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A Pilot Study into Bio-Behavioural Measurements on Air Traffic Controllers in Remote Tower Operations

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Abstract. What is the impact of shifting to remote tower operations on the Air Traffic Controller? In the joint HungaroControl-Netherlands Aerospace Centre NLR pilot project an assessment of bio-behaviour on three air traffic controllers was made in a remote tower and conventional tower. The research is motivated by HungaroControl's plans in shifting to remote tower operations at Budapest airport in the upcoming years. This pilot project is considered a feasibility study to investigate if an eye tracker and a heart rate sensor can be used to derive workload, the controllers' division of attention over information elements, and scanning strategies in two such different environments. Given the limited number of participants and challenges in measuring workload in the two different operational environments conclusions, can only be drawn with care. Nevertheless, preliminary results suggest that there might be an increase in workload in the remote tower environment, and thus further research is needed to clarify at what extend Air Traffic Controllers' workload could be different, what are the root causes of the increase and how that could be handled. Also the pilot study has given confidence that useful bio-behavioural measures can be obtained for comparison between the remote tower and the conventional tower, and to extend the research to a larger group of controllers.

Keywords: Air traffic control, remote tower, workload, eye-tracking, HRV

1 Introduction

Remote tower concepts are finding their way to Air Traffic Control (ATC) operations of European airports. In a remote tower, the traffic can be managed from a control room with real time video images from the airport displayed on a large video wall (Fig. 1), as an alternative for the out of the window view from an actual ATC Tower.

The concept was initially targeted at smaller, more remote airports as an optimisation of Human Resource allocation, allowing controllers to operate several airports simultaneously. More recently, larger airports such as Budapest are installing a remote tower as their primary control room. In this case the high cost of rebuilding a complete tower is the incentive to investigate the possibility to operate from a remote tower.

In the framework of Single European Sky Large Scale Demonstrations, several different approaches to remote tower solutions were demonstrated (either simulated or in live operations): airports with low traffic intensity (Sünderland, Saarbrücken), multi remote solutions (Dublin, Milan) and a middle-size, dual-runway airport solution (Budapest). Eye-tracking measurements were conducted at Budapest and Dublin, as a complimentary assessment method.



Fig. 1. Ground controller working position in the remote tower

With current technology developments, where bandwidth and processing power are no longer a bottleneck, the change from the conventional tower to remote tower operations might not seem tremendous. However, analysing the situation from a human performance perspective quite a few differences become evident:

- Cameras may cover another area than the normal view from the original tower at lower resolution compared to the real outside view;
- Pan Zoom Tilt cameras are used as an alternative to binoculars in the conventional tower;
- The information from different cameras needs to be integrated into a coherent picture on the monitors;
- Controllers need to redefine their attention division between the information elements.

In the pilot study, HungaroControl together with NLR looked into the change this shift encompasses from a human operator perspective. It was investigated if differences in the behaviour of controllers appear between the control from the conventional tower and the remote tower. The study focuses on answers to questions such as:

- How is workload affected by remote tower operations?

- Do controllers search for information in a different way when operating in a remote tower?
- Do controllers spend different amounts of time finding certain information elements?

Workload - in this case the mental effort someone experiences to perform a task - is dependent on the task load (e.g., the number of aircraft under control) and a number of personal characteristics (e.g., experience and fitness in general), but also the working environment. In this study the feasibility of using eye-tracking and heart rate measurements was investigated, to determine changes in workload and working strategies when shifting from the conventional to the remote tower, for a within subjects comparison.

2 Method

Measurements were performed during the live operation of traffic by three air traffic controllers (ATCOs). In these sessions traffic was controlled from the conventional tower and later from the remote tower. During the remote tower operations, a group of controllers was available in the conventional tower as a back-up in case something unexpected would happen. The aim was to record physiological data on each ATCO during comparable situations in the conventional tower and the remote tower for comparison to provide an insight in if, and how, ATCO bio-behaviour is different between both environments. The controllers worked for approximately one hour at the ground controller position and one hour at the aerodrome controller position, in both tower environments.



Fig. 2. Dikablis Essential eye tracker

For each measurement, one ATCO was subjected to measurements of eye scanning behaviour with a head mounted Dikablis Essential eye tracker (Ergoneers GmbH, Fig. 2) and heart rate with a Shimmer 3 system (Shimmer). An observer made time-stamped notes reflecting the traffic density to allow the selection of intervals for analysis with sufficient representativeness for the ATCO task, and to identify

comparable traffic loads under both conditions for workload comparison. The traffic density at Budapest airports fluctuates. At times 10 or 12 movements in 10 minutes were counted and at other times there was no traffic for 10 minutes. The eye tracker recorded the controllers' division of attention between areas of interest. In addition, eye blink frequency and eye blink duration was derived. Eye blink frequency negatively correlates with workload: a lower blink frequency implies a higher (visual) workload [1].

Heart rate variability is the physiological phenomenon of variation in the time interval between heartbeats. It also negatively correlates with workload or focused attention [2, 3]. With electrocardiography (ECG) measurements, the heart rate was assessed during the controllers' shift. The variation in the duration of inter-beat intervals was determined calculating the *root mean square of successive differences (RMSSD)*, the square root of the mean of the squares of the successive differences between adjacent intervals and is expressed in milliseconds. A delta was calculated between the RMSSD in a five minute rest period preceding the controller's operational shift and the selected interval during the shift. This was performed for both environments. For the analysis of eye tracker data, the following areas of interest were determined (Fig. 1 and Fig. 3):

- Outside view (and video wall in the remote tower);
- Radar (two displays for aerodrome control);
- Ground radar (two displays for ground control);
- Runway meteo status display.



Fig. 3 The aerodrome controller position in the tower (the black and white markers are necessary for the automatic recognition of areas of interest)

The communication display and the flight plan display were also distinguished in the analysis. However, the analysis showed that these areas were used infrequently and the use is not influenced by the control environment. Therefore only the main attention areas were considered for further analysis.

3 Results

For the division of attention, the average percentages of time spent looking at the areas of interest were calculated over the controllers (Fig. 4). The term 'Outside' refers in case of the remote tower to the video wall. The 'Ground radar' refers to the display(s) where the ground radar was presented, the radar refers to the display where the approach radar was visible. Green represents the tower and blue the remote tower.

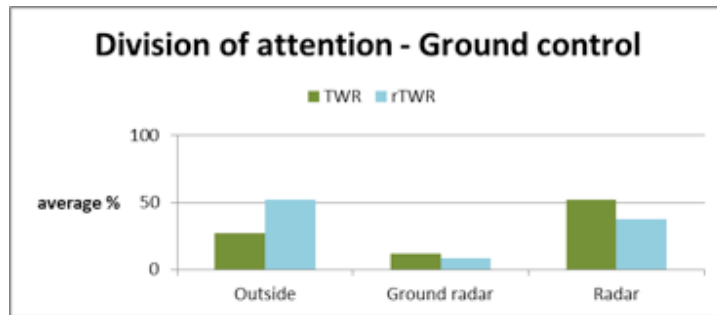


Fig. 4. The average dwell times of the ground controller between outside, ground radar and radar display (TWR: tower, rTWR: remote tower).

To look at individual differences in information acquisition behaviour, the division of attention to the outside world was compared between tower and remote tower. The distinction is made between the video wall and the Pan-Tilt-Zoom (PTZ) camera display. In Fig. 5, for controller 1, 2 and 3 the percentage of time looking at the outside world is presented.

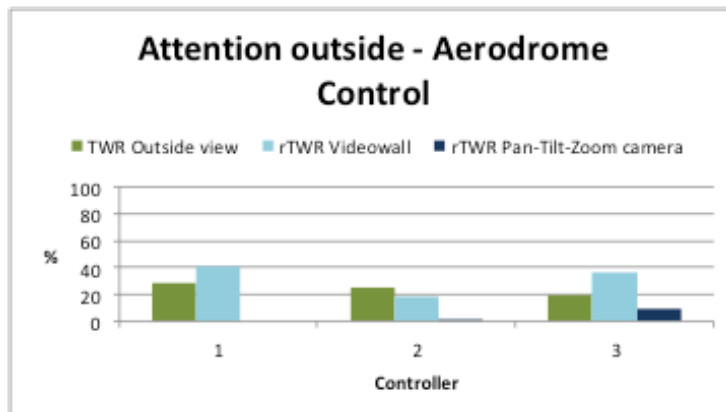


Fig. 5. Dwell times outside for the three controllers in the aerodrome controller position (TWR: tower, rTWR: remote tower)

The HRV data for controller 1 and 2 were analysed. The difference in variability between the rest period and the representative controlling periods is presented in **Fig. 6**. Because of a negative correlation between HRV and workload (higher HRV implies a lower workload), a decrease compared to the rest period was expected. For controller 1, the variability increased compared to the rest period, in the tower and remained more or less the same in the remote tower. For controller 2, the variability decreased in the remote tower.

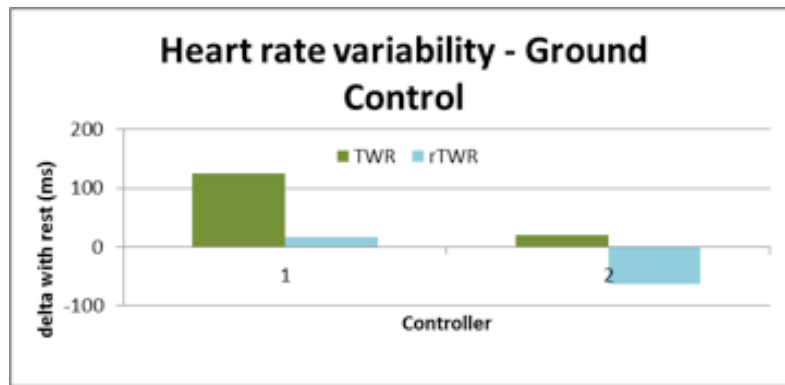


Fig. 6. The delta of the RMSSD between the rest period and during ground control for controller 1 and 2 (TWR: tower, rTWR: remote tower)

4 Conclusions

The current study is indicative and may be useful as starting point for future larger scale studies. Data were gathered in two locations, they stem from three ATCOs who controlled ground and/or aerodrome traffic. These data are presented in bar charts and enable the reader to form an overview of their meaning and to compare these data. The number of subjects is insufficient for statistical analyses in order to establish statistical significance.

A more thorough correction of the data may provide a slight shift in the division of attention in the tower and provide a more accurate answer to the research questions. In the analysis of the eye tracker data, it became apparent that the validity of the pupil recognition as well as the marker recognition was lower in the conventional tower compared to the remote tower. In the tower, the pupil recognition was sometimes obstructed by the reflections of daylight. And the marker recognition was suffering from the large contrast. The result was that when the controllers looked outside in the tower, sometimes the pupil was not recognised. This was apparent from the data on the attention to the outside view, which was rather low. Data were corrected for this effect: i.e. by using the total amount of time with valid eye and marker recognition (instead of the complete interval) to calculate the division of attention. This increased the realism of the data but the measured percentage of time spent looking outside is probably lower than the reality. For the blink frequency and duration unfortunately,

this effect resulted in incomparable data and were therefore not included in this article. The impact of the above is that the data should be interpreted with precaution, but the following was concluded.

In general there was a trend that controllers looked more to the video wall in the remote tower compared to looking out of the window in the tower, and a trend that controllers make use of the radar display more often in the tower compared to the remote tower. This can be interpreted as a result of the integrated visualization where flight labels appear on the video wall as well. Nevertheless, an underlying cause might be the longer searching time on the video wall. The eye tracker data show that the ATCOs have different strategies in their acquisition of visual information in the remote tower compared to the tower. In addition, controllers have their own strategy in how they assess the information they need. These individual differences are so significant that with such small sample size, results can help to understand personal scanning patterns or give personal feedback, but general conclusions should not be drawn. The analysis of the data indicates there may be an increase in workload in the remote tower, but the small sample size does not make this conclusive. And even though the intervals for analysis were carefully selected based on traffic density, the effect of the traffic load on workload cannot be completely mitigated in the operational conditions under which the measurements were performed.

The heart rate data is influenced by muscle activity in the area of the torso other than the heart muscles. Speaking, which is required as part of the task of air traffic control, influences the data. For future sessions, more filtering techniques will be applied including manual artefact correction.

The bio-behavioural measurement is planned to be continued with a bigger sample size and longer measurement periods. Other than that, it is planned to focus more on dedicated situations, like controlling an approaching aircraft, so that scanning patterns matching those situation can be identified. This may provide insights in potential improvements for the presentation of the outside view or the controller working position. Another area where the assessment can be strengthened is the incorporation of other kind of data such as detailed task execution analysis by an observer, tests and interviews with the ATCOs focusing on workload and stress. All these complementary information can contribute to better understand the causes behind the observed bio-behavioral data, therefore build up a complete picture about the workload related implications and other potential human factor originated requirements of the remote towers.

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