Using a Delphi technique to rank potential causes of scuba diving incidents

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Key words
Diving accidents, scuba accidents, ascent, buoyancy, risk factors, survey

Abstract

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Scuba diving experts suggested and ranked potential causes of three known risk factors for scuba diving incidents: running out of air, losing buoyancy control and making rapid ascents. Three types of scuba diving expert participated: medical experts, divemasters and expert divers. In three rounds, consensus was reached for 28 (58%) of 48 suggested causes. Inexperience was ranked highly for all three risk factors, as was anxiety/stress and diver failure (to monitor contents gauge or release air on ascent). Poor skill levels and inadequate training were also often suggested. Overall, the expert panel suggested potential causes that were more often human or equipment related, than environmental.

Introduction

Among recreational divers, the three leading causes of injury and death are drowning/near drowning, barotraumas due to expanding air during ascent, and decompression illness (DCI).[1–8] Running out of air, a loss of buoyancy control and making a rapid ascent have been found to be associated with these types of diving morbidity and mortality.[1,9–12] These risk factors are also known to occur concurrently.[12–14]

What remains to be investigated are the reasons why divers lose control of their buoyancy, make rapid ascents or run out of air. Nor is it known whether these injury risk factors share common causes. Before research can be conducted to investigate the potential strength of association between three risk factors and their potential causes, likely causes need to be identified. This paper presents the results of a Delphi study conducted between February and June 2007 using a panel of experienced recreational divers, diver supervisor/instructors and diving medicine/research experts.

DELPHI ANALYSIS

Developed in the 1950s, this technique is a useful method for reaching consensus of expert opinion regarding a complex or imprecise issue.[15] In its 'ideal' form, an expert panel is formed whilst anonymity is maintained and each expert contributes to an initial summary of expert opinion. This summary is then circulated to the panel and each expert makes revisions based on both their own opinion and bearing in mind the weight of opinion of the panel.[16] A second summary is circulated, usually with a higher level of agreement than the first and, once again, each expert makes revisions. After three or more rounds, a pre-defined consensus of opinion is reached for some aspects of the summary, while for the remainder the experts should be expected to reach 'terminal disagreement' where the likelihood of further agreement is diminished.[17]

Methods

INSTRUMENT DESIGN

A questionnaire comprising thirteen questions formed the basis of the first-round survey. This consisted of four questions addressing characteristics of respondents such as occupation and number of dives made, followed by nine questions related to running out of air (three questions), losing buoyancy control (three questions) and making rapid ascents (three questions). The first of each trio was an open-ended question asking why some divers might experience each of these risk factors, the next asked which single reason was the most common cause of each risk factor and the final question asked whether this had ever happened to the respondent. The study was approved by the Human Research Ethics Committee of the University of Western Australia.

The questionnaire was assessed for face and content validity, and was pilot tested by sixteen divers ranging in experience from novice to instructor. Minor revisions were made to the invitation to participate and the wording of the questions. Potential participants were identified based on their profession. Medical experts included researchers and hyperbaric clinicians identified from published research who were known to have treated injured divers and/or engaged in diving-related research. Expert divers, identified by reviewing the popular diving press, had published numerous diving feature articles, travelled extensively to popular dive destinations and were known to have made 1,000 dives or more. Expert divemasters and instructors were nominated by staff at the largest dive businesses within Western Australia. Each had worked as a professional divemaster or instructor for ten years or more. A search of diving industry journals identified two additional instructors who had received industry awards for teaching recreational scuba diving. Most potential participants had experience in at least one additional category other than that for which they were considered expert, e.g., some medical experts were also instructors and most instructors were accomplished divers.

Anticipating an initial response rate of 75%, 29 potential participants were each sent, by e-mail, an invitation to join the study. A copy of the first-round questionnaire was attached to each invitation. Prior agreement to participate was not sought. E-mail was chosen as the preferred method of communication because of its speed and cost effectiveness over traditional mail.[18] At the end of the first round all suggested possible causes were listed alphabetically and in the second round participants were asked to rank the five most common causes for each risk factor. In the third round possible causes not chosen at least once in the second round were removed from the list. The remaining causes were placed in order of how often each possible cause was chosen as significant and, based on this, participants were asked to re-consider and to re-rank the five most common potential causes of each risk factor.

Consensus was pre-defined to at least 90% agreement between participants upon whether a potential cause was likely, or not likely, to be commonly associated with each risk factor. Finally, potential causes were classified as relating to the diver (human), dive gear (equipment) or conditions at the dive site (environment). Classification was made using existing criteria, with the exception of equipment misuse, which was considered in this study to be equipment related.[5,19,20]

STATISTICS

Data were managed using Excel and analysed using SAS ver 9.1. Differences in mean number of dives made by each group in the previous year were tested for significance using the Wilcoxon rank sum test. Differences between groups (n = 3) in the mean number of potential causes suggested were tested for significance using ANOVA, with pooled variance. Reported correlations between rankings of potential causes are Spearman rank correlation coefficients. Differences between expert groups in correlation between second- and third-round rankings were tested for significance using Fisher's z transformation.[21] Significance in all tests was accepted at 0.05.

Results

Of 29 experts contacted, one declined to participate, three returned only one of the last two rounds and 25 (86%) completed both second and third questionnaires. Participation was evenly distributed across the expert groups, with nine from each group taking part in the third round. Participants reported having made a total of 2,736 dives (median = 90) during the previous year. Medical experts reported making fewer dives during the previous year (median = 18) compared with either divemasters (median = 100) or divers (median = 100).

Table 1
Suggested possible causes of divers running out of air (see text for explanation)

Round	**First**	**Second**	**Third**
Possible cause	**Nº times suggested**	**Rank[a]**	**Rank[a]**
Failing to monitor gauge	16	1	1[b]
Inexperience	12	2	2[b]
Overexertion/strong current	6	3	3
Inadequate training	8	4	4
Poor dive planning	4	5	5
Panic/anxiety/stress	7	8	6
Diving deeper than usual	4	7	7
Trying to match their buddy	4	6	8
Overweighting	3	9	9.5[b]
Task-loading	3	14[b]	9.5[b]
Faulty equipment	7	10.5[b]	12[b]
Narcosis	3	10.5[b]	12[b]
Low starting pressure	3	14[b]	12[b]
Entrapment	2	14[b]	16[b]
Tired or cold	1	14[b]	16[b]
Unplanned decompression	1	14[b]	16[b]
Drugs/medication	1	17.5[b]	16[b]
Using a smaller cylinder	1	17.5[b]	16[b]
Correlation with 3rd round	0.90	0.94	1.0

[a] Ranked by number of times in top five
[b] Consensus reached by ≥ 90%

In the first round, participants suggested 18 possible causes of divers running out of air, 14 possible causes of divers losing buoyancy control and 16 possible causes of rapid ascent. Medical experts suggested more potential causes overall (n = 40) than divemasters or divers (n = 31 and 32 respectively). The mean number suggested by medical experts (4.7, SD 1.3) was significantly higher ($P < 0.01$) than by divemasters (3.5, SD +/- 0.8) or divers (3.6, SD +/- 1.2). Suggested potential causes are provided in Tables 1, 2 and 3. Movement toward consensus is evidenced by the increasing consistency with which each possible cause was suggested during successive rounds. By round three, consensus was reached for 28 (58%) of the 48 suggested possible causes.

Correlation coefficients were calculated between second- and third-round choices for each participant's five most significant potential causes, to gauge how far each group moved towards consensus. Overall intra-rater correlation coefficient (r) for divemasters was 0.47, for divers 0.65 and for medical experts 0.75; these differences were significant. Divemasters were more likely than divers to move towards consensus ($z = 2.88$, $P = 0.004$), whereas medical experts were less likely to change their ranking than either divers ($z = 2.22$, $P = 0.026$) or divemasters ($z = 5.19$, $P < 0.003$).

Lastly, potential causes selected at least once in the third

Table 2
Suggested possible causes of divers losing buoyancy control

Possible cause	First N° times suggested	Second Rank[a]	Third Rank[a]
Inexperience	13	1[b]	1[b]
Failure to release air on ascent	4	4	2.5
Poor training/skills	6	3	2.5
Incorrect weighting	9	2	4
Panic/anxiety/stress	8	6	5
Unfamiliar equipment	6	5	6
Incorrect body position	5	10	7.5
Incorrect use of BCD	2	8	7.5
Loss of weight system	6	7	9
Wetsuit compression	1	10	10[b]
Carrying heavy objects	2	10	12[b]
Current or surge	2	13	12[b]
Faulty BCD	9	12	12[b]
Upwelling of water	2	14[b]	14[b]
Correlation with 3rd round	0.56	0.95	1.0

[a] Ranked by number of times in top five
[b] Consensus reached by ≥90%

Table 3
Suggested possible causes of divers making rapid ascents

Possible cause	First N° times suggested	Second Rank[a]	Third Rank[a]
Panic/anxiety/stress	20	1[b]	2[b]
Failure to release air on ascent	11	3	2[b]
Inexperience	12	4	2[b]
Running out of air	12	2	4
Incorrect use of BCD	4	5	5
Ignorance of safe ascent rate	3	9	6.5
Poor body position on ascent	8	7	6.5
Fail to monitor depth gauge	2	7	8
Loss of weight system	5	7	9
Equipment failure	3	10	10[b]
Bad visibility	1	11.5	13.5[b]
Upwelling of water	1	11.5	13.5[b]
Entanglement	1	14[b]	13.5[b]
Lifting a heavy weight	1	14[b]	13.5[b]
No computer	1	14[b]	13.5[b]
Narcosis at depth	1	16[b]	13.5[b]
Correlation with 3rd round	0.93	0.94	1.0

[a] Ranked by number of times in top five
[b] Consensus reached by ≥90%

Table 4. Classification of remaining possible causes, by risk factor

Risk factor	Human	Equipment	Environment
Running out of air (N = 8)	Inexperience Inadequate training Poor dive planning Panic/anxiety/stress Trying to match buddy	Failure to monitor gauge	Overexertion/strong current Diving deeper than usual
Losing buoyancy control (N = 9)	Inexperience Poor training/skill level Panic/anxiety/stress Incorrect body position	Fail to release air on ascent Incorrect weighting Unfamiliar equipment Incorrect use of BCD Loss of weight system	
Making a rapid ascent (N = 9)	Panic/anxiety/stress Inexperience Ignorance of safe ascent rate Poor body position Loss of weight system	Fail to release air on ascent Running out of air Incorrect use of BCD Fail to monitor depth gauge	
Overall (N = 26)	14	10	2

round were classified as human, equipment or environmental, (Table 4). The overall distribution suggests the three most common risk factors for diving morbidity and mortality are thought to be associated with either human error or equipment issues, and environmental conditions are thought to assume a less significant role in diving incidents.

Discussion

Although medical experts reported making substantially fewer dives during the previous year, they initially suggested significantly more possible causes for each risk factor and then changed their ranking of the importance of potential causes to a significantly lesser degree than the other expert groups. Given this group's probable exposure to published research relating to diving incidents, this difference is not surprising. Despite this apparent heterogeneity between types of expert, consensus was reached that diver inexperience was the most common cause of losing buoyancy control, the equal most common cause of rapid ascents and the second most common cause of running out of air. This is in keeping with results of previous studies that reported air embolism occurred more often in people who dove less frequently and that most severe air embolisms occurred among inexperienced divers.[22,23] Inexperience has also often been cited as important within diving fatality analyses.[6,7] In our study diver failure to check the contents gauge or release air during ascent ranked high, as did panic/anxiety/stress. Inadequate training and poor skill level were also suggested by the experts, implying that increased training and practice might reduce diver stress, improve skill-level and reduce diver error. The presence of such an association remains to be proven.

Although a high level of consensus was reached in this study, the actual causes of each risk factor remain undetermined. To address this, a prospective study is underway to determine which of these potential causes are significantly associated with running out of air, losing buoyancy control and/or making a rapid ascent. Though it is customary to define consensus as an arbitrary level of agreement, the ranking of potential causes, including even those for which consensus was not reached, may occasionally prove more useful, for example in the development of a survey. In such cases, the Delphi technique may even prove useful for investigating other issues related to diving injuries and deaths.

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