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ORIGINAL ARTICLE

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Situation awareness and safety in offshore drill crews

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Abstract In many industrial settings, the situation awareness (SA) of workers needs to be maintained at a high level to ensure the safety of their operation. This is particularly relevant to offshore oil-drilling and gas-drilling crews, given the interactive and hazardous nature of their work. This paper presents a review of SA in drilling incidents and results from interviews with oil and gas industry drilling personnel regarding SA in this environment. Accident analysis showed that most errors in SA (67%) occurred at the perceptual level, 20% occurred at comprehension, and 13% arose during projection. Interview findings concluded that isolation from events at home was perceived to be the largest contributory factor for reducing awareness, followed by fatigue and stress. Character change was the most cited indicator of reduced awareness, and communication was thought to be the best method of increasing awareness. Consistency, cohesion, adaptability, and trust were identified as requirements for good team SA.

Keywords Situation awareness · Offshore oil and gas · Drilling · Safety

1 Introduction

After a number of high-profile disasters (most notably the Piper Alpha disaster in 1988 in which 167 personnel lost their lives; Cullen 1990), oil and gas industry companies are making every effort to ensure that their accident rates are kept as low as possible. For most industrial accidents, there is a causal chain of organisational conditions and human errors (Turner and Pidgeon 1997), with Reason (1990) indicating that human-factor causes can be attributed to 70–80% of accidents in high-hazard industries. One critical factor in preventing accidents is the ability of workers to maintain an adequate understanding of their worksite situation. This means having a high level of awareness of task and environmental conditions, and judging how these may change in the near future to predict how the situation will develop. Cognitive psychologists have long been interested in attention (Baddeley 1995; Styles 2006), and the role of cognitive skill in safety is well established (Strater 2005). In industry, the necessary attentional skills are referred to as 'situation awareness' (SA). This concept has been mainly studied in aviation (Endsley & Garland 2000), but in more recent years, the research field has expanded to include aircraft maintenance (Adams et al. 1995; Shrestha et al. 1995), the military (French et al. 2004; Strater et al. 2004), driving (Gugerty 1997; McGowan and Banbury 2004), anaesthesia (Fletcher et al. 2004; Zhang et al. 2002), the maritime industry (Grech and Horberry 2002), and nuclear power plants (Patrick and Belton 2003). The concept of SA is discussed further below.

This study was designed to examine the role of SA in the offshore oil industry. A survey of 200 offshore installation managers indicated that they believed lack of care and attention to be one of the main causes of accidents on production platforms and drilling rigs (O'Dea and Flin 1998). This suggests that the workers' awareness of their work environment is not always of a high enough quality to ensure safe and efficient operations. Possession and maintenance of good quality SA appears to be of particular importance in the offshore oil and gas industry, where the work is hazardous, time pressured, and can be complex. On board an offshore drilling rig or production platform, the drilling crews are

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involved in one of the most dangerous activities. The drilling environment can change suddenly and for a drill crew an incorrect decision can cost millions of dollars (in both equipment damage and/or production loss), but safety costs can be far more severe, with the capacity to result in loss of human life.

1.1 Drilling for oil and gas

The activities of the different members of a drill crew are varied, but all centre around the successful boring of a well and subsequent oil production. This process is hazardous, as it involves the manual handling of heavy machinery and equipment as the process is not entirely automated. Initially, a hole (or 'well') is drilled into the seabed where the sub-sea oil reservoir is believed to be located (determined through seismic and geological surveys). This involves positioning the drill bit (the instrument which cuts through the rock), collar and drill pipe into the hole, attaching this assembly to the kelly and rotary table (the mechanism which rotates, lowers, and raises the drill pipe structure), and begin the drilling. Drilling mud is introduced into the centre pipe in order to allow the cuttings to be floated back to the surface and extracted from the hole, making the process slippery. As the well gets deeper, additional sections of pipe (known as joints) are added to reach the oil reservoir, forming the 'drill string.' The drill bit can require frequent replacement during drilling, depending on the composition of the rock. To replace the bit, the entire drill string must be removed from the well, and the pipes 'stacked' (disassembled from the string and stored in the derrick structure) in order to reach the drill bit at the end. This can be a very hazardous process due to the presence of slippery oil-based mud (from the cuttings) on the machinery and on the drill floor.

Once this is complete, flow of the oil up through the well is allowed by placing tubing (a smaller-diameter pipe) into the casing, and a packer down the outside of this (this forms a seal round the tubing, and also sets the production level). At the top of the tubing, a 'Christmas tree' is attached—this contains a number of valves which allows the drill crew to control the resulting flow of oil from the well. Owing to the pressures at which the oil is found, 'blow-outs' are possible, and are another added risk in the process. Blow-outs occur when the gas pressure inside the well suddenly forces the oil up and out at forces which can have the potential to destroy the rig if not controlled. While blow-out valves are placed on the seabed in order to stabilise the pressure and control the well when necessary, the potential for a catastrophic situation is very real for the drill crew.

As a result, these crews must be able to continuously monitor and understand their environment if they are to keep their accident risk to a minimum. With the exception of some conference papers (e.g. Hudson and van der Graaf 1998), and inclusion in Crew Resource Management training (O'Connor and Flin 2003), the concept appears to be under-investigated in the oil and gas industry, despite its apparent relevance, and remains little understood in this particular occupational context. The aim of this study was to determine the role of SA in drilling operations: to identify the relevance of SA in drilling incidents, and the factors contributing to decreases in drilling workers' SA.

2 The concept of SA

The notion of SA has been in existence for many years, with references to the concept believed to originate from the pilot community of World War I. Definitions of SA vary (see Rousseau et al. 2004), but are similar in their descriptions. The most cited definition of SA is "... the perception of the elements in the environment within a volume of space and time, the comprehension of their meaning, and the projection of their status in the near future" (Endsley 1988, p 97). SA involves concentration, attention to detail, and vigilance, which in turn create a sensitivity to cues in the environment signalling a change of state. Sarter and Woods (1991, p 50) state that SA "... is based on the integration of knowledge resulting from recurrent situation assessments," i.e. by continually appraising the situation and incorporating facts from it. The theory of SA draws upon the fundamentals of information processing, in that it is a cognitive process that involves the perception of information from the environment, and the amalgamation of this information with what is already known to form an understanding of the situation, all within the confines of the working memory (Smith and Hancock 1995). The result is three levels of SA: perception, comprehension/information integration, and projection (Adams et al. 1995; Shrestha et al. 1995). Notwithstanding some differing views by cognitive psychologists on the nature and function of SA (see Banbury and Tremblay 2004), Endsley's definition and triadic model (Endsley 1995) dominate the field, and her model has been adopted here for analytical purposes.

2.1 Levels of SA

2.1.1 *Level 1 SA: perception*

This is the basal constituent of SA: in order for SA to be achieved, the work environment should be continually monitored to encode sensory information and to detect changes in significant stimuli. Attentional processing (La Berge 1995; Shiffrin and Schneider 1977) is intrinsically linked to the theory of SA, but attention is bound by the limits of the working memory system (Baddeley and Hitch 1974). This means that workers are unable to pay close attention to every single detail of their environment. Consequently, attention is selective, and critical elements may be missed or ignored in the perception stage (Simons 2000).

2.2 Level 2 SA: comprehension

This involves the combination, interpretation, storage, and retention of the incoming information (Endsley 2000) to form a picture of the situation whereby the significance of objects/events is understood (Stanton et al. 2001)—essentially derivation of meaning from the elements perceived. This is partly driven by mental models (representations of objects, people, and tasks) already stored in long-term memory. The degree of comprehension that is achieved will vary from person to person, and Endsley (1995) maintains that the level attained is an indication of the skill and expertise (richness and accessibility of mental models) held by the operator. Klimoski and Mohammed (1994, p405) state that mental models "... provide a conceptual framework for describing, explaining, and predicting future system states." Possession of a poor or incorrect mental model can increase accident risk.

2.3 Level 3 SA: projection

The final level is projection, which occurs as a result of the combination of levels 1 and 2. This stage is extremely important, as it is the prediction of possible future states and events (Endsley 1988, 1995; Sarter and Woods 1991). Having the ability to correctly forecast possible future circumstances is vital, as it enables the formulation of suitable action courses to meet goals (Endsley 1995, 2000; Stanton et al. 2001). Endsley (2000, p7) states that "... experienced operators rely heavily on future projections" as this "allows for timely decision making," adding that "It is the mark of a skilled expert."

2.4 Team SA

Much of the work on an offshore installation/rig requires teamwork. The successful attainment of the drilling task is entirely dependent upon the crew collectively working together, therefore team members must have a mutual understanding of the situation. In essence, the team should have a collective SA: this shared awareness is known as team SA (Endsley and Robertson 2000; Salas et al. 1995; Shu and Furuta 2005). Team SA can be characterised as follows: "... compatible models of the team's internal and external environment; includes skill in arriving at a common understanding of the situation and applying appropriate task strategies" (Cannon-Bowers et al. 1995, p344). This shared knowledge and understanding of a given situation can then be called upon in order for the crew to make critical decisions and adapt, in order to react to and predict their working environment.

2.5 Factors affecting SA

Factors influencing workers' SA may be related to individual differences or to external influences on human performance. One study of SA in aviation crews included a new scale called Factors Affecting Situation Awareness (Banbury et al. 2006; see ESSAI 2004 for more detail). A similar scale refers to Workplace Cognitive Failures (Wallace and Chen 2005). These assess individual differences in aspects of cognition related to SA (e.g. attention management, cognitive efficiency), rather than organisational or environmental influences. In general, SA is likely to be affected by the standard range of factors influencing human reliability (see Salvendy 2006). Environmental conditions such as temperature, noise levels, and light can decrease reliability and make humans more error-prone, as can job factors, e.g. automation and task complexity (Hollnagel 1993). Two of the principal occupational performance-shaping factors that are particularly relevant to SA on offshore drilling rigs are stress and workload.

2.5.1 Stress

The effects of stress on human performance are well documented (Clarke and Cooper 2004; Driskell and Salas 1996; Flin et al. 1997). Stress can result in poor concentration/alertness as a result of an overload on the individual's cognitive resources. Stressors can be physical, such as vibration, crowding, noise, pollution, temperature, and high/low light levels (e.g. Endsley 1995; Poulton 1978)—elements which feature predominantly and are virtually inescapable in the harsh offshore environment (Sutherland and Cooper 1986, 1996; Sutherland and Flin 1991). There can also be psychological stressors, such as anxiety (Atkinson 1988), or social (a drilling rig is a small, isolated workplace). In relation to SA, Endsley (1995) reports that stress can interfere with the primary perception of the situation. The most common effect is narrowing of the attentional field to a restricted number of core aspects, whereas information on the periphery is less likely to be encoded. The term 'cognitive tunnel vision' is sometimes used to describe the increased tendency to focus on dominant sources of information (Tversky and Kahneman 1974). Although this can be a valuable adaptive strategy in a safety critical environment such as offshore, it is often the case that factors outside the central focus of attention are those which have most potential to be harmful. The levels of occupational stress on offshore installations have been measured in a series of studies (Parkes 1998; Sutherland and Flin 1991) and associations with accident rates established (Sutherland and Cooper 1986, 1996).

2.5.2 Workload

Unusually low or high workloads can impact on human performance (Hockey 1997). Low workload can result in boredom with consequent inattentiveness, decreased vigilance, and reduced motivation (therefore, less attention is being paid to the workplace conditions, which can lead to poor SA). Conversely, if the work volume is excessive or the tasks are inordinately complicated, it can mean that employees become 'caught up' in attending to particular tasks, or become distracted by other pressing issues to tackle, and so do not apportion adequate time to monitor their situation. In doing so, their SA will be impaired, as they may be unaware of situational changes, and may make inappropriate decisions based on incomplete or incorrect information (Jeannot 2000). Consequently, they may also be unable to react quickly enough should an unforeseen event occur.

Although oil and gas companies try to maintain the correct balance between production pressures and working safely (Mearns et al. 2003), in today's energy market, changing demand is an intrinsic feature of the offshore working environment and therefore work does not always occur at a constant rate. Low workload phases do occur (e.g. waiting on weather), but more typical are periods when workload sharply increases (e.g. due to production pressures, or when the number of personnel onboard is downsized). There is some evidence that increased workload has a detrimental impact upon offshore workers' psychological wellbeing (see Parkes 1992, 1998; Sutherland and Flin 1989).

2.6 Errors relating to SA

By examining the data provided in accident reports, causal factors relating to SA can sometimes be classified, e.g. misperceived, misidentified, misunderstood information. Jones and Endsley (1996) developed a taxonomy based on Endsley's (1995) model describing the areas in which errors in SA can be classified (see Table 1). Although her work was based on research conducted in the aviation field, this taxonomy appears to have applicability to the oil industry. As no previous research has been published on SA in offshore workers, the present investigation adopted a two-stage approach to examine SA in drill crews. Study 1 was an analysis of drilling accidents to determine whether problems with SA were present in the drilling industry. Study 2 consisted of interviews with onshore and offshore drilling personnel, to gain a more detailed understanding of SA within the industry.

Table 1 Classification of SA errors in drilling incidents

Level of error	No. of incidents	% of total incidents
Perception	90	66.7
Data not available	13	9.7
Hard to discriminate or detect data	21	15.7
Failure to monitor or observe data	36	26.8
Misperception of data	19	14.2
Memory loss	1	0.1
Comprehension	27	20
Lack of/poor mental model	9	6.7
Use of incorrect mental model	15	11.1
Over-reliance on default values	3	2.2
Projection	18	13.3
Lack of/poor mental model	17	13.2
Overprojection of current trends	1	0.1

3 Method

3.1 Study 1—accident analyses

In this oil and gas company, an incident is any event or situation that has the potential to cause, or caused actual loss, and includes accidents and near-misses; and loss is defined as injury to people, damage or destruction of equipment, plant, or materials, harm to the environment, or loss of production. An accident is an adverse event resulting in loss, whereas a near-miss is a situation whereby the current circumstances were prevented from developing into a situation with more serious consequences (i.e. no loss) (Shell International B.V. 2002). The aim of Study 1 was to discover to what extent SA had been identified as a causal factor in drilling related incidents.

3.1.1 Procedure

A search was performed on a multinational oil company's database of drilling activity incidents (on fixed installations, mobile rigs, and all other well operations) for the period January–October 2003, for incidents involving drilling operations. These include not just running drill pipes/tools in and out of the bore hole, but related operations such as lifting pipes and other materials onto the drill floor with cranes, and checking components on the drilling derrick. Incidents recorded in this database included accidents where persons involved were harmed, but also occurrences whereby there was no harm to people, but leaks, damage to plant or environment, or lost production. The reports contained in the system were filed by the supervisor of the individual(s) involved. Many reports were already coded with a root cause (which in most cases was merely 'human error,' in some cases going as far as stating 'lack of attention') but also had additional free text describing the incident in more detail. The volume of additional text contained within each report ranged from one sentence to a full A4 page of text. The free text of the incident reports was analysed in all cases, as many of the reports had no root cause assigned. In addition, recent research has suggested that reporting of human factors causes of offshore accidents is generally poor, and even when human-factor codes are present in the system, they are not well understood (Gordon et al. 2005), so the pre-existing codes assigned could not be relied upon to provide an accurate cause of the incident. At this point, the weakness of this approach should be noted—this method is based solely upon the incident information provided by the reporters, who may or may not have been recording human factors/cognitive information, or recorded it in a poor manner, therefore there is no guarantee that this analysis provides an accurate picture of SA issues in drilling—these results are possibly an underestimation of the true situation.

Of the 332 incidents, those which were not related to SA errors (e.g. technical faults, $n = 102$), or did not provide enough information to identify the error source ($n = 95$), were discounted, leaving 135 incidents in the sample. The incident texts were analysed and classified by the first author using Jones and Endsley's (1996) taxonomy of SA errors in order to classify into which stage of the cognitive process the SA errors fell. If it was found that an error could fall into more than one category, it was classified at the lowest taxonomy level. One root SA error cause was ascribed to each incident. Another industrial psychologist was asked to repeat the process, resulting in an inter-rater reliability of 99%. Table 1 shows the results of the drilling accident analysis.

3.1.2 Results

Overall, it was found that the majority of incidents were classified as Level 1 SA errors (66.7%). A total of 20% were classified as Level 2 SA errors, and the remaining were Level 3 SA errors (13.3%). As only one causal level was prescribed for each incident with a default to Level 1, then this is likely to have underestimated Level 2 and 3 failures.

3.1.2.1 Level 1 errors Most problems with SA in this sample occurred at the first stage of SA where information/data is perceived. Of these 90 incidents, each could be attributed to one of the five causal factors.

Data not available: In 13 of these incidents (14.4% of Level 1 errors, 9.7% of total errors), data were unavailable for perception. Most of the time this was due to the incident occurring down in the well shaft or within pipes, and if readings from instruments were available, the particular pieces of equipment or apparatus were not observable. One example of this occurred when two valves were placed down a well to stop the flow in order to allow a pressure test to be carried out. Although it was believed that these plugs were correctly in place, and readings indicated this, when they were withdrawn, it was discovered that only one was giving the isolation required. Another example involved the retrieval of a plug and hose (the plug was attached to the hose by a push-fit connection sealed with 'O' rings by pressurisation): when the hose was pulled to the surface, it was found to have parted from the fitting, which was then later recovered only to be found still attached to the running tool. This was not apparent while the hose was being removed and only could be noticed once it was completely taken out.

Hard to discriminate or detect: For 21 incidents (23.3% of Level 1 errors, 15.7% of total errors), data were difficult to detect. The majority of these regarded information being difficult to see due to obstruction from other pieces of equipment or machinery. One example of this occurred during winter whereby as a thaw began, pieces of ice began to fall onto the drill floor from the derrick. However, due to the pipe work and other structural limitations, it was extremely difficult to see where the pieces of ice were and from where they were falling. Also, a leak in a pipe was difficult to detect due to the leak point being obscured by a piece of cloth and equipment.

Failure to monitor or observe data: The majority of incidents ($n = 36$ and 40% of Level 1 errors, 26.8% of total errors) occurred where relevant information was not monitored or discerned. In these cases, workers were becoming distracted by a task and thus not paying attention to all relevant stimuli, or had poorer vigilance (in that the assessment of the environment was of a poor quality). One instance of this involved a data engineer who did not perceive the initial H_2S reading on the chromatograph. Another example of this occurring involved a member of the deck crew while running 20-in. casing. Joints were being tailed into the floor using the crane, and then picked up with single-joint elevators suspended from the bails. Procedures and toolbox talks (TBTs) highlight that the banksman must watch the load at all times to chart its movement. However, he placed his hand on the bumper bar and despite the aforementioned regulations and toolbox talk, did not watch the load as he 'talked it in.' As a result, he failed to observe that the casing was approaching his hand, and two fingers were nipped.

Misperception: Misperception of data/information accounted for 19 incidents (21.1% of Level 1 errors, 14.2% of total errors). An instance of this arose on investigation of a leak: a valve was installed and perceived to be in working order when in fact it was faulty. In another case, a sling parted, potentially harming workers (although personnel were standing clear of the lift at the time, and as a result there were no injuries)—this was due to the instructions the winch operator heard being "garbled radio transmission." He asked for clarification of the instructions, which he then interpreted as a pick-up instruction, which it was not, thus causing too much tension to be applied to the sling.

Memory loss: Memory loss (forgetting of relevant information) was the least frequent Level 1 SA error and occurred only once. Personnel observed loss of winch operation mid-task, causing a cable to swing, and the task was halted in order to discover power was lost. It was found that a maintenance electrician had inadvertently switched off the power while finding an unrelated electrical fault, and had not re-instated the power supply on realising this.

3.1.2.2 Level 2 errors Level 2 SA errors regard the incorrect understanding or assimilation of information.

A total of 20% (27) of all drilling incidents were due to this type of error, and sub-divided into the following categories:

Lack of/poor mental model: Errors which involved a poor or complete lack of a mental model were attributed to 6.7% of total errors (33.3% of Level 2 errors). The majority of these involved automation, in that the operator's mental model of how to work the equipment was incomplete. For example, a worker caught the side of their foot on a piece of machinery, as they were unfamiliar with how that particular piece of plant worked, and were unsure of the areas to observe.

Use of incorrect mental model: The majority of Level 2 errors (15 incidents, 55.6% of Level 2 errors, 11.1% of total errors) involved this factor. One instance occurred when slinging part of the derrick structure—the apparatus was slung in a manner not appropriate for its weight, but correct for a piece of equipment with which the operator had previously been dealing. Thus he was working with a mental model correct for the previous task, but incorrect for the present piece of equipment with which he was working. The worker was only made aware of his error when a supervisor informed him.

Over-reliance on default values: Over-reliance on default values occurs when individuals forget something and decide to follow the routine that conforms to the 'usual' method; habitual, routine behaviours are inadvertently performed in place of the prescribed, correct behaviours, or actions are performed based upon the pre-existing expectations of how the system operates. These types of error occurred only three times in total. An example of this category of error involved the belly pan (a container which sits below the rotary deck to collect drilling fluids). Under normal circumstances, the belly pan collects the fluid and drains it into a holding tank on the main deck. However, in this case, the hose connection to the holding tank had been damaged, and the drain point sealed, meaning that the pan had to be checked manually at regular intervals. During operations, there had been heavy rain, but this had not been taken into account, and the pan was left to fill with, in this case, oil-based mud, as normal (i.e. personnel were working in accordance to the usual system, and in the usual methods—working on their default values). As personnel were working on the assumption that everything was as normal, they had not borne in mind that the recent rainfall would also collect in the pan. The pan subsequently overflowed, causing approximately two gallons of oil-based mud to spill onto the drill floor.

3.1.2.3 Level 3 errors Level 3 errors occur when there is a problem with the projection of future states. In total, 18 incidents in total occurred at this stage (13.3% of the total SA errors). Level 3 errors can be divided into the following two categories.

Lack of or poor mental model: These accounted for the majority of Level 3 errors (13.2%). An example of a poor mental model being found to cause an incident was an individual who was walking through the door leading from the shaker area to the cantilever deck. While observing that conditions were relatively windy, he did not anticipate the effect that this would have upon the door, causing it to swing shut, trapping his fingers. Lack of mental model was exhibited in a number of incidents, including one in which it caused a failure to anticipate a dangerous situation. During the process of skidding the rig, lookouts were posted to check for any potential clash points. Two beams were observed, however, as an association had not been made that they could come into contact with another, the clash between them was not foreseen.

Over-projection of current trends: Only one incident was found to be due to this kind of error. Following operations, the drilling riser had been placed on the drill floor and required moving. The riser was slung, and two rope tag lines added to each sling in order to slew the riser away. As the crane lifted the riser, it caused movement to the riser, and the banksman attempted to compensate for this. However, he over-projected the movement of the riser, causing the load to move towards the doghouse window, cracking the glass panel.

3.1.3 Discussion

From the above analysis, it can be seen that the majority of incidents occurring appear due to errors with the perception level of SA (Level 1), i.e. people are failing to correctly perceive the situation. The analysis also gives an indication of the comparative occurrence rate of the different types of errors that can be made within the three levels of SA. As Table 1 shows, the most common class of error is 'failure to monitor or observe data,' which accounted for more than one-quarter of the total errors made. These types of errors were most commonly related to distraction and poor vigilance. Information that was difficult to detect or discriminate was also a prominent factor. Although this may in part be due to the design structure of installations, it presents itself as an issue that merits further investigation. There may be another reason that perception errors were the most common type of SA error to be found. Although the drill floor is a dynamic work environment, much of the work conducted tends to be routine. It is widely known that when tasks are frequent and routine, complacency can set in, and accidents are more likely (Perrow 1994; Reason 1990). This is supported by research in shipping (e.g. Hansen et al. 2002), who found that more accidents occurred during routine work than non-routine work, and Kines (2003) who discovered (when examining falls from heights) that more hazards were perceived during non-routine work than routine work. The reason that accidents are more likely is because the individual(s) involved have performed the task on so many occasions that the actions involved have become 'pre-programmed,' and attentional checks are performed less often. Klein et al. (2005) state that when involved in routine tasks, we should not allow actions to be carried out automatically, and must be aware enough to notice any hazardous conditions or disturbances in the usual pattern of events/conditions that signal that safety may be compromised. It is reasonable to suggest that the workers in this sample may have 'switched off' to any potential hazards or changes in conditions simply because they were conducting a routine task, were comfortable in their surroundings, and were not paying adequate attention to any emerging cues.

Errors relating to 'use of incorrect mental model' in Level 2 SA (comprehension) were relatively common, occurring in more than one in ten of the Level 2 failures. This could be associated with new hands or relatively inexperienced personnel, but it was also related to experienced personnel who were working with new types of machinery. This may be related to competence, if some personnel are sent onboard rigs with inadequate or incomplete training, then they cannot be expected to detect significant cues or comprehend their meaning, and may associate the wrong mental model to their work. Klein et al. (2005) state that expertise is extremely beneficial in realising where problems may be occurring. Mumaw et al. (2000) also mention that the mental model of the individual(s) involved helps them to judge the situation correctly and that the interpretation of the situation will depend on the suitability of the mental model being used. This supports the notion that if personnel are inexperienced with a given situation or piece of equipment, they may not have an accurate mental model upon which to base their actions, and therefore they will be at higher risk of accident involvement.

The category in which it was least common to have an SA error was Level 3 SA (projection), and the apparent poor quality of this. It is understandable that the lowest frequency of SA errors occurs at this level, as projection is dependant upon the successful progression through both levels 1 and 2 of perception and comprehension. The errors found here related to personnel being unable to accurately predict future situations and circumstances in order to develop appropriate courses of action. The above finding from Mumaw et al. (2000) also indicates that projection errors can be caused by a poor mental model for the prediction of events stage of the SA process. As with errors found with mental models in Level 2 SA, the role of experience is a prominent factor in the development of a mental model which accurately allows for adequate prediction of future events. This is supported by Doane et al. (2004), who report that expert pilots are more successful in anticipating the future state of the flight (and also more accurate in recognising inconsistencies with flight data).

It is apparent from this that there are several factors that can lead to problems with SA for drill crews. What is also interesting to note is that Jones and Endsley's (1996) research with pilots found that errors in Level 1 SA accounted for 76.3% of all errors, Level 2 SA errors 20.3%, and Level 3 errors 3.4%. Grech and Horberry's (2002) research on shipping accidents showed 58.5, 32.7, and 8.8% for Level 1, 2, and 3 errors, respectively. This study suggests that the relative frequency of types of SA errors in the offshore drilling industry are similar to those occurring in aviation and the maritime shipping industry, indicating that the comparative frequencies of SA error causal factors may be a pattern generalisable to other high-risk industries.

3.2 Study 2—interviews with drilling personnel

Once it was discovered that errors related to SA were an issue for the drilling industry, interviews were conducted with members of the drilling industry in an effort to understand how well the concept of SA is recognised within this industry.

3.2.1 *Procedure*

3.2.1.1 Participants Interviews were conducted with the drilling personnel of six oil and gas operator and contractor companies. In total, 17 personnel volunteered to participate and were interviewed by the first author who has a basic knowledge of drilling for oil and gas. Ten personnel were based onshore (either as HSE Managers, Operations Managers, or Well Engineering Managers) and all had previous offshore experience in the drilling field ranging from 6 to 15 years. Seven personnel were based offshore (positions included Barge Engineer, Offshore Well Engineer, Offshore Installation Manager, Safety Representative), and had been working offshore for between 5 and 26 years.

3.2.1.2 Procedure For logistical purposes, the offshore personnel were interviewed on their installation, either in the heli-deck lounge or the radio operator's office. Interviews for onshore staff took place mainly in a room in the company building. All interviews were informal, of a semi-structured nature, and lasted approximately 30 min. The interview schedule was based on the literature review. Questions included "How is the concept of SA known in the offshore industry"; "What factors can affect the quality of a person's awareness?"; "What are the indicators of reduced awareness?"; "How can reduced awareness be improved?"; and "How is team SA achieved?".

3.2.1.3 Confidentiality of information Interviewees were given background information to the study, and made aware that they could withdraw at any point. It was explained that all information gained would remain entirely confidential, and although de-identified quotes may be used to support points made, at no point would any individual's data be released to their company. Permission to record the interview was requested and granted by all interviewees, after which the interview was transcribed, de-identified, and the record erased.

3.2.1.4 Analysis Drawing from the theoretical literature based on aviation SA (e.g. Endsley 1995), coding of open-ended questions was carried out in order to discover any common themes and important points. The interviewees' responses from the interviews were extracted and are summarised in Table 2.

3.2.2 Discussion

The most salient themes from Table 2 are discussed below.

Q1. How is the concept of SA known/termed in the offshore industry?

Table 2 Main findings from interview analysis

- How is SA known in the offshore industry?
  - Safety awareness
  - Positional awareness
  - Safety accountability
- What factors affect the quality of a person's awareness?
  - Home/family problems
  - Fatigue
  - Stress and workload
  - Experience (and new personnel)
  - Routine tasks/complacency
  - Job prospects
  - Having a near-miss
  - Weather/seasons
  - Communication—good and bad
  - Conflict
  - Supervisory responsibility
  - Daydreaming
- What are the indicators of reduced awareness?
  - Character change
  - Reduction in communication
  - Repetition of instructions
  - Expressionless
  - Reduced work standards
- How can reduced awareness be improved?
  - Communication
  - Discussion of events
  - Place them in a different job
  - Removal from the situation
  - Alter the work level
  - Alter the crew line-up
  - Interaction
  - Increase involvement in rig activities
  - Training
  - Problem solving
- What can be done to check the awareness of workers?
  - TBTs
  - Risk assessments
  - Constant assessment of surroundings
  - Pocket TBTs
- How is team SA achieved?
  - Consistency
  - Adaptability
  - Co-operation
  - Trust
  - Time
  - Understand capabilities and traits planning
  - Experience
  - Increased interaction

All 17 personnel had slightly differing opinions as to what they regarded as SA, but their definitions centred around perception in that it meant being aware of what was going on around you at all times, being alert for changing situations, and keeping that at the forefront of your mind to enable you to react to changing circumstances. Most said that they would term SA as 'safety awareness', because due to the safety critical nature of the offshore environment, all operations have safety as the top priority. Therefore, being aware of the safety of the situation was crucial and is the first thing that is assessed—"so it includes knowing generally about your environment, that's the situation part, but also being aware of the inherent hazards in the surrounding area and formulating ways of dealing with them, that's the really important part for us, the safety awareness." Others commented that they would call it 'positional awareness' or 'safety accountability': the former term was used because it was felt to sum up making sure you knew what was going on and where everything was so that you could "always be in the correct position to avoid mishaps and keep working safely." The latter was due to the responsibility of everyone to ensure that they work safely and to ensure that those around them did also, ascertaining that the situation was always monitored. This accountability for safety was achieved by the behavioural observation systems in place in these companies such as STOP (Krause 1997) which encourage interventions in the workplace, both positively (when work is being carried out safely, to reinforce this) and negatively (when work is being performed in an unsafe manner, to step in and make the concerned worker aware of this, and offer advice on how to carry out the job safely).

Q2. What factors affect the quality of a person's awareness?

There were a number of different factors that were felt to affect awareness, most of them being perceived to cause a decrease in the quality. Having problems with family/at home was felt to be the most prominent factor that could affect awareness. Being offshore meant personnel had no control over the situation at home, which (depending upon circumstances) could weigh heavily on their minds. This was felt to distract them from work. Drill crews tend to work rotation patterns of either 2 or 3 weeks. For the first 2 or 3 weeks of the rotation, they are working offshore with no rest days, which can be a tiring experience. The 2 or 3 weeks at work offshore are then followed by 2 or 3 weeks onshore on leave. At the end of this period, their rotation begins again.

Fatigue was most problematic when on short change (the shift pattern whereby workers change in the middle of their offshore rotation from day shift to night shift, or vice versa), as this disrupted sleep patterns, although fatigue from work was also an issue. Most personnel agreed that physical fatigue was not as much of a concern as it used to be due to more processes being automated, but that mental fatigue sometimes occurred when they had been working on a task proving to be particularly problematic, or if the task was taking a long time.

Stress from several areas was also thought to affect SA—as heavy workload increases (it was felt that it was more difficult to concentrate on a task if there was a lot of work ongoing, as attention had to be divided among several jobs, and also there was danger of attention narrowing to focus on one task, and sight of the 'big picture' could be lost); supervisor pressure (to get a job done quickly), and also self-imposed pressure to complete a task by a certain time.

Experience impacted SA in two ways: new hands felt they required time to adjust to rig surroundings, infrastructure, regulations, etc., and were not as aware until this was accomplished; experienced crew felt more inexperienced workers impacted their awareness as they had to "look out for them" and compensate for their inadequate levels of SA, meaning attention was divided between their own job and the inexperienced worker.

Routine tasks/complacency impacted awareness in that if a task had been done many times beforehand, there was less inclination to focus on it as operations had gone smoothly in the past—this leads to complacency, less attention to the job, and thus reduced awareness.

Concern about job prospects was also cited as a factor that could cause a decrease in awareness. This is an issue which can be present in the offshore oil and gas industry, and respondents felt that often they were worried about the security of their job, and spent more time thinking about this, detracting from their awareness at work.

Finally, near-misses and accidents were mentioned. These were felt to impact upon awareness in two ways: personal experience of an accident or near-miss was thought to decrease awareness, as the person/people involved were "a bit shaken up," and not as focused due to this at the time. However, for those who had not experienced the incident, awareness was perceived to increase as workers became more alert to prevent a similar occurrence.

Although not declared by many, the impact of weather conditions on performance also merits mentioning, as it is particularly relevant to North Sea operations. This was thought to decrease awareness as dark and damp, or severe weather made workers fell unhappy and more inclined to pay less attention to their work. Seasonal affective disorder was alluded to, a mood disorder which is associated with depressive episodes and is related to seasonal variations of light (i.e. symptoms of depression are seen in dark winter months, but which subside in the lighter months of spring and summer; Partonen and Magnusson 2001). This is particularly relevant for the rigs in the Northern sector of the North Sea, where in the winter months, natural daylight can be reduced to around 4 h/day, and this notion is supported in this sample by accounts from rig medics.

Although the above were most likely to decrease awareness, three other factors were also perceived to increase awareness. Good communication around the rig was believed to do this, where information flow is constant and up-to-date, workers knew what the situation was and could plan accordingly. Experience of the work was another factor here: one respondent was documented as stating thorough knowledge of the job is "an essential pre-requisite for good awareness." By knowing and understanding both the work and the work environment, it is believed that the correct hazards will be perceived and overall awareness of the situation better due to this knowledge. Finally, the responsibility of being a supervisor was also perceived to increase awareness—those who were supervisors felt that they were required to have heightened awareness as they were not only responsible for themselves, but also for a number of personnel working for them. They reasoned that not only did they need to have their own personal SA, but that they also had to have high-quality SA with wider scope in order to look after and ensure the safety of their crews.

Q3. What are the indicators of reduced awareness?

All personnel interviewed stated that the most important indication of reduced awareness was any change in the character of the individual that was not within the norm for them, and familiarity with the individual concerned was a key driver in recognising this (i.e. by knowing the person concerned, any change in their behaviour would be immediately noticed). Communication was typically reduced, whereby the individual did not talk as much as usual, and became more withdrawn, not participating in the 'banter' that is commonplace onboard. As a supervisor or colleague, having to repeatedly give the same instructions over a relatively short space of time was also felt to be a good indicator, as it suggested that the person was not paying as much attention as they should. Blank, glazed expressions were also believed to indicate reduced awareness, and a drop in work standards of a normally productive individual were felt to be indicative of a decrease in awareness (although over a longer period of time).

Q4. How can reduced awareness be improved?

Communicating with the individual and having a discussion was believed to be the most important (and instantaneous) method of increasing awareness—this brings to the worker's attention the fact that they were not being as attentive as is appropriate, prompting them back to 'normality' ("... it snaps them out of it"), while also informing them of the rig situation at the same time. It was felt that due to the culture on board, that this could be simply carried out by a colleague or workmate with as little as a "You're not on the ball, mate!" but also more formally by a supervisor. If the reduced awareness was due to problems weighing on their mind, this provides the opportunity to voice the concerns, "getting them off his chest," thus alleviating the problem. Interaction was believed to aid awareness by keeping the crews alert and focused. Tasking the individual with a job out of harm's way was perceived as a remedy, as this allowed them to do a different job which was not as hazardous (so perhaps required less SA), meaning they personally were not in danger of coming to harm, but that they were also removed from causing any harm to colleagues in the same operation. Carrying out a different task also gave them time to regain their awareness levels. If the situation, however, was more severe, and despite being moved to another task the worker could still not regain concentration and awareness, removing them from the situation completely was believed to be the next option. In less serious cases, this may involve finishing the shift early, but in cases where a short break or reduced workload was found to be having no or little effect, sending personnel back onshore was felt to be the only solution (although rare). Reducing workload (if this was the problem area) was felt to have the same effect. A final point considered was the crew line-up. If the issue of decreased awareness lies with the crew itself, and not any other factors, awareness could be increased by moving workers around in shifts to gain variety in the teams, to find the correct 'mix' of workers who gel together and work effectively: "... stagnant crews will develop complacency and bad habits."

Q5. What can be done to check the awareness of workers?

There were four main methods used for checking awareness on the job. The first of these was TBTs, the talk which crews conduct at the start of the shift before they begin the job, to discuss the task at hand, and work through any problems that they may encounter, and how these would be dealt with. This was perceived as an excellent method of checking awareness, as it was direct evidence of how much the personnel knew of the job and what activities were ongoing. Participation of all concerned was essential to ensure that the crew had full attention on the job. Risk assessments also certify that they knew the potential hazards of the job, and what to look out for. Continual informal assessments of the situation are required as offshore is a dynamic environment and can change quickly, so continually surveying and monitoring the situation updates knowledge of the job. Supervisors can check on this simply by asking their personnel about the job at that particular time. A final check that can be made regarding awareness is the 'Pocket' toolbox talk. This is a pocket-sized paper version of the toolbox talk performed for that day which is carried around by the crew. They can check progress and things to look out for by reminding themselves of the things spoken of in the pre-shift TBT, thus bringing aspects of the job back to their attention, and maintaining their awareness.

Q6. How is team SA achieved?

A major component of offshore activity in the drilling sector requires crews to work together rather than as individuals. For this to be achieved successfully, the crews must maintain a common understanding of the situation. Consistency was felt to be the key factor in achieving team SA—by keeping the same crew together over a period of time, this allows the crew to fully get to know and understand each other. Changing a crew out regularly was felt to be counter-productive as the team members could not learn about each other. Consistency allows for learning how the other members work, their roles and capabilities, traits, strengths and weaknesses, eventually leading to a team which automatically knew how each crew member would react in a given situation due to their detailed knowledge and understanding: "... an unspoken understanding with everyone working from the same mental plan" and "... pulling in the same direction." The aforementioned results of maintaining a consistent crew meant that the teams felt that the acquisition of their team SA was eased, as they all quickly picked up on similar cues and formed the same mental picture of the situation. Adaptability and co-operation were cited as important determinants for team SA: allowing crews to alter their work patterns in response to the changing requirements of the task/situation quickly and easily, and work alongside each other; and trust was required for crew members to have faith and confidence in the skills and capabilities of the rest of the crew, having reliance upon them to work together.

Although not cited by the majority of respondents, several commented that having a strong supervisor helped the development of team SA. Where there were noticeable gaps in the awareness of the team (e.g., the same piece of data was missed on several occasions, or a near-miss occurred twice), it was noted that if a supervisor was supportive and directive in pointing out where the crew should direct their attention, participating as part of the team rather than merely being the supervisor, this "pulled the team together." Although this may be thought of by some as merely coaching on hazard awareness, this would appear to aid personnel in learning how to hone their skills to develop high-quality awareness levels. Although individuals may require different levels of SA depending upon their occupations, or the particular task they are carrying out at the time, by working closely together the team learns the overall level of awareness that is suitably robust to allow them to conduct their duties safely and effectively. In this way, each team member has a greater understanding of how his/her other team members work, allowing shared awareness to gradually be formed as the team grows together.

4 Conclusion

Situation awareness is a topic in which academic and practitioner interest has grown in the last 10 years, but despite this, there has been limited research into SA in high-risk industries, and more specifically, in the energy sector. The present research has addressed this topic by identifying the proportion of SA errors prevalent in drilling incidents, and gaining an understanding of the main issues underlying SA within the drilling industry. The initial accident analysis showed SA to be a very relevant skill for the drilling industry, indicating that perception errors were the most frequent type of SA error (followed by comprehension and projection, respectively). Failing to monitor or observe data in the fist instance was the largest cause of perception errors. Although this is undoubtedly an SA error, the underlying mechanism can be accounted for by Miller's (1956) information processing theory, which formed the foundation stone for many subsequent learning theories. Much of the information we perceive is processed in our working memory, which has a limited capacity (Baddeley and Hitch 1974), and is affected by factors which can place a strain on the already limited processing ability. If, e.g., a task is particularly complex, then this consumes much of the mental processing capacity, meaning that little is 'left over' to attend to other information.

The fact that the majority of errors were found at the perception level indicates that drilling companies can perhaps do more work to their training programmes in order to enhance the awareness. Safety training programmes in the offshore oil and gas industry usually contain an element of hazard awareness, with some companies having specifically developed safety/hazard awareness training sessions. However, they may not have a sufficiently explicit focus on the underlying cognitive skills and more specific training may be required as discussed below.

Problems due to a lack of, poor, or incorrect mental model were found to be prevalent in both SA stages of comprehension and projection, resulting in a total of 31% of SA errors found in the sample. These can be explained by Klein et al.'s (2005) and Mumaw et al.'s (2000) research as mentioned previously, and again act as evidence to extol the virtue of good training schedules. If many personnel are being sent offshore with inadequate training on recognised pieces of plant and equipment, then inevitably they will have poor mental models. However, if their training is up-to-date and they are familiar with the equipment that the need to use, then, for the most part, they will know the correct actions to take to maintain safe and successful operations, thus reducing accident risk. This may have implications for the training of technical as well as non-technical skills.

The frequency of errors in SA within the three different levels in the drilling community are comparable to those found in the aviation (Jones and Endsley 1996) and shipping industry (Grech and Horberry 2002) statistics, suggesting that this is perhaps a pattern also to be found in other similar work domains. One slight difference in the figures regards the frequency of projection incidents, whereby in the drilling sample, more incidents were found to occur here than both aviation and shipping industries. This may be due to the fact that although much of the drilling process is automated, there still involves a great deal of manual work, whereby consequently there is an increased risk of human error resulting in an immediate accident. This is less likely in both aviation and shipping industries, whereby errors may occur, but the consequences are less likely to be immediate, and corrective action may be possible. Drilling work is often reactive to the conditions in the well, e.g., a driller can misread a pressure level, which can result in a 'kick' (when reservoir fluids enter the uncased section of the well due to well pressure being too low). This kind of event calls for immediate action, and there may not be adequate time to accurately project consequences or future states. In contrast, a pilot who misreads the level indicated on the altimeter may have time to adjust the height of the plane when the mistake is noticed. This shows that it should not only be hazard awareness/perception which is focused upon, but safety training should also incorporate an element of projection training as well, to allow attendees to practice evaluating possible outcomes. In essence, this is a form of dynamic risk assessment (Fire Service 2002), allowing for control measures to be taken and the necessary levels of safety assured.

The aviation industry is one example of a profession that provides pilots with SA training, which has achieved positive results in improving levels of SA (e.g. Endsley and Robertson 2000; Hormann et al. 2004; Prince 2000). Similar training on SA and other cognitive skills are offered in the Crew Resource Management courses used in many industries and there is no reason why the oil industry could not embark upon a similar programme.

The interviews conducted with both onshore and offshore personnel provided insight into particular factors which can impact upon workers' awareness, which were primarily having problems with family at home, fatigue, workload, and stress. Indicators signalling a decrease of awareness were perceived mostly to concern a character change in the individual (becoming more withdrawn than usual), or having to give repeated instructions to the involved party, which signalled that they were distracted/inattentive. Remedial actions proposed which could be taken to maintain and improve awareness revolved mainly around maintaining good levels of communication with the whole crew so that they were actively involved in things. This could well be a viable solution to the perception errors discovered in Study 1. By maintaining crew communication and involvement, distractions and attention lapses might be alleviated.

Taking regular breaks was also suggested as a method to improve awareness, as individuals are allowed time to momentarily relax from their schedules and re-establish their level of attention and task focus. If the situation was more extreme, changing the workload, tasking the individual with another non-hazardous job, or even removing them from the worksite could be considered as safety measures. Findings also pointed towards methods that can be employed on a more frequent basis to check awareness levels, such as daily TBTs, job risk assessments, informal assessments, and pocket TBTs. These are all techniques that are already in place on offshore rigs, but perhaps are not used as a 'checking mechanism' for ensuring that SA is of the standard required. Finally, the interviews began to identify the factors that are required to develop good team SA. In summary, these were maintaining consistency among the team, adaptability of the team members, and co-operation. It is recommended that supervisors and management take note of this finding in particular—in the current state of oil and gas exploration and production on the United Kingdom Continental Shelf, the movement of personnel is more fluid than it has been for many years. Given that one of the most important methods cited by personnel for developing team SA is maintaining consistency within teams, the safety implications of regularly changing out team members, and even entire teams, should be given careful consideration due to the detrimental impact that it could have upon the SA of the team.

It should be acknowledged that these interviews only provide a partial insight into factors influencing SA. As the interviewees were mainly discussing how others have poor SA, there is likely to be some fundamental attribution error (Jones and Nisbett 1972). That is, observers are more likely to attribute the causes of a worker's behaviour to personal rather than circumstantial factors. Similarly, if workers who have just shown poor SA are interviewed, they are more likely to attribute their behaviour to situational factors (noise, distraction, and poor equipment design) than personal factors. Drilling rigs (especially the older ones) are not the most sophisticated ergonomic work environments, and drilling managers and crew may not always realise that some of the workers' cognitive problems will be due to poor workplace and equipment design.

A new study is currently underway, using a self-report measure to understand to what extent particular work factors affect drilling workers' SA, and how this relates to safety behaviour and accident involvement. This is being conducted by means of a specially designed questionnaire distributed to drilling personnel working for a multinational oil and gas exploration company. As mentioned previously, it appears that, despite its popularity, little research has been conducted examining the validity of Endsley's (1995) three-level model of SA. With this in mind, the SA scale in the new study is also designed to investigate the legitimacy of the widely accepted three-stage approach. It is hoped that, in addition to presenting new empirical data regarding SA in drilling and explaining some predictive variables, one practical application of the research will be to provide not only the offshore oil and gas industry, but also other high-risk industries, with a tool to measure workers' self-reported SA.

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