The nontechnical causes of diving accidents: Can U.S. Navy Divers learn from other industries?

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O’Connor P. The nontechnical causes of diving accidents: Can U.S. Navy Divers learn from other industries? Undersea Hyperb Med 2007; 34(1):51-59. Although U.S. Navy diving is remarkably safe, because of the high-risk environment in which military divers work, accidents and mishaps do occur. Failures in leadership and situation awareness (particularly in risk and time assessment) were found to be the two most common causes of fatal and nonfatal U.S. Navy diving accidents and near misses. Responses to an attitude survey showed that junior divers want to ask questions, but senior divers do not desire to be questioned. In other high reliability industries (e.g. aviation, medicine) methods have been developed to identify, analyze and mitigate human error. The relevance of these techniques for U.S. Navy diving are discussed.

INTRODUCTION

Although U.S. Navy diving is remarkably safe, because of the high-risk environment in which the divers work, accidents and mishaps do occur. Safety research has shown that human error, as opposed to mechanical failure, is a major cause of industrial and transportation accidents (1,2). In fact, the cause of approximately 80% of mishaps in high-reliability industries (e.g. aviation, nuclear power generation, offshore oil production, medicine, and diving) is generally regarded as human error (3). A review of 1,000 recreational diving mishaps found that 87% of them were caused by human error (4).

Effective teamwork is crucial for the success and safety of a U.S. Navy dive team. The size of the team may vary with operational requirements such as depth, type of equipment to be used, and number of divers required to complete a mission (5). A typical diving team may include the following personnel:

- Diving Officer: He/she is responsible for the safe conduct of all diving operations within a command, responsible to the Commanding Officer, and qualified as a Diving Officer.
- Master Diver (MDV): The most qualified person to supervise dives, he/she is in charge of overall diving operations, is responsible to the Commanding Officer via the diving officer, and has been both a second (a junior enlisted)- and a first-class diver before having passed MDV evaluation.
- Diving Supervisor: Possibly a second- but generally a first-class diver, he/she is in charge of the actual diving operations for a particular dive or dive series.
- Diving personnel: These second- and first-class divers carry out a dive, tend the divers, act as standby/safety divers, log a dive, and communicate with the divers.
- Diving Medical Officer (DMO): As a medical doctor with training in diving and hyperbaric medicine, he/she provides on-site medical care for divers and ensures that diving personnel
receive proper attention before, during, and after a dive.

This paper summarizes research designed to identify the contribution of human error to accidents and near-misses in U.S. Navy diving. It also makes recommendations about how techniques used in other high-reliability industries to address human error issues could be applied in U.S. Navy diving to improve the safety and productivity of divers.

**NONTECHNICAL CAUSES OF U.S. NAVY DIVING ACCIDENTS: RESEARCH**

A multifaceted method employing both quantitative and qualitative techniques to identify the non-technical skills required to reduce the likelihood of a diving accident was used to collect data. “Non-technical skills” refers to the types of behavior necessary for safe, effective performance in a technical context but not directly related to technical expertise or psychomotor skills (6).

Four data collection methods were employed: analysis of mishap reports, analysis of reports investigating fatal mishaps, critical incident interviews, and attitude questionnaire surveys. The findings are summarized in the following four sections (see O’Connor (7) for a detailed description of the methods and results).

**Diving mishap reports**

An examination of 263 U.S. Navy diving mishap reports from 1993 to 2002 was completed. The mishap reports were sent to the Navy Experimental Diving Unit by the U.S. Navy Safety Center. Experimental dives were excluded, because those reported mishaps resulted from tests of decompression tables in which some cases of decompression sickness (DCS) were expected. Diving mishap reports provide information about the types of injuries, the underwater breathing apparatus (UBA) used, the purposes of the dives, and the causes of the accidents. These reports give the diving command where the accidents occurred an opportunity to categorize the causes of the mishaps into “as many causes in each category [as] you determine to apply” (pp. A6–M-4) (8) and to write brief narratives of the events pertaining to these mishaps.

A mean of 26.3 reported diving mishaps a year across the 10 years were examined. For the total number of diving mishaps reported, there were a mean number of 12.2 cases of DCS, 9.7 cases of arterial gas embolism (AGE), 0.5 cases of oxygen toxicity, 0.5 near drownings, 0.5 deaths, and 2.9 incidents attributed to “other” causes.

The largest proportion (70%) of the diving mishaps were attributed to unknown causes; only 23% were attributed to human factors (7,9). The remaining mishaps were attributed to procedural factors (2%), material factors (3%) and the environment (2%). The narrative of the mishap can vary from a few sentences to a couple of paragraphs. The narrative tends to be an outline of the treatment rather than a discussion of the mishaps themselves.

The proportion of causes attributed to human error is far below the 80% generally attributed to this source in high-reliability industries (1). O’Connor, O’Dea and Melton (9) proposes some explanations for this finding: a lack of understanding of human factors, a reluctance to use the human factors category in classifying causes, and the fact that the manner in which decompression tables are constructed makes a certain number of decompression sickness (DCS) cases expected (10).

**Diving fatality mishap investigation reports**

Examining the narratives of the dive
mishap reports did not generally provide sufficient detail to identify the causes of those mishaps. Therefore, it was decided to use the more detailed Mishap Investigation Reports (MIRs) that are required to answer the who, what, where, when, and why questions about on-duty diving accidents that result in Navy diving fatalities (8). The MIRs contained detailed accounts of the incidents including information developed from interviews with the individuals involved, attempts to save stricken divers, and analyses of the equipment.

Five MIRs from fatal U.S. Navy diving accidents that had occurred within the last 15 years were examined. Three of the deaths were attributed to drowning; one, to an arterial gas embolism (AGE); and another to trauma. The consensual qualitative research (CQR) technique (11) was used to develop a framework and summarize the data from the MIRs.

A total of 152 applications of non-technical skills were identified for categorization from the five mishap reports that pertained to human error. The taxonomy of diver non-technical skills consists of six categories and 21 subcategories (7,9). Table 1 shows that poor situation awareness, poor leadership, poor supervision/leadership, and lack of personal resources were the most commonly used categories. The parenthetical numbers in Table 1 represent the percentages of effective behaviors that the dive team displayed in attempting to recover the situation.

A description of each of the categories is provided below:

- **Situation awareness** refers to the behaviors by which individual team members build and share a mental picture of the situations and use these shared “mental models” to provide a common understanding. The most commonly used subcategory of situation awareness was risk and time assessment (7,9).
- **Decision making** is concerned with following and using the procedures for carrying out a task and reviewing the outcomes of a solution to assess whether the goal has been reached.
- **Communication**, a major component of the teamwork process, is the mechanism that links the other teamwork components (12). It is concerned with the sharing of information among team members.
- **Supervision/leadership** includes the direction and structure provided by both the leader and other team members (13). Monitoring and managing team performance is critical for effective team performance (14,15). The most commonly used subcategories were those of maintaining standards, planning and coordination (7).
- **Team cohesion** is concerned with behaviors indicating a sense of “teamness” among team members.
- **Personal resources** refers to any factors (e.g., stress, fatigue, physical or mental fitness, and lack of experience or training) that act to reduce an individual’s level of performance.

<table>
<thead>
<tr>
<th>Category</th>
<th>Fatality reports</th>
<th>Cognitive interview technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Situation awareness</td>
<td>39.6 (5.3)</td>
<td>41.8 (4.0)</td>
</tr>
<tr>
<td>Decision making</td>
<td>2.6 (0.7)</td>
<td>3.9</td>
</tr>
<tr>
<td>Communication</td>
<td>5.8 (0.7)</td>
<td>8.5 (0.6)</td>
</tr>
<tr>
<td>Supervision/leadership</td>
<td>27.2</td>
<td>21.5</td>
</tr>
<tr>
<td>Team cohesion</td>
<td>2.0 (1.4)</td>
<td>5.2</td>
</tr>
<tr>
<td>Personal resources</td>
<td>15.0 (0.7)</td>
<td>13.6 (1.7)</td>
</tr>
</tbody>
</table>

**Critical incident interviews**

The taxonomy of diver non-technical skills was then used to classify the human factors causes of 15 accounts collected from U.S. Navy divers who either had been involved in a diving accident (as a victim or a member of the dive team) or had been involved in a situation (i.e.,
a near miss) that they felt could have resulted in an accident. Two of the incidents resulted in a death, one in a near drowning, another in a serious physical injury, and the remaining 11 were near misses in which no injury resulted, although the potential for death or serious injury had been high. The critical incident technique (CIT) — an interview method that enables the researcher to identify the knowledge of skills and level of expertise that respondents possess (7,9) — was employed to aid participants in recalling a diving accident or near miss in which they had been involved. The incidents occurred from between 1 and 10 years from the date the interview took place. It is recognized that the passage of time since the mishap may have a detrimental effect on the accuracy of the account. However, research suggests that the memories of emotionally intense experiences (such as a mishap) and for event that are rehearsed (e.g. by telling people) are more resistant to decay than memories for ‘normal’ events (16).

As Table 1 shows, the pattern of failures in non-technical skills appears to be similar regardless of whether the mishap was a fatal accident, a nonfatal accident, or a near miss.

Attitude survey
A 27-item questionnaire was developed to measure U.S. Navy diver attitudes to factors that influence the safety of diving operations. This attitude questionnaire was based on the Cockpit Management Attitudes Questionnaire (CMAQ)(17) and the Flight Management Attitude Questionnaire (FMAQ)(18), both of which have been widely used in aviation and adapted for use in other high-reliability industries (19). For each statement in the questionnaire, the degree to which participants agreed was assessed with a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). In addition to responding to the 27 attitude statements, participants were asked to list what they believed to be the three main causes of U.S. Navy diving accidents (see O’Connor (7) for a list of the items).

The attitude questionnaire was distributed to U.S. Navy divers at eight different diving commands, and a total of 272 responses were obtained from 55 second-class (junior enlisted diver), 148 first-class (enlisted diver more senior and experienced than a second-class diver, who generally supervises a dive), and 12 MDVs, in addition to 26 Diving Officers and 20 DMOs, a response rate of 90%. Responses were obtained from approximately 20% of the population of U.S. Navy divers.

A total of 19 items were retained and entered into confirmatory factor analysis (CFA). Because of excessive skewness or kurtosis, a total of eight items were discarded before CFA, and one item was discarded as part of the CFA process7. CFA resulted in three reliable subscales. The three subscales included:

- “Openness to questioning”: this assesses both how willing senior personnel (namely, the MDV and diving supervisor) are to accepting questions from junior divers and how open these senior team members are to being questioned.
- “Information sharing”: this assesses how well diving objectives and plans are communicated and team members are monitored.
- “Awareness of personal limitations”: this investigates how team members consider— and possibly compensate for— stressors and how they deny the effect of stressors on their performance.

Responses to the attitude questionnaire showed that, when the attitudes of second-class divers or diving officers are compared to those of first-class divers/MDVs, the latter group is
significantly less likely to believe that junior divers should question a MDV or a dive supervisor ($F_{(2,204)} = 5.3, p< 0.05$). Figure 1 shows that when the percentage of respondents agreeing with six statements in the “openness to questioning” factor is examined, the percentage of second-class divers agreeing is consistently lower than the percentage of first-class divers/MDVs.

Other noteworthy findings are that officers were significantly more likely to be aware of the detrimental effects that factors such as stress and fatigue have on their performance than are first-class divers/MDVs ($F_{(2,245)} = 7.7, p< 0.05$). A possible explanation for the significant difference in attitudes between more experienced and less experienced divers may be that as the inexperiance divers are more likely to spend more time in the water doing the physical work, than the more experienced divers, then they are more aware of the effects of factors such as fatigue on performance.

For the “information sharing” subscale, there were not significant main effects of type of diver ($F_{(2,245)} = 2.7, n.s.$), years of service as a diver ($F_{(1,245)} = 0.4, n.s.$), or a significant
interaction between the two variables \( F_{(2,245)} = 1.0, \text{n.s.} \).

When asked to identify the main causes of diving accidents or near misses, respondents identify non-technical rather than mechanical or environmental causes as the main sources of diving accidents. Complacency — followed by fatigue and inexperience — was the most commonly given cause of diving accidents or near misses. This response is consistent with findings from other high-reliability operations (e.g., aviation maintenance, offshore oil operators). Bradley states that the well-trained, experienced diver is at less risk than an inexperienced diver, with inexperience cited as a contributing factor in 25% of U.S. Navy fatal diving accidents from 1965 to 1975 (20).

The association between inexperience and diving mishaps has also been found in recreational diving. In a review of 1,000 recreational diving mishaps, inexperience and insufficient training accounted for 14% and 8%, respectively, of the contributing factors to the mishap(4). Also, in a review of 109 recreational diving fatalities that occurred in 2003, nearly 45% of the mishap victims had not dived in the 12 month prior to the mishap (21).

Therefore, it would appear that as in other high reliability industries, failures in non-technical skills are causal in diving accidents and near-misses. Further, divers also recognize that failures in non-technical skills are significant contributors to diving accidents and near-misses.

**NONTENATIONAL CAUSES OF ACCIDENTS IN OTHER HIGH RELIABILITY INDUSTRIES**

In a number of high reliability industries the need to confront failures in nontechnical skills has been triggered by catastrophic accidents (e.g., aviation, Pan-Am and KLM, Tenerife, 1977, Air Florida, Washington, 1982; nuclear power generation, Three Mile Island, 1979, Chernobyl, 1986; offshore oil production, Piper Alpha, 1988). These accidents have lead to changes in how the industries track and mitigate failures in non-technical skills and make improvements in the safety culture of the organization.

Cooper (22) defines safety culture as “that observable degree of effort by which all organizational members direct their attention and actions towards improving safety on a daily basis” (p31). Cooper opines that safety culture can be thought of as a triad of the organization (safety system), the person (safety climate) and the job (safety behavior) (23). Practices that have been adopted by other high reliability industries to improve safety culture, and regarded by the author to have relevance to U.S. Navy diving (based upon the research outlined earlier), are described below.

**Accident analysis**

The collection of accurate accident data is important for the improvement of industrial safety. Reason identifies four critical elements of an effective safety culture — a reporting, just, flexible, and learning culture (24). However, dive mishap reports provide limited information about specific failures in non-technical skills that contribute to diving mishaps. As described above, 70% of mishaps are classified as ‘unknown’ and there is great variability in the quality of the reports. The Navy Safety Center is taking measures to improve the accuracy of accident reporting. However, more guidance is required to aid the divers to complete an accurate diving mishap report, provide sufficient detail for analysis, and accurately code the causes of an accident.

**Near-miss reporting**

As operations become safer, and the number of accidents becomes lower, accidents cease to be a useful metric of performance.
Other high-risk organizations (including Royal Navy diving) track near misses — unplanned sequences of events that could have caused harm if existing conditions had been different or had been allowed to progress. Research in other industries suggests that as many as 600 near-misses may occur for every 10 minor injuries, and one serious injury (25). Therefore near-miss reporting could benefit U.S Navy diving by providing a large data set for conducting quantitative analysis and allowing any patterns of failures to be identified, analyzed, and addressed before they result in a major accident. It also can provide a mechanism for identifying scenarios that can be used for training and discussion.

For a near-miss reporting system to be used there must be a culture of reporting within the organization. There must be support for the system at both the senior manager and supervisory levels. For members of an organization to submit information about a near-miss, it is important to implement a policy not to punish the individuals involved, except in cases of extreme negligence. If individuals were to be punished every time a near miss occurs, the system would simply not be used. The reporting system must be simple to use and must require as little effort as possible to submit. There must also be some type of feedback system in place. For example, the Royal Navy Superintendent of Diving provides feedback to divers on any recent diving accidents and near-misses by way of a quarterly newsletter.

**Crew Resource Management training**

The aviation industry has been instrumental in developing training programs to reduce error and increase the effectiveness of flight crews known as Crew Resource Management (CRM) (26). Lauber defines CRM as “using all the available resources — information, equipment, and people — to achieve safe and efficient flight operations” (p. 20) (27). Now used by virtually all the large international airlines, CRM training is also recommended by the major civil aviation regulators (e.g., U.S. Federal Aviation Authority [FAA] and European Joint Aviation Authorities [JAA]) (28,29).

Topics covered in CRM training “are designed to target knowledge, skills, and abilities as well as mental attitudes and motives related to cognitive processes and interpersonal relationships” (p. 173) (30). An introductory CRM course generally is conducted in a classroom for two or three days. Teaching methods include lectures, practical exercises, role playing, case studies, and video films of accident reenactments. A course typically covers six core topics: teamwork, leadership, situational awareness, decision making, communication, and personal limitations (31).

Refresher training, normally a half or whole day course focusing on a specific CRM topic, is also recommended. For flight deck crews, CRM skills then can be practiced and assessed in flight simulator sessions known as line-oriented flight training (LOFT) and line operational evaluation (LOE). CRM training has been found to produce: (1) positive reactions, (2) enhanced learning, and (3) desired behavioral changes in a simulated or real environment (18,32). CRM training in naval aviation has also been found to result in decreases of up to 81% in accident rates (33).

Because CRM is the most widely applied technique for providing team training to operations personnel in aviation, it has attracted the attention of other high-reliability industries. Those who adopted it first were, unsurprisingly, involved in aviation: aviation maintenance, cabin crew, and air traffic control. However, CRM training has now begun to be used in many other high-reliability industries unrelated to aviation: nuclear power generation, anesthesia, the maritime industry, and offshore
It is suggested that Navy divers, particularly those in supervisory positions, would benefit from incorporating instruction in leadership, situation awareness (predominantly risk and time assessment), and ways that personal limitations affect performance. Although these issues are addressed implicitly during diver training, CRM training may offer a palatable method for providing explicit training in these non-technical skills. A guide to the non-technical skills required by U.S. Navy Diving Supervisors has already been written (35). Attempts were made to make it as relevant to U.S. Navy divers as possible, and this document could form the basis of a CRM course for U.S. Navy divers.

CONCLUSION

Areas have been outlined in which the safety culture of U.S. Navy diving could be improved by adopting techniques used by other high reliability organizations. Fleming (36) outlines a number of indicators of a high level of safety culture maturity: a sustained period without a recordable accident or high potential incident; no complacency in the organization, constant awareness that the next accident is just around the corner; there are also a range of measures to monitor performance; and there is confidence in the safety processes. This is the level of safety to which U.S. Navy diving should strive.

ACKNOWLEDGMENTS

The information presented is the opinion of the author and should not be construed as official or as reflecting the views of the U.S. Navy.

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