Scanning Analysis of Novice and Experienced Hoist Operators: Simulation Using a Virtual Reality Hoist Training System

Michael King
Marine Institute of Memorial University
St. John's, Newfoundland
e13mtk@mun.ca

Stephen Lenser, Barbarie Palmer
Bluedrop Training and Simulation
Halifax, Nova Scotia
stephenlenser@bluedrop.com, barbariepalmer@bluedrop.com

Derek Rogers
Total Response Solutions
Halifax, Nova Scotia
derek@trscanada.ca

Heather Carnahan
Marine Institute of Memorial University
St. John's, Newfoundland
heather.carnahan@mi.mun.ca

ABSTRACT

Helicopter hoist operators are crewmembers that use a winch to hoist objects or persons during a range of operations from utility tasks to emergency situations. Hoist operators are often required to perform these missions in unpredictable and dangerous environments necessitating the development of expert technical skills. Current hoist training methods are strongly reliant on live flight, costly and do not allow for training under high-risk conditions required of operations. Using a commercially available helicopter hoist mission training system we aimed to differentiate gaze behavior (safety scanning) for experienced and novice hoist operators during virtual reality (VR) hoist simulation training to facilitate adaptive feedback in simulation training. Head direction was used to reflect the hoist operator's gaze. The experienced group (12) were active military hoist operators. The novice group (11) were from the general population. A mock helicopter fuselage equipped with VR headset created an immersive environment that was matched 1:1 with the real world. The location of a participant's scanning was recorded in meters at 600 Hz according to the orientation of the headset. Convex hull and path length were calculated from a scanning heatmap of gaze data. ANOVA showed that the gaze of experienced hoist operators covered more area than novices (8019 vs. 3290 m^2), had a longer path length (4133 vs. 1784 m) and completed the mission faster than novices (146.2 sec vs. 243.9 sec). It was also clear from heatmaps that experienced hoist operators adopted a different scanning pattern than novices. This data suggests that experts are scanning more space than novices which would indicate better situational awareness. This will in future work be used as a source of dynamic feedback in training novices.

ABOUT THE AUTHORS

Michael King has a PhD from the University of Cape Town (UCT), South Africa in Exercise Science and Sports Medicine and recently completed a post-doctoral fellowship at the Marine Institute, Memorial University.

Stephen Lenser is the Senior Director Systems Engineering for Bluedrop Training & Simulation. Stephen has a BEng (Electrical) from Memorial University of Newfoundland and a MSc from Rensselaer Polytechnic Institute (RPI) in the USA. Stephen directs the design and implementation of virtual- and mixed-reality crew simulators for ab-initio and advanced force generation training in complex and adverse environments.

Barbarie Palmer (Lieutenant Colonel, ret'd) is the Senior Director Business Development for Bluedrop Training & Simulation. Barbarie has a BEng (Mechanical) from the Royal Military College of Canada and a MSc in Aerospace Vehicle Design from Cranfield University in the UK. She brings technical leadership and a passion for advancing operational training to Bluedrop. Having spent her career leading tactical and maritime helicopter support operations as an Aerospace Engineer in the Royal Canadian Air Force (RCAF), she has a detailed appreciation of the essential contributions of diverse teams as well as the need for collaborative relationships to meet operational objectives.

Derek Rogers is a retired Royal Canadian Air Force Search and Rescue (SAR) Technician currently working in Commercial Aviation and Marine Operations. He has an undergraduate degree in Paramedic Sciences and a Masters in Emergency Management with extensive industry experience in both military and civilian sectors. He specialises in EMS program development with a focus on standardisation and safety for technical crew members and medical staff.

Heather Carnahan is a Professor at the Marine Institute of Memorial University and currently holds the Lockheed Martin Research Chair in Marine Simulation and Learning. She has a PhD in Kinesiology from the University of Waterloo and is the former dean of Human Kinetics at Memorial University. She studies how people learn to become expert at performing motor skills in applied settings. The effective design and use of simulation based training is a focus of her research.

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Derek Rogers
Total Response Solutions
Halifax, Nova Scotia
derek@trscanada.ca

Heather Carnahan
Marine Institute of Memorial University
St. John's, Newfoundland
hcarnahan@mun.ca

INTRODUCTION

Search and rescue (SAR) helicopter hoist operators are helicopter crewmembers that use a winch to hoist objects, or persons during emergency situations. SAR hoist operators are often required to perform rescue missions in unpredictable and dangerous environments. As a result, the development of expert technical skills is critical for safe hoisting. However, developing hoist skills is challenging because helicopter training is costly, inherently dangerous, and those requiring the most training (i.e. novices) are potentially at the greatest risk to generate errors. Simulation training has long provided a safe way to train novices for dangerous occupations (Valverde, 1969) and often provides real world training scenarios that mitigate these problems (Gallagher et al., 2005).

In order to better understand hoist skill development, it is important to understand what differentiates experienced and novice skilled performance during hoist operation. Knowing these differences can facilitate skill development with key instructional points for learners (Guadagnoli & Lee, 2004). Hoisting can be described by three fundamental components. The first is communication and control of the aircraft as it approaches the target of interest. As the pilot is unable to see the load underneath the aircraft the hoist operator gives voice commands to the pilots as the helicopter closes in on a target to be hoisted, and even physically controls a small percentage of the motion of the aircraft using a crew hover controller. The second fundamental is cable management or the actual hoisting. The third is visual safety scanning to maintain situational awareness. The hoist operator needs to be aware of hazards such as overhead wires or an on-coming vessel or vehicle.

We have previously identified cable management and aircraft communication differences between novice and experienced hoist operators in a variety of environmental conditions (King et al., 2020). In this study it was reported that experienced hoist operators had faster mission time, fewer trajectory corrections as the helicopter approached the load, similar cable plumb, lower tension, and less variable hand position compared to novices. As well experienced hoist operators pulled the cable inward in the wind while novice hoist operators pushed the cable away. One conclusion from this work was that for hoisting, the simulator captured performance differences between skill levels. This is referred to as discriminant validity, which reflects whether an assessment measure adequately detects differences between groups hypothesized to perform differently (Cook & Beckman, 2006). However, the third important aspect of effective hoisting that has not yet been addressed in terms of expert versus novice differences is the ability of an operator to maintain situational awareness and continuously observe the local environment for anything that can interfere with safe hoisting. This is achieved by visual safety scanning that can be defined as the repetitive process by which a participant scans throughout the environment relative to the hoisted load. The purpose of the present study was to better understand safety scanning in SAR hoist operators when hoisting in a simulator and to learn what differentiates experienced and novice hoist operators. The findings could be useful as feedback to the learner or as a tool to evaluate improvements in the simulator. See Ziv (2017) for a review of gaze and eye tracking in aviation.

Initial observation of phase plots of gaze (inferred from head movement) showed that the gaze scanning patterns appeared to be more organized and purposeful for the experienced participants compared to the more irregular and disorganized gaze patterns produced by the novice participants. The experienced hoist operators followed a pattern of gaze that shifted between main rotor, aft to tail rotor and back to load.The novices appeared to either fixate on the load or direct their gaze to areas that were not of critical interest. The challenge we were faced with is how to provide this feedback to the learner or to quantify the gaze pattern such that this quantitative feedback about gaze could ultimately be used as a source of feedback to train subjects and to objectively measure gaze performance.

We did not have a direct measure of gaze because we did not record eye position. However, since the images the operators saw in the virtual reality environment were directly related to the position of the head and goggles, we inferred gaze position from head direction. Our aim was to determine whether experienced and novice SAR hoist operators showed differences in head motion during virtual reality (VR) simulation training. Knowing that performance of a trained skill is dependent on both the skill level and task difficulty, we examined several scanning metrics at two levels of wind difficulty (10 and 25 Kt) (Guadagnoli & Lee, 2004).

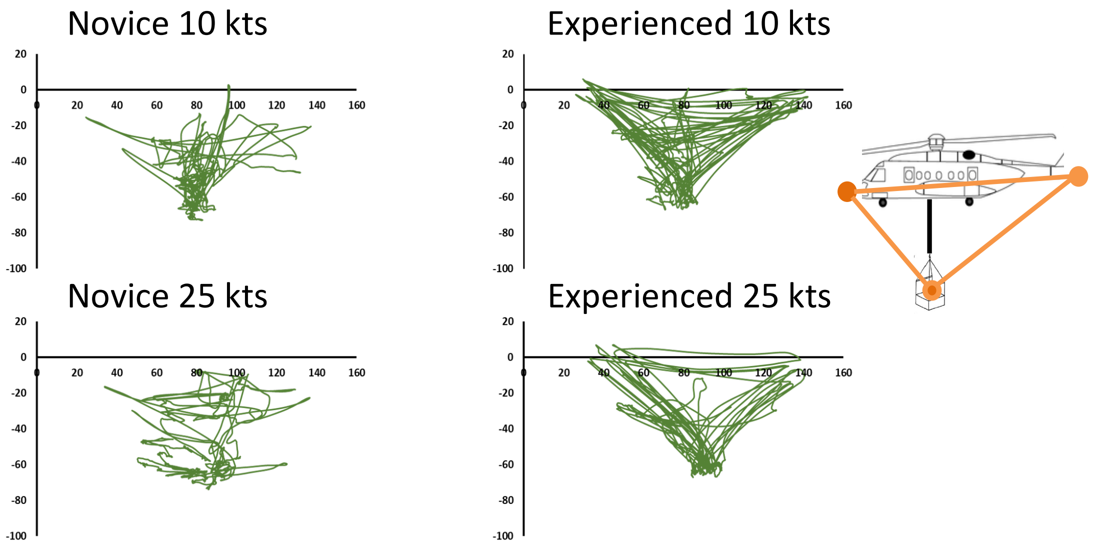

Figure 1. Exemplar gaze plots (yaw versus pitch) for a single experienced and novice hoist operator completing a land hoist in 10 kt and 25 kt wind conditions. Phase plots of the gaze scanning qualitatively show more organized and purposeful gaze patterns for the expert participant compared to the more irregular and disorganized gaze patterns of the novice participant.

METHOD

Participants and Simulator Design

Twenty-three (15M, 8F) right-handed participants were recruited. The experienced group was composed of twelve (12M) active military hoist operators from Shearwater and Comox Canadian Forces military bases. The novice group was composed of eleven participants (3M, 8F) from the general population and had no previous experience with hoisting, real or simulated. Preliminary analysis showed no gender differences so the data for all genders were collapsed into the same group for all subsequent analyses. We used a CH-148 helicopter hoist mission training system to teach the hoisting skills. A mock helicopter fuselage equipped with VR (HTC Vive headset) created a VR environment that was a 1:1 match with the real world so that participants interacted with real objects that had the same physical quality as the virtual objects (e.g. hoist cable) represented visually in the goggles. For example, the hoist cable moved with the same speed, directionality, and tension as the virtual cable system. As well, if wind was blowing, this was represented on the view of how the cable would normally respond under those circumstances, and its tension or feel. Other real objects represented in virtual space included switches to raise the cable on the hoist pendant, door aperture, and fuselage handholds.

Figure 2. Shows the hoist operator hoisting a simulated load as seen from the vantage point of the instructor station.

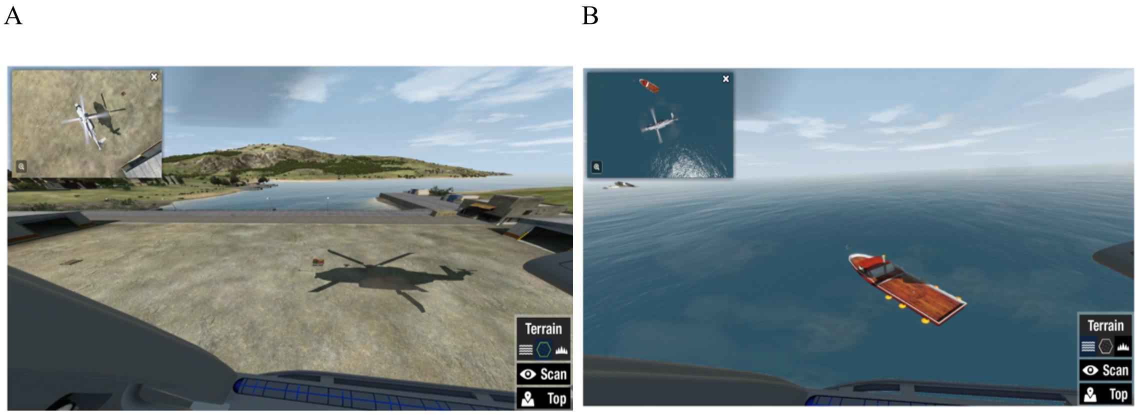

Figure 3A. A sample screen shot from a land hoist. Figure 3B. A sample screen shot from a sea hoist.

Experimental Design

Participants were given a safety briefing and then familiarized with the simulator. The safety briefing included an introduction to the physical exterior, VR headset, and pendant controls. All participants wore protective gloves and a tethered harnessed safety vest that allowed participants to freely observe the target for hoisting while leaning out of the simulated helicopter. Participants were fitted with the VR headset and allowed to freely raise and lower the virtual cable and interact with the virtual space. Participants were given as long as they needed to become familiar with the virtual environment and in no instance did this last longer than 10 minutes. No participants reported virtual motion sickness (Kennedy et al., 1993).

Data Collection, Scanning Metrics, and Analyses

Before starting the experiment, participants were given an outline of the missions they would be completing. Participants were instructed to (i) "con the aircraft to the target", which was a 136.3 kg (300 lbs.) rescue basket containing a virtual evacuee. Conning is a Canadian Military term for aircraft control and is also referred to as directional or prattle adjustments to approach a nearby target. Participants understood this before the mission started. Participants were instructed to "complete the mission by lowering the hook to the rescue basket and to completely raising the rescue basket up to the helicopter." The mission was considered finished when the rescue basket was completely hoisted to the helicopter and total mission time included conning to the target. The total mission time was recorded in seconds. Participants completed the mission in 10 and 25 kt wind over two landscapes (land and sea). Scanning metrics values for landscapes were averaged and we also averaged scanning metrics between 10 and 25 kt wind conditions. Participants were not given any feedback or instruction during the mission.

The location of a participant's scanning was recorded in meters at 600 Hz relative to the orientation of the VR headset. Scanning during hoisting was analysed using a custom written Matlab script (Matlab 2018b, The MathWorks Inc. Natick, MA, USA). Several built-in Matlab functions were used to quantify scanning differences between experienced and novice hoist operators for three measures: convex hull, path length, and dead space were all calculated from a scanning heatmap. These variables are defined below:

Heatmaps and dead space: Heatmaps are a two-dimensional color plots that illustrate a quantity in color. In this study, heatmaps were used to quantify the proportion of time (measured in percent of total mission time) that a hoist operator spent in a particular area of the VR space. We divided the scanned field into 25 segments in the X and Y planes (for a total of 625 scanned areas) and calculated the average time spent in each area as a percentage of total time. Heatmaps for each subject were individually generated and were averaged for each mission. In order to measure the difference between heatmaps we counted the number of areas in the field of view that were not covered by the participant and defined these areas as dead space.

Convex Hull: The convex hull of a set of points is the smallest possible polygon shape surrounding those points (Bradford et al., 1996). In a set of scanning locations, it represents the total spatial extent of a participant's scanning location. Convex hull was calculated using a gift-wrapping algorithm that locates the furthermost outer points of a scatter plot. A higher convex hull indicates that participant's scanning covers a larger area (measured in m^2) than a smaller convex hull.

Path Length: Path length is a measure of the total path that a participant has taken to get from one scanning location to another. Similar to convex hull, a longer path length indicates a longer total gaze movement was performed by a hoist operator and was measured in meters.

Statistical Analysis

The study was structured as a two-way mixed model where the between factor was skill level (two levels: experienced and novice hoist operators). The within factors were wind difficulty (two levels of wind: 10 and 25 kt forward to aft direction). To compare the incidences of dead space in the heatmaps we performed Fisher's exact test on each mission between experienced operators and novices. The possible outcomes for the Fisher's test were classified as areas scanned or not scanned. Statistical significance was defined as $p \leq .05$.

RESULTS

The ANOVA for convex hull was significant for skill ($F(1, 21) = 4.76$, $p = 0.041$) but not wind ($F(1, 21) = 1.24$, $p = 0.278$). As seen in Figure 4A, experienced hoist operators covered 4729 m^2 more area than novices (8019 ± 1087 standard deviation (SD) vs. 3290 ± 688.0 SD). The ANOVA for path length was also significant for skill ($F(1, 21) = 4.39$, $p < .05$) but not for wind ($F(1, 21) = 3.98$, $p = .06$). Figure 4B shows that experienced hoist operators had 2349 m longer path length than novices. (4133 ± 1299 SD vs. 1784 ± 213.6 SD). The ANOVA for mission time was significant for skill ($F(1, 21) = 14.80$, $p < 0.01$). Experienced operators completed the mission 97.7 seconds faster than novices (146.2 vs. 243.9 seconds).

The incidence of scanned dead space was lower for experienced hoist operators compared to novices for both levels of wind (Figure 5). Experienced operators had 26 and 35 fewer areas of dead space compared to the novices for the 10 and 25 kt wind conditions. Fisher's exact test p values for experienced operators versus novices in 10 and 25 kt wind conditions were p = 0.049, and p = 0.006, respectively. Average heatmaps for experienced and novice hoist operators are displayed in Figure 6. A heatmap showing the difference between experienced operators and novices can be seen in Figure 7.

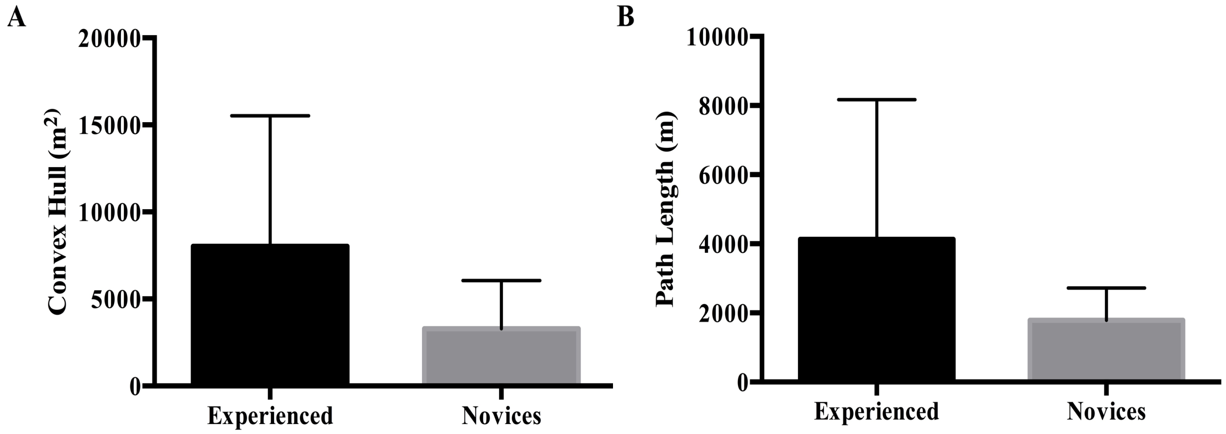

Figure 4. Experienced hoist operators show significantly higher convex (A) and path length (B) in comparison to novices.

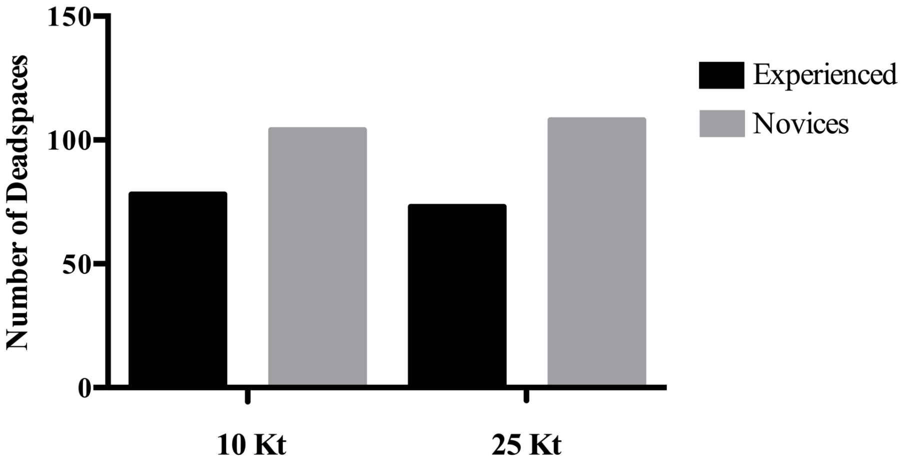

Figure 5. Experienced hoist operators show a lower incidence of dead space compared to novices in both wind conditions.

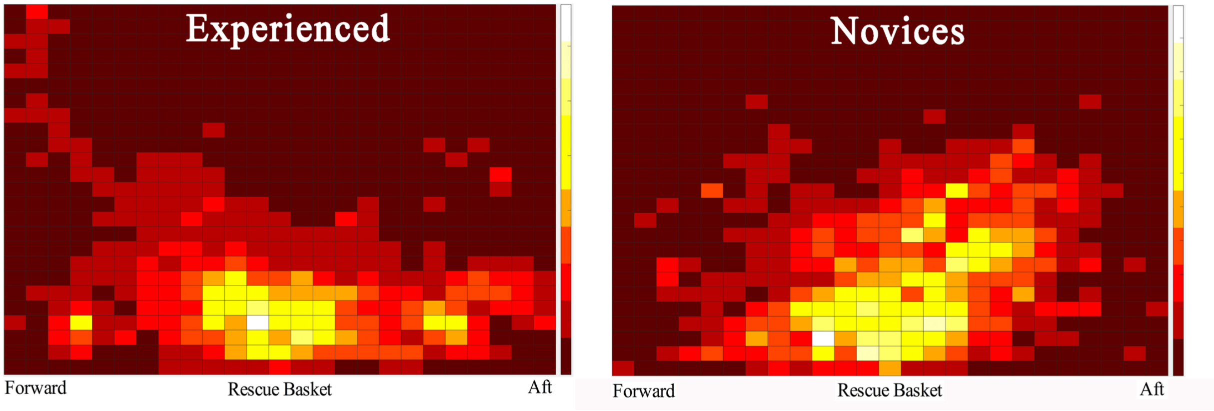

Figure 6. Scanning heatmaps of experienced (left) and novice (right) operators in percent time, where brighter shades indicate increased time and darker shades indicate decreasing time spent in a particular cell.

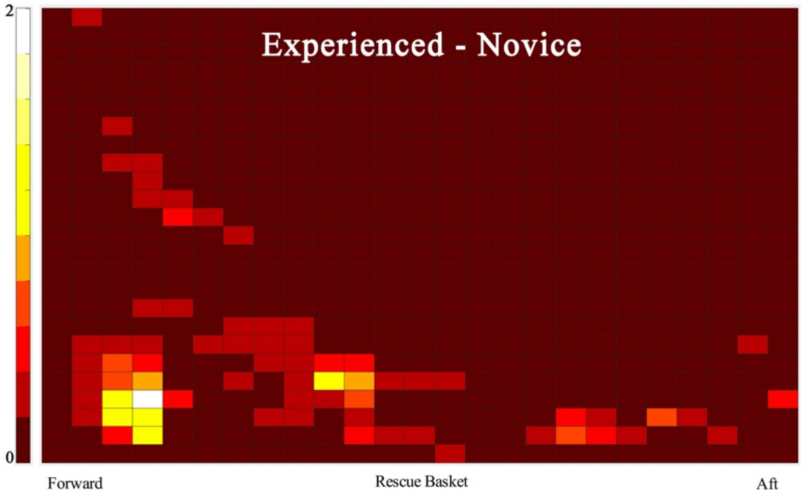

Figure 7. Heatmap showing the direct subtraction of experienced and novice operators. Brighter shades indicate increased time for experienced operators compared to novices and darker shades indicate decreased time for experienced operators compared to novices.

DISCUSSION

The main finding of this study was that experienced hoist operators demonstrated different scanning patterns than novice hoist operators. Experienced operators demonstrated larger convex hull, longer path length, and less dead space than novice operators. In addition, it is clear from heatmaps that experienced hoist operators adopted a different scanning pattern than novices.

Convex hull represents the total area that is covered while path length represents the total path that is taken to cover this area. Increased convex hull and path length in experienced operators shows they are scanning more space than novices. Further, experienced operators are able to achieve this 40% faster than novices (146.2 vs. 243.9 seconds) and this suggests that they are more quickly moving from area to area or scanning more frequently. This is an important distinction in skill because it illustrates that experienced hoist operators are more efficient with their scanning time and this better enables them to detect potential threats in the environment. Future experiments should further characterize scanning by quantifying the amount of time that operators are visually fixated on any particular spot, known as dwell time (Schriver et al., 2008). In conjunction with this, physiological indicators of attention (e.g. eye tracking and neurophysiological response using electroencephalogram) could be used to quantify the extent to which operators are attending to specific field regions of interest.

Hoist operator scanning heatmaps reveal two important differences between experienced and novice hoist operators. First, more dead space confirms our convex hull data and shows that novices are attending to less of the virtual space than experienced operators. It is critical for a hoist operator to identify potential threats during a mission (e.g. electrical wires, other aircrafts etc.) and if some areas are left in adequately scanned then it is possible for threats to go unnoticed. Second, the heatmaps show that novices concentrated their scan toward the rescue basket and while experience hoist operators do this as well, they also focused on regions forward and aft of the basket (see yellow areas on Figure 6). This illustrates that experienced hoist operators do not simply diffuse their scan over a larger area but have specific regions where they direct their scan.

Our study reveals key scanning differences between experienced and novice hoist operators. These differences provide the groundwork to teach SAR skill development more effectively. While using the CH-148 helicopter hoist mission training system, trainees could be instructed to: 1) not limit their scanning to the rescue basket, 2) move from one scanning location to another in a timely manner, and 3) lend visual attention to the peripheral space. Moreover, since scanning can be monitored by software, it is possible to instruct trainees to alter their scanning patterns in real time as part of an enhanced learning management system (Billiard et al., 2020).

Limitations to this study should be discussed. Scanning direction does not measure where the eye is focused and we can only comment on the operator's broad visual direction rather than what the operator actually attends to. As a result, this experiment provides rationale for a more detailed assessment of SAR eye tracking for a higher resolution measure of a trainee's visual attention. Second, simulator hoisting in virtual reality may not elicit the same performance as real-world contexts. For example, the level of arousal achieved in real world contexts of this setting is likely to be higher and this may influence performance by either improving or worsening performance depending on skill level (Diamond et al., 2007; Yerkes & Dodson, 1908). Thirdly, our novice group were untrained in hoisting so our results do not generalise to a comparison between graded skill levels of hoisting. Future work should attempt to compare expert, intermediate, and trainees as has been done in aviation (Kasarkis et al., 2001), surgical (Menekse Dalveren & Cagiltay, 2020; Praamsma et al., 2008), and athletics research (Vickers, 1995). Finally, our scenarios were relatively simple to accommodate the novice participants. However, scanning patterns will also be impacted by the complexity of the hoisting environment. Factors such as hoisting in a more confined space, or having a number of obstacles such as wires or oncoming vehicles, or hoisting loads off a dynamic hoist platform such as a boat heaving on the ocean, will all add to demands for situational awareness and thus influence scanning patterns. Future work needs to address these complexities.

To summarize, in combination with our previous work that differentiated cable performance and communications (King et al., 2020), these results together show that experienced and novice hoist operators also differ in their scanning patterns. Characterizing these differences enables one to offer instructional points during simulator training in order to augment hoist operator skill development.

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