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Operator situation awareness and physiological states during offshore well control scenarios

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ABSTRACT

Incident reviews of oil spill events (both large and small) suggest that human error is a contributor to 50% of well control incidents (primarily kicks). The purpose of this study was to examine operator situation awareness (SA) and associated physiological load, using heart rate and heart rate variability (HRV), during different simulated offshore well control scenarios (drilling and tripping) and criticality levels (failure presented or not). Ten trained participants completed four scenarios (tripping non-failure, tripping failure, drilling non-failure, and drilling-failure) in an experimental session, lasting ~6 h. Measures were obtained for each scenario, including speed and accuracy of the task performance, composite scores obtained from the Situational Awareness Rating Technique (SART), and operator heart rate and heart rate variability measures. Greater errors were found in kick-related failure events, and drilling scenarios were associated with longer reaction times. Participants perceived lower SA levels during drilling scenarios, and the was observed for lowest SA during drilling failure scenarios. Finally, while physiological responses did not differ significantly for any of the four scenarios, elevated heart rate was observed with drilling and failure-related scenarios. High variability in participant covert and overt responses may increase the challenges associated with classifying high-risk well control scenarios. It is critical that scenario planners understand and recognize the variability in driller situation awareness and associated physiological load when planning for alternative future scenarios.

1. Introduction

In offshore oil and gas operations, the driller plays a distinct role in maintaining safety for the entire rig. During the drilling phase (versus production or completion) of operations, the driller's primary responsibilities are essentially to supervise the rig floor staff and ensure that the drill plan (developed by the drilling engineer and others) is followed. Following the drill plan is a dynamic, complex, series of tasks such as, inserting more pipe into the wellbore (tripping in), creating greater depth of the wellbore (drilling), removing pipe from the wellbore (tripping out), as well as monitoring the pressure on the drill bit, pressure downhole, etc. At any given point during any of these operations, a kick can occur if the formation pressure gets higher than the hydrostatic pressure in the wellbore (Hutchinson and Rezmer-Cooper, 1998). The driller is primarily responsible for monitoring pressure levels to identify the precursors of a kick, and if those exist, respond in a way that prevents the kick from becoming a blowout—putting the rig and all its personnel at risk. As with other jobs, the nature of some of the tasks the driller perform are more complex and/or frequent than others and these two attributes of a task can reliably impact performance in many work domains (Roberts et al., 2015). More complex tasks require greater cognitive resources and over time these tasks may affect operator performance if sufficient rest/recovery is not provided, and/or the operator is not adequately trained. Alternatively, frequently occurring tasks may condition an operator to respond appropriately, i.e., "training on the job". However, it is not clear how operators respond to different types of tasks that may differ in complexity (tripping vs. drilling) and that vary in the level of criticality (e.g., a kick event rates high in criticality).

Situation awareness (SA) refers to a person's perception and understanding of their dynamic environment and can be contextualized within occupational safety as a worker's understanding of what is going

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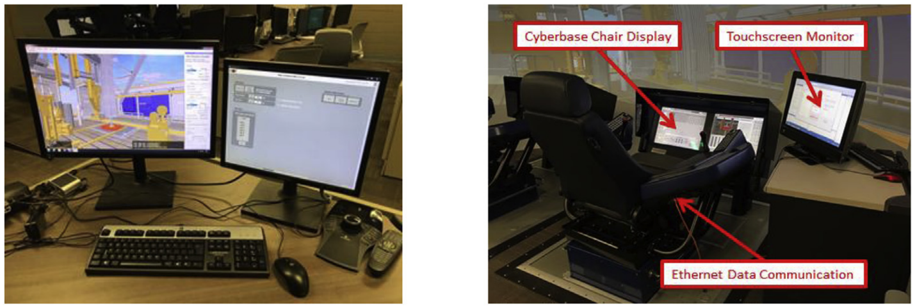

(a) (b)

Fig. 1. (A) Command station for specification and control of drilling environment. (b) Cyberbase chair with external touchscreen computer for wellbore simulation.

on around them as it relates to their performance and safety (Endsley, 1995a,b; Salmon et al., 2009). This awareness and comprehension is critical for making correct decisions that conclusively lead to correct actions in offshore environments. Improving worker SA has become an important objective for the offshore oil and gas industry. Offshore drillers need to maintain a high level of SA to sustain well control, ensure rig safety, and minimize risk. A drillers' ability to recognize and interpret indicators that can identify fluid influxes and losses within the wellbore (known as kick detection) is crucial for maintaining well control, and allowing the proper corrective actions to be made to deal with the situation (Roberts et al., 2016). SA can serve as a predictor of performance and has been particularly important where technical and situational complexity impacts the decision-making efforts (Durso et al., 1998; Endsley, 2016). However, experimental studies examining operator SA in offshore well control scenarios that vary in the levels of complexity and criticality, are lacking. These types of studies are necessary to predict operators' performance in different well control situations and with this information, effective methods for mitigating human error can be developed.

Heart rate and heart rate variability (HRV), measures of cardiovascular reactivity to cognitive and physical work, have shown strong associations with executive functions, specifically working memory and continuous performance abilities (Hansen et al., 2004; Hansen et al., 2003). Given that executive functioning may play a major role in operator SA, Saus et al. (2006) demonstrated that HRV and SA were positively associated in simulated shoot/no-shoot scenarios. However, Sætrevik (2012) showed that while HRV was correlated to objective measures of SA, no relationship was found for subjective measures of SA.

Recent attention has been placed on operator performance and associated SA during well control scenarios, primarily through observational studies (Sneddon, Mearns, & Flin, 2006a, 2006b; Stanton and Wilson, 2001). However, because SA and physiological states are critical indicators of operator performance and health in offshore operations, and that both have previously shown to be impacted by task complexity (Roberts et al., 2015; Sneddon et al., 2013), it is also important to examine both operator SA and physiological responses in such experimental investigations. The purpose of this study was to examine operator SA and associated physiological responses during simulated offshore well control scenarios that differed in their complexity and criticality levels through a repeated measures experimental design.

2. Methods

2.1. Participants

A convenience sample of 10 senior-level petroleum engineering students (8 males, 2 females) with mean age (SD) of 21.7 (0.67) years were recruited from a Drilling and Well Completion course at the University of Texas at Austin. Participants were recruited using study flyers distributed in relevant courses. Only those who had ~10 h of simulator experience were eligible to participate. Participants attended one experimental session (approximately 6 h), in which they performed different operations required for offshore drilling. Upon consent, participants completed a demographic survey and were instrumented with biosensors, described later. The study protocol was approved by the Texas A&M and University of Texas Institutional Review Boards.

2.2. Drilling hardware-in-the-Loop simulator

The Drilling Hardware-in-the-Loop (HIL) simulator used for the experimental setup in this paper is an offshore drilling rig simulator donated to the RAPID Lab at the University of Texas at Austin (UT Austin) by National Oilwell Varco (NOV). Since, in the industry, the NOV HIL simulator is used for training new drillers in a risk-free environment before they start working on a drilling rig, the simulator can simulate pipe handling, pipe connections, running pipe in and out of the well, drilling and all associated auxiliary functions. Further, this simulator is sufficiently realistic and has been used in training for operators and drillers that improved safety integrity, decreased downtime and increased efficiency for technical and non-technical skills (Dadmohammadi et al., 2017). Further, the NOV simulator was an effective environment for the development, testing, and improvement of stick-slip prevention systems (Kyllingstad and Nessjoen, 2010).

The NOV HIL simulator consists of a command station (Fig. 1a) for definition and control of the drilling environment, render computers for graphical representation of the rig, and offshore drilling rig hardware, including NOV Cyberbase chairs for the driller and assistant driller, and programmable logic controllers (PLCs). The command station controls the simulation itself and specifies the drilling environment seen by the driller. The render computers produce the graphics of the drilling rig, allowing the driller to see the visual response of the rig. These graphics are a result of specifications from the command station, and response signals from the PLCs. The NOV Cyberbase chairs include panels and joysticks for the driller and assistant driller to remotely control equipment on the rig floor (Fig. 1b). The chairs also include display panels that show drilling parameters, alarm warnings, and camera displays to monitor equipment from various angles. The PLCs take commands from the driller in the chairs and send control signals to the virtual rig equipment and to the chair displays. Drilling parameter data (e.g. top drive RPM, block height, etc.) from the simulator can be accessed by an external device from the PLCs via the Cyberbase chairs. More specific attributes of the simulator can be found in Berg (2011).

The limitations of UT Austin's version of the NOV HIL simulator include lack of wellbore environment simulation (e.g. wellbore pressure, pore pressure gradient, fracture gradient, etc.), and inability to access to certain drilling parameters (e.g. mud pit levels). Since the NOV HIL simulator does not include simulation of the wellbore environment and certain drilling parameters, it was necessary to create a wellbore simulation on an external computer that receives data from