiment protocol and supported the participants when required. After the participants completed each condition, they filled the SART questionnaire as well as the NASA-TLX questionnaire in a 6-minute break period before the initiation of the next condition. Operation errors and task completion time were recorded by the simulator, whereas the experimenter recorded inquiry communication. A week later, the participants were invited again and filled the memory retention test.

5 RESULTS

Repeated measures ANOVAs (analysis of variance) using SPSS (Version 22) were conducted to examine the effects of procedural methods, and pairwise comparisons were conducted (with Bonferroni correction) to compare the three types of procedural methods (i.e., ABPs, PBPs and CBPs). There were no outliers, and the data were normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was not violated, as assessed by Mauchly's test of sphericity for all dependent variables including task completion time $\chi^2(2) = 5.86$, $p \geq .05$, number of errors $\chi^2(2) = 4.18$, $p \geq .05$, mental workload $\chi^2(2) = 2.808$, $p = .246$, situation awareness $\chi^2(2) = .06$, $p = .970$, inquiry communication $\chi^2(2) = 2.208$, $p = .332$ and memory retention $\chi^2(2) = 1.238$, $p = .538$.

5.1 TASK COMPLETION TIME

The effect of procedural method on task completion time elicited statistically significant results, $F(2,22) = 11.365$, $p < .0005$, $\eta^2 = 0.508$ (Figure 5). The average task completion times for ABP, CBP, and PBP were 17.58 s (*SD* = 5.93 s), 20.25 s (*SD* = 5.10 s), and 30.42 s (*SD* = 8.61 s) respectively. Post hoc analysis with a Bonferroni adjustment revealed that the difference between ABP and CBP (*difference* = 2.67 s, $p = .986$) was not significant; however, the ABP time was significantly shorter than the PBP time (*difference* = 12.83 s, $p = .014$); the CBP time was also significantly shorter than the PBP time (*difference* = 10.17 s, $p < .05$).

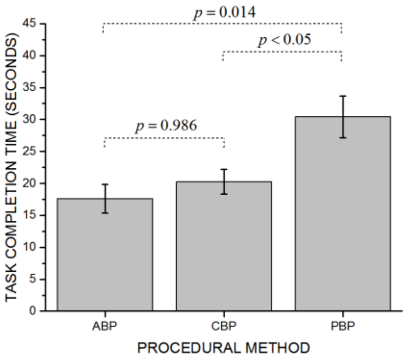

Fig. 5. The effect of procedural method on task completion time. Error bars represent 95 % confidence interval.

5.2 NUMBER OF ERRORS

The effect of procedural method on the number of errors elicited statistically significant results, $F(2,22) = 6.082$, $p < .05$, $\eta^2 = 0.356$ (Figure 6). The average numbers of errors for ABP, CBP, and PBP were 7.67 ($SD = 3.55$), 10.92 ($SD = 4.44$), and 16.42 ($SD = 8.21$) respectively. Post hoc analysis with a Bonferroni adjustment revealed that the numbers of errors from ABP and CBP conditions (*difference* = 3.25, $p = .223$) were not significantly difference; however, the ABP condition had significantly fewer errors than the PBP condition (*difference* = 8.75, $p = .029$). The difference in the numbers of errors between CBP and PBP was not significant (*difference* = 5.50, $p = .271$).

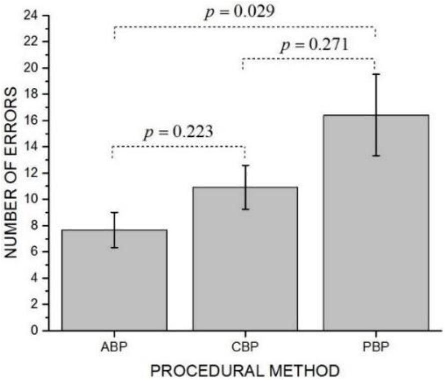

Fig. 6. The effect of procedure method on the number of errors. Error bars represent 95 % confidence interval.

5.3 MENTAL WORKLOAD

The effect of procedural method on NASA-TLX overall workload score elicited statistically significant results, $F(2,22) = 26.06$, $p < .0005$, $\eta^2 = 0.703$ (Figure 7). In the ABP condition, participants reported the lowest overall workload ($M = 33.35$, $SD = 3.35$) when compared against both CBP ($M = 40.65$, $SD = 7.30$) and PBP ($M = 54.06$, $SD = 10.96$) conditions. Post hoc analysis with a Bonferroni adjustment revealed that statistically significant difference was present between all the pairs, between ABP and CBP (*difference* = 7.29, $p = .029$), between ABP and PBP (*difference* = 20.71, $p < .0005$), and between

CBP and PBP (*difference* = 13.42, $p < .05$). ABP resulted in the lowest workload, whereas PBP resulted in the highest workload.

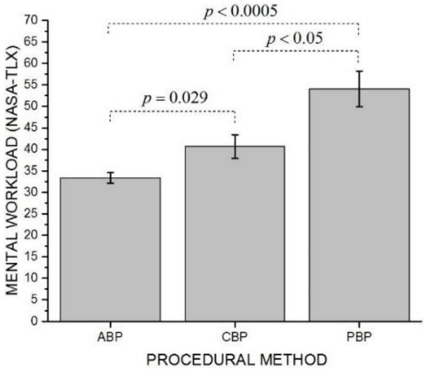

Fig. 7. The effect of procedural method on subjective workload (NASA-TLX). Error bars represent 95 % confidence interval.

5.4 SITUATION AWARENESS

The effect of procedural method on SART score elicited statistically significant results, $F(2,22) = 4.16$, $p < .05$, $\eta^2 = 0.274$ (Figure 8). Post hoc analysis with a Bonferroni adjustment revealed that the SART scores from ABP and CBP (*difference* = 2.83, $p = .354$) were not significantly different; however, the SART score in the ABP condition was significantly higher than the PBP condition (*difference* = 4.96, $p < .05$). The difference of SART scores between CBP and PBP was not significant (*difference* = 2.13, $p = .726$).

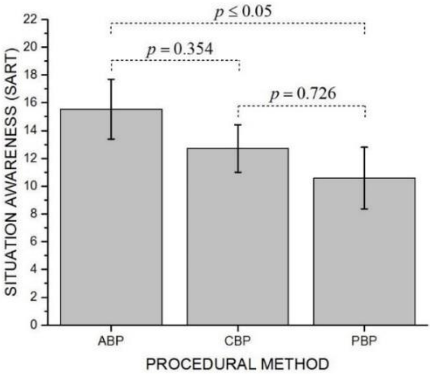

Fig. 8. The effect of procedure method on situation awareness (SART Questionnaire). Error bars represent 95 % confidence interval.

5.5 INQUIRY COMMUNICATION

The effect of procedural method on inquiry communication elicited statistically significant results, $F(2,22) = 15.963$, $p < .0005$, $\eta^2 = 0.592$ (Figure 9). ABP required least inquiry communication ($M = 21.67$, $SD = 6.11$), when compared against CBP ($M = 31.50$, $SD = 8.34$) and PBP ($M = 47.00$, $SD = 14.28$). Post hoc analysis with a Bonferroni adjustment revealed that statistically significant difference was present in the results of inquiry communication between ABP and CBP (*difference* = 9.83, $p = .042$), between ABP and PBP (*difference* = 25.33, $p < .05$), as well as between CBP and PBP (*difference* = 15.5, $p = .029$).

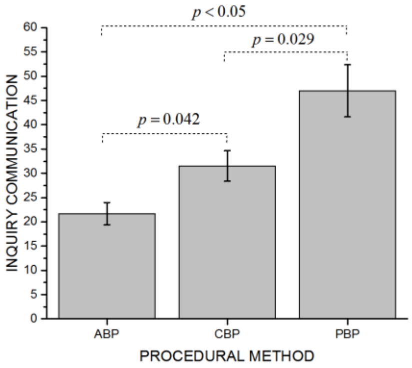

Fig. 9. The effect of procedural method on inquiry communication. Error bars represent 95 % confidence interval.

5.6 MEMORY RETENTION

The effect of procedural method on overall memory retention score elicited statistically significant results, $F(2,22) = 19.03$, $p < .0005$, $\eta^2 = 0.634$ (Figure 10). In the ABP condition, participants scored the poorest in the memory retention test ($M = 4.75$, $SD = .965$), when compared against CBP ($M = 6.50$, $SD = 1.17$) and PBP ($M = 7.75$, $SD = 1.06$). Post hoc analysis with a Bonferroni adjustment revealed that statistically significant difference was present in the memory retention scores between ABP and CBP (*difference* = 1.75, $p < .05$), as well as between ABP and PBP (*difference* = 3.00, $p < .0005$). There was no significant difference between CBP and PBP (*difference* = 1.25, $p = .148$).

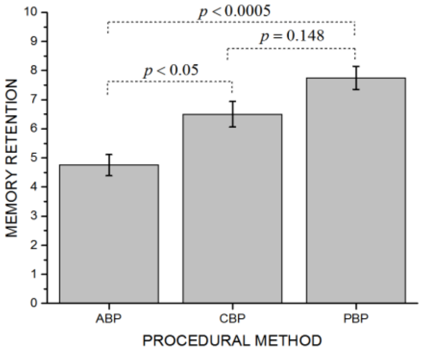

Fig. 10. The effect of procedural method on memory retention. Error bars represent 95 % confidence interval.

6 DISCUSSION & CONCLUSION

As an initial step, the current study aims to examine the feasibility of using AR to further improve procedural methods in MCR operations. In an experiment using a NPP simulator and testing with student population, we examined a prototype ABP application in comparison to both CBP and PBP conditions. ABP resulted in significantly better performance in comparison to CBP when evaluated in terms of mental workload. This could mainly be due to the fact that CBPs were spatially apart and required additional cognitive resources to account for information search, attention switching and extra working memory load.

The difference between ABP and CBP in terms of task completion time, number of errors, and SA was not statistically significant. This could primarily be attributed to the fact that ABPs were displayed on a handheld device that required constant concentration in order to be held in an optimal upright position. This also resulted in causing the participants' arm to be fatigued during the experiment and lead to extra time employed in aligning the device's camera with the control panel for proper rendering of the augmented information. The results also confirmed that ABP has benefits over PBP in terms of most dependent variables measured in this study including mental workload, task completion time, error, and SA measures. The ABP condition however resulted in worse memory retention and least inquiry communication when compared against the other two conditions. Although future research is needed to further compare ABP and CBP conditions, the current results showed that ABP is a feasible and valuable method of procedural assistance. Since AR technology can be implemented as an add-on feature without the need to fundamentally change existing control panels design in MCRs, it provides a unique alternative to traditional NPP upgrade projects.

The advantage of ABP, especially in terms of reduced mental workload, could be explained in the following aspects. *Information Search.* Implementing MCR procedures is an information-intensive undertaking that can place a high demand on human cognitive resources. Information acquisition from detached mediums such PBPs and CBPs was time consuming and tedious. In contrast, ABPs provide information on spatially strategic locations within the task environment by emphasizing specific target areas on the control panel. This augmentation substituted human cognitive processing for visual search and therefore reduced mental workload.

Attention Switching. ABPs address the drawbacks of attention switching between the task environment and the procedural method observed in CBP and PBP conditions. During CBP and PBP conditions, the control panel and the procedural aid were spatially apart, and participants had to divide their attention between the two areas. When participants used ABPs, their attention was exclusively geared towards a single task location because the control panel and the task operating instructions were visible in a unified field of view, thereby minimizing attention switching. Human attention is limited and difficult to concurrently delegate to different areas of interest therefore cognitive resources must be managed according to situational circumstances. Often in divided attention scenarios, operators need to address several task demands on multiple physical spaces. It is also important for users to recognize vital details in the procedures, which could potentially go unnoticed if they are not sufficiently salient. ABPs provide synthesized views that are more effective in guiding users' attention to these important elements because these visuals are spatially together and require minimal attention switching. In general, users also tend to prefer information presented closest to the task environment (Biocca, Owen, Tang, & Bohil, 2007). Overlaying information via AR reduces head and eye movements and offers users additional time to focus on the workspace (S. Henderson & Feiner, 2011).

Working Memory. Information acquired from procedural aids is initially kept in sensory storage and then transcribed into working memory. Information in the working memory deteriorates, and successful retrieval depends on the activation levels of interconnected units in working memory, which vary based on the amount of practice and recency of use (Fleetwood & Byrne, 2006; Proctor & Zandt, 1994). The retrieval of information from working memory could become a mentally demanding, time consuming, and error prone activity, especially when different pieces of information in excessive amounts are stored for different activities at the same time (Bujak et al., 2013). The limitations of working memory can therefore have far reaching consequences on user performance especially when users come across tasks that requires them to store procedural information in the memory for extended periods of time. Detached methods of procedural assistance such as CBP and PBP heavily utilize working memory resources thereby putting a heavy toll on mental workload. ABPs, however, reduce the use of working memory resources because the display of instructional information is on the task environment.

Excessive cognitive load can impede operator's ability to effectively implement task operating procedures. Cognitive load can increase when the procedural aid renders additional demands on the operator. The efficiency of operators to process procedural instructions is dependent on the design of procedural aids. Continuous exposure to complex procedures can increase load on working memory; this process however could be improved by utilizing technologies that take into account human cognitive limitations. ABP is an effective procedural aid because it moderates extraneous cognitive load (Bujak et al., 2013). AR can leverage human spatial cognitive abilities such as spatial orientation and spatial visualization to improve user's spatial knowledge (Tang, Owen, Biocca, & Mou, 2002, 2003). Moreover, augmenting multimodal instructions can help users better understand the procedural content since auditory and visual modalities both have independent working memories (phonological loop and visuospatial sketchpad respectively) that can function in synchrony to reduce information processing load (Tang et al., 2003). Although using AR may introduce additional workload pertaining to using the AR device, it seems that after learning and practicing with the device, users benefit more from AR overall. ABP aid can decrease cognitive load pertaining to the operation tasks as it simplifies task complexity by breaking it down into smaller and more comprehendible chunks (Wu, Lee, Chang, & Liang, 2013). The inherent advantage of utilizing ABP in comparison to traditional aids is therefore a reduction in overall cognitive load.

The memory retention results from the current study could be explained by the level of mental processing and mental traces. In the ABP condition, participants were primarily implementing given instructions without the need to deeply think about the procedures nor the need to manually identify target locations. Since participants utilized minimal cognitive resources during the ABP condition, the activities left weaker memory traces. As a result, in the ABP condition, participants were worse at retaining procedure related information as they were less actively involved in processing the information during task operations. These results are in synchrony with previous findings that automated AR aids reduced memory retention scores in comparison to manual conditions (Rehman & Cao, 2016).

Regarding communication results, the reason for the lack of inquiry communication in the ABP condition could be that participants experienced fewer problems that required them to ask each other. The CBP condition was also reasonably good at assisting users with task implementation as intra-operator inquiries were moderately low. Participants, however, did extensive inquiry communication exchanges during the PBP condition. Based on the experimenter's observation, the reason for more questions in the

PBP condition was because participants often had difficulty obtaining necessary information, and they felt the need to raise an inquiry with their team member in order to better understand the situation and efficiently accomplish the task.

It is necessary to examine the limitations of this current research when interpreting the results. Firstly, the investigated tasks were relatively simple and did not take very long to finish. A simulator was used rather than conducting the experiment in actual MCR settings. The whole experiment could be completed in approximately an hour. In contrast, NPP operators usually work for 8 hours per shift. Due to this limitation, the results may not reflect factors such as stress, boredom, tiredness, and loss of vigilance in the actual workplace. Future studies are needed to test more complex scenarios with longer duration, where sustained attention and fatigue might come into play. Secondly, the participants were university students, and they had very limited knowledge with regards to NPP operations. Due to this limitation, the results from the participants may not reflect the sociocultural aspects of the NPP setting such as coordination, social self-control, and informal communication. Future experiments conducted with actual plant operators in naturalistic settings are needed. Nevertheless, the current laboratory experiment could serve as a reference and guideline for future work. Moreover, the device (iPad Mini) for AR implementation in the current study was not specially designed for such a task. Some participants reported that it was challenging to hold the tablet device in one hand while moving the mouse with the other hand. We recommend that future studies should consider using an ergonomic handstand for holding the device. Alternatively, ABPs could be implemented on head-mounted displays. In that case, operators will no longer have the need to hold an extra device. Previous studies have demonstrated the benefits of head-mounted AR applications in guiding users' attention (Rehman & Cao, 2015) A head mounted display was not chosen for this study due to hardware limitations as discussed in section 3 of this paper.

The idea of ABP is very valuable for MCR upgrading in NPPs, because AR applications can be directly added to existing systems without the need to change previous software and hardware. Many NPPs still have physical control panels. Adding ABP to existing procedures does not bear the cost of revamping existing physical panels into computerized displays. The results from the current study demonstrated the feasibility and benefits of ABP in a simulated MCR setting. Since the current study is our first step to test a prototype design, we tested it using a simulator and student population. Nevertheless, future studies are needed to further examine ABP in more complex tasks implemented on physical control panels or computerized control panels with multiple displays. Given the positive results from the current study, we will continue to test improved versions of our prototype with actual NPP operators in more realistic settings in the future. Future evaluations of ABP aid should also take into account factors such as age and experience of operators, operator's sensitivity to stress, different workload and SA conditions etc. as independent variables in order to analyse how changing such factors would impact operator performance. Such studies can inform a better design of ABP aid which can ultimately allow optimized operator performance. In addition, future studies could also compare the effects of ABP in different situations such as complex vs simple task, high vs low stress, high vs low fatigue etc. The benefit of ABP in challenging and demanding situations may be more significant. The goal of the current study was limited to using AR as a way to improve operators' information perception. Directly controlling the power plant on the AR device was beyond the scope of the current study. Previous work has showcased how a bidirectional AR platform could be used to allow direct control of physical objects (Heun, Kasahara, & Maes, 2013). Future studies could consider combining both perception aids and control aids implemented in a unified application.

In conclusion, we evaluated an AR-based procedural method that could assist users with attention guidance and procedural instructions. The results showed that ABP has the potential to reduce user workload, increase user SA, and make task implementation swift and less prone to errors in comparison to CBP and PBP. However, ABP tends to have a negative effect on skill and memory retention. Currently, there is a lack of research studying AR applications in NPP control rooms. While there has been research outside the NPP domain, similar research is still in its early stages. In our follow-up studies, we plan to test AR-based technology with actual NPP operators in more complex scenarios and further explore the capability and effectiveness of AR applications.

ACKNOWLEDGMENT

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APPENDIX A

Sample Routine of AR based Assistive Device

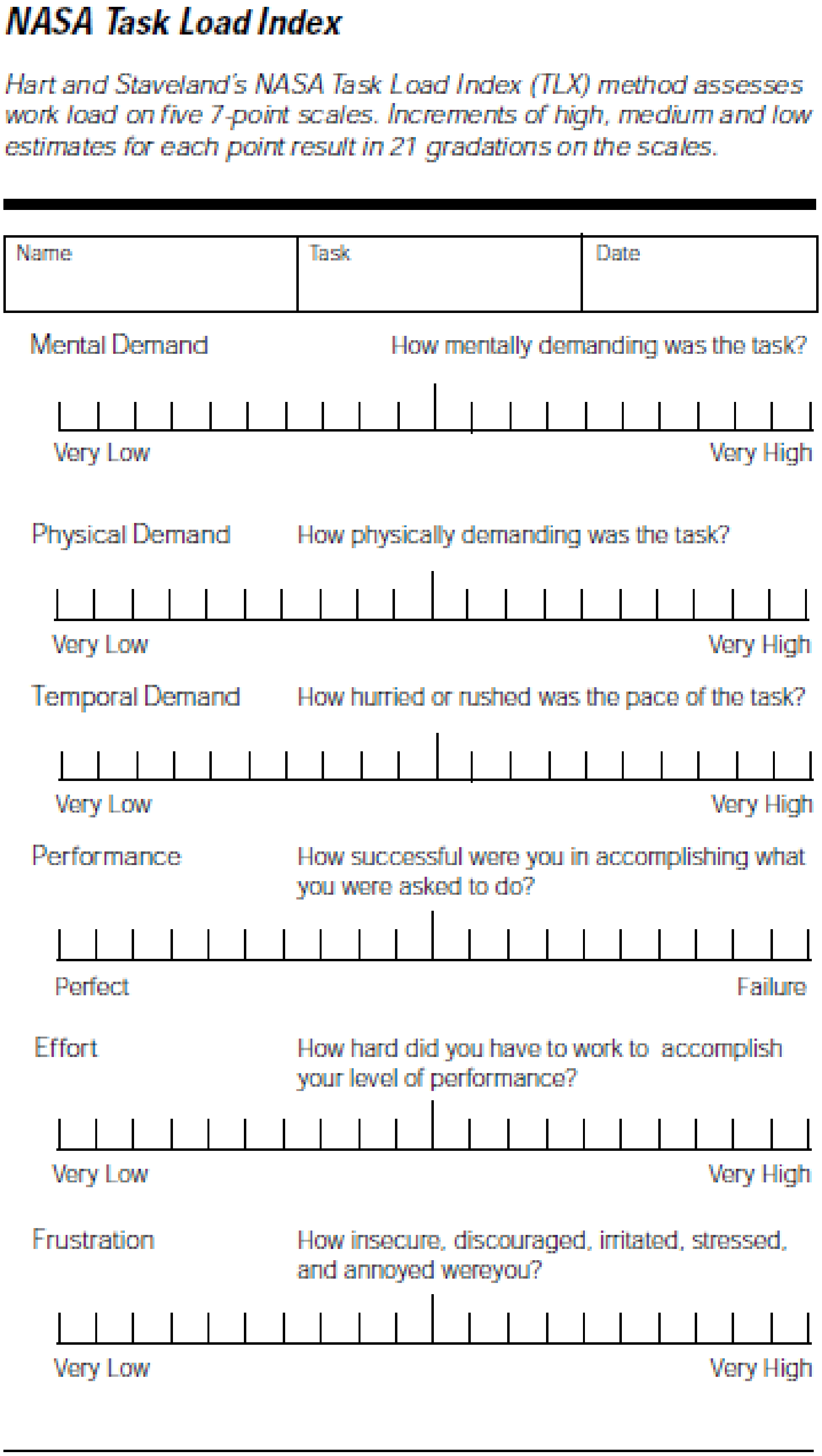
Step Stage Logic Routine					
Step Stage Level	Marker Code	Expected User Interaction (E)	Actual User Interaction (A)	Step Stage Logic	Message Content
SS1	SM 1	B11.0 to B11.1	K11.0 to K11.1	1. Display control panel 2. WHILE procedure is not complete 3. Operator makes a selection 4. Validate selection against tracking data 5. If E = A in SS1: 6. Update Control Panel with Marker SM 2 & Go to SS2 7. Else: 8. Update Control Panel with Marker EM1 & Go to ES 1 9. ENDWHILE	Press Button 1 (B11.0)
SS2	SM 2	S11.0 to S11.1			Slide Slider 11 to 40 %

Error Stage Logic Routine					
Error Stage Level	Marker Code	Expected User Interaction (E)	Actual User Interaction (A)	Error Stage Logic	Message Content
ES1/SS1	EM 1	K11.1 to K11.0	SW11.0 to SW11.1	1. Display control panel 2. WHILE procedure is not complete 3. Operator makes a selection 4. Validate selection against tracking data 5. If E = A in ES 1: 6. Update Control Panel with Marker SM 1 & Go to SS1 7. Else: 8. Update Control Panel with Marker EM2 & Go to ES 2	You made an Error. Rotate Knob 11 back to 15 %)

				9. ENDWHILE	
ES2/SS1	EM 2	SW11.1 to SW11.0 K11.1 to K11.0		1. Display control panel 2. WHILE procedure is not complete 3. Operator makes a selection 4. Validate selection against tracking data 5. If E = A: 6. Update Control Panel with Marker SM 1 & Go to SS1 7. Else: 8. Update Control Panel with Marker EM3 & Go to ES 3 9. ENDWHILE	You made another Error. Turn switch (SW11.1 to SW11.0) off. You made an Error. Rotate Knob 11 back to 15 %.

APPENDIX B

NASA-TLX Subjective rating Scale



NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

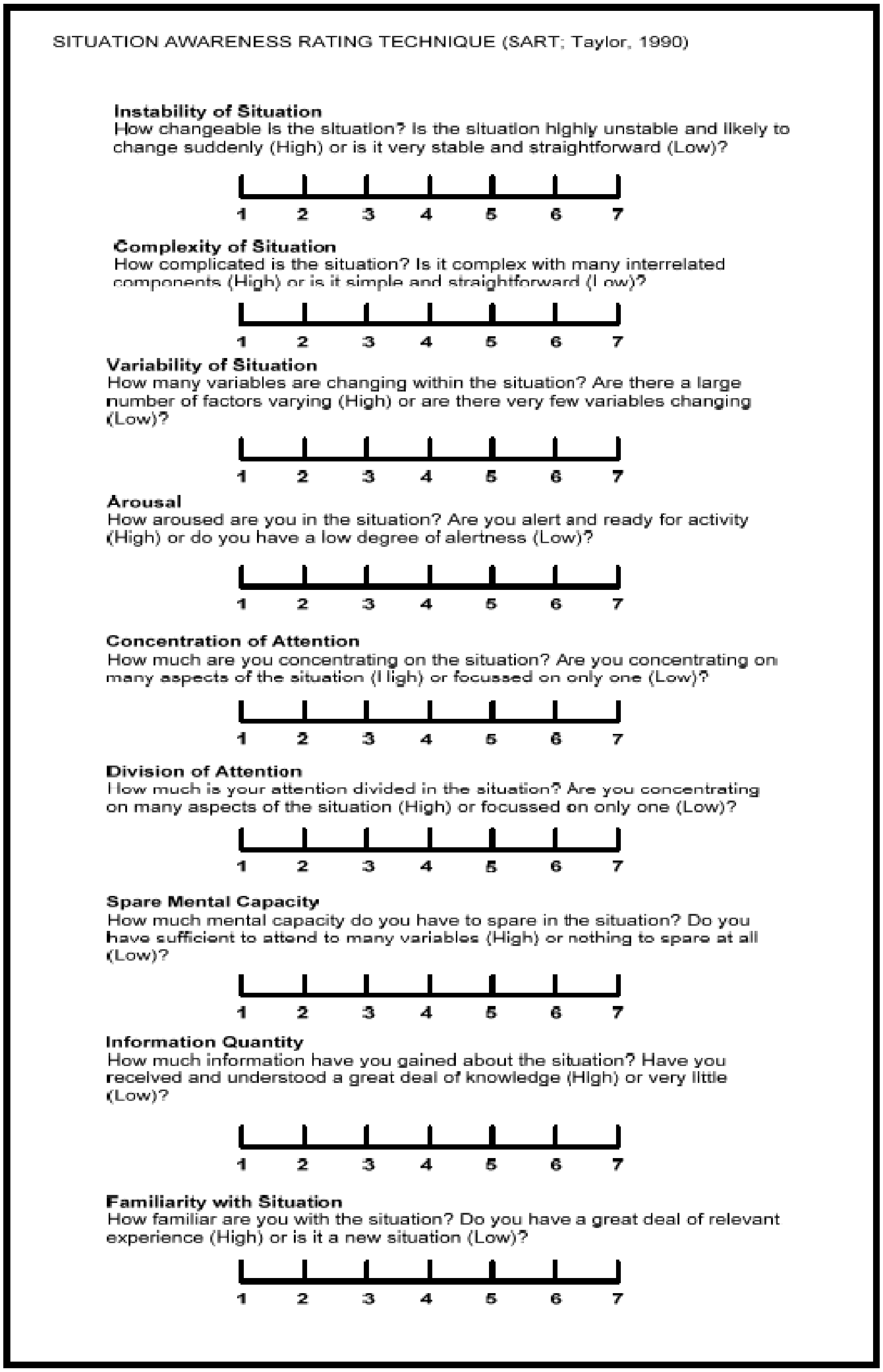
Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

APPENDIX C

SART Subjective Rating Scale



SITUATION AWARENESS RATING TECHNIQUE (SART; Taylor, 1990)

Instability of Situation
How changeable is the situation? Is the situation highly unstable and likely to change suddenly (High) or is it very stable and straightforward (Low)?

1 2 3 4 5 6 7

Complexity of Situation
How complicated is the situation? Is it complex with many interrelated components (High) or is it simple and straightforward (Low)?

1 2 3 4 5 6 7

Variability of Situation
How many variables are changing within the situation? Are there a large number of factors varying (High) or are there very few variables changing (Low)?

1 2 3 4 5 6 7

Arousal
How aroused are you in the situation? Are you alert and ready for activity (High) or do you have a low degree of alertness (Low)?

1 2 3 4 5 6 7

Concentration of Attention
How much are you concentrating on the situation? Are you concentrating on many aspects of the situation (High) or focussed on only one (Low)?

1 2 3 4 5 6 7

Division of Attention
How much is your attention divided in the situation? Are you concentrating on many aspects of the situation (High) or focussed on only one (Low)?

1 2 3 4 5 6 7

Spare Mental Capacity
How much mental capacity do you have to spare in the situation? Do you have sufficient to attend to many variables (High) or nothing to spare at all (Low)?

1 2 3 4 5 6 7

Information Quantity
How much information have you gained about the situation? Have you received and understood a great deal of knowledge (High) or very little (Low)?

1 2 3 4 5 6 7

Familiarity with Situation
How familiar are you with the situation? Do you have a great deal of relevant experience (High) or is it a new situation (Low)?

1 2 3 4 5 6 7

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