The Effect of Hand Immersion in 4°C Water on the Performance of Helicopter Evacuation and Survival Tasks

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Abstract - **Given a generally low year-round water temperature in the North Atlantic Ocean, individuals travelling to and from offshore petroleum installations in Canada must retain sufficient function of their hands to perform all the activities needed to exit a ditched helicopter and carry out subsequent survival tasks. The research objective was to test the amount of time subjects required to complete simulated ditched helicopter evacuation and survival tasks in cold water without hand protection. This research included two separate data collection phases. Phase one simulated tasks required to escape a helicopter after ditching in 4°C water, in two lighting conditions. Phase two simulated the tasks required to be completed after an individual had escaped the fuselage and is floating on the surface of the water, tested in 4°C and 20°C water temperatures. In both phases, most subjects completed the tasks in the time prescribed by the current Canadian Standards.**

Keywords
Helicopter ditching, survival tasks, hand dexterity, cold water, immersion.

INTRODUCTION

Water temperatures in the North Atlantic Ocean are generally well below the thermo-neutral temperature for the human body, even during the warmest periods of the year (Piantadosi, 2003). This creates challenges for individuals travelling to and from offshore installations in Eastern Canada, who must retain sufficient function and dexterity in their hands to perform all tasks essential to exit a submerged and inverted helicopter, swim to the surface and perform necessary survival tasks before donning hand protection (see Figure 1). The current Canadian National Standard ('CAN/CGSB 65.17-99') prescribes that hands remain bare until after helicopter evacuation and survival tasks have been completed, with the rationale that existing hand protection reduces manual dexterity and tactility, potentially hindering the execution of critical escape and survival tasks. During the initial stages of cold water immersion function of the limbs, in particular hand and finger performance are impaired and can be rendered useless, possibly leaving an individual unable to complete vital tasks (Brooks, 2003; Golden & Tipton, 2002).

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Figure 1. Helicopter ditching impact in open water.

OBJECTIVES

The objective of this research was to investigate the amount of time subjects required to complete simulated helicopter evacuation and survival tasks. Tests were conducted in various combinations of water temperature and lighting conditions.

METHODOLOGY

Testing took place in a laboratory equipped with a temperature controlled immersion tank (2m x 2m x 2.5m). Tank temperatures were monitored by an external temperature probe. Data collection included two separate phases. Phase 1 simulated the procedures an individual is required to perform during an evacuation from a helicopter fuselage using a simulator. The test encompassed the period beginning directly after helicopter impact against the water, as the fuselage begins to fill with water, to the moment when the individual escapes through the cabin exit. Subjects completed evacuation tasks while partially submerged in water at 4˚C in two lighting conditions: normal ambient daylight defined as "Light" and total blackout darkness defined as "Dark".

Phase 2 simulated survival tasks designed to be completed once an individual has successfully evacuated the helicopter cabin, has swum to a relatively safe area and is floating supine on the surface of the water. Phase 2 survival tasks are intended to secure and prolong the life of the individual who is now floating in open water and in direct contact with the elements. Subjects completed these survival tasks in two water temperature conditions: 4˚C and 20˚C, both in normal ambient daylight conditions.

In both experiments subjects wore an approved helicopter transportation suit, issued based on the manufacturer's specified anthropometric size ranges. Each subject was given a standardized pre-trial briefing, which included information and familiarization of the laboratory facility, equipment and experimental procedures, including the tasks they were required to carry out during the experiment. Key words were given verbally throughout the experiment to ensure all subjects performed the tasks in the same order. All trials were recorded (visual and audio) for further data reduction and analysis. Task times were derived to the nearest second from the video records. The Human Investigation Committee (HIC) of Memorial University of Newfoundland granted ethical approval to complete both phase of the study.

Phase 1 – Helicopter Evacuation

Thirteen subjects (see Table 1) completed simulated helicopter evacuation tasks while immersed in 4˚C water in both "Light" and "Dark" conditions within one laboratory session. The subject was seated and harnessed into a Sikorsky S-92 helicopter simulator which was secured to the interior of the immersion tank. Tank water depth was adjusted to clavicle level once the subject was seated. Care was taken to ensure the subject's hands did not touch the water until the trial began. The investigator reviewed experimental tasks, site locations and verbal cues which had previously been discussed in the pre-trial briefing. Depending on the trial order black-out goggles were donned by the subject for the "Dark" condition.

	Age (yrs)	Stature (cm)	Mass (kg)	Male	Female
Mean	23.2	173.9	74.9	6	7
SD	2.0	10.0	17.5		
Max.	29.0	196.0	112.9		
Min.	21.0	160.7	51.3		

Table 1. Phase 1 subject demographics.

When instructed by the investigator, the subject fully submerged both hands into the water for 30-seconds while assuming a bracing position (see Figure 2).

At the 30-second hand immersion mark, upon receipt of a verbal signal from the investigator, the subject executed the evacuation tasks in the following order:

1. Deployment of Helicopter Underwater Emergency Breathing Apparatus (HUEBA)
2. Jettison simulator window
3. Brace window frame
4. Release harness
5. Simulate egress through window frame

Key words used by the investigator, which were discussed in the pre-trial briefing and throughout the in-tank refresher sessions, were: "bracing position", "HUEBA – one, two", "lever down", "window out", "grab frame", "harness" and "hands up, head out".

Successful deployment of the HUEBA was defined as locating and releasing the unit from its storage site, orientating the mouthpiece against the side of the cheek and pressing it there for a period of two seconds, thus simulating the time it takes to fit the mouthpiece securely within the mouth and teeth.

Between trials the subject was removed from the tank for recovery by placing hands within a damp, warm towel for ten minutes (Sendowski et al., 1997). After the recovery period had lapsed the subject was then repositioned into the seat for the second trial. Prior to the start of the second trial, the subject was reminded of the experimental tasks verbal cues. Only subjects who successfully completed all tasks were included in the final data analyses.

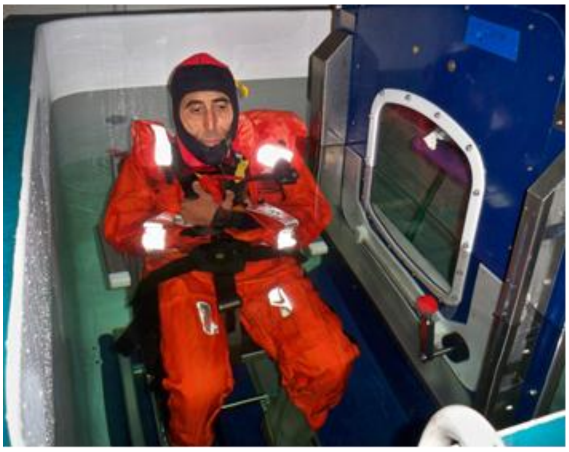

Figure 2. Subject starting position.

Phase 2 – Open Water Survival Tasks

Twelve subjects (see Table 2) completed the simulated survival tasks while floating, supine on the surface of the water. Over the course of two laboratory sessions the subject completed two different trials which included a two-minute barehanded immersion while floating in the immersion tank at water temperatures of 4˚C and 20˚C. The subject was instructed to carefully enter the tank, ensuring that the hands were not in contact with the water prior to the start of data collection trial. Once in the tank the subject lay in a supine position mimicking the body position of an individual in open water.

Pre-trail hand immersion duration reflected the moments after a helicopter ditching. The subject's hands were submerged for two standardized phases of sixty seconds in length each. On the verbal cue of the investigator, the subject fully submerged both bare hands underneath the water for a period of 60 seconds while keeping them motionless in one position (see Figure 3). Once a helicopter has ditched the subject must first escape from the fuselage. With a re-breathing apparatus this should give the individual approximately 60-seconds of air for helicopter evacuation, simulating the first hand immersion phase. From 61-120 seconds the subject continuously sculled water at a moderate speed within the immersion tank while floating in the same position. This active hand movement within the water mimicked an individual, now free from the helicopter, swimming away from the immediate crash site and debris to a safe area of water.

	Age (yrs)	Stature (cm)	Mass (kg)	Male	Female
Mean	22.2	170.0	75.8	6	6
SD	1.0	9.0	17.9		
Max.	23.0	193.6	101.5		
Min.	20.0	161.0	56.5		

Table 2. Phase 2 subject demographics.

Once successfully evacuated from the fuselage and floating on the surface of the water the individual is now in a position to complete the survival tasks studied in this experiment. At the 120-second hand immersion mark, on the verbal signal from the investigator, the subject executed the survival tasks in the following order:

1. Personal Locator Beacon (PLB) activation

2. Deployment of ancillary buoyancy device

3. Deployment of spray shield

4. Don gloves – including Velcro straps

Pre & Post Hand Grip Strength

Pre and post dominant hand grip strength tests were administered each trial using a hydraulic hand dynamometer (BASELINE® hydraulic hand dynamometer Irvington, NY, U.S.A). Both tests were taken while the subject was wearing the flight suit and standing within the immersion tank. The subject was handed the grip strength dynamometer and instructed to raise both arms above their head and squeeze (as was practiced in the briefing session). Before administering the post grip strength test the investigator first helped the subject stand upright in the immersion tank, released air from the buoyancy device, doffed the subject's gloves and spray shield, as well as dried the subject's dominant hand. Grip strength tests were administered this way to ensure that there was minimal recovery of hands after the trial ended, thereby obtaining a true measurement of grip strength immediately after the tasks were completed.

Figure 3. Pre-test bare hand immersion.

RESULTS

Phase 1 - Helicopter Evacuation

The data were submitted to a repeated-measures two-tailed student t-test (SPSS: V18.0). In all cases normality of homogeneity of variance was verified. For each data set the mean, standard deviation (SD), maximum and minimum values are summarized. The relative (%) differences between the two conditions are included for these data sets and are calculated as: (((Light- Dark)/Light) * 100%).

Four subjects failed to complete the window jettison task within the required 10-second period. The subsequent results are based on the complete data set from the 9 subjects who successfully completed all experimental tasks. Statistical analysis revealed a significant difference in total times between "Light" and "Dark" conditions (p=0.023). In most cases, it took longer (approximately 1.6 seconds) to complete the task in the "Dark" condition (see Table 3).

	Light	Dark	% Difference
Mean	16.5	18.1	9.6
SD	5.7	3.4	
Maximum	27.0	23.0	14.8
Minimum	8.0	13.0	62.5

Table 3. Total time for all tasks.

Phase 2 - Open Water Survival Tasks

The data were submitted to a repeated-measures two-tailed student t-test (SPSS: V17.0). In all cases normality of homogeneity of variance was verified. For each data set the mean, standard deviation (SD), maximum and minimum values are summarized. The relative (%) difference between the two conditions are included for data sets and is calculated as ({Cold- Warm}/ * 100).

Table 4 summarizes the time required to complete all the survival tasks. There was a significant difference between the two water temperature conditions (p=0.001). This increase in performance time is attributed to the glove donning times.

	Warm	Cold	% Difference
Mean	63.3	91.1	44.0
SD	13.3	16.8	
Maximum	91.0	117.0	28.6
Minimum	50.0	60.0	20.0

Table 4. Total time for all tasks.

Table 5 reports the total time to don both gloves. The statistical analysis reveals it took significantly longer (p<0.001) to perform this task in "Cold" water.

	Warm	Cold	% Difference
Mean	45.8	66.1	44.2
SD	11.9	14.4	
Maximum	76.0	87.0	14.5
Minimum	34.0	47.0	38.2

Table 5. Glove donning total times.

It should be noted that glove-donning time could be influenced by several factors:

a) In both the "Warm" and "Cold" conditions, several subjects incorrectly fixed the Velcro wrists straps, which required more time to undo and correct.

b) The "Cold" condition caused a loss in grip strength and tactile senses.

c) Some subjects were not able to fully don, or get hands fully within the glove hands due to its construction, loss of hand and finger performance or presence of water (see Figure 4).

Figure 4. Glove donning tasks.

Table 6 and 7 contain the grip strength changes. There were no significant differences, as expected, in the pretest grip strength (p=0.787). This was measured prior to hand immersion. These data also suggest the grip strength test was repeatable.

	Warm	Cold	% Difference
Mean	45.0	44.7	-0.7
SD	14.8	14.1	
Maximum	66.4	63.6	-4.2
Minimum	29.6	29.6	0.0

Table 6. Grip strength: pretest.

Table 7 reveals that the posttest grip strength was significantly decreased due to the "Cold" water immersion (p=0.002) compared to the "Warm" water condition.

	Warm	Cold	% Difference
Mean	40.6	36.7	-9.7
SD	11.3	9.5	
Maximum	56.4	51.4	-8.9
Minimum	28.2	23.6	-16.3

Table 7. Grip strength: posttest.

DISCUSSION

In Phase 1, 9 of 13 subjects completed all helicopter evacuation tasks in both the "Light" and "Dark" conditions after immersing bare hands in 4ºC water for a period of 30-seconds. All four subjects who failed to jettison the emergency exit were female and of generally smaller morphology in relation to the other subjects. Failure to jettison the exit occurred 3 times in the "Light" condition and 2 times in the "Dark" condition among these 4 subjects' trials. This may pose further research questions and investigation into the specific factors involved in jettisoning exits under real world evacuation scenarios.

Although task times increased due to the “Dark” condition, all times were within the required time prescribed by Canadian Standards (CAN/CGSB 65.17-99). The range in total time to complete the task in the “Light” condition was 8-27 seconds, while the same task took between 13-23 seconds to complete in the “Dark” condition (see Table 3). All subjects were naive to these tasks and did not have an opportunity to practice these skills prior to data collection. The “Light” and “Dark” conditions were presented to the subject pool in a balanced and randomized fashion to minimize any learning effects.

The HUEBA, window jettison, brace window frame and simulated egress tasks were identified as taking statistically significantly longer in the “Dark” condition. In each case, the increased time was approximately 0.5 seconds for each task. However, this had an overall more significant effect on the total time (1.6 seconds) to complete the task.

In Phase 2 all subjects completed the survival tasks in less than 2-minutes following a 2-minute barehanded immersion in both water temperature conditions which complies with Canadian standards (CAN/CGSB 65.17-99). There was no statistical difference in the time to complete these survival tasks when performed in both 4ºC and 20ºC water. However, when observing this in terms of total time, the “Cold” water condition took 44% longer then the “Warm” water condition, equating to a mean time increase of almost 28 seconds, representing valuable moments when in a survival scenario.

Of the total period subjects required to complete all survival tasks, glove donning made up the majority of time (see Table 5). For both “Warm” and “Cold” conditions the glove donning task time averages over 70% of the total time for all open water survival tasks.

Gross grip strength measured via a hand dynamometer, although not significant, decreased by a mean value of almost 20% post “Cold” water immersion (see Table 7). With increased barehanded exposure times tasks may take even longer and depending on hand and finger function degradation, may not be possible to complete. In reality, barehanded exposure to cold water and the loss of manual functioning is only part of the many factors at play during a helicopter ditching and evacuation at sea. From the moment of physical impact, potential injuries and disorientation produced from the ditching itself to the severity of sea conditions and the psychological stress the situation evokes, there are numerous elements involved which need to be considered when analyzing a helicopter ditching, evacuation and survival of individuals.

CONCLUSION

The purpose of this research was to examine the effects of realistic immersion and exposure times of bare hands in cold water for individuals involved in a helicopter ditching and how this might affect the performance of vital evacuation and survival tasks. Overall, the results and interpretations from both phases will provide important information to regulatory bodies as they evaluate current standards. Advancement of research and development in helicopter transportation suit systems, the suits interaction with individuals, the helicopter fuselage and evacuation tasks under real-world scenarios likely to be encountered in an emergency at sea, are necessary to better prepare the industry and its workers for reality. Further research would complement these findings in developing standard criteria and test methods that will allow regulatory bodies and manufacturers to address issues related to the completion of helicopter-related evacuation and survival tasks quickly in cold water.

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REFERENCES

Brooks, C.J. (2003). *Survival in Cold Waters: Staying Alive* (Transport Publication TP13822E). Ottawa: Transport Canada.

Canadian General Standards Board. National Standard of Canada. Helicopter Passenger Transportation Suit Systems Standard (CAN/CGSB-65.17-99).

Golden, F., & Tipton, M. (2002). *Essentials of Sea Survival.* Windsor, Canada: Human Kinetics.

Piantadosi, C. A. (2003). *The Biology of Human Survival: Life and Death in Extreme Environments.* New York: Oxford University Press.

Sendowski, I., Savourey, G., Besnard, Y., & Bittel, J. (1997). Cold induced vasodilation and cardiovascular responses in humans during cold water immersion of various upper limb areas. *European Journal of Applied Physiology, 75*, 471-477.