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Staying in the zone: offshore drillers' situation awareness.

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Staying in the Zone: Offshore Drillers' Situation Awareness

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ABSTRACT

Objective: The aim of this study was to identify the cognitive components required for offshore drillers to develop and maintain situation awareness (SA) while controlling subsea hydrocarbon wells.

Background: SA issues are often identified as contributing factors to drilling incidents, most recently in the Deepwater Horizon blowout. Yet, there is a limited body of research investigating SA in the offshore drilling environment.

Method: In the first study, critical incident interviews were conducted with 18 experienced drilling personnel. Transcripts were subjected to theorydriven thematic analysis, producing a preliminary cognitive framework of how drillers develop and maintain SA during well control. In the second study, 24 hr of observations (in vivo and video) of drillers managing a high fidelity well-control simulator were analyzed to further develop the framework.

Results: The cognitive components that enable drillers to build up an understanding of what is happening in the wellbore and surrounding environment, to predict how this understanding may develop, were identified. These components included cue recognition, interpretation of information in conjunction with the current mental model, and projection through mental simulation. Factors such as distracters, expectations, and information sharing between crew members can both positively and negatively influence the drillers' SA.

Conclusion: The findings give a preliminary understanding into the components of drillers' SA, highlighting the importance of SA for safe and effective performance and indicating that Endsley's model of SA can be applied to drilling.

Application: The results have consequences for training, task management, and work design recommendations.

Keywords: drilling, cognitive task analysis, nontechnical skills, expertise

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INTRODUCTION

On April 20th, 2010, the Deepwater Horizon drilling rig on the Macondo well in the Gulf of Mexico experienced a significant blowout that resulted in the death of 11 workers and the worst oil spill in U.S. history (Report to the President, 2011). A few months previously, the West Atlas drilling rig on the Montara well, off the coast of Australia, experienced a blowout that caused a substantial oil spill in the Timian Sea (Montara Report, 2010). In 2001, the largest semisubmersible 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 (U.S. Environmental Protection Agency, 2001). One factor that links these incidents is that inaccurate situation awareness (SA) was cited as contributing to the events and resulting outcomes (Reader & O'Connor, 2014; Woodcock & Toy, 2011). In essence, SA is the cognitive skill of knowing what is going on around oneself and using that understanding to predict how the situation may develop in the future (Endsley, 1995).

Drillers

An oilfield driller's job requires the execution of a task involving complex, precision engineering. The drill crew, including the driller, assistant driller, and tool pusher (supervisor), are responsible for conducting the hazardous task of boring, constructing, and maintaining a well to gain controlled access to hydrocarbons, hundreds of feet below the drilling deck. They are frequently drilling into subsea hydrocarbon reserves, which can be highly pressurized, at high temperatures, resulting in the wellbore having to be constantly counterbalanced to ensure that the flow of the volatile hydrocarbons is controlled. The task of maintaining a hydrostatic column of drilling fluid, which acts as a barrier against the pressurized hydrocarbons, is known as well control. The driller's accurate SA is vital to constantly monitor and comprehend the well state, as well as the activities on the drill floor, to be able to make the best decisions and keep accident risks to a minimum. When the formation pressure exceeds the hydrostatic pressure of the drilling mud, an influx of fluids from the formation can occur, referred to as a kick. Should the crew recognize that a kick is occurring, it is required to close the blowout preventer equipment on the sea floor, which will prevent the kick from traveling up to the rig and resulting in a blowout; this action is referred to as shutting in. 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 driller's SA will become ever more pertinent in the future.

SA

A crucial human aspect in ensuring safety and the reduction of operator error includes the ability of workers to maintain awareness of their work environment, to understand the information that it holds, and to predict how situations will develop (Flin, O'Connor, & Crichton, 2008). This cognitive skill, known as SA, has been given considerable attention by the human factors community over the past two decades. Yet there is still an ongoing debate over the concept itself, how it is achieved and maintained, and how it is measured. Theories of SA continue to be discussed and developed, including Smith and Hancock's (1995) perceptual cycle model; Wickens' (2002) spatial, task, and system awareness; and more recently, Stanton, Salmon, Walker, and Jenkins' (2009) distributed SA. Despite limitations (e.g., Dekker, Hummerdal, & Smith, 2010), Endsley's (1995) three-level model of SA, to date, dominates the field, being the most applied in industrial domains (e.g., health care; Stubbings, Chaboyer, & McMurray, 2012; navy/ maritime; Saus Johnsen, Eid, & Thayer, 2012). It describes SA as a cognitive product of three serial hierarchical levels, perception (Level 1), comprehension (Level 2), and prediction (Level 3), identifying a number of task and environmental factors as well as individual factors that can influence it.

SA 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, highreliability 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 nontechnical 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 neglecting 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 behavior and increased work accidents. Although 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 the cognitive processes in SA is cognitive task analysis (CTA). CTA involves a selection of techniques, mainly interviews and observations, to understand through knowledge elicitation how experts perform complex tasks. This includes the explicit and implicit knowledge, cognitive processes, and goal structures that underpin expertise (Militello & Hutton, 1998). This process is similar to Endsley's (1993) SA requirement analysis, with CTA methods having been previously used to study SA (e.g., military platoon leaders; Matthews, Strater, & Endsley, 2004; emergency dispatch units; Blandford & Wong, 2004). 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), surgery (e.g., Craig et al., 2012), and the military (Jenkins, Stanton, Salmon, Walker, & Young, 2008).

Aim

The aim of the two studies reported here was to identify the underlying cognitive components associated with offshore drillers' development and maintenance of SA, through critical incident interviews (Study 1), observation (Study 2A), and video analysis (Study 2B). These three forms of data can provide triangulation, increasing the reliability of the data (Angrosino, 2007) to feed into a future CTA. A supplementary aim was to apply Endsley's (1995) model of SA to the drilling domain, using it as a preliminary coding guide in Study 1.

STUDY 1: CRITICAL INCIDENT INTERVIEWS

Method

Procedure. Phone interviews were conducted over a 5-month period (April to 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, interviews were audio recorded and transcribed for analysis.

Interview schedule. Flanagan's (1954) critical incident method was adapted to produce the interview schedule, taking into account Endsley's (1993) SA requirement analysis and Klein, Calderwood, and Macgregor's (1989) critical decision method. It was pilot-tested 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 the crew ideally needed to make a decision (see Appendix A for interview schedule).

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 volunteered.

Drilling personnel are a small, specialized population, working 12-hr shifts in remote locations for between 2 and 4 weeks with no rest days. Interviews were carried out by telephone, around shift patterns on rigs and drill ships at sea, and across international time zones. In total, 18 interviews were conducted with male drilling personnel from one company. All had direct experience in the drilling domain (range 5 to 25 years). The sample consisted of 11 drillers, two assistant drillers, one tool pusher, three senior tool pushers, and one drilling superintendent. The average interview length was 28 min, with a range of 24 min to 50 min. After 18 interviews (total interview time = 8 hr 22 min), data saturation was reached (Glaser & Strauss, 1967). Data saturation refers to the point at which no additional new data are found that will further develop a conceptual component or model and, as such, data collection can cease.

Data analysis. Once transcribed, the interviews were analyzed using an adapted version of Braun and Clarke's (2006) thematic analysis via the software program Nvivo 10 (QSR International, 2013). This analysis is a structured method for identifying, analyzing, and reporting themes within the interview content to produce a richly detailed data set. This process followed a theory-driven, deductive method testing the suitability of Endsley's (1995) model in the drilling domain as well as including Wickens' (2002) spatial, task, and system awareness in the initial analysis.

A sample of five interview transcripts was selected and cross-coded using a set of coding rules as based on Mayring's (2004) guidelines. For example, "items can relate to any of the previously developed SA codes as provided to both coders or it can also be a new code. If it is a new code, please label it as other." The second coder was trained in using the coding scheme and basic drilling concepts by the first coder (the first author). Although there was a possibility of transferring the first coder's biases and expectations during the training period, the coding of nonfitting data was strongly emphasized and encouraged during the coding of the interview transcripts as well as in subsequent coding of the videos in Study 2. Cross-coding was conducted in which both coders practiced using the coding scheme together on a piece of transcript text not included in the analysis, after which they separately coded the five transcripts. Once completed, Cohen's (1960) kappa coefficient was calculated and found to be acceptable (0.869; Fleiss, 1981). The remaining transcripts were coded by the first author.

The thematic analysis of the interview transcripts was used to develop an initial framework of how drillers develop and maintain SA, which would later be used in Study 2.

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), suggesting that the model is a suitable fit for the drilling domain. 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 skills are important for the driller to successfully do this job (Level 1 SA). Exchanging information to achieve shared 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). Although anticipation was not mentioned as frequently, it was 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.

STUDY 2: OBSERVATION AND VIDEO ANALYSIS

Observation Method

Procedure. The first author conducted structured, nonparticipant observations of drill crews at a drilling simulator (DrillSim 6000, Drilling Systems) over a 7-month period (February to August 2013). Each scenario lasted approximately 2.5 hr. Typically, 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 (based on Endsley's [1993] SA requirement analysis), focusing on visible behaviors, for example, what the driller was doing, what the crew members appeared to be attending to, and where their information was coming from (see Appendix B for observational checklist). These observations were taken from a viewing 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 behaviors that might be indicative of SA.

Sample. In total, 13.5 hr of live observation were conducted at the simulator with five teams (19 drill crew members involved). It was not possible to collect demographic information on the drill crews taking part, but the majority were 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. When access to video recordings was given, these videos were used to review the simulation and to detect aspects that may have been initially missed or unclear. The narratives contained information on visible behaviors that appeared to be related to the driller's SA and what was happening, with comments on influencing factors. The analytic narratives were analyzed with Nvivo 10 (QSR International, 2013) and coded with use of the preliminary framework and coding rules from Study 1(critical incident interviews). It was not possible for a second observer to be present in the simulator; consequently, no interrater agreement could be calculated.

Video Analysis Method

Procedure. Recordings of a further four training simulations (May to October 2013) were provided. 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 hr of video recordings of five teams (14 drill crew members) were analyzed. Timelines were produced for each video recording from repeated viewing. Key sections included events in the timeline that were pertinent to SA as based on the live observations, which were then selected to be analyzed indepth, as is common in video analysis (McNeese, 2004). These selected sections were chosen based on criteria taken from the critical incident interviews, for example, aspects of well control and decision points.

Data analysis. In total, 25 key sections were selected from the videos. These ranged in length from 3 to 12 min, with an average length of 7 min. The video sections were analyzed with Nvivo 10 (QSR International, 2013) and coded according to Study 1's (critical incident interview) framework. Afterward, the framework was further refined with data from both the observation narratives and video sections as shown in Figure 1.

A sample of six video sections was crosscoded. The second coder was trained in using the framework, software, and basic drilling concepts. Cross-coding was conducted with both coders practiced using Study 1's framework and the software together on a section of video not included in the analysis, after which they separately coded the six video sections. 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. From the thematic coding of the video clips, the framework was further refined.

Results

In total, 16 themes were identified, with 11 cognitive components associated with drillers' SA during complex tasks, including well control (five at Level 1 SA, three at Level 2 SA, and three at Level 3 SA) and six influencing factors (experience, expectations, stress, distracters, work environment, and workload) according to Study 1's preliminary framework. The total number of times each theme was coded in the observations and video analysis, as well as illustrative quotes, is shown in Table 2. The observation and video analysis findings also identified eight subthemes, which are shown indented below their parent theme in Table 2.

The observation and video analysis findings show a similar pattern of results as the incident interviews, with attending to aspects of the situation (e.g., the drilling screens and activity on the drill deck), recognizing key indicators (e.g., increase in rate of penetration), gathering information, and monitoring the situation as it develops being frequently identified (Level 1 SA). Furthermore, sharing of information between crew members, through discussion in the drill cabin and phone calls, can make a considerable contribution to the driller's comprehension, being repeatedly identified in both the observations and video analysis (Level 2 SA). Metacognition was identified as a subtheme of understanding (Level 2 SA). It was observed that a more coordinated, supportive crew could aid the driller's awareness (e.g., by sharing information appropriately), particularly during more complex situations (e.g., experiencing an influx). Drillers who anticipated how the situation may develop (Level 3 SA) and who took action to prepare for that (e.g., doing calculations, preparing equipment) tended to have better outcomes in the scenarios. Projection was found to have the subthemes of mental simulation and preparation. Again, distracters were found to be the main influencing factor on drillers' awareness, including phone calls, problems with equipment, colleagues talking, competing tasks, and social or personal problems.

The themes identified varied, in part, depending on the data collection method. For example, internal processes, such as attention, cue recognition, implicit recognition, and mental models and the associated behaviors, were frequently identified in the observations but not as commonly in the video analysis. It is likely this finding was the result of fine-grained coding of the video snippets focusing on visible behaviors, whereas the observations took a holistic approach. Furthermore, stress was more frequently identified during the observations than during the video analysis despite there being similar scenarios and environment. This finding highlights the benefit of using multiple data collection methods to produce a more accurate and reliable data set (see Discussion). Nonetheless, the observation and video analysis data were used to further refine the preliminary framework of how drillers develop and maintain SA during complex tasks, including well control.

FRAMEWORK

The refined framework is shown in Figure 1, representing the cognitive components associated with drillers' development and maintenance of SA as well as the influencing factors that can shape this process positively and negatively. This framework was iteratively developed using the critical incident interviews and observation narratives in conjunction with the video analysis.

A number of subthemes were identified in Study 2, leading to development of the framework. Attention was found to have two subthemes: vigilance for change, which was associated with remaining alert to changes and deviations in the well parameters, and methods/strategies for maintaining the drillers' attention. The results suggest that in the drilling domain, the process of SA is referred to as monitoring, with a process of attention, cue recognition, and information gathering being informed by current comprehension and anticipation, reflecting the cyclic nature of Endsley's (1995) model (as shown in Figure 1). Study 2 also identified multimonitoring and techniques to aid monitoring as subthemes. Furthermore, metacognition (Flavell, 1979) was added as a subtheme of understanding/interpretation, as in order for drillers to seek assistance, reduce distracters, and build an accurate awareness of the situation, they would also require a self-awareness of their own cognitive abilities and current comprehension of the well. Finally, projection was found to have two distinct subthemes associated with mental simulation of possible developments or outcomes of the current situation and preparing for these anticipated situations.

The large gray arrows shown in Figure 1 indicate the functional relationships and feedback loops between the internal components, highlighting the cyclic nature of the SA process. Level 2 understanding in conjunction with the current, on-task mental model as well as Level 3 anticipated cues or events can be used to direct attention and gather additional information. This process may in turn aid cue recognition or conversely direct attention away from key aspects of the situation depending on the Levels 2 and 3 assumptions/expectations. For example, a current mental model that shows a new hydrocarbon rock formation close to the visualized drill bit position would focus attention toward the rate-of-penetration trend line, with the anticipation that the rate of penetration would soon increase, indicating that the new formation had been reached. The light gray arrow indicates the proposed effect that the influencing factors may have on the SA processes.

DISCUSSION

Critical incident interviews (Study 1), observation (Study 2A), and video analysis (Study 2B) data were used to develop a preliminary framework of the cognitive components associated with offshore drillers' development and maintenance of SA during well control as well as the key factors that can affect it. The framework suggests that Endsley's (1995) model is a suitable fit for the drilling domain. The factors that were found to influence a driller's SA also reflect previous research (Det Norske Veritas, 2007; Endsley & Garland, 2000; Sneddon et al., 2013).

For the offshore drilling domain, the drillers' term monitoring was found to represent the overall process of developing and maintaining SA, involving a constant/cyclic process of cue recognition and information gathering into an understanding of the situation and anticipation of how it may develop. The perceptual skills of attending to the situation, such as focusing on the drilling screens or activity on the drill floor, gathering information from multiple sources (e.g., phone calls, asking questions, calculations, and handovers) in a timely fashion, and recognizing a single or combination of indicators (or in some scenarios, the absence of changes in indicators) were identified as important for the driller to successfully do his or her job. Timely recognition of cues was found to be crucial for a quick response to a kick from the well (loss of pressure control) and mitigation against its evolving into a blowout. Implicit recognition was identified as a subcomponent of cue recognition in which drillers felt a sense of unease in response to implicit identification of cues, which led them to take action, often by gathering additional information.

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). Information regarding possible errors that can occur during attention and monitoring, as well as strategies to support them, is likely to be valuable for informing interventions, such as training.

As expected, the data suggested that comprehension was achieved in collaboration with mental models, expectations, and experience as well as sharing of information and awareness between crew members. Understanding and interpretation occurred in close relation with the current, situational mental model, with each interpretation feeding into the situational model, which in turn affects subsequent comprehension. As cognitive researchers have shown (e.g., Roschelle & Greeno, 1987; Rousseau, Tremblay, & Breton, 2004), the mental model containing prototypic, schematic information in long-term memory is likely to be operating in conjunction with a more transient situational mental model held in working memory representing the current task state. Similarly to Endsley (1995), other SA theories have highlighted the importance of schemas, including Stanton et al.'s (2009) distributed theory of SA. In this case, a driller's mental model possibly consists of abstract, tacit knowledge about well engineering, drilling fluids, pressures, and the rig layout, built up through work experience. These mental models could be used as templates on which situational mental models are initially built. The situational mental model could contain a dynamic, spatial representation of the current situation.

An advantage of using multiple data collection methods was that it allowed the development of finer-grained aspects of the framework, in particular, the identification of metacognition as a subtheme of understanding. It was observed that drillers displayed a self-awareness of their own cognitive abilities and current SA, for instance, when they became aware that they did not understand what is happening, were being distracted, or needed assistance, often resulting in action being taken. Having an awareness of one's own cognitive limitations (i.e., to some extent knowing what one is unaware of or missing) can support the quality of an individual's cognition. For example, airline pilots who recognize that they are tired use compensatory strategies to bolster their decision making (Petrilli, Thomas, Dawson, & Roach, 2006). Furthermore, pilots who had a more accurate meta-awareness of their Level 3 SA were found to perform better (Sulistyawati, Wickens, & Chui, 2011). Similarly, air traffic controllers who had better meta-cognitive judgments about their SA adopted better monitoring strategies and were more able to cope with automation failures (Sethumadhavan, 2011). How the situation may progress appears to be 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.

It can been seen from both studies that shared information and awareness between crew members plays a considerable role in the drillers' interpretation of information and development of an understanding of the situation. These behaviors represent the development of team SA, that is, collecting and exchanging information (e.g., Orasanu, 1994; Endsley & Robertson, 2000). In particular, accurately sharing information between crew members and the driller would be vital during shutting in (as a result of identifying a kick) as it requires communicating that a shut-in is about to or has occurred, coordination of conducting procedures, and communal anticipation of what will happen once they have shut in. It was observed that communal interpretation and sharing could aid the driller's SA, helping to focus attention, support monitoring, and support cue recognition but conversely could also lead to confirmation bias and groupthink.

A total of six influencing factors were identified with the potential to aid and hinder SA, consisting of distraction, experience, expectation, coping with stressful or demanding situations, work environment, and workload. Experience was built up through learning from training and previous events and operations and included information about geological formations, the crew, technical knowledge of drilling/engineering, working in the oil and gas industry, and tackling complex, difficult situations. It was also found that supervisors rated the ability to share experience and knowledge with less experienced crew members (e.g., assistant driller) as important characteristics of an ideal driller. Experience and expectations could lead to faster cue recognition, more efficient monitoring, and more accurate mental models but could also result in confirmation bias and complacency. Distraction could divert attention from the main task and cause one to lose focus on it but in some instances could refocus attention.

A good example is the numerous phone calls the driller receives. These calls provide a key source of information to the driller but can quickly become a distraction as workload increases. However, in some instances, the driller can become fixated on one aspect of the situation, missing a cue or zoning out (Schooler et al., 2006) during a monotonous task, and a phone call—sharing information—can quickly redirect the driller's attention. A fruitful avenue for future research may be to openly test the moderating effect of the influencing factors on the SA process to determine the level of effect of the different factors on each component. Such findings would likely provide valuable guidance for training and work design recommendations.

The analysis of cognitive components involved in drillers' SA provides an initial insight into how SA is developed and maintained by this occupation and indicates Endsley's (1995) model to be applicable to this domain. Furthermore, the findings, such as the identification of vigilance for change, implicit recognition, and metacognition, could be used to complement and expand her model. The findings suggest a close relationship between an individual driller's SA and the team's (drill crew) SA, which is reflected in Endsley and Jones's (2001) model of team SA as well as other theories of team SA (e.g., Salas, Prince, Baker, & Shrestha, 1995; Stanton et al., 2009).

The findings reflect those of Sneddon et al.'s (2006) drilling accident analysis: With the majority of the cognitive components occurring at the perceptive level, it is likely that a higher level of error would be associated with them. The results highlight the importance of maintaining an up-to-date on-task mental model to ensure an accurate understanding of the situation, reflecting the types of Level 2 SA errors. Sneddon et al. discuss the use of poor or incorrect mental models. In terms of influencing factors, problems at home (incorporated in distraction), stress, workload, the work environment, and experience were reported as affecting SA, echoing the findings of Sneddon et al.'s interview study, but fatigue was not commonly mentioned by the drillers.

The results also emulate those from other high-risk, high-reliability domains, for example, health care (e.g., Koch et al., 2012) and nuclear power control operators (Lee, Park, Kim, & Seong, 2012), where similar cognitive components required for developing and maintaining SA have been identified. Patrick, James, Ahmed, and Halliday (2006) identified very similar cognitive skills to those of the drillers that are 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 (Lini, Vallespir, Hourlier, Labat, & Favier, 2013) and surgery (Wauben et al., 2011).

It is important to consider the strengths and weaknesses of any study. In terms of the methodology adopted, interviews allow a certain degree of introspection from participants, but it is questionable to what extent an individual can be aware and comment on his or her own cognitive processes and SA (Dekker et al., 2009). Self-report interviews can also be subject to bias as well as motivational agendas (Rowley, 2012). Conducting phone interviews may reduce the rapport that can be built up between interviewee and interviewer, but this more anonymous method may have advantages in terms of interviewee candor and openness. Regarding observation and video analysis, it is questionable to what extent an observer can comment on internal processes and components, some of which may not have directly observable behaviors. It may also require considerable domain expertise to fully understand the purpose of these behaviors and their relation to SA. Interviews and observations can be prone to observer bias and expectations, skewing which data are collected and how they are represented (DeWalt & DeWalt, 2010).

We addressed these challenges in two ways. First, we used multiple data collection methods aimed at evaluating convergent validity through triangulation. Second, the researchers explicitly considered and discussed their backgrounds and how they might influence the research process, and what potential biases they might be bringing in terms of, for example, interview wording and data interpretation (Savin-Baden & Major, 2013). The use of a quantitative approach, whereby the researchers are considered less influential on the research process than is the case with qualitative approaches, may be fruitful to add further validity to the identified framework and further test Endsley's model within the drilling domain. The Quantitative Analysis of Situation Awareness (Edgar, Catherwood, Sallis, Brookes, & Medley, 2012), which uses signal detection theory to calculate a measure of SA, may be worth considering. Furthermore, the framework is preliminary, requiring subsequent research to test its reliability and validity to ensure that the components and their relationships reflect the real-world system and whether it can be replicated (Miles, Huberman, & Saldana, 2013). Research testing the model may include incident analysis, as is briefly discussed next, as well as using quantitative methods to examine relationships between components.

Finally, the framework shown in Figure 1 can be applied to drilling incidents, to test its fit against reported events. Roberts, Flin, and Cleland (2014) tested the preliminary SA framework with the evidence from a number of investigative reports on the large-scale drilling disaster involving Deepwater Horizon (e.g., Report to the President, 2011). They examined the development of the drill crew's SA during the final hours leading up to the blowout to try and understand why the crew continued despite an ever-increasing set of observable cues that indicated that the well was not under control. The analysis highlighted numerous SA errors, including difficulties recognizing cues (e.g., pressure increases on the drill pipe; Level 1 SA), inaccurate interpretations of the situation (e.g., the erroneous "bladder effect"; Level 2 SA), and failing to anticipate acceptable readings (e.g., estimated amount of acceptable back flow during the negative pressure tests; Level 3 SA), which ultimately culminated in the blowout. Thus this additional application of the model shown in Figure 1 indicated that it might hold additional value for incident analysis.

It is suggested that the components could be found in real events and that our preliminary framework can have practical applications regarding training and ergonomic design in the drilling domain. It could be used to inform crew resource management–style training, recently advised for wells operations (OGP, 2014), by providing specific information regarding cues (SA), information gathering and sharing between crew members (communication), strategies that crew members can use to improve SA (teamwork), and awareness of personal limitations (e.g., metacognition and distracters). The framework could be used to develop an SA-specific training program, such as conducted by Saus et al. (2006) for police officers, focusing on developing skills, such as cue recognition, mental simulation, and preparation for anticipated scenarios, as well as coping with distracters. These expertise-/evidence-based training programs are particularly appropriate as the demographic of the oil and gas workforce is changing, with large numbers retiring, pushing less experienced individuals into higher positions and producing a knowledge vacuum (Purdy, Webster, & Brady, 2006).

A less ambitious option could be to use the framework to develop an SA manual to assist less experienced drillers or assistant drillers who have the intention of advancing, such as was done for firefighters (see Crandall, Klein, & Hoffman, 2006). Moreover, these current findings could be applied to work design recommendations, for example, by considering the effect of phone calls on SA and how to use them to their greatest potential with the least negative impact on the driller or by examining console design to assist cue recognition and interpretation of information into a cohesive mental model, such as refining the layout of the information on the driller's screens.

CONCLUSION

The results provide a preliminary insight into how SA is developed and maintained by drillers in the oil and gas industry. Endsley's (1995) three-level model was found to be applicable, and these findings illustrate the importance of SA for safety and performance in drilling. With regard to nontechnical/crew resource management training in drilling (e.g., OGP, 2014), the identified cognitive components could be used to further refine these training programs. Once further developed, the framework could be applied to develop SA-specific training programs or work design recommendations.

APPENDIX A

Study 1: Interview Schedule

General questions

1. Could you tell me your job title?

2. How many years have you been doing that? (May want to know previous job if relevant.)

3. What do you think constitutes a good driller? What does their behavior look like (i.e., to an observer)?

4. Could you briefly tell me about your everyday tasks?

5. Generally, in your day-to-day tasks, what do you need to know and be aware of with respect to conducting a safe operation? (Could you describe how you do that?)

6. What types of things might alert you that things are not quite right?

7. Is there anything that you think might limit your awareness of what's going on (such as fatigue, displays)?

8. What do you think are the difficulties of keeping a good mental picture of the situation?

Incident instruction

I would like to ask you to recall an incident or day involving some aspect of well operations that was more challenging, such as a well control event or kick. Could you describe in your own words what happened?

Timeline

9. What did you need to keep track of?

10. How did you keep track of what was going on?

Critical incident questions

11. What do you think went well and what do you think did not go so well?

12. For the aspects that did not go so well, what do you think it was that contributed to it?

13. Do you think that your awareness of the situation (or picture of the situation) was important to the outcome of the event? (Describe why.)

Decision point identification

14. What decisions or actions did you take to manage the event?

15. What other actions or decisions could you have taken?

16. What were you were aware of when making these decisions, such as cues or noises?

17. Ideally, what information did you need to make that decision?

18. If another driller saw this situation, would they have interpreted it in the same way? (Describe how.)

19. *If this wasn't the best option to take, what do you think would have helped you make a better decision?

Additional probes

20. Could you describe if you knew how the situation was going to develop?

21. How do you think a driller with less experience would have acted in this event?

22. Is there anything that you think that a less experienced driller would have missed?

23. During this task, did you notice any details that others did not? (If so, could you describe them?)

24. What do you think that you learned from the event?

APPENDIX B

Study 2: Observational Checklist

1. What is the driller, assistant driller, or tool pusher doing?

2. What action/decision are they taking and possibly why?

3. What do they appear to be attending to?

4. Where is the information coming from, for example, crew, drilling screens, calculations, handovers, other?

5. What could be affecting their situation awareness positively or negatively?

6. Any inferences about possible cognitive components from behaviors (e.g., attention, cue recognition, memory, mental models, expectations, goals, automaticity, task switching)?

7. Any other comment on visible behaviors?

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KEY POINTS

1. Cognitive task analysis methods (interviews and observations) were used to develop a framework of how offshore drillers develop and maintain situation awareness (SA) during complex tasks, such as well control.

2. Factors that can influence driller SA were identified, including distracters, work environment, workload, and stress as well as sharing information and awareness between crew members.

3. The two studies apply Endsley's (1995) model to a new domain, adding to the specific SA and drilling literature as well as to a broader understanding of SA in the industrial context.

4. The preliminary framework provides insight into expert driller SA that can be used to inform interventions, such as training programs and system/ergonomic design.

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FIGURE 1: Framework of the cognitive components associated with an offshore driller's development and maintenance of situation awareness.

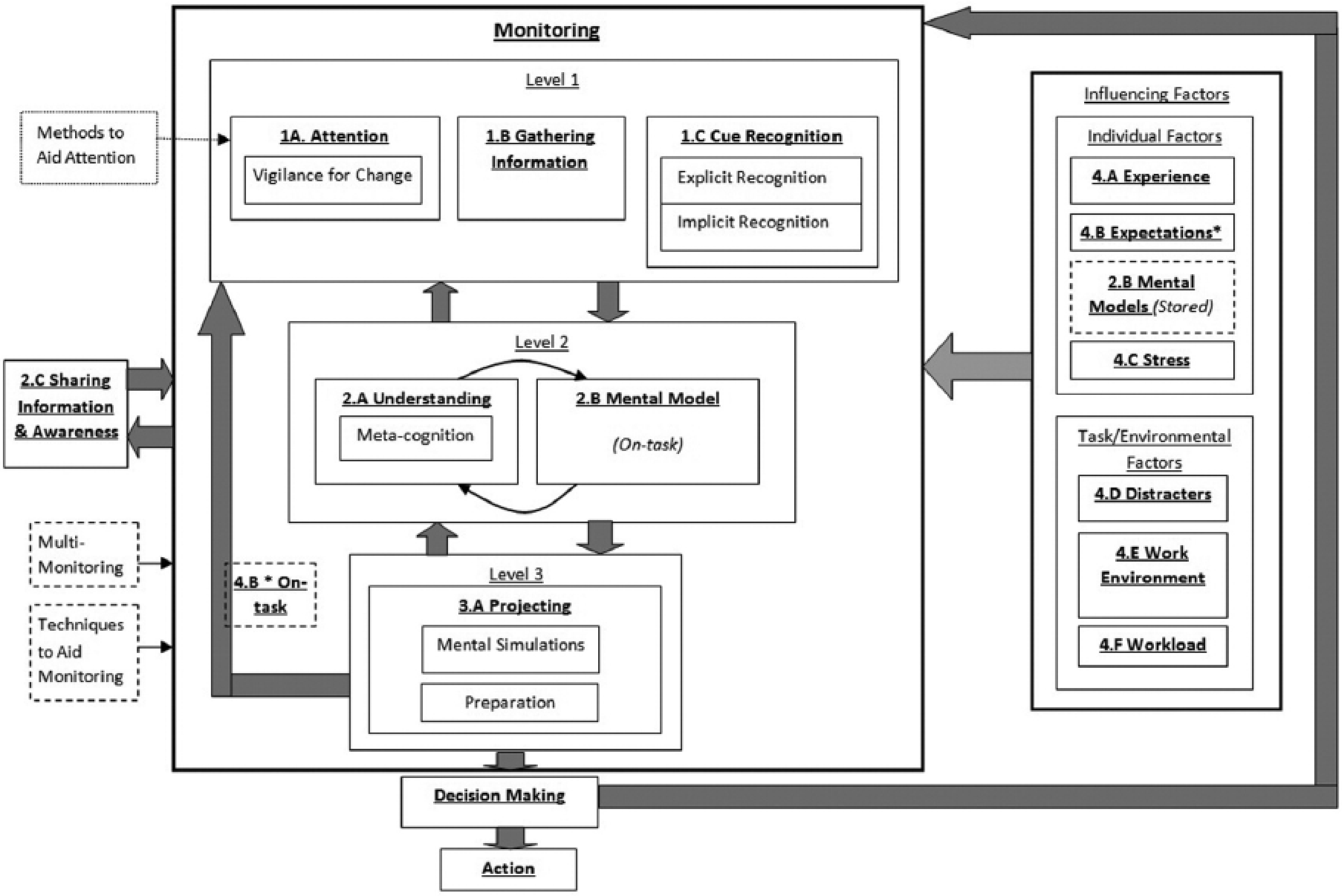

TABLE 1: Themes identified from the interview transcripts and the associated number of times they occurred in the interviews with illustrative quotes.

Theme	Total No. of Times Coded Across Interviews	Quotation
Level 1 SA		
1A. Attention	52	So you kind of have to zone in and block out certain things you don't need to know about. (I2[a])
1B. 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)
1C. 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)
1C. Implicit recognition	15	If he feels something is not right, he shouldn't do it. (I17)
Monitoring (Overall Process)	74	An ideal driller has to find the ideal way to keep a track of all of these things. (I6)
Level 2 SA		
2A. 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)
2B. 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)
2C. Shared information and 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		
3A. Projecting	26	Your better drillers will look ahead at least two steps and know what is coming up in the future. (I9)
3B. 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		
4A. Experience	51	I might react faster to stuff by just because maybe I have been exposed more to it. (I12)
4B. Expectations	22	We have a pretour 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)
4C. 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)
4D. Distraction	40	The fact that there is always a million things going on . . . and it is very easy to become distracted. (I4)
4E. Work environment	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)
4F. Workload	13	When you are sitting in the chair for maybe 2 hours and you are processing all this information, it is nice when I do get relief. (I2)

Note. SA = situation awareness.
[a]Interviewee label (e.g., I2 is Interviewee 2).

TABLE 2: Themes and subthemes identified from the observations and video analysis with the associated number of times they occurred in the observation notes with illustrative quotes plus observation number (ON) and video number (VN), respectively.

Theme	No. of Times Coded Across Observation Notes (ON 1–5)	Quotes From Observation Notes	No. of Times Coded Across Video Analysis (VN 6–16)	Quotes From Video Analysis
Level 1 SA: Perception				
1A. Attention	55	He is focused on his current tasks and appears undistracted by the other crew members who are busy preparing calculations. (ON4)	5	[The driller is focusing on the screens as TP takes calls] (27:12.0–27:30.5; VN7)
1A.1. Vigilance for change	9	Actively looking for a loss in the [mud] pits. (ON1)	0	—
1A.2. Methods to aid attention	8	TP focuses [driller]'s attention by physically pointing information out on the snap shot screens. (ON1)	1	"Guys, do me a favor and call the company man for me." (29:51.5–30:12.4; VN7)
1B. Gathering information	30	The driller has collected more information about the situation and other possible options from different pressures and looking at the different trip tanks. He also calls the tool pusher for advice on what to do. (ON4)	39	"Can you just give me a quick double check on this? I want to make sure it's [the well] dead." (13:57.8–14:16.0; VN11)
1C. Cue recognition	32	Pick up that extra pressure in the shut in standpipe is due to trapped pressure. (ON2)	17	"We're still showing losses there." (28:09.8–28:21.4; VN7)
1C.1. Implicit recognition	7	The driller starts to talk about his level of confidence on what he felt was happening—"I guess I didn't feel so confident about what I was seeing." (ON5)	0	—
Monitoring (overall process)	28	Driller appears to still be monitoring and keeping his trending sheet. (ON2)	95	Monitoring AD: "What's your torque?" Driller: "It's 25—it's broken over now." (13:21.4–14:16.0; VN10)
OP.1. Multimonitoring	9	During these tasks it would seem difficult to concentrate fully on the monitoring task (comment) as you can be standing watching the same screens for subtle changes in pressures in different places in the choke and kill line pipe systems (observation). (ON5)	15	[Driller monitoring number of strokes and drill pipe pressure] (35:08.3–35:41.0; VN7)
OP.2. Techniques to aid monitoring	18	Trend sheet that the driller keeps on his lap (ON1)	15	Driller: "About 24, 25 barrels out." (45:18.5–46:39.4; VN7)
Level 2 SA: Comprehension				
2A. Understanding	27	ROP [rate of penetration] shoots up which indicates that something has just happened down-hole. (ON4)	51	"We're nae taking losses, we're packing off. . . . Well, we had four barrels but that could be because we packed off." (13:44.8–14:00.8; 17:34.7–17:58.8; VN10)
2A.1 Metacognition	9	Driller answers phone to CM but hangs up as it is a crucial time and it's a major distraction [awareness of distraction on attention]. (ON2)	6	"I need somebody to come over here and help me do this, work the chair." (12:44.1–13:23.9; VN12)
2B. Mental models	29	As part of shutting in, the joints in the drill string need to be away from the BOP [blowout preventer] rams or else there will be problems with the seal and it may not close properly. They go to close the rams in the BOP but don't realise that this is in the middle of a drill string joint (observation) [current model of where the joint is]. (ON3)	10	TP to driller: "Yeh, it's because that 20 barrels went into the trip tanks and the trip tank is part of the active [model of pipes and manifolds]." (5:09.6–5:23.8; VN11)

(continued over)

(TABLE 2 – continued)

2C. Shared information and awareness	62	Proceed to call everyone about the situation and tell them to prepare to use the drillers' method (observation). (ON3)	86	Driller talking to tool pusher: "I'll let you know when I get my weight on bit back to zero and then we can open up the pipe rams." (33:51.7—34:14.0; VN11)
Level 3 SA: Anticipation				
3A. Projection	22	Start to bleed off pressure from well to strip tank, projecting that they should see a decreased pressure over time. (ON2)	14	"We haven't done a full, bottoms-up circulation since we stopped drilling so there are cuttings in the hole and that will be coming up through the choke, that's one thing we need to look out for. We could plug the choke." (1:06:45.81:07:11.9; VN14)
3A.1 Mental simulations	5	TPs discussing the different options, simulating the outcomes of different options. Lots of what ifs and doing calculations to simulate what will happen (observation). (ON1)	4	"When we have pumped 100 psi [pounds per square inch], you need to let your choke increase, with that amount, if we pump 100 strokes, we need to let it increase with so many psi." (25:29.8–26:29.8; VN16)
3A.2. Preparation	8	Prepare the fracture pressure calculations for pumping in case they pump at too high a rate. (ON4)	5	"Get ready for a flow check." (30:30.8–30:40.1; VN7)
3B. Awareness of the situation	13	—	0	—
Influencing factors				
4A. Experience	10	The driller uses this point to share his knowledge about the value systems with the lesser experienced AD (observation) which seems to help the driller himself work out a better plan (comment)—open the chokes all the way and carefully monitor. (ON5)	3	—
4B. Expectations	13	Driller is now expecting and looking for changes in the trends and pressures as they pump heavier mud down to flush out the lighter mud. (ON4)	15	"We won't go into underbalance. As soon as that cement starts coming out we can start going down. . . . And then we'll have the influx here [pointing to paper graphs at table]." (27:31.9–28:06.2; VN16)
4C. Stress	14	CM calls to remind them that they only have 10 minutes for making the connection—places stress onto the driller, distracting him and the AD who is setting the stand up. (ON2)	3	"I'm not stressed. I was stressed. I am a little bit stressed" [experiencing an influx]. (46:00.1–46:25.6; VN7)
4D. Distracters	19	The helicopter alert sound comes over which initially appears to be distracting him but he starts to ignore quickly. Moving closer to the screens to concentrate (observation). (ON4)	24	TP talking to everyone in the drill cabin: "OK, one thing gentlemen. What I would like to have is the driller doing his job and he is not distracted by anyone else. You only ask him for assistance when he is requiring assistance. Don't distract him at all. . . . You came for a reason or . . . ?" (39:18.8–39:49.3; VN6)
4E. Work environment	15	AD quickly says that they should set up different screens on AD's screens rather than Driller's screens otherwise his trends will be lost (observation). (ON2)	14	[Alarms go off] "That's us! We've broke over." (35:14.7–35:26.8; VN11)
4F. Workload	2	Starts to become more hectic, the company man (CM) keeps calling about numbers and the group starts to get confused about which numbers they are using. CM points out that they have forgotten to do a stand pipe pressure calculation so they are missing crucial piece of information (observation). (ON2)	12	[Alarms going off] "Would somebody please tell me what that is?" TP: "That would be the flow because you're picking up, dude. That should do, shut it in. . . . Kill everything." (13:35.5–17:32.3; VN11)

Note. AD = assistant driller; CM = company man; TP = tool pusher.