International Journal of Industrial Ergonomics 54 (2016) 65–72

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Mutual awareness: Enhanced by interface design and improving team performance in incident diagnosis under computerized working environment

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A R T I C L E I N F O

Article history:
Received 21 July 2015
Received in revised form
25 April 2016
Accepted 2 May 2016
Available online 12 May 2016

Keywords:
Team situation awareness
Mutual awareness
Incident diagnosis
Interface design

A B S T R A C T

Mutual Awareness, which measures understanding of the behaviors and status of other members in a team is supposed to influence team decision-making process in safety-critical tasks/systems. This study aims to explore enhancement of mutual awareness by adding a Mutual Awareness Tool (MAT) on a user interface and examining its effects on team diagnosis performance in emergency situations of a simulated nuclear power plant system. According to the experimental results, the embedded MAT on the operation interface enhanced team mutual awareness significantly, and improved incident diagnosis performance. The results also showed that the increase in mutual awareness led to a reduction of individual situation awareness, possibly due to the limited mental resources.

1. Introduction

Situation awareness is helpful and is necessary for tasks that require a comprehensive understanding of the whole system (Endsley, 1995; Salas et al., 2010). In process industries, the regular tasks such as monitoring parameters and conducting standard operations, are skill- or rule-based tasks that do not need a comprehensive understanding of the system (see Rasmussen (1983) for the skill-, rule-, knowledge-based behavior taxonomy). However, in emergency situations, especially those that are not included in the design basis incidents, a comprehensive understanding of the system becomes vital in diagnosing and solving the problem (Naderpour et al., 2016).

Large complicated process plants and critical safety systems, such as nuclear power plants, are usually operated by a team rather than individual personnel (Lin et al., 2016). A team understanding has advantages over individual operators, such as effectiveness, efficiency, robustness and knowledge complementarity (Nonose et al., 2010; Millot, 2015). To react timely and accurately to the dynamic situation, the team performs not only physical tasks but also cognitive and perceptual ones (Endsley and Garland, 2000; Lin et al., 2013). Situation awareness (SA) is a dynamic mental representation and understanding of the environment. The level of SA obtained by operators could influence the decision-making process (Adams et al., 1995; Endsley, 1995; Nonose et al., 2010). Endsley (1995) identifies three stages of SA: perception, comprehension and projection. The three stages are not linear but ascending levels of better SA (Endsley, 2015; Satuf et al., 2016). Studies have been conducted on individual SA, but with the increasing concerns on team cooperation, team SA has come into focus (Salas et al., 1995; Wickens, 2008).

In order to improve teamwork performance, team members must pay attention to the system, environment, as well as each other to maintain a certain standard of SA (Paris et al., 2000). Team SA is thought to be the glue that binds the system and team members together (Salmon et al., 2008b; Sorensen and Stanton, 2016). Team SA was treated as the union of individual SA subsets of each team member (Artman and Garbis, 1988), and the intersection of these subsets is defined as shared SA (Endsley and Jones, 2001). However, team behaviors are not only influenced by individual understandings of the system, they are also influenced by how much each team member realized what the other members are doing and how their work will affect their own parts of the system (Dourish and Bellotti, 1992; Wellens, 1993). Therefore, team

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http://dx.doi.org/10.1016/j.ergon.2016.05.001
0169-8141/

SA is more than the simple sum of individual SA (Salmon et al., 2009; Sorensen and Stanton, 2011) and it contains two parts: individual SA and mutual SA (Shu and Furuta, 2005). Schmidt (1998) defines mutual awareness as the perception and understanding of member A on the activity, including intention, status, possible results and influence, of member B, this is called A's awareness of B. Similarly, Member B will have B's awareness of A during their team operation. Apart from the consciousness of what B is doing, A will also have an estimate of how much B understands what he is doing, this is called reciprocal awareness, reflecting A's awareness of B's awareness of A (Schmidt, 1998). Villa et al. (2008) carried out an analysis in their research about multi-media searching. They defined watching awareness and watched awareness. If member A could observe member B's activities while member B could not observe A, then A has a watching awareness. If member A knows member B is observing him/her, but A himself/herself could not watch B, then A has a watched awareness (Villa et al., 2008).

In face-to-face working environments, mutual awareness can be accomplished naturally and smoothly. In a distributed groupware system, however, it is not easy to notice others' behaviors. As an example, in a traditional main control room (MCR) of a nuclear power plant where large analog control panels are installed, if one operator notices another one moving to a particular set of control panels, he could infer what the colleague is going to do and the consequence on his own work (Y. Kim, Jung, & S. Kim, 2014). Thus in traditional MCRs, operators could maintain mutual awareness through gestures, body languages and artifacts. This does not necessarily mean that operators in traditional MCRs always maintain high level of mutual awareness. The level of mutual awareness also relates to their general understanding of the operating system and is influenced by the level of automation.

By contrast, in a modern nuclear power plant where a computerized control system is adopted, operators sit at separate workstations and navigate on different screen displays to monitor and operate the plant. Although the physical tasks like manual operations are reduced, the amount of information required for monitoring and judging the system states are not decreased (Lin et al., 2013). The introduction of computerized system makes team members focus only on their own screens and cannot see what their partners are doing or going to do. The information sources are largely reduced (cannot get a glimpse of what others are doing or overhear their intentions and needs). The interactive mode between the operators has also been changed (mainly through intentional communication and system messages). The collaboration would be harder because members have to spend more time exchanging their information (Gutwin and Greenberg, 1998, 2002). In such situations, if there is an incident that could not be solved by an existing operation procedure, operators may not be able to deal with it in a short time due to the lack of mutual understanding (Patrick, Gregov, Halliday, Handley, & O'Reilly, 1999).

How to improve mutual awareness? Proper training helps operators possess more procedural and strategic knowledge of the system, so that they can react more quickly and accurately to the situation (Endsley and Robertson, 2000). This way, operators will have more spare attention resources to learn about other colleagues and the whole system (Vidulich and Tsang, 2012). Another effective way is to redesign the display interfaces, by adding situation awareness tools (SATs) to help improve team SA including mutual awareness (Nova et al., 2007; Smeaton et al., 2007). A well-designed interface should help the operator maintain a good awareness of the status of system under supervision and the teammates he copes with (Satuf et al., 2016). Studies have shown that people tend to choose different kinds of SATs in various task scenarios (Jang et al., 2002). Although adopting SATs can enhance awareness, they could also leak privacy, cause distraction, interfere with operator's own appointed task, or lead to information overload. Therefore, designers should balance the advantage and side effects when using SATs in interface design (Sohlenkamp, 1999). So far, there are studies exploring mutual awareness in teams (e.g. Shu and Furuta, 2005; Pauchet et al., 2007; Salmon et al., 2008a,b). However, the experimental studies regarding the effects of mutual awareness on team performance, especially for complex problem-solving or knowledge-based tasks, are scarce.

To enhance mutual awareness for teams in nuclear power plants, we designed a mutual awareness tool (MAT) on an existing user interface. Then we carried out a comparative experiment to examine the effects of the MAT on team diagnosis performance in emergency situations.

Here comes the question: how could we evaluate the design for mutual awareness? An effective method is to compare the operators' level of mutual awareness when using different designs. Situation Awareness Global Assessment Technique (SAGAT) and real-time probe are two direct and objective measures of SA, which can be used to measure mutual awareness as well (Endsley et al., 2003). Both measures require the development of queries based on the awareness requirements in a certain situation. To use SAGAT, the simulation scenario is frozen at a time unexpected by the operator, the displays are blanked, and the questions are presented to the operator. After the operator finishes the questions, the scenario goes on from where it stops (Endsley, 1988). Operator's response is scored based on what have occurred. SAGAT has been used in domains such as aviation (Endsley, 1988), power plant (Hogg et al., 1993) and driving (Bolstad, 2001). Operators usually participate in the SAGAT tests twice or more and the test-retest reliability is high, indicating SAGAT has good inter- and intra-reliability (Endsley and Bolstad, 1994). One limitation of SAGAT is that halts are impossible in some situations (Endsley et al., 2003). To use real-time probe, the questions are presented to the operator and the displays remain available (Jones and Endsley, 2000). The response time and accuracy in answering the questions are used to measure the level of SA. The advantage of real-time probe is that questions are embedded in the scenario and is suitable for the situations that cannot be halted. Since the questions appear one at a time, there are fewer questions in a scenario. Thus more scenarios are required in the experiment (Endsley et al., 2003). The scenario in our experiment is incident diagnosis in a simulated nuclear power plant, which is complicated and time-consuming, and can be stopped temporarily. Thus SAGAT is adopted to measure SA and mutual awareness in the experiment.

2. Method

2.1. Participants

A total of 40 male students aging from 20 to 32 (Mean = 23.7, SD = 2.13) were recruited as participants. They all majored in science and engineering departments at Tsinghua University. The experiment was designed based on tasks in MCRs of nuclear power plants. Two participants formed a team and acting as the nuclear island operator (NIO) and conventional island operator (CIO) of the plant. To avoid the communication barriers caused by unfamiliarity, the two students who knew each other were recruited together as a team. None of them had visual or hearing impairments. Nor did they suffer color blindness. Being informed of the experimental details, the participants voluntarily signed the informed consent and ethical approval for the experiment.

2.2. Independent variables

In the experiment, the NIO was responsible for monitoring and