Cognitive errors for radar target echo direction

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COGNITIVE ERRORS for RADAR TARGET ECHO DIRECTION

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Abstract: Radar is a useful instrument to get target information in restricted visibility and night navigation. If there are many similar targets in a close area, navigators sometimes make errors in recognizing the radar's target direction when they find the targets in a seascape using radar information. They sometimes indicate other targets instead of their intended target by mistake. We must prevent the errors, to reduce accidents and improve safe navigation. The purpose of this paper is to investigate why navigators make mistakes when identifying the direction between the radar's target echo on the display and the actual vessel in the seascape. We tackle this problem in three steps: 1) we propose a navigator's radar target cognitive model; 2) we evaluate the errors of the radar target cognition and its indication in the seascape and 3) we discuss the errors with the parallax.

1. Introduction

A ship's navigator (navigator) gets navigational information through five senses in attempting safe navigation. Most of the information comes from visual observation, and it is said that the visual data account for more than eighty percent of human information (Ueda and Maeno 2004). The navigator gets a lot of information from the seascape and RAdio Detection And Ranging (radar) through visual observation. We think that one mechanism the navigator uses to get navigational information is shown by finding the characteristics of the obtained data through visual observation.

Navigators use radar with which they can get target information (such as target direction and distance from their own ship) during restricted visibility. Radar is the useful navigational instrument on board and its effects are recognized in the shipping world. However, navigators sometimes confuse the relationship among target echoes on the radar display (display) for the targets in the seascape when many targets are in

close proximity. We must prevent small errors for safe navigation, because some vessel accidents/disasters happen when humans make trivial mistakes.

The purpose of this paper is to find the reason why a navigator mistakes the direction between the radar target echo and the real vessel in the seascape in the close proximity. In other words, we research the cognition of the radar target echo direction. We tackle the problem in three steps: 1) we propose the Radar Target Cognitive model (RTC model) which shows the processing of navigational information when the navigator gets the information and analyzes it; 2) an experiment to evaluate the characteristics of radar target cognition on the display is conducted with a simulated display. The subjects are eight students of Kobe University, Faculty of Maritime Sciences. We show the results of the characteristics of two-dimensional cognition of radar target direction and three-dimensional cognition of target direction in the seascape. Then, 3) we formulate a hypothesis for making errors in the target direction on the display with the parallax. We define the parallax as the difference in apparent direction or position of a target when viewed from different points (Bowditch 1995) and (JIN 1993).

2. Radar Target Cognitive Model (RTC)

We propose the RTC model in Figure 1. The RTC model which consists of two identical processes in decision-making about the cognitive direction, shows the relationship between two-dimensional information coming from the display and three-dimensional information going to the seascape about the target direction (Murai 2001) and (Murai and Hayashi 2004). The RTC model is the navigator's pattern model in maritime science (Miyoshi 1991) and (Miyoshi 1995).

In Figure 1, the navigator's perceive the target echo on the display, and obtain two-dimensional information of the target after they have analyzed the information. This process repeats itself as a feedback routine. Moreover, they convert two-dimensional information into three-dimensional information in order to recognize the target in the seascape and obtain three-dimensional information about the target after they have analyzed the information with the real target information. Using radar target cognition, they always confirm the relationship between the radar information (two-dimensional information) and the seascape (three-dimensional information). When converting two-dimensional information into three-dimensional information, they make three kinds of errors: two-dimensional cognitive errors, three-dimensional cognitive errors, and dimensional conversion errors (total error). The definitions are as follows:

1) Two-dimensional cognitive error is the difference between the reported radar target direction (D_1) and the true target direction (T) on the display. The error is calculated by an equation of $D_1 - T$.
2) Three-dimensional cognitive error is the difference between the reported radar target direction (D_1) and the indicated target direction in the seascape (D_2). The error is calculated by an equation of $D_2 - D_1$.
3) Dimensional conversion error (Total error) is the difference between the true target direction (T) and the indicated target direction in the seascape (D_2). The error is calculated by an equation of $D_2 - T$. This error refers to the total error from the subject's estimation of the radar target direction on the display to the subject's decision-making about the target direction in the seascape.

   Figure 1 is a general model which has some elements related to human action/behavior: perception, cognition, judgment, decision-making (cognitive direction) and action/behavior (report or indicate) (Hiwatashi 1997). We examine three kinds of errors in order to find the characteristics of the decision-making regarding the radar target direction with the RTC model.
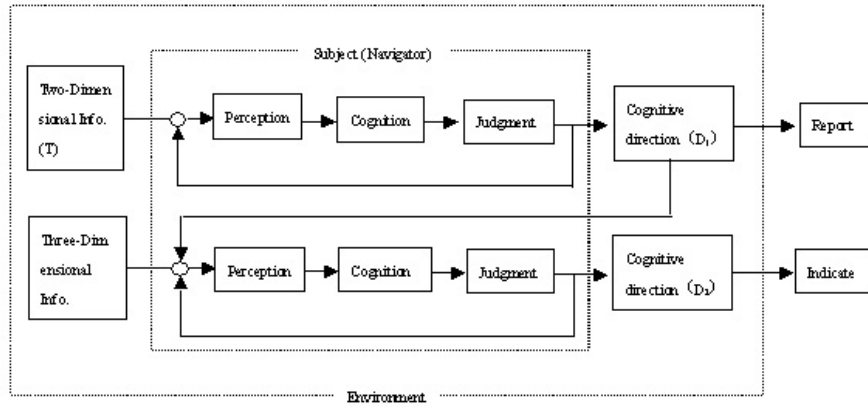

Fig.1. The Radar Target Cognitive model (RTC model)

3. Experiment

The experiment was carried out to simulate the display by using a Cathode Ray Tube (CRT) display in the dark (simulating night navigation) because we must limit the

visual information to the subject in an experimental room to avoid obtaining other information which influences the decision-making about target direction. We tested the subject's cognition of the radar target direction on the display (two-dimensional information) and the direction on a screen with two-dimensional information for eight subjects, and considered the relationship between two/three-dimensional information and its errors. The subjects, students in the navigation program at Kobe University, are males who had three months on-board experience.

3.1 Outline of the experiment

The outline of the experiment is shown in Figure 2. In Figure 2, 15 inches' CRT display is set the position 68 centimeters under the eye position of the subjects. The horizontal inclination of the display is 18 degrees which is used to a design of a marine radar, and we matched it. We display the headline, 12 nautical miles' range circle without the divisions of a gyrocompass and a target echo on the display. Here, the nautical mile is a unit of distance used principally in navigation and it is 1,852 meters (Bowditch 1995). The subject can't use any functions of the radar for measuring the target direction. The subject just measures the direction of the radar target echo by their visual observation. The screen has 110 degrees' horizontal angle, and the subjects indicate the target direction on it which is set up at 3.5 meters in front of the subject's standing position.
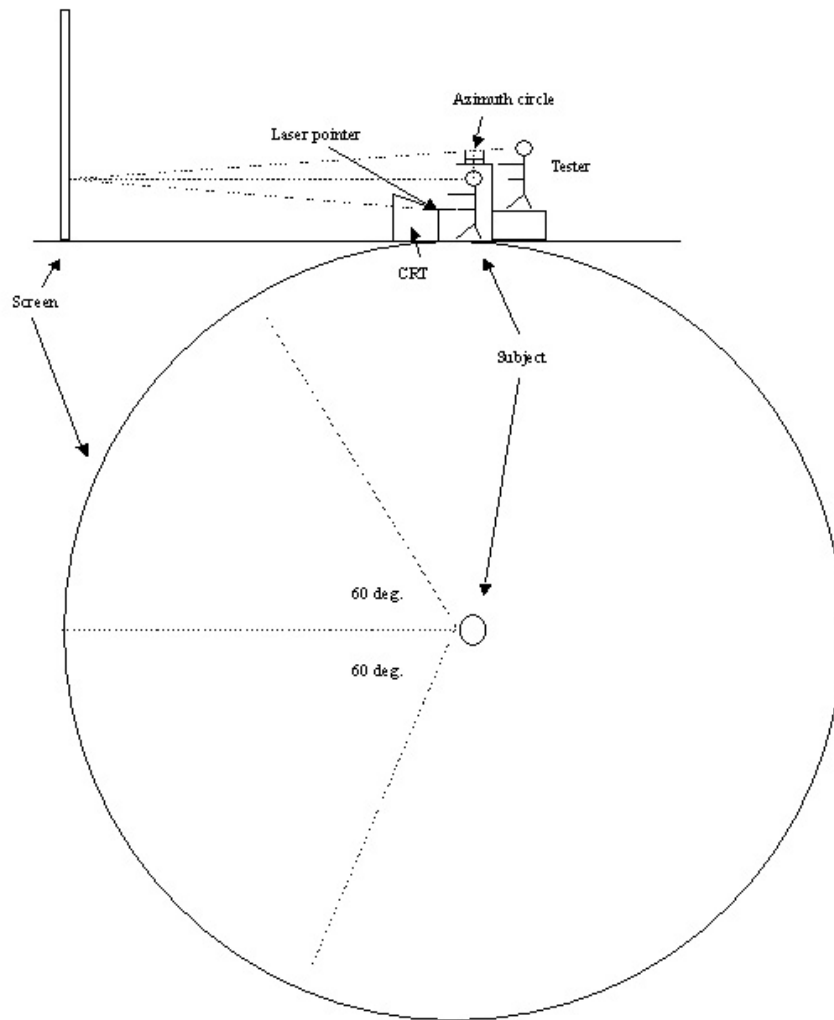
Fig.2. Outline of the experiment

3.2 Experimental method

The experimental method is as follows:

1) The tester makes the radar target echo by using a uniform random number from 0
    to 60 degrees with 1 degree and 1 nautical mile accuracy and shows it on the
    display. The display is set in the 12 nautical mile range and heading-up mode.

2) The subject observes the radar target echo on the display and reports the target direction (D_1).

3)   The subject indicates the target direction on the screen in front of the subject in the experimental room by a laser pointer (D_2). Then, the tester measures the indicated point with an azimuth circle which provides a means for observing compass bearings and azimuths (see Bowditch 1995).

4) The three types of errors are calculated by the equations of D_1 - T, D_2 - D_1, and D_2 - T respectively.

5) The process from 1) to 4) is repeated 44 times in an experiment and the experiment is carried out 8 times for each subject. We decided to use 44 times per experiment for two reasons: the experiment can be carried out for 5 to 6 minutes if the subject does not become fatigued; and we can keep 2 to 3 degrees accuracy for the direction.

4. Results

We show the results of three types of errors: two-dimensional cognitive error; three-dimensional cognitive error; and total error.

4.1 Two-dimensional cognitive error

Two-dimensional cognitive error (D_1 - T) is shown in Figure 3. Figure 3 shows the relationship between the true direction on the display and the mean, the standard deviation of all subjects. We also show the whole tendency with the regression line ($y = a_1 x + b_1$). The values of a_1 and b_1 for eight subjects are shown in Table 1. In Figure 3, the negative number of the x-axis shows the port (left) side of the subject's ship and the positive number shows the starboard (right) side. Therefore, in case of the starboard side, the positive number error means the subject's estimate is smaller than the true value; and the negative number means the subject's estimate is larger than the true value. On the other hand, in case of the port side, the relationship reverses.

   According to Figure 3, the mean value shows the subject's recognition is small for the true value. The same tendency occurs for all subjects. This tendency is shown well by $a_1 < 0$ of all subjects in Table 1.
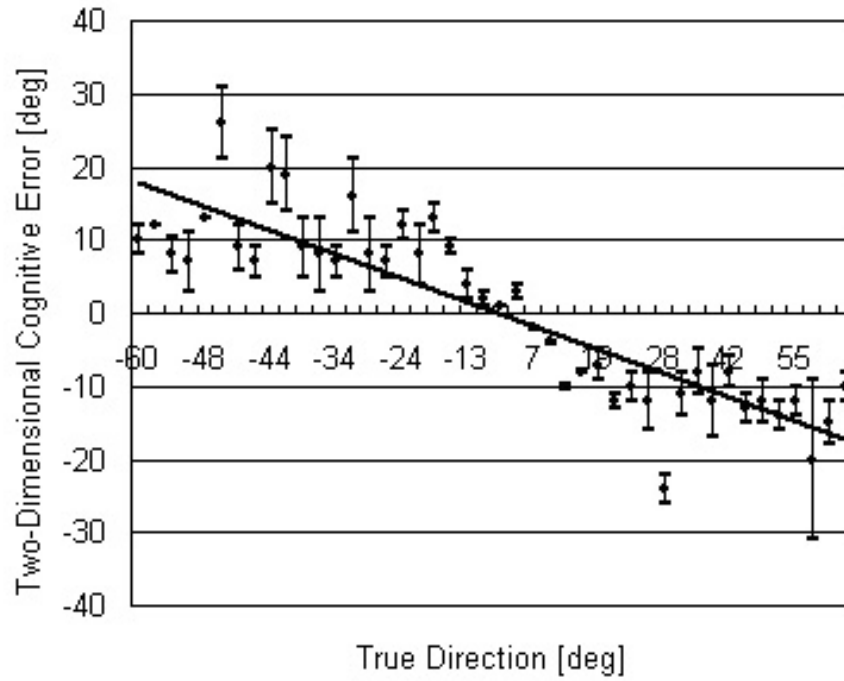
Fig.3. Two-dimensional cognitive error (mean and standard deviation of eight subjects)

Table 1. The values of a_1 and b_1 ($y = a_1 x + b_1$)

	1	2	3	4	5	6	7	8	mean
a_1	-3.14	-0.86	-1.17	-3.44	-2.32	-2.02	-0.55	-0.68	-1.89
b_1	2.32	-1.72	0.96	11.68	18.43	6.96	6.92	-21.52	3.40

4.2 Three-dimensional cognitive error

Three-dimensional cognitive error ($D_2 - D_1$) is shown in Figure 4. Figure 4 shows the relationship between two-dimensional cognitive error and three-dimensional cognitive

error with the mean and the standard deviation of eight subjects. Also, the line ($y = a_2 x + b_2$) of Figure 4 shows the whole tendency with the mean values like Figure 3. Each subject's value of a_2 and b_2 is shown in Table 2. In Figure 4, the negative number of the x-axis is the port (left) side of the subject's ship and the positive number is the starboard (right) side (same as Figure 3). Also, the positive number of the y-axis means the subject's estimate is large for two-dimensional cognitive error and the negative number means the subject's estimate is small.

According to Table 2, half of the subjects indicate small for two-dimensional cognitive errors. However, other subjects have the opposite tendency: four subjects are $a_2 < 0$ and four subjects are $a_2 > 0$. Moreover, Figure 4 shows the mean value of the errors is small and it is less than 7 degrees around two-dimensional cognitive error. Three-dimensional cognitive error of subjects, when they indicate the direction on the screen with two-dimensional decision-making, is smaller than two-dimensional cognitive error. In other words, most of the errors are two-dimensional cognitive errors for the cognition of the radar target direction. We discuss reasons for "Where do the errors come from?" in Section 5.
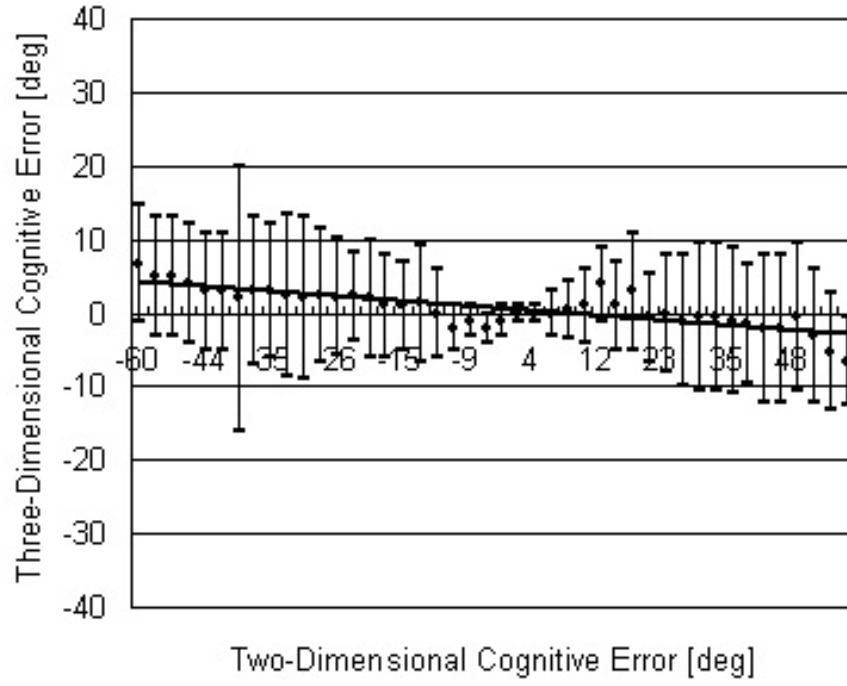
Fig.4. Three-dimensional cognitive error (mean and standard deviation of eight subjects)

Table 2. The values of a_2 and b_2 ($y = a_2 x + b_2$)

	1	2	3	4	5	6	7	8	mean
A_2	0.97	0.57	-1.87	1.67	-5.50	0.32	-1.89	-0.80	-0.76
B_2	-2.04	12.58	11.23	9.55	21.05	13.52	-3.52	16.08	7.08

4.3 Total error

The total error (D_2 - T) is shown in Figure 5. Figure 5 is the total value of Figures 3 and 4. In Figure 5, the line ($y = a_3 x + b_3$) shows the whole tendency with the mean similar to Figures 3 and 4. The values of a_3 and b_3 for all subjects are shown in Table 3.

According to Figure 5 and Table 3, we can confirm the dependence of the errors on radar target cognition; the navigator catches the targets from the radar target echo with a two-dimensional cognitive error (maximum of the mean: 25 degrees). Most of the errors come from two-dimensional cognitive error with the levels of the mean and the tendency of Figure 5, as it was described in section 4.2. Total errors strongly depend on the results of two-dimensional errors.
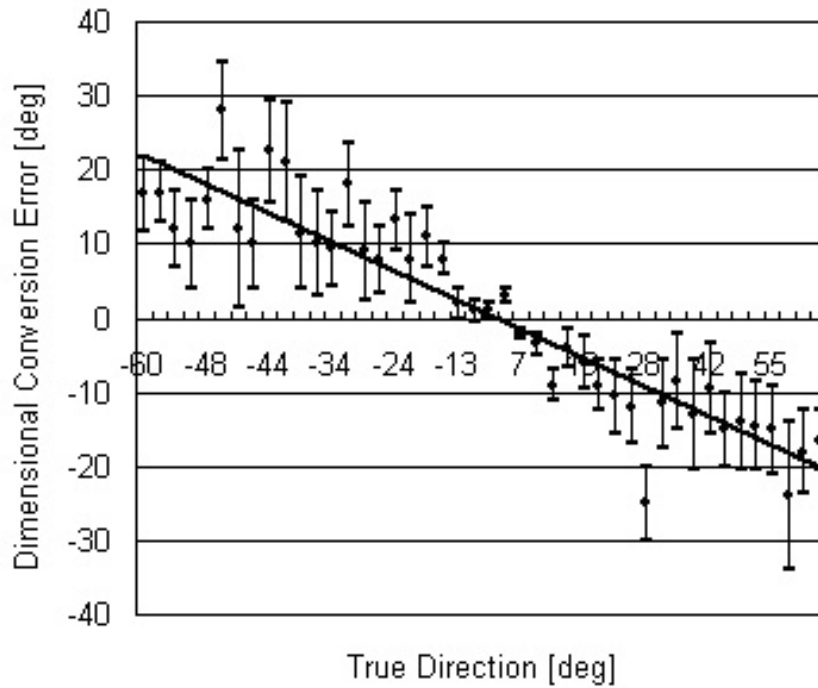

Fig.5. Dimensional conversion error (mean and standard deviation of eight subjects)

Table 3. The values of a_3 and b_3 ($y = a_3 x + b_3$)

	1	2	3	4	5	6	7	8	mean
a_3	-2.48	-0.40	-2.75	-2.25	-6.38	-3.95	-2.00	-1.32	-2.44
b_3	0.42	8.74	12.27	23.50	29.93	12.62	-5.71	-3.30	9.85

Moreover, correlation coefficients between two-dimensional cognitive error, three-dimensional cognitive error and total error are shown in Table 4. Table 4, the correlation coefficient between the two-dimensional cognitive error and total error is 0.98 (p < 0.01), and the coefficient between three-dimensional cognitive error occurs when the navigator recognizes the target echo on the display, but does not find the target in the seascape.

Table 4. Correlation Coefficient among errors

	Two-dimensional cognitive error	Three-dimensional cognitive error
Dimensional conversion error (Total error)	0.98[**]	0.67[**]

**p<0.01

4.4 Relationship between distance to target echo and error

We show the relationship between the distance to target echoes and two-dimensional cognitive error with the mean and standard deviation of all subjects in Figure 6. Figure 6 shows the error is large in close range from the center of the display.
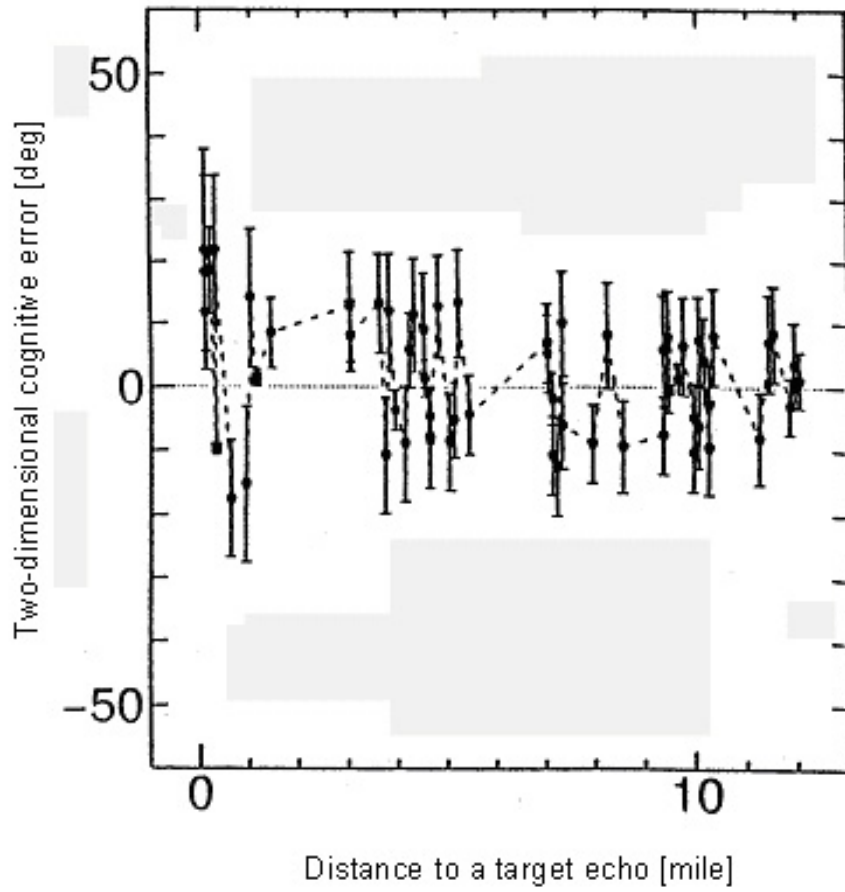
Fig.6. Relationship between distance to target echo and two-dimensional cognitive error (mean and standard deviation of eight subjects)

5. Discussion

We discuss the reason why the errors come from the two-dimensional cognitive error in the results of section 4. We propose that when the subject has an error, it comes from the parallax between the center of the display and the subject's measurement basis point for the radar target echo. The outline of our idea is shown in Figure 7, and equations (1) and (2) calculate the error.
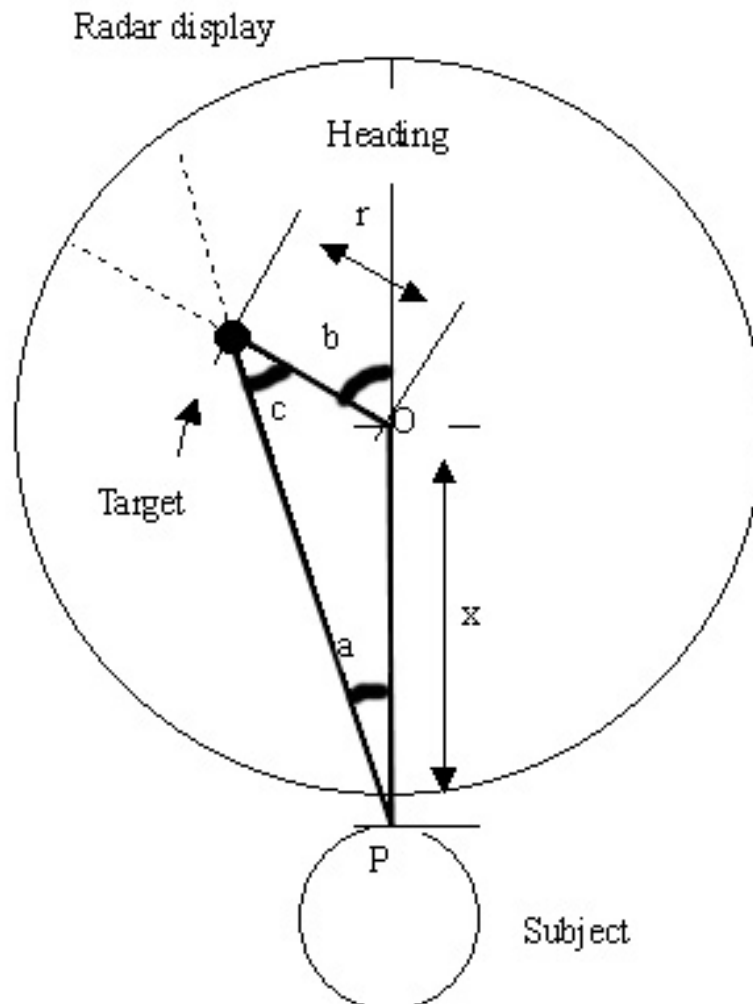
Fig.7. Outline of the parallax on the display

In Figure 7, O, P, a, b, c, r, and x is center of the display, eye position of the subject, cognitive direction of the target echo, set target direction (true direction), theoretical two-dimensional cognitive error, distance from the center of the display to the radar target echo, and distance from the center of the display to the basis point for measuring target echo respectively. The variables, used in equations (1) and (2), are the same in Figure 7. We can calculate the subject's cognitive direction (a) from the

right triangle with vertexes of target and eye position (P) and theoretical two-dimensional cognitive error from the relationship between two interior (a + c) and an exterior (b) for the triangle with vertexes of target, O and P.

$$a = \arctan \{ \ r \sin b \ / \ (\ x + r \cos c \ ) \ \} \qquad (1)$$
$$c = b - a \qquad (2)$$

We tried to calculate the theoretical two-dimensional cognitive error with x = 1 nautical mile. The values, except x are decided by the position of the simulated target echo with a uniform random number.

The result of the equations (1) and (2) is shown in Figure 8. Figure 8 shows the relationship between the measured data with a dotted line and the calculated data with a solid line. The solid line is theoretical value of two-dimensional cognitive error. The tendency is same as the mean values of Figure 3.
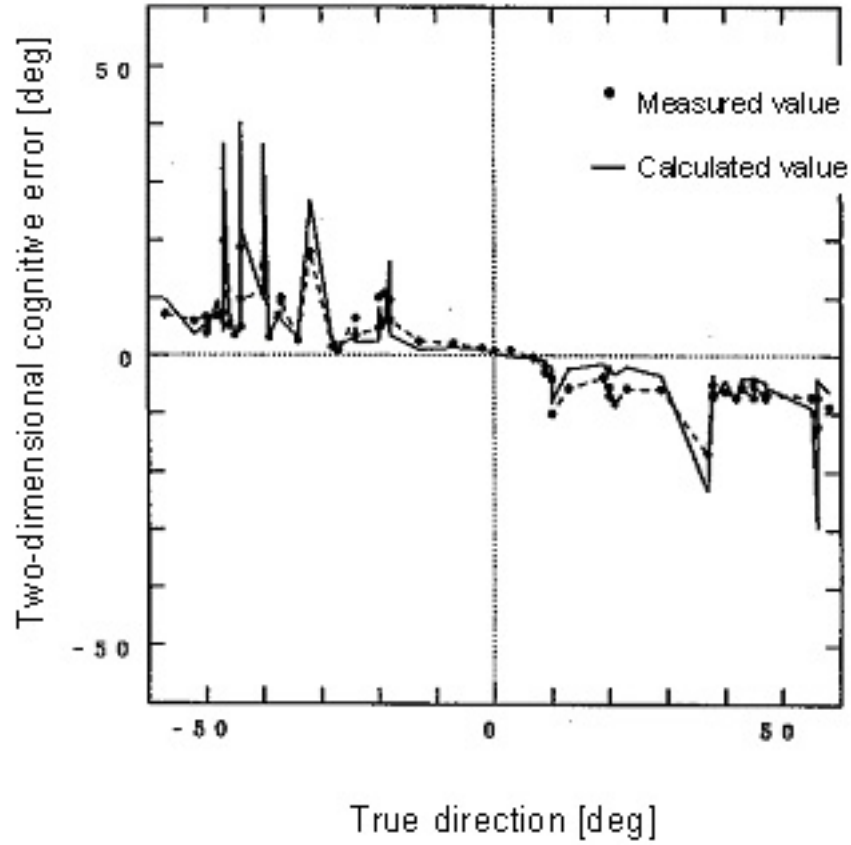
Fig.8. Relationship between the measured data and the calculated data of the radar target direction on the display

In Figure 8, we can confirm the reason why two-dimensional cognitive errors occur when the navigator finds the target on the display. In other words, the parallax is the main reason for two-dimensional cognitive error.

6. CONCLUSIONS

We proposed the RTC model and found the characteristics of two-dimensional, three-dimensional and total cognitive error. Moreover, we discussed the reason why the errors occur in the cognition of the radar target echo on the display.

According to the results, we can show the following points about the errors between the radar target cognition on the display and the target cognition in the seascape.

1) Two-dimensional cognitive error: subjects reported the radar target direction as small for the true direction.

2) Three-dimensional cognitive error: subjects indicated the target direction exactly for the two-dimensional cognition.

3) Dimensional conversion error (total error): the subjects' errors strongly depended on two-dimensional cognitive error.

4) The reason for the errors, occurring between the target echo on the display and the target, was the parallax on the display.

From the results, we can advise the students about the mistake in the recognition of the target position in the seascape from the target echo on the display. However, in real radar use, lots of information shows on the display except target echo and heading line which we used in this study: sweep, range ring and relationship are typical pieces of information. In future works, we will need to mimic reality more, and the experiment should be carried out using a ship-handling simulator and a real vessel.

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