Systemic assessment of the effect of mental stress and strain on performance in a maritime ship-handling simulator

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Abstract: Two studies will be presented as part of a systemic approach for assessing performance in nautical simulators. A mixed-methods quasi-experimental field study (N=6) was conducted, aiming at discerning the systemic causes behind nautical students' human errors during simulator exercises and to what extent these causes can be related to the layout of a new decision supporting display. Results indicate that all errors occur under the same kind of (demanding) man-machine interaction. Based on this, design requirements were proposed. The second study aims at exploring the impact of situation-related affective arousal on system safety. Anger- and frustration-like situations will be generated and the possible impact of these affect-laden situations on the risk- and error-related performance of simulator ship bridge crews assessed. The studies address different aspects of performance in complex environments and their modularity towards each other will be highlighted in the context of an overall systemic perspective.

Keywords: Systemic error analysis, resilience, Cognitive Couplings.

1. INTRODUCTION

Shipping is a distinctly international industry with 50,000 merchant ships operating worldwide. New crews, that enter the professional domain, have to be adequately prepared in order to be able to conduct their work in a safe manner in the face of an industry that is prone to catastrophes (Hetherington, Flin & Mearns, 2006). This training has to integrate a multitude of aspects as accidents and catastrophes cannot usually be traced to a single failure or mistake, but result from the confluence of a series factors or errors (Rothblum, 2000). Therefore training aiming at promoting safe behaviour needs to address a broad range of situational factors that can contribute to accidents.

A combination of two studies addressing this issue will be presented. The first study aimed at assessing the impact of a decision supporting display on nautical student's performance. The second study aims at incorporating current issues in the real-world domain of seafaring by investigating the safety-critical effect of emotions on performance.

2. THEORETICAL BACKGROUND

Central for both approaches is the concept Cognitive Couplings (Sträter & Bubb, 2003) that has been validated in the nuclear power industry (Sträter, 2003) and provided applicable results incorporated in pilot training (Günebak, 2010).

2.1 Cognitive Couplings

The individual mind is bound to the external world by means of interaction, thereby forming a system in which the human acts in continuous coordination with external stimuli in order to accomplish certain goals at hand (Sträter, 2005). The term mental workload is often used in order to denote the coupling between individual and working context. However, mental workload is not a unidimensional concept. It incorporates both mental stress (the stimulus side of metal workload) and mental strain (the response within the individual mind) as described in ISO 10075 (ISO, 1991).

The Cognitive Couplings further elaborate on the concept of mental stress by providing a classification scheme for the type of mental stress associated with a specific working situation (Table 1). Furthermore, the binary Cognitive Coupling modes associated with every Cognitive Coupling type classify the level of demand that situational, task-bound stimuli impose on the individual mind.

The actual effect of mental stress on a person may vary between individuals. Mental strain represents this variable effect of mental stress on the individual mind and always precedes any kind of performance (Figure 1). Thus, an observed action always has to be regarded as the result of both the task-bound stimuli preceding it (mental stress, classified by Cognitive Coupling types/modes) and the corresponding mental strain (the reaction within the individual). Therefore, errors occur when the individual is unable to cope with the mental stress stemming from the working environment (Sträter, 2005).

For instance, a student in the role of the captain of a (simulated) ship has the task of setting the heading for the entrance of a harbour. In order to accomplish this, he/she has to set multiple dimensions (Dimensionality, Table 1) in interrelation (current, wind, speed, etc) in order to discern when and with which force a rudder command should be given. As the attempt to find the correct solution and action takes too long (mental strain), the correct rudder command is initiated too late, leading to a collision. In order to improve training, the operating environment may be remodelled to facilitate the task by reducing the effort that is needed to find the correct action.

Fig. 1. Mental stress associated with a task leads to mental strain within the individual, which in turn precedes performance.

3. STUDY 1 – "HUMAN ERROR" IN AN EDUCATIONAL SHIP HANDLING SIMULATOR

As the layout of maritime simulator components is not predefined by national or international standards more than on a rudimentary basis (ISO 2007), the operators of maritime simulator facilities face the difficult task of fitting these components to the training needs of their nautical students. The object of interest of this study is the Conning (Information) Display that is currently being evaluated in order to meet nautical student training needs and to thereby improve simulator training.

3.1 Aim

The purpose of this study is to investigate how well the Conning Information Display fulfils its intended purpose in promoting safe behaviour in actual simulator training exercises. Between group and within group comparisons of student crews will provide insight into the question of whether the display influences performance at all while qualitative methods will reveal what the nature of this influence is.

3.2 Method

6 persons, all of whom male, participated in the study. The participants were students of Marine Science studying at the FH OOW (FH Oldenburg /Ostfriesland / Wilhelmshaven) and had the role of a captain of the crew on the simulator bridge. The average age of the participants was 22 years. All exercises took place in the simulator facility of the FH OOW in Elsfleth and were part of the manoeuvring exercises (Manövrieren) which consist of 6 different scenarios, requiring the students to enter a harbour, to berth, to pass other ships in narrow waters and to manoeuvre in strong current. The participants were chosen by means of administrator selection.

Within and between group designs were used in assessing the effect of the display on student performance. The dependent variable performance describes how the combination of mental stress (in terms of the level of demand posed individuals via Cognitive Couplings modes) and the corresponding mental strain influences behaviour. Performance is operationalized by the number of committed errors as identified by a seasoned maritime expert (for instance a crew leaving the designated waterway, thus violating scenario instructions). In order to discern how the presence of the display changes Cognitive Coupling modes, the status of the Conning Display was manipulated by switching it on/off (independent variable).

Semi-structured interviews were conducted with the captain of the crew. The aim of the interview was to generally discern the systemic causes leading to an error by setting them into relation with the level of demand associated with the Cognitive Coupling modes. Thus, the interview aimed at ruling out the modes of a Cognitive Coupling during an error sequence, for instance if the task at hand was mulitdimensional or unidimensional (Table 1).

Additionally, two types of observations were conducted for every participant. First, the participant behaviour was observed indirectly and online during the exercise in conjunction with an expert (training instructor). Subsequently, a second round of observations was conducted by evaluating the video recordings (eye-tracking, CCTV-recording and a recorded video of the instructor station), with special focus on the sequence where the errors occurred.

3.3 Results

With the quantitative analysis being inconclusive due to the low number of participants, no conclusion on whether the Conning Display influences performance can be derived.

However, when comparing the observational and interview data obtained during error sequences, a clear pattern emerges. All errors, irrespective of the status of the Conning Display (on /off), occurred under similar, demanding Cognitive Couplings modes (Table 1). This fits well with previous research indicating that performance will degrade for demanding Cognitive Coupling modes (Sträter, 2003). Thus, as the layout of the Conning Display does not seem to provide adequate support for the manoeuvring tasks in its current form, layout modifications reducing the demand from Cognitive Coupling modes should be implemented.

Table 1. Mental stress in terms of demanding Cognitive Coupling modes (+) for errors sequences. The less demanding modes are listed in brackets for the sake of completeness.

Cognitive Coupling Type	Mode	Description
Type of task	(+)Monitory (vs. Active)	Monitors ship's reaction to rudder commands
Dimensionality	(+) Multi-dimensional (vs. Uni-dimensional)	Speed, acceleration, rudder inertia, etc
Necessary Operation	(+)Simultaneously (vs. Sequential)	Can choose freely when to execute which actions; requires coordination
Information Presentation	(+) Compensatory (vs. Pursuit)	Difference between current state and desired state is not displayed
Internal Compatibility	(+) Internal Incompatibility (vs. Compatibility)	Mapping between rudder commands and ship reaction is unclear

3.4 Design Proposition

A possible design approach is illustrated by a statement of the most successful captain (his crew did not commit any errors), stressing that he constantly was thinking 3 minutes ahead when giving rudder commands. This statement offers an explanation on what the current state of a ship consists of in the maritime context. It extends into the future in the sense that it incorporates what the momentary orientation towards a desired state is. For the captain entering a harbour for instance, this means that the desired state is "the ship that has entered the harbour safely" and the current state is the ship's current orientation towards this state. This orientation is influenced by ship internal (e.g. speed, delayed effect of rudder commands) and external factors (e.g., wind, current).

If the current and desired state can be displayed clearly in the Conning Display, the difference between the two states would be visible directly and would not have to be inferred by the individual. Thus, the Cognitive Coupling modes demanded by the display would shift from the demanding compensatory to the less demanding pursuit mode (Table 1, Information Display would switch from compensatory to pursuit). In order to display the orientation towards a desired state, the ship's track has to be displayed as a projection into the future, taking all relevant ship-external and ship internal factors into consideration, thus displaying this information in an integrated way tailored to the task at hand.

This functionality would assist the students in identifying wrong actions and in countering them right away, before they lead to accidents, therefore encouraging resilient performance (Hollnagel, Woods & Leveson, 2006).

3.5 Discussion

Although the number of participants was low thereby limiting the ability to draw statistical inferences, the findings in the qualitative analysis were conclusive. All of the committed errors occurred in Cognitive Couplings modes associated with comparatively high demand. The design proposition was tailored to reduce the demand by shifting Cognitive Couplings modes offered by the Conning Display. Thus, the display will hopefully contribute to promoting safer behaviour of student crews during all simulator exercises by reducing the task-bound demand.

4. STUDY 2 – AFFECT-RELATED BEHAVIORAL INTERFERENCES, TEAMWORK PROCESSES AND OPERATIONAL SAFETY DURING COMPLEX SHIP-HANDLING TASKS ON THE SHIP BRIDGE

The role of emotions has become increasingly interesting for research regarding human reliability and system safety in high risk organizations (Straeter, 2005). Several studies in the recent past have also highlighted the close relationship of emotions, risk perception and risk-prone behaviour (Lerner & Keltner, 2001; Sjoeberg, 2007). Furthermore, (emotional) stress is found to be a significant impairing factor for mental and physical health in the maritime domain (Hetherington et al., 2006). Since induced (emotional) stress in terms of anger and frustration carries a negative effect on risk perception and performance (Schütte, 2002), the role of stress on mariner's performance should be further explored in order to uncover any important issues with possible safety-critical impact.

This will be achieved through the assessment of the effect of situation-related affective arousal on system safety and operationalized by the generation of anger- and frustration-like situations, which can occur in everyday life maritime operations. The investigation and evaluation of possible effects of emotional arousal on performance will also take the specific stress created by the task into consideration. The possible impact of these affect-laden situations on the risk- and error-related performance of ship bridge crews will be assessed in terms of committed errors, error management (error detection and correction) and therefore also system resilience. Furthermore the possible moderating role of non technical skills (between affective arousal and safety-related performance will be analyzed in order to rule out the usefulness of the concept for maritime ship handling operations.

The preliminary results, which will be provided within the framework of a doctoral thesis, will provide insight into the impact of emotions on system reliability and system safety and the possible moderating role of non technical skills (affecting mental strain) between affective arousal and safety-related performance.

6. OVERALL CONCLUSIONS

While the first study promoted safer simulator training by fitting the present technical layout to the needs of the students, the second study will investigate the role of emotions and arousal in simulator training in order to improved the safety-oriented behaviour of nautical students.

Both studies share the same theoretical framework but with different focal points. The first study addressed the task-induced demand (mental stress) and how to correspondingly reduce it by modifying the working environment, thereby promoting safety-oriented performance.

The second study will delve deeper into the concept of mental strain by investigating the effect of non-technical skills on the subjective experience of mental strain when facing affect-laden situations. Thus, training concepts may be derived, preparing the students for dangers possibly to be encountered in real-life seafaring.

The studies therefore complement each other in creating a more profound picture of simulator training in the maritime context and illustrate how both workplace and human-oriented improvements may be generated from a systemic analysis of human performance.

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