Breath-Hold Times in Air Compared to Breath-Hold Times During Cold Water Immersions

Michael J. Taber; Scott N. MacKinnon; Jonathan Power; Robert Walker

INTRODUCTION: Given the effects of cold water immersion on breath-hold (BH) capabilities, a practical training exercise was developed for military/paramilitary personnel completing a helicopter underwater egress training (HUET) program. The exercise was designed to provide firsthand experience of the effects of cold water exposure on BH time.

METHODS: After completing the required HUET, 47 subjects completed two BH testing sessions as well as a short questionnaire. The first BH was completed while standing on the pool deck. The second BH was completed while fully immersed (face down) in 2-3°C water. There were 40 of the volunteers who also breathed from an emergency breathing system (EBS) while in the cold water.

RESULTS: Results demonstrated that BH capabilities in cold water were significantly lower than those in ambient air. A significant correlation was also found between BH in air and the difference in cold water vs. air BH capabilities, which suggests that subjects who can hold their breath the longest in air experienced the greatest decrease in BH when immersed. Results indicate that 92% of the subjects reported that the practical cold water immersion exercise had a high value. Finally, 58% of those who used the EBS reported that it was harder to breathe in cold water than while in the training pool (approximately 22°C).

DISCUSSION: The BH times for this group were similar to those reported in previous cold water immersion studies. Based on the questionnaire results, it is possible, when carefully applied, to include a practical cold water immersion exercise into existing HUET programs.

KEYWORDS: helicopter underwater egress training, practical exercises, emergency breathing system.

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The importance of helicopter underwater egress training (HUET) has been well established.[15,22,23] Specifically, it has been shown that HUET programs provide an opportunity to prepared individuals, in a highly controlled setting, for the extreme conditions that are present during a helicopter ditching.[6,8,21] Cunningham[15] reported that survival rates are significantly higher for those who have completed a HUET program when compared to those who had not. Examinations of factors that cause injury or death in a ditching have consistently shown that drowning, and not impact injury, is the primary cause.[2,12,14] To address issues that contribute to drowning (e.g., disorientation, reduced visibility, exit design limitation, and breath-hold capability), HUET programs specifically focus on the development of skills necessary to egress a helicopter that has inverted and flooded after contacting the surface of the water.[9,11,20] Taber and McCabe[23] explored the influence of emergency flotation systems on overall survival rates and found that if the helicopter sank below the surface, significantly more fatalities occurred. It has also been noted that the majority (between 50% and 85%) of helicopters invert at some point during the event.[6,14,22] If the helicopter inverts and floods, the occupants will be required to hold their breath until they have successfully egressed the fuselage and surfaced. However, if an emergency breathing system (EBS) is available, the individuals may have the opportunity to use the system during the egress

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phase to ensure a successful escape by extending their breath-hold time.[7,21]

The human physiological response to cold water immersion is well understood.[10,16,19] Specifically, the effect of cold water has been shown to significantly reduce the capability to breath-hold (BH) when compared to BH in air or warm water conditions.[18,25] For example, Hayward and Eckerson[17] suggest that in air, BH time would be about 60 s, but would be reduced to approximately 50%, 40%, and 30% of that time in 20°C, 10°C, and 0°C water temperatures, respectively. More recently, Jay and White[18] showed a 46% reduction in BH times between 0°C water temperature and air. This reduction in BH capabilities has been cited as a contributing factor in several helicopter ditching fatalities.[12,24,]

Barwood et al.[5] have suggested that BH times can be increased through habituation and/or psychological preparation. During an examination of BH capabilities in 12°C water for two groups, it was noted that habituation alone increased BH by 73%, while the combined effect of habituation and psychological skills training improved BH by 120%. Although these improvements in BH appear to be of considerable benefit to those exposed to overwater helicopter operations, Barwood et al.[4] report that acute anxiety (i.e., just prior to ditching in the water) reduces the effects of habituation. Unfortunately, the effects of cold water on BH times are typically only provided in a theoretical lecture during HUET programs. At present no HUET providers are offering a practical cold water immersion exercise as part of their training protocol.

Similar to Hayward and Eckerson's[17] BH findings, Cheung et al.[11] showed that offshore workers could only hold their breath for 37 s on average in a water temperature of 25°C. It was also noted that 34% of the 228 subjects were unable to hold their breath long enough to complete a realistic ditching sequence evacuation of 18 passengers as outlined by Brooks et al.[9] In the Brooks et al.[9] underwater egress study, of the 132 sequences, egress time for the last person to reach the surface ranged from 28 to 92 s. Based on these findings, it was recommended that offshore helicopter passenger cabins should be designed to ensure that egress times do not exceed 20 s; however, in cases where this is not possible, there should be the provision of EBS.[9]

Recently the Civil Aviation Authority (CAA)[12] issued a report (CAPP 1145) that explored fatality rates for helicopter ditchings/water impacts within the United Kingdom Continental Shelf. It was reported that 73 accident events occurred between 1976 and 2013 (an average of 1.97/yr over the 37 yr). The aim of the review was to provide an overview of current operations and identify factors that could improve passenger and crew safety while minimizing the likelihood of fatal accidents. One of the primary actions items to be implemented for all offshore helicopter transport operations was to require that all passengers be trained to use and fitted with a Category A EBS (i.e., 10 s to deploy and can be completely operated after submersion/inversion underwater).

Limitations set out by the CAA[13] in an earlier report (CAPP 1034) suggest that only a compressed air type of EBS will meet the Category A requirements. As this type of EBS is already in use in the Canadian offshore petroleum industry, it is likely that the UK oil and gas community will also implement compressed air systems.[9] Taber and McCabe[21] provided support for a compressed air EBS in HUET egress sequences with multiple passengers by considering the systems as a way to mitigate egress issues for ground troops being transported in a modified Sea King helicopter. It was reported that the mean egress time for the troops on BH was between 32 and 37 s for the upper personnel and cargo doors, respectively. Not surprisingly, when asked to BH during an egress that included 12 troops, only 58% successfully completed the tasks compared to 100% successful egresses while using EBS.[21]

Interestingly, the majority of previous studies exploring the use of EBS have all been conducted in pool water (∼22°C). To date, only Barwood et al.[3] have explored the use of an EBS in cold water (5°C); however, the clothing ensemble and EBS used in the testing were different than those used by the current HUET trainees in their overwater flight operations. Although HUET trainees typically receive theoretical information regarding the influence of cold water on BH, they do not normally have a chance to practically experience how they would personally respond to the harsh conditions. Therefore, to explore the perceived importance of practical cold water immersion experience during HUET programs, this paper outlines BH capabilities and subjective responses of military/paramilitary members regarding the functionality of the EBS under more realistic environmental ditching conditions.

METHODS

Subjects

As this training was part of an existing program, informed written consent was not required (formal communication with the Interdisciplinary Committee on Ethics in Human Research – ICEHR from Memorial University). As part of a required HUET program, 47 male military/paramilitary HUET trainees completed a practical cold water exposure exercise. The mean age (yr) of the subjects was 38.2 (±8.3) and ranged from 25–56; mean stature (cm) was 178.0 (±7.5) and ranged from 157.5–195.6; mean mass (kg) was 84.8 (±11.1) and ranged from 61.2–108.9. The individual data in this study are considered a sample of convenience, as not all HUET trainees attending the courses were required to volunteer to take part in the cold water exposure sessions. Therefore only the individuals who decided to complete both BH sessions were included in the data analyses.

Procedure

Prior to collecting the BH data, the HUET trainees were informed of the goals for the practical cold water immersion exercise. They were informed that completion of the exercise was on a voluntary basis. They were also informed that they could choose to have their results excluded from the dataset even if they did participate in the exercise. For those who volunteered to complete the session and remain in the dataset, age, stature, and body mass information were collected before the practical testing. Performance data were then collected during two BH sessions that were conducted after the trainees had successfully completed the requirements for a HUET certificate. The first BH session (BH_{air}) was completed poolside (~21°C ambient temperature). The second BH session (BH_{cw}) was completed in 2 to 3°C water. During the BH_{cw} session, individuals were submerged to their neck prior to placing their face below the surface of the water. The immersions took place in a 1.5 m × 3 m × 1.5 m fiberglass tank that circulated cold water through a custom-built chiller and filtration system located on the deck of an indoor swimming pool at the HUET provider's facility.

Water temperature was maintained between 2°C and 3°C for all trials. In both BH sessions, HUET trainees wore an aviation immersion suit (Mustang, Bellingham, WA: MSF751 CF Constant Wear Aviation Drysuit; or Switlik, Trenton, NJ: U-ZIP-IT™; SW-S3320-XY2) and a helmet (Gentex™, Carbondale, PA: 97,427/91D8073-3, SPH-5®CF) (**Fig. 1**). The HUET trainees were informed that the data they provided during the practical cold water exposure sessions would be used for research and would be submitted for publication.

In addition to completing the two BH sessions, the HUET trainees breathed from a compressed air EBS (Survival Egress Air, SEA LV2; Aqua Lung, Vista, CA) while they were submerged (face down) in the cold water. After breathing from the unit underwater, the HUET trainees were asked to rate whether the EBS was "easier," the "same," or "harder" to use in the cold water when compared to the warmer water in the pool (~22°C). The HUET trainees were also asked to rate the value of the cold water training as "low," "medium," or "high."

Statistical Analysis

Prior to performing the statistical analysis for hypothesis testing, the data were plotted to check for data entry errors and outliers. Additional checks were performed to test for the assumptions of normality using the Kolmogorov-Smirnov test.[1] The Kolmogorov-Smirnov test was used to test the assumption (null hypothesis) that the data were normally distributed. If the resulting P-value is less than the alpha level selected (0.05 in this case), the data are not normally distributed and nonparametric tests were used. Normally distributed data from each of the post-egress skill performance dependent variables were compared in a within- and between-subject design. The difference in BH times (BHT) between conditions (BHT_{diff}) was calculated by subtracting BHT_{cw} values from BHT_{air}. All data were examined with GraphPad InStat (version 3.10) software.

Where appropriate, repeated measures analysis of variance (ANOVA) were used to explore changes in BH times for each test. Binary data (e.g., EBS functionality and value of cold water immersion training) were analyzed using a Chi-square test. A paired t-test was used to test parametric data; the Wilcoxon matched pairs test was used for nonparametric data. All values are presented as mean and (SD) unless otherwise stated.

Fig. 1. Practical cold water immersion exercise military ensemble.

RESULTS

A Wilcoxon matched pairs test of significance revealed that the mean BHT_{cw} times [19.21 (7.04) s] were significantly less compared to the BH_{air} condition [69.87 (25.45) s] (**Fig. 2**). BH times

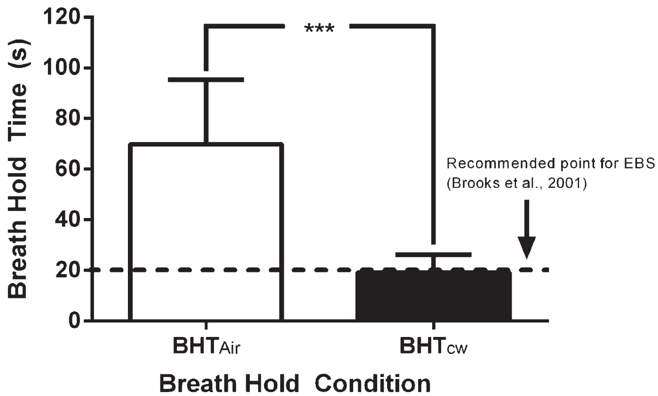

Fig. 2. Mean breath hold times (seconds) for the two breath hold conditions. Mean (SD); BHT_{Air} = breath-holding in air; BHT_{CW} = breath-holding in cold water; *** = $P < 0.001$.

in the BH_{air} condition ranged from 30–100 s, while those in the BH_{cw} condition had a smaller range from 10–42 s.

A correlation test was carried out to explore the strength of the relationship between BH_{cw} and BH_{air}, and between BH_{cw} and BHT_{diff}. Results indicate that there was a weak correlation between BH_{cw} and BH_{air} (r = 0.51) (**Fig. 3A**). In contrast, the results indicate there was a significant positive correlation (r = 0.97) between the two means for BH_{cw} and BHT_{diff} values (**Fig. 3B**). Finally, correlation analyses were used to explore the influence of age, height, and weight (BMI) on BH. The results of these analyses were not found to be significant.

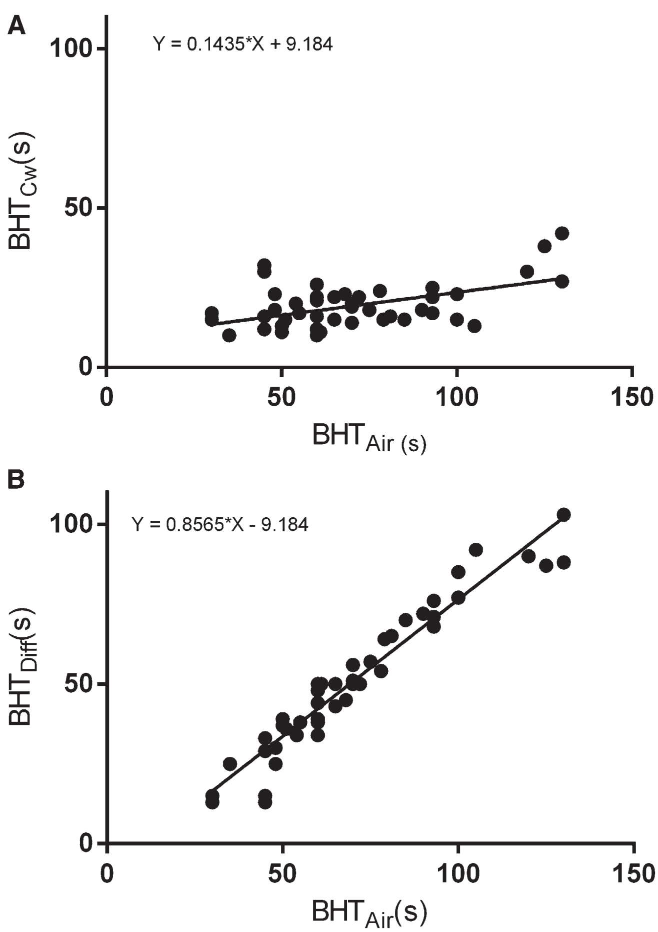

Fig. 3. A) Correlation between BHT_{Air} and BHT_{CW}. B) Correlation between BHT_{Air} and BHT_{Diff}.

Out of the 47 individuals surveyed, 7 individuals were not required to use the EBS during their HUET program and, therefore, did not respond to the survey question related to clearing the regulator. Of those who used the EBS, 23 (57.5%) responded that they found clearing the EBS (i.e., purging residual water from the demand valve of the regulator) in cold was at the same level of difficulty as clearing it in warm water during the standard HUET exercise training. Of the subjects, 17 (42.5%) reported that clearing the EBS in cold water was harder compared to when they performed it in warm water. None of the subjects (0%) indicated that the clearing procedures were easier in the cold water.

There were 43 of the subjects (92%) who reported that they found the value of the cold water training to be "high." Only four subjects (8%) reported that the training was of medium value. A Chi-square analysis did not reveal that there was any significant difference in the ratings. However, when exploring the ratings based on previous HUET experience, it was noted that 100% of those individuals who had not previously completed the training rated it as having a "high" value.

Use of the EBS in the cold water was also examined through a Chi-square analysis. The results indicated that there was a significant difference in the rating of difficulty between those who had some HUET experience and those who had none (χ^2 = 4.32, *df* = 1, *P* = 0.038). From these data, 75% of those with no previous HUET experience rated the EBS harder to use in cold water, while 65% of those with some experience rated it as no more difficult than in warm water.

DISCUSSION

This study sought to investigate the perceived benefit of practical HUET and EBS training in cold water. The differences in water temperature between real world and training conditions appear to result in a decrease in the ability of a person to use an EBS during a helicopter egress. Our data supports previous studies showing the detrimental effects of cold water on maximum BH time.[11,18,25] BH times were reduced 72% when comparing BH_{cw} to that in the BH_{air} condition. This significant reduction in BH time presents a considerable challenge to egressing from a capsized and flooded helicopter. The mechanisms underpinning this reduction in maximum BH time has been well covered by previous studies and is beyond the scope of this study.

The significant positive correlation between maximum BH times in the BH_{air} condition and reduction in maximum BH times due to cold water (BHT_{diff}) provides strong justification for the use of EBS during egress from a helicopter. The weak correlation between maximum BH times in the BH_{air} and BH_{cw} conditions suggests that longer BH times in air will not necessarily result in longer BH times in cold water. In fact, the opposite appears to be true: those subjects who had the longest maximum BH times in air also experienced the greatest reduction in times when breath holding in cold water. Facial immersion in cold water appeared to have an "equalizing" effect on BH times by reducing the range of the BH values in the BH_{cw} condition compared to BH_{air}. In the BH_{air} condition, maximum BH times ranged from 30–130 s; a difference of 100 s. In the BH_{cw} condition, it ranged from 10–42s; a difference of only 32 s. These results suggest that even people who think themselves competent swimmers and able to hold their breath for extended periods of time should still use an EBS during a helicopter egress due to the effect of cold water on reducing maximum BH times. These empirical findings should be included in the HUET/EBS training curriculum to highlight the fact that BH times in air do not necessarily transfer to cold water immersion situations.

The subjective evaluations were based on the differences in clearing an EBS in cold water vs. more traditional HUET requirements in warmer conditions. Given that a considerable number of ditchings occur in water temperatures below 15°C, current assessments of HUET performance may not provide a realistic approximation of actual performance. Support for the use of EBS during overwater operations has been debated in previous research, which has highlighted the benefits of supplemental air during situations for individuals not seated directly next to an exit or where more complex tasks are necessary to egress.[20,21] The BH_{cw} results in this study clearly show that the HUET subjects' average BH capabilities were below the recommended 20-s time for egress without EBS.[9] These results are particularly significant in light of these data being collected from military/paramilitary personnel who volunteered to take part in the practical exercise and are more likely fit, both physically and psychologically, in comparison to the typical offshore oil and gas employee. These study subjects were highly motivated and had been fully briefed on the effects of cold water and should be considered a best-case scenario sample population.

The feedback from the HUET trainees suggests that they understand the effects of cold water on maximum BH times and EBS use. The vast majority of all 47 subjects (92%) said that they found training in cold water to be of high value, while the remainder said it was of medium value. Of the subjects that used the EBS in the cold water, 42.5% reported that it was harder to clear compared to standard HUET requirements in the warmer pool water. Over half of the subjects (57.5%) indicated that clearing the EBS in the cold water was just as difficult as in the pool and no one found it easier. These results suggest that consideration should be given to having all personnel experience practical cold water immersion training during HUET to provide a better understanding of how the colder conditions will influence evacuation success. HUET programs are ideally suited to provide this type of training, as they are typically conducted in highly controlled environments with medically trained personal nearby. By providing opportunities for individuals to experience the equalizing effects of cold water in regard to BH capabilities, greater focus can be directed at developing EBS performance.

Based on the results, the following conclusion can be made:

1. Practical cold water exposure training sessions appear to be beneficial in providing an opportunity for "hands-on" experience in a controlled environment.
2. As in previous cold water BH studies, a significant decrease in average BH capabilities was found when comparing air to cold water conditions.
3. Previous HUET and EBS experience appears to influence ratings of difficulty and value of the practical cold water exercise.

Based on this study and the previous body of work related to the deleterious effects of cold water on BH capabilities, future HUET programs should consider offering a practical cold water exercise in which course trainees are given the opportunity to immerse their face in water that is at or below 5°C while attempting to hold their breath. However, individuals should be warned of the effects that the cold water face immersion will have on their ability to hold their breath and instructed not to push themselves beyond their perceived limits. HUET staff should be prepared to provide medical assistance to trainees that volunteer to take part in the cold water immersion exercise. As data was not collected on how the cold water influenced the ability to deploy and clear the EBS, future studies should be carried out with both military and civilian offshore workers. By exploring this aspect of the HUET program in more detail, it may be possible to provide better guidance regarding the EBS design criteria and how to best use the system in a real ditching.

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