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Drillers' cognitive skills monitoring task.

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Title: Drillers' Cognitive Skills Monitoring task

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Abstract: Drilling incidents have emphasised that offshore drillers require a high level of cognitive skills, including situation awareness and decision making, to maintain safe and efficient well-control. Whilst there are a number of tools for supporting operators' cognition available in other high-risk industries, there is not a specific tool for drilling. We developed a prototype monitoring task simulating drilling scenarios, Drillers' Situation Awareness Task (DSAT) with drilling experts and piloted with 14 drilling personnel. Preliminary results suggest that it is viable as a tool for examining drillers' cognition with the potential for training and formatively assessing cognitive skills in drilling.

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Keywords: Drilling; Cognitive Skills; Situation Awareness Measurement; Simulated Computer Tasks; Expertise

INTRODUCTION

At 9.45pm on the 20th of April 2010, the assistant driller on the Deepwater Horizon drilling rig in the Gulf of Mexico, calls the supervisor to say that the sub-sea well that had previously been thought to be stable had now blown out. This meant that there was nothing to stop the hazardous hydrocarbons from travelling up the pipes that connected the well to the drilling rig. The driller was trying to regain control by activating the mechanical cutters on the sea bed to stop the hydrocarbons from travelling up to the rig floor (Chief Counsel's Report, 2011). Four minutes later, gas which had escaped from the well ignites, causing the first of two explosions on the rig (see Figure 1). This results in the death of 11 members of the crew, including both the driller and assistant driller, the rig's destruction and the worst oil spill in US history.

Figure 1. Deepwater Horizon drilling rig engulfed in flames as fireboats pour water onto the rig. Courtesy of U.S. Coastguard.

In the wake of the disaster, investigations reports identified the drill crew’s situation awareness as contributing to the blowout (Report to the President, 2011; Chief Counsel’s Report, 2011). For example, Roberts, Flin and Cleland (2015a) identified problems such as failing to monitor the well, misunderstanding of the well state and strong erroneous expectations that the well was stable. The disaster clearly illustrated that offshore oilfield drillers require high level SA, particularly during complex tasks such as well control (well control refers to using a hydrostatic column of drilling fluid to maintain control of the highly pressurised hydrocarbons and other fluids within the well bore; Roberts, Flin & Cleland, 2016). The skills, associated with Situation Awareness (SA), are increasingly important given advancements in drilling technology resulting in more reliance on cognition. SA is the state of knowing what is going on in the situation and using that understanding to anticipate how it will develop (Endsley, 1995a, b).

Recent research has identified the key cognitive skills that expert drillers use to develop and maintain SA of the well state and surrounding environment (Roberts, Flin & Cleland, 2015b). Further research into SA in drilling has been identified as vital for offshore safety (e.g. OESI report, 2016). Measurement and training techniques for operator cognition associated with SA and Decision Making (DM; e.g. in aviation, Endsley, 1990; Hauss & Eyferth, 2003), have had limited application in the oil and gas industry despite their potential value.

Our focus for this study is to adapt an existing monitoring task to the new context of offshore drillers' cognition with the aim of supporting and training these vital skills. It is hoped that this will have ramifications for safety and performance in not only drilling but similar, high risk, high reliability domains which involve monitoring.

What do drillers do?

In essence, offshore oilfield drillers are responsible for the hazardous task of drilling into the sea bed, constructing a well bore to gain access to, and extract hydrocarbons (e.g. oil and gas). As hydrocarbons are highly pressurized with high temperatures, they need to be controlled using a hydrostatic column of drilling fluids. This complex task is referred to as well control. In conjunction with the drill crew, including the assistant driller, roughnecks, and tool pusher (supervisor), the driller controls the majority of the equipment, and subsequently the well, from the drill cabin.

Figure 2. Driller monitors the drilling screens with the drill floor shown in the background. Courtesy of Maersk Drilling.

On newer generation drilling rigs/cyber rigs, the driller is required to monitor up to eight LCD screens (displaying information from equipment hundreds of feet below the drill deck), and multiple CCTV video feeds, navigating between different control panels, as well as keeping an eye out the window onto the drill floor (for the safety of the crew working with powerful and heavy equipment) as shown in Figure 2. Thus, the driller has to interact with increasingly complex technology, requiring high level cognitive skills, principally associated with SA, to monitor and interpret the significance of the information coming from the well and surrounding environment.

Whilst the drilling industry has recognized the complexity of the drillers' task and the value of using low fidelity simulations to aid training (Letbetter, 1975), it is only recently that higher fidelity simulators have been introduced. Material on cognitive skills is being incorporated into simulation training via teaching non-technical skills (IOGP, 2014a, b) and team training methods (e.g. tactical decision games, Crichton, Henderson, &Thorogood, 2004), however, to the authors' knowledge there are no simulation training or measurement tools specifically designed for drillers' cognitive skills associated with SA.

Why do drillers need situation awareness?

Maintaining SA is critical for safe and effective performance in the drilling industry, yet research is limited with regard to understanding the underlying cognitive skills. Problems with drillers' SA have been identified, such as difficulties with concentration and interpreting information (e.g. Sneddon et al., 2006). Roberts et al. (2015a) identified the key cognitive components required by drillers to develop and maintain SA including: attending to the drilling screens and recognizing a pattern from available cues, comprehending the significance of cues to the situation using mental models, expectations and experience, and projecting how the situation may develop. We used interview and observation data to produce the Drillers' SA model (see Figure 3), based upon Endsley's (1995a, b) model of SA, in which SA is described as a cognitive product of three hierarchical levels, cue recognition and perception (Level 1), comprehension (Level 2) and prediction (Level 3).

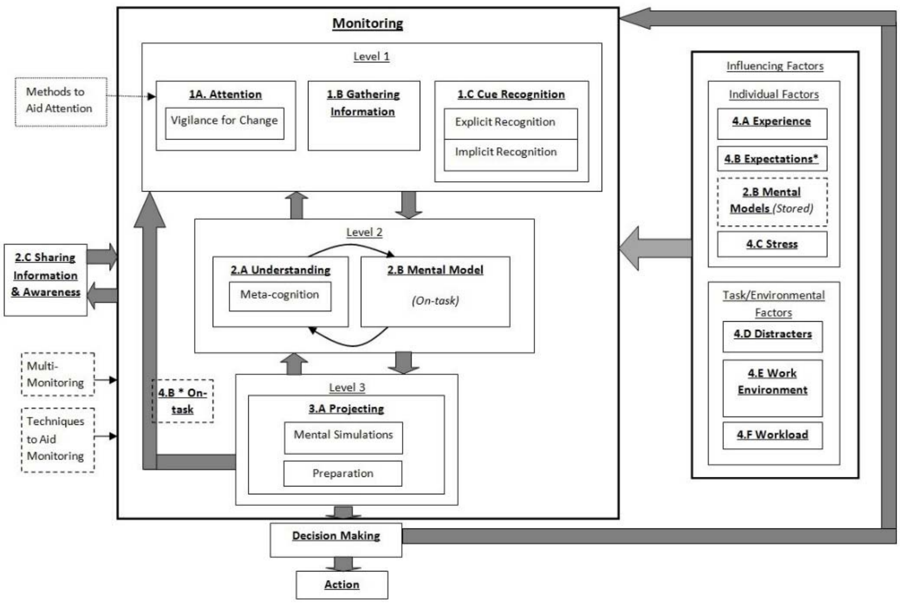

Figure 3. The Driller's Situation Awareness model illustrating the key cognitive components and associated skills required for developing and maintaining SA for safe well control.

The model has been subsequently used to examine drillers' SA in reports of the Deepwater Horizon blowout (Roberts, Flin & Cleland, 2015b) and in a cognitive task analysis of kick detection (kick detection refers to monitoring changes in readings from the well which may indicate that the pressure within the well may exceed the downward hydrostatic pressure, potentially resulting in a well control situation; Roberts, Flin & Cleland, 2016). We aimed to use the data and DSA model to inform the design of the simulation-based measurement task.

How to measure situation awareness?

A range of methods have been developed to examine expert operator SA (e.g. Loft, Morrell & Huff, 2013) including real time probes as they offer a direct and relatively objective measurement in which the participant responds to questions during a simulation task (e.g. Situation Present Assessment Method; Durso et al., 1998). An alternative but similar computer-based method, Expert Intensive Skills Evaluation (EXPERTise; Loveday, Wiggins, Searle, Festa & Schell, 2013), has been developed to examine aspects of SA expertise, including cue utilisation and pattern recognition (e.g. power control operators, Loveday, Wiggins, Harris, O'Hare & Smith, 2013). Similar to real time probes, participants monitor a domain specific display (e.g. intensive care unit screen) and respond when they recognise key cues during different tasks. In particular, two tasks appeared to be suitable to adapt to examine drillers' SA and decision making. One task measured the ability to extract diagnostic cues from the functional work environment (by clicking on an abnormal indicator) and other task measured the ability (accuracy) to discriminate the usefulness of available information via decision making.

AIM

Our aim was to develop a simulation-based monitoring task that examines drillers' cognitive skills, including cue recognition, comprehension and anticipation, and decision making. Firstly, we developed the prototype monitoring task with subject matter experts (Study 1) and then piloted it with a sample of drilling personnel to test its viability for examining drillers' cognitive skills (Study 2).

STUDY 1 TASK DEVELOPMENT

The authors of EXPERTise generously gave access to an early version (1.0) of their program to determine if it could be adapted but this proved impractical, so a new program was developed using the programming platform Delphi 6 (Borland Software Corporation, 2009) with an experienced programmer (JU). The interface was based on generic drilling parameter screen images supplied by the sponsoring company.

Scenarios

Four scenarios plus a practice trial were developed in conjunction with two drilling experts, both of whom had over 20 years' experience in drilling and were now drilling instructors. In addition, the sponsor's simulation training well control scenarios and well control incident reports, technical well control manuals, and a cognitive task analysis were used (Roberts et al., 2016). Situation awareness requirements (Endsley, 2016; what the participants would need to know) for key points of each scenario were identified with the drilling instructors. This included benchmarking data against which to examine the participants' performance (e.g. minimum cues that needed to be recognised to take the correct decision). The four scenarios developed were: drilling into a hard formation, drilling into a transition zone, drilling into a porous formation, and drilling into a hard formation whilst encountering equipment problems. Additional details on the scenarios, as well as example SA requirements, are in Appendix A.

Task

Participants monitored the simulated drilling parameter screen (See Figure 4 below). In drilling, cues are predominantly changes in the drilling parameters (e.g. increase in flow rate). Each line represents a drilling parameter/variable with the dips and peaks representing changes in that parameter. The reader will notice that these changes often occur in patterns across the parameters (i.e. one parameter effects another).

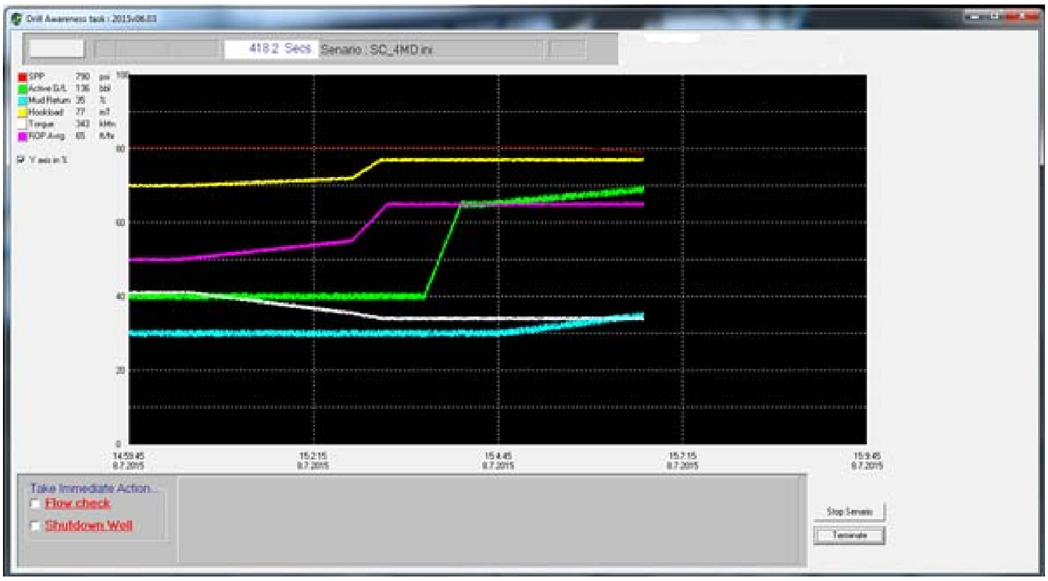

Figure 4. Screen shot of the completed scenario 4 running on the DSAT program as discplayed to particpants.

To indicate that they had recognised a cue, they clicked on the cue's location on the screen. This acted as a measure of cue recognition in the form of accuracy and latency (time taken to recognise cue since onset). Indicating recognition of a cue prompts a probe question with a multiple-choice response. A generic question, based on what the supervisor would typically ask the driller was used: "What is the current situation?" Four response options were presented, typically consisting of incorrect, partly correct, a correct level of understanding and the fourth indicated a higher level of understanding in the form of anticipation, depending on the scenario. Response scores consisted of: completely wrong = 0; recognising a cue = 1-3 (i.e. minimal awareness); comprehension of the situation = 4-6; and anticipating how the well state may progress =7-9. The score within each category (e.g. 7-9) depends on the pre-determined scoring of the particular option included in the MCQ, varying with the level of complexity and subtlety of the changes in the scenario (i.e. more complex scenarios required options to have a greater level of subtlety).

Similar to cue recognition, for each scenario there was a comprehension and anticipation minimum benchmark required needed to take the correct decision.

Two decision actions (based on the cognitive task analysis, Roberts et al., 2016) were included that could be selected at any time: either to flow check or shut in the well, both of which would terminate the scenario. The accuracy and latency of the choice of these two options was the performance measure of decision making.

Pre-Pilot

After development, these scenarios were piloted on five novices (four postgraduate psychology students and an individual with experience in the oil industry but not in drilling). We found that novice participants responded to obvious, sudden cues rather than gradual changes, generally selecting basic comprehension responses, and none took the correct decisions at the correct time. Two drilling instructors also completed the task identifying the cues, more frequently selecting the higher anticipation responses and making the correct decisions quickly (i.e. small latency responses). This pre-pilot illustrated that the task was functional in that both novices and experts understood what was required in terms of responses but that it still required a level of expertise to complete correctly (i.e. the task provided a basic differentiation between novice and expert).

STUDY 2 PILOT STUDY

The aim of study 2 was to pilot the prototype Drillers' Situation Awareness Task (DSAT) to test its preliminary viability for examining drillers' SA and decision making during four drilling scenarios.

Method

Procedure. The DSAT was piloted over a five-week period at two of the sponsor's training simulation facilities during training courses. Access was negotiated to a sample of drillers from the same company, attending level three and four, mandatory well control training courses (through personnel who had previously been involved in the project, i.e. 'snowballing' recruitment (Marshall, 1996)). Ethical approval was granted by the University's Psychology Ethics Committee.

Before starting the task demographic information was gathered: information on age, current job position, years' in that position and time since last in the driller's chair. This was followed by the task instructions. At the beginning of each scenario, hand over information was given (this could later be manipulated for priming). For example, *"You are drilling ahead at 4,450ft. You are not expecting any problems with the formation or equipment").*

Sample.

Drillers completed the DSAT typically in classes of three or four individuals. The sample (n=14) consisted of three drillers, an assistant driller, two tool pushers, five drilling instructors and three offshore installation managers from drilling rigs. The age of the participants ranged between 25 and 55 years (25-35 n=4; 36-45 n=4; 46-55 n=4; 56-65 n=2). More than half of them had spent time in the driller's chair in the last year (57%) (last month n=5; last 6 months n= 1; last year n=2; 18 months n=1; last two years n= 1; five years + n=4). The participants had a mean of 15years' experience in the drilling industry (range 5-30 years, S.D = 8). The majority had more than 10 years' experience (79%).

Data Analysis. The responses were analysed using SPSS 21 (IBM, 2012). The analysis consisted of cue accuracy and latency, comprehension accuracy, and the decision selected and the time taken (see above).

Results

The participants completed the DSAT in an average of 24 minutes (range = 18 - 34 minutes).

Cue Recognition. The results (see Table 1) showed that on average the participants responded to three cues (mean= 2.6 SD=1.1) out of a possible 5.5 cues (where two cues (mean=2.1 SD=0.5) were the minimum benchmark) within a mean of 20.9 seconds of the cue appearing (SD=30.5). This suggests that all participants were able to recognise and respond to sufficient cues to understand the developing situation.

Insert Table 1 approximately here

Comprehension & Anticipation. On average, the participants scored 17.9 (SD=6.9) out of a possible 43.8 for the comprehension and anticipation MCQs, where 9 was the minimum benchmark, with a similar score reflected across the scenarios (see Table 1). This suggests that the participants formed a sufficient understanding and/or anticipated how the scenario may develop to make a decision.

There is a discrepancy between the level 2 and level 3 SA responses (see Table 1). Whilst participants could be recognising the cues and going directly to anticipation, it is more likely that they had already understood the situation before selecting the anticipatory MCQ response.

Decision Making. The results suggest that despite variations in SA, the majority of the participants made the correct decision for each scenarios (Table 1). In general, the participants took a decision within a minute of the correct decision point (i.e. benchmark time; see Task Outline), suggesting that they were responding relatively quickly.

DISCUSSION

Considering the importance of drillers' situation awareness and decision making for maintaining well control, and consequently the safety of not only the drill crew, but also the drilling rig, it is crucial to have tools that support their cognition. The prototype Drillers' Situation Awareness Task (DSAT) was developed as a tool for examining drillers' key cognitive skills associated with situation awareness. Preliminary evaluation suggests that it is viable as a tool for measuring drillers' cognition using performance measures, in which participants were able to identify cues (cue recognition accuracy and latency) to develop a sufficient understanding of the well control situation (comprehension and anticipation accuracy) so as to take the correct decision (decision making accuracy and latency). These measures related to Endsley's three key SA cognitive processes, and so those in the DSA model, of perception and cue recognition (level 1), comprehension and understanding (level 2) and anticipation (level 3) as well as subsequent decision making. Informal feedback from the participants supported ecological validity, commenting that task and scenarios seemed realistic and that the tool would be valuable for training both technical and cognitive skills, particularly in less experienced drillers or assistant drillers. With further development and evaluation, the DSAT has the potential to be used as part of training and formatively assessing cognitive skills in drilling, supporting safe performance (see below).

The DSAT adds to the limited existing methods for supporting and training cognition in drilling which are mainly team class-room based exercises (e.g. non-technical skills training, IOGP, 2014a; tactical decision games, Crichton, Henderson & Thorogood, 2004). The DSAT has been derived from several established techniques (EXPERTise (Loveday, Wiggins, Searle, et al., 2013) and real-time probes (e.g., Durso et al., 1998). It has the potential to be a relatively objective measure of SA compared to self-rating techniques (e.g. Taylor, 1990) or observer rating tools (e.g. Matthews & Beal, 2002), as well as being portable. It does not require participants to travel to a large, costly training facility.

The DSAT is a prototype tool and as such has a number of limitations, possible solutions through future research are outlined. The MCQ options could be assisting or biasing the participants' SA by priming their awareness or re-directing their attention (Salmon et al., 2009). To give a more accurate measure of awareness, the MCQ options could include both comprehension and anticipation, requiring participants to select as many as they think are correct.

Once further refined, a study could be conducted to evaluate the reliability, sensitivity and validity of the DSAT, such as was done for the SAGAT (e.g. Endsley & Garland, 2000) as well as developing benchmarking data for assessments and individualised feedback. This tool could be further refined to train specific drilling skills as outlined in the DSA model (e.g., significance of patterns of cues and possible anticipated outcomes), examine influencing factors (e.g. distractions or expectations) and system changes (e.g. shift patterns, interface design or procedural change). In addition to applying the DSAT to other monitoring positions within drilling (e.g. mud logger) and oil and gas (e.g. crane operator). The computer based method has the potential to be customised for to measure domain specific cognitive skills, such as in nuclear power control (e.g. control room operators) and health care (e.g. anaesthetists), particularly for training low frequency, high risk situations. There are also potential applications for the DSAT to be used in conjunction with crew resource management training, to evaluate effectiveness of training transferring desired behaviours during routine and abnormal operation's, or as assessment alternative to large simulations. For example, using the computer simulation in combination with behavioural markers within drilling (Roberts & Flin, 2016). Employing novel solutions, such as our portable computerised simulation task, is essential for maintaining safe and effective operations in the current unpredictable, cost cutting climate.

CONCLUSION

A prototype monitoring task simulating well control scenarios, Drillers’ Situation Awareness Task (DSAT), was developed to examine drillers' key cognitive skills associated with situation awareness, such as cue recognition, comprehension and anticipation, and decision making. Preliminary results suggest that it is viable as a tool for examining drillers' cognition with the potential to be used as part of training and formatively assessing cognitive skills in drilling.

KEY POINTS

- The prototype monitoring task simulating drilling scenarios, Drillers’ Situation Awareness Task (DSAT), was developed as a tool for examining drillers' key cognitive skills associated with situation awareness and decision making.
- Preliminary evaluation suggest that it is viable as a tool for examining drillers' cognition.
- There is potential for the tool to be used as part of training and formatively assessing cognitive skills in drilling, as well as other monitoring positions in high risk industries supporting, safe performance.

REFERENCES

Borland Software Corporation (2009). Delphi 6 programming platform. Available from www.borland-delphi.software.informer.com

Chief Counsel's Report. (2011). *Macondo; the Gulf Oil Disaster. National Commission on the Deepwater Horizon Oil Spill and Offshore Drilling.* US Government Printing, Washington, DC.

Crichton, M. T., Henderson, W. G., & Thorogood, J. L. (2004). Command skills for drilling and completion teams: Managing the unexpected. *In SPE Annual Technical Conference and Exhibition*. Houston, TX.

Durso, F.T., Hackworth, C.A., Truitt, T., Crutchfield, J., & Manning, C.A. (1998). Situation awareness as a predictor of performance in en route air traffic controllers. *Air Traffic Quarterly, 6*, 1–20.

Endsley, M. R. (1995a). Towards a theory of Situation Awareness in Dynamic Systems. *Human Factors, 37,* 32-64.

Endsley, M. R. (1995b). Measurement of Situation Awareness in Dynamic Systems. *Human Factors, 37,* 65-84.

Endsley, M. R. (2016). *Designing for situation awareness: An approach to user-centered design.* CRC press.

Endsley, M. R., & Garland, D. J. (2000). (Eds) *Situation Awareness Analysis and Measurement.* Mahwah, NJ: Lawrence Erlbaum Associates.

Hauss, Y. & Eyferth, K. (2003). Securing future ATM-concepts' safety by measuring situation awareness in ATC. *Aerospace Science and Technology*, *7*, 417-427.

IBM (2012). SPSS 21 for Windows. Accessed December 2012 from : http://www-01.ibm.com/software/analytics/spss/products/statistics/

IOGP (2014a). Crew Resource Management for Well Operations teams (Report 501). Available from : http://www.ogp.org.uk/publications/wells-committee/wocrm-report/

IOGP (2014b). Guidelines for implementing Well Operations Crew Resource Management training (Report 502). Available from : http://www.iogp.org/pubs/502.pdf

Letbetter, S. C. (1975). Kick detection and well control training. In Proceedings of *SPE California Regional Meeting*. Ventura, California. doi:10.2118/5353-MS

Loft, S., Morrell, D. B., & Huf, S. (2013). Using the situation present assessment method to measure situation awareness in simulated submarine track management. *International Journal of Human Factors and Ergonomics*, *2*(1), 33-48.

Loveday, T., Wiggins, M. W., Harris, J. M., O'Hare, D., & Smith, N. (2013). An objective approach to identifying diagnostic expertise among power system controllers. *Human Factors*, *55*, 90-107.

Loveday, T., Wiggins, M. W., Searle, B. J., Festa, M., & Schell, D. (2013). The capability of static and dynamic features to distinguish competent from genuinely expert practitioners in pediatric diagnosis. *Human Factors*, *55*, 125-137.

Matthews, M.D., & Beal, S. A. (2002). *Assessing Situation Awareness in Field Training Exercises. U.S. Army Research Institute for the Behavioural and Social Sciences.* Research Report 1795. West Point Military Acadamy.

OESI (2016). Human factors and ergonomics in offshore drilling and production : Implications for offshore safety. Available from : http://oesi.tamu.edu/wp-content/uploads/Human_Factors_in_Offshore_Oil_and_Gas_final_8_Dec%2016.pdf

Report to the President (2011). *National Commission on the Deepwater Horizon Oil Spill and Offshore Drilling.* Washington, DC: US Government Printing.

Roberts, R. C., & Flin, R. (2016). Behavioural Rating of Drillers' Cognitive Skills. Paper presented at *SPE International Conference on Health, Safety, Security, Environment, and Social Responsibility*. Oslo, Norway. Doi: 10.2118/179270-MS

Roberts, R. C., Flin, R. H., & Cleland, J. (2015a). Staying in the zone: Offshore drillers' situation awareness. *Human Factors*, *57*, 573-590.

Roberts, R. C., Flin, R. H., & Cleland, J. (2015b). Everything was fine: An analysis of the drill crew's situation awareness on Deepwater Horizon. *Journal of Loss Prevention in the Process Industries, 38*, 87-100.

Roberts, R., Flin, R., & Cleland, J. (2016). How to recognise a kick: A cognitive task analysis of drillers' situation awareness during well operations. *Journal of Loss Prevention in the Process Industries, 43*, 503-513.

Salmon, P. M., Stanton, N. A., Walker, G. H., Jenkins, D., Ladva, D., Rafferty, L., & Young, M. (2009). Measuring situation awareness in complex systems: Comparison of measures study. *International Journal of Industrial Ergonomics, 39*, 490-500.

Sneddon, A., Mearns, K., & Flin, R. H. (2006). Safety and situation awareness in offshore crews. *Cognition, Technology and Work, 8*, 255–267.

Stanton, N. A., & Wilson, J. (2001). *Safety and Performance Enhancement in Drilling Operations by Human Factors Intervention (SPEDOHFI). HSE Report 264.* London : HSE Books.

Taylor, R.M. (1990). Situational Awareness Rating Technique (SART): The development of a tool for aircrew systems design. *In Situational Awareness in Aerospace Operations (AGARD-CP-478) (3/1 –3/17).* Neuilly Sur Seine, France: NATO-AGARD.

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