Measuring Situation Awareness in Engine Control Operation

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Abstract

Situation awareness (SA) as a framework to understand operator's behavior in doing work has been implemented well as theoretical and application in various work environments, including maritime operation. However, most SA studies in maritime operation only covered the work on the bridge and focused on the theoretical construction rather than the empirical studies. To fill the gap in the literature, this study aims to measure SA, especially in engine control operation. Two scenarios were built using the high-fidelity engine plant simulator: ocean-going scenario and entering port scenario. Students (N = 16) recruited as the participants were divided into two groups by their sea training experience. Two measurement types were used to examine the SA during each scenario: subjective measurement using the questionnaire and objective measurement using the freeze-probe technique. Also, the workload was examined using well-known workload subjective measurement. The result showed two scenarios successfully made different perceived workload; the entering port scenario was perceived with a higher workload than the ocean-going scenario. In contrast with the workload, SA was perceived higher in the ocean-going scenario than in the entering port scenario. Moreover, with the freeze-probe technique as the objective measurement, although all participants achieved the same degree in achieving the SA level 1 (perception), the participants with more extended sea training experience have higher sensitivity in achieving SA level 2 (comprehension). In summary, while the subjective measurement can only discriminate between different workloads, the objective measurement can also discriminate the level of the participant's experience. These measurement methods are beneficial for examining the non-technical skill in maritime education and training to support the cadet in recent and future work environments.

Keywords: engine control, situation awareness, workload

Introduction

SA is already known as the concept in the research literature and the seafarer's importance aspect in their work [1]. The issue of SA in maritime operations was amplified by the fact that

71% of human error in maritime operations is caused by SA failure [2]. It is supported by a statement that said the crew resources management in maritime operation is influenced by fatigue, SA, and communication [3]. To counter this issue, IMO has already included the non-technical skill into STCW by applying bridge resources management and engine resources management, where the additional point is to obtain and maintain SA [4].

SA is already known to construct human performance, besides the workload, task performance, user experience, and physiological-based measurement. Endsley defines the SA as the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status shortly [5]. By this definition, the SA is divided into three levels: perception (level 1), comprehension (level 2), and projection (level 3). This breakdown into three levels is not rigid and can be interpreted based on each work environment.

Have a good SA is a supplement to maintain a safe engineering watch for operators. Work at engine control relies on the extended vigilance task, where the portion of the operator's work in the engine control room increases as the automation puts more remotely equipment [6,7]. With the top-down sampling mechanism in engine control operation, effective monitoring tasks in process control rely on the correct and comprehensive understanding of the process parameters. By this background, the process parameter, either it digital or analog, are essential for operators to make a comprehensive overview of the process state [8]. Monitoring the parameters in engine control operation can be divided into two types: the context-sensitive, where the parameters are observed based on the overall operation state, and the fault-sensitive, where the parameters are observed based on the fault that occurred during the monitoring [9].

Several studies have been conducted to examining SA in maritime work experiments. Pazouki et al. conducted an experiment using the autopilot malfunction condition; the SA was measured when participants recognized the wrong decision of this autopilot [10]. The training effect in collision avoidance was examined by Okazaki and Nishizaki; in achieving SA, the participants need to recognize how many vessels can lead to a collision [11]. Moreover, SA was included when evaluating the Integrated Navigation System compare with the traditional bridge layout in a study by Motz et al. [12].

Literature shows the SA studies in maritime operation are very few, and most exist studies specifically examine the SA for navigation work. Thus, the recent study aims to fill the gap by examining the SA in the engine control operation environment. Through an experimental study by applying several measurement methods, the interaction between SA and the workload, also participant experience has been examined.

Method

We invited 16 undergraduate and graduate students from the marine engineering department, with an average age of 22.18 (±0.98). The recruitment was based on their training ship cadet experience. The participants were evenly divided into Group A with one month of experience and Group B with three months of experience. They have equally baseline knowledge and experience using the engine plant simulator. The recruitment and experiment procedures were under the code ethic that was proved by the faculty board. Every participant was given informed consent.

Quasi-experiment using the full-mission engine plant simulator was conducted. Two levels of scenario as within-subject variables were constructed: ocean-going scenario and entering port scenario. It aims to construct the actual engine control operation work and examine the interaction between different workload conditions with the SA. The entering-port scenario was designed to have a high task-load by mandating the participants to follow the standby engine procedure. The scenarios were made by applying the simulator function to record and replay the scenario. It prevents the process value of engine control operation changes by participation action during the experiment. Moreover, it able to create the condition where the participants deal with the same exposure and timeline of the scenario.

Figure 1. Experiment setup: a participant faced the engine control console during the scenario

Participants have to come to the simulator three times on different days. The first day was for a briefing and explanation about the experiment's aim and setup, proceed by standby engine procedure training. Within at least one day separate, the participants joined the first-time participation with two different scenarios (trials). After that, within at least six days separate, the participants joined the second-time participation, also with two different scenarios. In summary, three independent variables were included in this experiment: scenarios (ocean-going and entering port), participations (first-time and second-time), and experiences (Group A and Group B).

We employed the NASA Task-Load Index (NASA-TLX) [13] as the subjective measurement to measure workload. The six dimensions of the questionnaire in Table 1 were asked to the participants by 20-point Likert scale, ranging from low to high regarding each dimension. The total workload can calculate by summing up all dimensions after weighing with multiple comparisons of each dimension. The participants fill this questionnaire after finishing each trial in the experiment. Therefore, we collected four results from each participant.

Table 1. NASA-TLX dimensions and questions

Dimension	Question
Mental Demand	How mentally demanding was the task
Physical Demand	How physically demanding was the task
Temporal demand	How hurried or rushed was the pace of the task
Performance	How successful were you in accomplishing what you were asked to?
Effort	How hard did you have to work to accomplish your level of performance?
Frustration	How insecure, discouraged, irritated, stressed, and annoyed were you?

Table 2. SART dimensions and questions

Dimension	Question
Demands on attentional resources (D)	
Instability of situation	How changeable is the situation
Variability of situation	How many variables are changing within the situation?
Complexity of situation	How complicated is the situation?
Supply of attentional resources (S)	
Arousal	How aroused are you in the situation?
Spare mental capacity	How much mental capacity do you spare in the situation?
Concentration	How much are you concentrating on the situation?
Division of attention	How much is your attention divided in the situation?
Understanding of situation (U)	
Information quantity	How much information have you gained about the situation?
Information quality	How good information have you been accessible and usable?
Familiarity	How familiar are you with the situation?

Situation Awareness Rating Technique (SART) [14] was applied to examine the SA using subjective measurement, as shown in Table 2. Ten dimensions are categorized into three categories: demand on attentional resources (D), supply on attentional resources (S), and understanding of situation (U). 7-point Likert-type scale was employed for every dimension, ranging from low to high. The subjective SA was then calculated by eliminating the total understanding with the difference between attentional demand and attentional supply. Similar to subjective workload, subjective situation awareness was also probed after each trial was finished. In total, there were four results from each participant.

For the objective situation awareness, we modified the freeze-probe technique derived from SAGAT [5]. Although it has demerits, such as intrusive, it has the advantage of being objective and direct. Three times simulator freeze were introduced during the scenario to probe several questions regarding the operation condition. While answering the questions, the simulator was paused and participants did not face the engine control console. For each simulator freeze, there were 8 questions evenly consist of SA level 1 and SA level 2. The sample of questions is shown in Table 3. To discriminate, SA level 1 questions came from the existing parameters on the engine control console. While the parameters in SA level 2 questions were not. However, the participant can answer it by considering the existing parameter. There were three multiple choices for each question: decreasing, steady, and increasing. In total, there are 24 questions for one scenario or trial. These 24 questions have an even ratio between noise (the parameter is steady) and signal (the parameter is decreasing or increasing). To analyze the answer, signal detection theory (SDT) [15] was applied.

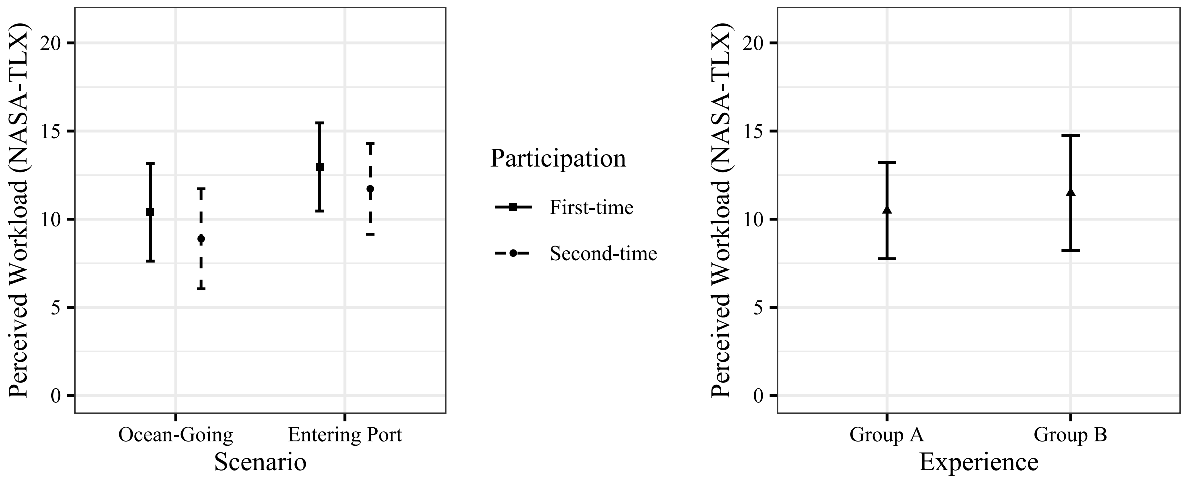
Table 3. Sample of Freeze-Probe Question

Level	Question
1	In comparison with the past, how was FO INLET TEMPERATURE developed?
2	In comparison with the past, how was FO INLET VISCOSITY developed?
1	In comparison with the past, how was CENTRAL CFW PUMP INLET TEMPERATURE developed?
2	In comparison with the past, how was M/E AIR COOLER 1 INLET TEMPERATURE developed?

Result

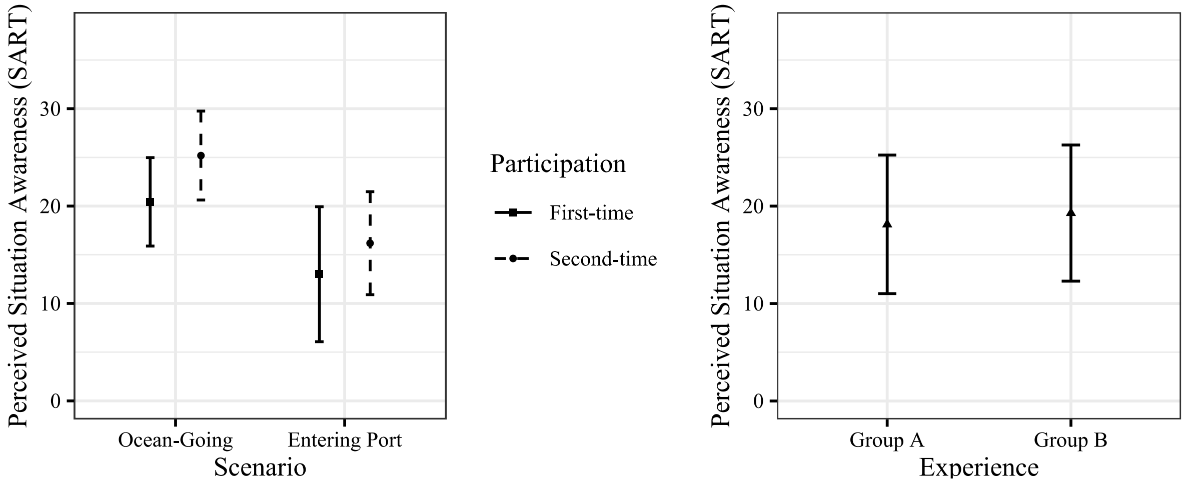
Two-way mixed ANOVA was used to compare the perceived workload measured using NASA-TLX. As the result, there was no two-way interference between scenario and experience.

For main effect analysis, the entering port scenario was perceived with a higher workload (*M* = 12.34, *SD* = 2.58) than ocean-going scenario (*M* = 9.63, *SD* = 2.86) with statistically significant difference ($F(1,15) = 31.23$, $p < .01$). The second-time participation was perceived with a lower workload (*M* = 10.30, *SD* = 3.03) than the first-time participation (*M* = 11.67, *SD* = 2.90), also with statistically significant difference ($F(1,15) = 6.73$, $p = .02$). However, the participant experience did not meet the statistically significant difference ($p = .18$) tested using a t-test. The interaction between variables are shown in Figure 2.



(a) (b)

Figure 2. The interaction perceived workload measured by NASA-TLX with (a) scenario and participation, and (b) participant's experience



(a) (b)

Figure 3. The interaction perceived situation awareness measured by SART with (a) scenario and participation, and (b) participant's experience

Similar to subjective workload, the result from SART questionnaire was analyzed using the two-way mixed ANOVA, as shown in Figure 3. There was no two-way interaction across the scenario and participation. The ocean-going scenario was perceived with higher SA (*M* =

22.81, *SD* = 5.09) than the entering port scenario (*M* = 14.59, *SD* = 6.27) with statistically significant difference ($F(1,15) = 41.09$, $p < .01$). The second participation was perceived with higher SA (*M* = 20.68, *SD* = 6.67) than the first participation (*M* = 16.72, *SD* = 6.89) with statistically significant difference ($F(1,15) = 10.32$, $p < .01$). The participation experience did not give the different ($p = .51$) tested by t-test.

For the SA objective measurement using the freeze-probe, two-way ANOVA unveiled there were no two-way interaction between scenario and participation. For individual main effect, the participants have higher SA sensitivity during the ocean-going scenario (*M* =1.36, *SD* = 0.52) than during the entering port scenario (*M* = 0.89, *SD* = 0.75), tested statistically significant difference ($F(1,15) = 20.75$, $p < .01$). The SA sensitivity also increase in the second-time participation (*M* = 1.40, SD = 0.59) from the first-time participation (*M* = 0.85, *SD* = 0.67), tested also statistically significant difference ($F(1,15) = 20.68$, $p < .01$). The participants experience gave statistically significant difference ($p = .02$) tested using t-test. The participants in Group B have higher SA sensitivity (*M* = 1.33, *SD* = 0.68) than participants in Group A (*M* = 0.92, *SD* = 0.68). The interaction between variables are shown in Figure 4.

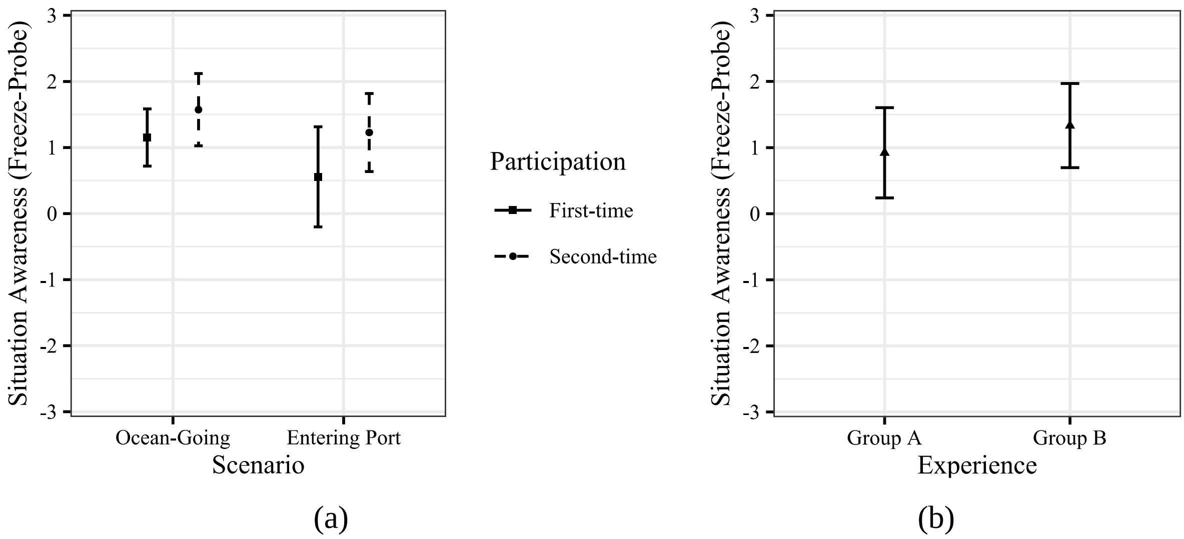


Figure 4. The interaction situation awareness measured by freeze-probe with (a) scenario and participation, and (b) participant's experience

The analysis also conducted for each level of SA in this study: SA level 1 and SA level 2. The finding in scenario effect similar from SA in general, the SA level 1 sensitivity was higher during the ocean-going scenario (*M* = 1.70, *SD* = 0.61) than the entering port scenario (*M* = 1.23, *SD* = 0.86), with statistically significance different ($F(1,15) = 10.22$, $p < .01$). As well as SA level 2 sensitivity was higher during the ocean-going scenario (*M* = 0.51, *SD* = 0.58) than the entering port scenario (*M* = 0.25, *SD* = 0.65), with statistically significant difference ($F(1,15) = 6.01$, $p = .02$). Also, the participants have higher SA level 1 sensitivity in the second-time participation (*M* = 1.79, *SD* = 0.65) than in the first-time participation (*M* = 1.14, *SD* = 0.77), with statistically significant difference ($F(1,15) = 16.53$, $p < .01$). So it is with SA level 2 sensititivity was higher in the second-time participation (*M* = 0.53, *SD* = 0.64) than the first-time participation (*M* = 0.23, *SD* = 0.58), with statistically significant difference ($F(1,15) = 4.73$, $p = .045$). The participants experience effect on SA level 2 ($p <.01$) tested with t-test. The participants with more experience (Group B) have higher in SA level 2 sensitivity (*M* = 0.60, *SD* = 0.57) than the participants with less experience (Group A) (*M* =0.16, *SD* = 0.61). While the interaction of participant experience effect did not occure in SA level 1 sensitivity ($p = .14$). The interaction between variables in each SA level are shown in Figure 5.

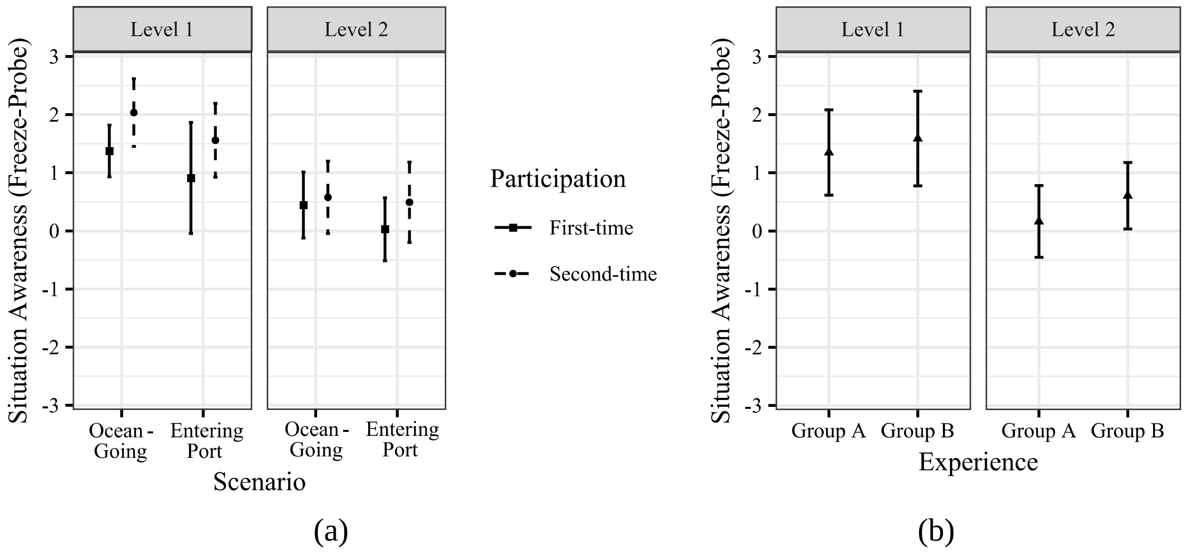


Figure 5. The interaction situation awareness measured by freeze-probe for each level with (a) scenario and participation, and (b) participant's experience

Discussion

Several studies regarding SA in maritime operation already exist, but the specific study that examines SA in the engine control operation is not specified yet. This study examined the SA in the engine control environment by applying subjective and objective measurements. The interaction between SA and workload has also been examined in this study. Using a full-mission engine plant simulator and the cadet student as the participants, the studies also aiming to provide such measurement to support non-technical skills.

Two scenarios, ocean-going and entering port, have already successfully made different workload levels, measured by subjective measurement NASA-TLX. The entering port scenario designed to have high demand was perceived with a higher workload than the ocean-going scenario in this experiment. This result is obvious because the participants were demanded by more information, such as standby engine procedure in the entering the port scenario. Moreover, the participants perceived a lower workload in the second-time participation. It reflected the familiarity effect because the participants getting used to the experiment setup and task. The results also revealed that workload, in this case, was not sensitive to the participant's experience.

Able to discriminate the workload of two scenarios made the following analysis between workload and SA can be done. In contrast with the workload, the subjective measurement of SA explained the participants perceived higher SA in a lower workload scenario. This effect was not discriminated across the participant's experience. The participants also perceived higher SA as the familiarization effect on the second-time participation. This result explains that the SART as subjective measurement was sensitive to the different task-load levels but not with the experience level.

In line with subjective measurement, the freeze-probe technique as the objective measurement in this experiment also explained that the participants have lower SA sensitivity in higher workload scenarios. The interesting finding is when the SA separated into SA level 1 (perception) and SA level 2 (comprehension). Although the participant experience did not reflect the difference in SA level 1, the participants with more sea training experience were observed to have higher SA level 2 sensitivity. This finding is prevalent because the participant with 3-month sea training (Group B) had more portion of an engine watchkeeping training.

The limitation of this study was that during the experiment, the participant's role was passive because no action to handle the alarm was needed. The future study must include the participant's active role in handling this. The second limitation was that the participant experience in this study had a slight difference in their sea training experience. Although the result can discriminate the two levels of experience in this study, it is better to compare with more experience cadets to confirm its sensitivity.

Conclusion

The subjective and objective measurements to examine the SA in this study have a different tendency in the sensitivity. Both measurements were confirmed to be sensitive to the different workload levels, but only the objective measurement is sensitive to the participant's experience. Preparing the training method for the cadets in attaining and maintaining attention during the engine supervisory work is notable in supporting the SA. Having appropriate and practical measurement methods then became the modal to evaluate its effectiveness.

Acknowledgments

This study was supported by JSPS KAKENHI, Grant No. 17K06964 and No. 21K04517.

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