Investigating the Effects of Fatigue, Distraction and Increased Mental Workload on Performance of Ship Engine Room Operators: An fNIRS study

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Background: Ship engine room operators play a key role in maritime operations. Previous research claimed that 80% of maritime accidents are due to human error within the engine room (1) (2). Operators in the engine room must often engage in troubleshooting activity if any function of ship engine systems indicates a fault (3). The ability to identify and resolve problems arising from the complex, engineering system within a large marine vessel depends on the level of training received by operators and their direct experience of working in the engine room (4). The aim of the current study was twofold: (1) to explore how the type of training influenced troubleshooting performance in the engine room, and (2) to capture the impact of common stressors (fatigue, increased workload and distraction) on activation of the prefrontal cortex during trouble shooting performance (5) (6) (7) (8).

Methods: A study was conducted using a TRANSAS engine room simulator where 40 participants (20 practically trained & 20 passively trained), were separated into four different groups (10 distracted, 10 fatigued, 10 increased workload & 10 standard test). Participants performed a pump fault detection and correction task during ballasting operations on the engine room simulator. Ballasting is the pumping of sea water in and out of tanks located on a ships lower desk, which is essential to optimize the stability of the vessel. If a ballasting pump fails for a period of time, then a ship will start to keel and eventually list (9), resulting in the damage of goods and injury to personnel on board (10).

Task Simulation: The Ballasting simulation task was defined in five different stages.:

1. Baseline 1 – This is a 300s monitoring task where participants would simply monitor tanks as they began to fill. This stage also permitted baseline recording of fNIRS data.
2. Fault Occurrence – a fault would occur indicated by a visual alarm on the interface. The participants would be required to acknowledge the alarm and record the time when the alarm was discovered.
3. Fault Detection – The participants must locate the part of the ballasting system with a problem and the cause of the fault.
4. Fault Solution – participants would navigate through the simulator screens, opening and closing up to six different valves to re-route the water line through an alternative ballast pump and activating the alternative pump.
5. Baseline 2 – when the fault was resolved, participants would return to the task of monitoring the ballast tanks as they were filled.

Training: 20 of the 40 participants were passively trained using ‘paper-based’ instructions detailing how to use the engine room simulator and navigate through the required screens, the interpretation of various alarms, and how to use all aspects of the ballast system. Passive training lasted for 2 hours. The other 20 participants were provided with practical training. Practically trained participants also received 2 hours of passive training with additional hour of practical tutorials.

Task Stressors: 10 of the forty participants performed the task simulation alongside a Distraction task where they must also report data from the interface once during each stage of the simulation. Fatigue was manipulated for 10 of the remaining thirty participants who performed the baseline 1 condition for 35 minutes prior to the second stage of fault occurrence. 10 of the remaining twenty participants performed the simulation under a condition of increased mental workload, i.e., participant must ballast six tanks instead of a single tank in the standard version of the simulation task. The remaining 10 participants were given a standard test, i.e., single tank scenario with no fatigue or distraction

fNIRS: Activation of the prefrontal cortex (PFC) was captured via a 15-channel (fNIRS) montage using the NIRx Sport. Data were filtered, corrected for movement artifacts and oxygenated haemoglobin levels were calculated (HbO). Two distinct analyses were performed on the HbO data. The first examined mean levels of HbO from all 15 channels, which were divided into three regions of interest (left, middle, right) across the three independent variables (task phase, distraction, participant experience).

Results: Greater levels of neurovascular activation of the right and left regions of the PFC was found for passively trained participants compared to actively trained participants. The fault solution stage of the workflow showed the highest level of activation compared to other stages of the simulation. Increased workload showed the highest levels of activation compared to other task stressors (see Figure 1).

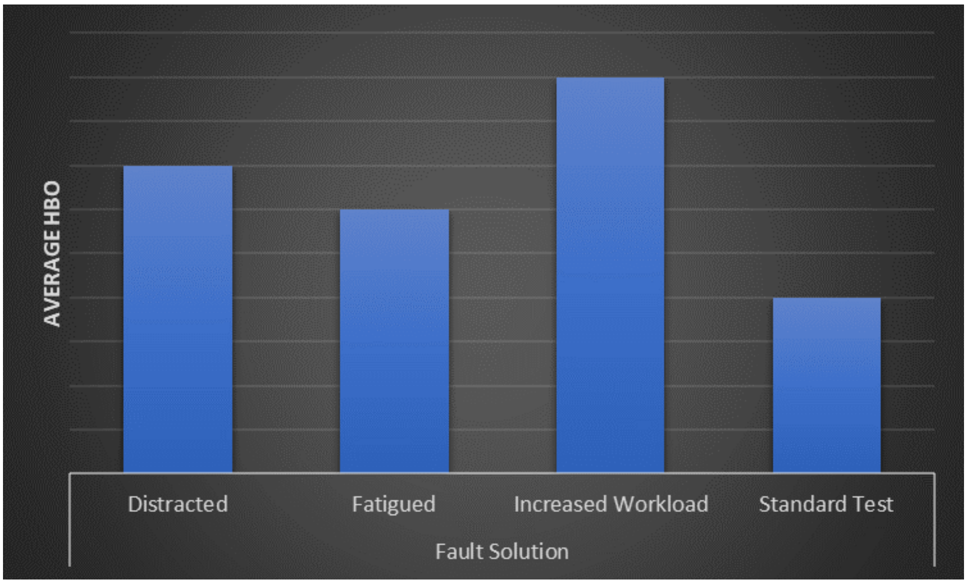

Figure 1 – Average level of activation (HbO) at Left Region of Interest for all conditions during Fault Solution Stage.

The fNIRS data was classified using linear discriminant analysis to categorise: (1) stage in the workflow, (2) passive vs. active training, and (3) presence of stressors. The classification performances against a standard test are; Distraction (79%), Fatigue (77%) and Increased workload

(86%). An example of one of the classification performance results bar charts is below (Increased Workload):

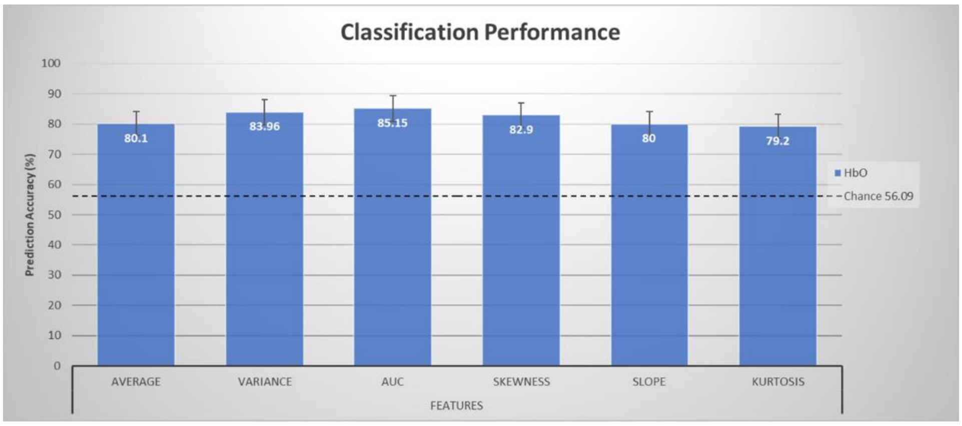

Figure 2 - Classification performance of Increased Workload Participants

Conclusions: Both, right and left areas of the PFC are sensitive to the presence of task stressors and troubleshooting activity during operational performance in the maritime engine room. On the basis of these findings, we can conclude that: (1) practical training was more beneficial (greater neural efficiency, lower activation) than passive training, (2) fNIRS can be used to detect increased activation of the PFC during troubleshooting, and (3) changes in neurovascular activation of the PFC were sensitive to different stressors experienced by maritime engineers on a regular basis.

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