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Simulation Fidelity and Skill Learning during Helicopter Egress Training: The Role of Vision

Stefanie Dawn Martina, Gal Ziv, Elizabeth Sanli and Heather Carnahan

Abstract

This project aimed to evaluate the effects of ambient lighting during practice and performance of simulated helicopter escape sequences. Participants were randomized to one of the following groups to practice a standard helicopter underwater escape sequence: Light (with room lights on), Dark (with room lights off), or Graduated (in the light for the first half and then in the dark for the second half of the trials). Following practice, participants had a minimum of 30 min break, followed by retention testing in the dark and then in the light. Dependent measures included accuracy and movement time. Results indicated that participants performed more accurately during the dark retention trial than during the light retention trial. This could be due to increased arousal elicited by performance in the dark or, alternatively, may suggest that performance of helicopter escape sequences is not visually mediated. Based on findings, it appears that training in the light is suitable for potential performance in the dark.

Keywords: learning specificity, helicopter escape, simulation, HUET, training

1. Introduction

Safety training for high-risk industries and scenarios requires an approach that optimizes learning for enhanced skill learning and retention. An example is helicopter underwater escape training (HUET) for surviving a ditching over water. HUET is mandatory for offshore oil and gas employees and relevant military personnel. Currently, no universal training standard exists [1].

When a helicopter ditches in water, it typically inverts and sinks [2–4]. Crew and passengers often have less than 15 s of notice to make an underwater escape [5]. Not surprisingly, drowning has been identified as the leading cause of death following a ditching [6]. Disorientation and limited vision have been hypothesized as contributing to reduced survival [1, 7]. These factors are influenced by darkness, which has been linked with higher mortality rates during egress [1, 5]. Arguably, all egress occurs in low-light conditions. A nighttime helicopter ditching would obviously occur in dark conditions. However, regardless of time of day, numerous factors degrade light availability and consequently may impact visibility. For example, the inversion of the helicopter directs windows away from daylight and transmissivity of light through water is much less than light through air. As the

helicopter sinks, light penetrance degrades. Indeed, at 35 feet of sea water, approximately 20% of light penetrates clear ocean water [8]. Debris presence [9] and water turbidity [8, 9] further impact light attenuation. Even at shallow depths with bright sunlight, very high turbidity can degrade visibility to less than 1 foot of distance [8]. Presumably, darkness would augment challenges that are exacerbated by poor visibility such as finding exits and getting oriented to the water's surface, thereby impacting survival. Research has shown that night flying is associated with reduced survival rates [1, 5]. One study reported that survival rates for a nighttime and daytime crash were 41 and 77%, respectively. Limited vision during egress was hypothesized as contributing to the reduced survival rate at night [1]. To mitigate this, emergency exit lighting has been incorporated in helicopter design, known as helicopter emergency escape lighting (HEEL). Some studies have demonstrated reduced escape times with HEEL in the laboratory setting [9–12]. However, the effectiveness of HEEL remains a concern, as there is some evidence to suggest that lights may not be detectable when seated by the aisle even with bright ambient lighting conditions [9].

To help prepare for emergency egress, many military organizations and industries have mandated that relevant personnel complete HUET. Since no universal training standard or assessment standard exists [13], whether trainees practice egress in low-light conditions will vary based on the best practices of individual training facilities. Limited research exists on optimal training curricula to improve performance and survivability. The principle of learning specificity states that practice is most effective when it closely matches actual performance conditions [14]. Skill learning is contingent upon the development of a sensorimotor plan that is sensitive to sensory information available during practice [14–16]. According to these principles, helicopter egress practice should be conducted in low-light conditions to optimize learning.

The 2009 Cougar Flight 491 helicopter crash off the Newfoundland, Canada coast prompted an increased focus on identifying and mitigating safety threats to helicopter night flying. Following the accident, the Commissioner's report recommended the restriction of night flying until adequate safety improvements were made [17]. A ban on night flights in the province has remained in effect. Another recommendation made was increased simulation fidelity of training. Simulation fidelity refers to "the degree of faithfulness between entities" [18]. The similarities between entities, or conditions, govern the degree of learning transfer [19, 20]. A high degree of simulation fidelity may be particularly important for optimizing learning when training for high-stress scenarios [1, 18, 21].

Although it was required that pilots demonstrate successful ditching during night flights, no attention has been given to the ability of passengers to demonstrate the ability to escape during low- or no-light conditions or to the fidelity of HUET to prepare for these conditions. Limited nighttime ditching training was identified as a potential factor contributing to the reduced survival rate [1]. Given the challenge of limited visibility during escape, it is plausible that training in dark conditions may be beneficial to learning and performance.

Since helicopter egress generally occurs in a low-light setting, the principle of learning specificity suggests that HUET would be most effective if also conducted in low- or no-light conditions. According to the principle of learning specificity, the most efficient sensory information available during acquisition dominates over other feedback sources and is utilized to develop a sensorimotor plan. Once developed, the sensorimotor plan remains sensitive to the optimal sensory information available during practice [14–16]. This principle was first demonstrated when participants who had practiced a manual aiming task with vision performed more poorly on transfer tests when vision was withdrawn, suggesting that vision is the

dominant and preferred sensory source [22–24]. Accordingly, lack of visual feedback due to low ambient light levels during practice would result in performance decrements.

Ambient vision is thought not to be affected by low levels of light [25]. However, decreased light levels could reduce the acuity of visual feedback. This may consequently affect aspects of sensory feedback such as eye and head movement patterns. Changes in lighting can affect perception and object appearance, for example by shadow production [26]. It is plausible that low lighting may reduce visibility range, which could affect end-target sight or object recognition. For goal-directed movements where terminal visual feedback is imperative for movement calibration, performance would decline in low light conditions [27]. It is possible that learning may be similarly affected. Motor learning refers to the changes in internal processes that occur with practice or experience, which affects an individual's ability to execute a motor task. Motor learning depends on the integration and interpretation of sensory stimuli. Retention testing is the preferred method to assess learning, which involves evaluation of a trained task after some time interval. Performance is the observable production of a motor skill, which is influenced by transient factors such as fatigue, motivation, and affective state [25, 28–30]. Although related, it is important to note that performance and learning are distinct processes [25, 30].

To examine the role of visual feedback on learning specificity, studies have typically examined effects of manipulated visual feedback (e.g., by distortion or narrowing) or withdrawn vision during motor tasks. Proteau and colleagues had participants practice a manual aiming task, which required the movement of a stylus to an end target while mechanically perturbed and time constrained, in either a light or dark room [14, 22]. When participants trained in the dark and then performed a retention transfer test in the light, performance deteriorated. This demonstrated the impact of training condition for retention and transfer. Importantly, the end-target was always visible in the dark condition. Additionally, subjects performed over 1000 practice trials and were given knowledge of results following each trial. These conditions may not be generalizable to real-life contexts.

The present study aimed to evaluate the effects of lighting on practice and retention (i.e., learning) performance during helicopter egress sequences conducted in a simulator. Practice occurred either with all trials in the light (Light Group), all trials in the dark (Dark Group), or half of the trials in the light followed by half in the dark (Graduated Group). The Graduated group was intended to evaluate effects of progressive learning [31].

We hypothesized that the Dark Group would have superior retention performance in the dark compared to the Light Group, supporting the principle of learning specificity and the Graduated Group (that practiced in both the light and then the dark) would have similar performance to both the Light and Dark Groups in the respective retention tests.

2. Methods

2.1 Participants

Thirty-eight participants (20 females, 18 males; average age (SD): 31 (11) years, range: 19–58) were recruited from the local community. All participants had self-reported normal or correctable-to-normal vision and gave written consent. Procedures complied with the Declaration of Helsinki and ethics was approved by the Interdisciplinary Committee on Ethics in Human Research at Memorial University protocol 20180377-HK.

2.2 Task and apparatus

Experimental procedures were conducted at the Marine Institute's Offshore Safety and Survival Centre (MI-OSSC), Conception Bay South, Newfoundland, Canada. Trials were conducted in the Help Quest Helicopter Ditching Simulator (Virtual Marine, St. John's, NL) without use of the motion platform or simulated helicopter noise. The interior of the simulator replicates a Sikorsky S-92, which is used commonly for operational purposes internationally. For practical reasons, the simulator contains only four seats (two seats each by a starboard side window and two each by a port side window, forming two rows) compared to 19 seats in the actual S-92.

Practice trials were conducted in the front and rear port window seats and front starboard window seat since these seats had push-out window exits. Retention trials were conducted in the front port window seat. The front port seat was always in a crash attenuated position (stroked), which is low to the ground. A stroke seat collapses upon impact as part of an energy absorption system that is intended to prevent primarily spinal injuries after a crash. However, evidence suggests that egress from a stroked seat position is more challenging than from a normally positioned seat because the evacuee is now situated lower relative to the window (escape route) and is in an orientation where it is more difficult to generate sufficient force to push out the helicopter window for egress [13, 32].

Participants performed a standardized escape sequence (Appendix) during a simulated submerged helicopter ditching. The sequence included the following: taking off a headset; putting on a hood; putting on a scuba-type mask; crossing arms and tucking the head to brace for "impact"; putting a scuba-type regulator (mouth-piece attached to a compressed air-filled cylinder) in the mouth; preparing to exit by pushing the window; and unbuckling a four-point harness. Participants were prompted to execute sequence steps by the following verbal commands (given in the order listed): "ditching, ditching, ditching"; "brace, brace, brace"; and "impact, impact, impact". Cues were given at regular elapsed time intervals - the brace call was given 30–45 s after the ditching call (time interval based on completion of ditching steps), and the impact call was given 15 seconds after the brace call.

2.3 Procedures

Permuted block randomization was used to allocate participants into one of the following training groups: with room lights on for all trials (Light); with room lights off for all trials (Dark); or in the light for half of the trials and in the dark for the other half (Graduated).

The experiment consisted of a didactic session followed by simulator-based trials. The didactic session consisted of a 20-min pre-recorded training video in which a qualified and experienced instructor presented adapted material from the existing HUET course offered by the MI-OSSC. Information relevant to helicopter egress using Helicopter Underwater Escape Breathing Apparatus (HUEBA) was given, while other non-pertinent material was removed. Didactic sessions included up to four participants. HUET is regularly taught using group instruction format.

Participants performed simulator trials individually. Each participant was allotted one orientation trial with real-time feedback immediately preceding practice trials. The orientation trial was conducted in the rear starboard position, which was not used for practice or retention trials. No feedback was given once practice trials commenced.

Practice trials consisted of six total sequence executions, which is similar to the amount of practice performed during a HUET course. Participants rotated through

each seat position (front and back port side; front starboard side) twice. Seat position order was counterbalanced. Practice trials took approximately 30 min to complete.

Following practice trials, participants were given approximately a 30- to 60-min break prior to retention testing. During this time, participants remained onsite and were permitted to engage in leisure activities of choice (e.g. reading, browsing on internet). For all participants, the retention tests consisted of one trial in the stroked seat in the dark followed by one trial in the light. Retention tests took approximately 10 min to complete. All practice and retention trials were recorded with a FLIR T430sc series infrared video camera that was able to capture video in dark conditions.

2.4 Dependent variables

Measures of performance included accuracy and movement time. Movement time was defined as the time in seconds (s) from the first action taken after the ditching command to when movement ceased. Participants were instructed to pause in the final position when he or she felt that the sequence was completed. Accuracy was measured with a checklist (refer to Appendix) where participants were awarded a point for every task in the sequence that was correctly performed. All subtasks had to be performed correctly and in the appropriate sequence to be awarded the point. The maximum possible score was seven. This checklist was developed through consultation with experienced HUET instructors at the OSSC and according to the training requirements of the Canadian Association of Petroleum Producers.

2.5 Analysis

Dependent measures during practice were analyzed by separate 3 (Group: Dark; Light; Graduated) X 3 (seat-position; front starboard; back port; front stroked port) Analyses of Variances (ANOVAs) with repeated measures on the seat-position factor.

Learning was evaluated by comparing practice trials conducted in the stroked seats, the dark retention test, and the light retention test. Data were analyzed in separate 3 (Group: Dark; Light; Graduated) X 3 (phase: practice trials in front stroked port seat; dark retention in stroked port seat; light retention in stroked port seat) ANOVAs with repeated measures on the phase factor.

3. Results

Data from 36 participants were included in the analysis. Two participants were excluded due to loss of performance data.

3.1 Practice accuracy

When the practice data were analyzed there was no main effect of Group ($F(2, 29) = 2.368, p = 0.112, \eta^2_p = 0.140$) or seat ($F(2, 58) = 0.865, p = 0.426, \eta^2_p = 0.029$). There was a significant Group by seat-position interaction ($F(4, 58) = 2.79, p = 0.035, \eta^2_p = 0.161$). Plots of each independent variable were used to assess interactions and inform post-hoc procedures. Post-hoc analysis was done by using three separate one-way ANOVAs for each seat positions. No significant effects were found (starboard ($F(2, 30) = 1.327, p = 0.280, \eta^2_p = 0.264$); back port

($F(2, 30) = 3.19, p = 0.055, \eta^2_p = 0.175$); and front stroked port: ($F(2, 29) = 1.758, p = 0.190, \eta^2_p = 0.108$)).

3.2 Practice movement time

For practice, there were no statistically significant main effects for Group ($F(2, 29) = 0.510, p = 0.606, \eta^2_p = 0.034$) or seat position ($F(2, 58) = 0.325, p = 0.722, \eta^2_p = 0.011$), or for the interaction of these two factors ($F(4, 58) = 0.580, p = 0.678, \eta^2_p = 0.038$).

3.3 Retention accuracy

Retention analysis revealed a statistically significant main effect of phase ($F(2, 58) = 6.012, p = 0.004, \eta^2_p = 0.172$). Least Significance Difference (LSD) post hoc tests revealed that accuracy during the dark retention trial (mean = 4.9) was significantly better than during the practice trials (mean = 4.4; $p = 0.006$) and the light retention trial (mean = 4.6; $p = 0.033$, **Figure 1**). There was no significant main effect of Group ($F(2, 29) = 1.168, p = 0.325, \eta^2_p = 0.075$) or interaction effect of Group and phase ($F(4, 58) = 0.819, p = 0.518, \eta^2_p = 0.053$).

3.4 Retention movement time

Mauchly's test indicated that the assumption of sphericity has been violated for the main effect of trial ($\chi^2(2) = 7.067, p = 0.029$); therefore, degrees of freedom were corrected using Huynh-Feldt estimates of sphericity ($\epsilon = 0.920$). A significant main effect of phase was found ($F(1.839, 53.335) = 5.911, p = 0.006, \eta^2_p = 0.169$). LSD post hoc tests indicated that participants took significantly longer during the practice trial (mean = 44.5 s) than during the light retention trial (mean = 39.2 s;

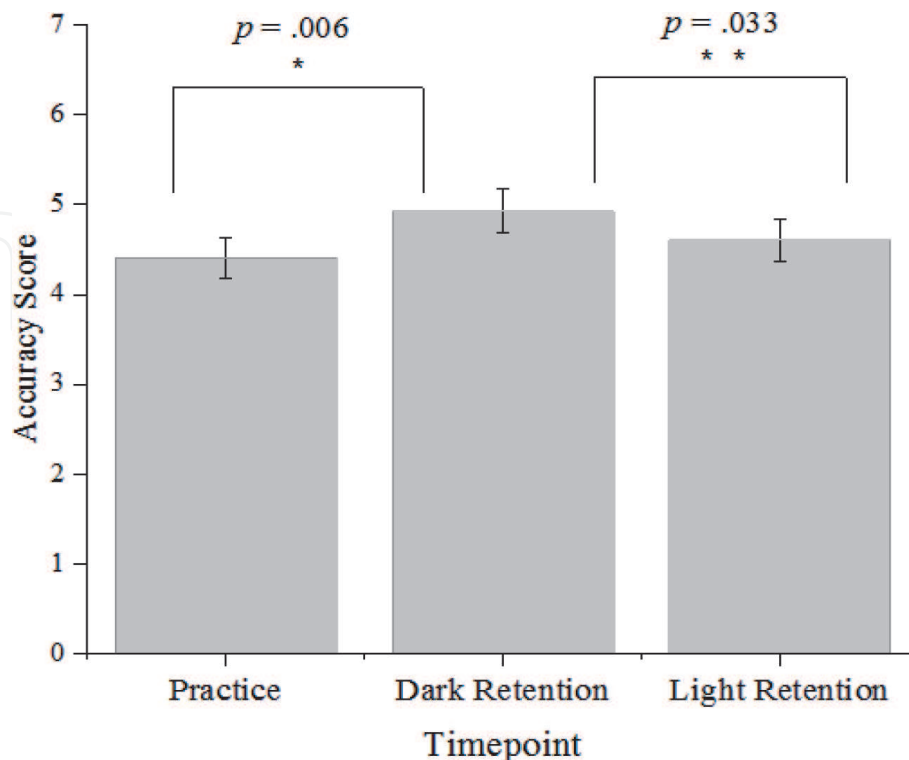


Figure 1. Comparison of accuracy scores in the stroked seat during practice trials, dark retention test, and light retention tests. Standard error is represented by error bars.

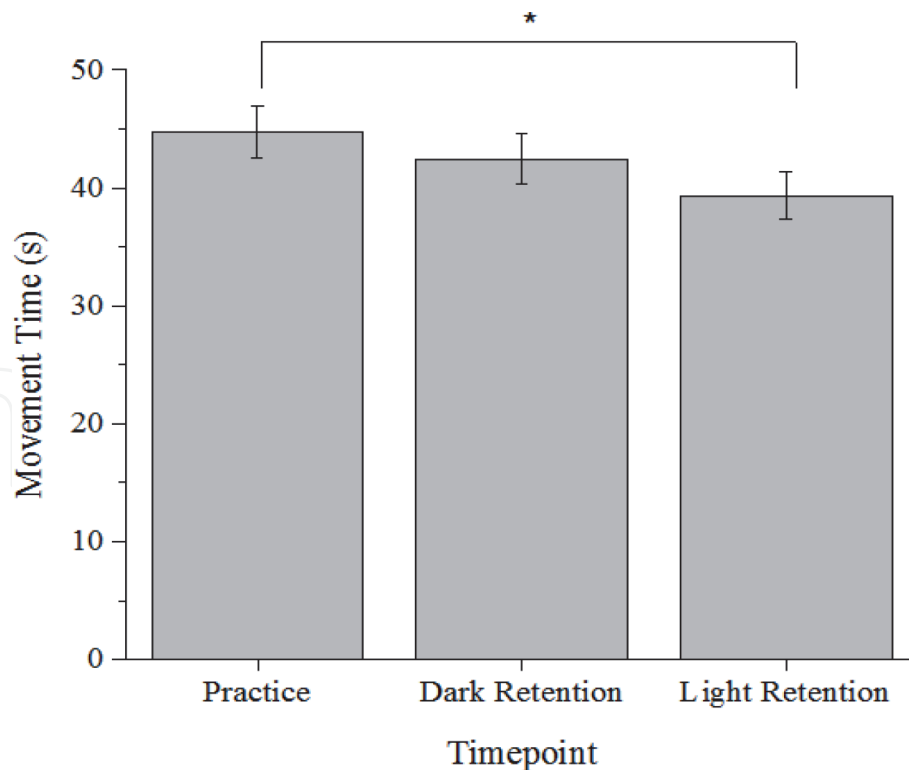


Figure 2. Comparison of movement time during practice trials in the stroked seat, the dark retention test, and the light retention test. Standard error is represented by error bars.

$p = 0.001$; **Figure 2**). No significant main effect of Group ($F(2, 29) = 0.544$, $p = 0.586$, $\eta^2_p = 0.036$) or an interaction of phase and condition were found ($F(3.678, 53.335) = 0.819$, $p = 0.625$, $\eta^2_p = 0.042$).

4. Discussion

This is the first study aimed to evaluate performance of simulated helicopter escape sequences conducted in low light conditions. We hypothesized that in comparison to the Light Group, the Dark Group would demonstrate superior overall retention. We also hypothesized that the Graduated Group would perform equivalently to both the Light and Dark Groups in the respective retention tests. Results did not support our hypotheses. Performance during practice and retention did not differ significantly across groups, indicating that ambient lighting during practice did not affect performance. Based on our findings, training in the light appears to be appropriate for performance and learning of helicopter escape sequences that will be eventually performed in the dark. Findings may inform training standards and be relevant to other extreme environments domains, such as within the search and rescue and cave diving, where ambient light levels may vary and may impact performance. However, it is possible that the task was too easy and that under more ecologically valid conditions (e.g., performing in a mockup helicopter that is being dropped into a pool) that are accompanied with increased anxiety, results would have been different.

Interestingly, all participants performed more accurately during the dark retention trial than during the light retention trial or during the practice trials conducted in the stroked seat. However, movement times were significantly shorter during the light retention trial. This is indicative of a speed-accuracy trade-off. It is possible that the dark retention trial conditions promoted more optimal arousal than the light retention trial conditions. The Yerkes-Dodson law states that increased arousal

will improve performance until optimal performance is achieved, after which point performance will decline as arousal further increases [33]. Attentional resources may be directed towards the task as self-awareness increases with anxiety. This may be detrimental to performance by disrupting automatic processes [34]; however, it can also benefit learning by inducing the allocation of more cognitive resources for task completion, which may attenuate aversive threat effects [35].

The principle of learning specificity has been primarily demonstrated in studies where participants have extensive practice. Evidence suggests that specificity effects are positively correlated with experience level, and thus are predominantly seen after the sensorimotor plan for a skill has been engrained and is automated [22, 23, 36, 37]. Participants in this study had either limited or no HUET experience. It is possible that experts, while outperforming novices, would experience performance decrements if escape occurred in the dark, but training had previously been conducted in the light. Another explanation may be that helicopter escape is not visually mediated. Lastly, it is possible that it is relatively easy to perform the set of required actions on a dry simulator with no motion and hence the lighting conditions did not affect performance.

It is important to discuss the meaning of the accuracy values. Mean accuracy score during the dark retention test was 4.9 (out of possible 7) but is this considered good performance? This is hard to answer directly as it is possible that on one hand, failure to properly execute two steps may still allow for helicopter egress whereas, on the other hand, it may prevent egress depending on what steps are involved. For example, if one mistakenly releases his/her safety harness before pushing out the window, the latter may not be possible. This is because once the safety harness is released, pushing the window while submerged will only lead to the being pushed away from the window. In other words, once the harness is released, the passenger may not have the necessary support or leverage to push out the window. If that happens, egress may not be possible. The passenger may need to egress through a different window that was opened by another passenger. Doing so would likely promote disorientation and, in the extremely high stress scenario, may not be realistically possible. Hence, we suggest that instructors may need to decide whether some steps in the sequence of actions are more critical than others. If so, in the limited time available for training, it may be prudent to emphasize critical steps and ensure accuracy and appropriate sequence of execution.

Two limitations of this study are noteworthy. First, as mentioned before, the conditions were relatively easy and did not fully mimic an actual ditching experience. It is anticipated that the inclusion of more naturalistic conditions such as noise and motion from the helicopter, heat stress and discomfort from the flight suits, and, perhaps most importantly, escape while underwater would affect the ability to learn and retain the required skills. Second, the retention period in this study was only 30 min. A longer retention period would have been more ecologically valid as passengers are certified in this procedure every 3–4 years, depending on the jurisdiction. Hence, it would be important to examine the ability to retain the egress skills in a longitudinal study.

5. Conclusion

Our results suggest that the practice of helicopter escape sequences in the light may be sufficient for performance during virtual reality simulation in the dark. It is interesting to note, however, that the average accuracy across groups for the dark and light retention tests were both 5 points out of a maximum of 7 points. Arguably, any score less than 7 could have severe consequences in the real-world. Higher

fidelity studies would help to better characterize optimal practice conditions to further inform training standards.

Appendix: accuracy assessment

Simulated Helicopter Escape Sequence Checklist (max score = 7 points)

Call 1: Ditching

1. Performed actions to get watertight

- Took off headset
- Put on hood (positioned correctly and tucked all hair inside hood)
- Pulled up hood zipper
- Put on mask (positioned correctly and placed skirt of mask below hood)

Call 2: Brace

2. Assumed brace position

- Crossed arms with fingers under shoulder harness (placed arm closest to exit on top and hooked HUEBA hose with thumb on hand farthest from the window)
- Placed feet flat on the floor and clear of seats

Call 3: Impact

3. Gazed out window and maintained gaze throughout subsequent steps

4. Opened window

5. Placed hand or elbow closest to exit on window corner and maintained contact throughout subsequent steps

6. Deployed HUEBA

- Removed dust cap from regulator with appropriate hand
- Placed HUEBA in mouth

7. Released harness

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