A Study on Evaluation Method for Ship Maneuvering Simulator Training

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Abstract—A ship maneuvering simulator is effective training tool for navigation officers. An instructor of simulator training executes the evaluation based on the check list. The trainee is told the evaluation at the de-briefing, and obtains the chance to improve his maneuvering skill. On the other hand, some objective evaluation methods for the simulator training were proposed, and also a method for estimating trainees’ mental workload from their physiological index during the training was proposed. If these assessment data can be shown at the de-briefing, effectiveness of ship maneuvering simulator training can be improved. Therefore, this study tried to examine relation between these evaluation methods and proposed usage of these methods.

Keywords—simulator training; subjective evaluation; situation awareness; nasal temperature; R-R interval

I. INTRODUCTION

Marine casualty causes oil spill then it gives huge damage for marine environment. 80 percent of cause of shipwreck is a human error. Therefore, improvement of seafarers’ skill is important factor for crew training organization. Ship maneuvering simulator training is one of the effective training method for mariners, then a lot of maritime academy uses ship maneuvering simulator training. Generally, their training performances are evaluated subjectively by an instructor who is specialist of navigation officer. On the other hand, some objective assessments for simulator training were proposed at previous research. For the ship berthing simulator training, a method for evaluating ship’s movement for approaching the pier was proposed[1]. In that method, standard maneuvering pattern was obtained from marine pilots’ maneuvering results. Then the standard maneuvering pattern was used for evaluation indices. For the evading navigation simulator training, method for evaluating trainee’s situation awareness was proposed[2]. In order to measure the trainee’s situation awareness, situation awareness global assessment technique (SAGAT) [3] was used, then ships those recognized by trainee during the simulation run was evaluated in that method. Also, a method for estimating trainees’ mental workload during simulation run from their physiological indices was proposed[4][5]. However, these methods were proposed individually. Therefore, it is required to integrate these method for effective assessment for ship maneuvering simulator training.

This study aims to propose the effective assessment of ship maneuvering simulator training, and examines the relation between the evaluation of trainee’s performance and trainee’s mental workload during the training. Therefore, this study executed two type of ship maneuvering simulator experiment. At the first experiments, we measured trainees’ hearts rate and estimated their mental workload, then examined relation between subjective evaluation results and fluctuation of their mental workload. At the second experiments, we measured trainees’ situation awareness and their mental work load at the training, then examined relation between objective evaluation results and fluctuation of their mental workload.

This paper introduced the subjective evaluation method for ship maneuvering simulator training and objective evaluation method which used trainee’s situation awareness in section II and III, respectively. Also, method for estimating trainee’s mental workload from his physiological index was showed in section IV. Then, section V and VI showed results of ship maneuvering simulator experiments which used introduced evaluation method. Consideration and conclusion were described in section VII and VIII.

II. SUBJECTIVE EVALUATION METHOD

The subjective evaluation of the simulator training is executed by the instructor. Therefore, the evaluation criteria and the checklist are different according to the educational organization. However, the substance is common. Then, the example of the evaluation criteria is shown in Table I. Using the performance evaluation list, the instructor fills in the score

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of each criteria with five grade such as, Very Good (4.0), Good (3.5), Satisfactory (3.0), Poor (2.5), Unsatisfactory (2.0).

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Score</th>
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<tbody>
<tr>
<td>Understands and applies COLREGs &amp; their application</td>
<td></td>
</tr>
<tr>
<td>Proper use of terminology</td>
<td></td>
</tr>
<tr>
<td>Sets adjusts radars correctly/knobology</td>
<td></td>
</tr>
<tr>
<td>Voyage planning - element understanding</td>
<td></td>
</tr>
<tr>
<td>Conns vessel properly (order) &amp; resists distractions</td>
<td></td>
</tr>
<tr>
<td>Uses appropriate scales to circumstances</td>
<td></td>
</tr>
<tr>
<td>Speed &amp; accuracy of work generally</td>
<td></td>
</tr>
<tr>
<td>Ability to maintain course</td>
<td></td>
</tr>
<tr>
<td>Calls out headings during C/C &amp; monitors PSC</td>
<td></td>
</tr>
<tr>
<td>Bridge equipment function &amp; layout familiarity</td>
<td></td>
</tr>
<tr>
<td>Generally applies solid BTM &amp; BRM skills (Inc. delegation)</td>
<td></td>
</tr>
<tr>
<td>Ensures accurate execution/monitor of voyage plan</td>
<td></td>
</tr>
<tr>
<td>Duplicates points/indexes on both radars</td>
<td></td>
</tr>
<tr>
<td>Maintains a proper lookout</td>
<td></td>
</tr>
<tr>
<td>Specific use of radio &amp; VTS for situation awareness</td>
<td></td>
</tr>
<tr>
<td>Contributes well during debrief</td>
<td></td>
</tr>
<tr>
<td>Has mentally oriented themselves to chart &amp; route</td>
<td></td>
</tr>
<tr>
<td>Oriented to traffic situation &amp; reports</td>
<td></td>
</tr>
<tr>
<td>Cross checks (Multiple systems, fathometer, etc)</td>
<td></td>
</tr>
<tr>
<td>Personally organized &amp; adequately prepared</td>
<td></td>
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<tr>
<td>Conforms to standing &amp; day orders</td>
<td></td>
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<tr>
<td>Display good subordinate behavior</td>
<td></td>
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<tr>
<td>Response during stress</td>
<td></td>
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<tr>
<td>Score (Ave.)</td>
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III. EVALUATION METHOD FOR TRAINEE’S SITUATION AWARENESS

In order to evaluate the trainee's navigation skill, it was effective to use a method of measuring which ship a mariner had been recognizing in the simulation run. Situation awareness global assessment technique (SAGAT) is a typical technique for measuring subject's situation awareness under the simulation run. Therefore, we used SAGAT to measure ships that the trainee was recognizing in the simulator training.

A. SAGAT

SAGAT was used to measure how the trainee had been recognizing other ships. In this technique, the simulation run was suddenly interrupted; the subject's situation awareness was measured by the questionnaire. While the subject answered the recognized situation; the simulation run was stopped temporarily and the screen of the simulator became all black. After the questionnaire, the simulation was restarted. If the simulation interruption time became too long, the continuity of the simulation run was decreased. Therefore, the interruption time was appropriate within two minutes [3]. However, there was a possibility that the reporting time interval exceeded two minutes if the subject answered in oral, because a lot of ships may appear in evading navigation simulator training. Moreover, there was a possibility that the expression of the position of the ship became ambiguous in the oral report. To overcome these problems, we adopted the method that the subject filled in the recognized ship on a radar chart instead of the oral report. The example of the radar chart was shown in Fig.1. The coordinate system of the radar chart was same as the marine radar screen. The center of figure showed own ship, y axis indicated the direction of own ship course, and x axis indicated the direction of abeam of own ship. In the figure, the concentric circles were drawn every one mile from the own ship. Then, the subject filled in the ship's picture in this figure based on the recognized ship's information such as distance from own ship, the bearing from own ship, and the aspect of the ship.

B. Evaluation

To evaluate the subject's situation awareness of the simulator training, significance of the recognized ship should be classified whether the recognized ship had risk of collision. Then, it is necessary to examine whether how many ships that had risk of collision was recognized by the subject. To define whether the ship had risk of collision, we use an index that focusing target ship’s changing rate of bearing. In this study, the ship which corresponded to this index was called "attention ship". The attention ship was the ship had possibility of the collision risk. If the ship had the possibility of the collision risk, the relative bearing seen from own ship did not change. Therefore, the caution ship was defined as the ship that the change rate of relative bearing satisfied the following constraint [6],

\[ a \cdot R^\beta < \dot{\omega} < a \cdot R^\delta \]

(1)

where, \( \dot{\omega} \) denoted changing rate of relative bearing, \( R \) denoted relative distance, \( a \) and \( \beta \) denoted weight coefficient. The value of \( a, \beta, and \delta \) was proposed from the experiment result data as follows,

\[ a = 5.8 \times 10^3, \quad \beta = -1.7, \quad \delta = -1.36. \]

(2)
IV. METHOD FOR ESTIMATING TRAINEE’S MENTAL WORKLOAD

In order to estimate mental workload of trainee who is under ship maneuvering simulator training, there are some method for measuring subject’s physiological index. In this paper, method for measuring subject’s nasal temperature and method for measuring subject’s R-R interval which is the time interval from a peak point R wave is one of waves of an electrocardiogram are introduced[4].

A. Nasal Temperature

If a human feel strong stress, his/her skin’s temperature decrease, because a blood flow volume decreases when a sympathetic nerve becomes dominant. Especially, this phenomenon appears remarkably in a nose, because peripheral blood vessel concentrates around the nose. Therefore, it is possible to obtain changing trend of subject’s mental workload using with subject’s nasal temperature that measured by thermal image video camera. Fig.2 shows an example of thermal image.

B. R-R interval

R-R interval is adjusted by the autonomous nervous system and the sympathetic nervous system predominates for human stress. Therefore, it is possible to evaluate the mental workload that influences the autonomous nervous system by measuring the R-R interval. To evaluate the mental workload, Sympathetic Nervous System values (SNS value) is calculated from the equation as follows,

\[ SNS(i) = LF(i) / HF(i) \]  

where LF is low frequency amplitude of R-R interval spectrum which frequency is from 0.04Hz to 0.15Hz and HF is high frequency amplitude of R-R interval spectrum which frequency is from 0.15Hz to 0.5Hz. The LF value is reflected by the sympathetic nervous system and parasympathetic nervous system, and the HF value is reflected by the parasympathetic nervous system. Therefore, increasing SNS value means increase of mental workload.

V. EXPERIMENT FOR SUBJECTIVE EVALUATION AND TRAINEE’S MENTAL WORKLOAD

In order to examine the relation between the subjective evaluation of trainee’s performance and trainee’s mental workload estimated by physiological index, we had ship maneuvering simulator experiment. Setting of the experiment and results were described as follows.

A. Setting of Experiment

In this experiment, a ship maneuvering simulator of California Maritime Academy was used. The simulator is full-mission type simulator and it has visual view of 360 degrees. We employed three subjects who had license of navigation officer and on-board experience. Three subjects trained respectively as mate, radar observer, and helmsman. Each role was changed and the simulator experiment was executed eight time. For the sake of space, we showed two scenarios’ outline as follows.

- Scenario 1
  Area: San Francisco bay, Alcatraz to Oakland
  Own ship: Tanker (L:261.21m,B:48.16,d:8.99)
  Objective: Traffic management will be a part of this scenario. Experience heavy traffic in normal condition of SF Bay. To develop a passage plan. Use Bridge Team, and available tools.

- Scenario 2
  Area: The Brothers to Richmond Inner Harbor
  Own ship: Bulk Carrier(L:199.95m,B:23.77m,d:6.64m)
  Objective: To utilize BRM procedures to raise situational awareness. To manage low speed maneuvers of vessel in mild wind. Decision making relative to environment.

During the simulation run, subjects’ behavior was recorded with the video camera and work sampling was done. Also, subjects’ hearts rate were measured by hearts rate monitor. Before the experiment, we explained the informed consent form for human research to all subject, and they accepted and signed the informed consent.

B. Results of Experiment

In this paper, we showed two results that subjects’ mental workload fluctuation were remarkably observed. Fig.3 showed subjects’ SNS value which indicates subjects’ mental workload at experiment 1 which used scenario 1. From the figure, it can be read that SNS value of three subjects at 17 minutes rises all together. This change shows that all subjects’ mental workload
increase in 16-17 minutes. In order to explain the reason of this phenomenon, time series of ship’s state value such as ship’s heading angle, rudder angle, speed, main engine’s revolution were indicated in Fig.4. When we looked the time series of main engine revolution, the revolution became zero at 15.3 minutes. Also, from the work sampling, it was confirmed that the mate was giving the order of astern for the main engine at 15.3 minutes. As shown in the outline of the scenario 1, target ship was very large crude carrier. Then, the deceleration control was an important phase for this scenario. Therefore, the mate and radar observer’s mental workload increased after the order of astern engine. Moreover, when the engine was set to astern, response of rudder became worth, then, the helmsman had to prepare the change of the ship’s maneuverability. Therefore, the helmsman’s mental workload was increased. From this phenomenon, it was clear that all subjects worked cooperatively by an important phase of the scenario.

Fig.5 showed subjects’ SNS value of experiment 2 which used scenario 2. From the figure, it can be read that all subjects’ SNS value at eight minutes rises all together and SNS values of mate and radar observer were increased at 31 minutes. For considering reason of these phenomenon, time series of ship’s state value such as ship’s heading angle, rudder angle, speed, main engine’s revolution at experiment 2 were showed in Fig.6. At first, we considered why the all subjects’ SNS value were increased at eight minutes. At the beginning of simulation run, ship’s speed was 11knots, but it was decreased to 4knots until ten minutes. As shown in the outline of scenario 2, it was difficult to manage low speed maneuvers of vessel in mild wind. From Fig.6, it was read that ship’s rudder was taken to 35 degrees for port side for changing her course at that time. Therefore, their mental workload were increased during this maneuvering. Next, we considered reason of increasing mental workload of mate and radar observer at 31 minutes. At this time, the ship turned corner of quay and predicted ship’s position had come off from the route as shown in left side of Fig.7. Therefore, the mate and radar observer felt stress at this moment. However, the helmsman couldn’t see the ECDIS then he was not recognizing that situation. Therefore, his SNS value didn’t increase at that time. The mate was giving the order for “Half ahead” to improve turn rate of heading, then the predicted ship’s position became inside of the sea route as shown in right side of Fig.7. Then, SNS value of the mate and
rider observer were decreased after that. From these phenomenon, it was clear that subjects worked together for difficult situation.

Subjective evaluation was filled by the instructor who was a specialist of marine pilot. The results of evaluation were shown in Table II. From the score of each subject, there was tendency that subject B’s score was lower than other subjects. However, it was difficult to find the relationship between subjects’ mental workload and their subjective scores.

<table>
<thead>
<tr>
<th>TABLE II. RESULTS OF PERFORMANCE EVALUATION</th>
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<tbody>
<tr>
<td><strong>Subject</strong></td>
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<tr>
<td></td>
</tr>
<tr>
<td>Subject A</td>
</tr>
<tr>
<td>Subject B</td>
</tr>
<tr>
<td>Subject C</td>
</tr>
</tbody>
</table>

VI. EXPERIMENT FOR TRAINEE’S SITUATION AWARENESS AND MENTAL WORKLOAD

In order to examine the relation between the evaluation of trainee’s situation awareness and trainee’s mental workload estimated by physiological index, we had ship maneuvering simulator experiment. Setting of the experiment and results were described as follows.

A. Setting of Experiment

We employed four subjects who had on board experience for captain. Their age was 46-62 years old. The experiment was executed at ship maneuvering simulator in Tokyo University of marine science and technology. The ship maneuvering simulator consisted of a bridge system, a visual system, and a control system. The bridge system was installed all equipment necessary for navigation. The visual system produces a seascape of 360 degrees in horizontal view and 40 degrees in vertical view. The control system was for creating and editing of scenarios and for operation of simulation runs.

In this experiment, we used the scenario which reproduced heavy marine traffic area. During the simulation, own ship keeps her heading course if there is no risk for collision. Total number of ship in the scenario is 24. During the simulation run, subject’s situation awareness was measured by SAGAT that described in section III. Also, subject’s nasal temperature was measured by thermal image video camera. Before the experiment, we explained the informed consent form for human research to all subject, and they accepted and signed the informed consent.

B. Results of Experiment

We executed ship maneuvering simulator experiment four times and we measured subject’s situation awareness. First measurement was executed when seven minutes passed from the start, and afterwards, subject’s situation awareness was measured every five minutes. The scenario took 22 minute, therefore four times of situation awareness were measured for each subject. Table III showed result of subject situation awareness. In the table, first row indicated ship ID which reproduced in the scenario and then from second row, which ship was recognized by subject was indicated. Total number of ship which recognized subject at each measuring time was indicated in 3rd column. Also, the attention ship that subject should recognize during simulation was indicated by shaded part. Then, the evaluation result of situation awareness was indicated in Table IV. The table showed the rate to which the
subject was recognizing the attention ship. From the result, it seemed that score of subject E, F and G were all most same. However, subject D’s score was lower than other subjects.

During the simulation, we took a picture of subject by thermal image video camera then we obtained four subjects’ nasal temperature data. Fig.8 indicated time series data of subject’s nasal temperature during the simulation run. In the figures, subject’s nasal temperature was drown by solid line and linear regression line was showed by broken line. From the figure, it was clear that mental workload of subject E, F, and G increased as the simulation was advanced. In the scenario, some vessels approach to own ship in the latter half of the simulation run. Therefore, subject should feel stress at that time. However, subject D’s mental workload was decreased as the simulation was advanced. This evaluation result was same as result of situation awareness. Therefore, there is relationship between subject’s situation awareness and mental workload.

In addition, subject F and G executed evading navigation at the end of the simulation run. The other two subjects (subject D and E) keep her course till end of simulation run.

VII. CONSIDERATION

It was difficult to find the relationship between subjective evaluation of trainee’s performance and trainee’s mental workload from the experimental result. However, it is thought that using the data of trainees’ mental workload in the debriefing is effective for their education.

VIII. CONCLUSION

In order to examine the relation between the evaluation of trainee’s performance at the ship maneuvering simulator training and trainee’s physiological index, we had ship maneuvering simulator experiment. From the experiment result of situation awareness, we found the relationship between subject’s situation awareness and mental workload. Therefore, the measuring trainee’s mental workload is effective to evaluate subject’s situation awareness for evaluating their navigation skill.

REFERENCES