Situation Awareness and the Decision-Making Process in a Dynamic Situation: Avoiding Collisions at Sea

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Abstract: In this study, the authors aim to determine the impact of situation awareness (SA) in the decision-making process of "young" watch officers of a Merchant Marine training facility. The trainees were shown an ambiguous interaction situation in which they could choose among several actions. The results show that Level 1 SA (perception of the elements in the environment) tends to be of secondary importance in decision making. The major variables of the decision-making process are the interpretation of the rules and anticipation of the other vessel's intentions. Moreover, four different trainee "profiles" emerged. The main difference between them lies in the distance at which they decided to change course, the direction of this maneuver (port or starboard), the way in which they interpreted the other vessel's intentions (is it going to change course?), and whether the trainees referred to the rules. Of the trainees, 55% performed a maneuver that was against regulations, and 34% did so in an unsafe manner. This result provides an incentive to rethink the training course to put more stress on recognizing prototypical situations and choosing which actions to take in situations such as the one presented here.

Introduction

Traffic situations are dynamic and complex because they involve moving objects of different characteristics (speed, maneuverability), as well as actors following diverse forms of logic. The major aim of traffic psychology is to explain and predict the behavior of system users (Brown, 1997; Summala, 1997), particularly in interaction situations or "traffic conflicts."

In vehicle traffic, problems (i.e., accidents) are frequently caused during interactions with other users (Risser & Nickel, 2004). According to Risser (1985), three aspects are important when trying to identify behavior that leads to accidents: the legality as well as the degree of danger, which coincides with certain

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types of behavior, and the ability of road users to communicate with other road users, including the ability to recognize the intentions of others (Risser, 1985).

In several ways, sea traffic is comparable to automobile traffic (Chauvin & Saad, 2004): The actors make their own decisions. Perrow (1984/1999) noted that ships always have been the preeminently centralized human system of any size or complexity – they do not communicate with each other and are bound to follow a set of rules (in this case, regulations for the prevention of collisions at sea). Whenever they interact, their behavior shows that their actions conform to different interpretations of the formal regulations (different kinds of vessels maneuver at different distances, for example), but they also conform to local customs and practices that make up a set of informal rules based on economical concerns: The actors attempt to save external resources (in altering course to port, for example, to save time even if it is against regulations) or internal resources. The implementation of these different sets of rules (formal or informal ones) leads to different choices and maneuvers in situations presenting identical characteristics. The behavior of a vessel is therefore difficult to predict (Andro, Chauvin, & Le Bouar, 2003; Habberley & Taylor, 1989; Hinsch, 1996). This unpredictability is the cause of a number of collisions: One watch officer tries to predict the action of the other and misjudges the intention of the master of the other ship, causing the maneuvers of both vessels to be uncoordinated and opposite to the pursued goal (Morel, 2002).

Knowing the major determinants of the decision-making process seems essential to being able to predict a decision. In natural and dynamic work situations, a person's situation awareness (SA) appears to be the driving factor of this process (Endsley, 1997). SA is formally defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1995b, p. 36).

In this research, we followed two former studies of collision avoidance. The first studies (Chauvin, 2000, 2001), carried out in naturalistic settings, used activity observation and concurrent verbal protocols to analyze the decision-making process of experts aboard the vessels. They highlighted the elements of the environment that are relevant to making decisions (i.e., the SA of watch officers). The second study (Chauvin, Letirand, & Delhomme, 2007), conducted with trainees in a maritime school, aimed at explaining the action that the trainees chose after having examined a collision avoidance situation. That study showed the possible effects of subjective norms on behavior: Trainees who choose an action are significantly more likely than others to think that a master would approve this choice and would perform this action, whether or not the choice follows a formal rule. In this study, elements of the situation did not seem to be the main determinant of the decision making.

To examine this result thoroughly, in this article, we focus more specifically on the SA of trainees. After a period of 1 year at sea, these trainees returned to the academy to build on their experience. The present study was designed to determine the impact of SA and individual strategies on the decision that young officers make in an interaction situation on a simulated ship bridge.

Theoretical and Methodological Framework

In complex, dynamic environments, many factors determine the decision-making process. To understand a decision, one must not only know the objectives of the people involved but also analyze their representations of the given situation.

The Situation Awareness Model

The SA model, designed by Endsley (1995b), takes into account the representation of an external situation as well as the aims and objectives of the individuals involved. SA has three levels. Based on the elements of the environment, it also includes the results of information processing and a projection of the possible state of the environment. It is a process that basically consists of correlating the characteristics of the current situation with memory-stored "patterns" representing prototypical situations. Endsley (1997) named these patterns *mental models*; they provide default information that may be used by individuals to predict system performance despite incomplete or uncertain information. Lipshitz and Ben Shaul (1997) reserved the term *mental models* to specific situation representations and labeled *schemata* the general cognitive structures that drive the construction of specific situation representations. In this article, the Lipshitz and Ben Shaul concept of schemata and the term *situation awareness* are used to refer to representation construction in a specific context.

In naturalistic decision making, experts are able to make quick and satisfactory decisions because they match the environmental features to a generic situation; pattern matching or simple matching represents the case in which a decision maker identifies a situation: "The goals are obvious, the critical cues are being attended to, expectations about future states are formed and a typical course of action is recognized" (Klein, 1997, p. 285).

Different SA measurement techniques exist (Endsley, 1995a; Pew, 2000; Salmon, Stanton, Walker, & Green, 2006): performance measurements, process indices (eye tracker), subjective techniques (self-rating techniques and observer rating techniques), freeze probe techniques, and real-time probe techniques. Each technique must be assessed for its reliability and validity. Endsley (1995a) reported that it is necessary to establish that the metric (a) measures SA and does not reflect other processes, (b) possesses the required level of sensitivity (the technique must be able to detect changes in SA caused by interface design or training programs), and (c) does not alter SA. According to Endsley, only the freeze probe techniques meet these criteria. These techniques consist of suspending the simulation while the operator quickly answers questions about his or her current understanding of the situation. These techniques are the most commonly used and have demonstrated their reliability and validity.

Salmon et al. (2006) mentioned, however, that they present several disadvantages: They require expensive simulators, need a substantial amount of work to develop appropriate queries, and are intrusive to the primary task. Our research was carried out in a simulated environment using existing data about the task and the appropriate queries. The last piece of criticism is, therefore, the only one that could be taken into account. Intrusiveness is a recurrent criticism of the technique. To dispel these concerns, researchers have undertaken several studies (Endsley, 1995a, 2000) and have shown that in a simulation to collect SA data, freezes have no demonstrable effect on performance.

Among freeze techniques, the Situational Awareness Global Assessment Technique (SAGAT) was developed to assess all elements of SA (Endsley, 1995a). After being collected, the participants' perceptions are evaluated as correct or incorrect. This method makes it possible to check that the critical elements were in fact perceived and understood. It is useful in the design of interfaces because it enables the designer to evaluate the different modes of presentation of these elements. It can also prove useful in a training situation; a training program employing the SA concept would stress the recognition of critical elements, their meaning, and the identification of prototypical situations and may be evaluated as a result of SAGAT.

Situation Awareness and Handling a Vessel

Real settings were used for previous studies of collision avoidance (Chauvin, 2000, 2001). Analyses of this activity were performed from ecological data collected aboard two ferries during 19 voyages between France (Ouistreham harbor) and England (Portsmouth harbor) and aboard one ferry operating in the Dover Strait. The data recorded were behavioral data (actions on radar recorded with a video camera set in front of the radar screen), the maneuver features (angle of course alteration, distance from the other ship when the alteration is initiated, distance at closest point of approach [DCPA] at the time of maneuver, distance to the original route), and concurrent verbal protocols collected with the thinking-aloud technique. According to Pew (2000), such data are suited to preliminary research in order to establish measures and understand SA requirements. In that sense, these existing studies may represent the first step of the SA assessment.

The aforementioned prior studies led to the design and assessment of a model of collision avoidance activity. The model consists of three parts (Chauvin, 2001, 2003): static, dynamic, and functional. The static part of the model describes the contents of the mental representation of watch officers, including the structure and contents of their knowledge. The dynamic part of the model shows the different states in the reasoning of watch officers, as well as the automated radar plotting aid (ARPA) functions used in each state and event, which sets off the transformation from one state into another. The functional part of the model deals with information processing and, therefore, with the reasoning of watch officers. From the functional model presented in Figure 1, it is easy to identify the SA requirement of the collision avoidance activity.

The factors considered in vessel crossing are presented in Table 1 and mapped with SA levels. Figure 2 shows the ARPA radar interface. Bole and Dineley (1990) explained the functioning of the ARPA: When a target is acquired, the ARPA computer starts collecting data related to that target. The course and speed information

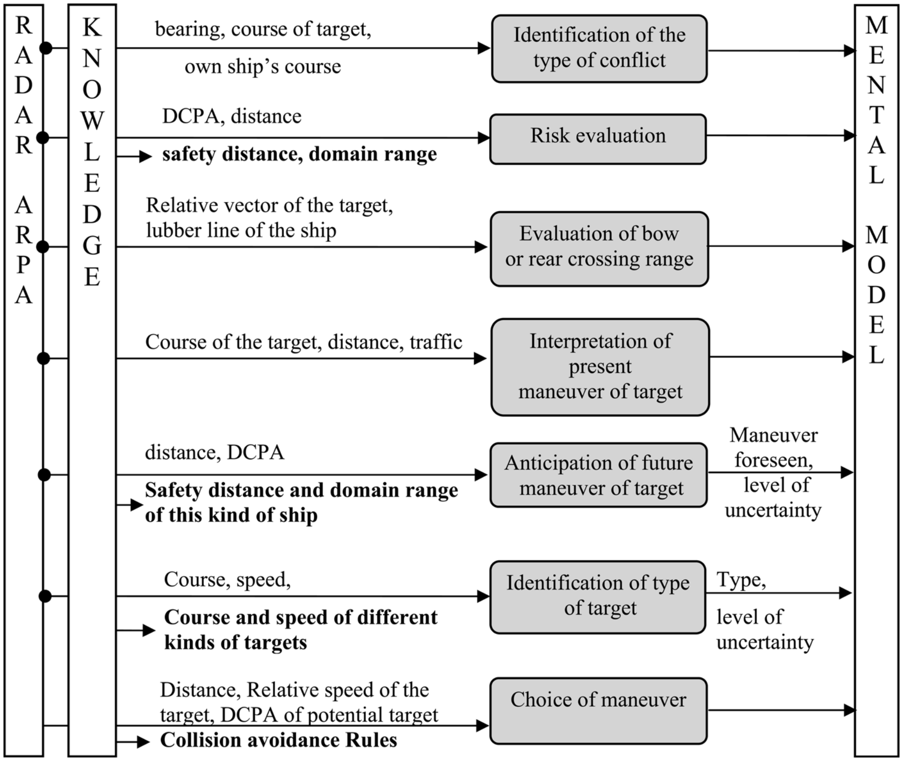

Figure 1. A functional model of the cognitive process involved in collision avoidance.

TABLE 1. A Classification of Factors Considered in Vessel Crossing According to the Three Situation Awareness (SA) Levels

Level 1 SA
Positions of echoes on radar screen
Target speed
Target course
Target bearing
Distance
Distance at closest point of approach (DCPA)
Level 2 SA
Type of situation (overtaking, head-on situation, and crossing situation)
Risk evaluation
Type of target (cargo ship, fishing vessel)
Level 3 SA
Bow or rear crossing range
Future maneuver of target

Figure 2. The ARPA radar interface (true vector presentation).

generated by the ARPA for acquired targets is displayed in vector form. Vectors indicate the rate and direction of the target's relative motion (relative vectors) or the rate and direction of the target's proper motion (true vector). At the request of the operator, the following information is available from the ARPA in alphanumeric form with regard to any tracked target: present range to the target, present bearing of the target, predicted target DCPA, predicted time to CPA (TCPA), calculated true course of target, and calculated true speed of target. Information that is available from the ARPA radar in alphanumeric form is considered Level 1 SA. Elements that are the results of identification or evaluation processes are classified as Level 2 SA. Elements that are the results of a projection process are classified as Level 3 SA.

In collision avoidance, decision making consists of choosing the side to which the course is to be changed (port or starboard), the distance at which this maneuver will take place, and its amplitude. It relies on the Collision Avoidance Rules (Her Majesty's Stationery Office [HMSO], 1972), which distinguish different kinds of situations (overtaking, head-on situation, and crossing). In a crossing situation, the Collision Avoidance Rules require a vessel that has another vessel on its starboard side to keep out of the way and to avoid crossing ahead of the other vessel (not altering course to port).

A crossing situation is cognitive costly for the watch officer who is aboard the stand-on vessel, which is supposed to keep its course and speed; the watch officer also must interpret the intentions and actions of the vessel that is supposed to give way. In these situations, a significant increase in workload can be observed (Hockey, Healey, Crawshaw, Wastell, & Sauer, 2003). The watch officer may decide to keep his course and speed in compliance with the formal rule or to take action. This action may consist of altering course to port or to starboard.

Former studies point out the cues (or elements of the situation) used to make the decision: Fishing vessels and some cargo ships (particularly small ones, identifiable by their slow speed) are assumed not to abide by the rules, and therefore their speed may prompt the other vessel to take action. The relative speed of the target vessel and the perception of the bow or rear crossing range (if no action is performed, then the target ship will cross ahead or astern one's own ship) are essential cues in determining the direction of the course alteration, as well as the distance evaluation (altering course to port does not conform to the formal rule except if this action is performed early enough that one may consider that the rule does not apply).

Other Determinants of Decision Making

SA cannot account entirely for the decisions made by any individual. Rasmussen (1997) showed that in the performance of any task, there is always a margin of freedom that allows operators to choose among different strategies. He expressed variations between individuals in terms of preferences, which he defined as the space within which operators can navigate freely, according to their individual resources and their subjective performance criteria, while fulfilling the requirements of the task. According to Valot, Grau, and Amalberti (1993), the operators integrate a great deal of personal cognitive processing data to define their activity's precision, efficiency, and cost, adapting dynamically to the requirements and the context.

In collision avoidance, a number of strategies can be observed. When several courses of action are available, watch officers may choose either the action that is in compliance with the formal rule or the most economical one (the one requiring the smallest course alteration). When they are aboard the stand-on vessel, they may decide to alter their course very early, in which case they no longer depend on the other's action and, therefore, master the situation.

The study presented here was carried out in a training situation. Its purpose was to study SA as elaborated by trainees who were confronted with a simulated collision threat: a crossing situation in which the participants were aboard the stand-on vessel. In this situation, there were several possible actions, depending on which schema were activated by the trainees. The objective of the study was to determine the impact of (a) SA content and (b) individual strategies in this decision-making situation.

Method

The experiment took place in a French Merchant Marine Academy with a group of fifth-year trainees who were chosen for their navigation experience. The experiment was conducted on ship-handling navigation simulator facilities. Three types of data were collected: answers to an SA questionnaire, answers to a questionnaire about the trainees' strategies, and performance (direction and amplitude of the change of course, distance between the two vessels when the maneuver was performed).

Participants

The participants in the experiment were 90 officers-in-training returning to a Merchant Marine Academy for their fifth and final year of study. Their navigation experience corresponded to that of a fourth-year trainee: 6 months at sea as a cadet, followed by 8 months as an officer. However, some members of the group had more experience, whereas others had moved up through the professional route, starting as seamen and obtaining their different certificates over the years.

The average age in this group was 28 years, with a standard deviation of 4.41. There were 81 men and 9 women. The experiment took place at the end of a training period and was carried out over 6 months, from October 2005 to April 2006, because there was a maximum limit of 16 trainees at a time and the simulations took place only once a month.

Tools Used

The experiment was conducted by using the Merchant Marine Academy ship-handling navigation simulator facilities, which are equipped with four bridge simulators (bridge or wheelhouse, the command post from which a vessel is steered).

Each simulator reproduces the bridge layout of a modern vessel. It provides users with a simulated field of vision and with the ship controls that are found aboard a real-world vessel. In addition to the engine and steering controls, the simulated instruments include, among others, radar and ARPA; surface and bottom speed indicators; a gyroscopic compass indicating the vessel's course; an automatic pilot; a sounder; and a GPS giving the vessel's position, course, and speed. The information relayed by these devices is available in basic form on the screens of each piece of equipment and is also reproduced and processed on two main screens: the radar screen and the information screen. (A third screen, the Electronic Chart Display and Information System, was not available here.) The processing makes it possible to display the data in several ways, according to circumstances and the operators' preferences.

This equipment allows four officers to undergo the test simultaneously, as if each was on his or her own bridge. All the participants handled the same vessel, a ferry, in the same interaction situation.

Experimental Protocol

The experiment lasted 43 min and was broken down into six phases, described in Table 2. Because the situation evolves slowly, the simulation was frozen only once.

TABLE 2. Phases of the Experiment

Phase	Duration	Place	Content	Data Collected
Phase 1	10 min	Briefing room	Presentation of the experiment	None
Phase 2	5 min	Simulated ship bridge	The situation is static. Participant discovers its features.	None
Phase 3	5 min	Simulated ship bridge	The situation evolves in a dynamic way. Participant handles the vessel.	Actions performed (changes of course or speed)
Phase 4	10 min	Simulated ship bridge	The situation is frozen. The situation awareness (SA) questionnaire is handed out to the participant.	Answers to the SA questionnaire
Phase 5	8 min	Simulated ship bridge	The situation evolves in a dynamic way. Participant handles the vessel.	Actions performed (changes of course or speed)
Phase 6	5 min	Simulated ship bridge	The simulation is stopped.	The participant fills out a final questionnaire focusing on the reasons for his or her choices.

Experimental Situation

The experimental situation was derived from a situation that was actually observed in the Dover Strait area aboard a ferry, on the Calais–Dover crossing, at the point where it intersects the vessel traffic crossing the strait in a northeastern direction.

The officer of the watch (OOW) sights to port a group of two cargo vessels, one of which poses a collision threat. In this situation, Rule 15 of the Collision Avoidance Rules, usually referred to as COLREG (Convention on the International Regulations for Preventing Collisions at Sea, or COLlision REGulations), states the following: "When two power-driven vessels are crossing so as to involve a risk of collision, the vessel which has the other one on her own starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel" (Cockcroft & Lameijer, 1996, p. 101). (The French regulations [Hollard, 1988] imperfectly translate *shall* as *must,* which implies that an external constraint is obeyed, whereas *shall* points to acceptance of a future outcome made certain by the pilot's own will.)

The ferry is then in a "stand-on" situation. Her OOW can expect the cargo vessel to maneuver so as to cross behind it. Moreover, the ferry is bound by another COLREG rule, Rule 17 on the "Action of the Stand-on Vessel" (Cockcroft & Lameijer, 1996):

a. i) Where one of the two vessels is to keep out of the way, the other vessel shall keep her course and speed.

ii) The latter vessel may however take action to avoid collision by her action alone, as soon as it becomes apparent to her that the vessel required to keep out of the way is not taking appropriate action in compliance with these rules.

b. When, from any cause, the vessel required to keep her course and speed finds herself so close that collision cannot be avoided by the action of the give-way vessel alone, she shall take such action as will best aid to avoid collision.

c. A power-driven vessel which takes action in a crossing situation in accordance with sub-paragraph A ii) of this rule to avoid collision with another power-driven vessel shall, if the circumstances of the case admit, not alter course to port for a vessel on her own port side.

d. This rule does not relieve the give-way vessel of her obligation to keep out of the way.

At the point where the situation is frozen (Phase 4), the participants see three vessels sailing in their own vessel's environment (see Figure 3). Two of these vessels are cargo ships. Cargo 2 is at 8 knots, its course is 44 deg, it is at a distance of 3.4 nautical miles (nm, a measure of distance used at sea, equal to 1,853 m), and its DCPA is 0.7 nm. Cargo 9, the most dangerous, is at 9.5 knots and heading 45 deg. Its distance is 3.7 nm, and its DCPA is 0.2 nm. On the bow of the participants' vessel, about a mile away, another ferry also crossing to England is in the process of easing its course to starboard to cross ahead of the two cargo vessels. The vessel aboard which the participant is OOW is at 18 knots and heading 295 deg.

According to the regulations and to limits given by experts, two courses of action are possible. The first (a in Figure 3) is to keep course and speed until it is obvious that Cargo 9 will not take action. In this case, an alteration of course to starboard is required. In fact, an alteration of course to port could be dangerous because it would not coordinate with a possible alteration of course of the give-way vessel. The second course (b in Figure 3) is to take action very early, at such a distance that it is possible to consider that the rule does not yet apply and that both vessels are free to take any action (in the Dover Strait, 3 nm seems to be an agreed limit).

The Multiple-Choice Questionnaires

Two questionnaires were used: a questionnaire on SA designed on the SAGAT model and one dealing with the trainees' strategies. Each relied on explanations given by experts (among them, the ferry master involved in the reference situation), observation of their activity, and the collection of verbal protocols.

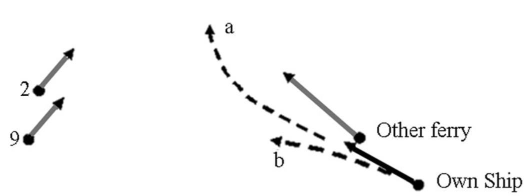

Figure 3. Experimental situation.

TABLE 3. Questions Asked on the Three Situation Awareness (SA) Levels and on the Action Planned

	Questions Asked
Level 1 SA	1. What is the target course?
	2. What is the target speed?
	3. What is the range to the target?
	4. What is the DCPA of the target?
Level 2 SA	5. Does it seem to go far faster than your vessel?
	6. Does it seem to go far slower than your vessel?
	7. Does it seem to be “far away” from you?
	8. Is this vessel “dangerous” for you?
	9. Is it hindering you?
	10. What is, according to you, the most dangerous target?
	11. According to you, this vessel maneuvers (with difficulty/normally/easily/you don’t know)?
	12. This situation seems, for you, to be very dangerous/dangerous/little dangerous/very little dangerous.
Level 3 SA	13. If no action is performed, this target will cross (ahead your vessel/astern your vessel/so close that collision is certain)?
	14. According to you, it is highly probable/probable/little probable/very little probable that it will take action.
Action planned	15. According to you, your vessel shall take action/shall keep her course/you are free to choose because you are still far away from the targets.
	16. You decide to keep your course/to alter your course.

Multiple-choice questionnaire on the trainee’s SA. This questionnaire was filled out by the participants while the simulation was frozen. The questions addressed all three levels of SA. First, the participant was asked to place all the vessels he or she observed before the situation was frozen on a schema representing a radar screen. Then the participant had to answer, for each vessel he or she identified, the questions listed in Table 3. From Number 10 on, questions dealt only with the most dangerous target.

SA Level 1 questions concerned information that could be read on the ARPA radar displays. Answers could therefore be assessed as correct or incorrect. SA Levels 2 and 3 questions were on the evaluation, interpretation, or projection made by trainees. Two of these questions could be assessed: one on the main target’s relative speed and one about the type of crossing range (bow or rear crossing range). The answers given to other questions remained subjective.

The last questions dealt with interpreting the regulation made in this situation and the action planned when the simulation was frozen.

Questionnaire on strategies. The first 15 participants did not fill out this questionnaire because it was available only from the second session of the experiment. First, the participants were asked to indicate which action had been taken (alteration of course to port or to starboard). Then the participants indicated the reason they chose this option; five possible answers were proposed:

1. It is more in compliance with the regulations.
2. It is more similar to common practice.

3. It is easier to perform than the other one (it requires less attention).
4. It is safer than the other one (doubt is quickly removed).
5. Other rationale

Expected Relationships Among Actions, SA Content, and Individual Strategies

In the situation submitted to the trainees, two different courses of action were possible, and two different schemata could have been used: If the regulations were strictly followed, trainees would change course to starboard as soon as they felt sure the target vessel was not going to move aside (closer than 3 nm). The SA elements used to activate this reaction were the distance of the target vessel (Level 1) and the interpretation of the other captain's intentions (Level 3). Following the rule in this situation would be costly from a cognitive point of view and would required good SA from participants, who had to correctly perceive the DCPA, the bow crossing range, and the relative speed of the target vessel.

Participants obeying common practice would choose to change course to port very early (before the regulations apply). Once again, the distance of the target vessel was an important factor in the distance interpretation of "she is far enough," as is the officer's reading of the "crossing point." In this situation, Cargo 9 would pass – if no maneuver was performed – ahead of the ferry. Consequently, coming to port enabled the ferry to cross astern of the target vessel, an action that was perceived as being safer than altering course to starboard. Moreover, this maneuver was the most economical one: A small change of course is enough to avoid the risk and loses less time.

Results

Ninety trainees took part in the experiment, and 71 protocols were usable. There were several reasons that the remaining protocols were set aside: 5 trainees did not properly fill out the questionnaire, and 14 did not correctly identify the dangerous target (they mistook the target or did not identify the collision threat). For 11 of these 14 protocols, error in identifying the dangerous target was caused by a very early maneuver that significantly changed the features of the situation.

The Decision Actually Made

The decision made related to the direction of the maneuver (change course to starboard or port) and to the distance at which the maneuver was to be performed. Of the trainees, 47 chose to change course to port and 21 to starboard, and 3 did not change course. The trainees maneuvered at an average distance of 2.86 nm (SD = 1.13). Distance was less important when course was altered to port than to starboard (2.88 nm, SD = 1.01 to be compared with an average distance of 3.24 nm in case of a course alteration to starboard, SD = 0.85). Given the limits stated by experts, responses concerning the distance of action have been classified into two classes: more or less than 3 nm (see Table 4).

TABLE 4. Trainee Distribution According to the Main Features of Action (Distance and Direction)

	Distance $<$ 3 nm	Distance $\geq$ 3 nm	Total
Port	24	23	47
Starboard	6	15	21
Nothing	3		3
Total	33	38	71

Five different profiles of the participants emerged: 32% of participants altered course to port very early at a distance that allowed them to consider that the rule did not yet apply; 9% altered course to starboard when it seemed obvious that the target vessel would not take action; 21% altered course to starboard very early, which was not expected; 34% altered course to port at less than 3 nm, which was not expected either; and 4% took no action.

Direct Determinants of Decision Making

Analysis of variance (ANOVA), using the Type III (marginal) sums of squares test shows that the distance of action is logically determined by the interpretation of regulations, $F(2, 68) = 5.04$, $p < .01$. Those who felt they had to change course did so at an average distance of 3.30 nm ($SD = 0.21$), those who felt they were still free to act maneuvered at an average distance of 2.98 nm ($SD = 0.24$), and those who believed they had to stand on maneuvered at an average distance of 2.36 nm ($SD = 0.21$).

The distance of action is also determined by the projected action, $F(1, 67) = 37.57$, $p < .001$. Those who intended to "change course now" while the scene was frozen changed course at an average distance of 3.37 nm ($SD = 0.14$), whereas those who answered that they would not change course did so at an average distance of 1.93 nm ($SD = 0.19$).

The amplitude of the course alteration depended on two variables:

- The direction chosen, $F(1, 66) = 65.13$, $p < .001$. Maneuvers to port show an average amplitude of 17 deg ($SD = 1.23$), whereas maneuvers to starboard show an average amplitude of 35 deg ($SD = 1.84$). This result logically stems from the geometrical features of the situation chosen for the experiment.
- The way in which the trainee perceived the target vessel, Cargo 2, $F(1, 65) = 4.79$, $p < .05$. Those who answered that it was "dangerous" gave a wider berth (safety space) between two ships (the adjusted average is equal to 24 deg, $SD = 2.06$) than did those who answered that it was "not dangerous" (the adjusted average is equal to 18 deg, $SD = 1.80$). Nevertheless, the confidence intervals overlap slightly. The differences in the adjusted averages, though significant, are not as high as for the modalities indicating the direction chosen.

TABLE 5. Crossing Table for the Modalities of the Intended Action and Rules Interpretation Variables

Rules Interpretation	Intended Action		
	Stand On	Change Course	Total
I must stand on	13	11	24
I must change course	0	25	25
I am free to choose	10	10	20
Total	23	46	69

The ANOVA results show that the interpretation of the rule and the intended action constitute the main pivotal variables in the decision-making process. These two variables are highly linked, χ^2 (2, 69) $= 19.68$, $p < .001$.

It is, however, interesting to examine the crossing table for both variable modalities (see Table 5) more thoroughly. In Table 5, *N* is equal to 69 because the 2 participants who did not answer the question concerning their intended action were not taken into account. We noted that the participants who felt they had to change course all decided to do so, but those who felt they had to stand on could also decide to alter course (this is true for 46% of them!). This table can therefore be read as a logical table: If P (I must change course), then Q (I change course), but in case of negation of the antecedent (non-P: I must not change course), nothing can be concluded (the Modus Tollens applies).

Decision and Situation Awareness

Various multiple correspondence analyses and chi-square calculations were performed to examine the links between the variables expressing the three levels of situation awareness and the action performed (direction in which the course was changed and distance at which the maneuver was performed).

Level 1 SA. The answers for Level 1 SA questions were often wrong. This is somewhat surprising because the answers were available on the radar interface. As far as the most dangerous cargo vessel was concerned (Cargo 9), 41% of participants were mistaken in giving this vessel's course (the course of the target vessel was 45 deg; any answer between 35 and 55 deg was considered correct, and tolerance values were determined to take into account the situation dynamics and the fact that values may have been memorized before the freeze). Only 35% of participants correctly memorized how far away the vessel was (3.7 nm; values between 3 and 4 nm were considered correct). Of the participants, 31% did not answer this question, 23% overestimated the distance, and 11% underestimated it. Only 20% of participants correctly noted the cargo speed. (The correct value was 9.5 knots, give or take 0.5 knots.) Finally, the DCPA was correctly given by 56% of trainees (as being lower than 0.5 nm); 24% did not answer this question, and 20% gave a wrong answer.

No direct link appears between Level 1 (perceived data) and the action performed (see Table 6). On the other hand, several links appear between Level 1 and Level 2 factors:

TABLE 6. Relationship Between the Factors of Level 1 Situation Awareness (SA) and the Characteristics of the Action

Characteristics of Action Level 1 SA	Distance of Action	Amplitude of Course Alteration
Course	$F(1, 69) = .13021, p > .7$	$F(1, 69) = .15253, p > .6$
Distance	$F(1, 69) = 1.1252, p > .2$	$F(1, 69) = 1.3613, p > .2$
Speed	$F(1, 69) = .02018, p > .8$	$F(1, 69) = .037525, p > .5$
Distance at closest point of approach (DCPA)	$F(1, 69) = 2.6163, p > .1$	$F(1, 69) = .00392, p > .9$

- Between the cargo speed value and the evaluation of its relative speed, χ^2 (2, 71) = 9.27, $p < .01$.
- Between the distance value (data that are perceived, Level 1 SA) and the distance evaluation (Level 2 SA), χ^2 (2, 71) = 7.32, $p < .05$. Those who had an inaccurate perception of the distance value were more likely to think the cargo was still far away.
- Between the DCPA and the way in which the trainee perceived the target vessel (dangerous or not), χ^2 (2, 71) = 16.98, $p < .001$. Those who had an accurate perception of the DCPA value were more likely to think the cargo was dangerous.

Levels 2 and 3 SA. Most Level 2 and Level 3 SA questions required subjective answers that could not be assessed, except questions related to the cargo ship's relative speed and the type of crossing range. Only 43% of participants correctly estimated the ship's relative speed (as being less than their own). Of the trainees, 20% did not answer this question, and 37% estimated that it was not slower than that of their vessel or even that it was faster. In addition, 92% of participants correctly estimated the type of crossing range, responding that the cargo ship would cross ahead (34% of answers) or that the crossing range was so low that the risk of collision was certain (58% of answers).

Factors related to SA Level 2 or 3 do not have a direct link with performance, but some of them have a strong link with the interpretation of the rules and with the intention of action. There is a relationship between the interpretation of the other vessel's intentions and the interpretation of the rules, χ^2 (2, 61) = 6.50, $p < .05$. Of those who answered that they must change their course, 75% thought the target would not change its course, whereas 65% of those who answered that they were free to choose thought the target would probably change its course. Half of those who answered that they must stand on believed that the target would probably change its course (see Table 7). In this calculation, N is equal to 61 because the 10 participants who did not answer the question concerning the intentions of the cargo ship were not taken into account.

There is also a relationship between the interpretation of the other vessel's intentions and the trainee's decision to act, χ^2 (1, 61) = 7.33, $p < .01$. Of those who were going to stand, 71% thought the target would probably change its

TABLE 7. Crossing Table for the Modalities of the Target Intention and Rules Interpretation Variables

Will 9 Change Course?	Rules Interpretation			
	I Must Stand On	I Must Change Course	I Am Free to Choose	Total
Probably not, very probably not	11	15	6	32
Probably, very probably	13	5	11	29
Total	24	20	17	61

TABLE 8. Crossing Table Between the Modalities of the Intended Action and Target Intention Variables

Will 9 Change Course?	Intended Action		
	Stand On	Change Course	Total
Probably not, very probably not	6	26	32
Probably, very probably	15	14	29
Total	21	40	61

course, whereas 65% of those who were going to change their course believed that the ship would probably keep its course. In Table 8, N is equal to 61 because the 10 participants who did not answer the question concerning cargo ship intentions were not taken into account.

Interpretation of the rules is also linked to evaluation of the risk, χ^2 (2, 71) = 9.26, $p < .01$. Of the trainees, 75% who believed they must change their course and 90% of those who thought they were free to choose evaluated the situation as not being very dangerous, whereas half of those who believed they must stand on evaluated the situation as dangerous. Thus, the ones who took the boldest actions felt the lowest amount of risk. This result is all the more interesting because it may be seen as counterintuitive.

Decision and "Strategies"

The questions relating to the strategies asked trainees to choose between the following reasons: Their maneuver was chosen because it followed regulations, followed common practice, was easier to perform, and eliminated feelings of doubt.

ANOVA showed no significant relationship between trainee strategies and their performance (namely, the distance at which they performed a maneuver). On the other hand, multiple correspondence analysis (MCA) bearing on the answers to the two questionnaires and on the characteristics of the selected maneuver showed links among SA, strategies, and the action performed. MCA is an extension of correspondence analysis that allows one to analyze the pattern of relationships of several categorical dependent variables (Burt, 1950).

A crosscheck of the answers on SA Levels 2 and 3, with the justifications given and the characteristics of the selected maneuver presented, highlighted three interesting contrasts between the trainees.

If Axis 1 (representing 18.06% of inertia) brings in no data (as it represents a gradient of nonanswers), then Axis 2, representing 11.26% of inertia, opposes individuals who answered that it was rather probable or very probable that the cargo vessel would change its course and that they themselves must stand on, choose to keep their course, and eventually come to starboard. They justified this decision by referring to the rules. On the other hand, some felt that it was not very probable that the target vessel would change course, and they believed that they must maneuver themselves and come to port. They justified their decision by a desire to get rid of a feeling of doubt.

Axis 3, which represents 9.04% of inertia, opposes trainees who answered that they had to stand on, decided not to change course, came to port, and did not mention the rules, as well as trainees who answered that they must change course, chose to change course, decided to come to starboard, and justified their decision by mentioning the rules.

Axis 4 (7.15% of inertia) separates trainees according to their appreciation of distance and of the dangerous nature of the situation. On the positive side, it opposes trainees who judged that the other vessel was still far away, that it was rather or very probable that it would change course, and that the situation was not very dangerous. These trainees felt free to choose, decided not to change course, and justified their decisions by referring to the rules. On the negative side, Axis 4 opposes trainees who judged that the cargo vessel was not far away and that the situation was dangerous. These trainees did not state an intention of action and did not mention the rules.

Discussion

These results call for a two-point discussion. One point relates to the role of SA in the decision-making process, and the other relates to an explanation of the different trainee profiles. One major finding underlined by the experiment relates to the wrong perception of useful information (Level 1 of SA). This first level was either not fully filled out or incorrectly filled out. Only 35% of the participants correctly gave the distance, and only 20% correctly gave the cargo speed; however, experts whom we observed aboard ferries considered these data as critical situation features.

Moreover, this level does not provide any information that could explain the trainees' decisions. It would seem that a superficial summary of the situation, made up of visual information gathered from the environment (noting the presence of the target vessel, observation of a collision threat), is sufficient to activate an action pattern: a following-the-rules pattern or a following-common-practice pattern observed aboard vessels during the fourth year of training. This relatively wrong perception of the information elements suggests several possible causes:

1. *There is insufficient proficiency on the trainees' part (most of them have only limited navigation experience) to grasp the relevant information from their environment.*

2. *The trainee was prone to abstraction, which was not accurate.*

Not filling out SA Level 1 could also suggest that it was enough for some trainees, at this point, to identify the interaction situation as belonging to a generic situation – "vessel in view on the port bow, closing in" – to trigger SA Levels 2 and 3. However, accurate abstraction, in the sense of reaching a functional level of analysis, does not mean ignoring the details but dropping the nonrelevant ones.

3. *The trainee's attention was focused more on the vectorial information displayed by the radar screen than on the alphanumerical data.* The ARPA can display a *true vector,* the direction and length of which represent the actual course and speed of the target vessel; and also a *relative vector,* the direction and length of which represent the relative progress of the target vessel in relation to the carrying vessel. This last vector in particular visually gives crucial information: By looking at the relative vector, the operators immediately know at what distance the target vessel will cross the course of their own vessel. This information, along with their "feeling" of the distance (near or far), can activate a pattern of successive choices: (a) the situation is stable and nothing is going to happen, or (b) the situation calls for a change of course by at least one of the vessels involved. This is followed by a reference to regulations: "I must change course" or "I must stand on."

4. *There was an error in timing when giving the questionnaire*. For some of the trainees who decided not to change course, the questionnaire may have been given too early, before they had grasped all the necessary information. At this point, however, there is nothing to show that they would not have done so a little later.

The other major result relates to Level 2 of SA and involves the importance of interpreting the rule. This variable seems pivotal in the choice of the intended action (change course early or maintain course and speed). It is correlated with the interpretation of the other vessel's intentions but also with an evaluation of the risk. This relationship can be read in two ways: Either the interpretation of the other vessel's intentions and the evaluation of the risk are the elements triggering action patterns, or the intended action will influence the perception of target intention. Expectations related to the intentions of the other vessel would come, in that case, from the actor (from his or her wishes) rather than from inferences about the behavior of the other vessel. When trainees do not change course, there is indecision when it comes to the other vessel's intentions, and it is mainly in this case that the situation is felt to be dangerous.

The third important result is the definition of four different main profiles among the trainees. An attempt must be made to explain these differences. The trainees differ as to the distance at which they change course and the direction of their maneuver. Two hypotheses were stated earlier: one regarding the trainees who chose to come to starboard once they felt certain that the other vessel would not change course (at less than 3 nm) and the other regarding trainees who chose to alter course to port very early on.

A few trainees (9%) chose to come to starboard at less than 3 nm. An analysis of the answers given in the SA multiple-choice questionnaire provides nothing that sets these trainees apart from the others as far as their perception or interpretation of information (in particular, the perception or interpretation of distance);

they are different, however, in that they thought it was rather probable or very probable that the other vessel would change course, and in that they justified their maneuver by referring to the rules. Some trainees (32%) chose to come to port at a distance equal to or greater than 3 nm. They stand out from the other trainees because they thought it unlikely that the cargo vessel would change course and because they justified their choice by a desire to “get rid of the element of doubt as early as possible.”

Two other profiles were unforeseen: those who altered course to starboard at a distance greater than 3 nm, and a large number who came to port at a distance smaller than 3 nm. Twenty-one percent of trainees changed course to starboard at a distance greater than 3 nm. Their answers to the SA multiple-choice questionnaire were not different from the typical answers of the trainees, except that they felt they had to change course. These trainees justified their decision by referring to the rules. They seemed to activate a very simplistic reaction pattern, which could be translated as follows: *This is a crossing situation; therefore, one of the two vessels must change course, and therefore I am altering course to starboard.* In this pattern, the reference to regulations is mistaken because the trainee should have invoked Rule 17(a)i, which states, “the latter vessel may however take action to avoid collision by her action alone, as soon as it becomes apparent to her that the vessel required to keep out of the way is not taking appropriate action in compliance with these Rules.” However, the trainee invoked Rule 17(a)ii, which is inappropriate in view of the relatively great distance that still separated the vessels. In this case, there seemed to be a desire to avoid in-depth abstraction and to keep to the most familiar solution – the one that statistically resolves the greatest number of interaction situations between vessels: a change of course to starboard.

Another group of trainees (34%) came to port at a late point in time. The questionnaire answers they provided do not explain their choice. In the previous profile, the action could be seen as a strategy – if a simplistic one – but this profile seems to have no defined logic leading to action. It also masks different patterns of actions because 13 trainees altered their course between 2 and 2.9 nm, 9 between 1 and 1.9 nm, and 2 at a distance smaller than 1 nm. There is no correlation between the action and the perceived elements (Level 1) or with a comprehension of the situation (Level 2). One can conclude that altering course to port at less than 3 nm may represent a “plagiarism-of-the-expert” pattern: The trainee had seen an officer perform this maneuver without grasping all the elements of the situation (particularly the element of distance). He or she then built up a tried-and-proven action pattern, “I have seen this done,” while lacking the key element: the distance. This decision might also represent a simple safety precaution to increase the DCPA slightly, irrespective of any other strategy and without any reference to regulations.

The 21% who invoked Rule 17(a)ii instead of Rule 17(a)i were just showing excessive caution and inefficient overreaction. However, the 34% who came to port late were moving into a much more dangerous zone. The issue here is not simply violating a rule but being unaware of the rationale for the rule and the types of risks incurred.

This study is obviously incomplete because it was not possible to question the trainees several times on their SA. It does, however, point out the importance, in the analysis of a situation and the decision-making process, of the interpretation of the rules, the interpretation of the other vessel's intentions, and the evaluation of an external risk. It also clearly highlights the large number of trainees who chose a maneuver that was against regulations or that was even dangerous. It also shows that there is a weak link between Level 1 SA and trainee decision making. This should lead to the proposal of new training tools that are aimed at confronting trainees with a situation that involves uncertainty and that requires that they consider important cues.

Conclusion

This experiment raises a general question – the part played by SA in decision making for a young professional in a learning situation.

The data gathered from the trainees do not enable us to identify consistent cue patterns expressing the different representations of the situation that would explain the differences observed between the various decisions made by the trainees. In this way, the trainees' answers are very different from experts' protocol, which seized on important cues and included both comprehension of the situation and an action strategy. This result had been observed by researchers studying the difference in the decision-making process between experts and novices in natural situations – specifically, in the analyses made by Lipshitz and Ben Shaul (1997) and by Fowlkes, Salas, Baker, Cannon-Bowers, and Stout (2000). These authors showed that experts collect more data than novices on a greater variety of aspects of the situation, and that they less frequently make the wrong decision. The researchers explain this by the fact that experts have access to schemata that enable them to build precise mental models of a situation and to make satisfactory decisions. In the same way, Endsley (1997) noted that an expert (a person having a sufficiently broad foundation of knowledge) can, when making a decision, adopt a "holistic" style, whereas a beginner will most often adopt an analytical style based on formal rules.

Clearly, these results could be applied to training situations. Cannon-Bowers and Bell (1997) noted that trainees can acquire expertise through exercises that must allow them to define cue patterns and build schemata to which they can associate relevant answers.

Following the approach developed by Pliske, McCloskey, and Klein (2001), it seems to be worthwhile to introduce new training tools in maritime training, such as decision-making games. These exercises are defined as low-fidelity simulations of situations that might occur in the field. Participants are presented with a dilemma in which a decision must be made. They are given a few minutes to determine their course of action. Then a debriefing is proposed to explore important cues that might have been seen, assessments that were mistaken, the type of uncertainties encountered, and how they were handled.

We are now conducting a new study to evaluate this training approach, relying not only on the rules but also on the situation features.

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