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APPLYING EYE-TRACKING TECHNOLOGY TO EXPLORE THE VISUAL SCANNING PRACTICES OF AIR TRAFFIC CONTROL TOWER CONTROLLERS

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In the domain of Air Traffic Control (ATC), visual scanning refers to a systematic and continuous effort to acquire all necessary information to build and maintain a complete awareness of activities and situations which may affect the controllers' area of responsibility. Our research team has supported FAA efforts to improve training of the important scanning skill, by conducting research to identify characteristics of successful tower visual scanning behavior. In addition to conducting multidisciplinary working groups and structured one-on-one interviews, we have collected eye-movement data from tower control experts while they controlled high fidelity air traffic simulations of airports at which they are certified. Participants included fifteen air traffic control tower instructors (employed by the FAA Academy) and twelve front line controllers (from Centennial, Denver, Minneapolis, and Orlando airports) each operating Local control for multiple 20-30 minute scenarios. Additionally we ranked instructor performance using time to detect off-nominal scenario events (e.g. smoking aircraft engine, noncompliant vehicles, occurrence of birds, etc.). We subsequently compared number and duration of eye fixations occurring during a scenario across our high and low ranked instructors and found no reliable differences. We also analyzed fixations within and transitions between identified Areas of Interest including Final, Touchdown, Downwind Midfield, Runway Midfield, Runway Intersection, and Departure Corridor. In this presentation, we will discuss what these analyses showed about the usage, by our participants, of scanning best practices identified by our working group (i.e. frequently scanning "hotspots", airfield-out, segmented scanning, and backward scanning).

Since 2014, researchers at the University of Oklahoma (OU) and the Civil Aerospace Medical Institute (CAMI) have been conducting research in support of the Federal Aviation Administration's efforts to improve the training of Air Traffic Control Specialists (ATCS) in the visual scanning skill. In the domain of Air Traffic Control (ATC), scanning refers to a systematic and continuous effort to acquire all necessary information to build and maintain a complete awareness of activities and situations which may affect the controllers' area of responsibility. ATCS must continually scan their environment to gather information that is vital to maintaining the safe and expeditious movement of air traffic. Initial research examined the usefulness of eye-tracking technology for the characterization of ATCS scanning behavior and focused on En

Route ATC (Kang, Mandal, Crutchfield, Millan, & McClung, 2016; Mandal & Kang, 2018). In 2016, however, a working group of FAA human factors specialists and pilot and controller Subject Matter Experts (SME) met to discuss the training of controller scanning in the airport tower environment specifically.

The working group produced a list of scanning best practices and a recommendation that research be done to examine the possibility of training tower controllers to use a specific scanning pattern in much the same way a pilot is taught to scan on the flight deck. Although Tower ATCS are trained to frequently scan hotspots (locations visible out the tower window where aircraft paths most frequently cross and where errors or off-nominal events can have severe consequences) and often rules of thumb, they are not currently taught to consistently use any specific scanning patterns in the way pilots are taught during their training. Our team subsequently initiated a program of research to determine:

- If eye-tracking technology could be used to characterize Tower controller scanning behavior and identify scanning patterns
- How the rules of thumb taught during training are applied in ATC and whether they can be linked to detection performance
- If individual controllers use particular scanning patterns consistently
- If particular scanning patterns are used across different controllers
- If identified scanning patterns can be linked to performance
- If controllers can be trained to use specific identified scanning patterns

During our research we found eye-tracking technology to be a very useful tool as have others (Kearny & Li, 2018; Pinska, 2006). In addition to structured one-on-one interviews with tower control experts, we recorded eye-movement data from the SMEs while they controlled high fidelity air traffic simulations of airports at which they are certified. We found that by demarcating Areas of Interest (AOI) for analysis around meaningful regions in the tower controller experts' visual field and examining the frequency of eye fixations in and the direction of transitions between the AOI we are able to characterize controller scanning behaviors and identify patterns. A fixation is said to occur when a participant's gaze stayed in one location for at least 100 ms.

In this paper we discuss what we found regarding the usage, by our participants, of scanning best practices that were identified by our working group. A review of the curriculum at the FAA Academy shows that Tower controllers are taught to frequently scan hotspots. Hotspots include both ends of an active runway and places where traffic crosses the runway. A rule of thumb also taught at the Academy, referred to here as Airfield-Out, is to prioritize looking at the airfield over looking further out into the airspace. Another rule of thumb that is taught by some instructors in the field, referred to here as Backward Scanning, is to look at where an aircraft is going and scan backward to where its current location. The last best practice we will discuss, referred to here as Segmented Scanning, is the practice of stopping ones eyes, long enough to take in sufficient visual information, between hotspots when scanning along an active runway. This best practice was initially suggested by human factors subject matter experts. When tower control SMEs have subsequently been surveyed and interviewed during our studies, roughly two thirds of them expressed doubt that they used Segmented Scanning or that it would be useful,

relating that a scan should be continuous and that slowing down one's scan would be ill-advised in a dynamic airport environment.

Method

Fifteen retired Tower controllers, employed as instructors by the FAA Academy in Oklahoma City, controlled simulated air traffic during 14 scenarios presented on an Adacel tower simulator. Twelve current front line Tower controllers (4 from Orlando International Airport, 2 from Denver International Airport, 2 from Centennial Airport, and 4 from Minneapolis-St. Paul Airport), controlled simulated air traffic during 4 scenarios presented on Adsync tower simulators located at their respective airports. Scenarios ranged between 22 and 38 minutes in length and represented busy air traffic during daylight hours with high visibility conditions. The instructor participants had between 10 and 42 years of experience as Tower controllers, averaging 26 years. The data from 3 instructors were dropped due to technical simulation and participant non-compliance issues. The current controllers had between 9 and 32 years of experience in Towers with an average of 16 years. Due to differences between Centennial operations and the operations at the other airports, the analyses in this paper does not include the data from the 2 Centennial controllers.

In all cases the training simulators used presented a high fidelity representation of an airport across ten or more 55" or larger screens configured to wrap greater than 180 degrees around trainees. All the simulations also included flight progress strips and simulated BRITE Radar displays. Operations at all airports (apart from Centennial) were configured to use two non-crossing runways. The airport presented to the instructors, although based on a real tower, was greatly modified to meet Academy training needs. Instructors therefore had never worked real traffic at this airport but were highly familiar with the simulation. In all cases the participants fulfilled the role of the Local controller, issued clearances to aircraft using a standard communication headset and wore a Tobii Pro Glasses 2, head-mounted eyetracking system (equipped with prescription lenses as necessary).

Results

We derived ATC performance levels for the instructors by measuring time to detect 6 off-nominal events scripted to occur within the scenarios. Off-nominal events included: a smoking aircraft engine, the appearance of a flock of birds, a non-compliant ground vehicle near the runway, an aircraft attempt to land on an incorrect runway, an aircraft attempt to taxi to the wrong runway and an aborted takeoff. Time to detect was measured using eye-tracking video recordings, starting at the time the participants verbally responded to an event and viewing backward until the initiation of the participant's last fixation on the presentation of a target associated with the event. Then we subtracted the time of event onset from the time of fixation initiation. Average fixation times for events ranged from 14 to 204 seconds. We designated the six instructors with the shortest detection times as the high scoring group and the six with longest detection times in the low scoring group. Given the short length of time the front line controllers were available to participate, we did not collect performance measures at the airports we visited.

Working with SMEs, we identified AOI based on operational significance. We identified AOI associated within the airspace (where aircraft could be seen on final approach, downwind midfield, the departure corridor, and the BRITE Radar), AOI associated with the airfield (where aircraft touched down on runways, runway crossings, runway midfield, the departure end of the runway and ASDE surveillance screens) and other general information sources like the flight progress strips and the Automatic Terminal Information Service display. Figure 1 shows the AOI for Academy Tower.

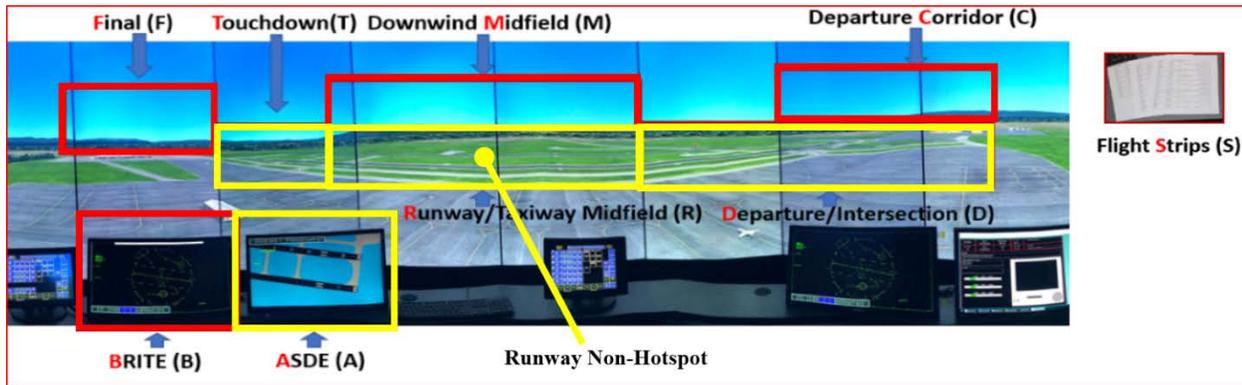


Figure 1. Areas of Interest (AOI) for Academy Tower. Yellow boxes indicate AOI associated with "Airfield" and red boxes indicate AOI associated with airspace or "Out".

Number of fixations at AOI was useful for characterizing participant scanning behavior. Heat maps, that depict relative number of fixations superimposed on pictures of the simulated environment, were a useful way to visualize those numbers. For example, Figure 2 shows how controllers do fixate more often at hotspots specified in the training curriculum, than at other locations on the surface.

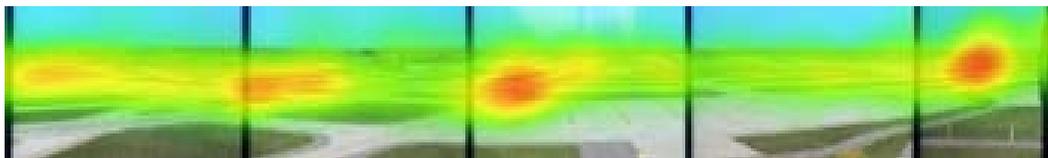


Figure 2. Heat map showing example of hotspots at Minneapolis-St. Paul Airport. Green shading indicates controller fixations with moderate frequency, yellow with higher frequency and red with the highest frequency corresponding to the ends of the runway and at runway crossings.

We compared number of fixations at AOI to answer questions about the usage of the Airfield-Out and Segmented Scanning rules of thumb as well. Both the high and low scoring instructors and the current controllers fixated roughly twice as often at Airfield AOI as they did at AOI associated with Airspace (see Figure 3). There were no significant differences between high and low scoring groups. Usage of Segmented Scanning was assessed by comparing the number of fixations at hotspot AOI (touchdown and runway crossing AOI at Academy Tower, Denver International and Orlando International airports) with an AOI not associated with hotspots that was located on the runway between the two hotspots. Although a greater percentage of fixations were at hotspots, between 7 and 14% of Airfield fixations did occur at the runway location between them (see Figure 4).



Figure 3. Percentage of fixations associated with Airspace, Airfield and Other Information sources across both instructor groups and the current controller group.

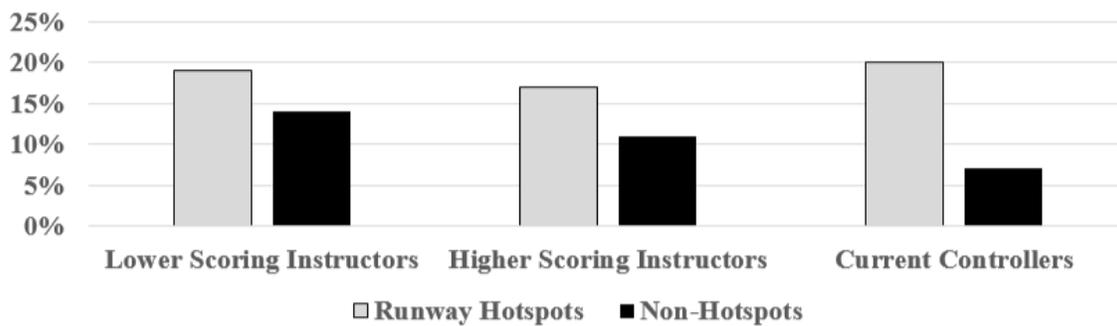


Figure 4. Average percentage of Airfield fixations for Hotspot and Non-Hotspot AOI across both instructor groups and the current controller group.

The usage of Backward Scanning was explored by looking at the eye-movement transitions that occurred after the cleared for take-off clearance. For aircraft arrivals, Backward Scanning is similar to Airfield-Out, with a controller's eyes moving from the runways where an arriving aircraft is headed, back to the airspace where the aircraft is currently located. For departures, Backward scanning means the controller's eyes will move from the departure corridor in the airspace back to the runway surface on the airfield. Therefore we looked at the number of transitions to and from the departure corridor that participants made during a time when they were working departures. We found no evidence of Backward Scanning over and that done in association with Airfield-Out.

Discussion

Analyses of eye-tracking data, recorded from both Tower controller instructors and current Tower controllers as they controlled simulated air traffic, allowed us to characterize the scanning behavior of air traffic controllers fulfilling the Local control function. Number of fixations at AOI and number of transitions between particular AOI support that expert controllers frequently scan hotspots on an active runway and practice the Airfield-Out rule of thumb. Additionally, data supported that controllers will sometimes use the Segmented Scanning rule of thumb although this usage is less prevalent.

We grouped the Instructors into low and high performing groups based upon the speed at which they detected off-nominal events. We compared the usage of rules of thumb across the groups but were unable to find an impact on detection performance related to usage. One consideration is that these rules of thumb may not impact performance. Other explanations for the lack of relationship include that our measurement was not powerful enough to detect the impact, that there weren't enough samples to test adequately, or that the performance of the experts who participated in the study produced a ceiling effect. Should further studies include novices that make use of the rules of thumb less often, the impact on detection performance may show up as statistically significant. Regardless, the fact that the three groups showed similar usage of the rules of thumb suggests that we could emphasize these in training novices to use standard visual scanning techniques.

Although the research presented in this paper addresses many of the questions we set out to explore in response to the 2016 working group recommendations, several questions still remain. The data collected up to this point have positioned us to address the questions about the use of specific scanning patterns as well. We are currently analyzing eye-movements made by our participants, during these scenarios, that occurred near in time to when the participants delivered certain types of clearances. Clearances include "hold short", "line up and wait", "cleared to land" and "cleared for takeoff". In our analyses we will try to find consistent patterns within and among controllers such that we can attempt to teach novices to practice the same patterns before, during and after delivering those clearances.

Acknowledgements

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