Helicopter Hoist Performance in Novice and Experienced Hoist Operators

Michael T. King; Stephen Lenser; Derek Rogers; Heather Carnahan

BACKGROUND: Helicopter hoist operators are highly skilled and critical crewmembers in search and rescue. However, hoist operator training programs are relatively underdeveloped in comparison to helicopter pilot training. It is critical that this simulator teaches the necessary skills for high-level performance given the dangers associated with helicopter hoist operation. As a result, we sought to validate and identify critical aspects of skilled hoisting.

METHODS: Through expert consultation, we identified several measures of hoist operation, such as mission time, cable plumb, cable tension, cable hand position, and cable displacement. We compared hoist performance between experienced and novice hoist operators in a simulated hoisting mission with two levels of difficulty (with and without wind). The experienced group (eight men/one woman) was composed of nine active or former military hoist operators who were working in commercial search and rescue. The novice group was composed of seven subjects (two men/five women) from the general population and had no previous experience with hoisting operations or the simulator.

RESULTS: We found that experienced hoist operators had faster mission time, similar cable plumb, lower tension, and less variable hand position. Further, experienced hoist operators pulled the cable inward in the wind while novice hoist operators pushed the cable away.

DISCUSSION: These findings suggests that this simulator captures performance differences between skill levels and, as a result, is a first step supporting the use of this simulator for hoist operator training.

KEYWORDS: simulation, hoist operation, search and rescue.

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Search and rescue (SAR) helicopter hoist operators are crewmembers who operate winch systems for hoisting objects or persons during emergency situations. The development of expert technical skill is a necessity to ensure the safety of the crewmembers and those involved in a hoisting operation. Other roles in aviation have used simulators to supplement training programs, but SAR hoist operator training is underdeveloped in comparison. Simulation training provides a unique learning opportunity for dangerous occupations,[9] such as SAR, aviation, or health care. Repetitive training sessions can be conducted in a real-world context that is controlled, safe, relatively inexpensive, and one that allows for effective learning approaches that cannot be easily executed in a real-world context.[4]

Performance of a trained skill is dependent on a multitude of interacting factors, such as the skill level of the performer, the difficulty of the task,[5] the level of arousal,[3] extent of practice,[1] and training specificity.[12] Perhaps not surprisingly, these are important factors to consider when designing a high-fidelity simulator. However, an often misunderstood[4] but important element is that a simulator must effectively train the psychomotor skills pertinent to the real-world task, regardless of fidelity or arousal. A simulator should function so that the correct motor skills are required for high-level performance; indeed, skill level should predict simulator performance. This concept is analogous to discriminant validity, which was developed in

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cognitive psychology to assess personality traits,[2] but has been adapted to evaluate simulator efficacy.[14]

Recently, Bluedrop Training & Simulation Inc. has developed a CH-148 helicopter Hoist Mission Training System to teach the technical skills required by hoist operators. As a first step to assess the validity of this simulator and to identify critical aspects of skilled hoisting, we compared simulation performance between experienced (highly skilled) and novice (low skilled) hoist operators in a hoisting mission with two levels of difficulty (no wind and high wind). We anticipated that experienced hoist operators would perform better than novice hoist operators and, since it is known that highly skilled persons are able to better perform under more complex conditions,[5] it was expected that this expert advantage would be exaggerated in windy conditions. Three critical components of hoisting operation include aircraft conning, hoisting, and safety scanning. After consultation with experts with over 20 yr of experience in hoist operation, we directed our analyses to technical hoisting skills such as cable plumb, cable tension, cable hand position, and cable displacement. Our hypotheses were that experienced hoist operators would complete a simulator hoisting mission: 1) faster than novice hoist operators; 2) have less deviation in cable plumb (i.e., cable swing) than novice hoist operators; and 3) have different cable performance, such as cable tension, hand position, and cable displacement.

METHODS

Recruited to participate in this study were 16 (10 male, 6 female) right-handed individuals. The experienced group was composed of nine (eight male, one female) active military hoist operators from Shearwater Canadian Forces Base or were former military and were working in commercial SAR. The novice group was composed of seven subjects (two men, five women) from the general population and had no previous experience with hoisting operations or the simulator. Subjects provided written informed consent and this study was approved by the Interdisciplinary Committee on Ethics in Human Research of Memorial University of Newfoundland, Canada.

A mock helicopter fuselage was equipped with virtual reality experienced through an HTC Vive headset (Xindian, New Taipei City, Taiwan). The helicopter in the virtual environment matched the mock fuselage with a 1:1 ratio so that subjects touched real and virtual objects (e.g., a hoist cable) in the same physical quality (speed, directionality, and tension). However, only certain objects in the helicopter fuselage were represented in the virtual space, such as switches to raise or lower the winch, the hoist pendant, hoist cable, door aperture, and handholds. The cable was winched between an upper and lower pulley system that collected the cable on a spool. Subjects wore protective gloves and a safety vest, which was tethered to the rear of the fuselage and allowed subjects to lean their body out of the fuselage door.

First, subjects were given a safety briefing and provided a brief outline of the mission. Second, subjects were familiarized with the physical exterior of the simulator and the pendant controls. Third, subjects were fitted with the HTC headset and instructed to become familiar with the virtual environment by using the controls to raise and lower the virtual cable. During this time they were asked to report if they had virtual motion sickness.[6] The familiarization period ended at the discretion of the participant, but in no instance did this period last longer than 10 min.

Two missions were conducted and were identical except for the presence of 105 km/h virtual wind in the second mission. In both missions subjects were instructed to: 1) con the aircraft to the target, which was a 136.3-kg (300-lb) rescue basket containing a virtual evacuee on flat ground; and 2) using the pendant controls to lower the cable to the rescue basket and raise the rescue basket up to the helicopter. The mission finished when the rescue basket was completely hoisted to the helicopter. Subjects were not given any feedback or instruction during the mission.

All parameters during the mission were recorded at 600 Hz (10 samples per second) and subsequently exported to a .csv file. Each variable was analyzed using a custom written Matlab script (Matlab 2018b, The MathWorks, Inc., Natick, MA, USA) and several indicators of performance were assessed that were expected to differentiate experienced and novice hoist operators: 1) time to complete the mission, and 2) measures of cable management, including cable plumb, mean tension, mean cable displacement in the x and z axis, and mean hand cable position. A description of these variables can be seen in **Table I**.

The study was structured as a two-way mixed model where the two factors were skill level (two levels: experienced and novice for between comparison) and task difficulty (two levels: no wind and 105 km/h wind for within comparison) with repeated measures on the task difficulty factor. In order to determine the effect of skill level and task difficulty, separate analyses of variance (ANOVA) models for each variable were performed. To evaluate equal group variances for each dependent variable we performed Levene's test of homogeneity (supplementary **Table A** online, https://doi.org/10.3357/AMHP.5516sd.2020). Statistical trends were defined as $P < 0.07$ and statistical significance was defined as $P = 0.05$ and a Sidak's test was performed in any instance where the ANOVA analyses

Table I. Definitions of Hoist Parameters.

VARIABLE	DEFINITION
Hoist time	The duration in seconds of when the cable was first moved until the end of the mission when the virtual basket was hoisted to the helicopter.
Cable plumb	The mean displacement of the virtual basket from the center point directly beneath the cable winch.
Mean tension	The mean tension in Newtons recorded on the cable throughout the entire mission.
Mean hand position	The mean distance in meters measured from the floor of the helicopter to the hand on the cable.
Mean cable displacement	The mean displacement of the cable in meters in the x and z plane away (+) or toward (−) the aircraft and forward (+) or aft (−) of the aircraft, respectively, where the origin is where the hand grips the cable.

showed a significant interaction. Intraquartile range (IQR) was computed as a dependent variable and used to assess variability for all variables except hoist time. IQR is defined as the range of the two middle quartiles of each variable's distribution. An IQR value was established for each variable for each participant and was entered into ANOVAs identically designed to those used to examine the cable management variables described in Table I. IQR was chosen over other measures of variability, such as standard deviation, since it can describe the range of values while accounting for outliers.

RESULTS

Summaries of the results for skill and difficulty are presented in **Table II**. Summary of variability results are presented in **Table III**.

The ANOVA of time to complete the mission demonstrated that there was a statistical trend for skill level [**Fig. 1**, $F(1,13) = 4.06$, $P = 0.065$, Table II] where experienced hoist operators completed the mission in less time. There was no effect of wind [$F(1,13) = 3.75$, $P = 0.075$, Table II] and no interaction [$F(1,13) = 0.00$, $P = 0.996$].

A mixed model repeated measures ANOVA of cable plumb shows an effect of wind [**Fig. 2**, $F(1,13) = 379.4$, $P < 0.0001$, Table II], where wind resulted in more deviating cable plumb, but no effect on skill level [$F(1,13) = 0.207$, $P = 0.658$, Table II] or interaction [$F(1,13) = 0.050$, $P = 0.827$].

The analyses of mean cable tension shows a main effect of skill level [**Fig. 3A**, $F(1,13) = 8.29$, $P = 0.013$, Table II], where experienced hoist operators applied less tension than novices. There was no effect of wind [$F(1,13) = 2.89$, $P = 0.113$, Table II] or interaction [$F(1,13) = 1.14$, $P = 0.305$].

Analysis of cable hand position shows an effect of skill level [**Fig. 3B**, $F(1,13) = 7.47$, $P = 0.017$, Table II], where experienced hoist operators placed their hand higher on the cable than novices. There was no effect of wind [$F(1,13) = 3.55$, $P = 0.082$, Table II] or interaction [$F(1,13) = 2.37$, $P = 0.147$].

Analysis of mean cable displacement in the x-axis shows a main effect of skill level [**Fig. 4A**, $F(1,13) = 58.36$, $P < 0.0001$, Table II] and interaction [$F(1,13) = 10.5$, $P = 0.006$], where experienced hoist operators pulled the cable toward themselves and novices pushed the cable away. A Sidak's test demonstrated that experienced hoist operators pulled the cable significantly closer to themselves in windy conditions while novices did not. There was no main effect of wind [$F(1,13) = 2.89$, $P = 0.113$, Table II]. Analysis of mean cable displacement in the z-axis shows an effect of wind [**Fig. 4B**, $F(1,13) = 55.5$, $P < 0.0001$], but no effect of skill level [$F(1,13) = 2.26$, $P = 0.156$, Table II] or interaction [$F(1,13) = 1.46$, $P = 0.101$]. Wind caused hoist operators to push the cable toward the rear of the helicopter.

Table II. Performance Summaries Between Experienced and Novice Groups (Column 1) and Between Wind and No Wind Conditions (Column 2).

VARIABLE	EXPERIENCED OPERATORS	WINDY CONDITIONS
Time	↓	=
Plumb	=	↑↑
Tension	↓↓	=
Hand Cable Position	↓↓	=
Cable Displacement (x)	↓↓	=
Cable Displacement (z)	=	↓↓

Arrows indicate direction of difference with respect to experienced operators except for cable displacement (x and z), where arrows indicate the cable was pulled closer to the body and to the rear of the helicopter, respectively. Two arrows indicate statistical significance; one arrow indicates a statistical trend.

DISCUSSION

The main findings of this study were as follows. 1) Experienced hoist operators had faster mission time than novices but had similar cable plumb. 2) Experienced hoist operators perform hoist missions with lower mean tension and hand position with less variability than novices. 3) Experienced hoist operators tended to pull the cable inward while novice hoist operators pushed the cable away. Interestingly, experienced hoist operators pulled inward to a larger extent in windy conditions while novices did not. Together, these findings indicate that the CH-148 helicopter Hoist Mission Training System captures performance differences between novice and experienced hoist operators and, as a result, provides evidence supporting the use of this simulator for hoist operator training. However, further testing will be required to establish this simulator as a tool for hoist operator training.

Table III. Main Effect and Interaction Summaries for Interquartile Range (IRQ) of Plumb, Cable Tension, Hand Cable Position, and Cable Displacement (x and z Direction).

VARIABLE		*F*(1,13)	*P*-VALUE	EFFECT
Plumb	Interaction	0.571	$P = 0.464$	--
	Wind	**994.0**	$\mathbf{P < 0.001}$	Higher variability with wind
	Skill	2.25	$P = 0.160$	--
Tension	Interaction	0.130	$P = 0.724$	--
	Wind	0.031	$P = 0.863$	--
	Skill	**7.75**	$\mathbf{P = 0.016}$	Higher variability in novices
Hand Cable Position	Interaction	2.37	$P = 0.147$	--
	Wind	3.54	$P = 0.082$	--
	Skill	**7.47**	$\mathbf{P = 0.017}$	Lower hand position in novices
Cable Displacement (x)	Interaction	0.521	$P = 0.483$	--
	Wind	**10.1**	$\mathbf{P = 0.007}$	Higher variability with wind
	Skill	**34.8**	$\mathbf{P < 0.001}$	Higher variability in novices
Cable Displacement (z)	Interaction	0.885	$P = 0.364$	--
	Wind	**47.3**	$\mathbf{P < 0.001}$	Higher variability with wind
	Skill	1.13	$P = 0.307$	--

Significant findings are in bold text.

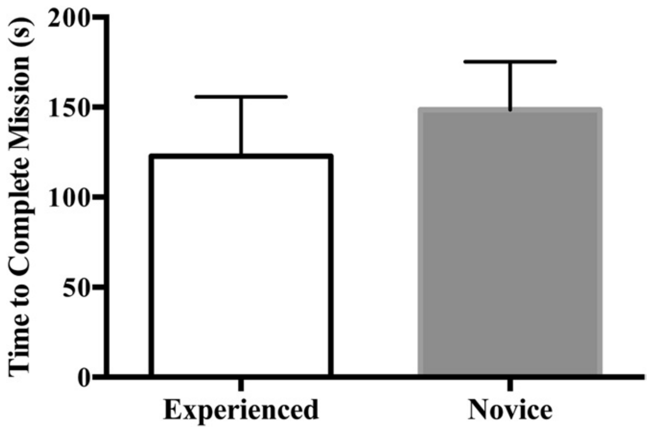

Fig. 1. Time to complete hoist missions for experienced (statistical trend, $P = 0.065$) and novice hoist operators. Error bars indicate standard deviation.

We found that experienced operators generate less mean cable tension with lower variability (Fig. 3A, Table III) than novice hoist operators. It is well known that higher force output leads to higher force variability[11] and novices have been shown to display higher force variability in both laboratory[13] and applied tasks.[7] Coinciding with this is the finding that experienced hoist operators had lower hand cable positions than novices (Fig. 3B). Given that the cable is attached to a winch above the hoist operator, a lower hand position requires less force to manipulate the cable.[8] Appropriately, the CH-148 helicopter Hoist Mission Training System was able to distinguish this skill between experienced and novice hoist operators. Based on our findings, a key instructional point for novice hoist operators is to maintain a low hand position, which may encourage lower forces and in turn reduced cable tension variability.

Experienced hoist operators pulled the cable closer themselves during operation while novices pushed the cable away (Fig. 4). The cable is under tension due to its own weight and the weight of the basket/evacuee and opposes displacement by the hoist operator. The force required to overcome this tension is proportional to the distance from the shoulder joint[8] and it has previously been shown that the effort to complete a reaching task is greater with increased reach distance.[10] Thus, the cable is easier to operate when closer to the body and experienced hoist operators may adopt this approach for better cable management. In addition, novice operators did not alter the way they pushed the cable during windy conditions, while experienced hoist operators brought the cable even closer. This may have been performed to gain additional control of the hoist cable to negotiate the force exerted on the basket by the windy conditions. Further, novices may push on the cable for support as they lean out of the helicopter fuselage to view the basket while experienced operators may not need to do this since they were lower on the cable (Fig. 3B). A lower position and lower center of mass may have reduced the need to use the cable for support. However, this interpretation should be treated with caution since we did not measure biomechanics or perform follow-up interviews with our subjects to ask them why they used a lower position.

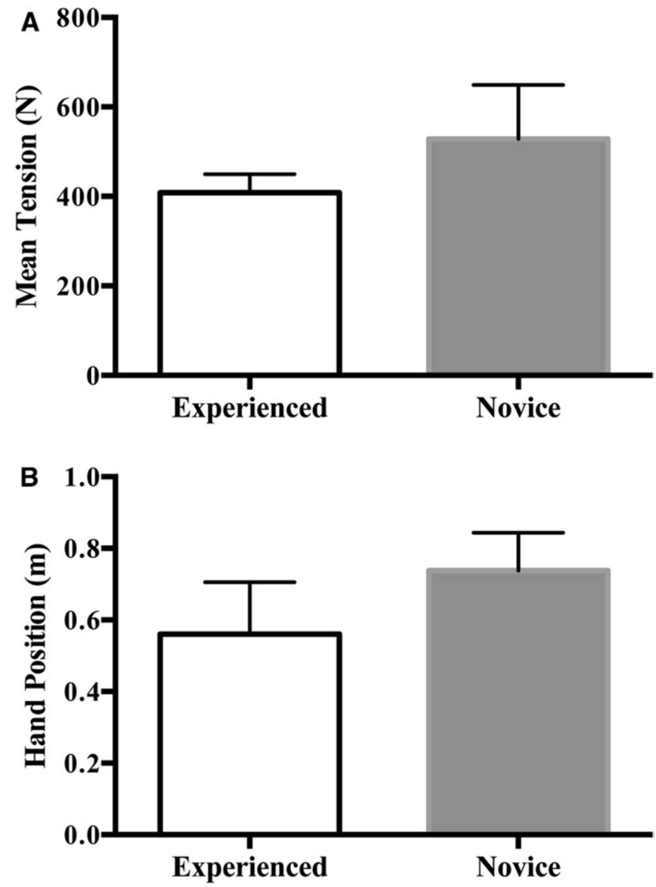

Fig. 3. Experienced vs. novice hoist operator results for A) mean tension and B) hand position. Error bars indicate standard deviation.

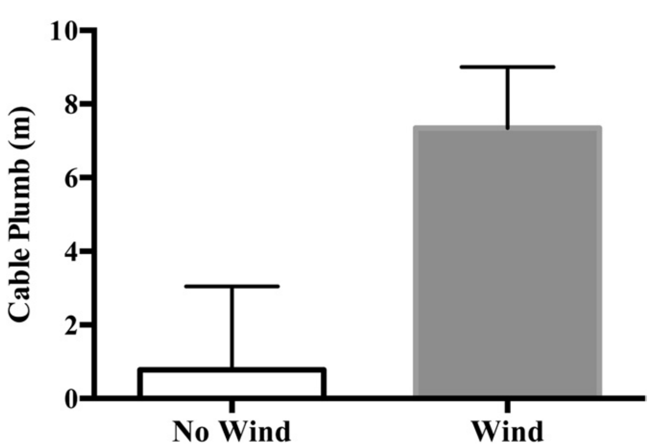

Fig. 2. Analyses of cable plumb for wind vs. no wind. Error bars indicate standard deviation.

Despite the differences we observed between experienced and novice hoist operators, not all measures could differentiate between experienced and novices, such as cable plumb. Cable plumb is an important indicator of hoist operator performance and one would anticipate that experienced hoist operators should demonstrate more centered cable plumb than novices. Further, one might expect that this difference be exaggerated in

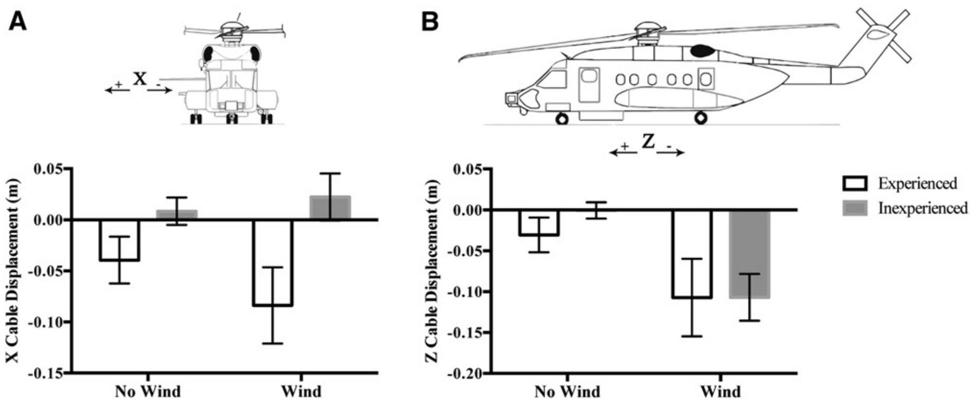

Fig. 4. A) Helicopter orientation for cable displacement in the x-axis. B) Helicopter orientation for cable displacement in the z-axis. Error bars indicate standard deviation.

windy conditions, but we did not observe either difference. As a result, the CH-148 helicopter Hoist Mission Training System captures many important aspects of performance, but not all critical tasks. This study provides evidence that this simulator demonstrates discriminant validity and warrants further testing for the use of this simulator for hoist operators. Similar to pilot training, hoist operators now have the opportunity to train in a simulated environment. Importantly, an integrated approach to simulator training can be developed where pilots and hoist operators can train simultaneously.

A potential limitation to this study was the difference in demographic characteristics between our novice and experienced groups. Our experienced group was composed mostly of men (eight men, one woman) who were SAR operators, active military, or former military hoist operators, while our novice group was composed of mostly women (five women, two men) from the general population. However, to our knowledge, there are not any documented sex differences in skilled performance such as the one studied here. Further, the submaximal forces applied to the cable are much lower than maximal force output and thus cable management is something not limited by strength or fitness. As a result, we interpret the differences found in this study to have minimal impact on the results of this study.

In conclusion, we show that the simulator developed by Bluedrop Training & Simulation Inc. is able to distinguish between experienced and novice operators in most, but not all aspects of hoist performance. As a result, we propose that the CH-148 helicopter Hoist Mission Training System is a welcome tool to augment current hoist operator training.

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