The effect of pressure and time on information recall

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Abstract

Mine countermeasures divers are required to investigate mines located on the seabed. The diver is required to first locate, then to memorize details about the mine for later reporting to the dive supervisor. This study evaluated the effects of diving to 40 msw and elapsed time on the processing and recall of information. Ten divers viewed detailed images of mine-like objects on six occasions in air and in dives to 40 msw in a hyperbaric chamber. Divers were asked to report information at three elapsed time intervals: immediate, 5 minutes and 2 hours. Exposure to 40 msw resulted in a 13% decrement in information processing and recall ($p<0.05$). Information recall also decreased with elapsed time ($p<0.05$) and with the complexity of the information ($p<0.05$). After 2 hours, divers recalled only 69% of the information viewed at 40 msw compared with 90% on immediate recall; and after 2 hours divers recalled only 49% of the most detailed information. It is concluded that providing divers with technologies to aid in the collection of detailed information and to report information at the earliest possible time will increase the quality of the information transmitted by the diver.

Résumé

Les plongeurs de lutte contre les mines sont tenus d'examiner les mines se trouvant sur le fond marin. Le plongeur doit d'abord repérer la mine, puis en mémoriser les détails pour ensuite en faire rapport au superviseur de plongée. Dans la présente étude, on a évalué les effets d'une plongée à 40 m de profondeur et du temps écoulé sur le traitement et la mémorisation de l'information. À six reprises, dix plongeurs ont vu des images détaillées d'objets ressemblant à des mines, dans des conditions simulées en surface et à une profondeur de 40 m en chambre hyperbare. On a demandé aux plongeurs de rendre compte de l'information à trois intervalles de temps : immédiatement, après 5 minutes et après 2 heures. L'exposition à une profondeur de 40 m a fait en sorte que les plongeurs ont traité et mémorisé 87 % de l'information ($p < 0,05$). La mémorisation de l'information a aussi diminué en fonction du temps écoulé ($p < 0,05$) et de la complexité de l'information ($p < 0,05$). Après 2 heures, les plongeurs n'ont retenu que 69 % de l'information visualisée à une profondeur de 40 m, comparativement à 90 % de celle-ci dans le cas d'un signalement immédiat. Après 2 heures, les plongeurs n'ont retenu que 49 % de l'information la plus détaillée. Il en est conclu qu'on peut rehausser la qualité de l'information transmise par les plongeurs en fournissant à ces derniers des moyens technologiques pour les aider à recueillir l'information détaillée et en rendant compte de cette information le plus rapidement possible.

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Executive summary

Introduction: One component of the mine countermeasures (MCM) diver's job is to investigate mines situated on the seabed. The diver is required to first locate, then to memorize details about the mine for later reporting to the dive supervisor. The dive supervisor makes important decisions based on the report from the diver, so it is vital that the diver proves complete and accurate information. This study was designed to quantify the amount and type of information that the MCM diver's are able to provide to the dive supervisor.

Methods: The ability to view an image of a mine like object (target) and to report specific information about that object was measured in six different conditions. Ten experienced divers completed three conditions in an air environment at surface pressure, and three conditions during simulated dives to 40 msw in a hyperbaric chamber. In each condition the divers viewed an image of a simulated target. The images viewed contained three types of information that corresponded to the levels of detail that divers are expected to report during MCM diving operations. The ability of the diver to recall the different types of information was measured after three distinct time intervals: immediate recall; 5 minute recall; and 2 hour recall.

Results: Exposure to increased pressure (40 msw) was associated with a significant decrease in information processing and recall capabilities of divers ($0<0.05$). The ability to recall information from long term memory decreased as the elapsed time increased ($p<0.05$). This decrement was more pronounced for more detailed information ($p<0.05$). Two hours after a dive to 40 msw, divers recalled only 69% of the target information, compared with 90% on immediate recall and, after 2 hours, divers recalled only 49% of the most detailed information.

Significance: Results show that the information processing capabilities of MCM divers are degraded in the operational environment. Providing divers with new technologies to aid in the collection of target information, and to report the information to the dive supervisor as soon as possible, will significantly increase the quality of the information transmitted by the diver.

Sommaire

Introduction. Une composante du travail des plongeurs de lutte contre les mines (LCM) consiste à examiner les mines se trouvant sur le fond marin. Le plongeur doit d'abord repérer la mine, puis en mémoriser les détails pour ensuite en faire rapport au superviseur de plongée. Comme le superviseur de plongée prend des décisions importantes en se fondant sur le rapport du plongeur, il est crucial que le plongeur fournisse des informations complètes et exactes. L'étude visait à déterminer la quantité et le type d'information que les plongeurs de LCM sont en mesure de fournir au superviseur de plongée.

Méthodes. On a mesuré dans six conditions différentes l'aptitude à visualiser un objet (objectif) ressemblant à une mine et à rendre compte de l'information particulière concernant cet objet. Dix plongeurs expérimentés ont effectué ce travail dans trois conditions simulant un environnement de surface à la pression en surface et dans trois conditions simulées de plongée à une profondeur de 40 m, en chambre hyperbare. Dans chaque condition, les plongeurs ont visualisé une image d'un objectif simulé. Les images contenaient trois types d'informations correspondant aux niveaux de détail que les plongeurs sont censés signaler pendant des opérations de plongée de LCM. On a mesuré l'aptitude des plongeurs à mémoriser les différents types d'informations à trois intervalles de temps donnés : immédiatement, après 5 minutes et après 2 heures.

Résultats. L'exposition à une pression accrue (à une profondeur de 40 m) a entraîné une diminution importante de la capacité des plongeurs à traiter et à mémoriser l'information ($p < 0,05$). L'aptitude à retenir l'information (mémoire à long terme) a diminué avec le temps écoulé ($p < 0,05$). La diminution était plus prononcée dans le cas de l'information plus détaillée ($p < 0,05$). Deux heures après une plongée à une profondeur de 40 m, les plongeurs n'ont retenu que 69 % de l'information sur l'objectif, comparativement à 90 % de celle-ci dans le cas d'un signalement immédiat. Après 2 heures, les plongeurs n'ont retenu que 49 % de l'information la plus détaillée.

Portée. Les résultats montrent que l'aptitude des plongeurs de LCM à traiter l'information diminue en fonction de l'environnement opérationnel. On peut rehausser la qualité de l'information transmise par les plongeurs en fournissant à ces derniers des moyens technologiques pour les aider à recueillir l'information détaillée et en rendant compte de cette information le plus rapidement possible.

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Introduction

One component of a mine countermeasures (MCM) diver's job is to investigate mines situated on the seabed. The diver is required to first locate, then to memorize details about the mine for later reporting to the dive supervisor for mine identification. The dive supervisor makes important decisions based on the report from the diver, so it is vital that the diver provides as complete and accurate information as possible. Although located in shipping channels, mines are often deployed in deep water to make them more difficult to locate and less accessible to the divers. Thus MCM dives can be technically difficult operations that require the diver to endure up to 2 hours of decompression.

In the current MCM diving protocol, the diver is expected to view the mine and obtain as much detailed information as possible within a short duration (approximately 2 minutes). The time available for gathering of information is limited because the diver may be at a considerable depth (up to 81 metres of seawater (msw)) and will have a restricted bottom time for search, location, and memorizing details of the mine. The diver completes the dive, including decompression, before reporting the information to the dive supervisor. The duration between viewing the mine and reporting to the supervisor can be up to 2 hours (or longer in extenuating circumstances).

There are many factors in MCM diving that may affect the diver's ability to process, and recall the information about the mine. Environmental stressors (such as narcosis, cold, low visibility, anxiety), duration between information processing and recall, and the cognitive load of the diver can all affect information processing and recall (Fairburn, 1993; Fothergill *et al.,* 1991; Fowler *et al.,* 1995; Leach and Morris, 1998; Morrison and Zander, 2005; Parsons, 2003). It is not clear how these factors interact to affect the overall ability of a working diver to process and recall information.

Environmental Stressors

Literature researching the effects of environmental conditions on memory shows that both narcosis and cold can cause significant decrements in short term (or working) memory (Coleshaw *et al.,* 1983; Baddedley, 1992; Fothergill *et al.,* 1991).

To date, most diving and narcosis research has not differentiated between short term and long term memory. In general, most of this research has focused on short term memory, using time intervals that range between a few seconds to half a minute (Leach and Morris, 1998, 1993; Fairburn, 1993; Fowler *et al.,* 1995). Some narcosis memory studies have used retention intervals up to one minute (Fowler *et al.,* 1995). Narcosis resulting from excessive Nitrogen or Carbon Dioxide partial pressures is associated with working memory deficits and transient amnesia (Emmerson, 1986; Bennett and Elliot, 1994; Hamilton *et al.,* 1985). Extensive research has shown that when suffering from nitrogen or carbon dioxide narcosis, subjects have slowed mental functions (Fothergill *et al.,* 1991).

For MCM diving it is important to quantify the effects of mild narcosis on short term memory to understand how much information the diver is able to gather about the mine. The information that the diver observes is first processed and stored in short term memory before being transferred and stored in long term memory (see "Information Retrieval" section). Thus, short term memory will limit the amount and type of information that the diver is able to store in long term memory. It is also important to quantify the effects of narcosis on long term memory. To report the findings after the dive, the diver must be able to retrieve the information from long term memory for periods of up to two hours. There is no available research documenting the effects of mild narcosis on long term memory (more than one minute). In particular, data are required to quantify the effects of duration between information stimulus and retrieval on the ability to recall varying levels of detail about the mine.

Both peripheral and core cooling can cause decrements in memory. Peripheral cooling degrades memory by causing distraction; the pain and discomfort of cold demand the attention of the individual making it difficult to attend to other stimuli (Parsons, 2003; Healy and Bourne, 1995; and Hadyn *et al.,* 1985). Core cooling also causes distraction, but in addition, it degrades the information processing lifecycle (Coleshaw *et al.,* 1983; Emmerson, 1986). The results of exposure to cold are decreased ability to recall information, either because it was not initially attended to or because of a failure during some stage of the information processing.

It is difficult to quantify the effects of cold on information processing, short term memory and long term memory components. Past research that has measured the effect(s) of cold on information processing supports the hypothesis that exposure to cold causes a decrement in information processing and working memory, but does not effectively define the measures. Coleshaw *et al.,* (1983) showed that mild hypothermia was associated with working memory deficits. Drops in core temperature of between 2 to 3°C were associated with amnesia (Coleshaw *et al.,* 1983). Baddedley (1992) showed that drops in rectal temperature of between 0.7 to 1.0°C were associated with significant impairments in information processing. Stang and Weiner (1970) suggested that, irrespective of core temperature, cutaneous cooling (by 30 to 90 minutes submersion in 6 to10°C water while wearing a wet suit) was associated with significant decrements in information processing. It is difficult to interpret these data with respect to MCM diving because each experiment that has been conducted appears to use slightly different definitions of information processing, memory, or cognitive function, and have tended to use exposure to extreme cold for an extended duration.

Exposure to cold was not included as a factor in this experiment. MCM divers wear protective clothing that prevents them from experiencing significant drops in core temperature during normal MCM diving operations. Although MCM divers do experience peripheral cooling, past research performed by the authors suggests that the divers have acclimatised themselves to peripheral cooling. As a result they do not experience the arousal effects to the same extent as unacclimatised individuals. In fact, MCM divers exposed to 4°C water for a duration of approximately 40 minutes, when asked about the cold, reported that they had not noticed it. This acclimatisation that seems to be displayed in MCM divers is similar to that of fisherman and other individuals that are repeatedly exposed to cold conditions (LeBlanc *et al.,* 1960).

Information Retrieval

The capacity of short term (working) memory or the ability to process information to short term memory is limited and small (Atkinson and Shriffrin, 1968). It is generally accepted that short term memory is stored in “chunks” of information with an upper limit of seven “chunks” of information at a time (Miller, 1956). Conversely, there is no limit to the capacity of long term memory (Atkinson and Shriffrin, 1968).

The way that information is encoded to long term memory affects the ability to retrieve the information. The primary method of encoding to long term memory is, semantically, by associating meaning to the information being encoded (Baddeley, 1966). “Deep encoding” refers to drawing associations between the information being encoded and information already existing in long term memory. Increasing the number of associations increases the likelihood of information retrieval. Information can also be stored into long term memory via rehearsal: repeating the information over and over in the head. Rehearsal uses superficial aspects of the system and results in “shallow encoding” which is more susceptible to information decay (Ericsson, 2001).

Complexity of Information

Both the type and amount of information being encoded affect the ability to retrieve information from long term memory. Information that has meaning is easier to remember than abstract information (Baddeley, 1966). Ability to encode information to long term memory is improved with information that is meaningful or familiar; the individual makes more associations between the new information and information that already exists in long term memory. Abstract information is likely to be encoded to long term memory via rehearsal, since it is difficult to create meaningful associations. When comparing ability to remember meaningful versus abstract information, an individual is able to recall the same number of random letters (consonants) as unrelated words, where each word represents one chunk (Miller, 1956). In this example the letter series and unrelated word series are random. However, the letter series within each word is meaningful and the series represents one chunk. Therefore, the letter series containing strings of meaningful letters (words) that can be recalled is much longer than the letter series containing random letters.

MCM divers who investigate mines are required to gather both meaningful, familiar information as well as abstract information. The design of the mine, including the size, shape and the type of attachments is meaningful since it represents to the diver the type of mine and the method of delivery. For example, a large lifting eye has a recognizable shape and a known function. Divers are also expected to collect more detailed and abstract information such as alpha-numeric symbols, words which can be in a foreign language and bolt patterns. The abstract information is more difficult to encode to long term memory.

Time interval

The ability to recall information decreases as a function of time. Although there has been a significant body of research devoted to the study of memory decay with time, it has been focused on much longer durations than those of interest to MCM divers. Much of the available literature is focused on long term memory recall in witness testimonials and degradation over a number of days, weeks and months. Thus, research on long term memory has not measured the ability to recall information within the first few minutes or hours following information storage and has not measured the effect of other factors such as narcosis, cold, arousal or cognitive load.

Long term memory degradation occurs via three main pathways: decay; interference; and retrieval failure. Information decay refers to a loss of data over time (Baddeley, Thompson, and Buchanan, 1975). Due to the diversity of information and memory it is not possible to model information decay. Interference describes the loss of information by distortion from other information in long term memory (Keppel and Underwood, 1962). Retrieval failure represents an inability to access intact information from long term memory (Norman, 1968). Retrieval can be stimulated by context or memory cues.

In MCM diving it is not possible to identify the specific pathway through which information is lost. However, it is possible to quantify the amount and type of information that divers are able to recall from short and long term memory.

Cognitive Load

The cognitive load of the diver also affects long term memory. From the time the MCM diver views a mine until he has an opportunity to recall the information, there are a number of factors that will require his full attention and concentration. He is responsible for underwater navigation, rope-pull communications with the dive supervisor, monitoring bottom time, monitoring his equipment, controlling the rate of ascent, body position, and line maintenance. During the decompression stops he must concentrate on his depth and time and monitor body position and buoyancy frequently. At the 12 metres of seawater (msw) and 9 msw decompression stops, gas mixture becomes critical and the diver is responsible for closing off the diluent valve and purging his breathing apparatus's counter-lung at 9 msw to ensure he is breathing pure oxygen. Throughout the dive, the diver may have the added anxiety that he is diving on a live mine. Although the diver is taught to mentally rehearse the information about the mine, it is not clear how well he is able to do this in parallel with other tasks.

The goals of this experiment were to quantify the amount and type of information that an MCM diver is able to process and later recall when investigating a mine-like object; and to determine if there would be a significant benefit to providing the diver with a method to report the information during the dive to decrease the time lapse between processing and information recall.

The factors considered in impairment of information recall include exposure to mild narcosis, time between information stimulus and recall, and the level of complexity of information. The experimental design controls for possible decrements due to failure of initial information processing and short term memory by using the initial observation of the target as the control data.

Objectives

1. To determine the effects of diving to 40 msw on the information processing and recall capabilities of divers;

2. To determine the effect of elapsed time on the ability of a diver to recall information gathered during the dive;

3. To determine the effect of the level of information detail (complexity of information) on the ability to process, store, and recall information.

4. To determine whether the effects of narcosis, elapsed time and information complexity are additive or synergistic.

Methods

Subjects

Ten experienced divers (nine male and one female) between the ages of 20 to 40 years were recruited for the experiment. Subjects were asked to avoid ingesting caffeine (coffee, tea, chocolate) or energy drinks, they were also asked to avoid smoking cigarettes for the 2 hours prior to participating in experiment. Subjects were asked to avoid exercising in the four hours before and twelve hours after the experiment (the latter to allow proper decompression).

Experimental procedures used in this experiment were approved by the Ethics Review Committee of Simon Fraser University. Each diver was provided with a description of experimental procedures and the risks of diving as well as potential benefits derived from this research. Divers completed a diving medical to certify that they were fit for diving and signed an informed consent form prior to participation.

Environmental Conditions

Experiments took place in the Environmental Physiology Unit at Simon Fraser University. Two environmental conditions were included to identify the effect(s) of diving on information processing and long term memory (recall). The first was an air atmosphere where divers wore normal interior clothing and sat at a standard office workstation. In the second condition, divers were immersed to the neck in water in the wet section of a hyperbaric chamber and compressed to an equivalent depth of 40 msw. The water temperature in the wet pot was maintained between 28 and 30°C. Divers wore bathing suits with an option of wearing a thin neoprene wetsuit if preferred. Divers breathed air throughout the bottom time.

Apparatus

A library of images of mine-like objects was constructed with input from MCM divers. The objects did not represent actual mines, but were designed to have the same level of detail and same type of features that are found on typical mines. MCM divers were consulted in developing the images and level of detail of the questions to ensure that the task adequately represented the level of detail expected in real MCM diving operations. Each image contained three levels of detail: basic size (dimensions in cm) and shape of the object; physical attachments to the object (fin, lifting bag, bolt pattern etc.); and markings on the objects (alpha-numeric strings, symbols and lines). Images were reproduced in light orange colour on a black background (figure 1) with markings and alpha-numeric details in black. The size of each image varied, but was approximately 20 by 12 cm, mounted on black card and laminated. Although all images contained the same amount of detail, each image was unique in terms of the combination and location of attachments, the language and content of alpha-numeric information strings, the type of symbols and line patterns.

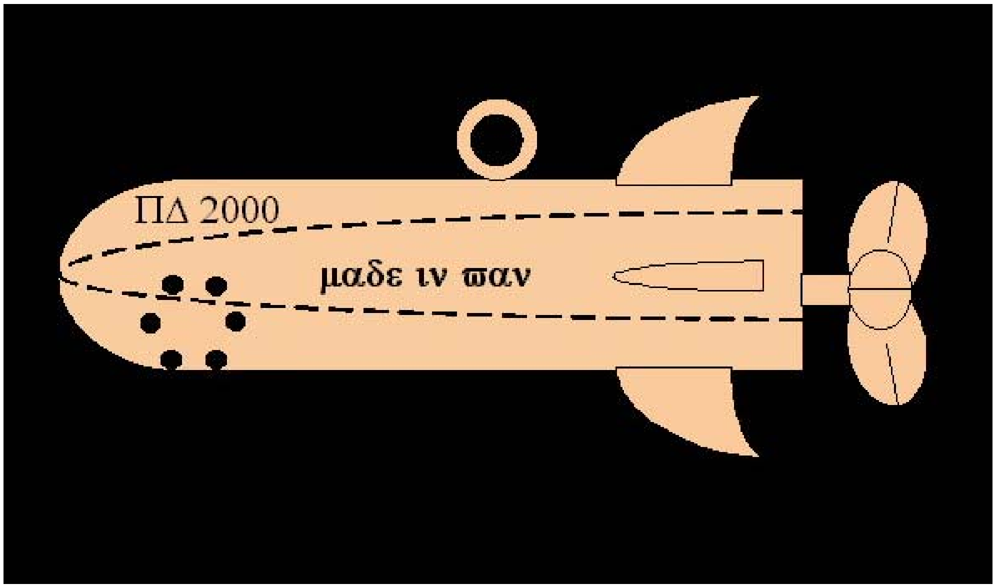

Figure 1: Example of mine like object to be viewed by divers.

Procedures

Subjects were acclimatized to approximately 21°C (in an air environment) for 30 minutes prior to participating in the experiment. Each subject completed the experiment on 6 separate occasions (2 environments by 3 recall times) that followed the same experimental protocol.

In each condition the diver was shown the two dimensional image of a mine-like object. The diver was then asked to recall the information at one of three specified time intervals and to describe the object in as much detail as possible. The time intervals for information recall were: immediate; five minute delay and two hour delay. In the delayed recall conditions the diver was given two minutes to view the image and memorize as much information as possible. The divers were told what type of information they would be expected to recall. They were given strategies for remembering the information, and during recall they were cued for specific information. The divers were asked a series of questions about the image.

Questions about each mine-like object were simple and straightforward and were related directly to the image that the diver viewed. A sample of questions is provided below. A copy of the questionnaire is provided in Appendix 1. The questions were designed to collect information in several levels of detail (see “Apparatus” section).

Sample questions

1. How long is the object (cm)?
2. What shape is the object?
3. Is there any writing on the object? What language is it?
4. Are there any numbers on the object?

As it was not possible to recreate the events of an actual MCM dive, the interference that was experienced by the divers in the experiment was different from a real MCM situation. For the dive condition, the divers viewed the object when immersed in water, then ascended from depth to the first decompression stop. The diver then moved from the wet section to the dry section of the chamber where they completed the decompression profile. The divers switched from breathing air to breathing pure oxygen at the 9 msw decompression stop. During the 9 msw decompression stop, the diver played cards with the dive tender. During the bottom time the divers also participated in a communications experiment that required water immersion. Although immersion was not essential to the present experiment, the immersion, communication procedures and the subsequent transfer to the main lock during decompression added further components of complexity to the dive protocol that made the overall procedure more comparable to an MCM dive.

In each environment, the diver was in voice communications with the experimenter. The experimenter directed the diver and controlled the experimental protocol. For the conditions that were conducted in the wet section of the hyperbaric chamber, a safety tender was located inside the chamber with the diver. The safety tender was in voice communications with both the diver and the experimenter throughout the dive.

Recall Condition

Three recall conditions were selected to represent the times during a dive at which a MCM diver is most likely to have an opportunity to relay information to the dive supervisor. The three time conditions were immediate recall, and five minutes, and two hours of elapsed time between observation and recall.

The immediate recall condition was included to provide baseline data. It is not likely that the diver would be able report all of the information while viewing the mine because it would require that he remain in close proximity to the mine while reporting. By including the immediate condition, it was possible to evaluate the deficits to short term memory associated with diving.

The 5 minute interval was included because it represents the first opportunity within the dive profile when the diver can safely report information to the dive supervisor (via a voice communications system). Five minutes represents the approximate duration between viewing the mine, returning to the shot line (a line between the seabed and the surface that the diver uses for descent and ascent), and ascending to the first decompression stop. The first decompression stop (or at subsequent decompression stops if the first stop is a very short duration) was selected for reporting because it does not add any additional bottom time to the dive and it is completed at a safer distance from the mine compared with immediate reporting. In addition, communications equipment that is independent of the diver's personal equipment can be located at the lazy shot on the decompression stops.

The two-hour time interval represents the strategy that is currently used in MCM diving. This procedure requires the diver to finish the dive and the decompression procedure before reporting mine details to the dive supervisor. Two hours represents the expected maximum time interval when executing a dive to 40 to 80 msw. In some circumstances, the time interval can be shorter or can exceed two hours depending on the procedures,

Diving to 60 msw would involve heliox; so, nitrogen narcosis would not be a factor and CO_2 narcosis would be minimal.

depth and bottom time of the dive. If diving deeper than 42 msw, the MCM diver will be breathing helium-oxygen mixture and therefore the narcosis effect will be absent or small. However, the diver will still be prone to other stressors such as cold, low visibility and anxiety that may affect information processing, and the effects of interference, information decay and retrieval failure that will affect information recall from long term memory (see "Introduction").

The three time conditions are described below.

Time 1: immediate recall: the diver recorded data as he inspected a mine like object (target). The diver was able to report characteristics via voice communications.

Time 2: Five minute delay: the diver viewed the target for 2 minutes. The target was removed from view and the diver then waited approximately 5 minutes before reporting his findings. Information recall took place during a decompression stop in the dry section of the chamber.

Time 3: Two hour delay: the procedure the same as Time 2, except that the diver waited two hours before recalling the information. Information recall took place in the laboratory after the dive was completed.

The complete set of experimental conditions is shown in Table 1.

Table 1: Experimental Conditions

Environmental Condition	Recall Condition	Description
1	1	Air, surface, immediate recall
1	2	Air, surface, 5 minute delay
1	3	Air, surface, 2 hour delay
2	1	Immersed, 40 msw, immediate recall
2	2	Immersed, 40 msw, 5 minute delay
2	3	Immersed, 40 msw, 2 hour delay

Experimental Measures

The experimental measures were designed to evaluate the amount and type of information that the diver was able to recall about the image that was viewed. The divers were then scored on their responses.

The scoring was designed to quantify the amount of information the diver was able to recall. This was based on the number of features that the diver was able to recall (verbally) compared to the total number of definable features of the object.. Each object had three categories of detail: basic, intermediate and high. The basic category included information such as size and shape. The intermediate category included information about the size and shape of attachments to the object (such as fins, bolts and lifting brackets). The high detail category included information such as location and content of Greek lettering. The divers were scored on how much of the information at each level of detail they were able to recall correctly. Each level of detail was scored as a percentage of the total number of details in each category.

Statistical Analysis

Figure 2 shows the experimental design, including the two environmental conditions, three elapsed times and three levels of detail of information.

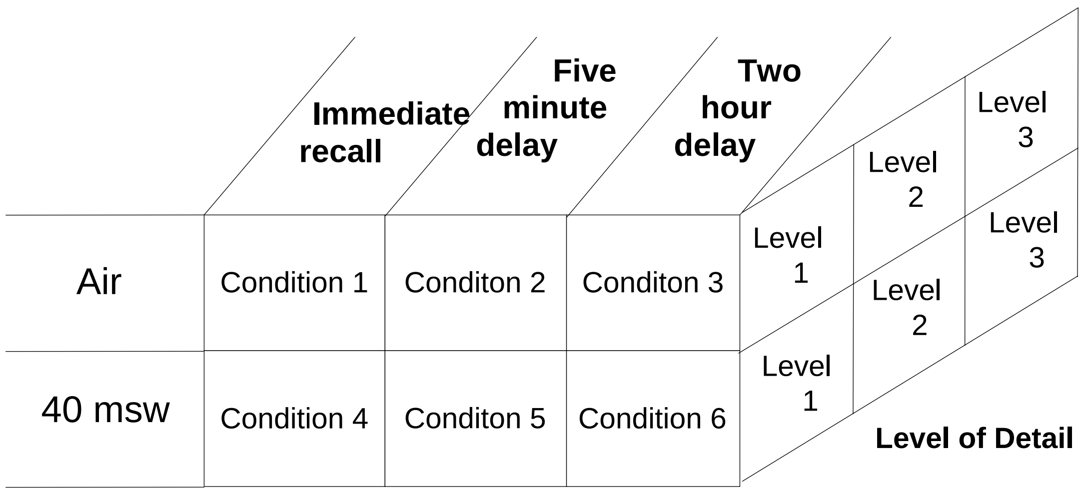

Figure 2: Experimental design

The effects of diving, elapsed time and information detail on information recall were analysed using a two (environment) by three (time) by three (level of detail) factorial design with repeated measures on each factor. Data were analysed to identify main effects of environment, elapsed time and detail, and interaction effects between the three factors. Data were tested for significant differences at the $p \leq 0.05$. To control for order effects, the order of environmental conditions and recall intervals was varied across subjects.

Results

Table 2: Descriptive data and statistical analysis of information recall scores (%)

Score: Mean ±SD (n=10)			
Elapsed Time	**Level of Detail**	**surface**	**40 msw**
Immediate	Level 1	100.00 ± 0.0	100 ± 0.0
	Level 2	100.00 ± 0.0	93.0 ± 12.5
	Level 3	92.00 ±1 6.7	78.0 ± 25.7
	Mean	**97.3±5.6**	**90.3±10.4**
5 minute	Level 1	100.0 ± 0.0	94.5 ± 11.7
	Level 2	100.0 ± 0.0	89.0 ± 10.2
	Level 3	82.5 ± 21.8	62.0 ± 33.8
	Mean	**94.2±7.3**	**81.8±16.3**
2 hour	Level 1	100.0 ±0.0	85.0 ± 26.9
	Level 2	90.5 ± 13.8	72.0 ± 21.0
	Level 3	63.0 ± 32.3	49.0 ± 36.9
	Mean	**84.5±13.0**	**68.7±14.5**

Statistics			
	F	Sig.	Power
Time condition	14.35	0.00	1.00
Pressure	26.21	0.001	1.00
Level of Detail	9.20	0.002	0.95
Time x Pressure	2.25	0.14	0.40
Time x Detail	2.35	0.07	0.62
Pressure x Detail	1.17	0.21	0.31
Pressure x Detail x Time	1.08	0.38	0.31

Results of the repeated measures analysis of variance are shown in Table 2. There was a main effect of environment on information recall (F=26.2, p=0.001). When averaged over level of detail and elapsed time, marginal mean scores decreased 13% when the image was viewed at 40 msw. At the surface, there was no loss of information on level 1 detail and a loss of information at level 2 only after a 2 hour interval. In comparison, at 40 msw, there was a loss of level 1 information after a 5 minute time interval and a loss of level 2 information on immediate recall. There was no significant interaction between environment (pressure) and elapsed time, and no interaction between environment and level of detail. However, statistical analysis showed a weak trend towards an interaction effect between environment (pressure) and elapsed time (p<0.14) and that the power of the test was low (i.e. a low level of confidence in the result).

There was a main effect of elapsed time on information recall (F=14.3, p=0.000). Results show that information recall decreased as the time between viewing the information and recall increased. When averaged for pressure and level of detail, marginal mean scores decreased approximately 6% after a 5 minute delay and approximately 18% after a 2 hour delay (p<0.05). There was no significant interaction between elapsed time and level of detail, but statistical analysis showed a trend toward an interaction effect (p=0.07) and a low power (0.6), or low level of confidence in result.

Data were further analyzed to identify the effect(s) of time on reporting the 3 different levels of detailed target information. For level 1 information, there was no significant difference in scores between the three time conditions. Scores for reporting level 2 and level 3 information were significantly lower as the time interval increased (p<0.05). Post hoc analysis showed that for level 2 information there was no significant difference between immediate recall and 5 minute recall, but there was a 16% decrease in recall score after 2 hours (p<0.05). For level 3 information, there was a decrement in recall scores of approximately 15% after 5 minutes (p<0.05) and approximately 34% after 2 hours (p<0.05).

There was a main effect for level of detail (F=9.20, p=0.002). As the level of detail of target information increased, ability to recall the information decreased. Simple effects post hoc analysis also showed that for both the surface and 42 msw pressure conditions, the majority of the decrement in recall was associated with reporting level 3 information. Averaged for pressure and elapsed time, there was no significant difference in the ability to recall level 1 and level 2 information, but that recall for level 3 information was significantly lower (p<0.05).

Discussion

Results indicate that diving to 40 msw causes a significant impairment (13%) of information recall. At 40 msw there was a loss of information at all time intervals and all levels of complexity except for the immediate recall of basic information (level 1). At two hours divers recalled only 69% of all information compared to 85% at the surface. The type of information and level of detail were designed to simulate that which MCM divers are required to observe and report. Consequently, it is concluded that in current MCM diving operations, the information provided by the diver suffers from substantial degradation.

The decrement in the ability to report more complex information (level 2 and 3 details) at 40 msw in the immediate recall condition indicated that the diver's information processing capacity was decreased. In real diving situations, this decrement may be exacerbated by other factors. In this experiment, the decrement resulted from the effects of pressure and is most likely due to mild narcosis, although there may be a slight difference in anxiety level between the dry air environment and the simulated 40 msw dive environment. In a real MCM diving task, the diver is also exposed to additional stressors, including anxiety, peripheral cold, equipment burden, low visibility, loss of spatial awareness, cues, and buoyancy control. All of these factors may contribute to a further degradation of information processing, due to either distraction (e.g. peripheral cold) or competition for attention (e.g. spatial awareness). It is expected that these additional stressors would more than offset any benefits from breathing helium oxygen mixture beyond 42 msw. Thus, the information gathering capabilities of MCM divers could be expected to be somewhat lower than in the present experiment. These data suggest that when exposed to high pressures (such as 40 msw) the baseline information processing capabilities of divers may be degraded to a level where they are not able to collect the level of information that is required for mine identification.

The amount of information retained and recalled by the diver is also affected by the elapsed time. Following two hours, divers can recall only 69% of information compared with 82 % after 5 minutes and 90% on immediate recall. Thus there are obvious benefits to be realized by having the diver report information earlier. With present technology it is not practical to have the diver report the information whilst at the mine. However, it may be possible to provide the diver with technology to aid with information gathering such as a low-light camera and imaging sonar to assist in data collection. If these devices were linked to the surface, the dive supervisor could review the information in real time and, if necessary, guide the diver to search for specific missing information via a head-mounted or head-down display.

The amount of detail that a diver can recall after two hours also warrants consideration in the design and planning of MCM operations. Results showed that information recall from long term memory is dependent on the complexity (or detail) of the information content. Thus, while divers could recall most of the basic information about the mine (85%), they were able to recall less than half (49%) of the detailed information such as alpha-numeric data. As different types of ordinance can have a similar basic housing, or may form part of a design series of which there are several variations, the more detailed information collected by the diver may be crucial to proper identification. In this scenario the divers ability to recall less than 50% of the information is inadequate. These results further emphasize a need for an improved strategy for mine identification. It may be impractical to use a camera to record the overall shape and structure of the mine due to low ambient light or turbidity in the water. However, the use of a camera at short focal lengths to capture fine detail may be easier and more practical than capturing the basic shape of the entire structure. This would relieve the diver of much of the cognitive load and allow more time to process and rehearse the more basic information.

The first opportunity for the diver to report information without prolonging bottom time is at the in-water decompression stops. For example, on arrival at the lazy shot the diver could connect to a voice communications system, and provide information to the dive supervisor. Alternately, the diver could use a hand held device to draw or enter details of the mine.

A further solution would be to provide the diver with an electronic display and a history of possible mines while the diver is completing the decompression stops. To be practical, the system would have to be designed to aid the diver in information recall and recognition rather than interfering with the information already stored in long term memory. To do this, the dive supervisor could work with the diver to collect basic information about the mine, then using the basic mine shape and type, together with the operational scenario, could select a small library of possible mines for viewing by the diver. The diver could cycle through a small number of mines to see if he could obtain an exact match for the target investigated. Further research is necessary to establish whether such a protocol would be beneficial to the information retrieval process.

The mine library should be programmed in an iterative fashion in order that the dive supervisor could call up specific features that are reported by the diver. A prototype of such a system was tested during a separate study in which the divers were required to identify a mine like object during a simulated wet dive to 42 msw. The diver viewed the object in clear water while indexing through a library of 27 different variations using a decision tree to home in on the correct match. By using an iterative approach, divers were able to identify the mine like object in less than 1 minute (mean=32 s) with 100% accuracy (Morrison and Zander, 2005). In this study only immediate recall was tested. The speed and accuracy of this approach warrants further investigation when compared to the performance data reported in this study for two hour information recall.

Based on the results of this study, lack of significant interactions suggests that the effects of exposure to pressure, elapsed time and level of detail are additive in nature rather than synergistic.

Results indicated that there was no significant interaction effect between pressure and the level of detail reported by the diver (for all time conditions). This suggests that the effect of narcosis does not affect the processing and retrieval of more complex information to a greater degree than simple information. An interaction effect would not necessarily be expected since divers were exposed to the effects of narcosis only during the immediate recall condition. Table 2 shows that for immediate recall there was a trend for more complex information to show a greater per cent decrement at pressure than more basic detail. Although this trend was also evident in the five minute and 2 hour recall data, it was strongest in the immediate recall condition when narcosis was present. In addition, statistical analysis showed that the power of the test was very low (0.3) and the possibility of a type 2 error (false negative) cannot be excluded. Thus, an interaction between pressure (narcosis) and level of detail cannot be dismissed based on the present results. Hence, further investigation of the effect of narcosis on different levels of information detail is warranted.

Results showed no significant interaction effect between pressure and time to recall information. An interaction effect would not necessarily be expected since divers were exposed to the effects of narcosis for only part of the elapsed time interval. In addition, the power of the test was low (0.4). Therefore, this experiment does not confirm whether the effects of narcosis and elapsed time on information recall from long term memory are additive or synergistic.

Although the interaction between elapsed time and level of detail was not significant at the $p<0.05$ level, results indicate a strong trend ($p=0.07$) toward an interaction effect. A lack of significance at the $p<0.05$ level may be due to low subject numbers and variance in the data. In this case an interaction effect might be expected due to the more “shallow encoding” of abstract information contained in the level 3 detail. It is concluded that further research into this aspect of information recall is required. .

Conclusions

Results indicate that there are significant decrements in information processing and recall due to the effects of pressure, elapsed time, and level of detail. In particular it was found that divers were able to recall less than 50% of detailed information about a mine-like object after a two hour time interval.

To improve the quality of information available for mine identification, the diver should be provided with a way to report information as soon as possible after viewing the target. At present it is not possible for the diver to report information in real time when viewing the mine. Possible solutions include providing the diver with a camera or imaging sonar with which to collect detailed information at the mine, and to provide the diver with a communications system that would enable him to report the information from the first (and subsequent) decompression stops.

By providing the diver with new technology to aid in the collection and recording of target information, as well as a way to report this information to the diver while still in the water, the quality of information from the diver would be substantially improved.

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Appendix 1: Questionnaire: Information Recall

Please complete the following questionnaire.

1. Free form recall: Please describe the object that you viewed with as much detail as possible. The following list is provided to help you remember the type of information that should be included:

    1. Shape: what was the basic shape of the object? (level 1)

    2. Relative size: length and width (level 1)

    3. Were there bolts on the object? (level 1)

        - Where were they? For example: top left, middle bottom etc. (level 2)

        - What was their pattern? (level 2)

        - How many bolts were in each bolt grouping? (level 3)

4. Were there other attachment (or other objects) that were added to the shape? For example fins, propellers, pockets etc. (level 2)

    - What was the shape or form of each attachment? (level 2)

    - What was the position of each of the attachments? (level 2)

5. How many symbols (i.e., icons, pictures or lines) were there added to the shape? (level 2)

    - What were the symbols or line patterns? (level 3)

    - What was the position of each of the symbols (or lines)? (level 2)

6. Was there lettering or numbering on the object? (level 2)

   - What were the positions of the lettering and/or numbering? (level 2)

   - Was the lettering in English? If not, what language was it (if known)? (level 3)

   - Can you recall the lettering or numbering? (level 3)

7. Are there any other details that you can remember? (for information about type of attachment or position score level 2, for detail about shapes, letters, numbers or lines score level 3)

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(U) Mine countermeasures divers are required to investigate mines located on the seabed. The diver is required to first locate, then to memorize details about the mine for later reporting to the dive supervisor. This study evaluated the effects of diving to 40 msw and elapsed time on the processing and recall of information. Ten divers viewed detailed images of mine−like objects on six occasions in air and in dives to 40 msw in a hyperbaric chamber. Divers were asked to report information at three elapsed time intervals: immediate, 5 minutes and 2 hours. Exposure to 40 msw resulted in a 13% decrement in information processing and recall ($p<0.05$). Information recall also decreased with elapsed time ($p<0.05$) and with the complexity of the information ($p<0.05$). After 2 hours, divers recalled only 69% of the information viewed at 40 msw compared with 90% on immediate recall; and after 2 hours divers recalled only 49% of the most detailed information. It is concluded that providing divers with technologies to aid in the collection of detailed information and to report information at the earliest possible time will increase the quality of the information transmitted by the diver.

(U) Les plongeurs de lutte contre les mines sont tenus d’examiner les mines se trouvant sur le fond marin. Le plongeur doit d’abord repérer la mine, puis en mémoriser les détails pour ensuite en faire rapport au superviseur de plongée. Dans la présente étude, on a évalué les effets d’une plongée à 40 m de profondeur et du temps écoulé sur le traitement et la mémorisation de l’information. À six reprises, dix plongeurs ont vu des images détaillées d’objets ressemblant à des mines, dans des conditions simulées en surface et à une profondeur de 40 m en chambre hyperbare. On a demandé aux plongeurs de rendre compte de l’information à trois intervalles de temps : immédiatement, après 5 minutes et après 2 heures. L’exposition à une profondeur de 40 m a fait en sorte que les plongeurs ont traité et mémorisé 87 % de l’information ($p < 0,05$). La mémorisation de l’information a aussi diminué en fonction du temps écoulé ($p < 0,05$) et de la complexité de l’information ($p < 0,05$). Après 2 heures, les plongeurs n’ont retenu que 69 % de l’information visualisée à une profondeur de 40 m, comparativement à 90 % de celle−ci dans le cas d’un signalement immédiat. Après 2 heures, les plongeurs n’ont retenu que 49 % de l’information la plus détaillée. Il en est conclu qu’on peut rehausser la qualité de l’information transmise par les plongeurs en fournissant à ces derniers des moyens technologiques pour les aider à recueillir l’information détaillée et en rendant compte de cette information le plus rapidement possible.

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(U) ergonomics; human engineering; underwater; diving; divers; immersion; hyperbaric; human systems interaction; HSI; information display; human performance; memory; recall; mine−like objects; mine counter measures; MCM