2014-07

Helicopter Pilot Scan Techniques During Low-Altitude High-Speed Flight

Kirby, Christopher E.

http://hdl.handle.net/10945/43663
Helicopter Pilot Scan Techniques During Low-Altitude High-Speed Flight

Christopher E. Kirby, Quinn Kennedy, and Ji Hyun Yang

INTRODUCTION: This study examined pilots’ visual scan patterns during a simulated high-speed, low-level flight and how their scan rates related to flight performance. As helicopters become faster and more agile, pilots are expected to navigate at low altitudes while traveling at high speeds. A pilot’s ability to interpret information from a combination of visual sources determines not only mission success, but also aircraft and crew survival.

METHODS: In a fixed-base helicopter simulator modeled after the U.S. Navy’s MH-60S, 17 active-duty Navy helicopter pilots with varying total flight times flew and navigated through a simulated southern Californian desert course. Pilots’ scan rate and fixation locations were monitored using an eye-tracking system while they flew through the course. Flight parameters, including altitude, were recorded using the simulator’s recording system.

RESULTS: Experienced pilots with more than 1000 total flight hours better maintained a constant altitude (mean altitude deviation = 48.52 ft, SD = 31.78) than less experienced pilots (mean altitude deviation = 73.03 ft, SD = 10.61) and differed in some aspects of their visual scans. They spent more time looking at the instrument display and less time looking out the window (OTW) than less experienced pilots. Looking OTW was associated with less consistency in maintaining altitude.

DISCUSSION: Results may aid training effectiveness specific to helicopter aviation, particularly in high-speed low-level flight conditions.

KEYWORDS: visual scan, low level flight, expertise, helicopter.

For helicopters, flying at high speeds and low levels is not the safest way to fly, but in times of war, it may be necessary for survival. A helicopter’s primary means of defense while flying in combat is to remain low and masked by the terrain. Maintaining high speeds is vital for reducing the time an enemy has to target the helicopter as it passes overhead.

The ability of a pilot to interpret information from a combination of sources while operating in the demanding low-level flight environment determines the success of a mission as well as crew and aircraft survival. These sources include the outside environment, the instrument panel, displays that inform the pilot of the aircraft’s status, and additional information from navigation charts or global positioning system displays. Competent pilots can move their scan from source to source in a way that maximizes the assimilation of information and react accordingly to safely maneuver the aircraft. The purpose of this study was to begin to understand the visual scan patterns used by active duty military helicopter pilots during a simulated low-level high-speed flight scenario.

Previous research has demonstrated that eye-tracking technology can successfully detect pilots’ visual scan patterns. Bellenkes et al. (1) measured attention control by analyzing the visual scanning behavior in expert and novice pilots during a simulated visual flight rules flight. Experts scanned the flight instruments, particularly the directional gyro and altimeter, more often than novices. Novices dwelled longer, on average, than experts, particularly on the vertical speed indicator and turn coordinator. As expected, experts performed better than novices in terms of altitude control, particularly on the two most difficult segments of the route.

The association between visual scan patterns and flight performance was investigated by Karsarkis et al. (2), who suggested that the focus on airspeed is a key strategy—this strategy was particularly evident during change in flight altitude. Results also revealed that experts had shorter dwells on all areas of interest, indicating automation (when a pilot is ‘locked in’ to a scan pattern and does not deviate from it), and that the experts had more time to scan other locations. Importantly, more fixations and shorter dwell times were also associated with good landings, suggesting that these visual strategies cause expertise differences in landing performance. Ottati et al. (5) extended these results (1,2) to test the hypothesis that expert pilots spend less time finding and fixating on individual landmarks, and are able to use landmarks to navigate more accurately than novice pilots. The authors concluded that novice pilots are more likely to use spontaneous fixations (a pilot fixates on an event that is outside of the task they are currently presented with) during flight tasks to gain an accurate orientation.

These studies demonstrate that learned differences exist in visual scanning patterns and some evidence suggests that certain visual scan patterns are associated with better flight performance. However, these studies focus on the scanning patterns of fixed wing pilots. Few studies have investigated pilots’ visual scan patterns during a low-level en-route flight in a helicopter. Sanders et al. (6) examined the visual workload of the
navigator/copilot during a terrain flight in a simulator designed to emulate a military helicopter, the UH-1. However, this study did not focus on the flying pilot. More recently, Sullivan et al. (7) found that during a simulated overland navigation task, increased flight experience was associated with a more efficient scan pattern; dwell time decreased and scan rate increased with longer total flight hours. In a follow-up study with the same participants, it was found that the more experienced pilots changed their visual scan pattern depending on navigational difficulty (7). For the easier routes, experts spent less time scanning out the window (OTW), yet had as many fixations as less experienced pilots. For the difficult routes, experts appeared to slow down their scan by spending as much time scanning OTW as the novices, while also having fewer overall fixations and fewer fixations on the aircraft diagnostic and navigation display (MAP).

These studies are limited in addressing active duty military helicopter pilots’ visual scan patterns: participation was not limited solely to helicopter pilots and the studies did not use a military flight simulator intended for training (7,8). Further research is needed to fully understand the scanning patterns of active duty military helicopter pilots, whose operating conditions are far different than those of fixed wing pilots. The purpose of this study (5) was to extend these results to active duty military pilots during a simulated low-level, high-speed flight. Because the ability to maintain a consistent, low-level altitude is crucial for this population of pilots, deviations from assigned altitude parameters were investigated. Two hypotheses were tested. Hypothesis 1 was that more experienced pilots will have greater fixation frequency and shorter dwell durations on the instrument display (ID), MAP, and OTW than less experienced pilots. Hypothesis 2 was that fixation frequency and dwell time are associated with deviations from assigned altitude parameters.

METHODS

Subjects

The 17 (14 male) subjects were all U.S. Navy helicopter pilots from 3 squadrons located at Naval Air Station (NAS) North Island, CA. Two different helicopter communities were represented: a carrier-based community (helicopter antisubmarine) and an expeditionary community (helicopter sea combat). All the pilots, except one, were current with the MH-60S. The most experienced pilot (3400 h total) was a female maritime pilot. The least experienced pilot (350 h total) was a man who had been recently certified to fly an MH-60S. The majority of the pilots had between 500 to 1000 total flight hours (mean = 1273.18 h, SD = 881.01 h). There was a trend for an association between total flight hours and pilot age (Spearman’s ρ = 0.430, P = 0.063). All participants reviewed and signed an Internal Review Board (IRB) approved informed consent statement before beginning the experiment.

Equipment

The simulator used in this study was the MH-60S fixed-base Tactical Operational Flight Trainer 2 (TOFT-2). This system continuously recorded the simulated aircraft’s status throughout the flight, as well as video of the cockpit environment during the flight. The program faceLAB, made by Seeing Machines Inc., collected face, head, and eye data using infrared light. Two pairs of remote stereo cameras, two infrared light emitters, and two laptop computers were used. Two laptop computers ran the software that collected, interpreted, and stored the data from the stereo camera system. Prior to each flight, the faceLAB system was calibrated to accurately capture each pilot’s head and eye data.

The flight route consisted of 10 checkpoints and 9 legs around the San Diego area; a total time of approximately 26 min was required to complete the route at 100 kn indicated airspeed. The chart was marked with course lines and “doghouses” (doghouse-shaped boxes that align with the legs of the route). Each doghouse consisted of a base heading for the pilot to follow, the length of the leg in nautical miles, and the time to fly the leg at 100 kn indicated airspeed. Details of the route can be found in Kirby et al. (3).

The main flight performance measure was variability in altitude over the duration of the flight, measured as standard deviation in feet. Mean altitude during the flight was also measured. Flight experience was measured by total flight hours. Main eye scan measures were percent dwell time, fixation frequency, and scan rate. Percent dwell time was calculated as the percentage of the total flight the pilot spent looking OTW, at the ID, and at the MAP. A fixation was defined as when a pilot looked at an area of interest for more than 70 ms. Fixation frequency, the total number of times a pilot fixated on OTW, ID, and MAP, were calculated. Scan rate (also called saccade frequency) was measured as the number of times pilots shifted their scan from one place to another per second.

Procedure

The experiment was conducted at NAS North Island under the stewardship of the Commander, Helicopter Sea Combat Wing Pacific. The procedure consisted of three distinct phases. First, it was necessary to obtain permission and cooperation from units and their command authority at NAS North Island to use a simulator for testing, and the squadrons needed to be polled for volunteers to participate in the experiment. Next, once it was apparent that the use of a simulator was possible and that pilots were available at North Island, approval was obtained from the Naval Postgraduate School IRB. After subjects signed the IRB-approved consent form, they were briefed on an overview of the route to be flown in the simulator and the flight parameters they were expected to maintain. They then completed a demographic survey. After a thorough review of the route, subjects were asked to fly the route in the simulator, keeping the helicopter between 100 and 300 ft above
ground level throughout the flight. The subjects were assisted in the navigation by a copilot who was also qualified to fly the same type of aircraft. At the conclusion of the flight, the subjects completed exit surveys.

RESULTS

Spearman’s correlations coefficient $\rho$ was used to depict relationships between variables. The significance level $\alpha$ was set to 0.05. Regarding performance to maintain altitude, all pilots except one stayed within the 100–300 ft altitude parameter as instructed (mean altitude = 195.0 ft, SD = 57.64 ft). More experienced pilots better maintained a steady altitude by having smaller altitude SDs ($\rho = 0.745$, $P = 0.002$). Consistently lower altitudes were associated with a more consistent altitude ($\rho = 0.639$, $P = 0.008$).

Preliminary analyses on the eye scan parameters showed that pilots’ average dwell duration was 0.82 s (SD = 0.45 s, median = 0.76 s). Average scan rate was 2.3 shifts per second (SD = 0.96 shifts per second, median = 2.09 shifts per second). Overall dwell duration and overall fixation frequency were not significantly associated with total flight hours. No eye scan parameters were associated with pilot age. Table I outlines the percent dwell time dwell duration and fixation frequencies in particular regions of interest.

To test the first hypothesis, we calculated correlations between percent dwell time in each ROI with total flight hours. With increasing flight hours, pilots spent less time looking OTW ($\rho = -0.563$, $P = 0.018$) and more time looking at the ID ($\rho = 0.431$, $P = 0.081$). We next examined fixation frequencies. There was a trend for more experienced pilots to fixate more frequently on the ID than the less experienced pilots ($\rho = 0.405$, $P = 0.075$). There was no correlation between MAP and OTW fixation frequency and total flight hours. Finally, overall scan rate was not associated with total flight hours.

Regarding the second hypothesis, a marginal negative correlation between the percent dwell time for OTW with altitude deviation showed that pilots who spent more time looking OTW had more variable altitude ($\rho = 0.401$, $P = 0.096$). No other correlations between dwell time or fixation frequency and altitude deviation were significant. Exploratory analysis was conducted to determine if a dominant scan pattern was evident among this sample of active duty military helicopter pilots. Pilots spent most of their time scanning from OTW to the ID (movements from ID to OTW or OTW to ID), with occasional glances to the aircraft diagnostics screen (movements from ID to MAP or MAP to ID) (Fig. 1). This development was key to understanding which scan patterns are used by experienced pilots; this knowledge can aid future pilot training programs.

Exploratory analyses also investigated whether the combination of eye scan parameters with flight simulator performance data could detect unusual pilot behavior. Two pilots, subjects 8 and 18, demonstrated unusual behavior. Subject 8 had 3400 total flight hours (mean of all pilots = 1273.2 h, SD = 881.0 h) and was by far the most experienced pilot of the group. However, Subject 8 reported low overland flight hours (just 100 h) compared to the mean of all the pilots’ reported overland flight hours of 636.7 (SD = 386.2 h).

Table II lists that Subject 8 performed within a standard deviation of the sample means with regards to scan rate, mean dwell time, and the percent of dwell time spent scanning the ID. However, Subject 8 spent a great deal more time scanning the map and less time scanning OTW than the other pilots. The “MAP” was actually the aircraft diagnostics page. No emergency situations were presented during the flight that would have caused Subject 8 to devote more time to scanning the diagnostics page than any other pilot. Also, the small amount of time Subject 8 spent scanning OTW is alarming. This indicates that Subject 8 flew the route primarily by referencing the flight instruments.

Subject 18 was the only pilot to fly above the 300-ft altitude parameter (mean of 310.6 ft compared to 195.0 ft) and who flew with an extremely high altitude standard deviation (mean of 146.3 ft compared to 57.6 ft). At this higher altitude, it would have been difficult to pick out prominent land features that were more easily discernible at lower altitudes. Flying at a higher altitude during these flights is problematic because the pilots were asked to simulate a tactical operating environment: the lower altitude may have been necessary during this mission to increase the

![Diagram](image-url)
chance of survival. Subject 18’s eye scan data was examined to see if it was also unusual. All eye scan variables were within 1 SD of the group’s mean values. For example, Subject 18 spent 60.1% of the flight scanning the ID compared to 58.4% (SD = 19.6%), the average among all pilots. Thus, from the available data, the only possible explanation for the increased variability in altitude is the high altitude Subject 18 held throughout the flight.

**DISCUSSION**

The results revealed that more experienced helicopter pilots better maintained a constant altitude above the ground and exhibited different scan patterns. With increasing flight hours, pilots spent more time looking at the ID and less time looking OTW. Increased dwell time OTW was associated with greater variability in altitude. The combination of flight simulator performance output and eye scan parameters was successful in pinpointing unusual behavior in two pilots.

These results seem intuitive to the experienced pilot. After years of flying at night or in bad weather, the more experienced pilots have learned that a good instrument scan will keep them “out of trouble” when it comes to flying. Current Navy training is leaning toward the overland environment, but most of that training occurs at night due to the operational realities helicopter pilots find themselves in. At night, a good instrument scan is necessary for survival, even when flying with the assistance of night vision devices.

Results agree with those found by Ottati et al. (5), who found that novice pilots were more likely to fly scanning OTW rather than relying on instrumentation to guide them through a navigational route. Sullivan et al. (7) also found that the more experienced pilots scanned OTW less frequently than the less experienced pilots. The lack of a strong correlation between flight performance and other eye scan parameters parallels the findings of Sullivan et al. (7), who reported that eye scan parameters did not predict root mean square error.

A limitation of this study is the small sample size, which might explain the several marginally significant correlations. Major strengths were the demographic characteristics of the sample of pilots and the flight simulator used. The pilots fell within a wide range of flight experiences, as measured by flight hours (min 350, max 3400), and were all in the midst of an operational flying tour. Of the pilots, 13 had all flown within a month of the trials and only 3 pilots had more than 1 mo since their last flight (maximum was 2 mo since last flight). Many of the studies cited above drew from populations consisting of civilian pilots. This study was successful in acquiring pilots from a military helicopter community that specializes in low-level high-speed flights.

TOFT-2, the simulator used in this study, was actually being used for military helicopter training at the time this study was conducted. All of the pilots in the study had experience with simulators similar to the TOFT-2. The research team was successful in showing that faceLab could be installed in an operational fleet simulator and produce usable data for analysis.

The information gained from understanding eye scan patterns during high speed low altitude flights could be used in the development of a viable heads-up display (HUD) for the MH-60S. Pilots spent 35% of the total flight time looking at the ID. Those who spent more time looking OTW were less likely to maintain constant altitude. Because the ID provides valuable information and the pilot must also regularly look OTW, the HUD would greatly reduce the distance that pilots would have to scan between OTW and the ID. It would allow pilots to keep their scan outside while still gaining valuable flight and navigation data from the HUD. The ID information coupled with limited aircraft diagnostics data would greatly reduce the amount of time a pilot would have to divert his attention from the outside world. Mumaw et al. (4) also came to similar conclusions in their study using informed instrumentation to set up training programs.

In summary, results from this research may aid training effectiveness. Allowing more time to be spent looking at the ID and less time looking OTW would aid pilots in maintaining required altitudes in today’s helicopters. A significant amount of time spent looking OTW may be particularly detrimental in maintaining low-level altitude. Now guidelines can be created on the basis of the knowledge of how the more experienced pilots scan while flying at low altitude levels. Because it was found from the surveys that Navy helicopter pilots spend approximately half of their total flight time over land, it is critical to understand the scan patterns of the more experienced pilots while they are flying in this regime and pass that knowledge on, via structured training, to future pilots.

**ACKNOWLEDGMENTS**

This work was funded by the Naval Modeling Simulation Office (NMSO). Professor Rachel Silvestrini reviewed the statistical analysis in this paper and we are very thankful for her efforts. We are also grateful to Mr. Jesse Huston for helping us in calibrating the experimental device.

Results in this paper were presented at the 2013 AIAA Atmospheric Flight Mechanics Conference, August 19–22, 2013.
Authors and affiliations: Christopher E. Kirby, M.S., Naval Auxiliary Landing Field, San Clemente Island, San Diego, CA; Quinn Kennedy, Ph.D., Naval Postgraduate School, Monterey, CA; and Ji Hyun Yang, Ph.D., Kookmin University, Seoul, Korea.

REFERENCES