FATIGUE AND PERFORMANCE IN BRIDGE AND ENGINE CONTROL ROOM WATCHKEEPING ON A 6 ON / 6 OFF WATCH REGIME

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SUMMARY

Financial pressures in the shipping industry have forced ship owners to reduce their onboard manning levels and increase workloads, potentially leading to a higher risk of accidents through human error. Project HORIZON is a highly significant European funded research project that seeks to investigate the problem of seafarer reliability, and to deliver measures that will help alleviate the safety hazards caused by fatigue. For this purpose, a realistic scenario was developed, in which watch keeper cognitive performance and fatigue levels were measured, using the bridge, engine and cargo operations simulator facilities at Warsash, linked together to provide a 7 day continuous voyage. Ten simulations runs have been performed with 40 certificated seafarers of varying experience. Analysis of the results shows a significant impact of the 6 on / 6 off watch pattern on the fatigue and performance of seafarers. It is hoped these results will lead to better fatigue management systems being developed, in order to improve the safety and reliability of ship operations and the welfare of seafarers. This paper describes the HORIZON project and illustrates some of the emerging results.

1. INTRODUCTION

The HORIZON project is a European Framework 7 sponsored research project to investigate the effects of fatigue on the cognitive performance of marine watch keepers, using a range of simulators and under different watch patterns and conditions of workload. The main partners in the project come from UK, France, and Sweden and there is also an international industry panel of stakeholders to advise the research team. The project began in June 2009 and is scheduled to complete in January 2012. The experiments were focussed on two different watch patterns – the conventional 4 hours on and 8 hours off regime, and the more arduous 6 on and 6 off watch pattern. A total of 90 officers undertook the experiments on both simulator sites at Chalmers University in Sweden and at Warsash Maritime Academy in the UK, completing sufficient experiments to ensure the statistical validity of the results. Chalmers University conducted experiments on the 4 on and 8 off watch, and a “disturbed” 6 on 6 off watch regime.

Meanwhile, at Warsash, 10 identical simulator-based “voyages” took place during 2010-2011, involving 40 watch keepers in linked bridge, engine room and cargo simulators. The participants undertook an “undisturbed” 6on/6off watch regime for 7 days, and during that period, measurements were taken of their watch keeping performance and their levels of alertness, including the use of EEG recording.

1.1. THE VOYAGE

The detail of the voyage route was designed by the research team and the relevant simulator instructors, and was conducted in exactly the same way during the ten sessions. The voyage was constructed to mimic a real voyage in the English Channel (see Figure 1), including port visits and cargo operations, standard engineering watch keeping tasks, navigation and collision avoidance situations, mandatory radio reporting points, etc.

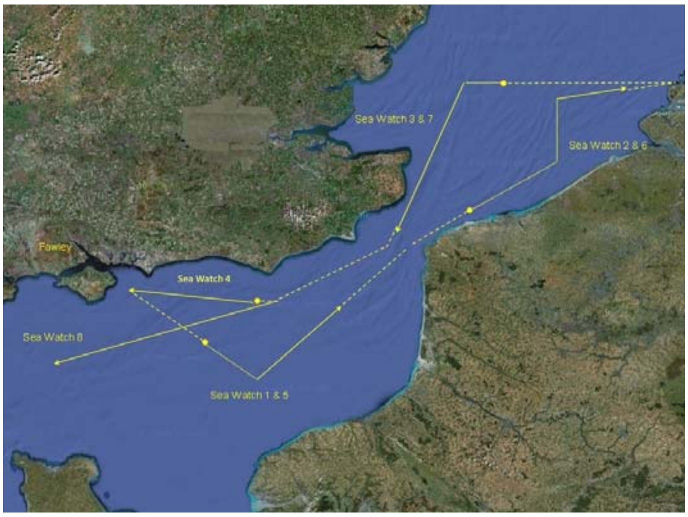

Figure 1: The voyage between Fawley and Rotterdam

The voyage between Fawley and Rotterdam was repeated twice in seven days. The amount of traffic was set the same for each run and was considered realistic for the waters involved. It varied in intensity from light to relatively heavy traffic. Given a maximum vessel speed of less than 14 knots, the maximum distance per watch was around 85 NM in a 6/6 watch.

The watch system was the traditional 6/6 system, without deliberate disturbances off watch, but with a change: a bridge participant in one watch team did not continue from where the participant before had finished; the bridge simulator was re-set at the same point at the start of the previous watch, and the second watch keeper did the same part of the voyage again. This method had a number of advantages, most importantly the ability to directly compare the same watch keeping conditions shifted by 6 hours.

A number of considerations influenced route choice and timings, and these were:

- Because the distance sailed in one watch period was not exactly predictable, the start position of one watch would not be the same, unless the simulator positions were re-set each watch thus giving identical conditions to each watch keeper.
- The application of EEG electrodes took up to 40 minutes of the watch time. The cognitive tests took approximately 5 minutes for each test.
- At the ship's normal full speed, the ports of Fawley and Rotterdam are about 24 hours apart. Two port visits in Fawley (Days 1 and 5) and two more in Europort (Day 3 and 6) were scheduled. Cargo operations occured during each port visit.
- No tidal conditions were used, thus avoiding the use of tide tables and times, since all participants were exposed to the same situation.
- Real time matched the time displayed in the simulated view from the bridge, and hence the levels of daylight in the simulator were adjusted to be identical to those outside.
- The weather conditions were consistent and benign. Traffic was realistic for the area and a basic voyage plan was given to the participants during the familiarisation period on the first day loading in Fawley.

The voyage scenario was constructed carefully to ensure a high level of realism. Performance evaluation took place on every watch. Events during the voyage scenario were classified into normal, communication, special and unplanned events. Normal events (or situations) were those which a seafarer on a similar sized vessel would typically encounter during a voyage in the English Channel, but without highly safety-critical or abnormal emergency situations. These normal events were, for example:

- Keeping the vessel's logbook (diary): participants were expected to keep the ship's log book, which is provided for each bridge, engine and cargo control room;
- Marking ship's positions on the chart: participants were required to mark the vessel's position on the relevant chart, according to the Master standing orders.
- Watch handovers: participants were given standing orders to exchange information with the next watch keeper or receive the watch from the previous watch keeper (which was a simulator instructor in both cases). Important events which occurred during the watch were reported.
- Since the route in the English Channel had high traffic density, it was likely that several close encounters with other ships would occur. Some of these were designed to be close encounters, and were recorded and evaluated by the instructor.
- Similar normal watch keeping tasks, such as monitoring the performance of the main engine during the watch, and the status of the cargo systems were conducted in the engine and cargo control room simulators, and assessed by the instructors.

The communication events were, for example:

- Internal communications: there were situations when the participants were expected to communicate with the Master, Chief Engineer, or Chief Officer, depending on the simulator.
- The bridge OOW was called by a VTS operator and required to give a position report.
- Standard communication with outside agencies, e.g. other vessels, pilot stations or coastguards, for example, a report to Maas Pilots, and at the arrival off Nab Tower.

The special events were designed to elicit specific behaviours for scoring performance change over the week, for example, on the bridge:

- A waypoint with a potential collision avoidance situation involving an early alteration of course.
- A Gyrocompass error
- A vessel crossing from the port side, which does not alter course as per the COLREGS.
- A man overboard incident occurring on another vessel in the vicinity

Unplanned events were those where a direct action by the participant might lead to an impact on other watch keepers, for example, a blackout in the engine room impacting on cargo operations, or a "near-miss" situation on the bridge.

Similar events were designed for both engineering and cargo control tasks.

1.2. THE SIMULATORS

Warsash Maritime Academy used its newest Bridge Simulator, produced by Kongsberg, for these experiments. It is equipped with standard equipment found on modern vessels. The simulator has its own room, thus allowing bridge work without disturbance from the outside. A chart table is also available. The instrumentation comprises GPS, Radar with ARPA, Autopilot, VHF radio, intercom, etc. The outside view is simulated with screens, and three displays show conning and radar. The simulator is monitored centrally from an instructor room, where the Bridge is controlled by its own set of computers ("instructor station").

The simulation runs were recorded by dedicated logging software. All relevant data, such as targets (other ships), radars, etc. were visualized. Radio and internal communication ("intercom") between participants and the Master, or engine room, or participants and other ships, was not recorded.

However, participants were monitored via an internal CCTV system, with two camera positions, one of which was recording throughout bridge use.
The simulated vessel in the cargo simulator (LICOS) was a larger tanker than the bridge model (the M/V NORSEMAN, a double hull product carrier of 36,000 DWT). The choice of this vessel came from the necessity to avoid complex cargo operations. It was considered that the straightforward operation of the chosen tanker put all participants, who all had some experience in liquid cargo handling, at a similar level of ease of operation for the purposes of scoring performance.

A photograph of a typical vessel, envisaged as the model for the voyage, can be seen in Figure 2 below.

Figure 2: A Products tanker as recreated in the cargo operations simulator.

Six simulator stations are normally available for training, and these are situated in one large lecture room, but for the HORIZON experiment, only one work station was used. Each station has 2 screens, and is controlled individually from the instructor station. All participants had a five hour familiarization with the cargo simulator before starting the actual experimental run. Participants also had the ship's cargo operation handbook in written form for further guidance. The instructor simulated a variety of roles, for example, jetty and terminal officers. Each participant used the same work station, and under the same conditions, as well as the same scenario.

The tasks included two loading and two discharging operations, at the same terminals, ie Fawley for loading, and discharging in Rotterdam. The participants needed to be familiar with tankers, and this was one of the selection criteria but the familiarisation session during the first day ensured that participants got acquainted with the liquid cargo operation simulator and the ship's cargo systems. During this session, instructors took the role of the watch keeper, and assisted participants through operations which were similar to those to be performed later in the experiment.

The model used in the Machinery Space Simulator (MSS) was a slow speed diesel engine and therefore matched both bridge and LICOS simulators without difficulty. The simulator consists of a Machinery Control Room with a control desk (MECD), switchboard and shaft generator breaker cabinet. The ships electrical system is comprised of two diesel driven alternators and one steam turbo alternator producing 60HZ and three phase 440 volts supply. An emergency diesel alternator complying with SOLAS requirements is also included within the system. The electrical system is fitted with the associated instrumentation and protective equipment.

As the simulation is reconstructing the real work environment of the participants, several events, foreseen and unforeseen, were designed to take place during the voyages, as well as the normal watch keeping tasks of the engineer on watch.

1.3. MEANS OF ENSURING REALISM

It was recognised at an early stage in the design process that there had to be a trade-off between voyage realism and experimental control. Control is important for obtaining valid and reliable data without variability which cannot be accounted for. A number of measures assured an adequate level of realism, without losing control of the scenarios and events:

1 All the participants were practising seafarers, except one qualified Chief Engineer, who was a shore-based Engineering manager at the time of the experiments. All participants had experience on the type of ship simulated, and this may have contributed to creating a work condition similar to reality.
2 Sleeping quarters were located in a building called "Hamblemeads", just a few minutes walking distance from the simulators and the mess room. Both the cabins and mess room were similar to such quarters on board ship.
3 All simulator instructors and most researchers were ex-seafarers, and this may have added to the sensation of being "at work". In the simulators, the instructors acted as Master, bosun, lookout, pilot, able seamen, etc., as required and kept in role, even when participants were encountered off watch.
4 Master's and Chief Engineer's standing orders were available, and had to be signed as read and understood. A bridge lookout was always available, but in the form of an instructor who could be contacted via radio. The ship's log had to be completed for each watch, and was a standard logbook (in English language). In the engine room, a motorman was also available and similar logs were kept. In LICOS, radio contact was present for ship to terminal communication. Vital communication with the participants working in the Engine Room Simulator was maintained at all time. Logs that needed to be filled in corresponded to standard logs used during liquid cargo handling.

Watch changeover procedures mimicked those in a real vessel.

1.4. THE PARTICIPANTS

A total of forty participants took part in the experiments. These were from different nationalities, including UK, Polish, Indian and Nigerian officers. A low prevalence of female participants in the experiment was considered to reflect reality: 39 of 40 participants were males (97%). A number of criteria had to be fulfilled in order for a potential participant to be signed up, and these generally related to health issues.

Travel arrangements and reimbursement for most participants was arranged by a marine manning company – SeaMariner, based near Warsash. A pool of seafarers was ready to be involved in the experiment, mainly because of the presence of suitable student candidates on campus. Yet, the assistance of the manning agency was vital in ensuring that a sufficient number of participants could be found. Any volunteers and student candidates from WMA had to join the manning agency in order to take part in the experiment. This was a necessary requirement, in order that professionals could check the visas of the overseas participants and to arrange their travel and payment.

2. FATIGUE MEASURMENT

2.1. EEG RECORDING

EEG recordings measure the electrical summed activity of the brain, through several electrodes that are placed on the head. EOG and ECG were also measured, but EEG was considered as the most important measurement. The participants were fitted with these twice during the week, on the second and 6th days.

2.2. ACTIWATCHES

Actiwatch is both a brand name and a common term used for small, portable activity measurement devices worn on the wrist (or leg) to measure acceleration, and thus calculate physical activity, sleep duration. The participants wore these throughout the week.

2.3. OTHER MEASURES

Several other measures of fatigue were made. These were:

2.3.1. PVT

The psychomotor vigilance task (PVT) is a vigilance test which is sensitive to fatigue. The PVT was performed on portable devices, always before starting a simulator watch, and once on completion of a watch. This means 28 test results were recorded for every participant by the end of the run. Figure 3 shows a participant performing the PVT. Each test lasted approximately five minutes, and reaction time, number of lapses, mean reaction time, etc. were stored.

Figure 3: The PVT Test

2.3.2. The Stroop Test

At the end of each watch and after completing the PVT test the participants carried out a Stroop test on a laptop located in the same area as the PVT. Again this task was undertaken whilst the participant was alone in the room to enable total concentration. The names of 2 different colours (green and red) appeared on the screen and the participants had to click the colour-name as quickly as possible, ignoring the meaning of the word displayed. The resulting data was stored on the laptop, backed up and transferred to the Horizon website at the end of each experiment.

2.3.3. Diaries

Each participant had to fill in diaries and a number of questionnaires before, during and after the experiments. These were presented in detail in Deliverable 6.
Sleep and wake paper diaries collected a variety of information, such as KSS and stress, but in addition, the following data were recorded:
Work diary:

- Food intake
- Symptoms of fatigue during work shift
- Work (difficult/easy)
- Satisfaction with own performance
- Workload
- Nodding off

Wake diary:

- Food intake
- Type of activity during free time
- Symptoms of fatigue
- Wellbeing (health)
- Recuperation

Sleep diary:

- Intake of coffee
- Intake of medications
- Awakenings
- Difficulty to fall asleep
- Sleep quality

- Waking up early
- easiness to get up
- Disturbed sleep
- Time awake during sleep
- Dept of sleep
- Anxiety
- Special occurrences
- Reason for waking up
- Comments

3. FATIGUE AND PERFORMANCE RESULTS

The results are being finalized so no detailed data can be presented here. However, the overall impression is that sleepiness, and neurobehavioral performance, as measured by the EEG electrodes, are particularly affected towards the end of the 00-06 watch. Sleepiness and fatigue are enhanced and performance reduced.

At this time, incidents of small periods of sleep are also seen – both on the bridge and in the engine room. In addition, there is a gradual increase of fatigue during the work periods as the week progresses.

4. ANALYSIS OF VIDEO

4.1. AVAILABLE DATA

All simulations were recorded using the CCTV used for monitoring. Image quality is good and infrared mode allows a good quality in low light conditions at night on the bridge. The chosen angle of the camera allows a view of most working areas in both the engine control room and the bridge.

Complete video recordings are not available for all watches due to technical issues. Yet the bridge recordings cover 54% (97) of the 180 watches and engine control room recordings cover 68% (189) of the 280 watches. Details for each run are listed in Table 1 and Table 2 below.

Simulation run number	Number of watches	Complete videos
1	28	0
2	28	28
3	28	28
4	28	0
5	28	14
6	28	20
7	28	28
8	28	18
9	28	28
10	28	28

Table 1: Complete videos of Engine control room

Simulation run number	Number of watches	Complete videos
1	18	2
2	18	18
3	18	18
4	18	0
5	18	13
6	18	12
7	18	15
8	18	9
9	18	18
10	18	18

Table 2: Complete videos of Bridge

4.2. RECORDING OF EVENTS

Videos were played using the CCTV software allowing quick control of the timeline of the videos as well as inactivity detection.
Timed actions and observations have then been listed on a spreadsheet. Several types of actions have been defined:

- Using controls/devices
- Communication by radio
- Communication by telephone
- Paperwork
- Making rounds
- Looking through windows/at controls
- Signs of fatigue (yawning, rubbing eyes, closing eyes…)

For each action, context information has also been noted:

- Location in the room
- Position of the participant

This processing is very time consuming and has not been completed on all recorded videos yet.

4.3. ANALYSIS

The list of recorded actions has then been processed using specifically developed programs in order to extract ergonomic and activity data.

4.3.1. Ergonomics data

Each working environment has been divided in small zones (See Figure 4 and Figure 5), allowing the analysis of space use and movements performed by the participant in the workspace.

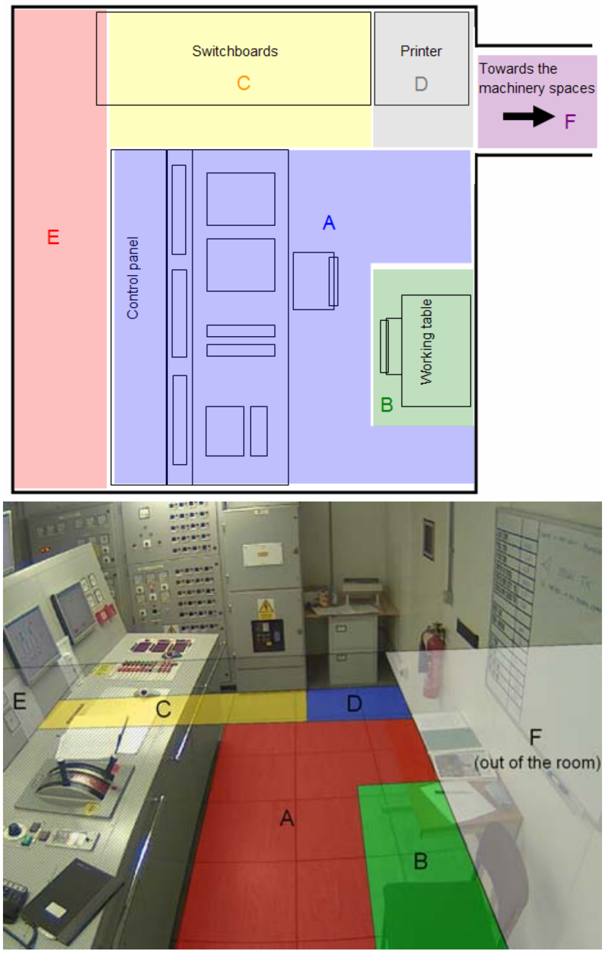

Figure 4: Areas division of the Engine Control Room

Visualisation of the data may be done in various ways, using an overview like in Figure 6 allows a quick understanding of areas occupancy and main movements.

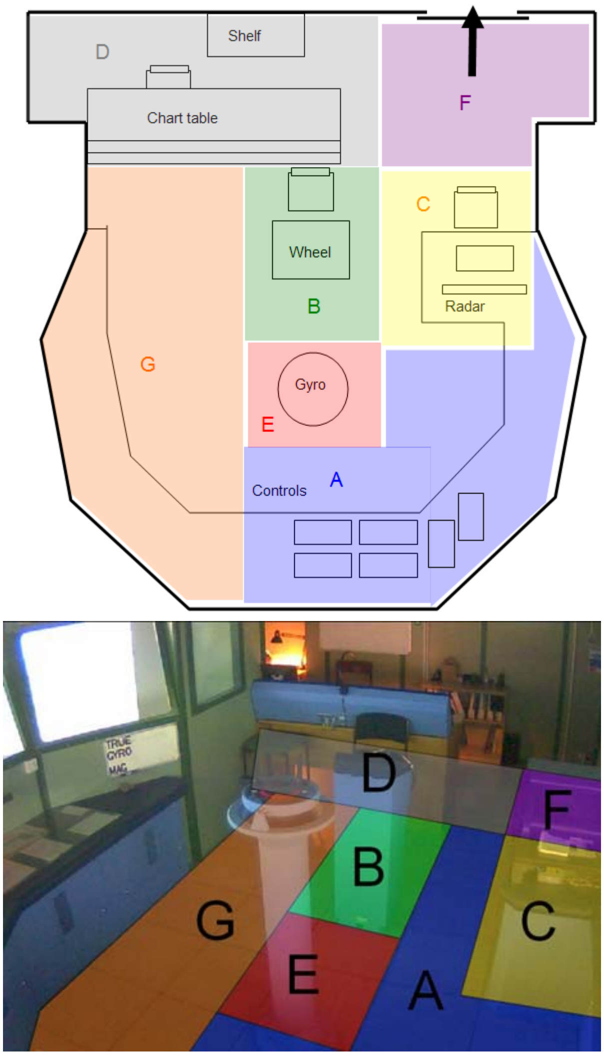

Figure 5: Areas division of the Bridge

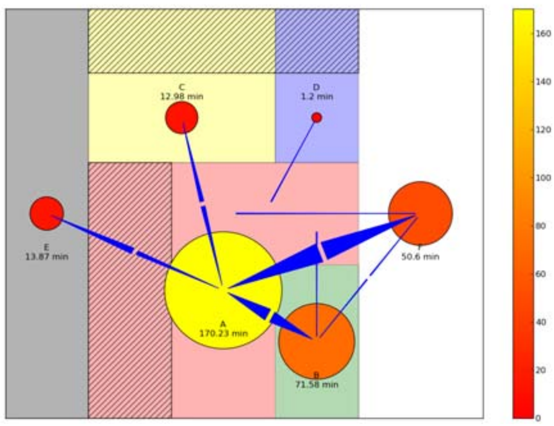

Figure 6: Example of visualisation of movements and location use for run 2, day 3, 0:00-6:00 in the Engine Control Room

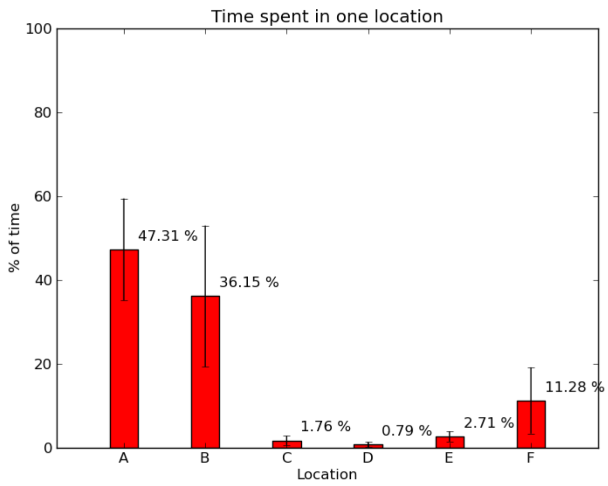

Figure 7: Use of space in the Engine Control Room by the first participant during run 2

This analysis shows the time spent in each area and the movements done between the different zones.
To reduce fatigue, routes between locations with lots of movements should be short and clear of obstacles.
For the same goal, areas where the participant spends most of his/her time should be comfortable, with good surroundings conditions (light, sounds, temperature…).

4.3.2. Activity data

Actions extracted from the video recordings allow an analysis of the activity of the participant. We divided those actions into three levels of activity:

- High level activities are actions directly related to work that the participant performs using lots of movements and/or thinking such as control operations, communication…
- Medium level activities are actions not directly related to work but still using movements and/or thinking such as reading magazines or eating.
- Low level activities are actions that require only an attentive state of awareness, without any large movements, typically when supervising operations and awaiting an event without actions.

Activity is also analysed using the position. As a matter of fact, looking at the time the participant spent seated and standing may give a hint of his level of fatigue and awareness.

4.4. RESULTS

Those preliminary results should be taken with caution as other factors than fatigue are weighting on the results such as habituation to the working environment and workload conditions that changes during the voyage. As much as possible, influence of those factors will be taken into account in the final analysis.

4.4.1. Ergonomics data

Main locations used by the participant in the Engine Room are locations A, B and F.
Results show a global tendency to spend more time in location B, where a chair is available.
On the contrary, time spent in location F is decreasing over time. Location F is a machinery space, which is noisier, and less comfortable than other locations.

Figure 8 shows examples of results illustrating these phenomena.

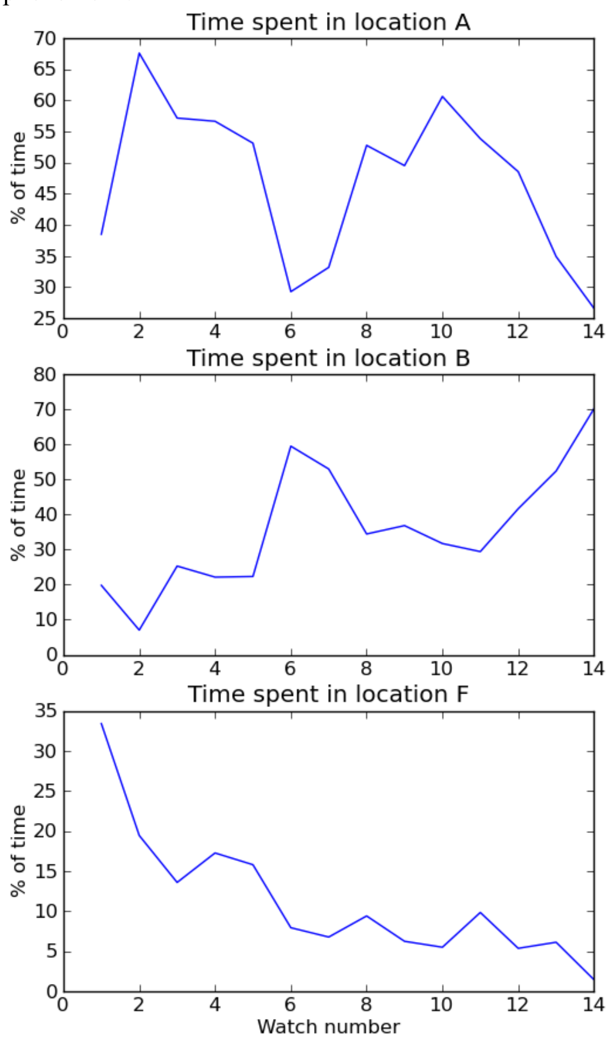

Figure 8: Evolution of time spent in locations A, B and F by the first participant during run 2 in the Engine Control Room

4.4.2. Activity data

Figure 9 shows a comparison between the first and the last watch of the same participant. We can observe that activity is lower during the last watch, and more time is spent seated. This supports the idea that participants have a higher level of sleepiness at the end of their week at sea.

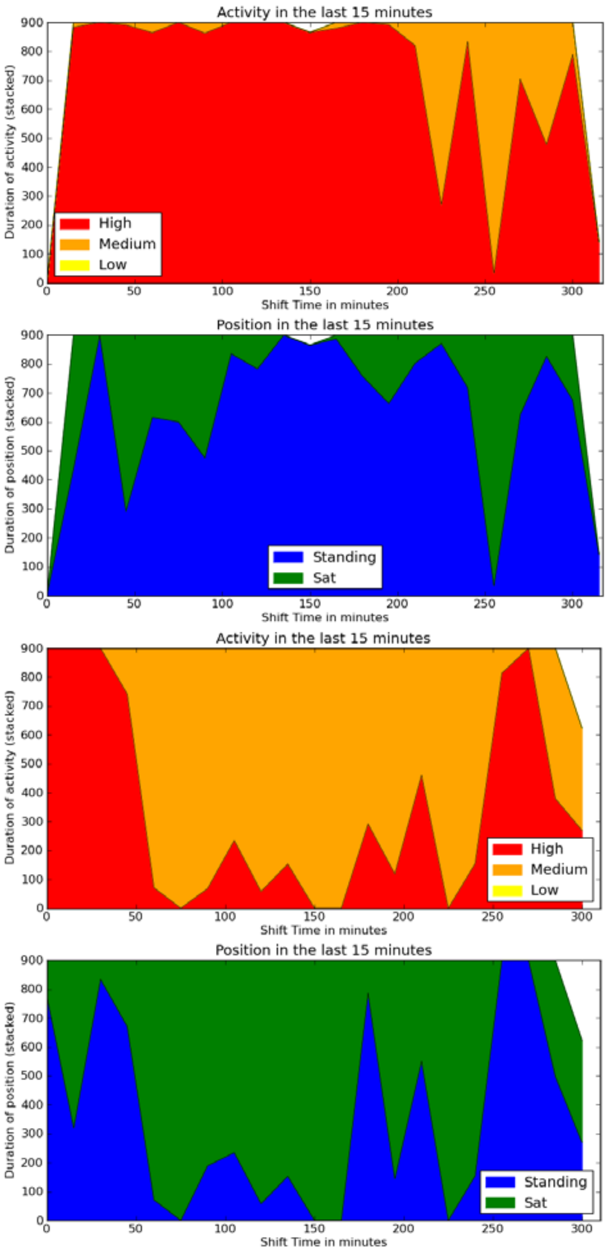

Figure 9: Comparison of activity of the first participant for his first watch (day 1, 12:00pm-6:00am) and last watch (day 7, 12:00am-6:00pm) during run 2 in Engine Control Room

5. CONCLUSIONS

Early results from this unique study show that a one week journey following a 6 on 6 off watch regime seems to have a significant impact on fatigue and performance of the seafarers. The main observed consequence seems to be an activity reduction.
Further development using those results will tell if the performance of seafarers is directly linked with their fatigue level.

6. REFERENCES

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7. AUTHORS BIOGRAPHY

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