Introduction

Air traffic controller activity combines the issuing of instructions with continuous visual assessment of the situations. As defined by [13], visual scanning in air traffic control is "a systematic and continuous effort to acquire all necessary visual information in order to build and maintain a complete awareness of activities and situations which may affect the [controllers] area of responsibility".

The introduction of new procedures or the implementation of new tools might induce modifications of controller working practices. Therefore, measuring the impact of changes on controller activity should not be limited to active control indicators such as number and duration of verbal instructions. Monitoring tasks, in terms of number, duration and content of fixations also need to be investigated.

In the present paper, we describe how we investigated jointly the impact of a new procedure on active control (i.e. communication and instructions) and on monitoring. In the first section, we will introduce the rationale for looking at monitoring, and more specifically why we decided to use eye tracker devices. In the second section, we will present the method and the experimental set up. In the results section, the impact of delegation on the monitoring (modification of fixation areas, scanning patterns, objects of fixation) will be analysed and related to the overall controller activity. Even though the reduced monitoring can be seen as a benefit in terms of workload, the issue of safety will be discussed, in investigating if modified monitoring is still effective.

Monitoring tasks in air traffic control

How to access it?

Questionnaires and debriefing items could provide feedback on perceived impact on monitoring activities. However, subjective feedback has some limits: first it might only reflects perception of the end of a simulation exercise, second it might be related to the monitoring load (as opposed to strategy) and third even if controllers perceive that their scanning pattern is modified, they might not be aware of how it is modified. Situation awareness assessment methods, such as SAGAT [5] or SAVANT [16], question the contents of monitoring and the subjects ability to detect events. Whereas they might inform about what subjects are aware of at a given moment (i.e. the result of monitoring), they do not provide data about the process of acquiring information. Typically, the duration and the location of the monitoring are not investigated. Eye trackers devices, previously used in air traffic control studies provide objective data enabling eye movement tracking analysis.

Benefits and limits of eye tracker analysis

Among indicators used in cognitive psychology (e.g. response times, verbal answers, implicit or explicit choices, ), eye movements are a spontaneous, direct and measurable trace of subjects attention [10]. Eye fixation analysis appear to be most useful when trying to trace psychological processes, both in reading and problem solving [8]. The assumption is to consider eyes movements as a translation of the underlying cognitive operations [4]. Tracing psychological processes in the context of eye fixation analysis

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refers to determining the sequence and duration of mental processes that operate on separate external stimuli. When looking at an object, the eyes move from one point of interest to another. This fast jumps, named saccades, are ballistic movements that, once started, will continue until they reach their target destination [2]. Visual information is analysed only during stationary periods between saccades called fixations. A fixation is a four steps process. First, the visual system stores an image in short-term visual memory. Second, the visual system encodes the raw image and stores the codes in working memory. In the third step, further mental processing takes place and, in the fourth step, the visual system prepares for the next saccade [9].

These visual scanning data can be collected with a device tracking the movement of the eye (one eye or both eyes) while it is scanning information displays. The device determines where the person is actually looking. Visual scanning data include information about fixations, saccades, blinks and pupil diameter. The most obvious limitation of the methodology is the costs in terms of instrumentation, training of personnel, and data analysis. A conceptual limitation is that eye fixation behaviour does not directly indicate the end product of the comprehension process: "looking does not imply seeing, understanding or remembering" [14]. It is usually worthwhile to supplement eye fixation monitoring with another measure like recall, question-answering, or retrospective protocols that indicate more about what has been comprehended. Eye tracking technology also needs to be used inside a rigorous experimental frame and the interpretation of the data to refer to cognitive models. The experimental protocols should privilege repeated measures (several measures made on the same subject and in the same experimental condition) and control the tested factors.

**Examples in air traffic control**

Measures of eye movements (visual efficiency, eye motion workload and pupil motion workload) were used as indicators of controller behaviour. Results showed for example, the impact of task load and expertise on fixations: busier controllers had shorter and more frequent saccades, and experienced controllers tended to make more fixations [13]. In the context of assessing controller recovery from failure, the suitability of methods such as eye movement tracking, situation awareness assessment (SAGAT) and workload assessment (NASA-TLX, ISA) was investigated [11]. The focus on general characteristics of fixations (frequency and duration of scanning) showed that eye tracking technique could provide a meaningful evaluation of changes in visual scanning behaviour induced by automation failures. In a recent study [7] visual information acquisition was included as a measure of team situation awareness. The analysis of fixations as a function of area and objects type (static versus dynamic) enabled the identification of two visual attention strategies: focused (i.e. looking at few chunks of information for longer period) and distributed (i.e. looking at many chunks of information for shorter periods). Eye tracker analysis was also used to measure the effect of moving a controller from the current active control to a monitoring position [17]. Results showed that changes in involvement and load did not affect general characteristics of monitoring (fixations, saccades, blinks and pupil size), nor objects of fixations (radarscope, flight strip bays, radar return and data blocks), but did influence the structure in the visual scanning pattern.

**Objectives in our study**

Even though eye movement tracking analysis provide an extensive range of data, from workload measurements to scanning patterns identification, few (if none) studies have related the structure of scanning patterns to the structure of the airspace itself nor to the controller strategies. In the present study, we investigate a new task allocation (denoted delegation), between controllers and flight crew. Starting with the analogy of visual separation, the proposed task allocation relies on the delegation of spacing tasks in which the flight deck is tasked to implement a solution defined by the controller. Restricting the delegation to implementation tasks (as opposed to decision making tasks) is expected to preserve controller authority and understanding of the situation (mental picture). The delegation of spacing is at controller initiative, who can decide to end it at any time. The flight crew however can only abort it in case of problem onboard such as a technical failure. The delegation applies to pairwise situations: one aircraft is delegated, the other being target.
To assess the impact of delegation on controller activity, we defined a geographical-based analysis [6]. It consisted in mapping manoeuvring instructions over the considered area, and more specifically in analysing their distribution as a function of their distance to the exit point. From this geographical-based analysis, we could infer strategies controllers used to build and maintain sequences. It allowed confirming our assumptions: delegation leads to anticipate the building of the sequences, and to relieve the controller of maintaining these sequences. Although these results suggested a positive impact on controller activity, they were limited to active control tasks (i.e. issuing instructions). In addition, delegation is expected to reduce the amount of time spent actively monitoring and thus to contribute to an overall reduction of workload. Consequently, beyond measuring the influence of delegation on general characteristics of eye movements (number and duration of fixations), the objective was to understand the impact on controller activity. The same analytical framework was applied to investigate globally the impact of delegation on the geographical occurrence of both instructions (active control) and fixations (monitoring). In addition, contextual analysis of fixations aimed at determining if delegation modified the number, duration and frequency of fixation per aircraft.

Method

**Hypotheses**

**General characteristics of fixations:** With the increase of the traffic (traffic very high), we expect that the controllers adopt a more economic strategy: the controllers restricted their field of investigation on the only information they consider important and neglected the other, useless or little relevant [1]. Despite the relevance of other areas (e.g. strip progress board, maps), we expect most of the fixations to be on the radar screen. The most fixated objects should be respectively not delegated concerned aircraft (arrivals), delegated concerned aircraft and not concerned aircraft (overflights).

**Influence of delegation:** The measured sectors can be decomposed in three areas: entry, middle and exit. In the entry area, controllers build sequences, in the middle area they maintain spacing between sequenced aircraft, and in the exit area, they transfer aircraft. We expect delegation to induce longer (and more frequent) periods of fixations on entry areas, and shorter (and less frequent) periods on middle areas, where the maintaining of spacing is delegated to aircraft. In addition, we expect the visual scan to cover sequences of aircraft rather than pairs.

**Cognitive workload:** Several eye activity measures have been shown to correlate with visual and/or cognitive demands imposed by tasks [15]. Generally, blink rate and duration decline as a function of greater workload. Pupil diameter has been shown to generally increase with higher cognitive processing levels. Although we expect reduced workload induced by delegation to be reflected in eye activities measures, this will not be addressed in this paper.

**Airspace**

The airspace simulated consisted of two extended terminal manoeuvring sectors and two approach sectors (INI position). We considered the Orly area (AO and INI-O) and the Charles de Gaulle area (AR and INI-R).

**Figure 1. Airspace dedicated to sequencing applications (snapshot of replay tool). The four sectors are denoted AO, INI-O, AR and INI-R. Delegation links between aircraft are visible.**

**Participants**

Six en-route European controllers with extended terminal manoeuvring area experience participated in the experiment.
**Independent variables**

Each experimental scenario was either high or very high traffic, and was played with and without delegation. Three traffic samples enabled each controller to play all conditions as an executive controller.

**Use of delegation:** The study compared controller performance with and without delegation.

**Traffic load:** A high traffic consisted of current maximal capacity of these sectors (27 aircraft per hour). A very high traffic consisted of 120% of the high traffic (31 aircraft per hour).

**Sector configuration:** Two different sectors were measured. The first sector (AR) with one converging point at the sector entry (DIJ), should enable early building of sequences. The second sector (AO) with two converging points, one at the sector entry (ATN) and the other at 50Nm before the exit point (OKRIX) should constraint a late building of sequences.

**Dependent variables**

The dependent variables were: gaze duration (msec) on each object, number of fixation on each object, mean pupil diameter, blink frequency and duration, scanning pattern.

**Procedure**

The eye tracker session lasted 4 days (the whole experiment lasting 3 weeks). Each experimental run consisted of the set-up and calibration of eye tracker, a simulation run and a post scenario questionnaire. Each run took approximately 80 minutes, including calibration. There were three runs per day.

**Devices**

The eye tracker we used was an eye link system (Figure 2), capable of extremely high spatial resolution (better than 0.01j), fast sampling rates (250 Hz), true gaze-position measurement and binocular eye-tracking. An Ethernet link connected the eye-tracking computer to an experimental-display computer, with support for real-time data transfer and control. Analysis of data into saccades, fixations, and blinks is performed on-line, and data may be recorded into a data file by the EyeLink software.

Two custom-built ultra-miniature high-speed cameras take simultaneously 250 images per second of both eyes to provide binocular eye-tracking. A third camera tracks 4 IR markers mounted on the visual stimulus display for head motion compensation and true gaze position tracking.

![Figure 2. The head band](image)

Before using this system some tests were carried out in laboratory in order to check its capacity to record long periods of test, the precision of the provided results, the ability for the subjects to support the weight of the head band during a one hour recording. Then, more tests were made to define the procedure necessary to synchronise the visual scanning patterns with air traffic events.

**Data reduction and analysis**

At the end of experimental recording, we had two distinct files: one containing the simulation data (air traffic events) and the other the eye measures. The system supplied all eye measures by using an algorithm based on speed named I-VT (Velocity-Threshold Identification). I-VT is a velocity-based method that separates fixation and saccade points based on their point-to-point velocities. The velocity profiles of saccadic eye movements consists essentially of two distributions of velocities: low velocities for fixations (i.e., < 100 deg/sec), and high velocities (i.e., > 300 deg/sec) for saccades. This aspect of saccadic eye movements makes velocity-based discrimination fairly straightforward and robust [12].

For all measures (fixations, saccades, blinks), we obtained temporal information (beginning and end of the fixation), co-ordinates of the fixation, eye concerned (right or left) and pupil diameter.
Results

Subjective feedback from controllers was collected via questionnaires items. Controllers thought delegation modified their monitoring, typically in reducing its frequency. However half of the controllers thought the monitoring with delegation was more detailed, the other half more global.

Eye movement tracking technique provided more objective evaluation of the impact of delegation on monitoring. General results are statistically significant (Chi2-test, \( p<0.0001 \)).

**General characteristics of fixations**

The initial investigation consisted in measuring the number and duration of fixations on the radar screen as opposed to outside it. In the AR sector (one converging point), with and without delegation, and in both traffic load the controllers spent 80% of their time monitoring the radar. In AO sector (one early and one late converging points), they spent 70% of their time on the radar. The need to integrate later flows might require longer consultations of the paper strips, located below the radar screen.

**Global monitoring**

At a macroscopic level, we investigated if delegation influences the number and duration of fixations, and if, similarly to what was observed with instructions, there was a correlation between number, duration and geographical position of fixations. To address the overall monitoring, we analysed the geographical distribution of fixations (results for the AR sector on Figure 3). In high traffic situation, the global monitoring was similar without and with delegation: more fixations occurred around the converging point (35% with delegation and 25% without over the [120-140NM] area). In very high traffic situation, curves are completely opposite: with delegation, most of the fixations are concentrated over the converging area, while without delegation, they are concentrated over the second part of the sector ([40-80NM] from the IAF): exactly where speed and heading instructions are still used.

It looks like without delegation, controllers are more in a reactive positive, the building of sequences being no longer anticipated. With delegation, controllers seem to be focusing over the most important area, where sequences need to be built. Similarly to what was observed about active control, delegation impact is more noticeable in very high traffic situation.

![Figure 3. Distribution of fixations in sector. Relevant areas are: sector entry (200NM), sequences building (140NM) and transfer to next sector (40NM).](image)

**Contextual monitoring**

The reduced monitoring in the second part of the sector with delegation raises few issues in terms of frequency of monitoring per aircraft: Is the monitoring frequency modified? Are aircraft still monitored? Are changes equally impacting delegated and not delegated aircraft?

**Average frequency of monitoring**

To process the data, a software was developed to synchronise air traffic events with eye measures and to calculate statistics. Spatial and temporal
synchronisation was ensured through controller mouse clicks on reference beacons every 15 minutes. An additional post processing synchronisation took place later. From these files, all the statistical computation was realised. In complement to analysing the distributions of fixations on the radar, we examined the frequency of monitoring of each aircraft, depending on its status (delegated or not). The calculation of fixations per aircraft was made by allocating to every fixation one or several concerned aircraft (positions or labels). In other words, for each fixation point, we determined which aircraft was (were) looked at by listing all the aircraft close to the point of fixation. We considered that an aircraft was close to a point of fixation if it was within a circle of 100 pixels radius (approximately 10NM) centred on the fixation point. This led to obtain a temporal distribution of fixations for every aircraft (Figure 4).

From this, we calculated the mean period of fixation (i.e. interval between two successive fixations on a same aircraft). No effect of delegation was observed. Typically, in AR, very high traffic, delegated and not delegated aircraft were fixed as frequently, approximately every 12 seconds (Table 1).

### Table 1. Mean period of fixations. AR sector, very high traffic, second exercise, 100 pixels fixation area.

<table>
<thead>
<tr>
<th>Aircraft status</th>
<th>Mean period</th>
</tr>
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<tbody>
<tr>
<td>Without delegation</td>
<td>Not delegated</td>
</tr>
<tr>
<td></td>
<td>In preparation</td>
</tr>
<tr>
<td>With delegation</td>
<td>Not delegated</td>
</tr>
<tr>
<td></td>
<td>Delegated</td>
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**Less frequent monitoring?**

In order to detect aircraft monitored less frequently, we analysed the distribution of the maximum period and more specifically extreme values (Figure 5).

![Figure 4. Example of a temporal distribution (15 minutes) of fixations for a specific aircraft. Delegation is indicated by the blue line, delegation status (preparation or active) is reflected with the P and A letters. High density of lines reflects gathering of fixations on the aircraft, while lower density reflects less frequent fixations.](image)

![Figure 5. Distribution of maximum period. AR sector, very high traffic, second exercise, 100 pixels fixation area. Without delegation (top) and with delegation (bottom). Delegation active (A), in preparation (A) and no delegation (O).](image)

2 In preparation refers to target selection phase, when the controller has prepared delegation but waits for the appropriate time to activate it. This usually corresponds to initial building of sequences.
Results show a few cases with surprising periods of more than 6 minutes in both situations (delegated and not delegated aircraft). Does it mean that these aircraft are simply not monitored?

As a first attempt to answer we checked if these aircraft received instructions. This was the case, not only they received instructions all along their flight in the sector, but for two of them instructions given reflected a complex situation.

The size of the "fixation area" (100 pixels) was thus questioned. A 200 pixels circle was used. However, there were still cases with large periods. In addition, the increased size led to the drastic reduction of the mean period, which did not seem realistic: controller can hardly perform a full scanning of all the aircraft in contact (typically 15) in 3 seconds (Table 2). The 200 pixels size clearly appeared as too large.

Table 2. Maximum and mean periods of fixations. AR sector, very high traffic, second exercise, 200 pixels fixation area.

<table>
<thead>
<tr>
<th>Aircraft status</th>
<th>Maximum period</th>
<th>Mean period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without delegation</td>
<td>Not delegated</td>
<td>261.7 sec</td>
</tr>
<tr>
<td></td>
<td>Not delegated</td>
<td>419.4 sec</td>
</tr>
<tr>
<td>With delegation</td>
<td>In preparation</td>
<td>54.5 sec</td>
</tr>
<tr>
<td></td>
<td>Delegated</td>
<td>210.7 sec</td>
</tr>
</tbody>
</table>

We then questioned the definition of the area as a circle centred around the fixation. We used the eye tracker replay tool to understand the scanning of these aircraft with extreme periods. We could identify that fixations were located in between two or more aircraft (Figure 6).

Figure 6. Example of fixation area excluding aircraft, which received instructions.

Note: Although this requires further investigation, we think that results issued from the relative comparison of mean period without and with delegation are still valid: delegation does not modify the frequency of monitoring.

Conclusion

In order to assess the impact of a new procedure on controller monitoring, eye movements tracking analysis was performed in the context of a controller in the loop experiment. The analysis investigated three levels: general fixation characteristics, global monitoring and contextual monitoring. Whereas mean data provided answers to initial questions, atypical values raised new issues.

In terms of method, how could we determine practically what is actually monitored? Fixations might not correspond to visual information processing. Conversely, does the absence of fixation mean an absence of monitoring?

In terms of results, can we associate a fixation located in the middle of a configuration of aircraft to each of the aircraft? This issue was previously raised for instance in the context of chess games [3]: in this typical spatial oriented activity, expert player fixations occur more frequently between objects rather than on them. This was interpreted as a more efficient pattern recognition. Similar strategies of pattern recognition might be used in air traffic control. By "linking" aircraft, delegation explicitly introduces the notion of pattern. Consequently, are patterns comparable without and with delegation? Do controllers apprehend them similarly? This will be investigated in the next controller in the loop experiments.
References


