

Analyses of variables underlying U.S. Navy diving accidents

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Blood C, Hoiberg A. Analyses of variables underlying U.S. Navy diving accidents. *Undersea Biomed Res* 1985;12(3):351-360.—U.S. Navy diving logs were examined to determine the most frequently occurring diving accidents and to identify significant underlying factors. Of the 1174 incidents reported during the course of 706,259 dives, decompression sickness and barotraumas were the most prevalent. Mishap incidence increased significantly with dive depth. Dives for selection or experimental purposes, as well as saturation diving and surface decompressions among decompression schedule types, were at an elevated risk of terminating in an accident. Older divers were disproportionately assigned to deep dives. Eighty-one percent of diving mishaps ended in complete relief for the diver while 18% terminated in substantial relief.

Navy divers
diving accidents
accident rates

Diving may be viewed as a complex activity in which many factors contribute to the success or failure of the dive mission. Underlying factors contributing to diving accidents presumably could derive from two domains. First, they could be intrinsic to the environmental circumstances of the dive. Such variables would include dive depth, dive purpose, time of day, decompression schedule type, and temperature (air, surface water, and bottom water). Deeper, longer dives, for example, have been shown to be associated with an increased risk of decompression sickness (1-3) while accident rates were reported to be higher among dives conducted in warm conditions (4). Second, individual diver characteristics such as age, weight, height, recent diving experience, and previous mishaps might contribute to the risk of a diving accident. In a recent study of hospitalization rates among U.S. Navy divers (5), the lowest admission rates for decompression sickness and toxic effects of gas were reported for divers 41 yr of age and older.

The purpose of the present investigation was to determine the most commonly occurring underwater accidents and to identify the most prevalent factors among

diving mishaps. Awareness of conditions influencing accident probability should aid in planning safer diving operations.

METHOD

Data

Since the late 1960s, the Naval Safety Center in Norfolk, Virginia, has collected descriptive data [Diving Log—Accident/Injury Report (OPNAV 9940/1)] on all dives performed as well as additional information on those dives that resulted in accidents. Computerized files containing information on all U.S. Navy dives (706,259) and accidents (1174) that occurred from January 1968 through May 1981 were provided by the Naval Safety Center to the Naval Health Research Center, San Diego.

Variables recorded on the diving log included dive depth, time of day, air temperature, surface temperature, bottom temperature, dive purpose, decompression schedule type, age, height, weight, and number of dives in the previous 24 h. Information extracted from the accident segment of the log included initial accident, most significant sign (symptom), initial sign occurrence, and accident outcome. Other variables existed on the diving log but were not analyzed because they contained an unacceptable level of missing data or were beyond the scope of the present investigation.

Procedure

The frequencies of responses for initial accident (24 categories) and most significant sign (22 categories) were compiled and their respective percentages were calculated. These two variables also were examined in conjunction with each other to determine any significant interactions.

Accident rates per 1000 dives were computed for each of the response categories of the aforementioned 11 variables which then were compared with the overall rate. The first step in this procedure was to compile a frequency distribution of each factor for all recorded dives on a 10% random sample of the 706,259 diving log records. The random sample was selected by using a preprogrammed sampling procedure (6); the obtained sample was actually 9.99% and the figures in the tables are the products of this number and the frequencies observed. Then, accident frequencies were tabulated for the 11 variables from the 1174 accident log segments. Accident rates per 1000 dives were computed by dividing the number of mishaps recorded for a particular response category by the overall number of dives occurring under the same condition and multiplying by 1000. Ninety-five percent confidence limits, based on the Poisson distribution (rarely occurring events), were calculated for the overall rate and levels of each factor to determine if rate differences were significant.

Because dive depth has been found to be a factor in mishap incidence (1,7), accident rates for the 10 other factors were depth adjusted using the direct method of adjustment (8). Depth adjustment yields rates based on the overall distribution of dives rather than the skewing that can occur within some categories (i.e., if very deep dives were performed in the morning and deeper dives were at greater accident risk, then time of day would mistakenly appear to be a factor). Confidence limits using the normal distribution were calculated for the adjusted rates as these rates are based on

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the ratios of accidents to dives within individual cells (depth category by each variable category) which do not necessarily conform to the Poisson distribution.

In addition, the dive records of the accident segments were sorted and categorized by identification number (Social Security/Service Number) to ascertain the reoccurrence of accidents among individual divers. Two other variables selected from the accident segment (initial sign occurrence and accident outcome) were analyzed in terms of response frequencies.

RESULTS

A wide range of responses to the variables of initial accident and most significant sign was observed. Table 1 provides a frequency and percentage distribution rank ordered by descriptors for both of these variables. As shown, decompression sickness and barotrauma were the most prevalent types of accidents while localized pain was the most common significant sign. Interactively, localized pain was the significant

TABLE 1
FREQUENCY AND PERCENTAGE DISTRIBUTION OF TYPES OF ACCIDENTS AND SYMPTOMS AMONG U.S. NAVY DIVERS, 1968-1981

Accident	No.	%	Significant Sign	No.	%
Decompression sickness	426	41.1	Localized pain	604	58.5
Barotrauma	227	21.9	Dizziness	80	7.7
Other	76	7.3	Numbness	55	5.3
O ₂ poisoning	49	4.7	Other	46	4.5
Mechanical injuries	49	4.7	Unconsciousness	44	4.3
Missed decompression	44	4.2	None	40	3.9
Air embolism	37	3.6	Bleeding	27	2.6
Unknown	23	2.2	Muscular weakness	24	2.3
CO ₂ poisoning	20	1.9	Muscular twitching	16	1.5
Injured by marine organism	13	1.3	Nausea/vomiting	16	1.5
Mediastinal emphysema	8	0.8	Visual disturbances	15	1.5
Drowning	8	0.8	Rash	14	1.4
Disorders of consciousness	7	0.7	Convulsions	10	1.0
Hypoxia	7	0.7	Itching	8	0.8
Subcutaneous emphysema	7	0.7	Parasthesia	7	0.7
Near drowning	5	0.5	Swelling	7	0.7
Blow-up	5	0.5	Dyspnea	6	0.6
Hyperventilation	5	0.5	Paralysis	4	0.4
CO poisoning	4	0.4	Acoustic aura	4	0.4
Mental	4	0.4	Unknown	4	0.4
Pneumothorax	3	0.3	Drowsy	1	0.1
Nonpressure related	3	0.3	Restlessness	1	0.1
Nitrogen narcosis	3	0.3			
Bad gas	3	0.3			
Total	1036	100.1		1033	100.2

sign in 75% of the cases of decompression sickness and 81% of barotraumas. Additionally, 83% of the localized pain was accounted for by these two types of accidents.

Dive conditions

In examining dive depth as a factor in accidents, the distribution showed that mishaps occurred at all subaqueous levels with the highest mishap rates observed at the greatest depths (Table 2). Rates at the three shallowest depths (representing 75% of all dives) were all significantly lower than the overall rate while the rates for the deepest dives were significantly higher.

To assess the effect of time of day (local time), mishap rates were computed on an hourly basis from 0600 through 1759 with the night dives (1800–2359) forming a composite rate. Table 3 shows a slight increase in accident risk for dives occurring between 0700 and 0759 and 1700 and 1759. Adjusting the rates for depth, however, eliminated these significant differences indicating that a disproportionate distribution of dive depths occurred during these time intervals or that individual depth by time cell frequencies were not large enough to yield certainty as to actual rate differences.

Analyzing accident rates by various temperature ranges of air, surface water, and bottom water yielded only minor rate differences, none of which were significant after depth adjustment.

Widely diverse activities were recorded for the variable of dive purpose which included such subcategories as recreation, work, and medical treatment. The values presented in Table 4 indicate that work dives (comprising 51% of all dives) and requalification dives had significantly lower accident rates than the overall rate, while those dives with an objective of medical treatment, experimental, selection, equipment testing, tender, and other reasons had significantly higher rates. When depth adjusted, only selection and experimental dives had rates significantly higher than the overall accident rate.

TABLE 2
DISTRIBUTION OF DIVES, ACCIDENTS, AND ACCIDENT RATES BY DIVE DEPTH
AMONG U.S. NAVY DIVERS, 1968–1981

Dive Depth		No. Dives*	No. Accidents	Rate/1000 Dives**
m	(ft)			
0–3	(1–10)	56,929	31	0.54†
3.4–7.6	(11–25)	176,111	125	0.71†
7.9–15.2	(26–50)	295,704	210	0.71†
15.5–30.5	(51–100)	90,868	211	2.32†
30.8–61.0	(101–200)	77,440	418	5.40†
≥ 61.3	(≥201)	8,143	168	20.63†
Total		705,195	1,163	1.65

*Number of dives is based on 10% random sample. **Significance levels of rates are based on Poisson distribution. †Rate differs significantly ($P < 0.05$) from overall rate as determined by non-overlapping confidence intervals.

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TABLE 3
 DISTRIBUTION OF DIVES, ACCIDENTS, ACCIDENT RATES, AND DEPTH-ADJUSTED
 ACCIDENT RATES BY LOCAL TIME AMONG U.S. NAVY DIVERS, 1968-1981

Local Time	No. Dives*	No. Accidents	Rate/1000 Dives**	Depth-Adjusted Rate/1000 Dives†
0600-0659	3,067	9	2.93	1.55
0700-0759	16,755	42	2.51‡	1.08
0800-0859	72,565	137	1.89	1.56
0900-0959	108,602	149	1.37	1.43
1000-1059	91,068	143	1.57	1.62
1100-1159	48,726	76	1.56	1.48
1200-1259	40,504	78	1.93	1.96
1300-1359	81,507	94	1.15‡	1.42
1400-1459	59,147	104	1.76	2.39
1500-1559	25,907	39	1.50	1.61
1600-1659	12,499	26	2.08	2.26
1700-1759	7,563	24	3.17‡	3.49
1800-2359	33,850	47	1.39	2.88
Total	601,760	968	1.61	1.64

*Number of dives is based on 10% random sample. **Significance levels of rates are based on Poisson distribution. †Significance levels of depth-adjusted rates are based on normal distribution. ‡Rate differs significantly ($P < 0.05$) from overall rate as determined by nonoverlapping confidence intervals.

Decompression schedule types and their accompanying rates are presented in Table 5. Saturation diving accounted for the highest accident rate, followed by surface decompressions. The rate for dives requiring no decompression (91% of all dives) was significantly lower than the overall rate, while all other decompression schedules except the repetitive dive tables yielded rates significantly higher than the total. Because decompression schedule type is depth dependent, an adjustment for depth would be inappropriate.

Diver characteristics

To ascertain the impact of diver-related variables, accident rates were computed by age, height, weight, and recent diving experience. Rates presented in Table 6 showed that those dives performed by individuals in the 21 to 24 age range terminated in accidents significantly less often than dives in general, and divers between the ages of 33 and 36 had a significantly higher accident rate. Mishap rates among older groups (> 24 yr) decreased with depth adjustment. Accident rates computed by height and weight showed no significant differences with or without depth adjustment.

Analysis of accident rates by the individual's recent diving experience was based on the number of prior dives in the previous 24 h. As indicated in Table 7, divers performing their first dive of the day had a significantly lower accident rate than

TABLE 4
DISTRIBUTION OF DIVES, ACCIDENTS, ACCIDENT RATES, AND DEPTH-ADJUSTED
ACCIDENT RATES BY PURPOSE OF DIVE AMONG U.S. NAVY DIVERS, 1968-1981

Dive Purpose	No. Dives*	No. Accidents	Rate/1000 Dives**	Depth-Adjusted Rate/1000 Dives†
Work	351,763	360	1.02‡	1.64
Training	218,173	353	1.62	1.67
Requalification	80,677	87	1.08‡	0.63
Other	12,459	41	3.29‡	2.71
Sport/Recreation	6,774	18	2.66	4.18
Tender	6,574	21	3.19‡	1.45
Equipment testing	5,995	24	4.00‡	3.74
Experimental	5,195	142	27.33‡	12.66‡
Selection	2,857	67	23.45‡	38.70‡
Medical treatment	1,069	35	32.74‡	31.44
Total	691,536	1,148	1.66	1.62

*Number of dives is based on 10% random sample. **Significance levels of rates are based on Poisson distribution. †Significance levels of depth-adjusted rates are based on normal distribution. ‡Rate differs significantly ($P < 0.05$) from overall rate as determined by nonoverlapping confidence intervals.

TABLE 5
DISTRIBUTION OF DIVES, ACCIDENTS AND ACCIDENT RATES BY DECOMPRESSION
SCHEDULE TYPE AMONG U.S. NAVY DIVERS, 1968-1981

Decompression Schedule Type	No. Dives*	No. Accidents	Rate/1000 Dives**
No decompression	631,022	545	0.86†
Standard air tables	32,670	238	7.28†
Standard HeO ₂	11,100	56	5.04†
Other	5,635	160	28.39†
Repetitive dive tables	5,515	17	3.08
Exceptional exposure air	3,916	60	15.32†
Surface decompression O ₂	1,019	27	26.50†
Saturation	430	48	111.63†
Surface decompression air	240	11	45.83†
N ₂ O ₂ equivalent air	210	4	19.05†
Total	691,757	1,166	1.69

*Number of dives is based on 10% random sample. **Significance levels of rates are based on Poisson distribution. †Rate differs significantly ($P \leq 0.05$) from overall rate as determined by non-overlapping confidence intervals.

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TABLE 6
DISTRIBUTION OF DIVES, ACCIDENTS, ACCIDENT RATES, AND DEPTH-ADJUSTED ACCIDENT RATES BY AGE AMONG U.S. NAVY DIVERS, 1968-1981

Age	No. Dives*	No. Accidents	Rate/1000 Dives**	Depth-Adjusted Rate/1000 Dives†
17-20	81,546	152	1.86	2.62
21-24	236,487	319	1.35‡	1.56
25-28	154,001	263	1.71	1.66
29-32	106,404	198	1.86	1.59
33-36	77,250	169	2.19‡	1.78
37-40	34,549	47	1.36	0.99
≥ 41	15,756	21	1.33	1.10
Total	705,993	1,169	1.66	1.65

*Number of dives is based on 10% random sample. **Significance levels of rates are based on Poisson distribution. †Significance levels of depth-adjusted rates are based on normal distribution. ‡Rate differs significantly ($P < 0.05$) from overall rate as determined by nonoverlapping confidence intervals.

TABLE 7
DISTRIBUTION OF DIVES, ACCIDENTS, ACCIDENT RATES, AND DEPTH-ADJUSTED ACCIDENT RATES BY NUMBER OF DIVES IN PREVIOUS 24 H

Dives in Previous 24 h	No. Dives*	No. Accidents	Rate/1000 Dives**	Depth-Adjusted Rate/1000 Dives†
0	454,930	683	1.50‡	1.38
1	177,670	398	2.24	2.57
2	49,785	55	1.10	1.40
3	14,747	13	0.88	1.55
4	4,856	9	1.85	1.66
≥5	4,246	12	2.83	5.18
Total	706,234	1,170	1.60	1.65

*Number of dives is based on 10% random sample. **Significance levels of rates are based on Poisson distribution. †Significance levels of depth-adjusted rates are based on normal distribution. ‡Rate differs significantly ($P < 0.05$) from overall rate as determined by nonoverlapping confidence intervals.

divers in general. Though not statistically significant, divers with five or more dives had the highest accident rate. No significant differences were observed after adjusting for depth.

The variable of previous mishaps was examined to determine the distribution of repeated mishaps among individual divers and the relationship to future accidents. Table 8 shows that the probability of a future accident increased with the number of previous accidents.

TABLE 8
 NUMBER OF PREVIOUS ACCIDENTS AS A PREDICTOR OF FUTURE ACCIDENTS
 AMONG U.S. NAVY DIVERS, 1968-1981

Previous Mishaps	No. Divers	Proportion of Divers Involved in a Future Accident
One	1009	0.12
Two	120	0.18
Three	22	0.23
Four	5	0.60

The variable of initial sign occurrence delineated when complications were first detected. Twenty percent of mishaps occurred during descent, 12% while on the bottom, 14% during ascent, and 47% after surfacing and/or completed decompression. The remaining 7% occurred either prior to descent or during interrupted or surface decompression.

The severity of the mishaps was indicated by the variable of accident outcome. Responses to this item yielded the following percentage distribution: 80.7% experienced complete relief; 17.7% substantial relief; 0.9% a recurrence; and 0.7% a fatality.

SUMMARY AND DISCUSSION

United States Navy diving records indicated that 1174 diving incidents occurred during the course of 706,259 dives, yielding a probability of 0.0017 that any dive would result in a mishap. Decompression sickness and barotrauma were the most prevalent accidents and accounted for 63% of the defined mishaps. The intent of the present investigation was to ascertain if there were any identifiable factors (dive conditions or diver characteristics) on current Navy diving logs that may have contributed to the occurrence of accidents.

Dive depth was shown to exert considerable influence on mishap incidence. Accident rates for dive depth intervals shallower than 15 m (50 ft) were extremely low while rates beyond this depth showed significant increases. Accident rates also fluctuated considerably by dive purpose. After adjusting for depth, two categories of dive purpose, selection and experimental dives, yielded accident rates significantly higher than the overall rate. A selection dive represented the first time the potential Navy diver was suited up and observed by a qualified officer. Experimental dives were those dives during which recent technological developments were tested. The probational nature of these two dive purposes portends an increased risk, and elevated accident rates are understandable if not anticipated. Decompression schedule type, a highly depth-dependent factor, also showed marked variability in accident rates. The lowest rate in this variable was observed for dives requiring no decompression (91% of all Navy dives) and the highest rate was for saturation dives which represented 0.06% of all dives and averaged 186 m (610 ft) in depth.

In the domain of diver-dependent variables, accident rates for two age ranges differed significantly from the overall rate, but were not significant within the depth-

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adjusted values. The finding that accident rates among the four oldest age ranges declined with depth adjustment implied that divers over the age of 24 were disproportionately assigned to deeper dives. That these assignments are sound policy was evidenced by the low mishap rates of the oldest divers in the present study. Such assignments are further supported by Biersner et al. (3) who reported a lower accident rate among older divers and by Hoiberg and Blood (5) who showed that the lowest admission rates for environmentally induced disorders were among the oldest divers.

Eighty-eight percent of accidents were the first recorded for the diver involved. Although future accident probability increased with number of previous mishaps, it should be noted that only five individuals had more than three mishaps. More than 97% of the diving accidents ended in complete relief or substantial relief for the diver. Finally, the presence of missing data on the diving log report forms should be acknowledged. Among the six variables on which rates were tabled in the current investigation, complete data averaged 96%. The diving log represents a massive and commendable undertaking by the U.S. Navy in its quest of accident prevention—success in this endeavor depends on complete and accurate reporting.

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Blood C, Hoiberg A. Analyses des variables à la base des accidents de plongée dans la Marine américaine. *Undersea Biomed Res* 1985; 12(3): 351–360.—Les carnets de plongée de la Marine américaine furent examinés afin de déterminer les accidents de plongée qui surviennent le plus fréquemment et d'identifier les facteurs significatifs sous-jacents. La maladie de décompression et les barotraumatismes furent prédominants chez 1,174 cas rapportés au cours de 706,259 plongées. L'incidence d'accidents augmenta significativement avec la profondeur de la plongée. Les plongées expérimentales ou à fins de sélection, ainsi que la plongée à saturation et les décompressions de surface parmi les types de tables de décompression, risquaient considérablement de se terminer en un accident. Les plongeurs plus âgés étaient assignés de façon disproportionnée à des plongées profondes. Quatre-vingt-un pourcent des accidents de plongée résultèrent en un soulagement complet du plongeur tandis que 18% se terminèrent en un soulagement substantiel.

plongeurs de la Marine américaine
accidents de plongé
taux d'accidents

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