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ROBERTS, R.C., FLIN, R. and CLELAND, J.

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Staying in the Zone: The Cognitive Components Associated with Offshore Drillers' Situation Awareness

Ruby C. Roberts, Rhona Flin, & Jennifer Cleland

University of Aberdeen, Aberdeen, Scotland

Situation Awareness (SA) issues are often identified as contributing factors to drilling incidents, most recently in the Deepwater Horizon blowout. Two studies aimed to identify the cognitive components required for offshore drillers to develop and maintain SA whilst controlling subsea hydrocarbon wells. In study one, critical incident interviews were conducted with 18 experienced drilling personnel. Transcripts were subjected to thematic analysis, producing a framework of cognitive processes that enable drillers to build up an understanding of what is happening in the well bore and surrounding environment, predicting how the situation may develop. In the second study, analysis of 24 hours of observations (in-vivo and video) from a high fidelity well control simulator suggest behaviors such as monitoring and crew sharing information contribute to the drillers' SA. The findings highlight the importance of SA for safe and effective performance in drilling and are being used to develop a cognitive task analysis.

INTRODUCTION

In April 2010, the Deepwater Horizon drilling rig on the Macondo well in the Gulf of Mexico experienced a significant blowout which resulted in the death of 11 workers and the worst oil spill in US history. A few months previously, the West Atlas drilling rig on the Montara well, off the coast of Australia experienced a blowout which caused a substantial oil spill in the Timian Sea. In 2001, the largest semi-submersible rig at the time, the Petrobras P-36 sank, killing 11 men as a result of a series of explosions in the rig's columns (USEPA, 2001). What links these incidents is that inaccurate situation awareness (SA) was cited as contributing to the events and resulting outcomes (Report to the President, 2011; Reader & O'Connor, 2014; Montara Report, 2010; Woodcock & Toy, 2011).

Drillers

A driller's job requires complex precision engineering. The drill crew, including the driller, assistant driller and tool pusher are responsible for conducting the hazardous task of boring, constructing and maintaining a well, hundreds of feet below the drilling deck. They are frequently drilling into subsea hydrocarbon reserves which can be highly pressurised, at high temperatures, resulting in the wellbore having to be constantly counter-balanced to ensure that the flow of the volatile hydrocarbons is controlled. The driller's accurate SA is vital to constantly monitor and comprehend the well state and the activities on the drill floor to be able to make the best decisions and keep accident risks to a minimum. Taking into consideration the increasing complexity of drilling, due to growing expansion into deep water as well as more sophisticated drilling software and technology, the importance of the drillers' situation awareness will become ever more pertinent in the future.

Situation Awareness in Offshore Drilling

Despite its relevance for drilling activities, there is a limited body of work examining SA in this domain compared to other high-risk, high-reliability occupations. The literature provides some insight into SA in the drilling environment and identifies influencing factors. SA has so far been investigated in the offshore drilling environment in the context of non-technical skills for well operations (Flin & Wilkinson, 2013) including training (Thorogood & Crichton, 2013) and incident command skills (Crichton, Lauche & Flin, 2005). Stanton and Wilson (2001) identified a number of issues associated with drillers' SA, particularly in relation to concentration, poorly designed displays, problems with interpretation of information, inaccuracies in analysis and omitting to read monitor data. More specifically, Sneddon, Mearns and Flin (2006) investigated the role of SA for drilling crews through accident analysis and interviews. The results showed that 67% of SA errors investigated were classified as level 1 errors with the majority relating to failure to monitor or observe data, 20% of the errors related to problems with comprehension and mental models (level 2) and the remaining 13.3% of errors were associated with failures to anticipate (level 3). Furthermore, isolation from events at home, fatigue and stress were perceived to be the main contributory factors for an individual's reduced SA. In a later study Sneddon, Mearns and Flin (2013) developed the Work Situation Awareness (WSA) rating scale and found that higher levels of stress, sleep disruption and fatigue were significantly associated with lower levels of WSA, with stress being the strongest predictor. Lower WSA was related to more unsafe behaviour and increased work accidents. While this body of work provides preliminary insights into SA in this context, it does not give a full understanding of how drillers develop and maintain SA or of the underlying cognitive processes that drive SA in this high-risk work domain.

A method for identifying these cognitive processes is Cognitive Task Analysis (CTA). CTA uses a selection of techniques mainly interviews and observations, to understand how experts perform complex tasks through knowledge elicitation. This includes the explicit and implicit knowledge, cognitive processes and goal structures that underpin expertise (Militello & Hutton, 1998). Information gathered from CTA can be used to inform interventions such as systems design and training (e.g. Schaafstal, Schraagen & van Berl, 2000). These CTA methods have been applied in a wide range of high risk work domains including aviation (O'Hare, Wiggins, Williams & Wong, 1998), healthcare (e.g. Laparoscopy, Craig et al., 2012), and the military (Jenkins, Stanton, Salmon, Walker & Young, 2008).

Study Aim

The aim of this study was to identify the underlying cognitive components associated with offshore drillers' development and maintenance of SA through critical incident interviews, observation and video analysis. These three forms of data can provide triangulation, increasing the reliability of the data (Angrosino, 2007). It is planned to feed this information into a future cognitive task analysis.

STUDY 1 CRITICAL INCIDENT INTERVIEWS

Method

Procedure. Phone interviews were conducted over a five month period (April-August 2013). Typically the interviewees were on a drilling rig or drill ship at sea at the time of the interview. With the permission of the interviewee, they were all audio recorded and transcribed for analysis.

Interview Schedule. Flanagan's (1954) critical incident method was adapted along with Endsley's (1993) SA requirement analysis and Klein, Calderwood and Macgregor's (1989) Critical Decision Method. The interview schedule was first piloted with a drilling expert. It consisted of two parts. First interviewees were asked a set of general questions about a driller's SA and to briefly describe a well control incident that they had experienced. The interviewer then asked a set of probing questions about the event, such as what information did the crew ideally need to make a decision.

Sample. The industrial supervisor of the sponsoring company invited potential drilling personnel to take part. Information about the project and the purpose of the interview was given beforehand. The researcher directly contacted those who had agreed to take part. Drilling personnel are a small, specialized population, working 12 hour shifts for between 2-4 weeks with no rest days. In total, 18 interviews were conducted with male drilling personnel from one company. All had direct experience in the drilling domain with a range of 5 to 25 years. The sample consisted of 11 drillers, two assistant drillers, one tool pusher, three senior tool pushers and one drilling superintendent. After 18 interviews, data saturation was reached (Glaser & Strauss, 1967).
Interviews were carried out by telephone, around shift patterns on rigs and drill ships at sea, and across international time zones. The average interview length was 28 minutes with a range of 24 minutes to 50 minutes. The total interview time was eight hours and 22 minutes.

Data Analysis. Once transcribed, the interviews were analyzed using an adapted version of Braun & Clarke's (2006) Thematic Analysis via the software program Nvivo 10 (QSR International, 2013). This is a structured method for identifying, analysing and reporting themes within the interview content to produce a richly detailed data set. This process followed a theory-driven, deductive method testing the application of Endsley's (1995) model in this domain as well as other theories of SA such as Wicken's (2002) spatial and task awareness in the initial analysis.
A sample of five interview transcripts was cross-coded. The second coder was trained in using the coding scheme and basic drilling concepts. Cohen's (1960) kappa coefficient was found to be acceptable (0.869) (Fleiss, 1981). The remaining transcripts were coded by the first author.

STUDY 2A OBSERVATION

Method

Procedure. The first author conducted structured, non- participant observations of drill crews at a drilling simulator over a seven month period (February-August 2013). Scenarios lasted approximately 2.5 hours. Typically the scenarios involved the driller, assistant driller and tool pusher responding to challenging situations such as dealing with a kick and loss of well control.
Structured observations were taken in the form of field notes with the aid of an observational checklist. These observations were taken from an observation room which had a number of video feeds from the simulator as well as the training instructors present. Observation focused on the driller's actions and interactions with crew members to identify behaviours that might be indicative of SA.

Sample. In total 13.5 hours of live observation was conducted at the simulator with 19 drill crew members involved. It was not possible to collect demographic information on the drill crews taking part, but the majority was male and most had at least several years of drilling experience. All of those taking part in the simulations gave written consent for the researcher to be present.

Data Analysis. The field notes were written up in the form of analytic narratives shortly after the training. The video recordings were re-watched to review the simulation and to detect aspects which may have been initially missed or unclear. The narratives contained information on visible behaviors that appeared to be related to the drillers' SA and what was happening with comments on influencing factors. It was not possible for a second observer to be present in the simulator, consequently no interrater agreement could be calculated.

The analytic narratives were analyzed using Nvivo 10 (QSR International, 2013) and coded using the preliminary framework from the critical incident interviews. In conjunction with the narrative data and thematic analysis, the framework was further refined.

STUDY 2B VIDEO ANALYSIS

Method

Preliminary findings from the ongoing observation and video analyses suggest that visible activities such as monitoring the developing situation through information gathering, as well as interactions with the surrounding crew, take up a considerable

Procedure. Recordings of additional training simulations (taken over a six month period, May-October 2013) were provided to the researcher, extending the amount of observation time. The scenarios were principally the same as those in the observation study. Video analysis gives the researcher the opportunity to examine complex situations in rich detail that would not be possible with live observation (Mackenzie & Xiao, 2003). All participants in the recorded simulations had consented to having their videos analyzed.

Sample. In total, 10.5 hours of video recordings of 14 drill crew members were analysed. The researcher produced time lines for each video recording, watching them repeatedly. Key sections from the time lines were then selected to be analyzed, as is common in video analysis (McNeese, 2004). These selected sections were chosen based on criteria taken from the critical incident interviews e.g. aspects of well control.

Data Analysis. In total 25 key sections were selected from all of the videos which ranged in length from 3 to 12 minutes, with an average length of 7 minutes. The video sections were analysed using Nvivo 10 (QSR International, 2013) and coded using the preliminary framework developed from the critical incident interviews.

A sample of six video sections was cross-coded. The second coder was trained in using the framework, software and basic drilling concepts. Cohen's (1960) kappa coefficient was found to be acceptable (0.857) (Fleiss, 1981). The remaining video sections were coded by the first author with the intention of further refining the framework.

RESULTS

In total 16 themes were identified during the interview analysis with 10 cognitive components associated with drillers developing and maintaining SA during complex tasks including well control (six at level 1 SA, three at level 2 SA and one at level 3 SA) and six influencing factors. In the main these themes reflected the components defined by Endsley (1995). The total number of times the theme was mentioned in the interviews and illustrative quotes are shown in Table 1.

Attending to the situation, monitoring and cue recognition of changes/indicators in the drilling parameters were the most frequently identified perceptive skills from the interview transcripts, suggesting that these are important for the driller to successfully do this job (Level 1 SA). Sharing information and awareness between the driller and the rest of the drill crew was also found to be critical in the interpretation of the situation (Level 2 SA). Whilst anticipation was not mentioned as frequently, it is associated with better, more experienced drillers (Level 3 SA). A number of factors that influence SA were identified with the most frequently mentioned being distraction and experience.

Preliminary findings from the ongoing observation and video analyses suggest that visible activities such as monitoring the developing situation through information gathering, as well as interactions with the surrounding crew, take up a considerable amount of the drillers' time and cognitive resources. Sharing of information between crew members through discussion in the drill cabin and phone calls makes a substantial contribution to the driller's comprehension and subsequent awareness of the situation. It was observed that a more coordinated, supportive crew would aid the driller's awareness particularly during challenging situations. Similarly, the assistant driller and tool pusher could positively impact on the influence of distracters, stress and workload, by alleviating their cognitive effect on the driller (e.g. the AD screening calls whilst the driller was busy).

Drillers who anticipated how the situation may develop and who took action to prepare for that (e.g. doing calculations, making plans) tended to have better outcomes in the scenarios.

DISCUSSION

Critical incident interviews, observation and video analysis data were used to develop a preliminary framework of the cognitive components associated with offshore drillers' developing and maintaining SA during well control. Cognitive processes could be identified that support situation awareness at each of the three stages defined by Endsley (1995). The preliminary observation and video analysis findings support and complement those found in the interviews and will be further discussed at the conference.

The perceptual skills of attending to and monitoring the situation, gathering information, and cue recognition of changes, in the drilling parameters were identified as most important for the driller to successfully do his or her job. Implicit recognition and processing of information was also identified in which drillers felt a sense of unease in response to unconscious processing of information or implicit recognition of cues which lead them to take action. It is likely that this cognitive component is associated with Klein's (1993) Recognition Primed Decision Making, as well as the more recent concept of chronic unease (Fruhen, Flin & McLeod, 2013).

Comprehension of gathered information was found to be achieved in collaboration with mental models, expectations and experience, as well as sharing of information and awareness between the crew. These crew behaviors suggest a close relationship between individual driller's SA and the drill crew (team) SA (e.g. Stanton, Salmon, Walker & Jenkins, 2009). Mental models were found to consist of complex, dynamic mental representations of situational aspects. How the situation may progress was anticipated through mental visualizations based on which action can be prepared. Just as in other high risk, high reliability domains such as aviation (Endsley & Garland, 2000), it is this anticipatory skill that defines an experienced, if not yet expert, driller and is a skill that is looked for when considering promotion.

The findings also reflect those found in other high-risk, high reliability domains in which SA has been researched. This suggests that these cognitive processes are not specific to a single domain or task. SA research in areas including health care (e.g. Koch et al., 2012) and nuclear power control operators (Lee, Park, Kim & Seong, 2012) identify similar cognitive components required for developing and maintaining SA. For example, Partick, James, Ahmed and Halliday (2006) identified very similar cognitive skills to the drillers, required for nuclear control team operators including anticipation, knowing what everyone has to do, identifying the significance of cues and monitoring. The characteristic of being able to anticipate and project how the situation may develop is associated with expertise not only in drilling but also in aviation and surgery (Lini, Vallespir, Hourlier, Labat & Favier, 2013; Wauben et al., 2011).

Six influencing factors were indentified with the potential to aid and hinder SA including distraction, experience, expectation, coping with stressful or demanding situations, system and design features and workload. Experience and expectations could lead to faster cue recognition, more efficient monitoring and more accurate mental models but could result in confirmation bias and complacency. Distraction could pull attention away from the main task, losing focus but in some instances could re-focus attention when the driller had become fixated.

Our analysis of cognitive components involved in drillers' SA provides an initial insight into how SA is developed and maintained by this group, and indicates Endsley's (1995) model to be applicable to this domain. The current study echoes Sneddon et al.'s (2006) findings as the majority of cognitive components occurred at the perceptive level, consequently it would be expected that there would be a higher level of error associated with them. For example, drillers can experience difficulties concentrating on the prioritised task when distracted. The interview study also found that problems at home (incorporated in distraction) and stress were reported as negatively impacting on SA but fatigue was not commonly mentioned by the drillers.

The limitations associated with the current study are as follows. Interviews allow a certain degree of introspection form participants, but it is questionable to what extent an individual can be aware and comment on their own cognitive processes and SA. In addition, interviews are self-report and can be subject to bias as well as motivational agendas (Rowley, 2012). Furthermore, conducting phone interviews may reduce the rapport that can be built up during an interview but, on the other hand, this more anonymous, confidential method may have advantageous in terms of interviewee candor and openness. To give the fullest picture of drillers' SA observation and video analysis were aimed at evaluating the convergent validity of the data through triangulation. Furthermore, these methods' strengths and weaknesses should counterbalance and complement each other. The observation and video analysis will also be used to further develop and refine the framework.

CONCLUSION

In conclusion, the results provide a preliminary insight into how SA is developed and maintained by drillers. Endsley's (1995) three level model was applied to a new industry, adding to the current body of research. In the wider context, these findings illustrate the importance of SA for safety and performance in drilling. With regard to non-technical/crew resource management training in drilling, (e.g. OGP, 2014) the identified cognitive components could be utilized to further refine these training programs. Once further developed, the framework could be applied to system design recommendations such as informing the layout of the information on the drillers' screens. Future research aims to validate these findings and further develop the framework.

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Table 1. The themes identified from the interview transcripts and the associated number of times they occurred in the interviews with illustrative quotes plus interviewee number.

Theme	Total No. of times coded across interviews	Quotes
Level 1 SA		
Attention	52	*So you kind of have to zone in and block out certain things you don't need to know about. (I2)*
Implicit Recognition & Processing	15	*If he feels something is not right he shouldn't do it. (I17)*
Cue Recognition	50	*You've got total volume, if that changes at all, there's something happening down hole and you can usually pick it up.(I18)*
Monitoring	74	*An ideal driller has to find the ideal way to keep a track of all of these things.(I6)*
Gathering Information	39	*It's a combination of him collecting it. There is a series of questions and also some of that information being given to him. So a good driller is a guy that asks a lot of questions. (I13)*
Level 2 SA		
Comprehension & Understanding	33	*The well is sending all kinds of signals up which you need to interpret and I'm the first one who looks at them.(I14)*
Mental Models	46	*You can't do the job unless you have that mental picture because you wouldn't really know what you are doing.(I15)*
Shared Information & Awareness	73	*Someone that is open to all of the information on the rig and knows then how to distribute it when he sees it. I don't need someone that is there and takes in all the information and then doesn't share it. (I9)*
Level 3 SA		
Anticipating & Projecting	26	*Your better drillers will look ahead at least two steps and know what is coming up in the future. (I9)*
Awareness of the Situation	47	*He has to be aware of what's going on round about him. The driller, he can make the difference between a disaster and being hurt. (I18)*
Influencing Factors		
Distraction	40	*The fact that there is always a million things going on ... and it is very easy to become distracted. (I4)*
Experience	51	*I might react faster to stuff by just because maybe I have been exposed more to it. (I12)*
Expectations	22	*We have a pre-tour meeting 50 minutes before I go on shift where we discuss with the crew and people around us, telling us what the next coming 12 hours, what's been happening during the day and what's the next operations. (I3)*
Stress	36	*So it can get overwhelming if you let it but I have grown to not let it get overwhelming. There are ways of coping. (I2)*
System & Design	19	*These rigs are so automated now the driller is expected to know and do a lot more now than he has in days past. (I13)*
Workload	13	*When you're sat in the chair for maybe two hours and you are processing all this information, it's nice to get relief. (I2)*