Human error and violations in 1,000 diving incidents: a review of data from the Diving Incident Monitoring Study (DIMS)

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DIMS, scuba diving

Abstract

(Acott, CJ. Human error and violations in 1,000 diving incidents: a review of data from the Diving Incident Monitoring Study (DIMS). *SPUMS J*. 2005; 35: 11-7.)
Incident reporting is a method of identifying, classifying and analysing incidents/events in the context of contributing and associated factors including, but not limited to, human error. It is an established part of safety analysis and risk assessment in aviation, the nuclear-power industry and medicine (particularly anaesthesia). The incident-reporting technique was used to examine the types of human error and violations of safe diving practice that occurred in 1,000 recreational diving incidents reported to the Diving Incident Monitoring Study. Whilst errors can be classified, violations are not predictable and cannot be classified.
Human error: The 'psychological' classification of error was used. Error contributed to 87% of the incidents reported. 'Knowledge-based' (type 1) and 'rule-based' (type 2) errors predominated. Corrective strategies to minimise knowledge-based errors include improvement to educational programmes involving buoyancy-jacket use, air-supply management, ear-equalising techniques and coping with unexpected sea conditions. Rule-based errors can be minimised by the development of specific protocols and checklists. Failure to do an adequate pre-dive equipment check contributed to 15% of all incidents. 'Skill-based' (type 3) errors due to haste or inattention featured in 26% of incidents and can be minimised by overlearning a particular task. 'Technical' (type 4) errors are associated with inadequate training and featured in 12.5% of incidents.
Violations: There were 148 reports received that contained 201 violations; 65 (44%) of these incident reports involved morbidity. Twenty of these reports (containing 19 violations) involved untrained divers (no formal tuition or supervision), of which 15 (75%) described incidents that were the cause of the total morbidity in the untrained divers.

Introduction

Safety in diving is dependent upon an adequate understanding of the associated risks. Accident and fatality data are used as an index of safety and risk but are retrospective. Accidents are unpredictable,[1,2] such that the development of strategies to prevent future accidents through retrospective analyses of accidents is imprecise and difficult.[3]

Other limitations associated with accident and fatality data are:

- events are often reconstructed from a jigsaw of information that lacks substantiation of events by the victim;
- valuable information may be forgotten during the turmoil of the rescue and resuscitation, such that the recorded events may be an oversimplification of what happened;[1]
- events are often changed to suit the perception of what happened and are seen in the light of 'doing the right thing';[1,3]
- reports may be subject to investigator bias and report: 'what must have happened' rather than 'what did happen';
- only legal issues may be addressed.[4]

INCIDENT REPORTING

Errors are a part of everyday cognitive function, occur repeatedly, are usually trivial and are usually recognised and corrected before they cause harm.[1] It is easier to predict and prevent errors than accidents, because errors are methodological, taking on predictable forms that can be classified.[1,5] Because an accident is often the product of unlikely coincidences or errors occurring at an inopportune time when there is no 'system flexibility', it is reasonable to assume that error prevention will also prevent accidents.

Incident reporting is a method of identifying, classifying and analysing incidents/events in the context of contributing and associated factors including, but not limited to, human error.[3,6–8] This method is now established in aviation, the nuclear-power industry and medicine (particularly anaesthesia).[7,10–13] It is not a new concept, having been first used in the 1940s to improve military air safety, although the idea had its foundations much earlier in nineteenth-century Britain.[14]

Incident reporting is anonymous and has no interest in culpability or criticism. Therefore, it allows for accurate reporting without the fear of legal redress. It focuses on the process of error, regardless of outcome. Because of its unconstrained nature, the application of such a technique will also result in a description of recreational diving practices and demography.

The safety implications of the application of incident monitoring to recreational diving are obviously the identification of commonly occurring and dangerous errors, their contributing factors and the development of corrective strategies to address these.[6–8,12,14] Hence, if errors can be identified and their effects minimised or eliminated, there will be an inevitable decrease in the number of accidents and their consequences.

The main criticism of incident reporting is that only the incidents considered important are reported. Monitoring of incidents will, therefore, not identify the absolute incidence of error, but will show the relative incidence of errors or identify 'clusters' of errors.[1–3,7,8,11] Although often represented in a quantitative manner, the data obtained are qualitative and not quantitative.[14] It is, therefore, important when designing corrective strategies to address all errors and not just the ones reported frequently.

Accidents may also be caused by violations of acceptable safe practice even in a 'flexible' system. Accidents due to violations are difficult to decrease because no corrective strategies can be designed to prevent their occurrence. Identifying violations, however, may contribute to the design of quality-assurance procedures or impact on educational programmes.

Data from 1,000 incident reports to the Diving Incident Monitoring Study (DIMS) were examined for human errors and violations and analysed to suggest corrective strategies. Any incident may contain both a human error and a violation.[15–18]

Methods

The Diving Incident Monitoring Study (DIMS) commenced in 1989 with a pilot study and has since been refined.[8] A diving incident is defined as any error or unplanned event that could or did reduce the safety margin for a diver on a particular dive. The error may have been made by anybody associated with the dive and can occur at any stage during the dive.[8,19]

Table 1
Classification and characteristics of errors and how they are represented on the DIMS form

Type of error	Characteristic of error	DIMS factors
Knowledge-based (type 1)	Due to a lack of or inadequate knowledge	Inexperience Unfamiliar with diving conditions Error in judgement Failure to understand equipment Unfamiliar equipment
Rule-based (type 2)	Failure to apply a correct protocol or the application of an incorrect protocol	Failure to check equipment Poor dive planning Lack of/poor servicing of equipment Lack of a buddy check Inadequate supervision Poor communication Lack of post-dive maintenance
Skill-based or slips and lapses (type 3)	Failure to respond to a particular stimulus	Inattention Haste
Technical (type 4)	Could be 'knowledge-based' or 'rule-based' error	Insufficient training Poor technique Inadequate knowledge
Latent (type 5)	Interaction between the diver and buddy, the marine environment, equipment, physiological adaptation to immersion and increased ambient pressure	Anxiety Poor physical fitness Sea sickness Recent illness Drug or alcohol intake Fatigue
Violation, stupidity	Deliberate action contrary to protocol	Nil

The current DIMS form is available on the websites of SPUMS (<www.spums.org.au>) and the Divers Alert Network South East Asia Pacific, (<www.danseap.org>). Divers are encouraged to fill out one of these forms as soon as they have witnessed or have been involved in an incident. Anonymity is assured by the design of the questionnaire in that it does not record any identifying features. Once reported, the data are collected and analysed according to the psychological classification of errors (see below). Violations are noted and listed, and some are categorised as 'stupidity'.

Errors are classified as either 'active' or 'latent'.[2,3] Active errors are the immediate precursors to the accident or incident, while latent errors are the 'scene setters' or the 'shaping factors' that establish the scene in which active errors can occur.[2,3,7,22] Active errors can be further categorised into contextual, modal or psychological. The contextual classification of error describes how a series of actions are performed in a particular environment and hence is only relevant to that environment. The modal classification involves the manner in which the action is performed; the error is one of substitution, repetition, insertion or omission. This system is useful in collecting data from diverse environments and for calculating error probabilities. The psychological classification of error provides insight into the cognitive functions that cause the error and is represented on the DIMS form as the 'contributing factors' section. Although this is an oversimplification of events it is useful in the development of preventive strategies.[21] 'Psychological errors may also be subdivided into four 'active' categories as well as a 'latent' category:

- 'Knowledge-based' errors, type 1
- 'Rule-based' errors, type 2
- 'Skill-based' errors, type 3
- 'Technical' errors, type 4
- 'Latent' errors, type 5

A violation is defined as any action that is contrary to accepted 'safe diving practice' as defined by the recreational diving agencies.[15–18] A violation subcategory of 'stupidity' is defined as any action that involved no appreciation of risk or forethought, or lacked sensibility.[20]

Table 2
Contributing factors ranked by frequency of occurrence and categorised into types of error (see Table 1)

Contributing factor	Number (%)	Error
Error in judgement	249 (15.0)	1
Inexperience	224 (14.0)	1
Inattention	212 (13.0)	3
Poor dive planning	196 (12.0)	2
Failure to check equipment	193 (12.0)	2
Haste	143 (8.8)	3
Insufficient training	129 (7.9)	4
Anxiety	124 (7.6)	5
Failure to understand equipment	109 (6.7)	1
Unfamiliar with diving conditions	109 (6.7)	1
Poor communication	96 (5.9)	2
Poor physical fitness	83 (5.1)	5
Lack of a buddy check	64 (3.9)	2
Lack of servicing equipment	51 (3.1)	2
Failure to understand dive table	42 (2.6)	1
Inadequate supervision	40 (2.4)	2
Sea sickness	37 (2.3)	5
Poor servicing of equipment	34 (2.1)	2
Drug or alcohol intake	25 (1.5)	5
Feeling unwell	5 (0.3)	5

One thousand DIMS incident reports were examined by the author for data concerning human errors and violations. From these data corrective strategies are proposed. Violations were noted from the narrative reports. Table 1 lists the types of error, the characteristics of these errors and how each type is represented in the contributing factors section on the DIMS form.

Results

The results are tabulated for human error in Tables 2 and 3, and for violations in Tables 4 to 8. Twenty reports were obtained from untrained divers (the 'untrained' box was ticked on the DIMS form) and even though diving while untrained is a violation in itself, analysis involved separation of violation reports into trained and untrained divers for comparative purposes.

Table 3
Types of error identified in the first 1,000 DIMS reports and proposed corrective strategies (percentage of the total number of errors (1,618) reported, types 1 to 5, shown in parenthesis)

Type of error	Number	(%)	Corrective strategy
Knowledge-based (type 1)	498	(30.8)	Additional training and quality-assurance programmes
Rule-based (type 2)	458	(28.3)	Development of specific protocols or check lists
Skill-based (type 3)*	259	(16.0)	Overlearning of a task, reduce distraction
Technical (type 4)	129	(8.0)	As for type 1 or 2
Latent (type 5)	274	(16.9)	Education or 'change the system'
'Violations'	201		Quality-assurance and continuing education programmes?

*when present, skill-based errors were associated with morbidity or had the potential for causing harm in 75% of cases

Table 4
The 10 most common violations listed in order of frequency, including incidents with multiple violations (untrained divers in parenthesis). There were 201 violations, 19 in untrained divers

Violation	Number	
Diving without essential equipment	76	(15)
Continuing to dive with symptoms	19	(2)
Stupidity	14	(2)
Continuing to dive while breathing from an octopus, one out of air	10	
Dive leader/instructor ignorant of divers' ability (placing divers in danger)	9	
Diving with known faulty equipment	9	
Returning to surface alone without notifying buddy	9	
Diving with inadequate air supply	8	
Diver lying about his dive profile or medical fitness	6	
Dive leader or instructor not responding to a diver underwater	6	

HUMAN ERROR

The contributing factors in 1,000 incidents reported are listed according to error type in Table 2. At least one contributing factor was acknowledged in 869 (87%) reports. A total of 1,618 errors were reported. Table 3 lists the frequency with which each error type occurred and the proposed corrective strategies. The reporting of one type of error was not mutually exclusive of reporting other errors or violations.

VIOLATIONS

There were 148 reports received that contained 201 violations. Nineteen of these violations involved untrained divers (divers who had not undergone any educational or practical training programme in compressed-gas diving). The 10 most common violations are listed in order of their frequency in Table 4. Others included lack of a boatman during the dive, diving outside the recreational diving limits (i.e., greater than 50 metres sea water (msw) depth on air) and divers returning to the surface alone when out of air.

There were 21 reports which contained two violations and one which contained three. Interestingly, multiple violations did not involve untrained divers. Sixty-five (44%) of the violations by trained divers caused harm, in contrast to 15 (75%) of those by untrained divers. Morbidity associated with violations is listed in Table 5.

Diving without essential equipment for a particular type of diving activity was the most frequently reported violation in both trained and untrained divers. Table 6 lists the frequency with which this occurred with each piece of equipment. The incidence of diving without reference to a set of diving decompression tables or diving computer (23.6% of violations) was highlighted by these data and, not surprisingly, was associated with a majority of the reported cases of decompression illness (DCI) and represents 8.1% of the total morbidity reported to DIMS. The majority of the dives concerned were to depths greater than 15 msw.

Violations subcategorised as 'stupidity' occurred frequently and are listed in Table 7. Unfortunately, dive instructors and divemasters featured prominently in this sub-category. The qualification of the divers and the number of violations, including stupidity, committed are listed in Table 8.

Table 5
Violations associated with morbidity (untrained divers in parenthesis)

Violation	Number	
Diving without essential equipment	30	(7)
Continued to dive with symptoms suggestive of decompression sickness	15	
Diving outside the limits of recreational diving (> 50 msw on air)	4	
Diving while unwell or ill	2	
Stupidity	2	
Diving with known faulty equipment	1	
Dive instructor's poor advice after a dive – ignoring diver's symptoms	1	
Multiple violations	**Number**	
Diving without essential equipment plus continuing to dive with symptoms	3	(2)
Diving without essential equipment plus stupidity	0	(1)
Diving with known faulty equipment plus dive leader not responding to a diver	1	
Dive leader/instructor ignorant of diver's ability plus lack of equipment	1	
Dive leader not responding underwater plus lack of equipment	1	
Diving with inadequate air supply plus lack of equipment	1	

Table 6
Lack of essential equipment listed in order of frequency (untrained divers in parenthesis)

Lack of equipment	Number	
Dive tables and/or dive computer	43	(13)
Octopus regulator	7	
Depth gauge	5	
Watch or timing device	5	
'Bailout bottle' (using surface supply)	4	(2)
Reel line (wreck or cave penetration)	4	
BCD	2	
'Safety sausage' or surface-signalling device ('drift' diving)	2	
Torch (night diving)	2	
Knife (kelp diving)	1	
Contents gauge	1	

Table 7
Violations classified as stupidity
(untrained divers in parenthesis)

Violation	Number	
Diving with a speargun	3	
Diving without a boatman	3	
Diving in a boating lane	2	
Diving in a boating lane without a diving flag	1	
Diving where fishermen are burleying for sharks	1	
Playing with a shark	1	
Diver not checking entry site and colliding with diver in water	1	
Divemaster switching diver's air supply off in rough conditions on exit ladder	1	
Diving without a compressor attendant (hookah)	1	(2)

Discussion

ERRORS

In 50% of the incidents reported, a knowledge-based error was involved. The most common of these errors were with:

- buoyancy-jacket (BCD) use (especially buoyancy control at decompression stops or in the last 5 metres of an ascent)
- ear-equalisation techniques
- air-supply duration
- dive planning
- diving in a current
- coping with unexpectedly rough surface conditions, particularly at the exit.

Forty-six per cent of incidents reported involved rule-based errors. The aviation industry has addressed this type of error with comprehensive written check lists that pilots are compelled to use before and during flight. Nearly 15% of all incidents reported here involved divers who failed to do an adequate pre-dive equipment check, especially on their BCDs, primary and secondary regulators, and air supply. A comprehensive check list, which requires divers to tick boxes and to calculate the duration of their air supply prior to diving, would decrease the incidence of these errors.

Table 8
Diver qualifications, violations and stupidity
(more than 1 violation per incident in parenthesis)

Qualification	Number of incidents	(%)	Stupidity
Open water diver	43	(8)	6
Advanced diver	26	(6)	1
Divemaster	10	(0)	0
Dive instructor/leader	27	(6)	3
Dive student	3	(0)	0
Other/unknown	17	(2)	4

At least one skill-based error was identified in 259 (26%) reported incidents. Seventy-five per cent of these incidents were associated with morbidity or had the potential for causing harm. Commonly, these errors realated to improper use of a BCD's deflate and inflate buttons causing a consequent undesirable and rapid change in buoyancy.

Technical errors were identified in 13% of reported incidents. Techniques that the incident reporters thought to be inadequately taught were BCD use, ear equalisation, dive planning, the conduct of an adequate pre-dive check and shared-breathing ascents.

All types of error were reported in association with BCD use. Problems with BCDs are often associated with morbidity and mortality.[22–25] BCD use should be highlighted in training programmes and a thorough instructional programme should accompany the purchase or hiring of a particular BCD. Specific problems associated with BCD use, misuse and design have been reported in detail previously.[23]

Knowledge-based, rule-based and technical errors were made in the planning and conduct of dives to depths equal to or greater than 27 msw. Areas of particular concern were in the understanding of the decompression tables for determining any required decompression stops, and the calculation, checking and provision of any additional air supplies for these stops. These issues should be addressed by the recreational diver training organisations in their deep diving courses.

The frequency of problems associated with diving in a current, adverse surface conditions and ear-equalisation techniques is of concern as these are basic skills that should be acquired in basic training.

Medical fitness issues were emphasised in reported latent errors. Anxiety was the most frequently reported latent error and was a precursor to panic in many incidents. Poor physical fitness became evident with adverse environmental conditions, particularly swimming against a current. Medical fitness issues will not be discussed here. All incidents in which the reported diver was unwell prior to the initial dive resulted in morbidity (DCI, pulmonary and aural barotrauma). These data have both 'fitness-to-dive' and educational implications.

VIOLATIONS

The number of reports involving violations is disturbing. Unlike errors, violations are unpredictable and are not methodical or part of everyday cognitive function. No corrective strategies can be designed to prevent recurrence. If violations can be identified then educational and quality-assurance programmes may minimise them.

Nearly 40% of the violations occurred in incidents involving divers with only basic open water qualifications. However, of note was the high incidence (> 25%) of violations (including stupidity) involving dive instructors, dive leaders and divemasters (Table 8). These reported violations involved:

- placing a diver at risk by conducting a dive in a diving environment that exceeds his/her experience of a diver's ability due to ignorance;
- conducting a dive following a poor dive briefing;
- ignoring a diver underwater who is indicating that a problem exists with his/her air supply;
- dismissing a diver's symptoms post dive;
- sending an 'out-of-air' diver unaccompanied to the surface; and
- cave penetration knowing that the divers concerned had a depleted air supply or had faulty equipment but reassuring the divers that there was no need for concern.

Any violation involving dive instructors, dive leaders or divemasters could be addressed in part by targeted quality-assurance programmes.

Common causes of an out-of-air problem have been reported previously.[26] This paper, however, failed to address the continuation of a dive by an out-of-air diver by using a buddy's octopus regulator, which inevitably resulted in both divers having to do an emergency ascent when there was depletion of the donor's air supply. This violation could have been sub-categorised as 'stupidity' and disturbingly was frequently associated with dive instructors and dive leaders.

Diving without reference to a set of diving tables or a diving computer to depths greater than 15 msw was reported in both trained and untrained divers (56 reports received) and in many instances these dives were repetitive. Forty cases of DCI were recorded in these reports. Diving outside recommended recreational limits (Table 5) was a violation reported in five incidents (all involving trained divers); four of these resulted in DCI. These data have implications for educational programmes regarding decompression theory.

Specialised diving environments require additional essential equipment. However, a lack of:

- a guiding reel line in both cave and wreck diving in planned and unplanned penetrations;
- a boat watchout and surface-signalling devices in drift diving;
- a diving knife in kelp diving;
- a functioning torch in night diving; and
- a compressor attendant or a bailout bottle (in case of compressor failure) while using surface-supply (hookah) equipment

were all reported. These equipment violations can be addressed in part by specialised diving courses, thorough dive briefings and dive checks emphasising the requirement for additional equipment.

Continuing to dive with symptoms that developed after a previous dive was the second most common violation reported (Table 4). This was noted in cases of DCI, inner-ear, pulmonary and other aural barotrauma. Other violations reported, involving all qualifications, were diving without depth or content gauges, dive watch/timer, BCD or a functioning octopus regulator. Interestingly, these violations were not reported in untrained divers. Any violation categorised as stupidity (Table 7) deserves little discussion except to note that three (21%) of the 14 reported involved diving instructors (Table 8), which is of concern.

It is also of concern that untrained divers are still able to gain access to diving equipment, in particular a full air cylinder. In part, this may be due to the laxity of regulations governing 'air fills' in that divers must produce validation of their training before an air cylinder is filled.

In the context of human error and accidents these data compare favourably with similar data from surveys in anaesthesia practice, aviation and the nuclear-power industry, in that between 80 and 90% of serious incidents or accidents in systems where human beings interact with equipment are actually due to human error.[3,10,11,13] These data, however, compare unfavourably in the number of accidents caused by violations.

Conclusions

Errors associated with the use of a BCD and the adequacy of the air supply predominated. An instructional programme should accompany the purchase or hiring of a particular BCD and each dive should be preceded by a pre-dive air-supply check.

Knowledge-based errors could be eliminated by training programmes emphasising more thoroughly the problems of diving in a current, coping with rough surface conditions and ear-equalisation techniques. Additional training programmes are needed for divers who intend to perform dives to depths of 27 msw or greater. This is clearly recognised by the recreational diving industry with the provision of advanced and deep diving training courses and the depth limitations imposed on divers with varying levels of qualification and experience. Unfortunately, this approach is not routinely applied throughout the industry.

A significant improvement in safety could be obtained by reducing the frequency of 'rule-based' errors. A 'pre-dive' checklist should be developed which has to be read and each item checked before each dive. This pre-dive check should include an air-supply (depth and time) calculation. Such a check list on a waterproof card could be issued to all divers as part of their training package.

The violations of acceptable safe diving practice by diving instructors, dive leaders or experienced divers featuring in these reports are disturbing but should, at least in part, be addressed by quality-assurance and annual continuing educational programmes, such as those described by Nimb.[27] These programmes should be guided by analysis of incident reports (which would involve using the DIMS model of incident reporting).

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Extreme breath-hold diving

In October 2004, a French freediver, Loic Leferme, achieved a new No Limits world freediving record with a 171 msw dive off Villefranche-sur-Mer, on the Cote d'Azur. Leferme took two minutes to descend to depth on a sled, and ascended using a lifting balloon. The dive took 3 min 40 sec.

In a recent talk, Carl Edmonds estimated the death rate amongst extreme breath-hold divers may be as high as one in 50. One suspects that, if something goes wrong on one of these dives, Dr Acott might put it firmly in his 'stupidity' category.

Nevertheless, the physiological changes occurring during these deep dives must be remarkable, but appear to have been little studied.