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Measuring mental workload and physiological reactions in marine pilots: Building bridges towards redlines of performance

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ABSTRACT

This paper investigates the effects of shiphandling manoeuvres on mental workload and physiological reactions in ten marine pilots. Each pilot performed four berthings in a ship simulator. Those berthings were differentiated by two factors, level of difficulty and familiarity with the port. Each berthing could also be divided into five phases, three during the execution and two resting periods, one before and one after the execution (dedicated to baseline physiological data collection). Mental workload was measured through two self assessment scales: the NASA TLX and a Likert scale. Power spectral densities on Beta bands 1 and 2 were obtained from EEG. Heart rate and heart rate variability were obtained from ECG. Pupil dilation was obtained from eye tracking. Workload levels were higher as berthings increased in difficulty level and/or the pilots completed the berthings in unfamiliar ports. Responses differed across specific phases of the berthings. Physiological responses could indirectly monitor levels of mental workload, and could be adopted in future applications to evaluate training improvements and performance. This study provides an example of an applied methodology aiming to define an upper redline of task demands in the context of marine pilotage.

1. Introduction

Shipping represents the major player in transportation with commercial vessels carrying around 90% of the world trade. As reported by the International Chamber of Shipping, the maritime industry generates an annual income of over half a trillion US dollars in freight rates, with a worldwide population of seafarers serving on internationally trading merchant ships on the order of 466,000 officers and 721,000 ratings (ICS, 2016). Even though some authors consider the shipping industry having a fairly good safety record (Hetherington et al., 2006), it does not compare particularly well to other mass transport modes, and is not necessarily improving its performance.

A study conducted in the US comparing different transport modalities, reports that the workplace fatality rate per 1000 employees in the maritime transportation (0.24) is four times as high as the one in the air transportation (0.06) (Savage, 2013). In 2013, a report from the IMO (international Maritime Organization) Correspondence Group on E-navigation provided some statistics based on the IHS Fairplay casualty database (considered the most complete and reliable maritime data source in the world). This report highlighted how the total number of navigational accidents on cargo, passengers and offshore ships increased between 2001 and 2010 (from less than 400 in 2001 to more than 700 in 2010). The report showed also how the number of accidents per ship increased from 0.5% in 2001 to 1% in 2010. Of the total number of accidents considered, 22% were groundings, 22% were collisions and the rest were classified as other types (IMO, 2013).

Many systemic factors have been identified as contributing to maritime accidents (Perrow, 2011), such as the social organization of the personnel on board, economic pressure, 'hidden' ownership structures, and difficulties in international regulation. At an individual level, long contracts, limited sleep opportunities between shifts and short turn-around times can create fatigue, stress and work pressure (McNamara et al., 2000). An example can be found in a Scandinavian study that compared the psychosocial working conditions and mental health of a group of maritime engine officers with a group of British shore based professional engineers. The study highlighted that while the British shore based engineers reported significantly higher role ambiguity the Swedish engine officers perceived a significantly higher degree of role conflict and higher perceived stress (Rydstedt and Lundh, 2010). A Canadian report (CMPA, 2017) explained how one of the most effective measures that are adopted in the shipping industry to mitigate groundings and collisions is the use of Marine Pilots. The reports highlighted how piloted ships are able have their risk reduced 44 times compared to not piloted ships (from 0.094 to 0.0021 probability of accident per vessel). The risk of collision and grounding drops 12 times

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more if a piloted vessel has also tugs in assistance (from 0.0021 to 0.00018 probability of accident per vessel).

Within this context, marine pilots were chosen as participants in this study. Marine pilots are ship's captains that are specifically trained and certified to manoeuvre vessels within critical coastal and port waters. They embark a ship outside port waters and then work with the bridge team to navigate the ship to berth. While ship's Captains still retain the full charge of the vessel, pilots generally take the “conduct”. They manoeuvre the ship in enclosed and or critical waters until a safer position is reached or the vessel is alongside the assigned mooring. Piloting involves a complex interaction between the pilot and a bridge team, tug masters, a vessel traffic service and electronic equipment.

Pilots can be defined as “experts” following the definition of those who acquired noticeable skills or knowledge of a particular subject, through training and practical experience, capable of recalling complex, task specific patterns gaining access to the right information (Scardamalia and Bereiter, 1991). As experts, pilots are expected to be specialists having specialised knowledge (Mieg, 2001); they are able to restructure, reorganize, and refine their representation of knowledge, applying it more efficiently into their environment. Pilots, with their expertise being the result of a complex adaptations of mind and body, should be able to exploit substantial self-monitoring and control mechanisms to the tasks and goals imposed to them by the environment (Ericsson and Lehmann, 1996). Their actions should be smoother and more efficient, and performance should be achieved with a minimal effort, running essentially automatically, with minimal cognitive control (Posner and Snyder, 2004). They should be able to run more processes in parallel, thanks to the reduction in the mental workload due to automaticity (Shiffrin and Schneider, 1977).

Mental workload is a multidisciplinary concept (Young et al., 2015) and has long been recognized as an important element of human performance (Eggemeier et al., 1991) (Parasuraman et al., 2008), particularly important in high risk environments (Jou et al., 2009) and those demanding high levels of reliability (Carswell et al., 2005) (Yurko et al., 2010). Mental workload varies around a combination of task demands and resources that a particular individual has available (Noyes et al., 2004) (Young and Stanton, 2005). From this “resource-based view”, mental workload can be seen as the level of attentional resources required to meet both objective and subjective performance criteria, which may be mediated by task demands, external support and experience. For the purposes of this study, mental workload followed the definition of subjects’ direct estimate or comparative judgment of mental or cognitive effort experienced at a given moment (Luximon and Goonetilleke, 2001).

Even though qualitative studies have been conducted (Lützhöft and Nyce, 2006), we still cannot define what would be an acceptable level of workload and what are the physiological implications for pilot's workplace health and safety. The levels of mental workload in shipping, compared to other areas of the transport industry are relatively unknown, as indicated in a recent review (Young et al., 2015), with only few papers published in the last thirty years. A 2008 study, involving 20 Norwegian Navy cadets, investigated the relationship between workload, navigational method and performance in a shipping simulator. The use of electronic chart and information systems (ECDIS) was compared against traditional methods of navigation (paper charts). The use of ECDIS highlighted advantages in terms of ship position accuracy and handling, but did not provide significant differences in workload, as measured by heart rate variability and skin conductance (Gould et al., 2009). A previous study used heart rate variability to assess the workload of a single officer of the watch. Significant differences in workload were found while conducting a real vessel in six different geographical areas (Murai et al., 2004).

Anecdotally, marine pilots would appear to face considerable variation in workloads when managing different manoeuvres, working in changing environmental conditions and due to the dynamic nature of commercial shipping. For pilotage organisations, the main concern is that workload experienced might breach acceptable levels, exceeding what has been defined as the “red line” of workload/performance (Brookhuis et al., 2003). Given that a single accident has the potential to close an entire port, establishing this “redline” is of value to port authorities and pilotage organisations. In a study conducted on car drivers, Horrey and Wickens introduced the possibility of analytically calculating the impact of competing pairs of tasks on workload and performance (Horrey and Wickens, 2003) and were able to account for almost 100% of the variance in task performance and hazard response.

With these elements in mind, this study aims to quantify and evaluate the impact on pilots workload of different shiphandling conditions while berthing ships in a simulator, adopting concurrent self reported and physiological measures. The hypotheses investigated are:

- Berthings with different levels of difficulty should elicit different levels of self reported scores as well as different levels of physiological reactions.
- Berthings performed in a foreign port should elicit higher levels of workload.
- Concurrent measurements known from the literature to be related to workload, should show similar trends.

2. Methodology

2.1. Experimental design

To investigate pilots’ workload and its related measures, four different berthing manoeuvres were set as experimental conditions. Exactly the same four berthings were conducted by each participant, even though in random order, to mitigate a possible learning effect. Each berthing included the whole process necessary to transfer the ship from a defined initial position to a berth within constrained port waters, with the use of own and/or external means of propulsion (i.e. tug boats to assist, when allowed). The berthings were presented to pilots before being performed in the simulator, since every participant was required to provide a plan, such as the one normally discussed by pilots and ship masters before a ship enters into a port (Wild and Constable, 2013).

2.2. Participants

The participants to this study were a group of ten marine pilots from an Australian pilot company. They were all males in good health, as required by national professional medical standards set by the Australian Maritime Safety Authority (AMSA, 2010). An Analysis of Variance (ANOVA) for age and service confirmed no significant difference between the participants and the rest of the pilot population working for the same company. All the pilots involved in the research had more than ten years of previous experience in pilotage, even if not in the same Company. The number of participants is comparable to similar studies focused on niche professional categories (Di Stasi et al., 2015) (Sirevaag et al., 1993) (Itoh et al., 1990). Before completing the berthings in the simulator, pilots had one (or more, if required) face to face session(s) with the researcher in order to provide their passage plans, a detailed descriptions of their shiphandling expectations sketched on a navigational chart (Orlandi et al., 2015). Once the passage plans were completed for all the four required berthings, each pilot spent a whole day at the simulator facility to perform the exercises (five in total, including the familiarization). The two simpler berthings had a duration of about 1 h, while 2 h were necessary to complete the two most difficult ones. During the berthings (and also before and after, for specific physiological measurements) the studied variables were continuously recorded, obtaining for each pilot between 6 and 8 h of continuous physiological data collection, as elicited by the different manoeuvring scenarios. The authors assert that all procedures contributing to this work comply with the ethical standards of our University and the relevant national and institutional committees on