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A Characteristic of a Navigator's Situation Awareness for Crossing Ships

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ABSTRACT: Many ship collisions have been caused by a navigator's error in the situation awareness (SA) of the navigator. In congested sea areas, navigators classify ships on the basis of different priority levels. For safety measures against ship collision, it is imperative for navigators to recognize the ships with high priority levels. In previous study, navigators' SA was measured in a ship maneuvering simulator using the Situation Awareness Global Assessment Technique (SAGAT). From the results of the previous study, we proposed a new risk category, named as "attention area," that covers ships with high priority level in the SA of navigators. However, the extent of data for navigators' SA was limited. Therefore, the purpose of this study is to confirm the validity of the category using additional data of navigators SA. In this study, the validity of the proposed category was confirmed, and a limit line surrounding ships with high priority levels was identified. In addition, it was evident that the category was able to detect ships with high priority level around the time when the collision avoidance was performed.

1 INTRODUCTION

Many marine accidents are caused by errors on the part of the navigator. In particular, ship collisions are often caused by improper lookout of navigator. The improper lookout that is pointed out as the major cause of ship collisions is regarded as an error in situation awareness of navigators. Grech and Horberry indicate that 71% of navigators' errors are SA related problems (Grech et al. 2002).

In order to decrease the number of ship collisions, many analytical studies of marine accidents have been published (Romer & Petersen 2009, Corovic & Djurovic 2013, Akyuz & Celik 2014). One of these studies focused on the assessment of navigators' SA using the Situation Awareness Global Assessment Technique (SAGAT) (Endsley 1988, Koester & Sorensen 2003). In pilot training using a ship maneuvering simulator, the possibility that trainees' navigation skills could be measured by SAGAT was indicated (Okazaki & Ohya 2012).

Authors have confirmed the features of navigators' SA with bridge simulator experiments and behavioral analysis (Nishizaki & Itoh 2015). However, it is difficult to understand the priority level of other ships by relying solely on behavioral analysis. Consequently, in previous study, interviews on priority levels of recognizing ships for navigators are conducted, and navigators' SA were measured in ship maneuvering simulator experiments using SAGAT. As the results, a new risk category designated as the "attention area," which covered ships with high priority level in navigators' SA was proposed (Nishizaki & Takemoto 2016). The category was created based on two risk categories (danger area and caution area) that proposed by Kiyoshi Hara (Hara & Nagasawa et al. 1990, Hara & Nakamura 1995).

We employed only three subjects who had onboard experience as captains in previous study, so the extent of data about SA in navigators was limited in the previous study (Nishizaki & Takemoto 2016). Therefore, the purpose of this study is to confirm the validity of the risk category of "attention area" using additional data on the SA in navigators.

In the current study, four subjects employed were different from previous studies. They were interviewed about their informal lookout using same list of questions as in previous studies, and the SA in navigators was measured using SAGAT under the same experimental conditions as in previous studies.

The "attention area" was defined by a function of distance and rate of bearing change of other ships. Because 3 subjects employed in previous study put emphasis on them in determining priority level. Therefore, in current study, through the interview questions, it was reconfirmed that navigators emphasized distance and rate of bearing change of other ships in determining priority level.

In addition, it became obvious from the simulator experiments with SAGAT in this study, that the "attention area" covered ships with high priority level in navigators' SA as in this study. As the results, the validity of the "attention area" was confirmed, and it became obvious that there was a limit line covered ships with high priority level. Furthermore, it was evident that the "attention area" can assist in detecting ships with high priority level around the time when the collision avoidance was performed.

In this paper, the methods employed in simulator experiments with SAGAT are explained in Section 2. Subsequently, the experimental conditions and scenarios are described in Section 3. The results of the interviews and simulator experiments are presented in Section 4. Based on these results, discussions are explained in Section 5. We provide the conclusions of this study are highlighted in section 6.

2 METHOD FOR MEASURMENT OF NAVIGATORS' SITUATION AWARENESS

SAGAT is an effective method to measure navigators' SAs in the simulator experiments. The original SAGAT was developed and proposed to measure the SA of aircraft pilots in cockpits, and the procedural standards of SAGAT were established (Endsley 1988). Through the use of SAGAT, it is possible to measure a pilot's situation awareness directly, independent of their memory of the experiments after these experiments are over.

In order to maintain the continuity of the simulation, the interruption time should be selected to be as short as possible. However, there are ambiguities in the oral reports about all ships in a congested sea area, and it is difficult to account for all recognized ships in a short interval.

In order to measure the situation awareness of ship navigators, we adopted the method where subjects fill in recognized ships on a radar chart. This method was proposed as an evaluation method for marine pilot trainees (Okazaki & Ohya 2012). We set interruption time as one minute to enable test subjects to answer based on radar watch information by use of the radar chart. A sample report based on the radar chart is shown in Figure 1.

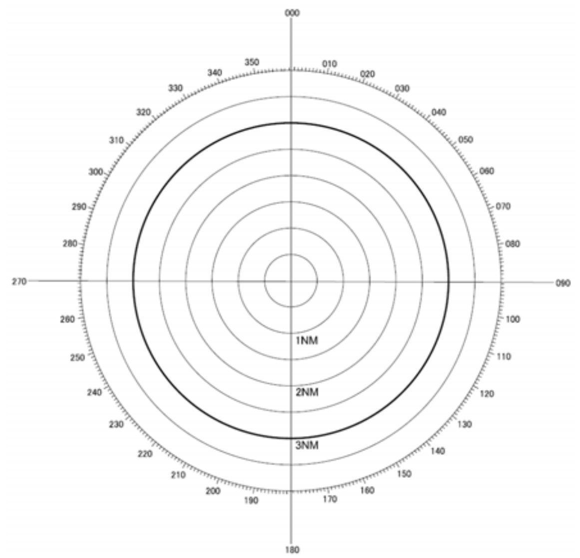

Figure 1. Example of a report for SAGAT.

3 EXPERIMENTS

3.1 *Bridge Simulator*

The purpose of the simulator experiments is to obtain data on navigators' SA in keeping watch by the use of SAGAT. Experiments with SAGAT were conducted in the ship maneuvering simulator of the National Maritime Research Institute. Within the bridge of the simulator, general navigational equipment were installed, such as a compass, pair of binoculars, radar, ECDIS, and steering stand. It is possible to record behaviors of the subject in response to navigational orders and other ships situations using behavioral analysis systems in the simulator.

3.2 *Subjects*

In this study, four subjects different from the previous study and with onboard experience were employed. The information of subjects in a previous study and that in this study are shown in Table 1.

Table 1. Comparison between the previous and current study on subject information.

Experimental Season	Subject ID	Appointment
Previous study	Sub.A	Captain
	Sub.B	Captain
	Sub.C	Captain
Current study	Sub.D	Chief Officer
	Sub.E	2nd Officer
	Sub.F	3rd Officer
	Sub.G	Chief Officer

In this study, the subjects kept watch using the general navigational equipment (compass, pair of binocular, radar, ECDIS and steering stand). Furthermore, they were instructed to keep their simulated ships on a steady course and speed if possible. When the subjects felt an imminent risk of collision, they were instructed to maneuver to avoid the collisions.

Before the experiment, to conform with ethical standards in human research, we requested that the all subjects fill informed consent forms for human research, which all subjects accepted and signed to signify their informed consent.

3.3 *Experimental Scenario and Measurement Method for navigators' SA*

Navigators' SAs were measured using SAGAT under the same experimental scenario as used in the previous study (Nishizaki & Takemoto 2016). Therefore, an open sea was used as the sea area for the experimental scenario, and there are 24 other ships with each having various encounter situations to the simulated ship of the navigator. The basic tracks of the other ships are shown in Figure 2.

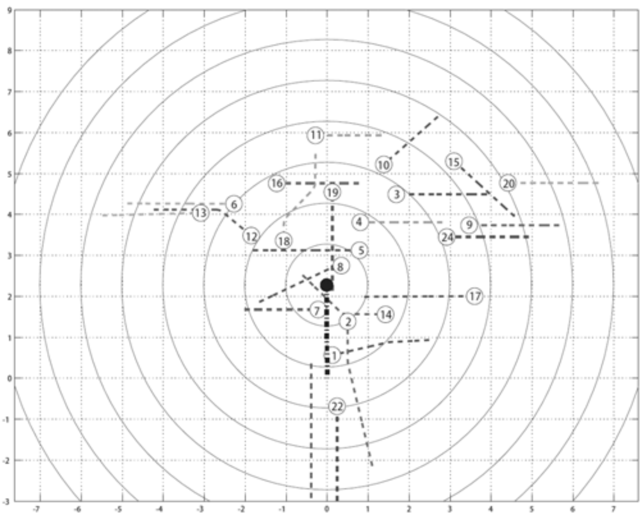

Figure 2. Example of a report for SAGAT.

In the current study, the SA in navigators was measured using SAGAT under the same experimental conditions as in previous studies. Therefore, the scenario spanned about 30 minutes including interruption time for SAGAT, and the experimental scenario was suspended 4 times after 7 minutes, 12 minutes, 17 minutes, and 22 minutes. In order to set aside enough time to collect information about surrounding ships, the first measurement time was set at 7 minutes. The interruption time was set to be one minute, and second to fourth measurements were conducted every 5 minutes.

In the interruption time, the situation awareness of the navigators was measured by means of the report, which the subjects filled in based on the displayed radar chart (Figure 1). Subjects filled in ships they recognized in the report. In particular, after they filled in all the recognized ships, the priority rankings of these ships were also filled in the same report.

3.4 *Interview after Experiments*

Subjects in current study were interviewed about their informal lookout using same list of questions as in previous studies. The list of questions is divided into two parts. The first part consists of questions about personal history such as license and number of years onboard. The second part deals with questions about informal lookout and situation awareness of other ships. In particular, four items from the following were included in the second part.

- Maximum number of ships simultaneously
- Radar ranges used in watch keeping
- Rank order level of information
- Rank order level about encounter situation

Shortly after the simulator experiments, subjects were asked to provide their responses to the list of questions in turn.

4 RESULTS

In this chapter, we show the results combining subjects in previous study (Sub.A, Sub.B and Sub.C) with subjects in current study (Sub.D, Sub.E, Sub.F and Sub.G).

4.1 *Results of Interview Research*

As a result of the interview for Sub.A to Sub.G, the maximum number of ships simultaneously recognized by navigators was determined to be about five (Table 2). Additionally, navigators selected radar ranges depending on the congestion of the sea area. The radar ranges used by navigators are shown in Table 3.

Table 2. Maximum number of ships simultaneously recognized.

Sea Area	Maximum number of ships							
Sub ID	A	B	C	D	E	F	G	Average
Open Sea	2	5	3	5	8	-	5	4.67
Coastal Sea	4	5	5	5	8	4	5	5.14
Bay (heavy traffic area)	5	5	5	5	8	4	5	5.29

Table 3. Radar ranges used in keeping watch.

Sea Area	Radar Range [NM]
Open Sea	12 or 24
Coastal Sea	6 or 12
Bay (heavy traffic area)	3 or 6

In a manner similar to the previous study, four subjects were asked to provide the types of information they employed to determine the priority level of other ships. Consequently, the subjects ranked the importance of nine sets of information. The response about the rank order level of information varied among subjects. Consequently, data for the rank order level were normalized to reduce inconsistencies. Figure 3 shows the normalized rank order level of the aforementioned nine pieces of information.

In this figure, the ordinate denotes the normalized rank order level, and the abscissa denotes the nine sets of information. The higher the rank order level, the more critical the information was to the subjects in deciding the priority level of other ships. As represented in Figure 3, navigators focused mainly on three pieces of information (the rate of bearing change, the distance, and the type of encounter situation) to decide the priority level of other ships.

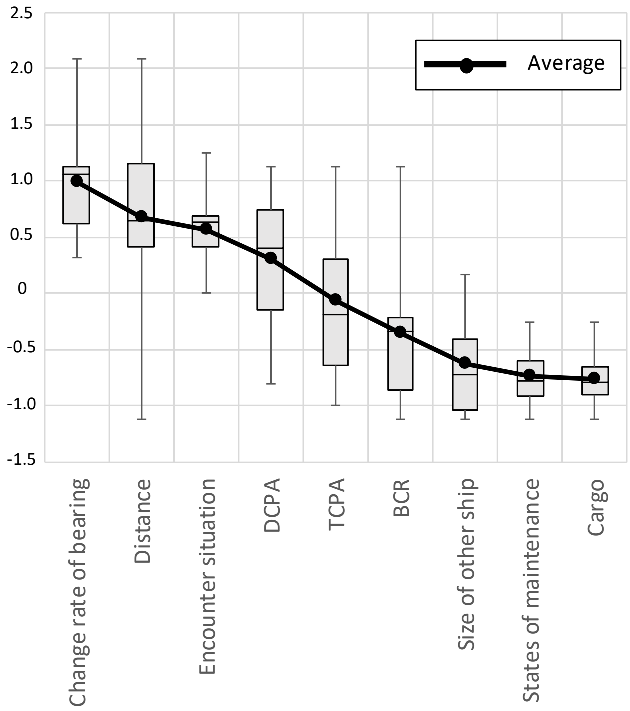

Figure 3. Normalized rank order level for nine information.

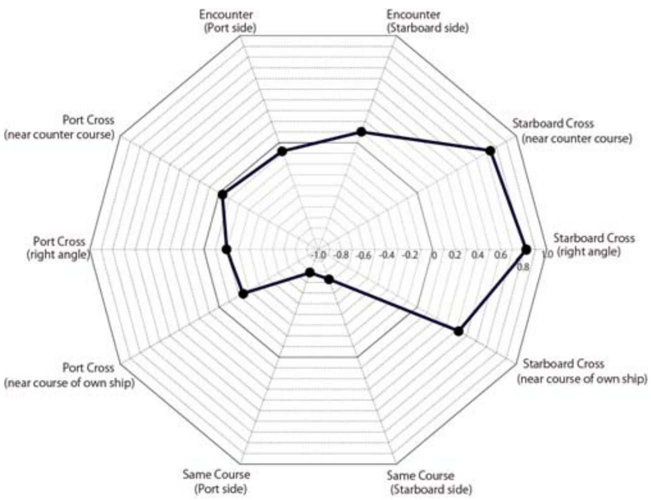

Figure 4. Normalized rank order level about encounter situation

Consequently, the priority level of ships should be investigated in each encounter situation. Furthermore, it is important to analyze SA in navigators based on the rate of bearing change and distance. These results were comparable with the results of the previous study.

In addition, each subject ranked the importance of ten encounter situations. Figure 4 shows normalized rank order level for ten encounter situations of all seven subjects. In this study, a higher rank order level indicates a more critical encounter situation to decide the priority level of other ships.

Figure 4 indicates that navigators placed emphasis on crossing situations from starboard as compared to other encounter situations. The results obtained in the current study corroborate that of the previous study.

4.2 *Results of navigators' SA Measurements*

Measurement results of navigators' SA are shown in Table 4. The first column in Table 4 indicates ship ID including the scenario. The second and third columns indicate encounter situations of the other ships. The right side beyond the fifth column indicates the resulting navigators' SA. The total number of ships were recognized by each subject at the time of measurement is indicated in the 3rd row. As I mentioned before, the maximum number of ships simultaneously recognized by navigators was determined to be about five. Therefore, we defined ships ranked higher than 5th as ships with high priority level. Circle symbols (o) are used to indicate ships ranked higher than 5th and cross symbols (x) are used to indicate ships ranked 6th or lower in Table 4. No symbols (blank space) were used to indicate ships that went unrecognized by anyone.

In addition, Table 4 shows that there are ships that are recognized by several subjects. For example, Ship 3 in the 2nd and 3rd measurements is recognized by all subjects. On the other hand, Ship 11 and Ship 21 were not recognized by any of the subjects. Interestingly, despite ship 4 in 4th measurement being recognized by several subjects, it ranked as having a low priority level. From these results, it can be deduced that many of the subjects agreed on similar ships having a high priority level.

5 DISCCUSSIONS

Based on the interviews, it became evident that subjects placed more emphasis on crossing situations from starboard as compared to other encounter situations. Therefore, in this paper, we focused on five ships that cross ahead of the subjects' own ships from starboard to port (ship IDs for such ships are 3,4,10,11 and 16)

Furthermore, based on the observations of the interviews, it was considered to be important to analyze the SA of navigators with the changing rates of bearing and distance. Adapting from previous work reported by Nishizaki (Nishizaki & Takemoto 2016), the emphasis is placed on the rates of bearing and distance.

Table 4. Results of navigators' situation awareness.

Ship ID	Relationships		Measurement No. (time)	1 (7minutes)							2 (12minutes)							3 (17minutes)							4 (22minutes)						
			Subject ID	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
			Total Num. of Ships	5	6	6	7	5	4	5	8	6	5	6	7	4	4	7	7	7	4	6	3	4	7	6	7	5	3	3	3
1	S to P*1	Cross				O																									
2	S	Overtake				O		O		O			O		X		O	X		O			O	O	O	O	O		O	O	O
3	S to P	Cross		O			X	O	O		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O		O	O	
4	S to P	Cross					O	O	O	O	O	O		O	X	O	O	X	X												
5	P to S	Cross		O	O		O			O																					
6	P to S	Cross						O							O		O	O		O		O		O			O	O			
7	P to S	Cross				O	O																								
8	P to S	Cross		O	O	O	O		O	O		X		O		O															
9	S to P	Cross			O	X					O	O	O	O					O	X	O						O				
10	S to P	Cross						O	O		O			O	O	O			O	O	O	O	O	O	O	O	O				
11	S to P	Cross																													
12	P to S	Cross											O		O							O									
13	P to S	Cross																				X						X			
14	P to S	Cross			O																O										
15	S to P	Cross																							X		X				
16	S to P	Cross									X																			O	
17	P to S	Cross		O																											
18	P	Head on							X				X				O														
19	S	Parallel		O	O						O	X	O					O	X						O	O					
20	S to P	Cross																							X	X	X	O	O		
21	S	Head on																													
22	S	Parallel								O																					
23	S	Head on																X	O						O	O	O		O		O
24	S to P	Cross			O	O	O				O	O	O	X					O	X	O	O						O			

*1 "S" denotes the starboard side and "P" denotes the port side

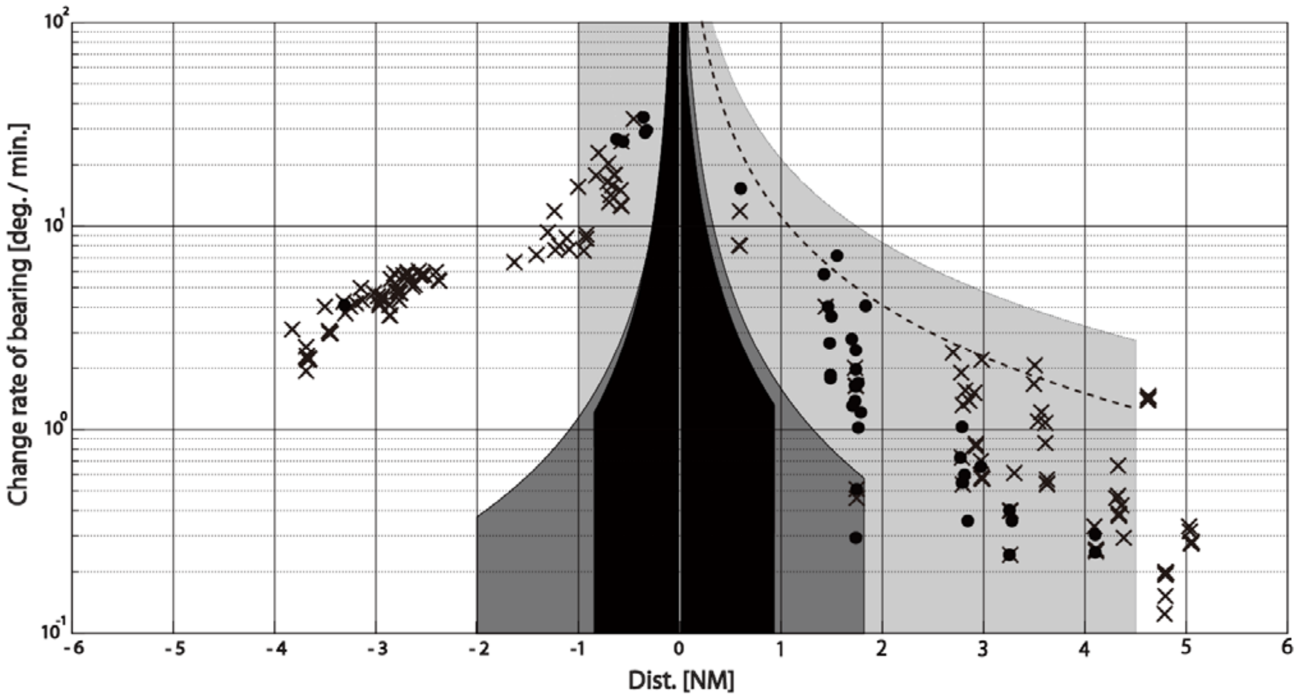

Figure 5. Results of navigators' situation awareness and attention area.

Figure 5 shows results of SA in navigators for five ships that cross ahead of the subjects' own ship from starboard to port. In Figure 5, the x-axis indicates the distance to other ships, while the y-axis indicates the rate of bearing change. The right side of the figure indicates the likelihood of the other ship crossing ahead of the subject's ship in the future, while the left side of the figure indicates if this other ship has already crossed ahead of the subject's ship. In Figure 5, the black and dark gray colored areas show danger and caution areas of Hara's risk categories, respectively (Hara & Nagasawa et al. 1990, Hara & Nakamura 1995). It was observed in the previous study, that some ships were collectively sighted /agreed upon by several subjects as having a high priority level. Thus, a new risk category: the "attention area," was proposed. The attention area is represented as the light gray colored area in Figure 5. Black circle symbols were used to indicate high priority level ships and cross symbols were used to indicate low priority level ships or ships unrecognized by anyone. In this study, some subjects maneuvered to avoid collisions in the simulator experiments. Therefore, there are variations between the plot of the current study and that of the previous study (Nishizaki & Takemoto 2016). However, results of the SA measured at the time of avoidance actions were not included in Table 4 and Figure 5.

It is obvious that the attention area covered ships with high priority level in SA of navigators in current study. Therefore, the validity of the "attention area" was confirmed. Furthermore, results indicate that there was a limit line that covered ships with a high priority level. The interrupted line in Figure 5 shows the limit line surrounding high priority level ships. The corresponding equation and weighing coefficients of attention area and the limit line are shown in Table 5. ω is the rate of bearing change, R is the distance, while, α , β , γ and δ are weighing coefficients.

In this study, some subjects maneuver to avoid collisions in the simulator experiments. Due to the ability of the subjects to maneuver using the simulator without any collisions, the assumption that the risk category of attention area was available to detect ships with high priority level around the time when the collision avoidance was performed.

Table 5. Equation and weighing coefficients.

Equation	Weighing Coefficients
$\alpha \cdot R^{\beta} < \dot{\omega} \le \gamma \cdot R^{\delta}$	*attention area* $\alpha = 5.8\times10^{5}$, $\beta = -1.7$, $\gamma = \alpha = 5.8\times10^{5}$, $\delta = \beta\times0.8 = -1.36$
	Limit Line $\alpha = 5.8\times10^{5}$, $\beta = -1.7$, $\gamma = \alpha = 5.8\times10^{5}$, $\delta = \beta\times0.85 = -1.45$

6 CONCLUSION

In order to confirm the validity of the risk category (attention area), subjects employed were different from a previous study, and navigators' SA were measured with the SAGAT under the same experimental conditions in previous study. Based on the interviews and measurements of the navigators' SA, the following were confirmed:

1 It was reconfirmed that navigators prioritized the distance and rate of bearing change of other ships in determining a priority level.
2 The risk category (attention area) covers ships with high priority level in SA of navigators in this study. Thus, the validity of the "attention area" was confirmed.
3 There is a limit line that includes ships with high priority level.

The attention area was available to detect ships with a high priority level around the time when the collision avoidance was performed.

Because size of navigators' SA data in previous and current study are very small, it is necessary to verify the validity of attention area by increasing navigators' SA data.

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