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RESEARCH ARTICLE

A Prefatory Study on the Effects of Alcohol on Ship Manoeuvring, Navigational and Decision-Making Abilities of Navigators

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Abstract
Adverse effects of intoxicated driving have been well documented over the years, with clear conclusions. In addition, it is evident that the cognitive and neurological functions and reaction times deteriorate with the consumption of alcohol. Addressing the lack of literature on the subject, this paper focuses on studying the effects of alcohol on manoeuvring, navigational and decision-making ability in ship navigation. Ten participants – five cadets and five experienced navigation officers – volunteered and carried out a standard manoeuvre using a computer-controlled vessel simulator, under three different blood alcohol concentrations (0·00%, 0·05% and 0·08% BAC). Results from the simulations were used to assess the performance and the decision-making ability of participants under the influence of alcohol. In addition, the responses and behaviour of the simulated vessel when the navigators were intoxicated were analysed. Workload experienced by participants during the simulations were also assessed using the NASA Task Load Index. Findings of this preliminary study proved that the ability to make the correct decisions at the right time was drastically deteriorated when the blood alcohol concentration was increased.

1. Introduction

Unregulated alcohol consumption has long been one of the most serious concerns across several fields, such as public health and transportation. In terms of transportation, several approaches have been followed over the years to limit the severity and frequency of traffic violations and accidents caused under the influence of alcohol: however, with minimal success (Armstrong and Howell, 1988). With the aid of epidemiological and experimental studies, both scientists and law enforcement agencies have contributed to enforcing blood alcohol concentration (BAC) limits required for driving as well as operating machinery. However, the adverse influence of alcohol and unregulated alcohol consumption remain dominant reasons behind the increased rates of traffic accidents and related mortality rates (Evans, 1991; Baker et al., 1992). Studies have shown that alcohol consumption at moderate doses significantly affects neurological and cognitive functions, which are vital in driving performances (Mitchell, 1985; Moskowitz and Robinson, 1987; Holloway, 1995). Moreover, it should be noted that there still can be negative impacts on driving performance, even when the BAC levels reach zero after consumption (Morrow et al., 1990; Bates, 2002). Effects of alcohol on driving in both on land and in airspaces have been well documented over the years, with clear conclusions (Lacefield et al., 1975; Finnigan and Hammersley, 1992). However, literature on the effect of alcohol on ship manoeuvring and

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operations is limited. Moreover, there is a lack of regulatory standards for ship simulations as opposed to, for example, aviation and driving simulations (National Research Council, 1996).

Alcohol consumption undoubtedly affects occupational safety, and this can be more dangerous at sea. Environmental stress, as well as human elements, are identified as dominant factors which contribute to accidents at sea (Sampson and Thomas, 2003; Hetherington et al., 2006). Poor or outdated navigational equipment, operational errors and faults in decision making as well as the fatigue experienced by seafarers have been identified as the aforementioned human elements. Among them, human fatigue can be a major concern, since most other factors are being rectified through legislations, research and implementations. When seafaring is considered, fatigue demands additional attention since numerous factors, such as tight work schedules, boarding conditions and lack of sleep and rest, can cause fatigue more than it would in other occupations. Within the maritime domain, seafarers are exposed to alcohol dependency more than are people in other professions, given that they experience more stress due to isolation and extreme work hours (Nitka, 1990). As a result, unregulated alcohol consumption as well as drug abuse have been identified as rising concerns among seafarers (O'Connor and O'Connor, 2005). Navigating a vessel – while rectifying all possible control problems – is the responsibility of navigators (Hansen and Clemmensen, 1993), and this demands unhindered cognitive functions, as it does in general in similar domains and systems such as aircraft cockpits and nuclear plants (Hollnagel, 1996; Mosneron-Dupin et al., 1997). Alcohol can be considered a perilous factor in navigation, since it adversely affects visual functions, as well as motor skills and psychological reactions, which are imperative in ship operations (Grütters et al., 2003).

Based on the aforementioned literature, this study focuses on assessing the effects of alcohol on ship-manoeuvring abilities, as a prefatory study. Since the effects of alcohol exposure on ship manoeuvring have not been sufficiently documented in previous literature, a preliminary experiment was conducted to study the changes of navigational capabilities of ship officers under different levels of blood alcohol concentrations. An experimental simulation-based approach was followed since it eliminates the risks of injury as well as property damage. For the study, 10 participants with navigational experience volunteered. Five of them were cadets and the other five were experienced navigation officers. They were requested to carry out a manoeuvring simulation along a standard course under different levels of BACs. In order to reach desired BAC levels, a strict dosing schedule with an absorption period of 20 min was followed. Previous studies have shown that this would ensure participants reaching the peak of BAC during the simulations (Fillmore and Vogel-Sprott, 1996; Friel et al., 1999; Liguori et al., 1999). The decision-making ability of navigators under different BAC levels was also measured, and the results of those decisions were assessed considering the responses of the vessel in simulations. Participants were grouped as officers and cadets based on their experience. The effects of alcohol on both of these groups were assessed during the study. In addition, the study focused on assessing the subjective workloads experienced by the participants. The standard version of the NASA Task Load Index (NASA-TLX) was used as a tool. Based on this approach, mental demand, physical demand, temporal demand, performance, effort and frustration experienced during the manoeuvring task were assessed. The study was also designed to determine whether or not the navigational experience would play a role with the effects of alcohol during an operation. The first section of this paper is focused on previous literature as well as an introduction to the study, and the second section describes the practical approaches and methodology which were followed to conduct the experiments and simulations and to assess the data. The final section focuses on the conclusions and findings of the study, as well as the future work of the research.

2. Methodology

To carry out the experiment to assess the ship personnel's operational abilities under the influence of alcohol through simulations, five cadet students and five navigation officers volunteered to be and were selected as participants. Cadets were in the senior year of their training at Korea Maritime and Ocean University (Busan, Republic of Korea), with adequate navigational experience. The average age of the

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Table 1. Principal particulars of the vessel used in simulations.

Ship type	LBP (m)	Breadth (m)	Depth (m)	Draft (m)	C_B	C_P
LNG carrier	283	44	26	9·6	0·7339	0·7385

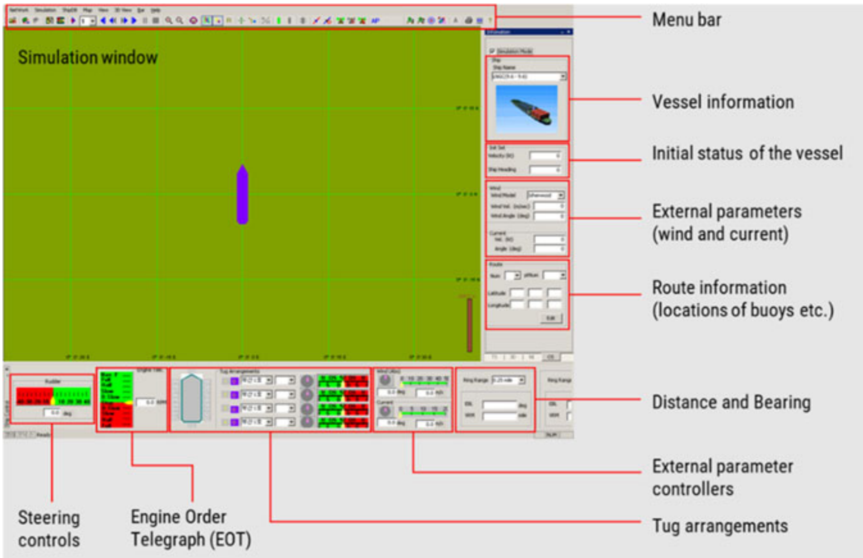

Figure 1. Graphical user interface (GUI) of the simulation program.

group was 23 years, and the average weight and height were 72 kg and 176 cm, respectively. Navigation officers had an average of six service years as navigators. The group of navigation officers were 39 years old on average, and the average weight and height were 75 kg and 176 cm. The tests included three different BAC levels: 0·00%, 0·05% and 0·08%, and alcohol was administered to the participants according to the formula in Equation (1) to achieve the desired BAC levels. Prior to conducting the experiment, BAC levels were measured at regular intervals using a breathalyser. The one used for this study is the Alcoscan AL8800, which is a fast-reacting fuel cell sensor portable breathalyser, with the ability to measure BAC levels from 0·00% to 0·40%, and with an accuracy of ±10% at 0·050% BAC.

$$\text{Alcohol dose } (g) = \left(\frac{10 \times \text{BAL} \times \text{TBW}}{0.8}\right) + (10 \times \text{MR} \times (\text{DDP} + \text{TPB})) \times \left(\frac{\text{TBW}}{0.8}\right) \quad (1)$$

The alcohol dose required to produce a specific peak blood alcohol level (BAL) is a function of the participant's total body water (TBW), duration of the drinking period (DDP), time to peak BAL (TPB) and alcohol metabolism rate (MR). In Equation (1), the alcohol dose is measured in grams, BAL in g/100 ml (e.g. 0·010 g/100 ml), DDP and TPB in hours, and TBW in litres. TBW is determined from gender-specific regression equations based on previous literature (Watson, 1989). A rate of 0·015 g/100 ml/h is used as the average metabolism rate for all participants. Additionally, it was assumed that participants reached their peak BAL at 0·3 h after cessation of drinking.

The experiment was designed to assess the manoeuvring and navigational ability of officers under the influence of alcohol. Therefore, designing the scenario included two aspects: planning the route/fairway for simulation, and the process of the experiment. Principle particulars of the vessel used in simulation are listed under Table 1, where C_B and C_P denote block coefficient and prismatic coefficient, respectively. Figure 1 illustrates the graphical user interface of the vessel simulator used for the experiment.

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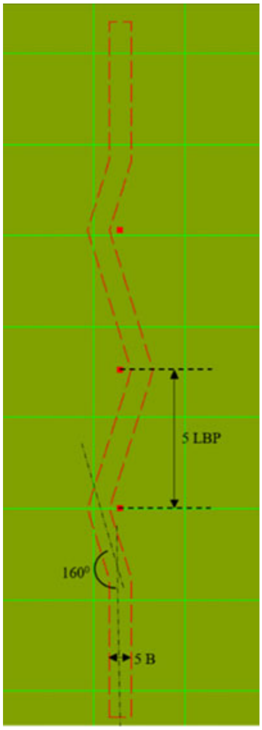

Figure 2. *Designed route and fairway dimensions.*

2.1. Route design

The test scenario was intended to assess the influence of alcohol in navigation under common circumstances. Therefore, the route could not include unrealistic circumstances. It was designed to include several course alterations, and included navigational limits. Following the aforementioned considerations and adapting the PIANC rules and regulations (PIANC, 2014), the route was designed as follows (Figure 2).

Participants were able to change the rudder angles and speed of the vessel throughout the simulation, and the vessel was given an initial speed of 20 kn. Essentially, the course alterations at each manoeuvre could be noted as 000° –340° –020° –340°.

2.2. Experiment process

First, the BAC level of the participant was measured using the breathalyser. Once it was clarified that the BAC level was 0·00%, the participant was asked to carry out the simulation for the first time. Once it was completed, the participant was asked to complete the questionnaire to measure the workload. Next, the participant was given 108 ml of 80-proof alcohol (2·4 standard shots) at t = 0 s. At 20 min after the consumption of the given alcohol, a 0·05% BAC level was reached and was later measured using the breathalyser. The participant was then asked to conduct the simulation and the aforementioned responses were measured. When the simulation was completed, the BAC level was measured again with the breathalyser. In addition, the participant was asked to complete the questionnaire to record the responses.

Next, the participant was given an additional 50–60 ml of 80-proof alcohol within a period of 20 min. The second dose/amount of alcohol was flexible because the participants had different rates of metabolism, and the completion time of the simulation varied from one participant to another. Once the

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second dose of alcohol was consumed (after 20 min), the BAC level was measured to ensure that it had reached the 0·08% level, and the participant was asked to carry out the simulation for the final time. Similar to the previous instances, the participant was asked to complete the questionnaire to measure the experienced workload at the end of the simulation. This was carried out for all participants, without exceptions.

Measured and recorded data were then analysed further to understand the effects of alcohol on navigational abilities. The results are discussed in the following section.

3. Results and simulations

The simulation program used for the study provided not only the trajectories through the main simulation window but also the instantaneous manoeuvring data, such as velocity, drift angle variation, heading angle variation, rudder angle variation, turn rate and respective locations in a Cartesian plane (as (x, y) coordinates) as well as in the geographic coordinate system (latitudes and longitudes). Changes in the vessel's speed and rudder angle variations are a result of participants' manoeuvring decisions, drift angle and heading angle variations are an indicator of vessel's instantaneous state, and the respective coordinates show the vessel's instantaneous position and, cumulatively, the trajectory. The 10 participants of the study were given separate IDs (M01, M02. . . , and M10) and these IDs are used hereafter for the clarity of the analysis. M01–M05 participants denote the five cadets (Group A) and M06–M10 participants denote the experienced navigation officers (Group B). Results were analysed for each candidate under three BAC levels, which were explained in the previous section. Figure 3 illustrates the trajectories followed by Group A participants: (a), (b) and (c) denote 0·00%, 0·05% and 0·08% BAC, respectively.

It can be seen that the participants, on average, were able to manoeuvre the vessel along the desired course when no alcohol was administered, i.e. when the BAC level was 0·00%. However, participants struggled to simulate the manoeuvres within safe limits when the BAC levels were increased. This is clearly visible in figures M01(c), M03(b), M05(b) and M05(c), where the vessel was run off-course near buoys. In addition, M01 and M03 could not complete the simulation, as shown in Figure 3 – M01(c) and M03(b), where the Variable Range Marker (VRM) and Electronic Bearing Line (EBL) controllers are turned on to illustrate the course and position of the vessel.

Similarly, Figure 4 shows the trajectories followed by the navigation officers under three different BAC levels. When the blood alcohol concentration was zero, navigation officers were able to manoeuvre the vessel with ease. Even though the initial trajectory of M06 seemed different, the candidate was able to retain the shape with ease. However, the results show that it was difficult – and sometimes almost impossible – to maintain the course of the trajectory as the BAC levels were increased from 0·00% to 0·05% and from 0·05% to 0·08% BAC. The VRM and EBL controllers were turned off during the Group B simulations.

Figures 5 and 6 are the complete illustration of data obtained from the simulator program at the end of each simulation of Group A and Group B participants, respectively. These include (a) the route trajectory in the Cartesian plane, (b) rudder angle variation, (c) velocity variation and (d) and rate of turn (RoT) variation of the simulation carried out by each participant. Simulation results of the three different BAC levels are superimposed to analyse the variations further.

Figure 7 shows the number of rudder commands (left) and engine telegraph commands (right) made by each participant in Group A (cadets) throughout the simulations under the three different (i.e. 0·00%, 0·05%, and 0·08%) BAC levels. Similarly, Figure 8 shows the same results obtained for the participants in Group B (officers).

When the average number of rudder commands made during the simulations is considered, it is clear that the participants tended to make more alterations as their blood alcohol concentration increased from 0·00% to 0·05% and to 0·08%, respectively. When the engine telegraph commands are considered, note that the number of decisions made with the engine telegraph commands decreased with alcohol intake. This is observed with both Group A and Group B. However, the importance of the dataset is that the only decision made by the participants was to increase the ship's speed to the maximum value,

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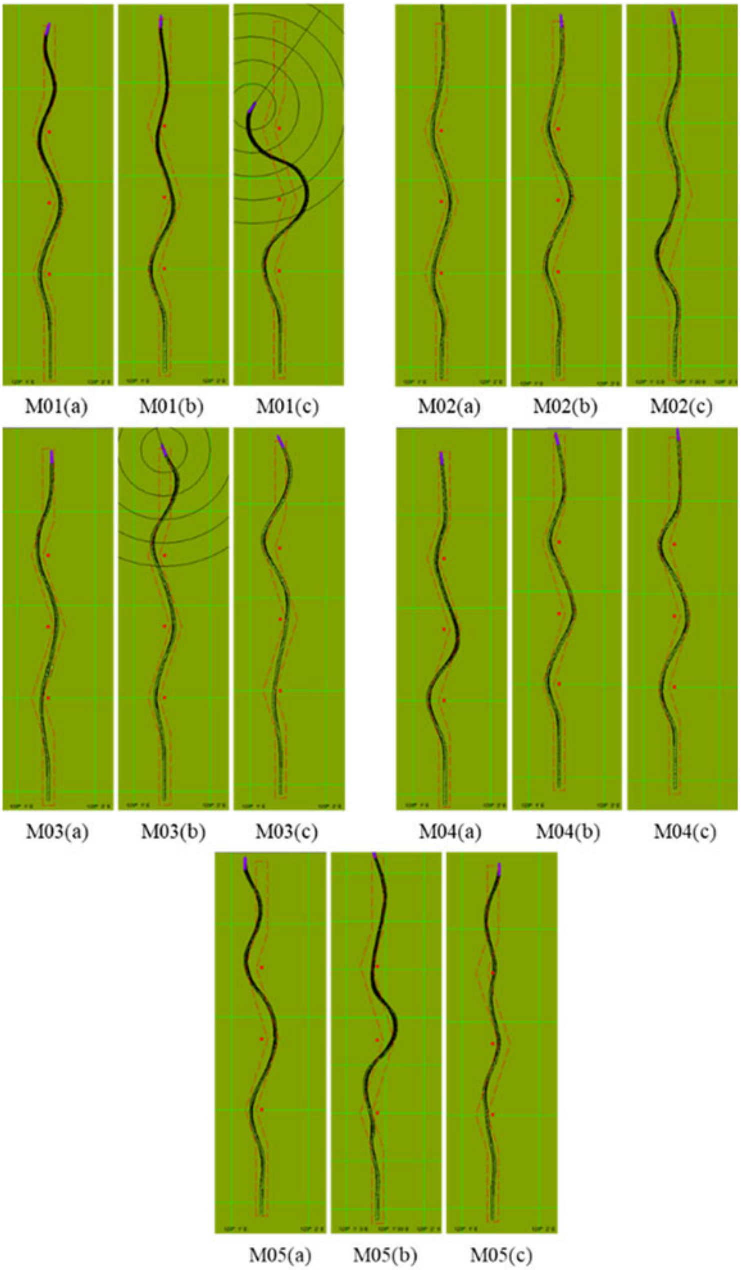

Figure 3. *Trajectories followed by Group A participants (M01–M05) under three different BAC levels [(a) 0·00% BAC, (b) 0·05% BAC, (c) 0·08% BAC].*

i.e. 'Full Ahead', when they were under the influence of alcohol. Except for one outlier in Group B, all participants tended to increase to and maintain a higher speed when the ship was manoeuvred under 0·05% and 0·08% BAC. Figure 9 shows the average alterations made by Group A and Group B. This clearly shows that navigators tend to make more sudden and questionable decisions to alter speed and course when under the influence of alcohol, regardless of how experienced they are.

The overall workload experienced by the participants throughout the simulations were assessed using the NASA-TLX, which is a multidimensional assessment tool used to assess the effectiveness and/or

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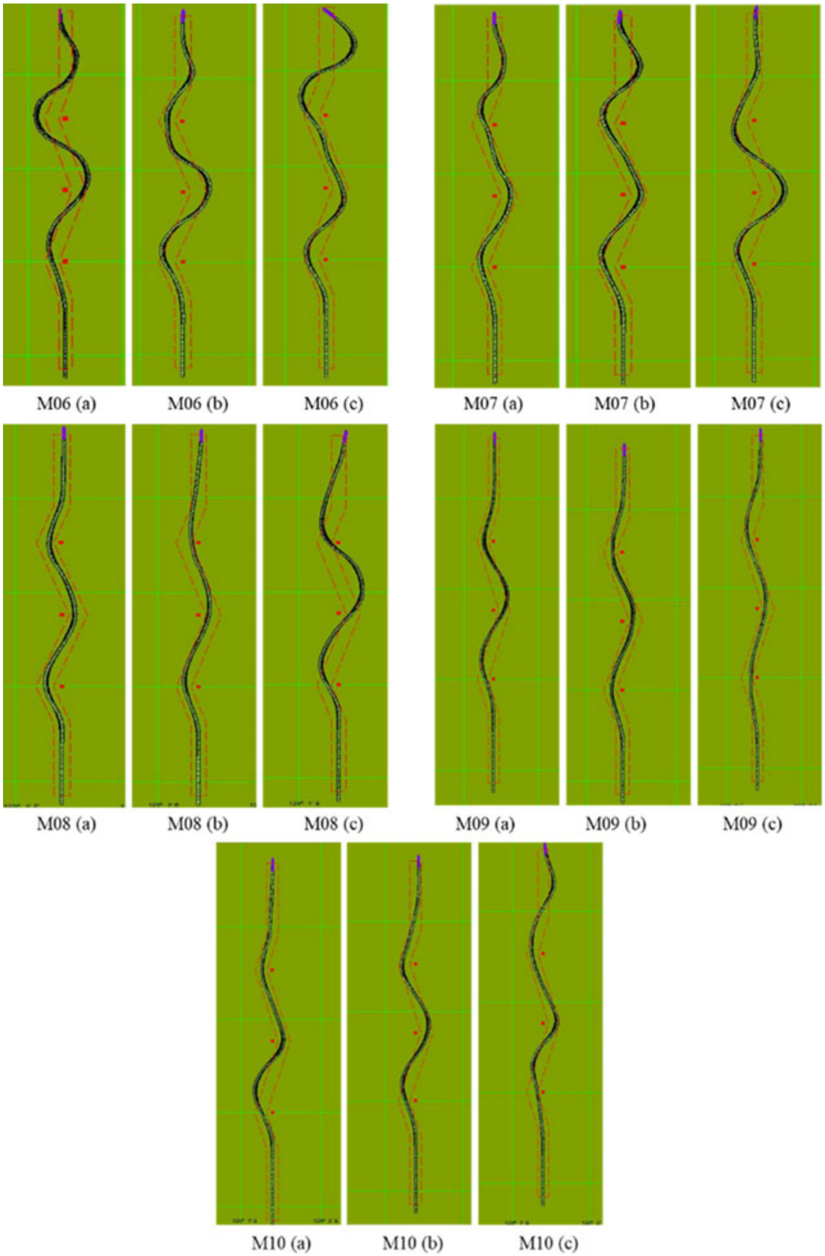

Figure 4. *Trajectories followed by Group B participants (M06–M10) under three different BAC levels [(a) 0·00% BAC, (b) 0·05% BAC, (c) 0·08% BAC].*

other aspects of performance under different categories. A standard workload assessment was followed in this study, and mental demand, physical demand, temporal demand, performance, effort and frustration were used as the subscales. Participants completed the questionnaire, which was designed according to the NASA-TLX, after each simulation under the three different BAC levels. After calculating the weighted workload averages of each participant, the overall workload was averaged again, including all 10 participants under two groups. The average workload distribution of the five cadets (Group A) along

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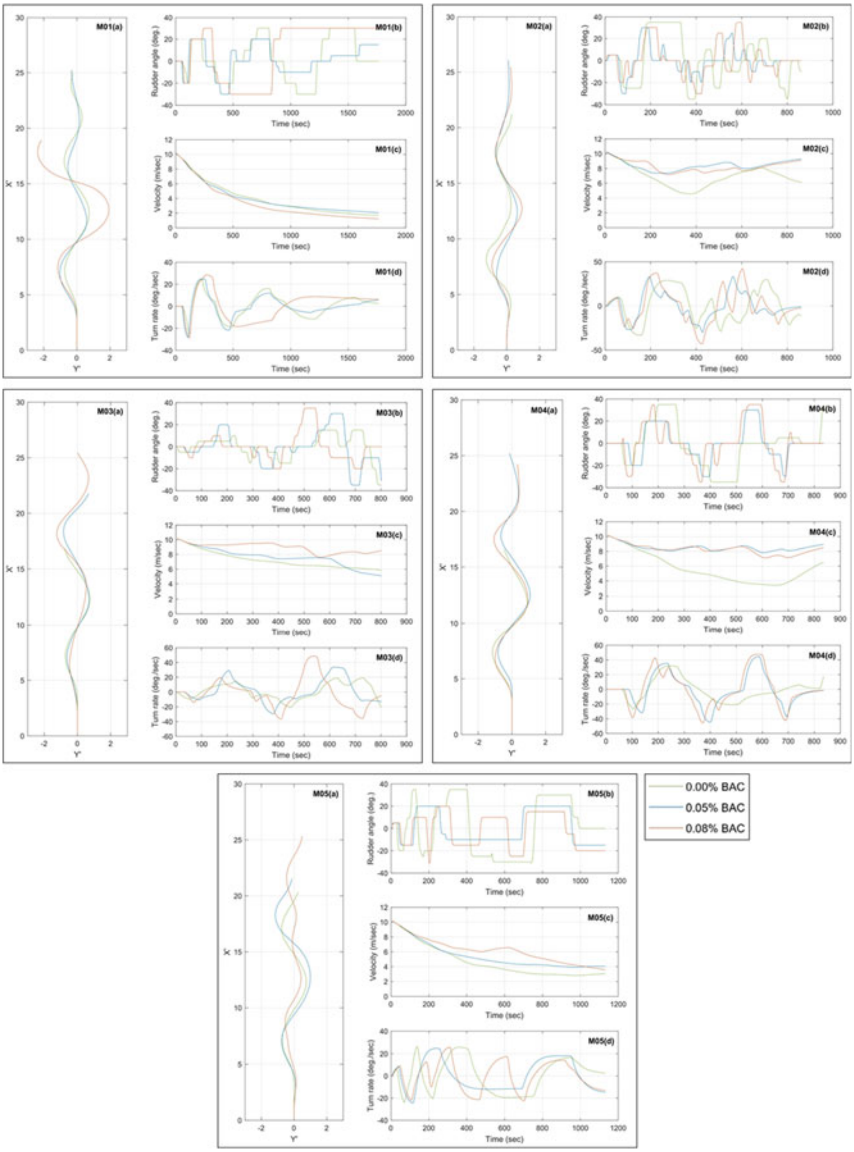

Figure 5. *Summary of Group A (M01–M05) data obtained from 15 simulations [(a) route trajectories in Cartesian plane, (b) rudder angle variation, (c) velocity variation, and (d) rate of turn (RoT) variation].*

a spectrum of six subscales are shown in Figure 10(a). Similarly, the workload distribution analysis results of the navigation officers are shown in Figure 10(b).

As seen here, the mental demand of both cadets and officers increased significantly as BAC level increased, which means that the participants found it more demanding and complex to carry out the simulations under the influence of alcohol. Similarly, physical demand and temporal demand increased with alcohol intake. This means that the participants found it more strenuous and laborious as the BAC levels increased. In addition, the overall effort also increased significantly with alcohol intake. Agreeing with the aforementioned subscales, the last parameter – frustration – drastically increased, which means that the participants felt insecure, irritated and discouraged when carrying out the simulations as more alcohol was administered. On the other hand, performance of the participants was considerably decreased

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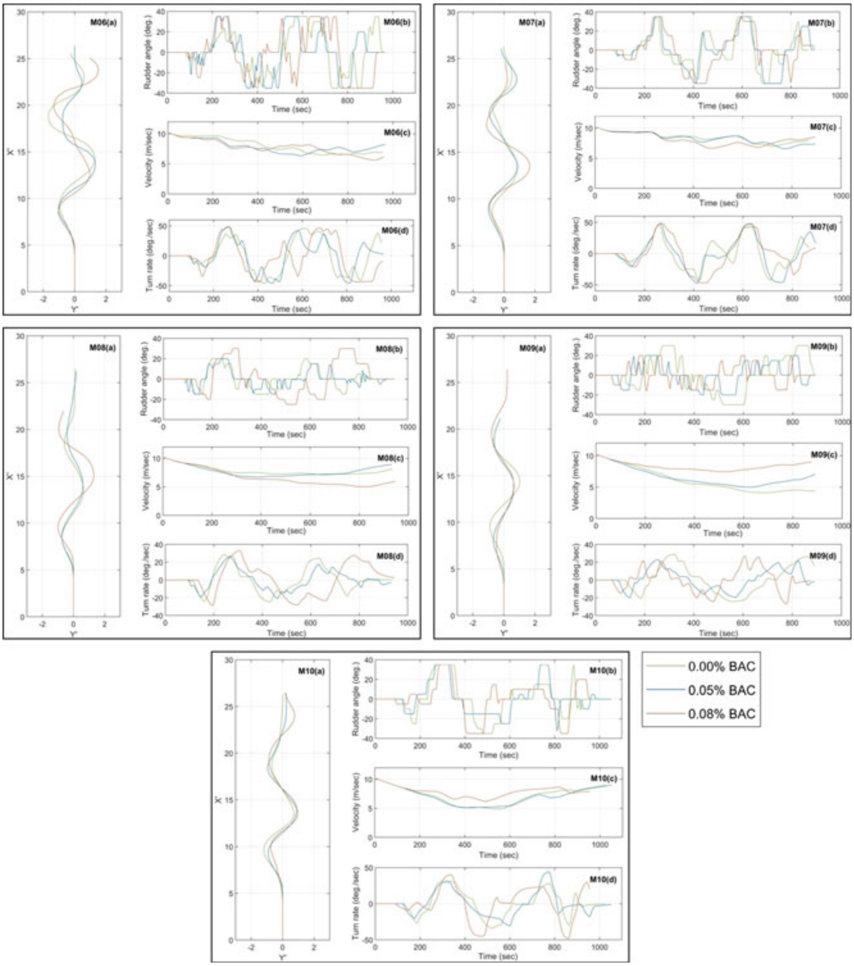

Figure 6. Summary of Group B (M06–M10) data obtained from 15 simulations [(a) route trajectories in Cartesian plane, (b) rudder angle variation, (c) velocity variation, and (d) rate of turn (RoT) variation].

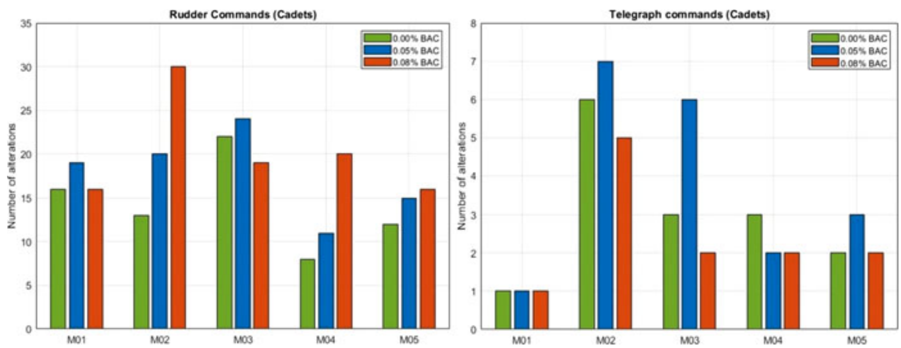

Figure 7. Number of rudder commands (left) and engine telegraph commands (right) made by Group A participants (cadets) under different BAC levels.

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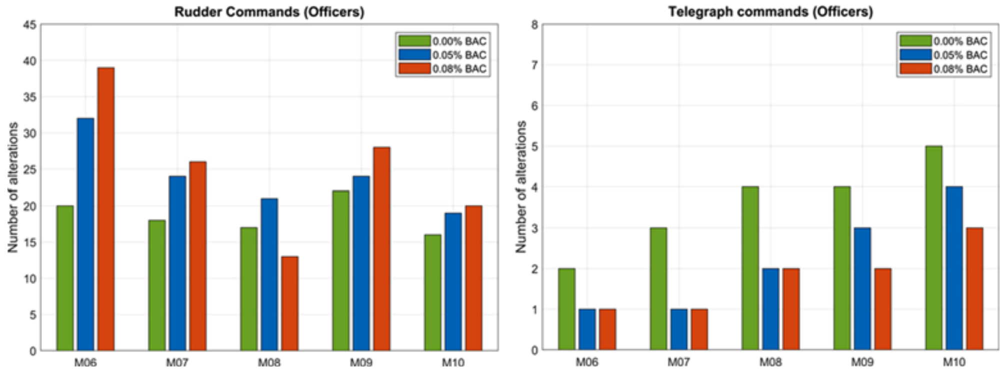

Figure 8. *Number of rudder commands (left) and engine telegraph commands (right) made by Group B participants (officers) under different BAC levels.*

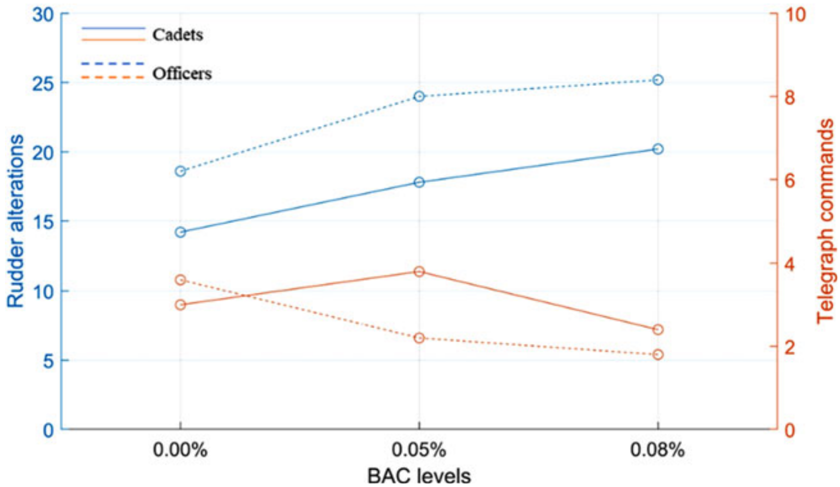

Figure 9. *Average speed and course alterations made by Group A (cadets) and Group B (officers) participants under three different BAC levels.*

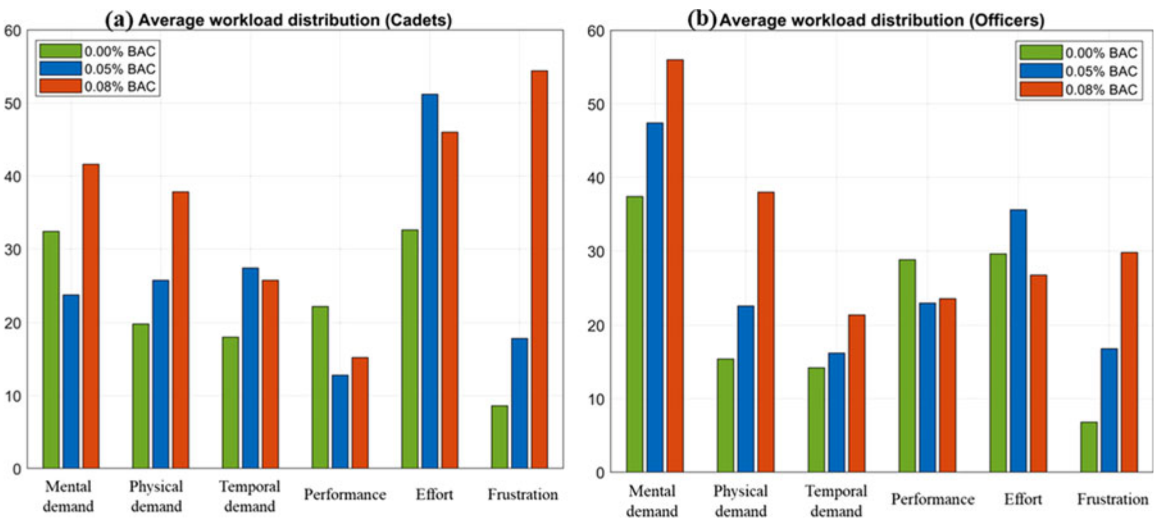

Figure 10. *Changes of average workloads under six subscales based on NASA-TLX of (a) cadets, and (b) navigation officers.*

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in both groups, which means that the effect of alcohol is significant regardless of the experience levels of seafarers.

4. Conclusions

The purpose of this study was to assess the influence of alcohol on ship operation and decision-making abilities of navigators with different levels of experience. Several laws have been implemented to limit the alcohol usage aboard vessels within the maritime domain, however, they fall short of addressing all the gaps related to navigation under the influence of alcohol. In addition, some of these laws can vary across countries, making it difficult to develop a stricter framework of international laws. The fact that the literature related to this particular topic is limited makes it even more difficult. In addition, one would believe that the navigators' experience would have an effect on how alcohol influences their decision-making abilities. Thus, this research was focused on providing literature through comprehensive analyses which can be used in developing safety protocols and rules, as well as legal frameworks in the maritime domain related to ship operations under the influence of alcohol.

The results obtained from the ship simulations clearly showed the effects of alcohol on motor functions, logical thinking and decision-making capabilities of navigators regardless of how experienced they are. When the BAC levels were zero (0·00% BAC), both cadets and officers had no trouble following the desired course with proper speed and rudder alterations. However, the ability to make the correct decisions at the right time was drastically deteriorated when the blood alcohol concentration was increased. The vessel was at risk and participants were not able to keep the vessel within the safe limits of the fairway when they were intoxicated. When decision-making capabilities are considered (i.e. the number of times that participants altered their course), the influence of alcohol is obvious. When the cadets were considered, on average, the number of rudder alterations increased by 25% when the BAC was increased from 0·00% to 0·05%. Similarly, the number of rudder alterations increased by 42% when the BAC was elevated from 0·00% to 0·08%. The second group of participants (officers) showed similar results, where on average, the number of rudder changes increased by 29% as the BAC was increased from 0·00% to 0·05%. The number increased by 35% when the BAC was increased to 0·08% from 0·00%. In terms of speed alterations, participants of Group A (cadets) were more careless than the officers (Group B) and tended to ignore safety when alcohol was administered. As a result, the number of engine telegraph commands obeyed decreased by 30% when the BAC levels were elevated from 0·00% to 0·08%. Experienced navigation officers too showed similar results, where the number of engine telegraph commands obeyed decreased by 50% when the BAC level was increased to 0·08% from 0·00%. This means that the participants on average, regardless of their experience levels, tended to keep the vessel speed at a maximum (i.e. Full Ahead). This evidently caused the vessel to run off-course in respective simulations.

In terms of workloads experienced during the manoeuvres, which were assessed with the NASA-TLX assessment tool, participants reported that the mental demand, physical demand and temporal demand increased with the increments of BAC levels. More precisely, the mental demand of the cadets increased by 28% when the BAC level was elevated from 0·00% to 0·08%. Similarly, physical demand and temporal demand increased by 91% and 43% at 0·08% BAC, respectively. As a result, the performance of the cadets, on average, decreased by 32% at 0·08% when compared to 0·00% BAC level. On a more emotional scale, the frustration levels of cadets (on average) increased by a factor of 1·07 when the BAC level was increased from 0·00% to 0·05%. Moreover, this drastically increased by a factor of 2·05 when the BAC level was 0·08%. Intriguingly, it was observed that the experienced navigation officers showed similar results when the average workload distribution of Group B was assessed along a spectrum of six subscales using the same tool. The mental demand and the temporal demand of the officers increased by 50% and 51% as the BAC levels were elevated to 0·08% from 0·00%, respectively. Physical demand showed a dramatic increment, where the physical demand at 0·00% BAC increased by a factor of 2·4 as when the BAC was increased to 0·08%. This means that the navigators found it demanding and strenuous to operate the vessel when they were intoxicated. Moreover, their performance was clearly affected by

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their BAC, and it decreased by 18% when the BAC levels were increased to 0·08% from 0·00%. While this is less than the effect on the performance of the cadets, it still clearly denotes that alcohol directly affects the performance of navigators regardless of how experienced they are. In addition, the experiment showed a significant increase in frustration levels with BAC levels. Overall, the frustration increased by a factor of 4·38 when the BAC was increased to 0·08% from 0·00%. The latter denotes that the participants felt annoyed and frustrated with their performance, conditions and decisions under the influence of alcohol, which can describe their poor decisions and failures to comply with the rules of the sea.

Seafarers often use alcohol due to their strict schedules and workloads to cope with crew fatigue. Even though the rules and regulations are implemented, they must be further strengthened to limit the use of alcohol on-board, as well as to develop better crew fatigue models that can include better sleep cycles and well-distributed work schedules. In addition, it is important to investigate whether a navigation officer's experience would have an effect on how alcohol affects navigation abilities. This study clearly shows that the influence of alcohol directly affects the navigators' ability – regardless how experienced they are – with ship operations, navigation and decision making. Based on the findings and the discussed premise, future studies could be carried out to further quantify the effects of alcohol, and ultimately to develop better legal frameworks in terms of intoxicated navigation and boating in the maritime domain. For this particular purpose, a larger experimental group shall be used, where a Gaussian distribution can be formulated to obtain more confirming results of the hypothesis. Current study, therefore, shall serve as a foundation of a prefatory study into the effects of the use of alcohol onboard vessels.

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