Visual scanning in an air traffic control tower – A simulation study

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Abstract

Air traffic controllers at an airport tower ensure for safe and efficient movements of aircraft at the airport and its vicinity. Their decisions always depend on the current situation. To assess the relevant situational aspects information is mostly acquired visually. During take-off and landing in particular a sufficient picture of the situation is crucial to safe decision making. The acquisition process can be modelled using the SEEV model [1] taking into account the importance of an area of interest. Especially in complex high-traffic situations more areas are considered to be important. It is assumed that controllers also scan more crucial areas in complex than in simple situations. Therefore an eye tracking study was conducted in a high fidelity tower simulator. Six air traffic controllers handled IFR traffic at a local airport with simple as well as more complex situations. Their scanning behavior while giving take-off- and landing-clearances was assessed by a state-of-the-art eye tracking system. Results show similarities among participants and situations regarding visual movements while delivering clearances. Slightly more scans were made in complex than in simple situations. The attended areas indicate highly trained behavior of the controllers. The data were merged to provide reference values to be compared to real time eye tracking. The applicability of such a system as a tool to detect inattentiveness in air traffic control is discussed.

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1. Introduction

Air traffic is an important driver in our globalized world. Growing numbers of both passengers and freight require a high volume of traffic. In recent years air traffic has constantly been growing and latest forecasts expected to exceed 10 million annual commercial flight movements within Europe in the year 2016 [2]. As a result more aircraft must be coordinated and safely separated from each other while airborne. At an airport tower air traffic controllers ensure safe and efficient aircraft movements in the airport vicinity on the ground and in the air. Therefore the responsible controller delivers clearances and instructions to the pilots via voice radio. One of the most critical parts at an airport is the runway where aircraft take off and land. This is because aircraft move at high horizontal and vertical speeds, accelerate and decelerate, and move with great relative velocities. Thus a safe handling of the traffic is necessary, especially to allow for high throughputs and hence high capacity. During standard operation only one single aircraft may be cleared to use the runway. The controller must detect safety infringements like runway incursions and make sure that the runway is safe to use. Also he/she must keep a sufficient picture of the situation and needs to gather all relevant information to be certain that there is no threat to the corresponding aircraft and that the clearance is within the mandatory safety margins.

Besides the radio most information at the controllers working position is presented visually. Information about aircraft is presented on flight strips, a radar screen shows the air space and the traffic around. Also other devices like the weather display which mainly gives information about the prevailing wind as well as air pressure are available. And of cause there is the outside view where for example can be assessed if there is any vehicle or obstacle on the runway. In order to stay aware of the current situation the controller should check these different information sources regularly.

Some studies have investigated the overall visual attention of air traffic controllers at airport towers [3,4]. These studies shed light on the most observed information at the controllers’ working position and found high percentages of time controllers spent looking out of the window. However they did not take into account that attention is not always focused. So looking out of the window for a significantly long time could indicate either the importance of that particular information source or simply boredom. Thus the period of looking at an information source does neither necessarily reflect its importance nor does it mandatorily imply attention.

Wickens and McCarley proposed the so called SEEV model to predict visual attention [1]. The model combines the four components Salience, Effort, Expectancy and Value to a score that is meant to predict the probability of attending to an information source. In a simplified version of the model for professionals Wickens and colleagues [5] reduced the model to the only top down components of it – Expectancy and Value. Expectancy means the event frequency or simply the probability of a change of information over time and the need to look at it repeatedly. Value can be translated as the importance of information. So the authors suggest combining the need to look repeatedly with the rated value of the corresponding information in order to model visual attention. In other words observable visual attention should thus consist of both the expectancy and the importance of information.

This model is only applicable to focused attention. It seems obvious that the easiest way to assess where a tower controller will draw attention to is to observe his/her eye movements. Unlike earlier studies [3,4] in which the whole time of working was measured for controllers attention this study is based on the assumption that controllers most likely show focused attention situation-based in the moment of a clearance delivery [6]. Especially while delivering the most critical take-off or landing clearances controllers are supposed to pay attention to the relevant information sources. The purpose of the current study is to figure out which sources are relevant and thus looked at. To take into consideration the expectancy not only the probability to look at an information source in general must be regarded but also the probability to look repeatedly.

2. Method

The German Aerospace Center in Braunschweig (Germany) operates several high fidelity air traffic simulators. At the Institute of Flight Guidance these simulators are used to observe e.g. air traffic controllers at work under realistic working conditions. Therefore traffic situations can be precisely defined and simulated accordingly with an appropriate outside view [7]. The most sophisticated Apron and Tower Simulator (ATS) provides a 360° panoramic
view and is highly adaptable to research needs [8]. Additionally, well-trained operators take part in the simulations as simulation pilots to react to the controller’s commands by handling the radio and the aircraft behavior. The ATS contains a broad bandwidth of data measurement and recording tools. Among others the integrated head-based eye and head tracking device (a combined system by SensoMotoric Instruments and Advanced Realtime Tracking GmbH) enables detailed observations of the controllers’ visual attention with a visual angle accuracy of 0.5°-1°.

To investigate airport tower controllers’ visual attention and scanning behavior in distinct situations the VISual Information values in Tower OPerations study (VisiTop) was started and carried out in the ATS. The setting of the study is shown in figure 1.

Six male air traffic controllers of the Deutsche Flugsicherung GmbH (the main German air traffic control provider) participated in the study. Their age ranged from 23 to 41 years ($M = 31, SD = 8.85$) with a mean experience of 8.9 years ($SD = 8.5$) in tower operations. They were briefed to handle the ground and air traffic at Braunschweig/Wolfsburg Airport (EDVE), a regional airport in Germany with a single runway (26/08). A simplified depiction of the airport layout is shown in figure 2. The simulation consisted solely of IFR-traffic (instrument flight rules). There were no significant weather conditions (see figure 1). After a training scenario the controller worked three scenarios each lasting for 45 minutes with nine arrivals and as much departures. The scenarios were standardized and designed to contain comparable and reproducible traffic situations. During the simulation the gazes of the controller were measured by the eye tracking device. Therefore each information source at the working position had been defined as an area of interest (AOI) so every fixation on the AOIs could be counted and analyzed.

Fig. 1. VisiTop airport tower operation layout at Braunschweig/Wolfsburg Airport (EDVE). The air traffic controller with the eye tracking device is placed in the middle surrounded by simulation operators.
Fig. 2. Airport layout (EDVE) and depiction of the areas of interest (AOIs) with the outside view on top and the tower controller working position below.

To analyze the controllers’ visual attention during take-off and landing clearances first the points in time of the clearances were identified and the fixations during the radio transmissions to deliver the clearances were extracted. Then consecutive fixations on the AOI could be combined to macro fixations. The fixation times were neglected as they differ with the information type and thus distort the measure. Thereafter the probabilities of attending to an AOI based on the number of macro fixations were calculated for every clearance and participant and finally aggregated to total scores. Furthermore the probabilities for a single glance up to four gazes were split to analyze the complexity of scan patterns and gather indications for the expectancy value of the simplified SEEV model.

Landing clearances were rated as simple or complex with respect to possible differences in the participants’ scanning. In simple situations the decision to clear an approaching aircraft to land was independent from other traffic. Complex situations however implied clearances depending on arriving or departing traffic ahead. Take-off clearances could not explicitly be classified as complex or simple as the controllers only cleared aircraft on the runway for take-off when there was no apparent pressure or hazard whatsoever.

3. Results

The results show that during simple landing clearances controllers observed 8.82 AOIs on average (SD = 3.06) towards 9.55 mean gazes (SD = 3.74) during complex landing clearances. A take-off clearance required about 10.20 gazes (SD = 3.44).

The scanning patterns and the probabilities of attending show clearer consistencies among controllers and situations. Table 1 shows the corresponding probabilities for one to four gazes on the relevant AOIs during simple landing clearances. For example flight strips and the weather display were at least looked at once with a certainty of 100 percent. This indicates highly trained scanning behavior of the controllers.
Table 1. Probability of attending to an AOI during simple landing clearances.

| AOI        | number of gazes | 1   | 2   | 3   | 4   |
|------------|-----------------|-----|-----|-----|-----|
| Approach sector | 0.13            | 0.03| 0.00| 0.00|     |
| Departure sector | 0.18            | 0.05| 0.03| 0.00|     |
| Runway exit      | 0.05            | 0.00| 0.00| 0.00|     |
| Final approach sector | 0.10           | 0.03| 0.00| 0.00|     |
| Flight strips    | 1.00            | 0.90| 0.44| 0.10|     |
| Holding point    | 0.00            | 0.00| 0.00| 0.00|     |
| Radar display    | 0.90            | 0.54| 0.38| 0.23|     |
| Runway           | 0.54            | 0.26| 0.08| 0.03|     |
| Taxiways         | 0.36            | 0.10| 0.03| 0.03|     |
| Weather display  | 1.00            | 0.18| 0.05| 0.00|     |

Regarding complex landing clearances the scanning patterns appeared less obvious. Only probabilities of about 70 percent were measured for gazes on flight strips or the weather display. Detailed data can be found in table 2.

Table 2. Probability of attending to an AOI during complex landing clearances.

| AOI        | number of gazes | 1   | 2   | 3   | 4   |
|------------|-----------------|-----|-----|-----|-----|
| Approach sector | 0.17            | 0.03| 0.01| 0.00|     |
| Departure sector | 0.17            | 0.09| 0.02| 0.02|     |
| Runway exit      | 0.08            | 0.02| 0.02| 0.01|     |
| Final approach sector | 0.12           | 0.03| 0.00| 0.00|     |
| Flight strips    | 0.70            | 0.56| 0.36| 0.15|     |
| Holding point    | 0.04            | 0.01| 0.01| 0.00|     |
| Radar display    | 0.63            | 0.40| 0.15| 0.05|     |
| Runway           | 0.47            | 0.32| 0.15| 0.03|     |
| Taxiways         | 0.28            | 0.13| 0.03| 0.00|     |
| Weather display  | 0.71            | 0.08| 0.01| 0.00|     |

The results show that scan patterns in both simple and complex situations are very similar and follow highly trained procedures. Accordingly there is a very strong correlation ($r = .996$) between the scanning probabilities of one gaze in the simple and complex landing condition. Similar results could be observed during take-off clearances. As can be seen in table 3 the probabilities to look at the AOIs while delivering the clearance show consistent values. They strongly correlate by $r = .976$ with the simple landing probabilities and by $r = .972$ with the complex landings. Amongst all participants similarities in their scanning patterns could be observed. It may not be ignored that there might have been inaccuracies in the measurement.
Table 3. Probability of attending to an AOI during take-off clearances.

| AOI          | number of gazes | 1   | 2   | 3   | 4   |
|--------------|-----------------|-----|-----|-----|-----|
| Approach sector |                 | 0.11 | 0.03 | 0.01 | 0.00 |
| Departure sector |                 | 0.24 | 0.11 | 0.03 | 0.00 |
| Runway exit |                   | 0.21 | 0.09 | 0.03 | 0.00 |
| Final approach sector |             | 0.19 | 0.03 | 0.02 | 0.01 |
| Flight strips |                    | 0.97 | 0.76 | 0.44 | 0.23 |
| Holding point |                     | 0.14 | 0.03 | 0.01 | 0.01 |
| Radar display |                        | 0.81 | 0.50 | 0.25 | 0.10 |
| Runway |                         | 0.66 | 0.34 | 0.17 | 0.11 |
| Taxiways |                            | 0.57 | 0.25 | 0.11 | 0.03 |
| Weather display |                      | 0.95 | 0.09 | 0.01 | 0.00 |

4. Discussion

The purpose of this study was to investigate which information sources are relevant when giving a take-off or landing clearance. Also situation specific probability scores of attending to the AOI should be calculated. Strong similarities could be found between the different clearances. Also the study revealed a highly trained visual scanning behavior among the tested controllers. It was shown that there are information sources that were looked at in most of the cases and others that could be neglected. There are also AOIs with a high probability to be attended to several times during a critical clearance. As the scanning behavior amongst the controllers showed strong similarities it is assumed that the data from the few controllers can be generalized to others as well. The similarities also indicate that the situation based approach is a good method to extract only the apparent focused visual attention.

The probability of looking at an AOI several times may be a valid method to take into account the expectancy value mentioned in the SEEV model. Nonetheless, there might be doubts concerning the usefulness of this measure as such. Particularly the flight strips might be the information source which most unlikely changes its information without the controller’s input. Interestingly they reach high probability values and even the probability of a third look is consistent in all conditions at around 40 percent.

It was mentioned that the actual scanning does not necessarily cover the importance of different information sources. In another study from 2013 the importance of the different information sources at the controllers’ working position has been rated by air traffic controllers independently [6]. These data will be compared to the actual gaze data of the current study and combined to a probabilistic prediction model in subsequent studies. The model could then be used to predict air traffic controllers’ visual attention. Moreover, with an eye tracking system that is able to calculate gazes in real time and compare it to the predicted model data an assistance tool could be built to monitor the controller at work and give indication when the controller missed to check an AOI.

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