Visual Acuity Standard for Divers

Completed by:
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PWGSC Contract No. W7714-000403/002/SV

On behalf of
DEPARTMENT OF NATIONAL DEFENCE
as represented by
Defence Research and Development Canada
Rideau St
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DRD Canada Scientific Authority
Major R. Poisson

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Abstract

This report documents an experimental analysis conducted to assess the current Canadian Forces diving visual acuity entrance standards. Two experiments were conducted at Fleet Diving Unit Atlantic (FDU(A)), one subsurface experiment and one surface experiment. Nine participants took part in the experiments; the participants were qualified divers from the Canadian military (either Army Combat divers, Navy Clearance divers, or Reserve Port Inspection divers). Based on the results of the analysis and experiments, diving visual acuity recommendations were made depending upon whether or not vision can be corrected.

If divers are not permitted subsurface vision correction (through the use of contact lenses), the following recommendations apply:

Navy Divers: the standard should reflect a minimum requirement of 6/12 binocular uncorrected acuity for subsurface tasks, correctable to 6/6 binocular best corrected acuity for surface tasks conducted ashore or aboard a diving tender.

Army Divers: the standard should reflect a minimum requirement of 6/6 binocular uncorrected acuity, unless spectacles can be carried on all dives to allow immediate correction to 6/6 for surface tasks conducted throughout the mission. If spectacles can be carried while diving, the minimum requirement would be 6/12 binocular uncorrected acuity for subsurface tasks, correctable to 6/6 binocular best corrected acuity for tasks conducted directly after surfacing.

If divers are permitted to wear contact lenses while diving, the following recommendation applies:

Navy and Army Divers: the standard should reflect a minimum requirement of 6/30 uncorrected binocular acuity, correctable to 6/6 binocular acuity. The use of disposable contact lenses while diving would be mandatory for those below 6/12 binocular uncorrected acuity.

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Executive Summary

The Canadian Forces requires justification of the current visual acuity recruitment standard for the Canadian Forces diving community. Greenley and Associates Incorporated (G&A) was contracted to assess the current standard under PWGSC Contract No. W7714-000403/002/SV. The assessment of the standard was based upon a targeted review of relevant literature and a scenario based task analysis conducted with Subject Matter Experts (SMEs), both clearance and combat divers, to develop a prioritized set of visual task requirements performed by divers. The information on diving tasks and procedures in this report is based on SME descriptions of their tasks and procedures as performed in the field. Therefore, the tasks and procedures described in this report do not necessarily correspond directly with published regulations or procedures.

Two routine tasks and two emergency tasks were identified as representing the highest levels of visual acuity demand for Navy and Army divers; these four tasks require visual acuity standards. The task analysis indicated that two tasks required simulation to determine the minimum visual acuity requirements for Navy and Army divers while the visual acuity for the other two tasks are previously documented in the literature (Casson, (1999a) and Casson, (1999b)). The routine and emergency tasks are outlined below.

Critical Visual Task	Environment	Acuity Required	Simulation
Routine: Locating and Identifying Subsurface Ordnance	Subsurface	unknown	**Yes**
Routine: Conducting Surface Surveillance	Surface	6/6	Not needed
Emergency: Withdrawing to Rendezvous Under Fire	Surface	at least 6/60	Not needed
Emergency: Locating Diving Boat	Surface	unknown	**Yes**

Two experiments were conducted to determine the uncorrected visual acuity necessary to perform typical diving tasks in an operational environment.

The first experiment was conducted subsurface in a pool at Fleet Diving Unit Atlantic (FDU(A)), with 9 divers. The divers were tasked to detect and identify submerged ordnance at the far side of the pool.

There were 8 scenarios developed for the experiment; each experiment involved different types of ordnance and clutter placed at various locations along the bottom of the pool. The divers underwent 4 trials each, while wearing optically altered masks to simulate visual acuity of 6/6, 6/12, 6/18 and 6/30 (as measured above water).

The results indicate that although the performance at 6/12 had deteriorated from 6/6, the difference was not significant. However, diver performance at 6/18 and 6/30 were significantly different from 6/6.

The second experiment tested the participants' ability to locate a Rigid Hull Inflatable Boat (RHIB) during night time hours, 1 km from the FDU(A), in Halifax harbour. While on board a diving tender, the divers were required to locate the RHIB at a distance of 200 m while wearing prescription eyeglasses of different diopter strengths; the RHIB was driven in an arc

approximately 270 degrees around the tender. There were 9 participants involved in the experiment and each participant underwent 4 trials while wearing eyeglasses simulating 6/6, 6/30, 6/60 and 6/120 (as measured above water).

The results of the experiment indicate that a visual acuity of at least 6/30 is necessary in order to perform the task. Very few of the participants were able to locate the RHIB in the 6/60 and 6/120 trials.

The ensuing recommendations are based on the visual requirements identified for the 4 tasks representing the highest levels of visual acuity demand for Navy and Army divers. The recommendations are divided into two categories: uncorrected (i.e. contact lenses are not permitted for visual correction) and corrected (i.e. contact lenses are permitted for visual correction). A discussion is also provided based on the literature review concerning the effects associated with refractive surgery and with contact lens use underwater.

If divers are **not** permitted to wear contact lenses, the following recommendations apply:

<u>Navy Divers:</u> the standard should reflect a minimum requirement of 6/12 binocular uncorrected acuity for subsurface tasks, correctable to 6/6 binocular best corrected acuity for surface tasks.

<u>Army Divers:</u> the standard should reflect a minimum requirement of 6/6 binocular uncorrected acuity, unless spectacles can be carried on all dives to allow immediate correction to 6/6 for surface tasks. If this is the case, the minimum requirement would be the same as the Navy Divers (6/12, correctable to 6/6).

If divers **are** permitted to wear contact lenses while diving, the following recommendation applies:

<u>Navy and Army Divers</u>: the standard should reflect a minimum requirement of 6/30 uncorrected binocular acuity, correctable to 6/6 binocular acuity. The use of disposable contact lenses while diving would be mandatory for those below 6/12 binocular uncorrected acuity.

These recommendations are summarized in the table below:

Diver	Current Standard	Suggested Standard **UNCORRECTED**	Suggested Standard **CORRECTED**
Army	**V2** (6/12)	6/6 binocular, (≈**V1**) -Army divers do not carry eyeglasses with them, so when they surface, their visual acuity is required to be 6/6 in order to perform surface tasks. -Surface task (local security) recommendation of 6/6 is based on task similarities to previous vision standard based on a simulation of infantry Observation Post tasks. -Note, if eyeglasses were carried with the divers, the recommendation would be the same as Navy divers: a minimum of uncorrected 6/12 for subsurface tasks, correctable to 6/6 upon surfacing.	6/30 binocular, **(≈V2-V3)** -Army divers require 6/30 visual acuity to remain safe in an emergency and a minimum of 6/12 to perform subsurface tasks. -6/30 is the minimum requirement to locate a boat upon surfacing in an emergency (based on experimental results). -The divers should be correctable to 6/6 for surface tasks. -Disposable contact lenses would be mandatory for visual acuity below 6/12.
Navy	**V2** (6/12)	6/12 binocular (≈**V2)** -Navy divers have access to their eyeglasses for tasks prior to leaving and after re-entering the dive tender. Therefore, this recommendation is based on the minimum subsurface visual acuity of 6/12 required by divers, correctable to 6/6 upon re-entering the dive tender (based on experimental results). -This subsurface 6/12 recommendation is based on the subsurface experiment	6/30 binocular **(≈V2-V3)** -Navy divers require 6/30 visual acuity to remain safe in an emergency (based on experiment) and a minimum of 6/12 to perform subsurface tasks (based on experiment results). -the divers should be correctable to 6/6 for surface tasks (based on similarities to task simulated in a previous study). -disposable contact lenses would be mandatory for visual acuity below 6/12.

Table of Contents

List of Figures

List of Tables

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1 Introduction

This document is a summary report of a study investigating the visual acuity requirements for Navy and Combat divers. The objective of the study was to assess the current Canadian Forces entrance standard for visual acuity and to provide justification and guidance to update the standard. This work was sponsored by Defence Research and Development Canada (DRDC) Director of Science and Technology for Human Performance (DSTHP) and was completed by Greenly & Associates Incorporated (G&A) under PWGSC Contract No. W7714-000403/002/SV.

Information on diving tasks and procedures in this report has been generated directly from groups of clearance and combat divers based on their descriptions of their tasks and procedures as performed in the field. Therefore, the tasks and procedures described in this report do not necessarily correspond directly with published regulations or procedures.

1.1 Background

Military divers have a difficult but important role to play in the Canadian Forces (CF). Military divers perform tasks that require high levels of skill, physical fitness and judgment. Their work also involves considerable risk of injury and/or property damage, thus requiring a high level of vigilance. As a result, it is particularly important for all divers to meet specific medical and physical standards to ensure that they can conduct all tasks safely and effectively. Conversely, human rights legislation and the need to maintain adequate enrollment in this profession dictate that these same standards be set at the minimum level required to ensure both safety and effectiveness, so that no reasonable candidates are unnecessarily excluded.

To ensure that the entrance standards for divers are set at a level that is both fair and safe, the CF requires a review of the current visual acuity standard for the Army Combat Divers (generally referred to in this document as Army Divers) and Navy (includes Clearance, Port Inspection and Ship's Team divers) diving community. Specifically, the CF requested a review of the "uncorrected visual acuity standard" (i.e. the medical standard for the ability to see detail without the use of corrective lenses, either with spectacle correction or the use of contact lenses). This request encompasses two important issues, including visual acuity, and determining whether a vision standard is both fair and safe. These two issues are briefly addressed in Section 1.1.1 and 1.1.2 respectively.

1.1.1 Visual Acuity

Visual acuity, or the finest spatial detail which may be resolved, is perhaps the most commonly used index of visual capacities. Visual acuity is most commonly measured with the use of high contrast (black on white) letters constructed such that their thickness is one-fifth the size of their overall width and height. The minimum size of letters that can be accurately recognized at a given distance (usually 6 meters or 20 ft) determines the visual acuity measure. By convention, the ability to resolve a detail with a resolution of 1 minute of arc corresponds to a visual acuity of 6/6 (metric) or 20/20 (Snellen notation). The Snellen acuity notation is reciprocally related to minimum angle of resolution, so that as the ability to resolve detail decreases to 2 minutes of arc, corresponding to 6/12, 10 minutes of arc corresponding to 6/60, and so forth. Uncorrected visual acuity (UCVA) refers to visual acuity tested without optical correction. Best-corrected visual acuity (BCVA) refers to acuity tested with the best-possible optical correction in place.

Using standard assessment conditions, Owsley *et al.* (1983) have reported that better than 95% of the normal adult population under age 45 have been found to have BCVA values of 6/6 or better, with 95% of the normal population under age 50 at, or above 6/7.5. There are no readily-available statistics on the prevalence of uncorrected visual acuity levels in the normal population. However, calculating approximate acuity values from the known distribution of refractive errors (Borish, (1970), Johnson and Casson, (1995)), it can be conservatively estimated that 20% or more of the adult population have an UCVA worse than 6/12 and 10% have UCVA's worse than 6/18. These numbers increase for older individuals where reduced accommodative power combined with hyperopic refractive error will reduce UCVA.

Some statistics on UCVA are available from within specific occupations, however, most of these numbers underestimate the number of individuals with poor UCVA who are excluded due to existing standards. In the CF, where the standard for UCVA is quite liberal (6/120 or 20/400), a review of statistics from Western Zone recruiting centers in the early 1990's indicate that 71 out of 8352 applicants (approximately 1%) were excluded due to poor UCVA, suggesting that the percentage of young adults with very poor UCVA is within this range. This is supported by the data in Table 1, which lists the distribution of UCVA, in terms of cumulative percentages, in 5197 infantrymen in the CF between 1990 and 1994 and of 169 naval personnel in 1988 (Kaufman *et al.*, 1988). While these data can not be considered representative of the overall population, they provide an indication of the variability in UCVA for the young men and women at entry level in the CF.

Table 1: Distribution of uncorrected VA (Cumulative Percentages).

UCVA	>6/12	>6/18	>6/120
CF Infantry	72.5	88.5	99.4
CF Navy	68.1	81.6	98.3

1.1.2 Determining a Vision Standard

A fair and effective vision standard must be based on the Bona Fide Occupational Requirements (BFOR) for visual acuity. This requires an analysis of the tasks conducted by divers and an identification of those tasks that are: (1) essential to program completion; (2) present a high risk for injury and/or property damage if performed incorrectly; and (3) have high visual acuity requirements. These tasks will represent the BFOR for a visual acuity standard. They also form the basis of an experimental program which will help to determine the visual acuity standard necessary to perform these tasks in an operational environment.

A model of the process used to establish task-based, validated vision standards is presented in Figure 1. G&A followed a model similar to the one shown during the execution of this project.

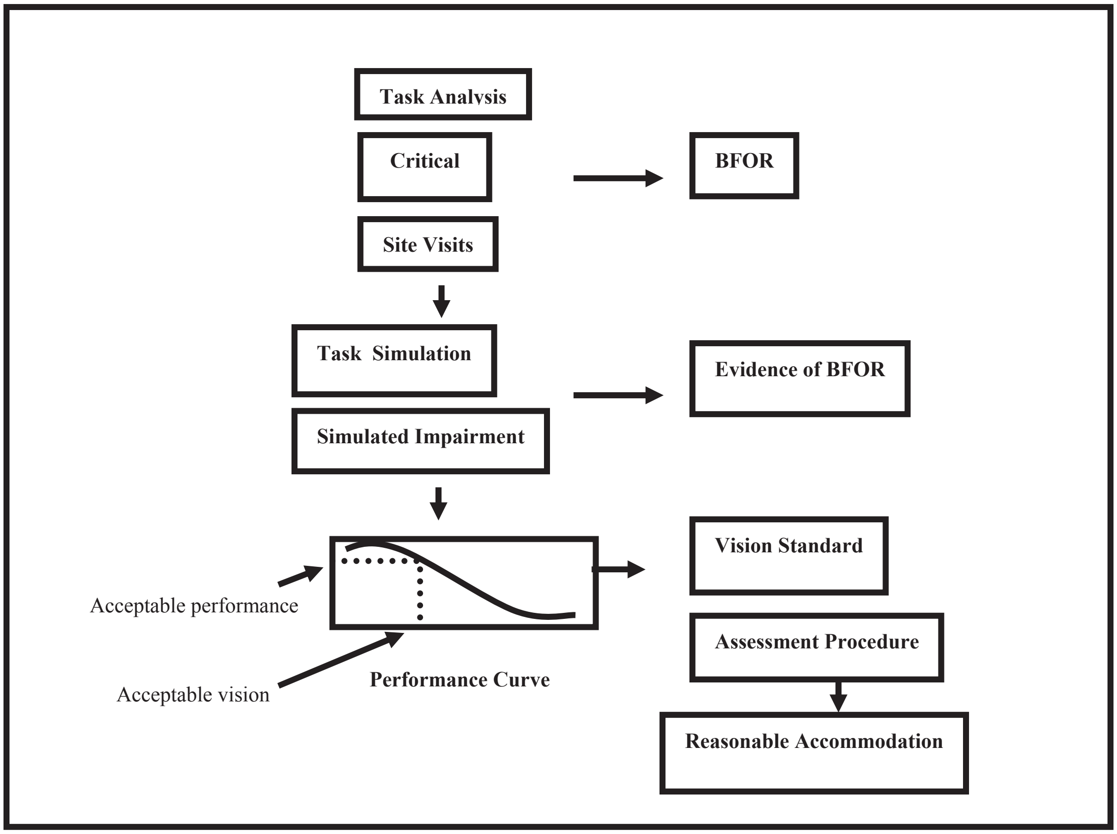

Figure 1: Flow Diagram: Task based vision standard (Casson, 2001).

1.1.3 Report Outline

This report documents the:

- Introduction – provides the background, objective, and scope of the project;
- Method - outlines the study's experimental framework and methodology;
- Results - the data gathered and subsequent analysis;
- General Discussion - impact of the findings in terms of the current uncorrected visual acuity standard for CF divers, and the issues associated with using contact lenses as a visual acuity accommodation; and
- Conclusions and Recommendations - recommendations for updating the standard.

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2 Method

This section contains a description of the method used in this project. The major project tasks are outlined and discussed below..

- Literature Review
  Visual Acuity Standards for Divers
  The Subsurface Visual Environment
  Visual Acuity and Related Tasks
- Task Analysis
  Review Task List and Questionnaire Results
  Design, Conduct, and Report on Subject Matter Expert (SME) Sessions
  Review Vision Questionnaire Results
- Task Simulations:
  Experimental Plan
  Equipment
  Procedure
  Results
  Discussion
- Experimental Design
  Equipment
  Locating and Identifying Ordnance: Subsurface Experiment Design
  Locating a Boat in an Emergency: Surface Experiment Design

2.1 Literature Review

A brief literature review of the existing Canadian Forces visual acuity diving standards for recruiting was conducted, as well as a review of the visual acuity standards in other countries (United States and New Zealand). A brief search was also performed regarding diving masks and visual acuity based on the most readily available and current resources (i.e. the World Wide Web). Concurrently, literature was reviewed on visual acuity and task performance in related occupations to assess the existing evidence on task based visual acuity requirements. A summary of the literature review can be found in Section 3.1, while the complete literature review is outlined in Annex A.

2.2 Task Analysis

The task analysis was conducted in two main thrusts; a preliminary analysis and diver SME interview sessions.

The preliminary analysis included the following steps:

- A list of the tasks performed by the FDU(A) divers was reviewed.
- A risk questionnaire of the task list was developed and sent to both Navy and Army divers. This questionnaire was developed to identify particular tasks as being associated with high degrees of risk in terms of diver safety.

- Analysis of the nature of risk associated with each task is a component of identifying the critical, high risk tasks associated with military diving occupations.

This process produced specific tasks to analyze in more detail with divers (SMEs) in terms of demand for visual acuity, which was required for selection of tasks for the experimental simulation.

Two SME sessions were designed and conducted; one with Navy divers in Shearwater (FDU(A)) and one with Army divers in Gagetown (Canadian Forces School of Military Engineering (CFSME)). The sessions were conducted to:

- develop comprehensive and realistic Army and Navy diving scenarios,
- breakdown the scenarios into component tasks,
- validate the task list,
- prioritize the diving tasks in terms of mission criticality and diver safety,
- determine and characterize the visual demands of critical diving tasks, and
- review emergency diving procedures and critical incidents.

A vision questionnaire was also sent to the Navy and Army divers to gather information relating to the use of glasses and/or contact lenses while on duty in both surface and subsurface operational environments. The purpose of determining the use of glasses and contact lenses was to acquire information regarding the current practices of divers with less than 6/6 vision.

A summary of the task analysis results, including the results to the risk questionnaire, SME sessions, and vision questionnaire are outlined in Section 3.2: Task Analysis. The complete report of the risk questionnaire results, SME session results and vision questionnaire results are contained within Annexes B, C and D respectively.

2.3 Task Simulations

Based on the task analysis and literature review an experimental plan was devised to conduct two simulations which were used to obtain objective evidence of the relationship between visual acuity level and task performance. These simulations involved the use of optical lenses to simulate a series of reduced visual acuity levels. 9 divers participated in the simulations and each participant was tested at 4 different levels of simulated visual acuity reduction. The data gathered was analyzed to generate descriptive and inferential statistics, and were then discussed and evaluated against the current uncorrected vision standard and policy on corrective lens wear. The experimental plan is described in Section 2.4; additional experimental plan details, including the Experimental Introductory Form, Participant Information Sheet, and Vision Assessment Form are contained within Annex E. The results of the experiments are outlined in Section 3.3.

2.4 Experimental Design

Upon completion of the SME Sessions, an experimental plan was developed in collaboration with the Navy and Army. Two task simulation experiments were developed to test visual acuity of the divers. The first experiment involved locating and identifying subsurface ordnance and the second experiment involved locating a diving boat at night from the surface following an emergency. The goal of both simulations was to provide a controlled experimental environment that simulates the visual aspects of each task and allows for objective measurements of performance.

2.4.1 General Experimental Design

Both experiments were within-subjects randomized designs and the independent variable was the level of reduced visual acuity. Four levels of simulated visual acuity were used in the experiments. The simulated visual acuity levels tested during the subsurface and surface experiments were selected to be appropriate for their respective tasks and conditions; the levels were 6/6, 6/12, 6/18 and 6/30 for the subsurface experiment and 6/6, 6/30, 6/60 and 6/120 for surface experiment.

2.4.1.1 Randomizing Conditions

The conditions were randomized across trials so that some participants were tested with the 6/6 condition on the first trial while others were tested with the worst visual acuity condition on the first trial. Care was taken to ensure the test order of the conditions and the presence and location of a specific target item was evenly distributed across participants to minimize learning effects.

2.4.1.2 Environmental Control

In the subsurface experiment, testing was conducted in an unheated indoor pool with interior lighting reduced to 0.1-0.3 cd/m^2. A dark tarpaulin was used to cover the bottom surface of the pool on both test days to provide contrast and luminance levels similar to those that might be found in relatively clear waters of limited depth. Thus, the subsurface experiments had reasonable environmental control and any differences between test times were unlikely to have a confounding effect due to the randomization of the conditions.

The environmental conditions in the surface experiment were more difficult to control, as this experiment was conducted over two nights in the center of the Halifax harbour close to navigation channels. However, the site was selected to give a variety of visual backdrops within a 360 degree radius of the observation boat, ranging from city lights to dark forested areas. Similar to the subsurface experiment, conditions were randomized across participants to reduce the effect of these variations. Seastate and lighting conditions (night, cloud cover) were relatively constant. However, there is a tradeoff between conducting task simulations in realistic environments and having complete control over the experimental environment.

2.4.1.3 Participants and Participant Bias

The participants were all trained divers with either 6/6 uncorrected vision or with contact lenses to correct vision to 6/6. Participants with small amounts of refractive error were permitted to participate. There was a total number of 9 participants involved in the experiments, with a distribution of 5 Navy and 4 Army divers, and 8 male divers and 1 female diver. Table 2 outlines general statistics regarding the participants' age, diving experience, and vision.

Table 2: Participant statistics.

Participants	Age (yrs)	Diving Experience (yrs)	UCVA (20/)	CV Normal
Army	34.2	15.5	16.5	75%
Navy	31.4	10.5	14.6	100%
Overall	**32.6**	**12.7**	**15.4**	89.9%

Work area limitations made it difficult to ensure that a participant did not know the level of visual acuity being tested in each trial. However, the scoring system made it difficult to bias the data significantly. In addition, as soon as a participant put on the blurring glasses they were quite aware of the level of impairment, so changes in confidence and task performance associated with the knowledge of the level of impairment were unavoidable.

2.4.2 Equipment

Nine different prescription scuba masks were obtained for use in the subsurface experiment. Each mask was laminated with a different prescription lens. The diopter strengths were: -1.0, 0, +0.5, +1.0, +1.5, +2.0, +3.0, +4.0, and +5.0. Ten sets of spectacles were used in the surface experiment with corrections ranging from of -1.0, to +8.0. The large range of dioptric values was necessary to achieve higher levels of blur and thus larger reductions in visual acuity.

The items for detection in the subsurface environment were actual examples of ordnance, selected to represent a wide range of potential targets with small differing details on them. Items were classified by their size: small, medium, and large (see Table 3 and Figures 2, 3 and 4).

Table 3: Ordnance items.

No. of Items	Item Description	Size Classification
2	Tilt Rod Mines	Large
3	Anti-tank Mines	Large
1	Large Mortar	Medium
1	Marker	Medium
2	Mortars	Small
2	Fuses	Small

Figure 2: Large sized ordnance - anti tank mine (left) tilt rod mines (right).

Figure 3: Medium sized ordnance - marker (top) large mortar (bottom).

Figure 4: Small sized ordnance - small mortar (left) small fuse (right).

A full list of the equipment used in the subsurface experiment includes:

- Arctic scuba regulators, tanks, buoyancy compensators, and wet suits
- Pool, unheated, 17 feet x 21 feet x12 feet deep
- Camouflage tarps and ties (for covering sides and bottom of the pool)
- Non-target objects: Lead weights, dumbbells, rope, milk crates, floor mat, scuba tanks
- Target objects: small, medium, and large sized ordnance (as shown in Figures 2 to 4)
- Plexiglass boards and grease pencils (underwater recording)
- Scuba diving prescription masks

The surface experiment target item was a 22 ft RHIB, a typical small boat used to tend divers. The target boat and the main diving tender with bow and stern platform areas for subject viewing are presented in Figures 5 and 6.

Figure 5: RHIB (left) and diving tender (right).

Figure 6: Diving tender and RHIB.

A full list of the equipment used in the surface experiment includes:

- Diving tender
- RHIB
- Radio communications between the diving tender and RHIB

- Life jackets, flotation suits
- Prescription eyeglasses
- Score Sheets
- Pens
- Stopwatch

2.4.3 Locating and Identifying Ordnance: Subsurface Experiment Design

The experiment took place in an indoor, unheated pool (approximately 17 x 21 ft x 12 ft deep). The far side of the pool and part of the adjacent sides and bottom (approximately 4 and 6 ft respectively) were darkened with camouflage tarp. A distance line was placed along the bottom of the pool and marked in 4 ft intervals from the starting point to the edge of the tarp underwater. Participants began the trials approximately 20 ft away from the ordnance. Lead weights and dumbbells of various size and dimension were added to the pool to hold the tarp in place as well as to simulate clutter that may be present in a seabed environment. Other clutter objects added to the pool included two milk crates, rope, and a black floor mat. A set of scuba tanks was also placed in the pool with a stream of bubbles being released during some trials and no bubbles released during other trials (randomly determined).

Ten scenarios were developed in which the different types of ordnance and clutter were placed at various locations along the bottom of the pool. Prior to undertaking the simulations, the divers were briefed on the types of ordnance that could be present in the underwater environment but were not informed of the number and type of ordnance that were used in the various scenarios.

2.4.3.1 Experimental Procedure

- Participants were introduced to the experiment, underwent visual acuity testing, completed participant information and consent forms.
- The participants were re-briefed on the experimental protocol and safety issues and then donned the scuba mask and entered the pool.
- Beginning at the 16 ft mark, the participant viewed the scenario and attempted to detect and identify as many target items as possible.
- The participant surfaced and reported the items and their locations (10 possible locations, see Annex F for the Scenario Set-up Form).
- The experimenter recorded the items and distances. Errors or misidentifications were recorded; however they may have been corrected if accurate identification occurred when the participant moved to a closer distance.
- The participant returned to the bottom of the pool and proceeded forward to the second marker at 12 ft. The process was completed when the participant was at the front of the target area (considered 0 ft) and they were satisfied all ordnance had been detected/identified.
- The participant surfaced and reported any remaining items.
- The participant exited the water.

Each participant repeated this process 4 times with different levels of visual acuity reduction. Between trials, the participants remain in the dim environment or, if exposed to more light between trials, they are adapted for at least 1 minute prior to the next trial.

2.4.3.2 Measures

Independent measure: Level of simulated visual acuity
Dependent measure: Distance for accurate detection and identification of each object (if not detected/identified, distance=0).

2.4.4 Locating a Boat in an Emergency: Surface Experiment Design

The experiment took place during night time hours (20:00 to 23:00 hours) on March 19 and 20, 1 km from the FDU(A) in Halifax harbour. The participants and experimenters were aboard a diving tender tied to a buoy in Halifax harbour. A RHIB was driven in an arc approximately 270 degrees around the stern end of the diving tender, between 200 and 250m away. Predetermined cardinal points of a compass were randomly selected for the location of the boat for each participants' trials (8 possible locations) ensuring the RHIB locations were varied across trials and conditions. Radio communication was used to communicate and send directions between the diving tender and the RHIB to position it for the various trials. The lights of the RHIB were extinguished during the trials.

2.4.4.1 Experimental Procedure

- Participants were introduced to the experiment, underwent visual acuity testing, completed participant information and consent forms.
- The participants stayed inside the darkened cabin of the diving tender with eyes covered to maintain dark adaptation.
- The participants' ears were also covered to avoid noise cues while the RHIB was directed to its location for the trial.
- Each participant was re-briefed on experimental protocol and safety, and then was brought outside of the cabin to the stern of the boat and asked to locate the RHIB.
- The trial was timed, and the clock was stopped once the participant made an estimate of the RHIB location, or once the 2 minute time limit was reached.

Each participant repeated this process 4 times with different levels of visual acuity reduction. Between trials, the participants remained in the dim environment.

2.4.4.2 Measures

Independent measure: Level of simulated visual acuity
Dependent measure: Time required to locate the RHIB (if not detected within 2 minutes, RHIB determined to be 'not detected').

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3 Results

The results of this report are divided into the following sections:

1. A summary of the literature review results;
2. A summary of the task analysis including the results to the risk questionnaire, SME sessions, and vision questionnaire; and
3. The results of the task simulations

3.1 Literature Review Results

The literature review was conducted using a variety of sources, including the Canadian Forces manuals for visual acuity entrance standards, the World Wide Web for the most recent information on the effects of diving masks on vision underwater, military diving standards from other nations, and scientific literature most relevant to this project. The key results of this literature review are presented in Section 3.1.1, 3.1.2, and 3.1.3. The complete literature review is contained within Annex A.

3.1.1 Entrance Standards

Currently, Canadian Forces (CF) diving entrance standards require all divers (Army and Navy) to meet a visual acuity level of V2. A V2 level requires uncorrected visual acuity, measured separately in each eye, to be a minimum of 6/12 in the better eye with 6/30 in the worse eye or 6/18 in both eyes. Similarly, the diving standard of the U.S. Navy Sea Air & Land (SEALS) special forces indicates that uncorrected visual acuity should not be worse than 6/12 for the better eye and 6/21 for the worse eye, correctable to 6/6 (unstated, but assumed to be in each eye) (U.S. Navy SEALS, 2003). The New Zealand Navy recruitment office was also contacted to assess their policy on visual acuity entrance standards for divers. The minimum uncorrected acuity requirements are 6/6, as new diving recruits are not permitted to wear either glasses or contact lenses (Royal New Zealand Navy, 2003).

3.1.2 Vision Underwater

The analysis of the visual demands of diving tasks presents a particular challenge due to the underwater environment of many critical tasks. When images are viewed underwater through a face mask the image becomes distorted in 3 ways:

1. Magnification: Refraction makes objects appear about 34% bigger and 25% closer than they are in reality.
2. Fuzzy Edges: When looking straight ahead (in the direction that the nose is pointing), images are clear and sharp. However, images become fuzzy with increasing off-axis viewing angles.
3. Warped Shapes: Straight lines warp outward at the corners of a face mask.

3.1.3 Visual Acuity and Surface Tasks

Two main studies were identified in the literature that have direct relevance to the current project. These studies investigated surface tasks that are similar to diver tasks. Each study is discussed below.

Casson et al (1999a) investigated the critical tasks of the infantry soldier in the CF using task simulations to determine the relationship between visual acuity and the following tasks (which were identified to have the highest demand for visual acuity):

- Observation Post: Surveillance;
- House Clearing: Detection of Hazards;
- Section Attack: Negotiating Rough Terrain; and
- Blackout Driving: Night visibility.

In addition, an emergency task 'Withdrawl Under Fire', was simulated to investigate the minimum visual acuity requirements in an emergency situation where the goal is to reach safety with or without glasses. The overall result was similar for all non-emergency tasks simulated: Performance decreased rapidly for most tasks when visual acuity was reduced below 6/6, which supports a minimum best corrected visual acuity requirement of 6/6 for infantry soldiers. The Withdrawl Under Fire task simulated an emergency procedure in which the main goal was to reach safety (the Rendez-Vous (RV) point). This simulation was used to determine the minimum *uncorrected* visual acuity required to keep a soldier safe in an emergency. The results indicate that a visual acuity of at least 6/60 is required. However, the task was performed as a group (the team members assisted the individual with simulated impaired vision), and therefore it is assumed that a soldier performing this task alone would actually require greater visual acuity than 6/60.

Casson (1999b) also conducted a similar investigation of the critical tasks of the boatswain trade in the CF. The following tasks were simulated to determine minimum visual acuity requirements:

- Identifying errors in set-up of refueling at sea (RAS) operations;
- Detecting man overboard;
- Detecting small navigation lights;
- Detecting hazards while maintaining tension on a rope; and
- Escape to upper deck in blackout conditions.

In the simulations which were designed to assess minimum visual requirements for routine tasks, it was found that performance decreased when visual acuity was reduced below 6/6. The overall results of the simulations suggest that there are a number of critical Boatswain tasks that require a minimum level of visual acuity of 6/6 corrected, and at least 6/60 uncorrected.

Considering it is likely that the Naval and Combat divers will have to perform similar surface tasks, the results of these task simulations can be used to predict the same level of visual acuity requirements in these occupations. However, no studies were found that directly address the issue of determining the minimum visual acuity requirements for underwater tasks.

3.2 Task Analysis Results

To identify the critical tasks associated with military diving, all tasks performed by these occupations were ranked in terms of risk and how essential or critical they are to program completion. This was accomplished by:

- A review and analysis of the supplied task list and the administration of a risk questionnaire;
- SME interviews sessions;
- The administration of a vision questionnaire

A complete description of the Risk Questionnaire results, the SME session results, and the Vision Questionnaire results are contained within Annexes B, C and D respectively.

3.2.1 Task List Review and Risk Questionnaire Results

A task list was initially provided to G&A indicating the various responsibilities of the different types of divers. Tasks were listed under the following Duty Areas:

- Diving Operations
- Maintenance
- Diving Tender Operations
- EOD/Demolition
- Port Inspection
- Hyperbaric Chamber Operations
- Salvage and Repair.

This task list was used to develop a questionnaire to determine the amount of risk associated with the diving tasks.

Navy and Army divers rated the risk associated with performing the task (i.e. the amount of danger to the diver associated with performing the task). Each task was rated as either Always High Risk, High Risk, Medium Risk, Low Risk, or Not Applicable.

A total of 24 divers ranked all tasks (20 Army and 4 Navy). The results of the task list questionnaire were analyzed descriptively and the tasks rated as either 'Always High Risk' or 'High Risk' by the Army and Navy divers are marked with an 'X' in Table 4. The tasks that were rated by the majority of Army or Navy respondents as 'Always High Risk', or 'High Risk' were selected for further review.

Table 4: **High risk diver tasks.**

TASK #	TASK NAME	ARMY	NAVY
AT001	Conduct diving operations	X	X
AT002	Perform underwater search and rescue operations	X	X
AT004	Perform standby diver duties		X
AT015	Perform closed circuit equipment dive		X
AT016	Perform semi-closed circuit dive		X
AT017	Conduct beach/bottom survey	X	
AT018	Rig underwater lifting devices	X	

DT001	Perform EOD procedures on surface ordnance	X	X
DT002	Perform EOD procedures on underwater ordnance	X	X
DT003	Clear harbours and beaches for landings	X	X
DT004	Maintain an explosives storage facility		X
ET001	Search seabed for non-influence ordnance and sabotage devices		X
ET002	Search hulls for non-influence ordnance and sabotage devices		X
ET003	Search port/harbour structures for non-influence ordnance etc		X
ET004	Search ship's hull underwater for explosive devices		X
ET005	Identify ordnance		X
ET006	Mark ordnance		X
ET007	Neutralize underwater anti-ship sabotage devices		X
ET008	Dispose of underwater explosive ordnance	X	X
ET009	Support EOD team in recover operations		X
ET010	Prepare demolitions	X	X
ET017	Influence ordnance		X
GT001	Inspect/repair hull and hull fittings		X
GT002	Remove/replace hull fittings		X
GT003	Fabricate cofferdams, patches and blanking arrangements		X
GT005	Salvage sunken vessels and aircraft		X
GT006	Assist in ship/submarine docking		X

Of the 27 tasks rated as 'Always High Risk' or 'High Risk', 7 tasks were given either one of these ratings by both the Army and Navy divers. The 7 tasks include:

- Conduct diving operations
- Perform underwater search and rescue operations
- Perform EOD procedures on surface ordnance
- Perform EOD procedures on underwater ordnance
- Clear harbours and beaches for landings
- Dispose of underwater explosive ordnance
- Prepare demolitions

Many of these tasks are related to working with explosive ordnance and their disposal. As a result, further discussion of the visual cues and visual tasks involving ordnance was required. Thus, the results of the questionnaire provided an understanding of the risk associated with performing different diving tasks and also provided a basis for developing the scenarios, SME sessions and experimental designs.

3.2.2 SME Session Results

Two SME sessions were conducted. Navy divers were interviewed in Shearwater FDU(A) and Army divers were interviewed in Gagetown (CFSME).

The sessions were conducted to perform the following tasks:

- validate the task lists;
- expand the diving tasks into subtasks using a scenario-based approach;

- analyze the critical sub-tasks; and
- prioritize the diving tasks and subtasks in terms of their effects on mission criticality and diver safety.

Diving equipment, procedures and environments were discussed in depth both during the interviews and during tours of the facilities. In particular, examples of ordnance and different types of mines (surface and subsurface) were examined and discussed to determine the visual cues used in their detection and identification. Information was systematically gathered in scenario based task walkthroughs on the visual demands of typical, critical, and emergency diving tasks, as well as the procedures and visual conditions that may be present. Anecdotal information was also gathered on critical incidents or near misses in which vision played an important role.

Prior to the SME sessions, the Navy and Army each developed two brief typical diving scenarios, which were used as a basis to determine the detailed tasks that must be performed to undertake the required dives. Information provided in the scenarios consisted of:

- the overall mission;
- expected environmental conditions;
- diving plan;
- key equipment; and
- the number of personnel required.

The Navy scenarios and their corresponding task analysis are outlined in Annex G and H respectively. The Army Scenarios and their corresponding tasks analysis are outlined in Annex I and J respectively.

3.2.2.1 Shearwater FDU(A) Results

The first clearance diver scenario involved searching for unexploded ordnance (Annex G). The scenario was developed by 5 SMEs; the scenario included 50 subtasks which were identified by all SMEs on a 5 point scale for "essential or critical to program or mission completion" and "diver safety". The results of the Mission Criticality and Diving Safety questionnaire, along with the list of all subtasks identified are provided in Annex K. A summary of the results is provided below.

Mission Criticality: Most tasks (90%) were rated as having at least a severe impact on the mission if not completed properly and 50% were also rated by at least one diver as resulting in total failure of the mission if not completed properly. Of these, 5 were rated by at least two SMEs as being essential to mission completion. These are as follows:

- Prepare diving equipment
- Charge canisters
- Pump flasks (to initiate the flow of air)
- Conduct dive
- Swim to depth

Similarly, most of tasks (90%) were considered by one or more of the 5 SMEs to have at least a severe impact on diver safety if not properly completed. 23 of the 50 tasks were considered to have catastrophic consequences by one or more of the SMEs if not properly completed. 6 tasks were identified by two or more of the SMEs as having catastrophic consequences if not performed correctly. These tasks, which overlap somewhat with the mission critical tasks, are as follows:

- Charge canisters
- Pump flasks (to initiate the flow of air)
- Plan dive time and schedule
- Don dive gear
- Complete safety checks
- 40 ft, shut DIL off, write depth on slate

The second scenario (Port Inspection - searching a ship's hull for unexploded ordnance) was developed and analyzed in a similar manner. In addition, emergency procedures and critical incidents were discussed which allowed for significant coverage of the tasks that a diver may have to perform, and the associated visual conditions. The emergency procedures and critical incidents are outlined in Annex L.

3.2.2.2 Gagetown CFSME Results

The first combat diver scenario involved conducting an underwater obstacle breech undetected (Annex H). The scenario was developed into its component tasks and sub-tasks by 5 SMEs and a detailed task analysis was performed on the scenario and the visual requirements of the corresponding tasks were determined from the meeting.

Combat diver tasks associated with the duties as combat engineers were also identified. These involve standard operating procedures similar to that of the infantry soldier, and include the following (visually demanding) tasks:

1. Manning an observation post (a related surveillance task)
2. Withdrawing under fire (emergency procedure)

These tasks have been previously examined in other studies (Casson et al., 1999a), and they remain a critical component of the duties of the Combat Divers.

The second scenario, recovering a sunken tank and Medium Floating Raft (MFR) hit by enemy fire, was similarly discussed and task analysis followed by a discussion of emergency procedures and critical incidents. The emergency procedures and critical incidents are outlined in Annex M.

Both of the SME sessions (at Shearwater and Gagetown) were invaluable in providing the experimenters with the necessary information used to develop two valid and reliable experimental designs. Locating and identifying explosive ordnance proved to be an important and high risk task that both Navy and Army divers perform. Also, locating a diving tender or rendez-vous point in an emergency were found to be important tasks of which both Navy and Army divers must be able to perform.

3.2.3 Vision Questionnaire Results

A vision questionnaire was also completed by Navy and Army divers to gather information related to the use of glasses and/or contact lenses while on duty in both surface and subsurface operation environments. The results were recorded separately for the Navy and Army divers, and descriptively analyzed. The response rates were 7 and 17 for the Navy and Army divers respectively. A summary of the results is provided below.

Only one Navy diver (14%) wore contact lenses while diving, however, three divers (43%) report wearing glasses or contact lenses for other duties. The diver that wore contact lenses while diving reported having ‘no difficulties’ with the lenses while diving.

Eleven of the Army divers (78%) reported wearing some form of optical correction for duties other than diving, and 7 (39%) divers report wearing optical correction at least some of the time while diving. Of the 7 divers, three reported wearing contact lenses; none of the three divers reported having difficulties with their contact lenses while diving.

These results were useful in determining the current practices of the divers, and the number of divers requiring vision correction. Note that no divers reported having difficulties with their contact lenses while diving. However, due to the limited sample size, and the possibility of bias, it is difficult to draw strong conclusions on this subject without objective evidence.

3.2.4 Overall Task Analysis Findings

The results of the risk questionnaire and SME sessions including the task analysis discussion, and mission criticality and safety questionnaires, indicated that the essential high risk tasks for both Army and Navy divers were subtasks associated with conducting a dive or detecting/interacting with ordnance. The visual demands involved in these subtasks vary widely from reading gauges and checking for leaks at close range, detecting and identifying ordnance and hazards at mid range, searching for a line or a diver at longer ranges. The level of visual acuity demand for these tasks depends on the distances at which the tasks are carried out, the size of the critical details the divers are looking for, and the visual conditions underwater.

A number of routine tasks were selected to have the highest visual demands. These tasks were identified as (1) essential to mission completion and (2) high risk and include:

- Locate Ordnance
- Identify Ordnance
- Avoid Subsurface Hazards
- Conduct Surveillance at Surface or on Beach (Army only)

Each of these tasks is further discussed below.

3.2.4.1 Locating and Identifying Subsurface Ordnance

Divers reported that when they are dealing with subsurface ordnance, where possible, they maintain a distance of approximately 3 m (10ft) until they can ascertain the level of risk. The largest stand off distance at which the mine can be identified is preferred to avoid accidentally detonating the mine. The level of visual detail on various mines and other ordnance can be quite small and indistinct (lettering, fuse shape, indentations, and markings). Shining a flashlight may not be possible (magnetic) or may actually disturb vision (night vision/ scatter in turbid water). Thus, this task can be identified as one requiring a high level of visual demand. The visual demand for detecting hazards will be similar; thus if a diver has adequate visual acuity to perform one of these tasks successfully, he/she should also be able to perform the other. This task was simulated and results are outlined in Section 3.6.

3.2.4.2 Conducting Surface Surveillance

Army Divers must perform local security tasks involving surveillance from a position on shore, similar to an observation post, immediately following their exit from the water. Therefore, they do not have the opportunity to use additional correction; they must use the same vision they are using under their masks. Previous work has identified this task as very demanding in terms of visual acuity. Results reported in the literature review (Casson, 1999a) indicate that 6/6 visual acuity is a minimum requirement to perform this task optimally. Since simulations of this task have already been conducted, it is identified a critical tasks but it was not necessary to include this in the task simulations.

3.2.4.3 Emergency Procedures

The analysis of emergency procedures for visual demand is an important component of establishing a vision standard. If an uncorrected standard is established along with a best corrected standard where optical correction is required for diving operations, it remains important to assess the impact of poor uncorrected vision on diver safety. An emergency situation may occur when visual correction is lost and there is no time to replace it. For example, if a diver is wearing contact lenses and they lose them, they will have to use their uncorrected vision in all situations, including emergencies. When a diver surfaces, poor uncorrected acuity may be a distinct disadvantage in reaching safety. For both the Navy and Army divers, the discussion of emergency procedures and critical incidents revealed circumstances in which poor uncorrected acuity would be a problem. Examples of this are discussed below.

3.2.4.3.1 Locating Dive Boat in an Emergency

Considering Navy divers work as a team, there are few emergency circumstances where the vision of a single individual is critical to diver safety. However, the discussion of critical incidents revealed a circumstance when single divers had to surface in an emergency and locate the dive boat. In this instance, the dive boat personnel were unable to move closer to the divers, thus, the divers had to locate the boat using visual cues (in fact it had drifted out of sight). Although this is an infrequent occurrence, it represents a critical emergency task with significant requirements for uncorrected acuity. This task was simulated and results follow in section 3.6.

3.2.4.3.2 Withdrawing to Rendezvous Under Fire

Army divers have a very different emergency environment than Navy divers as they are dealing with covert combat situations where individual divers may get separated from the team. In this case, the emergency procedure is to proceed to a pre-determined RV point, usually a landmark. If this occurred during a diving operation, the diver would have to make his/her way to the rendezvous in an uncorrected state. Previous work with the CF (Casson, 1999a and Casson, 1999b) (Infanteers and Boatswains) as well as other studies all indicate a minimum visual acuity requirement to ensure safe escape: 6/60 or better. Since this simulation has already been carried out, no further task simulations were determined necessary. However, this remains a critical visual acuity requirement for Combat divers.

3.2.4.4 Summary

Two routine tasks and two emergency tasks have been identified as representing the highest levels of visual acuity demand for Navy and Army divers. These are listed in Table 5. The analysis indicated that two tasks required simulation to complete the determination of the minimum visual acuity requirements for Navy and Army divers.

Table 5: Summary of visual acuity analysis.

Critical Visual Task	Environment	Acuity Required	Simulation
Locating and Identifying Subsurface Ordnance	Subsurface	unknown	**Yes**
Conducting Surface Surveillance	Surface	6/6	Not needed
Emergency: Withdrawing to Rendezvous Under Fire	Surface	at least 6/60	Not needed
Emergency: Locating Diving Boat	Surface	unknown	**Yes**

3.3 Task Simulation Results

This section of the report summarizes the results of the two experiments conducted to simulate two critical visual tasks identified in Table 5 above. The analysis of the data in this report includes both descriptive and inferential statistics. The task simulations raw data, and summarized results are contained within Annexes N and O respectively. In addition, participant visual characteristics are contained within Annex P

3.3.1 Detecting and Identifying Ordnance: Subsurface Experimental Results

The scores for each participants' trials were derived to represent the average distance required to locate the ordnance and to correctly identify the items. For the purpose of this analysis, objects that were not seen were scored as being located and identified at 0 ft.

Accuracy scores were also obtained for each trial for both the location and identification of the items. The distance scores were analyzed across participants for each blur condition to determine if there was a significant change in task performance with increasing levels of visual impairment or blur.

3.3.1.1 Participant Results

Figure 7 illustrates the results for the average distance scores of 9 divers for detection and identification. The error bars indicate the standard error of each average value. Note that higher values for the distance score indicate a better result (i.e. the further away the participant was able to correctly locate and identify each item). A lower distance score indicates that the ordnance was not detected or identified until the participant moved closer to the objects.

Note that there is a continuous decrease in the average distance score for both detection and identification as the level of blur or visual acuity impairment increases. At 6/6, participants were able to stay almost 7 ft away from the ordnance on average and still detect the items. At this level of visual acuity, they could identify the ordnance accurately at over 5 ft distance on average. However, at 6/12, the participants had to move up almost 2 ft to be able to accurately detect (just less than 5 ft) and identify (approximately 3.5 ft) the same items. At 6/18, they had to move up again by just under 2 ft on average. When they were blurred to 6/30 the distance to detect and identify the items was reduced to 2 ft on average (less than 2 ft for identification), a two-thirds reduction in the amount of distance they were able to maintain between themselves and potentially dangerous objects.

The distance scores were analyzed using paired t-test statistics for comparisons across groups. A * symbol is used on Figure 7 to indicate where significant differences ($p<0.05$) occur between 6/6 and the other levels of blur.

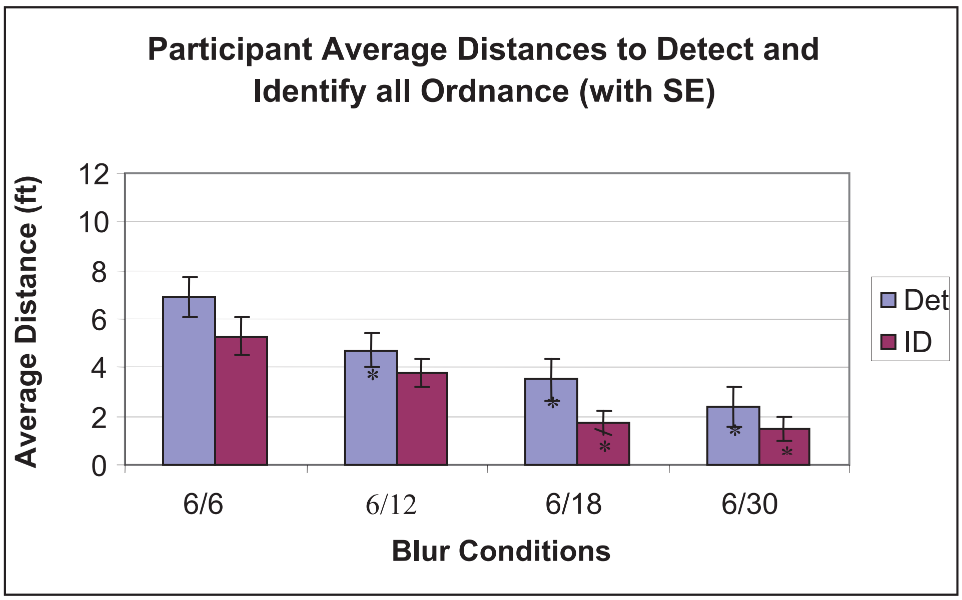

Figure 7: Participant Results- average distance to detect and identify all ordnance (with SE).

Significant results were found in the distance to detect all ordnance between 6/6 and 6/12 ($t=1.966$; $df=16$; $p<0.05$), 6/6 and 6/18 ($t=2.819$; $df=16$; $p<0.05$), as well as 6/6 and 6/30 ($t=3.877$; $df=16$; $p<0.001$). Significant results also occurred in the distance to identify all ordnance between 6/6 and 6/18 ($t=3.873$; $df=16$; $p<0.001$), as well as 6/6 and 6/30 ($t=4.010$; $df=16$; $p<0.001$).

These results indicate that there is a significant difference between the performance at 6/6 and the performance at 6/18 and below. This means that participants had to get significantly closer (i.e. approximately half the distance) to the ordnance to accurately locate and identify it when their vision was reduced to 6/18 than when their vision was at 6/6.

3.3.1.1.1 Accuracy

The results were also analyzed in terms of the percent of correct detections and identifications from the participants. Occasionally, the participants failed to see an object and in such instances, this was scored as an incorrect detection and identification. For example, if a scenario had nine objects in it, but the participant only detected and identified 7 of those objects, the total score would be 7 out of 9 or 77.7%. The results for both detected and identified are the same, as the participants correctly identified the objects that they detected. The results of the percent correct (±SE) across the blur conditions are illustrated in Figure 8.

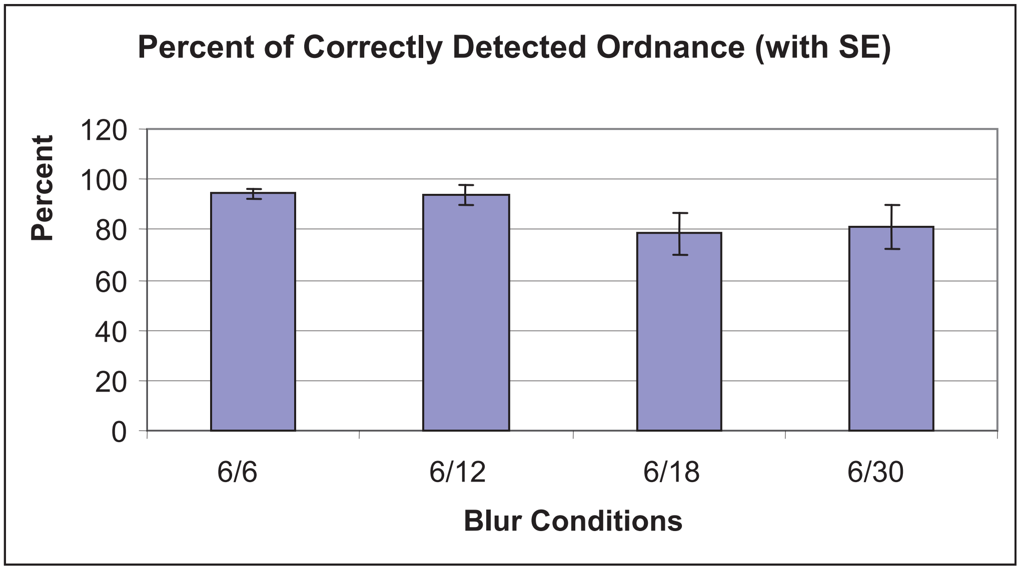

Figure 8: Accuracy of detection and identification across blur conditions (Error bars indicate the size of the standard error of the average values).

This figure demonstrates that participants were able to identify nearly 80 percent of the items at even the highest level of blur. While the graph shows a slight decrease in accuracy with the higher levels of blur, individual variability was such that there was no significant difference in the percentage correct between the 6/6 and 6/30 blur conditions. This can be attributed to the fact that the participants were generally able to make their identifications once they moved closer to the scenario. This graph indicates that both 6/6 and 6/12 yield (approximately) a 92% correct score while the 6/18 and 6/30 conditions yield (approximately) an 80% score.

3.3.1.2 Ordnance Results- Analyzed by Size

The overall ordnance results were further analysed by the general size of ordnance to determine whether the pattern of results described above was consistent for all sizes of ordnance. The large ordnance group includes the anti-tank and tilt-rod mines (Figure 2). The large mortar and marker (Figure 3) represent the medium sized ordnance used in the experiment, and the small mortar and small fuses (illustrated in Figure 4) represent the small sized ordnance.

It was generally found that the larger ordnance was easier to detect and identify than the smaller ordnance from greater distances (as can be expected). Figure 9 depicts the results of the average distance to detect the various ordnance sizes and Figure 10 represents the average distance to identify the ordnance.

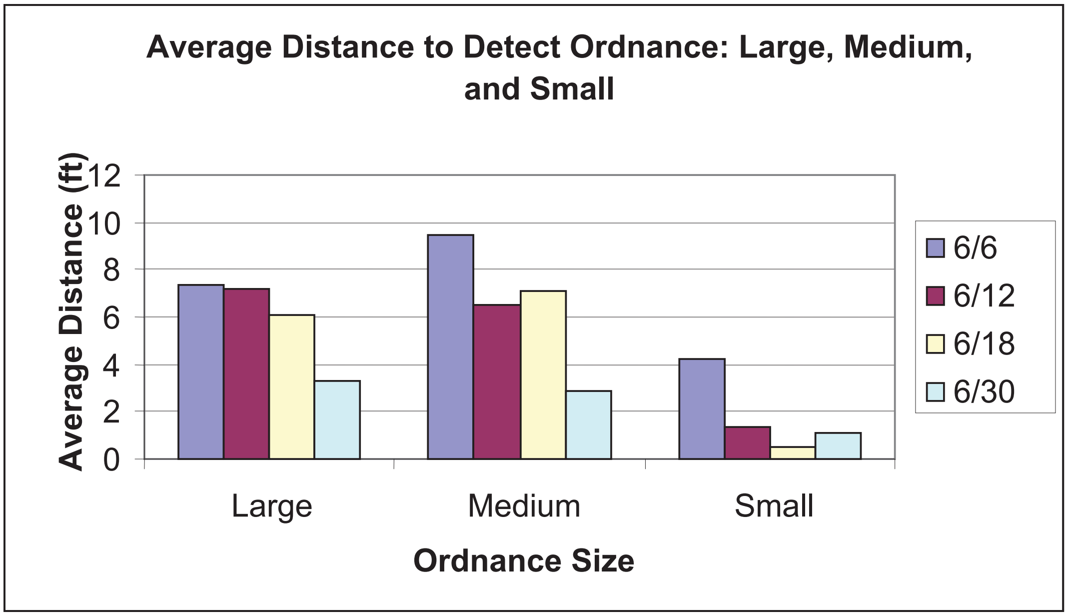

Figure 9: Average distance to detect large, medium, and small ordnance.

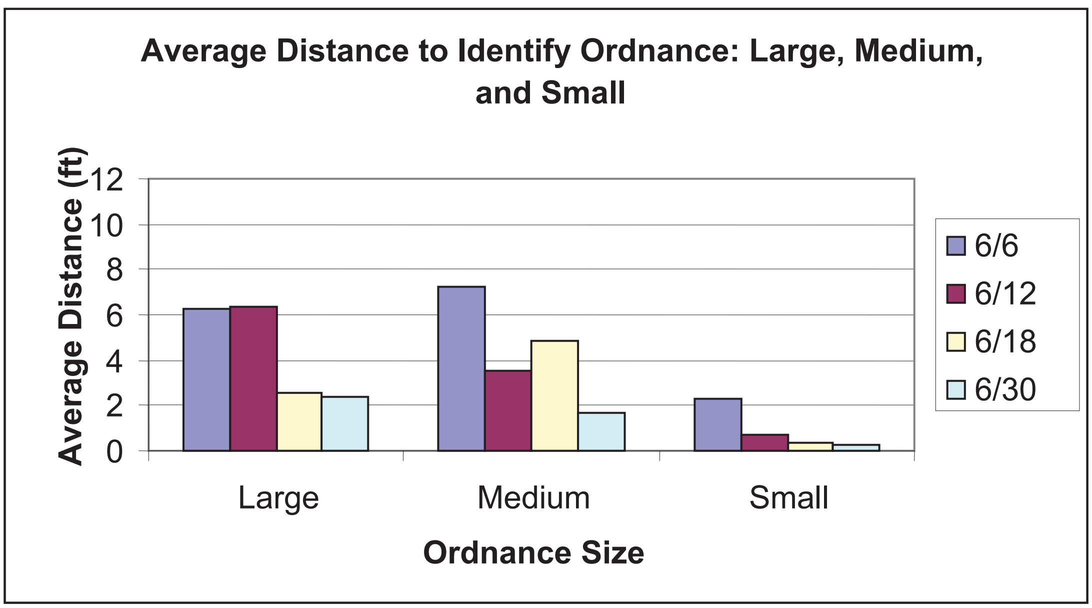

Figure 10: Average distance to identify large, medium, and small ordnance.

In general, the results for the different sized ordnance follow the same pattern as the overall distance scores: participants must reduce the distance to detect and identify large, medium or small ordnance when they are subject to increasing levels of visual acuity impairment. Due to the small number of each specific item in each condition, a statistical analysis was not deemed informative. However the trends are clear; in some cases at 6/12 and in others at 6/18, participants had to dramatically reduce their distance to accurately locate and identify dangerous ordnance. The smaller the item, the closer the participants had to get. At 6/6, small mortars and fuses could be seen at 2 ft; at 6/12, participants had to be right next to them to see them accurately, even in 20 ft visibility.

Analyzed together, the results indicate a strong deterioration in the ability to detect and identify the ordnance under the 6/18 and 6/30 blur conditions. Also, overall the results illustrate that the small ordnance was more difficult to detect than the large and medium sized ordnance under all the blur conditions.

3.3.1.3 Scuba Tanks

The participants were asked to detect and identify whether a scuba tank was placed in the pool scenario and upon detection and identification, they were also asked to determine whether or not a small gas leak in the tank was present. The results for the scuba tanks were not analyzed as a number of variables prevented the capture of reliable data. In particular, there were problems regulating the flow of air when the tanks were supposed to be leaking; the regulator would automatically shut down or decrease the flow of air if it was sustained. In some cases the regulator shut off the air, making it difficult to ascertain the accuracy of participant responses regarding leaks. However, it should be noted that all of the participants were able to detect and identify the scuba tanks in all scenarios and under all conditions with relative ease at either 12 or 16 ft. This indicates that detecting a lost diver in 20 ft visibility is not a difficult task even with 6/30 simulated visual acuity.

3.3.1.4 Subsurface Experiment Summary

To summarize, the overall ordnance data shows a linear decrease in the ability to detect and identify the ordnance from 6/6 to 6/30. The difference in performance between 6/6 and 6/12 is generally not significant, however the difference between 6/6 and 6/18, as well as 6/6 and 6/30 is significant. This indicates that, even in a limited sample of 9 individuals, there is evidence to suggest that performance in a simulated task of locating and detecting ordnance is significantly decreased at binocular visual acuity levels lower than 6/12.

3.3.2 Locating a Boat: Surface Experiment Results

The surface experiment results were analyzed and graphed in terms of the time taken for 9 divers to detect the RHIB and whether the detection was correct (percent correct). Note that a greater time score indicates the participants had to search for a longer period of time before making a decision regarding the RHIB location. The time was cut off at two minutes and the participants were asked whether they could make a best guess regarding the RHIB location. Incorrect guesses were scored as errors, with a time score of 2 minutes. A lower time score indicates that the participants were able to find the RHIB with greater ease under that particular blur condition.

3.3.2.1 Time to Locate RHIB and Percent Correct

The results of the surface experiment were calculated in terms of the time (in seconds) it took for the participants to locate the RHIB under the different blur conditions. Figures 11 and 12 illustrate the findings.

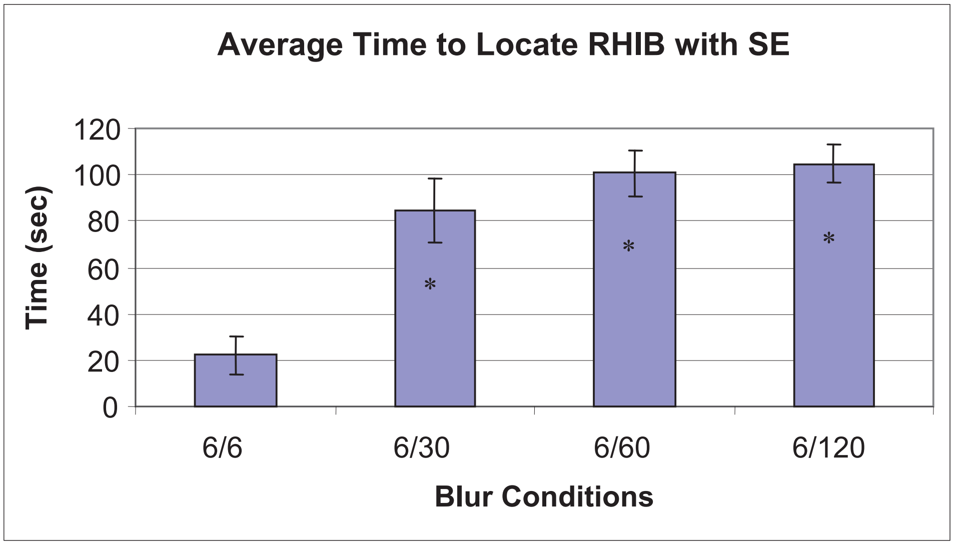

Figure 11: Average time to locate RHIB with SE.

Significant results were found in the time to locate the RHIB between 6/6 and 6/30 (t= -3.882; df=14; p<0.001), 6/6 and 6/60 (t= -5.997; df=15; p<0.001) as well as 6/6 and 6/120 (t= -6.397; df=14; p<0.001).

The results were also analyzed in terms of the percent correct for each blur condition. These results are shown in Figure 12.

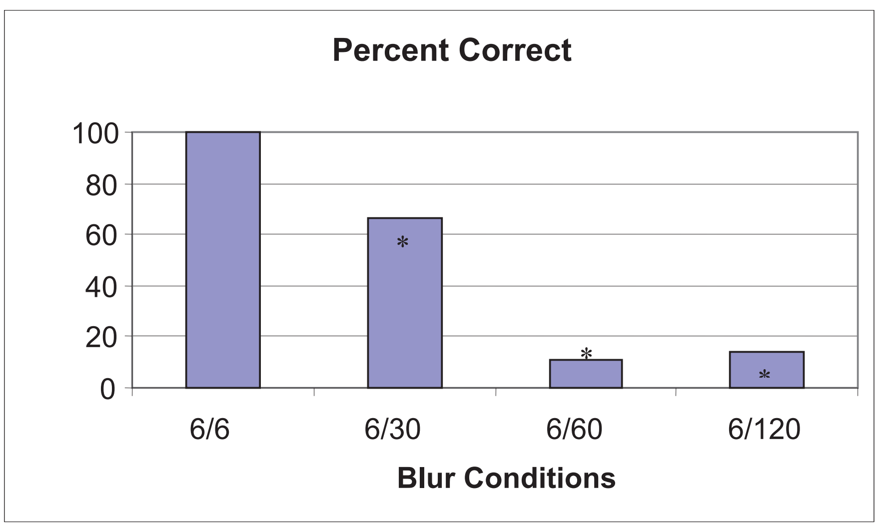

Figure 12: Surface experiment percent correct.

Significant results were found in the percent correct between 6/6 and 6/30 (t=2; df=8; p<0.05), 6/6 and 6/60 (t=8; df=8; p<0.001), as well as 6/6 and 6/120 (t=7; df=14; p<0.001).

The figures illustrate a great difference in the ability to detect (and correctly detect) the RHIB location under the various blur conditions. The 6/6 visual condition results yield 100% correct results in usually under 25 seconds. In the 6/30 condition, it generally took over 80 seconds to locate the RHIB, with a correct rate of approximately 65%.

Performance deteriorated markedly once the blur conditions reached 6/60 and 6/120, with the search time increasing and the accuracy decreasing. There were many trials in the 6/60 and 6/120 conditions in which the participants were unable to locate the RHIB within the allotted time of 2 minutes, and it was not clear if they would have been able to locate the RHIB in any length of time on these particular trials.

3.3.2.2 Surface Experiment Summary

This experiment simulated an emergency situation in which participants lost any means of optical correction, and as a result, had to rely on their uncorrected acuity to find the dive boat and get to safety. If we assume that the dive was deep enough to require decompression and the divers had surfaced without decompression, there is an important time limit to get to a decompression chamber. In addition, the water environment, if cold or contaminated may impose its own time limitations. Thus, the ability to locate the RHIB in 2 minutes simulates an important task. The participants were able to perform this task within approximately 25 seconds with 6/6 acuity, and were usually able to locate the RHIB at 6/30, but with significant delays. At 6/60 and 6/120, they were unable to consistently locate the RHIB and their average time was very close to the limit of 2 minutes on their successful trials. This experiment indicates that an uncorrected visual acuity of 6/30 is required to ensure the ability to perform this task safely.

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4 General Discussion

This section provides a discussion of the following:

- Visual requirements for routine tasks;
- Results specific to Army divers;
- Visual requirements for emergencies;
- The impact of changing the visual acuity standard; and
- Options for visual acuity correction

4.1 Visual Requirements for Routine Tasks

Both Navy and Army divers need to be able to locate and identify subsurface ordnance as part of their routine duties; the subsurface experiment was designed to simulate this task. The results of this simulation support a linear relationship model between performance and the level of visual acuity, indicating that a reduction in visual acuity forces divers to move closer to potentially dangerous ordnance before being able to detect it. The statistical analysis illustrated that the impact of reduced visual acuity on performance becomes significant at levels of 6/18 and lower. This indicates that while divers with 6/12 have a tendency to perform less adequately in this task, the statistical breakpoint for this small data set is between 6/12 and 6/18. Thus a binocular visual acuity of 6/12 may be considered adequate. However, the data also suggests that, if a larger group were tested, having an acuity better than 6/12 would ensure greater performance.

4.1.1 Binocular Summation

The value of 6/12 discussed here represents visual acuity measured with both eyes open. Other research suggests (Bertand and Casson, 2000; Rubin *et al,* 1995) that individuals who meet the current V2 uncorrected standard of 6/12 in the better eye, or 6/18 in both eyes will have 6/12 or better when tested binocularly (with both eyes open), due to the summation that occurs between information obtained by two eyes (binocular summation). Thus the results of this task simulation experiment support having a vision standard at the V2 level, assuming divers must be able to work underwater in an uncorrected state (i.e. without contacts/glasses or the use of prescription masks).

4.1.2 The Impact of Reduced Visibility

Some SMEs commented that they felt the V2 standard was too strict, as in many circumstances they are working in poor visibility conditions and thus do not "use their visual acuity". This is a common misconception, as studies have shown (Johnson et al, 1995) that visual acuity, whether 6/6 or 6/60 is linearly degraded in poor visibility conditions (low luminance, low contrast). Thus, if a person with 6/6 vision can detect ordnance or other dangerous hazards at 10 ft, they might be reduced to 2 ft in poorer visibility. The individual with 6/18 vision would not even see the item in good visibility conditions until 3 ft and would have to be within half a foot of the item before knowing that in the item was present in poorer visibility. Although, all divers either with good or bad vision, are going to be similarly disadvantaged in totally dark conditions, or when the water is extremely turbid. However, whenever there is any visibility at all, the divers will tend to use whatever information is available and thus a diver with 6/30 will have to work significantly closer to dangerous items such as ordnance, lines, or other underwater hazards, than a diver with 6/6.

4.2 Results Specific to Army Divers

While the sub-surface task described above (locate and identify subsurface ordnance) was a critical task for both groups of divers, the Army divers must also perform some of the military tasks of an infantry soldier upon surfacing on a beach or in a harbour. One of these tasks is to conduct local security involving surveillance from a position on shore, similar to infanteer surveillance from a forward observation post. This task, which is often conducted at night, has been simulated previously, as reported in the literature review (Casson, 1999a). The results suggest that 6/6 is required to perform this task well. Since divers must carry out this task immediately after surfacing, this would require at least 6/6 binocular uncorrected visual acuity, assuming they must dive in an uncorrected state. This would be equivalent to the current V1 standard, and would in fact require a stricter standard than is currently applied to the divers (V2).

Some of the SMEs feel the current standard for Army divers (who are also Combat Engineers) is not consistent, as other Combat engineers who do not dive must only meet the V3 standard of 6/120 uncorrected with 6/6 in the better eye. While the surveillance task is also a critical task for these individuals, they do not have to undertake it immediately after surfacing from a dive. They are normally wearing glasses or contacts while they perform this task, while combat divers have to be able to perform the same task without correction under the current policy.

One might question how Combat divers who are currently V2 are successfully performing their surveillance tasks after surfacing from diving. Further investigation would be required to determine if this is a problem. Possibly this scenario is an infrequent occurrence in the CF today. Possibly some divers are using contacts as a personal choice to maximize their vision above the current minimum.

4.3 Visual Requirements for Emergencies

If for the moment, it is assumed that it would be possible to accommodate divers by allowing them to depend on the use of optical correction while diving, the appropriate level for a standard is considerably altered.

If individuals can safely wear contact lenses while diving and on the surface, then the V2 standard can be lowered, and individuals may still be able to perform all critical tasks well, as long as they are correctable to 6/6 measured binocularly. In this instance, the uncorrected standard has to reflect the ability to perform emergency escape procedures in worst-case scenarios where correction has been lost. For example, a subsurface explosion might cause a divers mask to come off and possibly dislodge contacts. As a result the diver would then have to surface and find her/his way to safety without correction. The second task simulation was specifically designed to assess the visual acuity requirements in this case.

From the interviews with Navy divers, it was determined that in an emergency a diver may have to locate a RHIB or make his/her way to shore, and this would represent a critical visual demand if divers had to perform this task in an uncorrected state. The results of the task simulation of locating a RHIB in an emergency indicate that the ability to perform this task in a timely fashion decreases as visual acuity is reduced to 6/30 and then becomes difficult to do at all when acuity is reduced to 6/60 or below. This indicates that uncorrected visual acuity should be at least 6/30 to ensure that the diver is able to locate a boat in an emergency when contact lenses or glasses have been lost.

Interviews with Army divers revealed that a similar emergency (underwater explosion resulting in loss of masks and correction) would involve individually making their way to shore and finding a pre-determined rendezvous point. This procedure is similar to that of infantry soldiers and has been simulated in previous work in the task simulation "Withdrawal under Fire" (Casson, 1999a). The results of that experiment indicate that the ability to get to safety on land in an emergency situation requires at least 6/60 when the individual is moving within a team (the team members helped the individual with the simulated impaired vision). In the case of the Army divers who might have to get to safety on their own, the level of visual acuity required is likely to be at least as high and possibly higher (performing the task without the aid of a team would be more difficult).

4.4 The Impact of Changing the Standard on the Candidate Pool

The results of the task analysis and literature review suggest the possibility of tightening the standard to V1. This would have a negative effect on the ability to recruit and retain divers as they age. Such a change might decrease the candidate pool by more than one third as well as excluding some divers as they fail to meet the standard on re-examination.

If, on the other hand, one assumes that it would be possible to allow divers to use correction to bring their acuity to 6/6, the vision standard could be set based on the visual requirements of the emergency tasks outlined above. This might allow the standard to be set so that the majority of those in the V3 category would be eligible to enroll as divers. Based on the data presented in Section 1.1.1 Table 2, one can estimate how lowering a standard might increase the potential pool of candidates. Based on these estimates, Table 6 provides predictions of cumulative percentages for potential candidates if the standard is lowered. Approximately 98% of all young adults meet the current V3 (not taking other standards into consideration). Of that group (treated as 100% in Table 6) approximately 30% of those candidates should fall between the V2 and V3 standard. Lowering the standard from 6/12 to 6/18 would add one third of that group and lowering the standard to 6/30 would include at least three quarters of the group. Although these calculations are very rough and are based on data from other sources that may not be directly applicable to the current situation, the calculations provide an idea of how the candidate pool increases as the standard is lowered.

Table 6: Predictions of cumulative percentages for potential candidates (with lowered standard).

UCVA	6/12 (V2)	6/18	6/30	6/120 (V3)
Cumulative %	70%	80%	95%	100%

Conversely, the standard cannot be safely lowered unless a reasonable, effective and safe accommodation can be found for poor uncorrected acuity. The question remains, could contact lenses be used by divers to correct their vision in a safe and effective manner? To provide information on this data, a brief review of some of the contact lens literature has been performed. Another alternative, which is used by the US Navy SEALS, is to increase enrollment by allowing and even offering candidates the option of refractive surgery. This option, which also has risks in terms of safety and performance, has been reviewed to allow a comparison of the two options. A summary of these options is provided in section 4.5, with the complete report contained within Annex Q.

4.5 *Options for Visual Acuity Correction*

One of the advantages of contact lenses is that they provide a flexible and accurate method of correcting refractive error in circumstances where glasses cannot be worn. In addition they are far less likely to be dislodged than spectacles. The potential disadvantages of contact lenses include the risk of dislodgement, irritation, non-compliance, physiological changes, contamination, and discomfort due to changes in pressure. These potential disadvantages depend upon the type of contact lens worn. Research indicates that users of daily disposable soft contact lenses are less likely to experience these problems.

The advantages and disadvantages of refractive surgery versus allowing contact lens use require an in-depth analysis of the relative risk associated with these two options. Based on the information available in this brief review, the following points can be made:

1. The use of disposable contact lenses does not appear to produce any visual distortions, while refractive surgery is associated with this risk.
2. The medical complications from refractive surgery are very low, while the risk of infection, irritation, and inability to continue use are probably higher with contact lenses if they are worn all the time.
3. The problems associated with physical stress in the diving environment are likely to be low for both contacts and surgery if the appropriate lenses/techniques are prescribed.

Based on this brief analysis, contact lenses remain the least visually disruptive option and may be more feasible if the analysis of the risks associated with the use of modern daily disposable soft contact lenses is found to be acceptable.

5 Conclusions and Recommendations

5.1 Conclusions

The following conclusions have been determined through evidence obtained in these task simulations or through review of the pertinent literature:

- Critical Routine Tasks in the Navy require at least 6/12 and would benefit from 6/6.
- Critical Routine Tasks in the Army require at least 6/6 because of surface requirements that immediately follow diving in this occupation.
- Critical Emergency tasks in the Navy require at least 6/30.
- Critical Emergency tasks in the Army require at least 6/60 and would benefit from 6/30.

All requirements are binocular. The acuity required for routine tasks could be achieved by good vision in both eyes but also could be achieved by good vision in only one eye as long as an adequate binocular visual field (120 degrees) is maintained. Thus the worse eye could have best corrected acuities as low as 6/60.

Contact lenses may offer a better solution to the issue of reasonable accommodation due to the possibility of vision changes associated with refractive surgery.

5.2 Recommendations

5.2.1 Uncorrected Visual Acuity

If the use of contact lenses is not considered a reasonable accommodation for diving tasks the following visual acuity requirements are recommended:

<u>Navy Divers:</u> the standard should reflect a minimum requirement of 6/12 binocular uncorrected acuity for subsurface tasks, correctable to 6/6 binocular best corrected visual acuity for surface tasks.

<u>Army Divers:</u> the standard should reflect a minimum requirement of 6/6 binocular uncorrected acuity for both surface and subsurface tasks. If spectacles are carried on all dives and worn upon surfacing, the minimum requirement would be the same as for Navy Divers at 6/12 binocular uncorrected acuity for subsurface tasks, correctable to 6/6 for surface tasks.

The current standard of V2 reflects these requirements. The candidate pool could be increased by approximately 3% by allowing amblyopic candidates to meet the binocular requirement with 6/12 in their better eye, correctable to 6/6, but allowing the best corrected acuity of the worse eye to be as low as 6/30 as long as the binocular visual field was normal. This could be accomplished by issuing waivers on a case by case basis, as is done by the US Navy SEALS.

5.2.2 Corrected Visual Acuity

If the use of disposable soft contact lenses is permitted as a reasonable accommodation, the following visual acuity requirements are recommended:

Navy and Army Divers: the standard should reflect a minimum requirement of 6/30 uncorrected binocular acuity, correctable to 6/6 binocular acuity. The use of disposable contact lenses while diving would be mandatory for those below 6/12 binocular uncorrected acuity.

This requirement would lie in the middle of the current V3 category. Either this category could be split or V3 candidates could participate in a waiver program on a case by case basis.

While the potential pool of candidates using this standard would be larger, it could be further enlarged by allowing amblyopic candidates to meet the binocular standard with the vision in their better eye, provided the worse eye has no less than 6/30 best corrected acuity and a normal binocular visual field. Table 7 below illustrates these recommendations.

Table 7: Summary of new standard recommendations.

Diver	Current Standard	Suggested Standard **UNCORRECTED**	Suggested Standard **CORRECTED**
Army	**V2** (6/12)	6/6 binocular, (≈**V1**) -Army divers do not carry eyeglasses with them, so when they surface, their visual acuity is required to be 6/6 in order to perform surface tasks. -Surface task (local security) recommendation of 6/6 is based on task similarities to previous vision standard based on a simulation of infantry Observation Post tasks. -Note, if eyeglasses were carried with the divers, the recommendation would be the same as Navy divers: a minimum of uncorrected 6/12 for subsurface tasks, correctable to 6/6 upon surfacing).	6/30 binocular, **(≈V2-V3)** -Army divers require 6/30 visual acuity to remain safe in an emergency and a minimum of 6/12 to perform subsurface tasks. -6/30 is the minimum requirement to locate a boat upon surfacing in an emergency (based on experiment results). -The divers should be correctable to 6/6 for surface tasks. -Disposable contact lenses would be mandatory for visual acuity below 6/12.
Navy	**V2** (6/12)	6/12 binocular (≈**V2)** -Navy divers have access to their eyeglasses for tasks prior to leaving and after re-entering the dive tender. Therefore, this recommendation is based on the minimum subsurface visual acuity of 6/12 required by divers, correctable to 6/6 upon re-entering the dive tender (based on experiment results). -This subsurface 6/12 recommendation is based on the subsurface experiment	6/30 binocular **(≈V2-V3)** -Navy divers require 6/30 visual acuity to remain safe in an emergency (based on experiment) and a minimum of 6/12 to perform subsurface tasks (based on experiment results). -the divers should be correctable to 6/6 for surface tasks (based on similarities to task simulated in a previous study). -disposable contact lenses would be mandatory for visual acuity below 6/12.

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Annex A: Literature Review

In the Canadian Forces, all diving candidates are currently examined in accordance with CFMO 27-07 and must meet the medical standard prescribed in A-MD-154-000/FP-000: Annex D for initial assignment to a military diving specialty or occupation. A summary of these standards are presented in Tables 1, 2 and 3.

Table 1: Geographical and occupational vision standards system for visual acuity.

	Uncorrected Vision		Corrected Vision	
Grading	Better Eye	Other Eye	Better Eye	Other Eye
V1	6/6	6/9	N/A	N/A
V2	6/18 or 6/12	6/18 6/30	6/6 6/6	6/9 6/9
V3*	6/120	6/120	6/6	6/9
V4**	N/A	N/A	6/9	6/120
V5***				

* V3 is assigned irrespective of the member's refractive error except in some aircrew MOCs. Those members who do not meet the V3 standard of uncorrected acuity must have a (current) refractive error measured.

** In order to qualify for the V4 standard, the refractive error must not exceed plus or minus 7.00 diopters spherical equivalent in the better eye.

*** V5 is assigned to those whose visual acuity is less than V4 standards. In the case of serving members, it will be assigned only by an ophthalmologist to those who cannot qualify for a higher grading.

Table 2: Geographical and occupational vision standards system for colour vision.

CV1	Colour Vision Normal	Pass PIPs (Ishahara Plates)
CV2	Colour Vision Safe	Fail PIPs, Pass Farnsworth D-15
CV3	Colour Vision Unsafe	Fail PIPs, Fail Farnsworth D-15

Table 3: Vision standards for selected trades.

Trade	Visual Acuity	Colour Vision
Clearance Diver (Navy)	2	2
Port Inspection Diver (Navy)	2	2

Ship's Diver (Navy)	2	2
Combat Diver (Army)	2	2
Combat Engineer (Army)	2	2

The Canadian Forces vision and colour vision requirements are identical for all types of divers. Clearance diving officer, Clearance diver, Clearance diver technician, Ship's diving officer, Ship's diver, Submarine diving medical officer, Combat diving officer, and Combat diver all require a visual acuity of V2 and colour vision level of CV2. A V2 level requires uncorrected visual acuity, measured separately in each eye, to be a minimum of 6/12 in the better eye with 6/30 in the worse eye or 6/18 in both eyes. The minimum best corrected acuity standard is 6/6 in the better eye with a minimum of 6/12 in the worse eye.

Similarly, the diving standard of the U.S. Navy SEALS indicates that uncorrected visual acuity should not be worse than 6/12 for the better eye and 6/21 for the worse eye. The vision of a Navy Seal should be correctable to 6/6 (unstated, but assumed to be in each eye). No optical correction is permitted without a waiver; however, refractive surgery is permitted and even suggested as a viable alternative for individuals who do not meet the uncorrected standard. For other U.S. Navy divers, optically corrective masks or underwater glasses are permitted for use by the divers to allow them to meet the best corrected standard of 6/6 (unstated, but assume in each eye). For example, the qualification for a Navy Civil Engineer CORPS Diving Officer is vision correctable to 6/6 (unstated but assumed to be in each eye), and not less than 6/60 in each eye, uncorrected. Waivers may be granted on a case-by-case basis for visual acuity less than 6/60 in each eye, and contact lenses are not permitted unless accompanied by a waiver (US Navy SEALS, 2003).

The New Zealand Navy recruitment office was also contacted to assess their policy on visual acuity entrance standards for divers. The minimum uncorrected acuity requirements are 6/6, as the recruiting office indicated that they do not permit new diving recruits to wear either glasses or contact lenses (Royal New Zealand Navy, 2003).

The Impact of the Diving Environment on Visual Acuity- World Wide Web Search

The analysis of the visual demands of diving tasks presents a particular challenge due to the underwater environment of many critical tasks. While in contact with air, the normal human eye is capable of sending accurate visual information to the brain; however, when images are viewed through a water medium the image becomes distorted and depending on the nature of the water, will also be altered in colour and contrast (Diving Medicine Online, 2003).

As humans we are poorly adapted to see well under water since most of our focusing ability comes from the curvature of the cornea and the refractive power of the air/fluid interface. Since the refractive index of water is almost exactly the same as that of the cornea itself, the focusing action of the cornea is almost completely lost underwater which results in a blurry, poorly-focused image (Straight Dope Science Advisory Board, 2003). The illustration below depicts the ability of the cornea to refract light onto the retina, which then brings an image into focus. In air, the cornea can function properly, however in water, light is refracted well behind the retina.

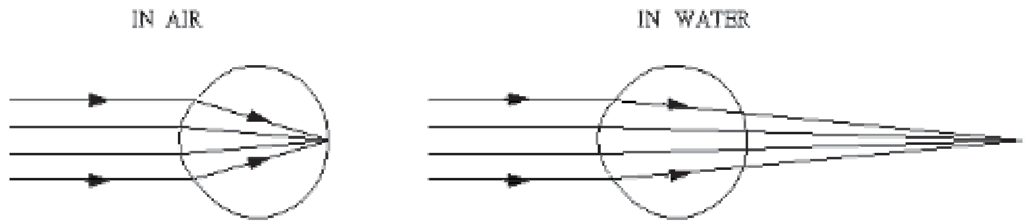

Figure 1: Vision in air and in water (Sable: underwater vision, 2003).

A face mask restores the ability to focus underwater because it provides a pocket of air, forming an air-corneal boundary and restores refraction to near normal. However, there is also refraction at the surface of the face mask (the water-glass-air boundary) which causes an apparent increase in object size, thus making them appear closer than they are in reality (Diving Medicine Online, 2003; Protective Eyewear, 2003). The flat surface of most masks and lenses also adds to the distortion of the image due to the varying distance of the interface from the entrance pupil of the eye.

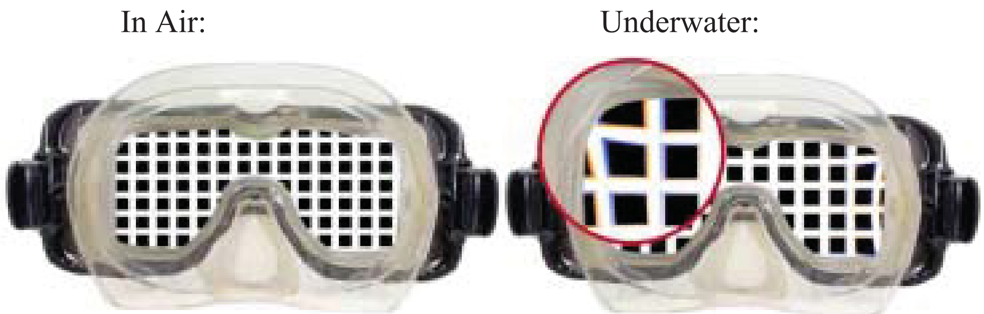

Figure 2: Vision through a facemask (Hydro Optics, 2003).

There are three main concerns associated with viewing underwater through a facemask:

1. Magnification: Refraction makes objects appear about 34% bigger and 25% closer than they are in reality.
2. Fuzzy Edges: When looking straight ahead (in the direction that the nose is pointing), images are clear and sharp. However, images become fuzzy with increasing off-axis viewing angles.
3. Warped Shapes: Straight lines warp outward at the corners of a face mask.

Many other factors alter visual acuity underwater, including the absorption of light by the depth of water and the scattering of light by particulate matter. Water clarity can also affect the appearance of objects in the water. For example, in spite of the tendency of masks to magnify objects and make them appear closer, under certain conditions, objects may appear farther away than they are in reality. This phenomenon called visual reversal, depends upon depth and appears to result from decreased brightness and reduced contrast, as well as an absence of familiar visual/distance cues found on land. For example, in highly turbid water (decreased brightness, reduced contrast), even relatively close objects can appear farther away than they truly are (Coral Springs Scuba, 2003).

Despite the magnification of underwater objects and the appearance of objects being closer by approximately 25%, optical correction may still be required to maximize visual acuity in individuals who normally wear contact lenses or glasses. Prescription lenses may be inserted in or attached to specially made masks, or contact lenses may be worn under the mask. If contact lenses are worn, soft contact lenses are recommended, as hard contact lenses may cause symptoms of eye pain and blurred vision. These symptoms occur as a result of gas bubbles that may form between the cornea and the contact lens (All About Vision, 2003). In the case of deep dives, hard contact lenses may also cause 'corneal edema' (swelling) after dives and during decompression. This swelling can produce clouding of the cornea and significantly decrease vision. With regard to soft contact lenses, they are more difficult to clean than hard contact lenses. As a result, disposable soft lenses are typically recommended for use (Divers Alert Network, 2003; Protective Eyewear, 2003; Diving Medicine Online, 2003).

Diving Vision Experiments

A number of experiments have been conducted in the past relating to vision underwater. Luria and Kinney (1975) conducted an experiment to determine the differences in distance and size estimates as well as stereoacuity judgments by divers with and without facemasks. Their results indicate that while stereoacuity is markedly degraded when estimated without a facemask, the lack of facemask did not increase the errors of distance or size estimates.

Allen, Brennan, and Richardson (1988) investigated the visibility of specific light sources made up of arrays of LEDs in the underwater environment and assessed the impact of distance, luminance and turbidity. Their study demonstrated that higher levels of ambient illumination and turbidity reduced the reliability of visual detection, as did increasing the viewing distance from 1.5m to 3.0. These results confirm the fact that visibility is often limited underwater even at relatively short distances.

Kinney, Luria, and Weitzman (1967) determined the relative visibility of various fluorescent and non-fluorescent paint colours in four different water clarities: 5% (Thame's River), 50% (Long Island Sound in Fort Pond Bay), 90% (Gulf of Mexico off Panama City) and 91.5% (Morrison Springs fresh water). Their results indicate that for turbid bodies of water (Thames River), fluorescent orange is the most visible while for clearer water, (Gulf of Mexico, Morrison Springs), fluorescent greens and white are the best colour choices. These results demonstrate the range of visibility conditions and some of the distortions that can occur underwater, as well as the feasibility of obtaining reliable scientific data from underwater vision experiments.

Visual Acuity and Specific Tasks

<u>Visual Acuity and Reading:</u>

Visual acuity (VA) has been found to be important for a number of tasks including reading text or identifying letters. Whittaker and Lovie-Kitchen (1993) have found that both normal and low-vision individuals require print at least two times greater than their VA limit to read at an optimal rate, indicating a direct relationship between these two variables. Donderi, Kawaja, Smiley, Henderson and Zadra (1994) also reported a relationship between acuity and reading text or dials with Coast Guard employees. Similar results were obtained when Avionics technicians were asked to identify printed wire codes in an electrical compartment of a large aircraft (Casson, 1999c).

The relationship between acuity and letter detection is also clear in the results of a study of police identification of license plates or signs (Sheedy, 1980), where it was demonstrated that officers defocused to 6/12 VA had to get much closer to the car (15 m vs. 30 m) to correctly identify the license plate than when they were not defocused (6/6 VA). Fine and Peli (1995) amongst others, have demonstrated that the ability to discriminate letters or symbols on a moving or rapidly changing display is also determined by visual acuity.

Visual Acuity and the Identification of Individuals:

The ability to recognize faces is also influenced by visual acuity (Sheedy, 1980; Bullimore, Bailey and Wacker, 1991). These studies indicate that facial identification for an individual viewed at 20 feet or for a small photograph at normal viewing distance decreases substantially below 6/6 VA and that identification is at chance when vision is defocused to 6/24 VA. Similarly, in trials involving correctional officers, the ability to distinguish individuals, to distinguish a guard from an inmate, or to determine the presence of a weapon is significantly reduced when visual acuity is reduced below 6/6 (Johnson, Casson and Zadnik, 1992; Giannoni, 1981; Good and Augsburger, 1987).

Visual Acuity and Surveillance Tasks:

Similar results were obtained when performance of a surveillance task was assessed. Johnson *et al,* (1992) found that any amount of defocus that reduced acuity below 6/6 impaired the ability of correctional officers to locate and identify suspicious behavior/presence of weapons within a group of inmates moving about in a yard or in a day-room situation. Similar results have been found with Youth Authority Counselors (Johnson and Brintz, 1993), as well as Fish and Game Wardens (Johnson, Day and Brintz, 1994). Also, Casson and Gibbs (1998) determined that the ability of soldiers in an observation post to detect and identify hostile vs. non-hostile events was reduced when VA was degraded to below 6/6.

In the marine environment, Casson, Gibbs and Cameron (1999b) demonstrated that the ability to detect a life-sized object 60 m behind a ship (man-overboard scenario) was compromised by small reductions in acuity. Donderi *et al* (1994) demonstrated that the ability to accurately detect simulated buoys was related to the level of visual acuity, with 6/6 required for 75% detection at the equivalent of 0.75 nautical miles. In a related study, watchkeepers were scored on their ability to detect life rafts in a search and rescue exercise. The main determinant of search performance were the weather conditions, however, low contrast VA was also a factor in daylight searches with binoculars. Stager and Hameluck (1986) found similar results for a simulated airborne search task. In both search and rescue scenarios the relationship between performance and other visual functions, such as colour vision and contrast sensitivity was more significant.

Visual Acuity and Driving:

Although visual acuity is often the single visual test given to most driving candidates, the relationship between acuity and driving is tenuous even when it is studied in large samples (17,000 to 30,000 drivers). Numerous investigators have found little or no relationship between VA and driving (Burg 1967, 1968; Henderson and Burg, 1974; Hills and Burg, 1977; Hills, 1980; Shinar, 1977, Shinar and Schiever 1991). This may be due to self-limiting behavior (reducing speed) by drivers who experience a loss in acuity. This is also reinforced by the results of a black-out driving simulation conducted for the Canadian Forces, where the number of driving errors remained fairly constant until acuity was reduced below 6/36, mainly because the drivers reduced their speed as acuity was degraded (Casson, Gibbs and Cameron, 1999a).

Owsely and McGwin (1999) have reviewed the literature and demonstrated through their own studies, that overall age groups, visual functions such as peripheral vision and contrast sensitivity, as well as attention and cognitive factors may be more important than acuity in driving performance. However, Hennessey (1995) suggests that visual acuity is a good predictor of poor driving record for a younger age group (26-39yrs).

Visual Acuity and Other Tasks:

As one might expect, even slight reductions in visual acuity below 6/6 affect the ability to perform well in a flight simulation of a fighter or a commercial jet (Draeger, Brandl, Wirt and Burchard, 1988). The results of this study (which concentrated on the visual issues inside the cockpit) indicated that levels of acuity better than 6/7 are required to read charts and maps displayed in the cockpit accurately at the time of approach. Visual acuity is also very important for the detection of ship-to-ship signals at a distance of 0.7 nm at sea, as even a slight drop to 6/12 reduced performance to near chance levels (Casson *et al.,* 1999b).

In the job of a fish and game warden, the type of detail that must be discriminated relates to the identification of game in and out of season. In an experiment by (Johnson, Day and Brintz, 1995), a VA of 6/6 was necessary to ensure effective performance in distinguishing between a male and female deer by identifying the presence of antlers while concealed at a distance from the hunting site.

Visual Acuity and Lower Demand Tasks:

Not all visual tasks require a high level of visual acuity, although visual acuity reduction can affect their performance if it is sufficiently degraded. In examples of intermediate tasks, Johnson and Groome (1993) found that drawbridge operators could still detect the position of a car relative to the bridge barrier nearly 80% of the time with 6/12 VA. Casson, Gibbs and Cameron, (1999c) found that trained avionics technicians were able to detect over 70% of snags in an A/B check simulation with 6/12 acuity (a check that avionics technicians perform before and after each flight). Also, Draeger *et al* (1988) reported that pilots would able to discern enough of the cockpit functions to land their aircraft in an emergency with 6/18 acuity.

Similarly, Casson *et al.,* (1999a, b) determined that Army personnel could withdraw to safety from a combat position with 6/36 vision, and naval personnel could find their way to emergency stations from the lower decks of a darkened ship with 6/60 vision. Although, when the terrain is uneven or when it is important to maintain a certain level of performance, greater VA is required. For example, when attempting to advance a combat position, soldiers with VA degraded to 6/12 were both less effective team members and less confident with their performance. Similarly, Fish and Game wardens indicated they would not be confident running down a rough hillside with less than 6/6 VA, although they felt they could walk it safely with 6/12 VA (Johnson *et al,* 1995).

Visual Acuity Varies with Luminance and Contrast:

Many of the results reported above were obtained in clear daylight conditions or when the target was well lit. The tasks required of Navy and Army divers may not be completed during daylight conditions and frequently do not take place in well lit conditions. Therefore, it is important to determine the possible effects of reduced luminance (such as occurs at night) or reduced contrast (such as occurs during a fog or snowstorm) on VA and performance of specific tasks. Johnson and Casson (1995) have shown that reductions in either contrast or luminance reduce visual acuity in a linear and additive fashion. This means that 6/6 vision can be degraded to 6/18 vision under night time driving conditions and 6/18 vision will be degraded to 6/60 vision under the same circumstances. If a thick fog is added to the night time driving conditions, acuity will be further degraded to 6/72 and 6/240 respectively.

Near vs. Far Acuity:

Visual acuity is important for obtaining information from a distance (search, detection of signals or lights, identification of faces, licences, driving). Considering these tasks are carried out at a distance the visual function is referred to as far acuity. When visual acuity is used to perform tasks within arms length (reading text, computer monitors or dials or gauges, fine manufacturing or repair), it is referred to as near acuity. The visual processing and physiological mechanisms involved in both far and near visual acuity are identical, with the exception of the optical requirements; near acuity requires accommodation of the lens to bring the near object into focus while far acuity requires little or no accommodation. Near and far acuity are generally tightly correlated except in circumstances where spectacles for far and/or near correction cannot be used. Uncorrected near acuity decreases with age, as the ability to accommodate for near focus decreases. This will present problems to uncorrected hyperopes (farsighted) at an earlier age than others. Conversely, uncorrected myopes (shortsighted) will have better near acuity than far acuity. Factors other than optical correction, such as luminance, contrast and eye disease, will have similar effects on both near and far acuity.

Visual Acuity Assessment:

Visual acuity, both corrected and uncorrected, can be measured quickly and reliably in a wide range of circumstances as long as safeguards for repeatability are instituted (Hawkins, 1995). A number of systems for both automated and manual testing are available. Standard letter charts, for example the ETDRS, the high contrast Bailey-Lovie (produced by Lighthouse) or the 96% Regan chart (produced by Paragon Inc. of Canada) are all good selections, because these tests are well designed and have published normative data. The Bausch and Lomb Orthorater also provides a suitable alternative. Care should be taken to ensure that the charts are brightly and evenly illuminated (100-120 cd/m²). This may be a problem with some automated vision testers where the background illumination is considerably lower than these values (Casson, 1995). It is also recommended that a second set of charts using different letter sequences should be available from the same manufacturer. Testing on alternate charts and varying the reading direction between backwards and forwards helps to prevent memorization of characters.

Binocular vs. Monocular Measurement of Visual Acuity:

Acuity can be measured while wearing glasses or contacts to obtain a best corrected visual acuity (BCVA) or without correction to obtain an uncorrected visual acuity (UCVA). In a clinical setting, acuity is measured in each eye separately to detect monocular changes in vision that may be associated with disease progression in one eye. However, from an occupational point of view it makes sense to assess VA binocularly. If measured binocularly, it is often up to 15% better (Rubin, 1994; Rubin, Munoz, Fried and West, 1995). This binocular advantage increases substantially in low luminance (night) and low contrast (fog, snow) environments, and when detection is time-limited (as it may be in identification/surveillance tasks) (Johnson and Groome, 1993; Rubin, 1994). The majority of the task based vision standards work is based on binocular acuity measurements, while much of the basic research findings are obtained using monocular acuity and performance assessments.

Visual Acuity and Closely Related Tasks

Infantry Tasks:

In an investigation of the critical tasks of the infantry soldier in the CF, Casson et al (1999a) used task simulations to determine the relationship between visual acuity and the following tasks (which were identified to have the highest demand for visual acuity):

- Observation Post: Surveillance
- House Clearing: Detection of Hazards
- Section Attack: Negotiating Rough Terrain
- Blackout Driving: Night visibility

In addition, an emergency task, 'Withdrawl Under Fire', was simulated to investigate the minimum visual acuity requirements in an emergency situation where the goal is to get to safety with or without glasses. The overall result was similar for all non-emergency tasks simulated: Performance decreased rapidly for most tasks when visual acuity was reduced below 6/6. Of particular interest from the perspective of the CF divers (particularly the Combat Divers, who must also perform the duties of the Combat Engineer) were the scenarios investigating surveillance and the detection of hazards. The results for these scenarios are presented below in Figures 3 and 4.

In each case, between 8 and 10 trained infanteers were required to perform a detection and identification task (detect and identify suspicious behaviour vs. non suspicious behaviour (Observation Post); or the detection of booby traps, trip wires, and weapons (House Clearing). This task was carried out under various levels of visual acuity reduction. In the case of the House Clearing both individual and group performance were assessed. As illustrated in these figures, performance decreased as soon as acuity was lowered from 6/6. However, total clearing time for the group did not change, as the non-impaired members of the team actually increased performance to compensate for the impaired member. The results clearly indicate the importance of 6/6 vision for the performance of these visually difficult tasks. In addition, the House Clearing results demonstrate the impact of an impaired individual on the group.

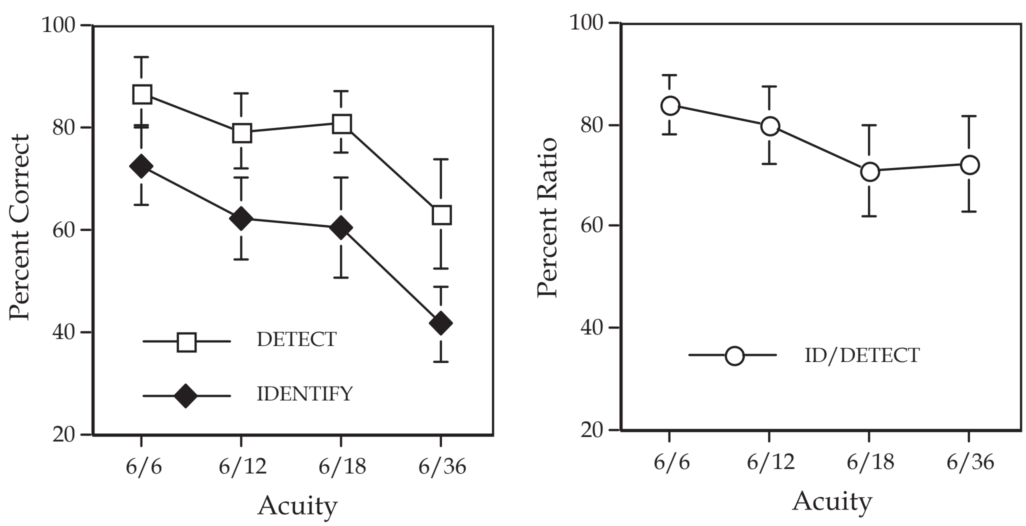

Figure 3: Observation post- The effect of change in visual acuity on target detection and identification in the Observation Post simulation during daylight conditions. Error bars indicate ± one standard error.

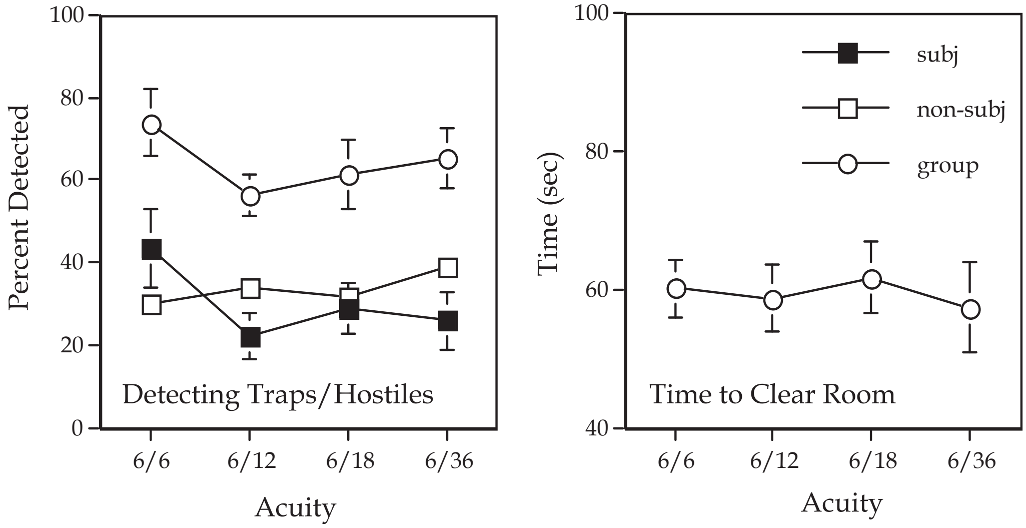

Figure 4: House clearing- The effect of change in visual acuity on performance during house clearing. Error bars indicate ± one standard error.

The results of the Blackout Driving Simulation also illustrate the importance of good visual acuity in night-time maneuvers. The graph of time to complete a driving course and number of errors in avoiding road hazards (Figure 5) demonstrate that performance decreases when visual acuity is reduced below 6/6. Taken together these results support a minimum best corrected visual acuity requirement of 6/6 for infantry soldiers.

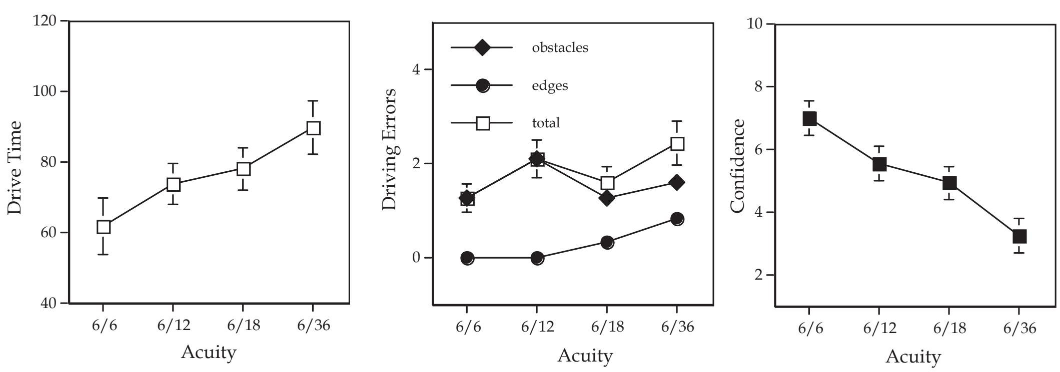

Figure 5: Blackout driving- Impact of reduced visual acuity on night driving performance. Error bars indicate ± one standard error.

The results of task simulation of Withdrawl Under Fire, presented below in Figure 6, are also pertinent. In this scenario, a section of 8 men are withdrawing from a forward position upon command. This is an emergency procedure, where the main goal is to get to safety (the RV point). This task was simulated to determine the minimum uncorrected visual acuity required to keep a soldier safe in an emergency. The graphs in Figure 6 demonstrate that at 6/60, time to get to safety increases significantly, suggesting that the uncorrected visual acuity standard should be less than 6/60.

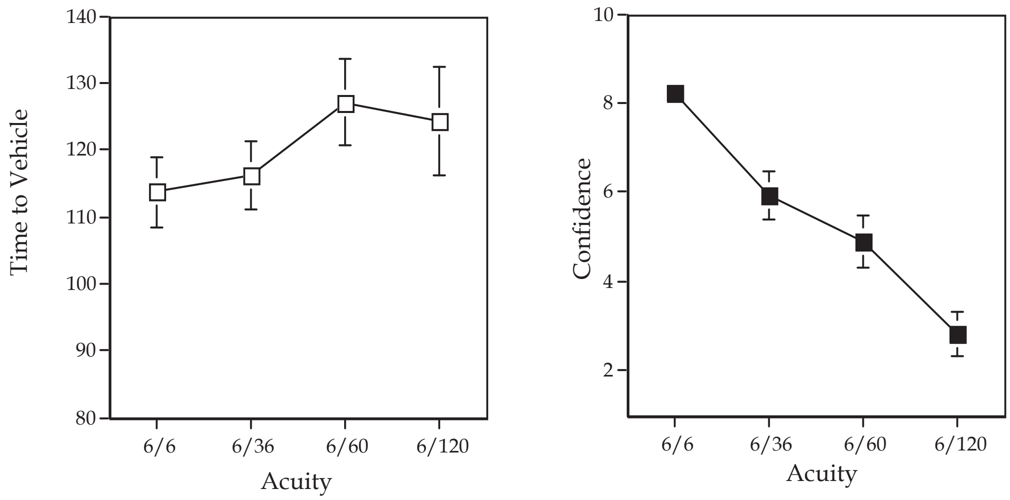

Figure 6: Withdrawl under fire- The impact of reduced visual acuity on withdrawal under fire. Error bars indicate ± one standard error.

Naval Tasks:

A similar investigation of the critical tasks of the boatswain trade in the CF was conducted (Casson 1999b). The following tasks were simulated to determine minimum visual acuity requirements:

- Identifying errors in set-up of refueling at sea (RAS) operations;
- Detecting man overboard;
- Detecting small navigation lights;
- Detecting hazards while maintaining tension on a rope; and
- Escape to upper deck in blackout conditions

In all cases where the simulations were designed to assess minimum visual requirements for routine tasks, it was found that performance decreased when visual acuity was reduced below 6/6. The results of task simulations for detecting small navigation lights at night (approximately 750 m away) and searching for a man overboard are particularly relevant to Naval divers who have similar tasks when not diving.

Detection of Navigation Lights:
In this experiment, colour normal individuals were asked to detect and identify signals from an Aldus Lamp flashed from a nearby ship (under 1 km) while moving forward in parallel through calm seas on a moonlit night. The subjects had their visual acuity reduced from 6/6 to 6/36 in four steps. Figure 7 shows the results, which indicate a substantial drop in performance at visual acuity reductions as slight as 6/12.

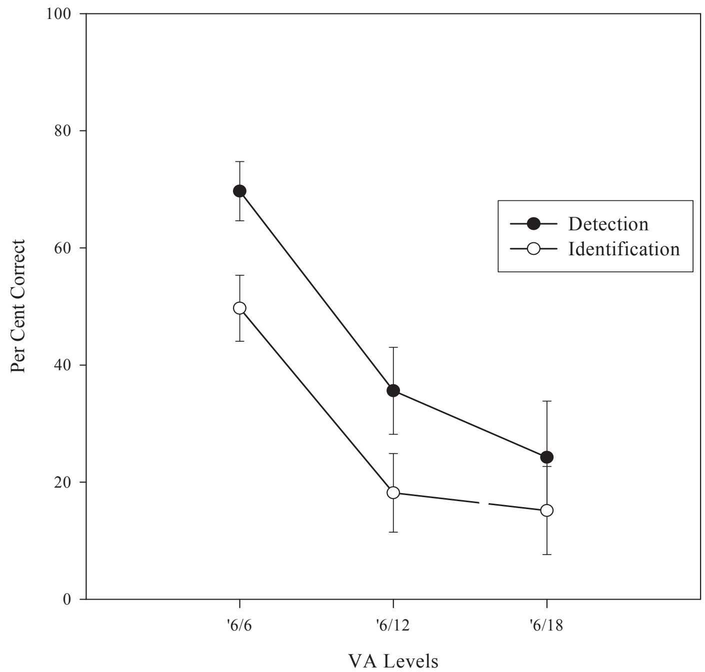

Figure 7: Navigation Lights- Effect of simulated visual acuity impairment on the detection and identification of navigation lights.

Detecting Man Overboard:

This experiment required individuals to use standard searching techniques to detect a dummy floating 200 m behind a moving ship. The results of this experiment showed performance improving slightly at 6/12 before decreasing again with greater visual acuity reductions. The time to detect increased slightly as well. These results suggest that a minimum requirement for visual acuity to perform this task could be set lower than 6/6.

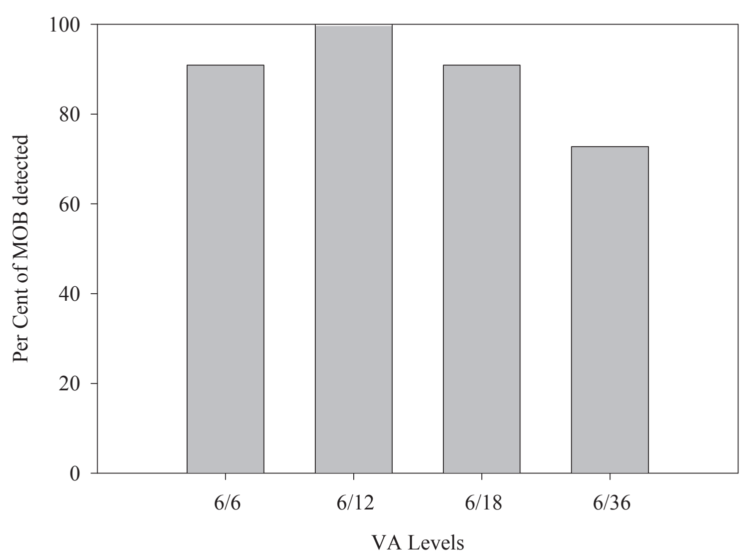

Figure 8: Man Overboard- Effect of simulated visual acuity impairment on the ability to detect man-overboard (percent detect on left; time to detect on right).

Escape to Upper Deck during Blackout:

The results of this emergency task simulation are similar to those from the Infantry Emergency Task Simulation. Performance decreased for visual acuity reductions greater than 6/60. This is demonstrated in Figure 9 below.

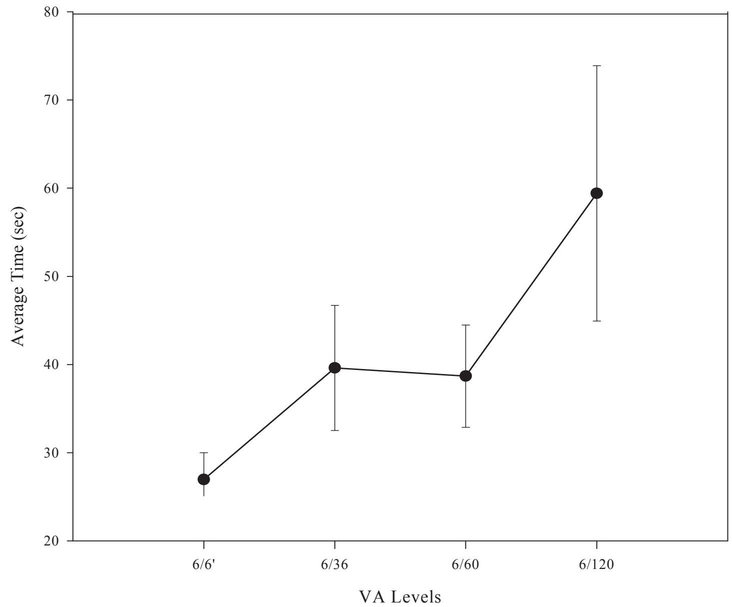

Figure 9: Time to Escape- The effect of simulated uncorrected visual acuity impairment on the time to escape to the upper decks of a ship (data corrected for fastest and slowest routes).

Summary:

The results of these simulations suggest that there are a number of critical Boatswain tasks that require a minimum level of visual acuity of 6/6 best corrected, and at least 6/60 uncorrected. Similar results have been found for the Infantry soldier. Considering it is likely that the Naval and Combat divers will have to perform similar surface tasks, the results of these task simulations can be used to predict the same level of visual requirements in these occupations. However to our knowledge there have been no studies that directly address the issue of determining the minimum visual acuity requirement for underwater tasks.

Annex B: Risk Questionnaire Results

To identify the critical tasks associated with military diving, all tasks performed by these occupations were ranked in terms of risk and how essential or critical they are to program completion. This was accomplished by an initial questionnaire for risk followed by a more focused questionnaire (following SME sessions) to identify particular tasks as being highly essential to program completion. This process produced specific tasks to analyze in terms of demand for visual acuity, the final step before selecting specific tasks for experimental simulation.

Risk Assessment: A task list was initially provided to Greenley and Associates indicating the various responsibilities of the different types of divers. This list subdivided the diving tasks under the following Duty Areas:

A. Diving Operations
B. Maintenance
C. Diving Tender Operations
D. EOD/Demolition
E. Port Inspection
F. Hyperbaric Chamber Operations
G. Salvage and Repair.

Under each of these subheadings, a variety of tasks were listed. This list was then used to develop a questionnaire to determine the amount of risk associated with the diving tasks. Analysis of the nature of risk associated with each task is a component of identifying the critical, high risk tasks associated with military diving occupations. The list was sent to the Navy and Army divers and they were asked to rate the tasks in terms of the risk associated with performing them (risk was to be interpreted as the amount of danger to the diver associated with performing the task). Due to time and personnel limitations, all divers were asked to assess all tasks. Each task was rated as either: Always High Risk, High Risk, Medium Risk, Low Risk, or Not Applicable.

A total of 24 divers ranked all tasks (20 Army and 4 Navy). The results of the task list questionnaire were analyzed separately between the Navy and Army divers. The full list of tasks is provided in Table 1 below, which also shows a list of the percentages of responses in the 'Always High Risk' and 'High Risk- Depending Upon Environment' categories. Table 2 below provides a summarized list of the tasks (indicated with an 'X') that were rated by either the Army or the Navy groups in the 'Always High Risk' or 'High Risk- Depending Upon Environment' categories.

Table 1: Diving task list with percentages.

Task #	Task Name	High Risk: Army Resp N=20	High Risk: Navy Resp N=4
	DUTY AREA A – DIVING OPERATIONS		
AT001	**Conduct diving operations**	**70%**	**75%**
AT002	**Perform underwater search and rescue operations**	**70%**	**75%**

AT003	Perform diver attendant duties	15%	25%
AT004	**Perform standby diver duties**	25%	**50%**
AT005	Operate diver hot water heater system	10%	0%
AT006	Operate diver gas panels		
AT007	Operate small craft	15%	25%
AT008	Taking a breathing gas sample		
AT009	Support underwater operations of ROV	5%	0%
AT010	Drive support vehicles towing trailers	10%	0%
AT011	Drive EOD vehicles	5%	25%
AT012	Update diving log		
AT013	Complete maintenance routine detail and control cards		
AT014	Complete dive charts		
AT015	**Perform closed circuit equipment dive**	5%	**100%**
AT016	**Perform semi-closed circuit dive**	5%	**100%**
AT017	**Conduct beach/bottom survey**	**50%**	25%
AT018	**Rig underwater lifting devices**	**75%**	25%
	DUTY AREA B - MAINTENANCE		
BT001	Perform first line maintenance on small engines		
BT002	Perform first line maintenance on vehicles/trailers		
BT003	Perform first line maintenance on diving equipment		25%
	DUTY AREA C – DIVING TENDER OPERATIONS		
CT001	Navigate small craft under visual conditions	15%	25%
	DUTY AREA D – EOD/DEMOLITION		
DT001	**Perform EOD procedures on surface ordnance**	**55%**	**100%**
DT002	**Perform EOD procedures on underwater ordnance**	**65%**	**100%**
DT003	**Clear harbours and beaches for landings**	**65%**	**75%**
DT004	**Maintain an explosives storage facility**	10%	**50%**

	DUTY AREA E – PORT INSPECTION		
ET001	**Search seabed for non-influence ordnance and sabotage devices**	30%	**50%**
ET002	**Search hulls for non-influence ordnance and sabotage devices**	25%	**75%**
ET003	**Search port/harbour structures for non-influence ordnance and sabotage devices**	30%	**75%**
ET004	**Search ship's hull underwater for explosive devices**	30%	**75%**
ET005	**Identify ordnance**	35%	**75%**
ET006	**Mark ordnance**	35%	**75%**
ET007	**Neutralize underwater anti-ship sabotage devices**	15%	**100%**
ET008	**Dispose of underwater explosive ordnance**	**65%**	**100%**
ET009	**Support EOD team in recover operations**	30%	**75%**
ET010	**Prepare demolitions**	**55%**	**75%**
ET011	Charge HP gas cylinder	10%	25%
ET012	Operate portable HP compressor	5%	25%
ET013	Perform minor repairs to diving suit		
ET014	Perform first line maintenance on EOD equipment		
ET015	Perform first line maintenance on HP compressor		
ET016	Perform first line maintenance on underwater imaging and detection devices		
ET017	**Influence ordnance**	25%	**75%**
	DUTY AREA F – HYPERBARIC CHAMBER OPERATIONS		
FT001	Operate hyperbaric chamber console		
FT002	Tend patients in hyperbaric chamber	5%	25%
FT003	Record hyperbaric chamber events		
	DUTY AREA G – SALVAGE AND REPAIR		
GT001	**Inspect/repair hull and hull fittings**	10%	**50%**
GT002	**Remove/replace hull fittings**	10%	**50%**
GT003	**Fabricate cofferdams, patches and blanking arrangements**	5%	**50%**
GT004	Fit/remove cofferdams, patches, blanking		

	arrangements and calibration equipment	10%	0%
GT005	**Salvage sunken vessels and aircraft**	45%	**100%**
GT006	**Assist in ship/submarine docking**	0%	**75%**
GT007	Survey seabed for underwater installations	25%	25%
GT008	Prepare seabed for underwater installations	15%	25%
GT009	Provide bottom sample	10%	25%
GT010	Survey underwater installations	25%	25%
GT011	**Remove/replace underwater fittings**	15%	**50%**
GT012	**Effect underwater repairs**	20%	**50%**
GT013	Install specialized equipment	10%	25%

Table 2: High risk diver tasks

TASK #	TASK NAME	ARMY	NAVY
AT001	Conduct diving operations	X	X
AT002	Perform underwater search and rescue operations	X	X
AT004	Perform standby diver duties		X
AT015	Perform closed circuit equipment dive		X
AT016	Perform semi-closed circuit dive		X
AT017	Conduct beach/bottom survey	X	
AT018	Rig underwater lifting devices	X	
DT001	Perform EOD procedures on surface ordnance	X	X
DT002	Perform EOD procedures on underwater ordnance	X	X
DT003	Clear harbours and beaches for landings	X	X
DT004	Maintain an explosives storage facility		X
ET001	Search seabed for non-influence ordnance and sabotage devices		X
ET002	Search hulls for non-influence ordnance and sabotage devices		X
ET003	Search port/harbour structures for non-influence ordnance etc		X
ET004	Search ship's hull underwater for explosive devices		X
ET005	Identify ordnance		X
ET006	Mark ordnance		X
ET007	Neutralize underwater anti-ship sabotage devices		X
ET008	Dispose of underwater explosive ordnance	X	X
ET009	Support EOD team in recover operations		X
ET010	Prepare demolitions	X	X
ET017	Influence ordnance		X
GT001	Inspect/repair hull and hull fittings		X

GT002	Remove/replace hull fittings		X
GT003	Fabricate cofferdams, patches and blanking arrangements		X
GT005	Salvage sunken vessels and aircraft		X
GT006	Assist in ship/submarine docking		X

A total of 27 tasks were ranked as Always high risk or High risk by either Army or Navy divers. Seven tasks were given one of these ratings by both groups:

- Conduct diving operations
- Perform underwater search and rescue operations
  Perform EOD procedures on surface ordnance
  Perform EOD procedures on underwater ordnance
- Clear harbours and beaches for landings
  Dispose of underwater explosive ordnance
- Prepare demolitions

Many of these tasks are related to working with explosive ordnance and their disposal. As a result, further discussion of the visual cues and visual tasks involving ordnance was required. Some of the other tasks required further break down prior to analysis for essential components and visual acuity demand. Thus, the results of the questionnaire provided an understanding of the risk associated with performing different diving tasks and also provided a basis for developing both the SME sessions and experimental designs.

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Annex C: SME Session Results

Two SME sessions were conducted. Navy divers were interviewed in Shearwater and Army divers were interviewed in Gagetown.

The sessions were conducted to perform the following tasks:

- validate the task lists;
- expand the diving tasks into subtasks using a scenario-based approach;
- analyze the critical sub-tasks; and
- prioritize the diving tasks and subtasks in terms of their effects on mission criticality and diver safety.

In addition, information was collected to aid in the characterization of visual demands in various tasks. Equipment, procedures and environments were discussed in depth both in the interviews and during tours of the facilities. In particular, examples of ordnance and different types of mines (surface and subsurface) were examined and discussed to determine the visual cues used in their detection and identification. Anecdotal information was gathered on incidents or near misses in which vision played an important role. Information was also gathered on the visual demands of typical, critical, and emergency diving tasks, and the procedures and visual conditions that may be present.

The meeting with the Navy divers from Shearwater took place first, followed by a meeting with the Army divers at Gagetown. Prior to the Shearwater meeting, a SME from the Navy developed two typical diving scenarios, which were based on fictional (yet realistic) diving tasks. This diving scenario was used as a basis in the SME meeting to determine the detailed tasks that must be performed to undertake the required dive. Information provided in the scenario consisted of:

- the overall mission;
- expected environmental conditions;
- diving plan;
- key equipment; and
- the number of personnel required.

Upon arrival at the site, an initial tour was taken to introduce the various diving units, including their responsibilities and typical equipment.

Shearwater:

5 SMEs participated in the SME Shearwater meeting. A detailed task analysis was performed on two scenarios (developed by the SME) and the visual requirements of the corresponding tasks were derived from the meeting. The first scenario involved locating and classifying unexploded ordnance. This scenario was divided into 4 main tasks, which were further divided into a number of sub tasks. The 4 main tasks to be performed in the scenario were:

1. Deploy from unit to dive site
2. Prepare for dive in transit and on site

3. Conduct dive
4. Conduct post-dive tasks

Each of these tasks was further divided by a number of sub tasks to be performed under them, producing a total of 50 subtasks. These tasks were then submitted to the SME's in the form of a questionnaire to obtain information on which subtasks were essential or critical to program or misson completion. A similar questionnaire was distributed to assess risk (diver safety). The questionnaires consisted of a five point rating scale in which the SMEs were asked to rate the impact on both mission criticality and diving safety in terms of finishing the sub tasks or not performing the sub tasks correctly. A summary of the results is provided below.

Mission Criticality: Subtasks were rated according to what impact would result if they were not completed properly. Many tasks (45/50) were rated as having at least a severe impact on the mission if not completed properly and 50% were also rated by at least one diver as resulting in total failure of the mission if not completed properly. Of these, five were rated by at least 2 SME's as being essential to mission completion. These are as follows:

- Prepare diving equipment
- Charge canisters
- Pump flasks (to initiate the flow of air)
- Conduct dive
- Swim to depth

A similar analysis was performed on the dive safety questionnaire. 45 of the subtasks were considered to have at least a severe impact on diver safety if not properly completed by one or more of the five SME's. Twenty-three of the 50 tasks were considered to have catastrophic consequences by one or more of the SME's if not properly completed. Six tasks were identified by 2 or more of the SME's as having catastrophic consequences if not performed correctly. The subtasks, which overlap somewhat with the mission critical tasks, are as follows:

- Charge canisters
- Pump flasks (to initiate the flow of air)
- Plan dive time and schedule
- Don dive gear
- Complete safety checks
- 40 ft, shut DIL off, write depth on slate

The items determined to have a high impact on mission criticality and diving safety were further discussed in terms of their visual requirements. This lead to a detailed discussion of the visual requirements of the divers, and the visual conditions under which the subtasks are performed.

Following this, the second scenario was discussed with a similar task analysis and division of tasks into sub-tasks. The scenario involved searching a ship's hull for unexploded ordnance and included the following six main tasks:

1. Deploy from Unit to Dive Site
2. Prepare for dive in boat and on site
3. Conduct Dive 1- Limpet Search
4. Prepare for LDME Dive 2 (surface mock-up of mine, set up LMDE on surface, determine angles)
5. Conduct Dive 2- Limpet Search
6. Conduct post-dive tasks

Following the task analysis of the second scenario, emergency scenarios and critical incidents were discussed. The discussion of the emergency scenarios and critical incidents allowed for a complete coverage of all the tasks that a diver may have to perform, and the associated visual conditions. The emergency scenarios and procedures include:

Lost Mask/Regulator	No air
Lost dive buddy	Equipment failure
Trapped diver	Ship repair
Stricken diver	Locate dive boat

Each of these tasks were discussed in terms of the appropriate response and possible visual conditions under which they may exist.

Critical Incident Analysis: The critical incidents describe incidents that have happened to divers in the past where vision has played an important role. These are summarized below:

- Missed the Lazy Shot (this affects decompression stops and hence gases in the body. Missing stops usually results in compulsory time in a decompression chamber).
- Lost Search Line (a diver would have to surface if he/she could not find the search line again. In surfacing, they would probably miss their decompression stops and may also have to visually search for the dive tender).
- Boat Engine Failure – Free swimming divers would surface following thunderflashes and would have to wait for a second boat to pick them up.

Gagetown:

An SME combat diver developed two typical scenarios which were again used to develop a diving task analysis. 5 SMEs were present in the meeting at Gagetown. A detailed task analysis was performed on the two scenarios and the visual requirements of the corresponding tasks were determined from the meeting

The first scenario involved conducting an underwater obstacle breech undetected. This includes searching a foreign shore for unexploded ordnance and obstacles. The scenario was broken down into 5 main component tasks which include the following:

1. Prepare dive plan (weeks in advance)
2. Reconnaisance divers enter water (max 15-20 ft usually)
3. Divers prepare for dive
4. Divers enter water
5. Divers exit water and meet at pre-determined rendez-vous point

Each of these tasks were further analyzed into a number of sub tasks. A detailed discussion ensued regarding the visual requirements of the tasks and the typical conditions under which they may be performed.

Combat diver tasks associated with the duties as combat engineers were also identified. These involve the standard operating procedure of the infantry soldier, and include the following (visually demanding) tasks:

3. Manning an observation post
4. Withdrawing under fire (Emergency procedure)

These tasks have been previously examined in other studies (Casson et al., 1999a), and they remain a critical component of the duties of the Combat Divers.

The second scenario was then discussed which involved recovering a sunken tank and Medium Floating Raft (MFR) hit by enemy fire. The scenario was discussed with a similar task analysis and breakdown of tasks into sub-tasks. The main tasks included the following:

1. Prepare dive plan
2. Send out two recce divers
3. Prepare to dive
4. Enter water
5. Patch hole
6. Attach balloons
7. Bring tank to shore

Following the task analysis of the second scenario, emergency scenarios and critical incidents were discussed. These include:

- Lost diver - divers are expected to continue on with the mission. If divers are lost, they are aware of the rendez-vous point and will endeavour to meet there.
- Stricken diver - return, or go directly to rendez-vous point.
- Emergency procedure - one diver signals distress to the surface, thunderflashes are thrown and the safety diver goes in to help (all emergency procedures are bells and pulls if connected to a shot line).
- Ice dive - if the life line comes undone the diver will go to the surface and hold himself in place with his knife in the ice. The safety diver will be sent in and will do a 360 degree sweep to pick up the diver.

Each of these tasks were discussed in terms of the appropriate response and possible visual conditions under which they may exist. The critical incidents describe incidents that have happened to divers in the past and include:

- Regulator freeze – the diver had to show his buddy with a chemical light that his regulator had frozen. The procedure is to buddy breath up to the surface.
- Running out of air on an ice dive – the diver started to dive with spare air tank (instead of breathing from the full tank) and ran out of air. The procedure again is to buddy breath up to the surface.

A tour was then conducted in which various mines and ordnance that combat divers encounter were viewed, followed by a viewing of the combat diving equipment. In addition, the site visits allowed the consultants to view potential sites for task simulations and equipment and materials that might be used to re-create the appropriate visual environment.

Both of the SME sessions (at Shearwater and Gagetown) were invaluable in providing the experimenters with the necessary information used to develop two valid and reliable experimental designs. Locating and identifying explosive ordnance proved to be an important and high risk task that both Navy and Army divers perform. Also, locating a diving tender or rendez-vous point in an emergency were found to be important tasks of which both Navy and Army divers must be able to perform.

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Annex D: Vision Questionnaire Results

A vision questionnaire was also sent to the Navy and Army divers to gather information related to the use of glasses and/or contact lenses while on duty in both surface and subsurface operation environments. The purpose of determining the use of glasses and contact lenses was to acquire information regarding the current practices of divers with less than 6/6 vision. The results were recorded separately for the Navy and Army divers, and descriptively analyzed.

Navy Divers (7 respondents)

1. Do you routinely wear optical correction on duty (other than diving)?
Yes 3   No 4

If yes, please indicate what type of correction you regularly use by typing an 'X' next to the appropriate category:
Glasses: 2 Contacts: 1 Both: 0

2. Do you use either reading glasses or bifocals?
Yes 2   No 5

3. Do you need glasses/contacts to legally drive (i.e. as stipulated on your license)?
Yes 2   No 5

4. Do you wear optical correction while diving?
Yes 1   No 6

If yes, please indicate what type of correction you use while diving by typing an 'X' next to the appropriate category:
Glasses: 0 Contacts: 1 Prescription Diving Mask: 0

5. How frequently do you use correction while diving?
Always: 1
Sometimes: 2
Not often: 3
Never: 4

6. Have your contact lenses ever dislodged or fogged up while diving, enough to interfere with your vision?
Yes 0   No 7

7. Have you ever lost a contact lens while diving?
Yes 0   No 7

8. Have you ever lost both lenses at the same time while diving?
Yes 0   No 7

9. Have your eyes ever been sufficiently irritated (from overwear, infection, injury, etc.) that you were unable to wear your lenses while diving?
Yes 0   No 7
a) If yes, how frequently during the last two years?_______

b) If yes, how much "down time" did you have with your contact lenses in the last year?_______

Army Divers (17 respondents)

1. Do you routinely wear optical correction on duty (other than diving)?
Yes 11 No 6

If yes, please indicate what type of correction you regularly use by typing an 'X' next to the appropriate category:
Glasses: 7 Contacts: 2 Both: 2

2. Do you use either reading glasses or bifocals?
Yes 6 No 12

3. Do you need glasses/contacts to legally drive (i.e. as stipulated on your license)?
Yes 7 No 10

4. Do you wear optical correction while diving?
Yes 7 No 10

If yes, please indicate what type of correction you use while diving by typing an 'X' next to the appropriate category:
Glasses: 2 Contacts: 3 Prescription Diving Mask: 2

5. How frequently do you use correction while diving?
Always: 5
Sometimes: 0
Not often: 2
Never: 8

6. Have your contact lenses ever dislodged or fogged up while diving, enough to interfere with your vision?
Yes 0 No 12 N/A 3

7. Have you ever lost a contact lens while diving?
Yes 0 No 13

8. Have you ever lost both lenses at the same time while diving?
Yes 0 No 13

9.Have your eyes ever been sufficiently irritated (from overwear, infection, injury, etc.) that you were unable to wear your lenses while diving?
Yes 0 No 13

a) If yes, how frequently during the last two years?_______
b) If yes, how much "down time" did you have with your contact lenses in the last year?______

Annex E: Complete Experimental Plan Details

The two experiments were conducted at FDU(A) during the days of April 1-4, 2003. The following general procedure was used:

- Introduction to the Experiments
- Participant Information Sheet and initial instructions
- Vision Assessment

Introductory Dive Brief

1. Introducing the team
2. The purpose of the experiment
3. Explain the two experiments (and the time demands)
4. Explain the role of the participants
5. Ensure that participation is voluntary
6. Explain the information sheet

<u>Introducing the Team:</u>

Many of you have met with us previously, however for those of you who do not know who we are, the following introduction is more for your benefit. We are:
Evanne Casson- Vision Scientist
Sheri Williams- Human Factors Specialist, consultant with Greenley and Associates
Jean Nadeau- Human Factors Specialist, consultant with Greenley and Associates

We are the team that has been contracted by Defence Research and Development Canada (DRDC) to assess and review the entrance visual acuity standard for the diving community.

During our first visit to FDU(A) Shearwater and CFB Gagetown, our mission was to establish a prioritized set of visual requirements for divers. Using fictional (but realistic) scenarios developed by Subject Matter Experts, we were able to determine the main tasks associated with a general dive. These main tasks were broken down further into sub-tasks and the visual conditions under which they are performed. Critical incidents and emergency procedures were also included to ensure we discussed the full range of visual conditions and diving environments possible. The discussions we had with divers at both locations were very informative and helpful to us in meeting our requirements.

Upon further assessment of the information gathered, we decided on a number of possible test scenarios that could be used to perform the experiment. The list was then narrowed down to 2 experiments: one underwater and at surface.

<u>Purpose of the Experiments:</u>

The purpose of these experiments is to assess whether the critical tasks performed by divers can be performed successfully by a diver with lower visual acuity. One critical task performed by both Navy and Army divers is to identify mines/ordnance in low visibility water. Therefore, the first experiment simulates this task. It was also decided that an emergency scenario was an important task to simulate. An emergency task performed by both Navy and Army divers is to locate either a boat or a rendezvous point in low visibility surface conditions. The second experiment to be conducted simulates this task.

Explaining the two Experiments:

Experiment #1: The experiment will take place in the pool, with low levels of ambient light. This is to simulate the low levels of light most divers encounter on a regular basis when they are in water. We are trying to emulate real life conditions to the greatest extent possible during the experiment.

The divers will be asked to don their dive gear and enter the pool at one end, submerging to the bottom of the pool. They will be wearing one of 4 prescription dive masks (6/6, 6/12, 6/18 or 6/30). At the opposite end of the pool, a number of mines will be placed amongst lead shots and other visual clutter. The divers will be asked to detect and identify as many mines as they can from as far away as possible. Should no mines be detected from where the diver entered the pool, they will be directed to move forward toward the mines in 4 ft intervals.

Once the diver has detected and identified all the mines thought to be in the pool at that time, they will be asked to exit the water and the next diver will perform the experiment. Each diver will be asked to perform this experiment using all 4 prescription masks. Once each diver has run through the experiment using one prescription mask, the mines in the pool will be switched around prior to commencing the experiment with a different prescription mask. In-between experiments, divers will be asked to wait in a room until their turn to participate comes again.

The time to participate in the pool will be approximately 10 minutes per trial (although divers will have to wait approximately 30 minutes in-between pool trials for the other divers to complete their trial).

Experiment #2: This experiment will take place at night, aboard a diving tender boat, in Halifax harbour. This is to simulate night time visual conditions over water. The divers will be driven out to Halifax harbour in the diving tender at 8pm. The boat will be anchored to a buoy in the middle of the harbour. A rigid hull inflatable boat (RHIB) will be positioned 200 m away anywhere along a 270 degree radius of the stern of the diving tender. The RHIB will be positioned by radio command from the diving tender at a randomly selected cardinal point, along the 270 degree arc, with the lights turned off. The participating divers on the diving tender will be wearing prescription eyeglasses that will blur their vision. The prescriptions are 6/6, 6/30, 6/60, and 6/120. The diver will be asked to stand at the stern of the diving tender and to locate the RHIB which contains only the driver (not moving during trial). The time it takes for the diver to locate the RHIB is recorded by the experimenter in the diving tender. After 2 minutes if the participant can not locate the RHIB, the trial will end. The diver will then change to a different pair of prescription glasses for another condition of blur, while the RHIB is moved to new position. Once 4 trials are completed, by all the divers, the diving tender and the RHIB will return to the base.

Explain the Role of the Participants:

In experiment #1, the divers will be asked to detect and identify the mines from as far away as possible (Distance to the mines is the variable that we are measuring). In experiment #2, the divers will be asked to locate RHIB#2 as fast as possible (Time to locate the RHIB is the variable that we are measuring).

Voluntary Participation:

We would like to stress the point that participation in this experiment is entirely voluntary. You are under no obligation whatsoever to participate or continue participating in the experiment should you not feel like doing so. If you feel uneasy, sick or unwell in any way, please inform one of the experimenters as soon as possible and we will stop the experiment at that time.

Participant Information Sheet:

We have a participant information sheet and volunteer form that we would like you to read and fill out. This form describes the experiments, and has a short request for participant details (age, type of diver, etc). Once you have read this information sheet, we ask that you sign and date it to signify that you understand what's expected of you as a participant and you understand your participation is on a voluntary basis.

Thank you

Participant Information Sheet:

Visual Acuity Experiment: As a continuation of the visual acuity standard contract, we are conducting experimental trials to determine the visual acuity requirements for specific surface and subsurface tasks of Canadian Forces divers. We are asking for your participation in two different experiments to determine the relationship between levels of visual acuity and task performance. The first experiment takes place in the indoor pool at FDU(A) during the day. The second experiment will take place outside on the water near FDU(A) during night time hours (approximately 8pm). Your participation in both experiments is very much appreciated. We would like to test 5 participants at a time; this will cut down on the actual amount of downtime the divers will have as a result of participating in the experiment.

Pre-experiment data: We will need to test your vision prior to running the sub-surface experiment. This will involve reading an eye chart and filling in information about your age and experience. We will also fit you with standard diving masks that will blur your vision to different levels of visual acuity from normal to 10 times worse than normal. Glasses of a similar type will also be fitted. These masks or glasses will be worn at different times during the experiments for brief periods of time. The masks and glasses both temporarily blur and distort vision, which can cause dizziness if rapid movements are taken. However, there will be no rapid movement in the experiments while wearing the masks or glasses. Furthermore the blurring caused by the masks or glasses does not have any lasting affect on the eyes and has no long term harmful effects. Similar glasses have been used in over 20 other experiments like this with both military and non military personnel experiencing no harmful effects.

Experiment 1: (Underwater task) One at a time, divers will be asked to don their CABA equipment and submerge themselves in the pool. They will be wearing one of the blurring prescription masks. The task of the diver will be to move forward slowly along the bottom from one end of the pool to the other end of the pool while locating and identifying ordinance. On some trials a set of air tanks will also be present and divers will be asked to locate these and move towards them to observe whether or not there are bubbles present. The divers will surface to report the location and type of object they detect and the experimenter will record the information. This sequence will be repeated, with breaks to rearrange the objects on the bottom of the pool until all divers have done the experiment four times, each time with a different level of blur: from no blur (high visual acuity) to extremely blurry (low visual acuity).

Experiment 2: (Surface task) Divers will be asked to be at the wharf near FDU(A) at approximately 8pm, in warm outdoor clothing. The experimental area on the water will be predetermined. The experimenters and divers will be taken by a diving tender to a central location in Halifax harbour and tied to a buoy. Divers will be wearing blurring glasses (similar to the masks in Experiment 1) and will be asked to locate a RHIB which will be stationary on the water 200 m away, anywhere along a 270 degree arc. The trial ends when a response for the RHIB location is made, or when 2 minutes is reached. Four trails will be conducted with each diver. Once all divers have completed the trials, they will be returned to the wharf.

Participants: If at ANY TIME you are feeling sick/dizzy/unwell or unable to complete your trials, please let one of the experimenters know and we will stop the experiment at that time. Please let the experimenters know if you are uncomfortable with any of the tasks you have been asked to perform. If at any time you do not wish to continue with the experiment, you are under absolutely no obligation to do so, your participation is entirely voluntary.

I________________________________ have read the above experiment description and understand that my participation is entirely voluntary. I reserve the right to withdraw my participation from the experiment at any time.

Signed:_____________________________ Date:_________________________

We would like to express our gratitude to you in taking part in this study. We appreciate your time and effort in this matter.

Vision Assessment

Specific details of each participant's diving experience level and surface visual acuity were gathered. Also, all participants were assessed for colour vision, as significant colour defects may interfere with the performance of these tasks. The blurring masks and spectacles required for each participant to bring them to the visual acuity levels specified for each experiment were determined and recorded in the form below. Note that all simulated visual acuity reductions were binocular, that is, if an individual was said to be blurred to 6/12, this indicates that his/her binocular visual acuity was 6/12.

Surface Vision Assessment Form:

Name: ____

Location: ____

Diver Type:______________ Number of years diving:_________

Other Diving Experience: ____

Age:________ Gender:_________

Visual Acuity Standard for Divers

Uncorrected Visual Acuity (OU):___________Glasses? Y / N / S

Contacts: Surface? Y / N / S Diving? Y / N / S

Colour Vision: (PIPs) Normal Abnormal

Ocular Problems?:____

____

Physical Disabilities:____

____

Masks for Exp 1	Glasses for Exp 2
20/20	20/20
20/40	20/100
20/60	20/200
20/100	20/400
Comments:	Comments:

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Annex F: Scenario Set-up Form

Targets

Scenario #________________________

LL Rear	L Rear	Center Rear	R Rear	RR Rear
LL Front	L Front	Center Front	R Front	RR Front
		Participant at 0 ft		

Items:

Large: Tilt Rod: **TR1**_________**TR2**_________

Large: Anti Tank: **AT1**_________**AT2**_________**AT3**_________

Marker/Mortar: **LM1**_________**LM2**_________

Small Fuse/Mortar: **SF1**_________**SF2**_________**SM1**_________**SM2**_________

Scuba Tanks (L/R) **SC0**_________**SC1**_________

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Annex G: Navy Diving Scenarios

Scenario #1- **<u>ClDiv Task</u>**

Overall mission:_ PRIORITY TASKING – Immediately Locate & classify suspected unexploded ordnance picked up on side scan sonar inside Bedford basin, approx 500 yds due south of jetty NN at Lat: xxxxxx Long: xxxxxx . Anticipated water depth 65 meters.

Expected conditions

- 23:00 (night dive)
- Salt water / Mud bottom / Reduced visibility (10 ft max)
- Air temp – minus 15 deg C.
- Water temp – 2 deg C.
- Winds – NNE @ 10 kts

Duration of Task (in water/out of water)

- Mark Location using GPS (PLGR)
- Conduct dive using CUMA
- Search using HHS (Hand Held Sonar)
- Sketch & gather identifying marks off suspect Ordnance.
- Planned dive Schedule 66m / 15 min bottom time.
- Planned surface decompression (RCC on board Granby)
- Req in water decompression stops:
  4min @24m
  2min@21m
  3min@18m
  3min@15m
  3min@12m
  PLUS 40 min @ 12m in RCC Total time of dive 77min.

Key equipment
Dive Tender c/w RCC
Mk5 Zodiac c/w shot line assy
Hand Held Sonar
GPS
3 CUMA diving equip

Number of divers/personnel required/
3 divers
1 dive supervisor
2 dive tenders
1 RCC operator
1 RCC inside tender
1 Boats O / Tender Charge
1 Engineer
Total Min pers req: 10

Scenario #2 – Ships Team Diver Task

Overall mission :_Clear ships hull of suspected Ordnance: While alongside jetty NG – Halifax Dockyards, HMCS Neversail has reason to believe that the left wing radical group DDMP "Divers Deserve More Pay" has places limpet mines on her hull. Ships dive team are to immediately search and dispose of all suspected ordnance placed on the hull.

Expected conditions
Daylight dive – 10:00
Reduced visibility (less than 5 feet)
Water around Jetty NG is to be considered moderately contaminated.
Temperature:
Air temp – zero deg C.
Water Temp 4 deg C.
Winds from the South @ 20 kts.
Anticipated max depth 40 fsw

Duration of task (in water/ out of water)
Dive # 1 – Hull Search – Anticipated Schedule 30ft / 20min
Dive # 2 – Place LMDE – Anticipated Schedule 30ft / 5min.
Consider all dives "No Decompression" dives.

Key equipment
Dive Boat (10 man Zodiac)
CABA – MCW equipment
Dive Safety gear
LMDE (Limpet Mine Disposal Equipment)

Number of divers/personnel required
6 Divers to search hull / 1 diver to place LMDE
1 Standby Diver
1 Dive Supervisor
1 Boat driver
1 Dive Tender
Total Min Personnel - 10

Annex H: Task Analysis- Navy Divers

Diving Task Analysis: Navy Divers- Scenario 1 Clearance Diving Task
Immediately locate and classify suspected unexploded ordnance

23:00 (night dive) Over 150 fsw, therefore one diver (if under 150 fsw, 2 divers). Deep diving (CUMA) you're never free swimming (you always have a shot line and a life line). Non-deep diving (CCBA), you can do the job with only the shot line (no life line).

Related Tasks From Occupational Requirements Task List:

Duty Area A- Diving Operations
AT001- Conduct diving operations
AT002- Perform underwater search and recovery operations
AT003- Perform diver attendant duties
AT004- Perform standby diver duties
AT008- Take a breathing gas sample
AT012- Update diving log
AT014- Complete dive charts
AT015- Perform closed circuit equipment dive
AT017-Conduct beach/bottom survey
Duty Area B- Maintenance
BT003- Perform first line maintenance on diving equipment

Duty Area C- Diving Tender Operations
CT001- Navigate small craft under visual conditions
Duty Area E- Port Inspection
ET001- Search seabed for non-influence ordnance and sabotage devices
ET005- Identify ordnance
ET006- Mark ordnance
Duty Area F- Hyperbaric Chamber Operations
FT001- Operate hyperbaric chamber console
FT002- Tend patients in hyperbaric chamber
FT003- Record hyperbaric chamber events

Task	**Task Description**	**Visual Conditions**	**Equipment Used**	**Task Difficulty**	**Task Criticality**
1.0 Deploy from Unit to Dive Site					
2.0 Prepare for Dive in Transit and on Site	**2.1** Prepare Recompression Chamber (RCC) -bring RCC on line. Pre dive it with no	-using a small flashlight at night			

	one in it, check gauges, check air				
	2.1.1 pre dive, check gauges, supply lines outside shelter	Interior lighting conditions			
	2.2 Prepare diving equipment				
	2.2.1 pre dive at unit and on some tendered				
	2.2.2 charge canisters	-small flashlight			
	2.2.3 pump flasks				
	2.3 Mark dive location				
	2.3.1 float shot line	23:00 hrs, outside environment	using GPS to locate spot		
	2.4 Load boat				
	2.4.1 safety equipment in boat (pre-checked) Supervisor checks boat to ensure everything is there (using checklist).				
	2.5 Prepare dive plan				
	2.5.1 obtain environmental conditions				
	2.5.2 plan dive time and schedule				
	2.5.3 determine required personnel				
	2.5.4 determine equipment				

	2.6 Conduct dive brief (standard). Supervisor gives info of plan and debriefs divers, reminds divers of key things.	Exterior visual conditions			
	2.7 Don dive gear -The tender helps with this task	Exterior visual conditions			
	2.8 Complete safety checks: Routine to locate all gear by tender to diver- buckles, quick-release, lifeline, etc. Directed to go 'on gas' and check both pressure gauges, directed to go 'on mask' and breathe from set. Supervisor has a check-out list. Diver gives 'thumbs-up' and starts the dive with a red light in the mask	Exterior visual conditions, 23:00 hours Supervisor has a pen light	Dive Tender c/w RCC Mk5 Zodiac c/w shot line assy GPS Pen light CUMA rebreather Mask Dry suit + fins Hand held sonar Chem lights Search line	Effort= simple Knowledge = high level	
3.0 Conduct Dive	**3.1** Enter water				
	3.1.1 leak check for bubbles				
	3.2 Swim to depth				
	3.2.1 dive to 20 ft (CUMA) Divers held at 20 ft by life line.	Visual check LED light- supposed to be green by the time you reach 20 ft. It's red when the ratio between oxygen and helium is off. With increased depth though, the light looks orange and it's difficult to tell when			

		it's changed to red.			
	3.2.2 one pull				
	3.2.3 carry on to bottom (check air in drysuit, operate bypass valve)				
	3.2.3.1 clearing CUMA eqt by feel				
	3.2.3.2 ten ft before bottom chem. light	**Vision** -Zero visibility -Feel for light with hand on shot line -Looking down occasionally to see light -Checking gauges to see depth	All dive equipment Chem light Tender lets down line (they control the speed)	Effort= extremely simple	
	3.2.3.3 one pull				
	3.3 Check depth, air, time under (diver gauges, tender rope and timer)	Zero visibility Use chem light to check gauges	All dive equipment Gauges Chem light		
	3.4 Locate ordnance using HHS (acoustic) and visual searching				
	3.4.1 hook up search line (spring/snap hook to bottom of shot line). Pay it out and circle the shot line to do search	**Vision** Zero visibility. Perform task by feel.	All dive equipment Search line + hook Chem light		Critical task: if you lose your search line, use your life line as a reference to establish where the shot line is and get back

					to shot line. Usually, you can reacquire the search line. Have to keep in mind your time limits
	3.4.2 operate the HHS				
	3.4.2.1 listen to HHS signals				
	3.4.2.2 set range volume, freq,may have to plug in (diver's know these knobs by heart, and can perform this by feel)				
	3.4.2.3 swim out using sound based on acoustic signature				
	3.4.3 **search visually.** Once HHS frequency is high, bottom scan for objects and hazards. Look for the shape/ silhouette of object. Try to locate nose/tail of object and approach perpendicular to it. Look for colour, letters, welds, etc.	**Visually searching underwater** Close to zero visibility. Low visibility more often than good. Essentially looking for the silhouette of an object. Have to get as close as necessary to ordnance to see identifying features.	All dive equipment Search line HHS (acoustics)	Effort = ??	Critical task: try not to get too close to object (the closer you get, the more likely you are to setting it off).
	3.4.4 identify ordnance				
	3.5 Place stake (about 10ft) at ordnance location (stake is preattached to search				

	line)				
	3.6 Sketch and gather identifying marks (not at night, sometimes use a cheat sheet on the boat)				
	3.7 Measure object (eyeball approximation)				
	3.8 Swim to surface from shot line				
	3.8.1 see or feel lazy shot to determine decompression stops	**Vision** Close to zero visibility. Running hand up the shot line and feeling for lazy shot. Looking for chem. light on lazy shot.	Hand (feeling for shot line)		Critical task: omitted decompressio n if you miss a shot. If the diver doesn't see/feel the lazy shot, he likely won't check his depth gauge to determine that he needs to stop.
	3.8.2 check gauges				
	3.8.3 40 ft, shut DIL (dilliant) off to breathe pure O2, write down depth on slate (this gets brought back up to the surface and the super visor can confirm and set the next lazy shot.				

	3.9 Surface				
	3.10 Exit water (7 minute window).				
	3.11 Undress drill (doff CUMA equipment in water and pass up)				
Post-Dive Tasks:	**3.12** Debrief team/examine diver				
	3.13 Complete decompression profile in RCC				

Scenario 2- **Navy Divers:** Ship's Team Diver Task: Clear ship's hull of suspected ordnance
Daylight dive 10:00, reduced visibility (less than 5 feet), anticipated maximum depth 40 fsw. 2 separate dives: first to find limpet mine, second to deactivate.

Related Tasks From Occupational Requirements Task List:

Duty Area A- Diving Operations
AT001- Conduct diving operations
AT002- Perform underwater search and recovery operations
AT003- Perform diver attendant duties
AT004- Perform standby diver duties
AT008- Take a breathing gas sample
AT012- Update diving log
AT014- Complete dive charts
Duty Area B- Maintenance
BT003- Perform first line maintenance on diving equipment

Duty Area E- Port Inspection
ET002- Search hulls for non-influence ordnance and sabotage devices
ET004- Search ship's hull underwater for explosive devices
ET005- Identify ordnance
ET006- Mark ordnance
ET007- Neutralize underwater anti-ship sabotage devices
ET008- Dispose of underwater explosive ordnance
ET017- Influence ordnance

Task	**Task Description**	**Visual Conditions**	**Equipment Used**	**Task Difficulty**
1.0 Deploy from Unit to Dive Site	**1.1** muster personnel and equipment	Zero to 5 feet	CABA- MCW eqt Rope lines attaching divers Chem lights LMDE Dive Boat (10 man Zodiac)	
	1.2 conduct seamanship evolutions			
2.0 Prepare for dive in boat and on site	**2.1** prep RCC			
	2.2 prepare diving equipment			
	2.3 load boat			

	2.4 prepare dive plan			
	2.4.1 obtain environmental conditions			
	2.4.2 plan dive timeand schedule			
	2.4.3 determine required personnel			
	2.4.4 determine equipment			
	2.5 conduct dive brief			
	2.6 don dive gear			
	2.7 complete safety checks			
3.0 Conduct Dive 1- Limpet Search	**3.1** enter water			
	3.2 swim to depth			
	3.3 conduct half necklace search			
	3.4 check depth, air, time under (diver gauges, tender rope, and timer)			
	3.5 locate limpet mines	**Visually searching underwater** 6 divers searching half the hull at a time (or at least cover off all visual areas of the hull they're searching)	CABA- MCW eqt Rope lines attaching divers Chem lights LMDE Dive Boat (10 man Zodiac)	
	3.5.1 when mine located, signal all to stop by pulling on the line			
	3.5.2 put marker near mine			

	3.5.3 chem light to surface (or pelican marker- foam float)			
	3.6 swim to surface			
	3.7 exit water (by boat or billy pugh)			
4.0 Prepare for LDME Dive 2 (surface mock-up of mine, set up LMDE on surface, determine angles).	**4.1** prep RCC			
	4.2 prepare diving equipment			
	4.3 load boat			
	4.4 prepare dive plan			
	4.4.1 obtain environmental conditions			
	4.4.2 plan dive time and schedule			
	4.4.3 determine required personnel			
	4.4.4 determine equipment			
	4.5 conduct dive brief			
	4.5.1 single, free- swimming diver			
	4.6 don dive gear			
	4.7 complete safety checks			
5.0 Conduct Dive 2- Limpet Search	**5.1** enter water- one diver, untended			
	5.2 swim to depth			

	5.3 check gauges			
	5.4 locate limpet mines	**Visually searching underwater**		
	5.5 use LMDE- adjust LMDE underwater by setting angles, (30º angle) place finger length away		LMDE eqt	
	5.6 swim to surface			
	5.7 exit water (diver is out of water when the LMDE is fired).			
6.0 Conduct Post-dive Tasks	**6.1** stripping down set, clean and store (in transit)			
	6.2 seamanship and navigate back to unit/ship			
	6.3 unload equipment			
	6.4 update diving log likely back at the unit or at the base			

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Annex I: Army Diving Scenarios

Scenario #1: The task is to conduct an underwater obstacle breech undetected. This task includes:
-underwater navigation carrying a 20kg load
-fastening of explosives on targets using miscellaneous methods
-installing of detonation cord ring main using junction clips
-marking the breech with various means

The operation will be done at night, in zero visibility conditions in a current up to 1 m/s. The task is usually executed in groups of 4-6 persons and time spent on the objective is minimal (1 hour). The preparations of demolitions is also 1 hour.

Scenario #2: The task is to recover a sunken tank and Medium Floating Raft (MFR) hit by enemy fire. This task includes:
-preparation of the tank and MFR surfaces to be patched using and underwater oxygen cutting torch, pneumatic grinding and shearing tools and hand tools such as files, etc.
-emplacement of a watertight patch or coffer dam.
-securing the lifting bags or balloons onto the tank and MFR strong points using steel wire rope, sling and chain and miscellaneous hardware such as shackle and carabineers.
-air is blown into the bags and the objects are brought to the surface
-air is forced into the MFR to force the water out

The operation will be done during daylight hours in visibility conditions varying from zero to 5 feet in a current up to 1 m/s. The task is done with a minimum of 2 pairs of divers using Full face masks with communications equipment. The task is very lengthy- the patching will take up to 3 or 4 hours and the lift will take up to 2 hours.

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Annex J: Task Analysis- Army Divers

Diving Task Analysis: **Army Divers** - Scenario 1 Conduct an underwater obstacle breech undetected.
Underwater navigation towing a 20kg load; Fastening of explosives on targets; Installing detonation cord; Mark the breech.
-operation done at night, zero visibility water conditions, current up to 1m/s
-they plan all their dives so they don't have to do decomp stops in the water. If someone blows the tables, they'll come up, reassess charts and dive again to decomp underwater.

Related Tasks From Occupational Requirements Task List:	
Duty Area A- Diving Operations	
AT001- Conduct diving operations	Duty Area E- Port Inspection
AT008- Take a breathing gas sample	ET005- Identify ordnance
AT012- Update diving log	ET006- Mark ordnance
AT014- Complete dive charts	ET008- Dispose of underwater explosive ordnance
AT017- Conduct beach/bottom survey	ET010- Prepare demolitions
Duty Area B- Maintenance	ET017- Influence ordnance
BT003- Perform first line maintenance on diving equipment	
Duty Area D- EOD/Demolition	DT004- Maintain an explosives storage facility
DT002- Perform EOD procedures on underwater ordnance	DT003- Clear harbours and beaches for landings and re-supply

Task	Task Description	Visual Conditions	Equipment Used	Task Difficulty
1.0 Prepare dive plan (weeks in advance) Diving Section: 4-8 ppl. 2 guys ashore as defence, 2 guys stay with vehicle, 6 guys in water doing tasks	1.1 Rehearse dive plan close to site			
	1.2 Deploy to Dive Site	Limited visibility in	Std CABA set	

		air (night time and hopefully raining/windy) Zero visibility in water	Twin 80 tank (air cylinder) AGA mask or scuba mask (depending upon water and possibly needing comms) Nav board: (plexiglass with phosphorus compass, non-back lit depth gauge and phosphorus watch) Chem light Dry bag (with required supplies) C8 rifle Underwater mine detector	
	1.3 Get kit ready in the Recce Vehicle and put it on			
	1.4 Perform individual eqt check; supervisor does secondary check			
	1.5 Check to make sure air is on at water's edge			
	1.6 Check demolition eqt			
	1.7 Take compass bearing			
	1.8 Look for landmarks on other side	**Visual Task**- look for trees, hills, radio towers, etc. Night time/distance viewing		
2.0 Recce divers	2.1 Work in pairs (one holds navigation board, the other	Zero visibility		

enter water (max 15-20 ft usually)	has hand out in front feeling for objects)			
	2.2 Swim to opposite shore or target location			
	2.3 Search for obstacles (underwater mines, concrete blocks, etc)	**Visually searching-underwater**		
	2.4 Write recce report on plexiglass of measurements and distances		Using rope with knots tied in it at predetermined intervals	
	2.5 Report back to friendly side of river and debrief team			
3.0 Prepare for Dive	3.1 All divers familiar with recce report and supervisor determines dive plan.			
	3.2 Divers prepare dive eqt and demolition eqt			
	3.3 Perform individual eqt check; supervisor does secondary check			
	3.4 Check demolition eqt			
	3.5 Take compass bearing			
	3.6 Look for landmarks on other side	**Visually looking for targets at distance**		
	3.7 Check to make sure air is on at water's edge			
4.0 Divers enter water	4.1 Work in pairs (one holds navigation board, the other has hand out in front feeling for objects)	Zero visibility		
	4.2 Swim to opposite shore or target location			
	4.2.1 Security divers- swim to beach and secure site			

	4.2.2 Following recce rope, charge divers lay the charges on pre-determined targets	Must be able to **visually locate the recce rope and targets underwater**		
	4.2.3 Following the recce rope, Detonation divers lay the detonation cord	Must be able to visually locate the recce rope and charges underwater		
5.0 Divers exit water and meet at pre-determined rendez-vous point	5.1 Gather gear and bring to rendez-vous point			
	5.2 At a predetermined time, the explosives are blown up			
	5.3 Divers debrief at rendez vous point			
	5.4 Divers secure landing site			
	5.5 Divers enter water again and set chem. lights/flares to guide craft across through safe area			
	5.6 Once everyone has crossed, divers hook up with their vehicle again			

Scenario 2: Recover sunken tank and Medium Floating Raft (MFR) (non-threatening environment).

Divers prepare the surface to be patched underwater using underwater oxygen cutting torches, pneumatic grinding and shearing tools. Emplace watertight patch or coffer dam, in daytime conditions, visibility ranging from zero to five feet; current up to 1 m/s. -surface supplied air with comms. Secure lifting bags onto tank and MFR strongpoints, blow air into bags and bring objects to surface

Related Tasks From Occupational Requirements Task List:

Duty Area A- Diving Operations
AT001- Conduct diving operations
AT002- Perform underwater search and recovery operations
AT003- Perform diver attendant duties
AT007- Operate small craft
AT008- Take a breathing gas sample
AT012- Update diving log
AT014- Complete dive charts
AT018- Rig underwater lifting devices

Duty Area G- Salvage and Repair
GT003- Fabricate cofferdams, patches and blanking arrangements
GT004- Fit/remove cofferdams, patches, blanking arrangements and calibration equipment
GT005- Salvage sunken vessels and aircraft
GT011- Remove/replace underwater fittings
GT012- Effect underwater repairs
GT013- Install specialized equipment

Task	Task Description	Visual Conditions	Equipment Used	Task Difficulty
1.0 Prepare dive plan	1.1 Determine repair equipment required			
	1.2 Determine diving equipment required			
2.0 Send out two recce divers	2.1 Tended dive with supervisor and zodiac			
	2.2 Free dive from zodiac to tank and attach float line to tank (which is attached to zodiac)			
	2.3 Determine damage to raft and positioning of tank			
	2.3.1 pick out hazards, recover expensive eqt, bring camera and sketch pad and make mental notes of important items	Up to 5 feet in the water	Diving with MCW eqt (AGA mask, dry suit, CABA eqt)	
	2.4 Recce divers return to boat, go back and debrief team			

3.0 Prepare to dive	3.1 supervisor conducts dive brief			
	3.2 dive checks done at dive site			
	3.2.1 Buddy check			
	3.2.2 Supervisor check			
4.0 Enter water	4.1 leak check			
	4.2 dive down to site			
5.0 Patch hole	5.1 cut around hole to smooth jagged edges	Visibility low, but working up close to surface. Have to feel around the edge of the cut to make sure you got the entire hole	Oxygen cutting torch Chem lights to help with visibility Welder's mask when using torch	
	5.1.1 diver requests eqt using comms			
	5.1.2 surface attaches eqt to shot line and sends it down to diver			
	5.2 patch inside and outside the hole			
6.0 Attach balloons	6.1 fill balloons with air		Divers are free-diving (untendered) because lines could get caught up in lift	
	6.2 divers work as buddies- one guy fills balloons with air, the other watches tank to let him know when to stop filling and pull buddy clear			
	6.3 float tank and MFR to surface			

7.0 Bring tank to shore	7.1 hook up winch from recovery vehicle			

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Annex K: Mission Criticality/Diving Safety Questionnaire Results

Mission Criticality/ Diving Safety
Questionnaire Results

Mission Criticality:	1	2	3	4	5	Total	Top Scores
	No Impact	Slight Impact	Moderate Impact	Severe Impact	Total Failure		
1. Prepare for dive in transit			4	1		16	
2. Prepare RCC			2	3		18	
3. Pre-dive, check gauges, supply lines			1	4		19	
4. Prepare diving eqt				4	1	21	21
5. Predive at unit			1	4		19	
6. Charge cannisters				3	2	22	22
7. Pump flasks				4	1	21	21
8. Mark dive location			3	2		17	
9. Float shot line			3	2		17	
10. Load boat			4	1		16	
11. Safety eqt in boat checked		1	2	2		16	
12. Prepare dive plan		1	4			14	
13. Obtain envt'l conditions		1	4			14	
14. Plan dive time and schedule			4	1		16	
15. Determine reqd personnel		1	4			14	
16. Determine eqt		1	4			14	
17. Conduct dive brief		1	2	2		16	
18. Don dive gear			3	1	1	18	
19. Complete safety checks			3	2		17	
20. Locate all gear by tender		1	2	2		16	
21. Conduct dive			2	1	2	20	20
22. Enter water		1	2		2	18	
23. Leak check		2	2	1		14	
24. Swim to depth			2	1	2	20	20
25. Dive to 20 ft		2	2	1		14	
26. One pull		2	3			13	
27. Carry on to bottom		1	1	1	2	19	

28. Clear, operate CUMA by feel	1		2	1	1	16	
29. 10 ft before bottom chem.lgt		1	2	1	1	17	
30. One pull		2	2	1		14	
31. Check depth and gauges			4	1		16	
32. Locate ordnance using sonar		1	1	1	2	19	
33. Hook up search line			2	2	1	19	
34. Operate the HHS		1	1	2	1	18	
35. Listen to the HHS signals		1	1	2	1	18	
36. Set range, volume, detents		1	1	2	1	18	
37. Swim out using sound		1	1	2	1	18	
38. Search visually		2	1	1	1	16	
39. Place stake		2	1	1	1	16	
40. Sketch and gather id'g marks		1	2	2		16	
41. Measure object		2	2	1		14	
42. Swim to surface usg shot		1	2	2		16	
43. See/feel lazy shot		2		3		16	
44. Check gauges		2	1	2		15	
45. 40 ft, shut DIL off, write depth on slate		1	2	2		16	
46. Surface	1	1	2	1		13	
47. Exit water	1	1	2	1		13	
48. Undress drill	1	1	2	1		13	
49. Debrief team, examine diver	1	3		1		11	
50. Complete decomp profile in RCC	1	2	1	1		12	

Diving Safety	1	2	3	4	5	Total	Top Scores
	No Impact	Slight Impact	Moderate Impact	Severe Impact	Catastrophic		
1. Prepare for dive in transit		1	2	2		16	
2. Prepare RCC			1	2	2	21	
3. Pre-dive, check gauges, supply lines		1		3	1	17	
4. Prepare diving eqt				4	1	21	
5. Predive at unit			1	3	1	20	

6. Charge cannisters					5	25	25
7. Pump flasks					5	25	25
8. Mark dive location			5			15	
9. Float shot line			5			15	
10. Load boat			4	1		16	
11. Safety eqt in boat checked			1	3	1	20	
12. Prepare dive plan			2	3		18	
13. Obtain envt'l conditions			4	1		16	
14. Plan dive time and schedule				3	2	22	22
15. Determine reqd personnel			4	1		16	
16. Determine eqt			2	2	1	19	
17. Conduct dive brief			2	3		18	
18. Don dive gear			1		4	23	23
19. Complete safety checks			1	1	3	22	22
20. Locate all gear by tender			1	2	2	21	
21. Conduct dive	1		1	2	1	17	
22. Enter water	3	1		1		9	
23. Leak check			2	3		18	
24. Swim to depth	2	1		2		12	
25. Dive to 20 ft	1	1			3	18	
26. One pull		1	2	2		16	
27. Carry on to bottom	1	2			2	15	
28. Clear, operate CUMA by feel		1	1	2	1	18	
29. 10 ft before bottom chem.lgt		1	4			14	
30. One pull		2	2	1		14	
31. Check depth and gauges			4	1		16	
32. Locate ordnance using sonar	2	2			1	10	
33. Hook up search line	1	2	1		1	13	
34. Operate the HHS	2	2		1		9	
35. Listen to the HHS signals	2	2		1		9	
36. Set range, volume, detents	2	2		1		9	
37. Swim out using sound		3	1	1		13	
38. Search visually	1	3		1		11	
39. Place stake		2	1	2		15	
40. Sketch and gather id'g marks	1	2	2			11	
41. Measure object		2	2		1	15	

42. Swim to surface usg shot			3	2		17	
43. See/feel lazy shot			1	4		19	
44. Check gauges		1	1	2	1	18	
45. 40 ft, shut DIL off, write depth on slate			1	1	3	22	22
46. Surface	1	1	1	2		14	
47. Exit water	1	1	1	2		14	
48. Undress drill		1	3		1	16	
49. Debrief team, examine diver	1	2	1	1		12	
50. Complete decomp profile in RCC		1		1	3	21	

Annex L: Emergency Procedures and Critical Incidents- Navy Divers

Emergency Procedures:

1. Lost Mask/Regulator – This is a drill technique that is practiced by the divers so they can respond calmly and appropriately should the situation arise.
2. No air – Dive buddy will open his partner's bail out bottle and press the bypass button if partner fails to do so. Unload CO2 to get to the surface as fast as possible.
3. Lost buddy - ascend a few feet and search for buddy's bubbles (no more than 1 minute). If unsuccessful, start a surface ascent, circling 360 degrees on the way up looking for bubbles. Report to dive supervisor on surface, drop thunderflashes, and send in safety diver.
4. Equipment failure – If a regulator fails for example, it will depend upon the diving scenario. If diving with a buddy, the buddy is signalled and provides air from his regulator or spare regulator. If diving solo, must ascend as quick as possible (despite the averse effects of ascending fast).
5. Trapped diver - 6 pulls on the shot line calls in the safety diver. Buddy diver stays with partner. On a free dive, the buddy would do a quick surface to alert the standby diver.
6. Ship repair work using a tractal, or come along – two divers bring it down, however there is a risk that they can sink and drag a diver down by a life line or buddy line.
7. Stricken diver – Determine the state of diver. Bring the diver to the surface if required. If the diver is having convulsions, his buddy should try to wait until the convulsions have stopped and then bring him to the surface.

Critical Incidents:

1. Missed the Lazy Shot – A diver missed the lazy shot while ascending after a dive. The lazy shot became detached from the shot line and so the diver did not feel it on his way to the surface. The diver did not show any signs of decompression sickness, however he was taken to the recompression chamber as a precaution.
2. Lost the Search Line – Two buddy divers were searching for an object using a search line connected to the shot line. They dropped the search line and had to look for it again. They were lucky as they were successful in finding it.
3. Boat Engine Failure – The dive boat engine failed. None of the divers were attached to the boat via a shot line (all free diving with float markers). Thunderflashes were dropped to bring the divers to the surface. Divers surfaced and waited for a second boat to pick them up.

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Annex M: Emergency Procedures and Critical Incidents- Army Divers

Emergency Procedures:

1. Lost diver – continue on with mission. If diver is lost, they know the rendez-vous point and they will get themselves to that point.
2. Stricken diver – go back or go directly to rendez-vous point.
3. If something goes wrong on a recovery dive (comms, entanglement), then one diver signals distress to the surface, thunderflashes are thrown and safety diver goes in to help.
4. All emergency procedures are bells and pulls if connected to a shot line.
5. In an ice dive, if the line comes undone the diver goes to the surface and holds himself in place with his knife stuck in the ice. The safety diver will be sent in and will do a 360 degree sweep to pick up the diver.

Basically, achieving the objective is more important than looking out for the team.

Critical Incidents:

1. Regulator freeze – diver had to show his buddy with a chem. light that his regulator had frozen. They buddy breathed back to the surface.
2. Running out of air on an ice dive – One diver started the dive with his spare air tank (instead of the full tank regulator) and ran out of air. He buddy breathed with his partner up to the surface.

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Annex N: Task Simulations Raw Experimental Data

Subsurface Data:

missed, counted as zero
artifact, removed from performance data

Distance to Detect/ID

Subject 1		Scenario	AT mines		2		3		TR mines		2	
			Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
	20/20	G	4	4	12	12			4	4	16	16
	20/40	F	8	4			16	12	16	12		
	20/60	E					16	8			16	4
	20/100	H							8	8		

Subject 2			AT mines		2		3		TR mines		2	
			Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
	20/20	F	8	8			12	4	16	8		
	20/40	E					4	4	4	0		
	20/60	H							8	4		
	20/100	G	4	4	8	4			8	4	8	8

Subject 3			AT mines		2		3		TR mines		2	
			Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
	20/20	D	4	4			4	4	4	4		
	20/40	A	4	4	12	12			4	4		
	20/60	B					0	0			0	0
	20/100	C	0	0			0	0				

Visual Acuity Standard for Divers

Subject			AT mines		2		3		TR mines		2	
			Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
Subject 4	20/20	E					8	8	8	4		
	20/40	B					8	4			4	4
	20/60	C	16	0			4	4				
	20/100	D	0	0			4	0	0	0		

Subject			AT mines		2		3		TR mines		2	
			Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
Subject 5	20/20	E					12	4			12	12
	20/40	F	8	8			8	8	4	4		
	20/60	H							4	0		
	20/100	G	0	0	0	0			0	0	4	4

Subject			AT mines		2		3		TR mines		2	
			Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
Subject 6	20/20	G	0	0	4	4			8	8	8	8
	20/40	F	8	8			4	4	8	8		
	20/60	E					12	4			8	8
	20/100	H							0	0		

Subject			AT mines		2		3		TR		2	

7									mines			
		Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
20/20	E					16	16			16	16
20/40	G	4	4	8	8			8	8	16	16
20/60	H							4	4		
20/100	F	4	4			4	4	8	4		

Subject 8		AT mines		2		3		TR mines		2	
		Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
20/20	A	4	4	0	0			8	8		
20/40	C	4	4			4	4				
20/60	D	8	0			0	0	0	0		
20/100	B					4	4			4	0

Subject 9		AT mines		2		3		TR mines		2	
		Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
20/20	D	4	4			0	0	0	0		
20/40	B					4	4			4	4
20/60	A	4	4	0	0			4	4		
20/100	C	0	0			4	4				

Subject1						
	L	L	S	2	S Fuse	2

Visual Acuity Standard for Divers

	Mortar		Marker		Mortar							
	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
									0	0		
	12	0	8	0	0	0					0	0
			8	0					0	0	0	0
			8	8	0	0	0	0	4	0		

Subject2

	L Mortar		L Marker		S Mortar		2		S Fuse		2	
	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
	12	8	12	4	0	0			0	0		
			4	4					4	0	0	0
			8	4	0	0	4	4	0	0		
									8	0		

Subject3

	L Mortar		L Marker		S Mortar		2		S Fuse		2	
	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
	4	4	4	4	0	0			0	0	4	4
	4	4	4	4	0	0	0	0			0	0
					0	0			0	0		
	0	0					0	0	0	0		

Subject4

	L Mortar		L Marker		S Mortar		2		S Fuse		2	
	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
			8	4					4	0	4	0
							0	0	0	0		

	4	0					0	0	0	0		
	4	0	0	0			0	0	0	0	4	0

Subject5

	L Mortar		L Marker		S Mortar		2		S Fuse		2	
	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
			8	4					0	0	4	4
	8	**8**	4	4	4	0			0	0		
					0	0	0	0	0	0		
									0	0		

Subject6

	L Mortar		L Marker		S Mortar		2		S Fuse		2	
	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
									4	0		
	8	8	**0**	**0**	4	4			0	0		
			4	4					0	0	4	0
			0	0	0	0	0	0	0	0		

Subject7

	L Mortar		L Marker		S Mortar		2		S Fuse		2	
	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
			12	8					8	4	8	8
									4	0		
			0	0	0	0	0	0	0	0		
	8	4	**0**	**0**	4	4			0	0		

Subject8

	L Mortar		L Marker		S Mortar		2		S Fuse		2	
	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
	8	8	8	8	8	8	8	8	16	8		
	4	4			0	0			4	4		
	12	8	8	8			0	0	0	0	0	0
					0	0			0	0		

Subject9

	L Mortar		L Marker		S Mortar		2		S Fuse		2	
	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID	Det	ID
	12	12	16	16			0	0	0	0	12	0
							0	0	4	4		
	4	4	16	16	0	0	0	0			4	4
	0	0							0	0		

Subject1

	SC#			Score	Score	Items	
		Det	ID	Det	ID	N	
	1	4	4	7.2	7.2	5	large mortar not included in scenario
	0	16	12	8.571429	4	7	SM1 and SF2 missed
	0	16	12	8	2.4	5	missed SF2
	1	0	0	4	3.2	5	missed SM1; tank ran out of air

Subject2

SC#	Det	ID	Score Det	Score ID	Items N	
0	4	4	8.571429	4.571429	7	missed SM1
0	0	0	3.2	1.6	5	
1	0	0	4	2.4	5	tank ran out of air
1			7.2	4	5	large mortar not included; no tank data

Subject3

SC#	Det	ID	Score Det	Score ID	Items N	
0	8	0	3	3	8	missed SF1; mask was fogged up
1	4	0	3.5	3.5	8	missed 2 SM's
1	0	0	0	0	4	missed SF1
0	0	0	0	0	5	missed SM2

Subject4

SC#	Det	ID	Score Det	Score ID	Items N	
0	0	0	6.4	3.2	5	
1	0	0	3	2	4	
0	12	0	4.8	0.8	5	missed SM2
0	8	0	1.5	0	8	missed SM2

Subject5

SC#	Det	ID	Score Det	Score ID	Items N	
0	16	16	7.2	4.8	5	
0	4	4	4.666667	4	6	LM obstructed by billowing tarp
1	0	0	1	0	4	missed SM1,2, SF1, LMKR- window was closed at 12; NV affected
1	12	12	0.8	0.8	5	missed SF1; placed SM's in that were not there;

						LM not in scenario

Subject6

SC#	Det	ID	Score Det	Score ID	Items N	
	1	12	12	4.8	4	5	LM not in scenario; SF hidden a bit by mat
	0	8	8	5.333333	5.333333	6	MRKR hidden by tarp
	0	8	0	5.6	3.2	5	missed SF1
	1	0	0	0	0	5	missed SM1,2; SF1, and MRKR

Subject7

SC#	Det	ID		Score Det	Score ID	Items N	
	0	16	16	12	10.4	5	
	1	12	12	8	7.2	5	LM not in scenario
	1	4	4	0.8	0.8	5	
	0	4	4	4.666667	3.333333	6	Tarp billowing in front of MRKR

Subject8

SC#	Det	ID		Score Det	Score ID	Items N	
	1	16	16	7.5	6.5	8	Missed AT2
	0			3.2	3.2	5	No tank in the scenario
	0	8	8	3.5	2	8	Missed SM2 and AT3
	1	12	12	2	1	4	

Subject9

SC#	Det	ID	Score Det	Score ID	Items N

0	8	8	**5.5**	**4**	**8**	missed SM2
1	12	12	**3**	**3**	**4**	
	16	12	**4**	**4**	**8**	
0			**1**	**1**	**4**	no tank in the scenario

Percent Correct

Subject 1		N Total	N Det	N ID	Percent Det	Percent ID	LG	MED	SM	N
G	20/20	5	5	5	100	100	4		1	5
F	20/40	7	5	5	71.4	71.4	3	2	2	7
E	20/60	5	4	4	80	80	2	1	2	5
H	20/100	5	4	4	80	80	1	1	3	5

Percent Correct

Subject 2		N Total	N Det	N ID	Percent Det	Percent ID				
F	20/20	7	6	6	85.7	85.7	3	2	2	7
E	20/40	5	5	5	100	100	2	1	2	5
H	20/60	5	5	5	100	100	1	1	3	5
G	20/100	5	5	5	100	100	4		1	5

Percent Correct

Subject 3		N Total	N Det	N ID	Percent Det	Percent ID				
D	20/20	8	7	7	87.5	87.5	3	2	3	8
A	20/40	8	6	6	75	75	3	2	3	8

B	20/60	4	3	3	75	75	2	0	2	4
C	20/100	5	4	4	80	80	2	1	2	5

Percent Correct

Subject 4		N Total	N Det	N ID	Percent Det	Percent ID				
E	20/20	5	5	5	100	100	2	1	2	5
B	20/40	4	4	4	100	100	2		2	4
C	20/60	5	4	4	80	80	2	1	2	5
D	20/100	8	7	7	87.5	87.5	3	2	3	8

Percent Correct

Subject 5		N Total	N Det	N ID	Percent Det	Percent ID				
E	20/20	5	5	5	100	100	2	1	2	5
F	20/40	6	6	6	100	100	3	1	2	6
H	20/60	5	1	1	20	20	1	1	3	5
G	20/100	5	3	3	60	60	4		1	5

Subject 6		N Total	N Det	N ID	Percent Det	Percent ID				
G	20/20	5	5	5	100	100	4		1	5
F	20/40	6	6	6	100	100	3	1	2	6
E	20/60	5	4	4	75	75	2	1	2	5
H	20/100	5	1	1	20	20	1	1	3	5

Percent Correct

Subject 7		N Total	N Det	N ID	Percent Det	Percent ID				
E	20/20	5	5	5	100	100	2	1	2	5
G	20/40	5	5	5	100	100	4		1	5
H	20/60	5	5	5	100	100	1	1	3	5
F	20/100	6	6	6	100	100	3	1	2	6

Percent Correct

Subject 8		N Total	N Det	N ID	Percent Det	Percent ID				
A	20/20	8	7	7	87.5	87.5	3	2	3	8
C	20/40	5	5	5	100	100	2	1	2	5
D	20/60	8	6	6	75	75	3	2	3	8
B	20/100	4	4	4	100	100	2	0	2	4

Percent Correct

Subject 9		N Total	N Det	N ID	Percent Det	Percent ID				
D	20/20	8	7	7	87.5	87.5	3	2	3	8
B	20/40	4	4	4	100	100	2		2	4
A	20/60	8	8	8	100	100	3	2	3	8
C	20/100	5	4	4	80	100	2	1	2	5

Annex O: Task Simulations Summarized Results

Participant average distance to detect and identify ordnance (Subsurface Experiment)

Blur	Det Mean	ID Mean	Det SD	ID SD	Det T Statistic	Det P Value	ID T Statistic	ID P Value
6/6	6.91	5.30	2.53	2.37				
6/12	4.72	3.76	2.18	1.70	1.966	<0.05	1.581	>0.05
6/18	3.52	1.73	2.56	1.41	2.819	<0.05	3.873	<0.001
6/30	2.35	1.48	2.44	1.59	3.887	<0.001	4.010	<0.001

Participant average accuracy scores (Subsurface Experiment)

Blur	Total	Det	ID	Percent	SD	SE
6/6	**56**	**52**	**52**	**94.2**	**6.85**	**2.28**
6/12	**50**	**46**	**46**	**94**	**11.85**	**3.95**
6/18	**50**	**40**	**40**	**78.3**	**24.62**	**8.21**
6/30	**48**	**38**	**38**	**80.8**	**26.57**	**8.86**

Surface experiment results table

Blur Condition	Average Time	Standard Deviation	Percent Correct	T Statistic	P Value
6/6	22.12	24.21	100		
6/30	84.88	41.15	66.66	-3.882	<0.001
6/60	100.66	29.73	11.11	-5.997	<0.001
6/120	104.85	25.18	14.28	-6.397	<0.001

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Annex P: Participant Visual Characteristics

			Masks			
CL dive	VA (u or cl)	CV	20/20	20/40	20/50	20/100
n	25	2	0.00	0.50	1.50	2.00
y	12.5	1	1.00	2.00	3.00	4.00
n	12.5	1	1.00	1.50	2.00	3.00
n	16	1	1.50	2.00	3.00	4.00
n	12.5	1	1.50	2.00	2.50	4.00
n	16	1	0.50	1.50	2.00	3.00
n	16	1	0.00	1.00	1.50	2.00
n	16	1	0.50	1.50	2.00	3.00
n	12.5	1	1.00	1.50	2.00	3.00
			Spectacles			
			20/20	20/100	20/200	20/400
			0.00	1.50	3	6
			1.00	2.50	4	7
			2.00	2.50	4	7
			1.00	2.50	4	7
			1.50	4.00	5	7
			0.50	2.00	5	6
			0.50	2.00	4	6
			0.50	2.50	4	6
			1.00	2.50	4	5
	16.50					
	14.60					
11.11	**15.44**					

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Annex Q: Vision Correction Options

The issue regarding contact lens use as a reasonable accommodation has been ongoing for as long as contact lenses have been available. Many of the current policies in many different occupations date back to research done 20 years ago, when hard and rigid gas permeable contact lenses were more prevalent and when all contact lenses had to sterilized between uses. There have been many advances in contact lenses in terms of comfort, infection control and ease of use, which should be reviewed to determine relative risks and advantages of this method. The issues regarding contact lens use are covered extensively in a recent review of contact lens wear and the environment (Cullen, 1993).

One of the advantages of contact lenses is they provide a flexible and accurate method of correcting refractive error in circumstances where glasses cannot be worn. Furthermore, contact lenses do not distort the image in the way spectacles can, and there is only a minute amount of contrast sensitivity (the ability to detect faint objects) loss associated with wearing them; similar to or less than that produced by spectacles. In addition they are far less likely to be dislodged than spectacles (see below).

The potential disadvantages involve the risks of dislodgement, irritation, non-compliance, physiological changes, contamination, and potential for discomfort due to changes in pressure. As will be demonstrated, the risk of these disadvantages occurring depends considerably on the type of contact lens under discussion.

Dislodgement: Good and Augsburger (1987), investigated this issue for police occupations and determined that contact lenses are far less likely to be dislodged than spectacles but the chances of dislodging were still considerable- almost 20% over the span of employment. A study by Wells et al (1999) demonstrated that the likelihood of police officers losing one contact lens while on duty has decreased to 10% during career, probably due to the fact that most officers were wearing soft contacts by that time. Hard contact lenses, on the other hand have been reported to dislodge spontaneously during swimming (Lovsund et al, 1980). This finding is supported by the results of our glasses questionnaire where none of the Combat or Navy divers who reported experiencing contact lens dislodgement. Given the refractive error in this group, it is very likely that most of these individuals are wearing soft contact lenses. Conversely, in interviews the SME's all reported circumstances where they had lost their mask. This suggests that the probability of losing a contact lens is low and the probability of losing both is much smaller. The risk of losing a contact lens while diving also appears to be small compared to the risk of losing the mask, which has a severe impact of the ability to perform the task at hand.

Irritation: The frequency of having episodes of inability to wear contact lenses due to irritation has also been reduced with the onset of soft contact lenses. Good *et al* (1987) reported levels of over 50% of wearers reporting such episodes for hard and rigid gas permeable lenses and slightly lower levels for soft contacts. By 1999, Wells was reporting a rate of 36%, while Goldberg *et al* (1994) reported levels of 15% of individuals who were not wearing their lenses at any given time.

Non-compliance with requirements for continuous wear: Goldberg *et al* (1994) reported that irritation was not the only reason for non compliance in a group of LAPD police officers who were accepted into the force based on a commitment to wear contact lenses at all times (as a reasonable accommodation to the uncorrected standard). When random checks were instituted, non-compliance accounted for 5 % of the group not wearing their contact lenses at any time. In this case, the officers could wear glasses. This is a more worrisome statistic if contact lenses are required to allow a diver to perform critical diving tasks such as locating and identifying ordnance.

Physiological Changes: Irritation and non-compliance are probably closely associated with the physiological changes that can occur with extended contact lens wear (Liesegang, 2002). These changes, which result primarily from reduced corneal function, can lead to changes in the morphology of the surface of the cornea as well as increased risk of edema, inflammation and infection. These effects are more related to extended wear contact lenses, and are also a function of the thickness of the contact lens. While the problems are worse with hard contacts, soft contacts and even disposable contacts can still cause problems if worn for extended periods of time. Liesegang indicates that truly disposable, daily wear contact lenses with very high oxygen transmissibility may avoid most of the problems outlined above. However, proper procedure must be followed and these lenses should not be worn for extended time periods to minimize the risk of adverse effects.

Contamination: In the water environment and particularly in the case of moderately contaminated water, there is always a concern that the contact lenses will trap bacteria that may cause severe eye infections. This has been reported for extended wear lenses (Soni et al., 1986) and may also be a function of improper hygiene (Stehr-Green et al, 1987). However, if the contact lens can be removed and replaced (e.g. disposable lenses) this will effectively remove the contaminant (Brown et al, 1997). The individual who exposes their cornea to the same source of contamination cannot similarly remove the contaminated cornea. Cullen (personal communication, 2003) points out that contact lenses can actually have a protective effect by temporarily shielding the cornea from contaminants. Again the use of disposable contacts in this circumstance may actually be an advantage, rather than a potential risk. However that is only true if proper procedure is followed and contact lenses are not worn for extended time periods. Padgett (1989) reports a similar finding for firefighters wearing contact lenses. In this case the lenses were reported by some individuals to have protected against the irritation of smoke particles getting into the eye.

Discomfort with Contact Lenses when diving or decompressing: With hard and rigid gas permeable contact lenses, there have been numerous reports of gas bubbles forming under the lens during decompression and edema resulting from pressure of the lens on the cornea during pressurized dives (Cullen 1993; Butler, 1995; Simon et al, 1978). However, these problems do not occur if soft contact lenses are worn (see Cullen, 1993 for a review of the evidence).

Contact lenses are not accepted as a reasonable accommodation within the Canadian Forces. Some of the reasons cited for this decision are as follows:
- the potential for eye irritation and/or lens dislodgment as compared to combat glasses;
- the problems of contact lens hygiene in primitive field conditions;
- difficulties of inserting contact lenses in emergency situations; and
- the impact of contact lens wear in the presence of fires or chemical agents.

For divers there is the additional concern that the lenses may promote infections when in contact with water contaminated with bacteria. However, in light of the literature and availability of ultra thin disposable lenses with high oxygen transmissibility, these problems appear to be somewhat less significant than originally supposed. Furthermore, USAF reports from the gulf war do not indicate significant reports of problems with chemicals or heat. In fact several recent studies of contact lens use in the USAF and US Army suggest that there are advantages to contact lens wear in situations where specialized equipment such as helmet-mounted displays and gas masks must be used, and that the potential problems in an operational environment may not be as significant as previously thought (Lattimore, 1992, Moore and Green, 1994). Furthermore hygiene problems in the field that may have been experienced with earlier soft contact lenses are no longer the problem with the advent of truly disposable daily wear lenses. In addition, Cullen (personal communication, 2003) reports that the cost of maintaining an annual supply of disposable contact lenses for diving purposes is no greater that obtaining a new pair of glasses each year.

It is worth noting that in 1996, the US Navy SEALS changed their policy on contact lens wear and began issuing waivers for contact lens wear as an acceptable accommodation to the uncorrected standard of 20/40. They also pay for contact lenses if the Commanding Officer requires a diver or a pilot to wear them.

The US Navy SEALS will also provide waivers for refractive surgery, however they carefully screen candidates and provide the surgery through their investigative program. Candidates who have had refractive surgery in other, non-military centers are not considered acceptable. Refractive surgery provides an alternative to the use of contact lens wear for individuals who cannot meet the V2 uncorrected standard while having the same positive impact on the pool of potential candidates. However, these procedures come with their own advantages and disadvantages which must be weighted to determine if this is a viable option for CF divers.

Surgical Correction of Refractive Error

Refractive surgery techniques have progressed significantly in the past 10 years. In 1990, the only technique available was radial keratotomy (RK). This surgery is rarely performed in Canada now. Photorefractive keratectomy (PRK) ablates and reshapes the front surface of the cornea to provide better refractive characteristics. However this method has a long recovery period as the top layer of the cornea, the epithelium, grows back and has a significant level of discomfort associated with the healing process. In Laser in-situ keratomilesis (LASIK), a thin flap of corneal tissue is lifted and the reshaping is done under the flap, which is then replaced. The recovery from this surgery is more rapid than PRK, but the results tend to be slightly less precise. Lasek is a combination of PRK and LASIK, in which the top layer of cells are lifted prior to treatment and then replaced. This procedure has many of the advantages of both PRK and LASIK. However, it is important to remember that all of these surgical procedures are irreversible and only somewhat amenable to retreatment if they are unsuccessful.

Each of these methods surgically alters the shape of the cornea and thus alters the eye's refractive power. Although these methods may have medical risks associated with them related to post-operative infections or corneal erosions or trauma, the risks are usually small. Studies have demonstrated that RK can result in instability of refraction (McDonnell *et al.*, 1996), glare disability (Applegate *et al.*, 1987), and there is significant risk of damage to the eye due to trauma (McDonnell, 1996; Vinger *et al.,* 1996). As a result, the CF has developed a policy of excluding candidates who have undergone this procedure. PRK, LASIK, and LASEK procedures have not produced the same risk of eye damage with trauma, and the initial refraction and visual acuity results (2 to 5 years) have been very encouraging. For example, a study of active personnel in the US Navy (Schallhorn *et al.,* 1996) who underwent PRK for myopia indicated that the majority of subjects experienced only transient glare problems and obtained good post-operative visual acuity (6/6 in all cases at one year post-op tests). However, several individuals experienced significant visual distortions in spite of 6/6 acuity. Investigators have determined that such distortions are only detectable using low contrast charts under dilated conditions (Casson *et al.,* 1996, 1996; Butuner *et al.,* 1994; Jackson *et al*, 1998).

Depending on the study centre, the type of surgery, and the initial level of refractive error, poor visual outcomes (in terms of poor visual acuity and reduced contrast sensitivity), can affect anywhere from 5 to 20% of the patients. These patients often complain of night-vision problems, which indicates that the poor visual outcomes are more likely to have an impact in low luminance environments. These types of low luminance environments are common in diving. Thus, it may be important to understand the impact of such visual distortions on task performance and to consider developing a standard for contrast sensitivity before proceeding to allow candidates to have refractive surgery to meet the vision requirements for divers.

The discussion of the advantages and disadvantages of refractive surgery vs. allowing contact lenses requires an in-depth analysis of the relative risk of these two options in producing divers who are non-operational. This type of analysis is beyond the scope of this document. However, based on the information available in this brief review, the following points can be made:

1. The use of disposable contact lenses does not appear to produce any visual distortions, while refractive surgery is associated with this risk.
2. The medical complications from refractive surgery are very low, while the risk of infection, irritation, and inability to continue use are probably higher with contact lenses if they are worn all the time.
3. The problems associated with physical stress in the diving environment are likely to be low for both contacts and surgery if the appropriate lenses/techniques are prescribed.

Based on this brief analysis, contact lenses remain the least visually disruptive option and may be more feasible if the analysis of the risks associated with the use of modern disposable lenses are found to be acceptable.