ABSTRACT
A series of controller-in-the-loop experiments was conducted to assess the impact of a set of new air traffic control instructions on the efficiency and safety of controller activity. Eye tracker devices were introduced in the experimental set-up to focus more specifically on the impact on monitoring activity. Six European controllers handled a very high level of traffic in conditions without and with the new instructions. Macroscopic and microscopic levels of analyses were performed. At the macroscopic level, a geographical analysis of fixations confirmed results previously observed: the use of the new spacing instructions enables controllers to focus their attention upstream, where most of the instructions are also issued. Microscopic analysis showed that aircraft were still monitored once spacing instructed and that the frequency of monitoring was the same for all aircraft, whatever their status.

Keywords
Air Traffic Control, Airborne Spacing, ASAS, Monitoring Task, Controller-in-the-Loop Experiment, Eye Movement Analysis, Eye-Tracker.

INTRODUCTION
A new allocation of spacing tasks between controller and flight crew is envisaged as one possible option to improve the management of arrival flows. It relies on a set of new spacing instructions and consists in tasking the flight crews to maintain a given spacing (in time or in distance) with respect to a designated target. There is no modification of responsibility for separation provision. This task allocation – denoted airborne spacing – is expected to increase controller availability. This could lead to improve safety, which in turn could enable better management of the traffic and, depending on airspace constraints, more capacity.

To assess benefits and limits of this new task allocation, two streams of controller- and pilot-in-the-loop experiments have been conducted, using a unified perspective. For controller experiments, the same analytical framework was applied to investigate globally the impact on the geographical occurrence of both instructions and eye fixations [12]. This framework consists in mapping manoeuvring instructions and fixations over the sector, and more specifically in analyzing their distribution as a function of their distance to the sector exit point. This macroscopic analysis allowed the confirmation that the use of spacing instructions leads to anticipate the building of sequences and to relieve the controller of the maintenance of sequences. In terms of monitoring, under very high traffic, the use of spacing instructions enabled controllers to focus upstream, as opposed to downstream when not using these instructions. However, a microscopic analysis of the frequency of fixations per aircraft in both conditions, brought out cases of aircraft not fixated during long periods (e.g. 5 minutes), which would be surprising from an operational perspective. A contextual analysis of these cases (using replay tools) showed that those aircraft, who were receiving instructions, could not have been ignored by controllers. This questioned the method used to relate fixations to objects on the radar screen. Different options were identified to improve the method, namely the distinction between the foveal and parafoveal vision, the relation between fixations and patterns recognition.

A new experiment has been conducted to extend the scope towards the use of time-based spacing and the introduction of downstream sectors (approach sectors). A sub-objective of the experiment was to improve the contextual analysis of fixations, in distinguishing foveal and parafoveal fixations. The present paper reports more specifically the monitoring tasks analysis. It is composed of three sections. First, methods to address monitoring task in air traffic control domain are introduced. The objectives, scenario and levels of analysis are described in the second section. In the third section, results from both macroscopic and microscopic analysis are presented and discussed.

MONITORING TASKS IN AIR TRAFFIC CONTROL
Monitoring 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 [control] area of responsibility” [8]. The assessment of air traffic controller monitoring tasks in simulation environment usually relies on subjective data, collected through questionnaires and debriefing items. This feedback on perceived levels or changes in monitoring activities has some limits: (1) it might only reflect perception at a given moment (e.g. the end of a simulation exercise), (2) it might be related to the monitoring load (as opposed to strategy) and (3) even if a modification is
perceived, it might be difficult to express. Situation awareness assessment methods (e.g. SAGAT [1] or SAVANT [10]) investigate the contents of monitoring and the subjects ability to use their monitoring to detect events. Whereas these techniques address what subjects are aware of at a given moment, they do not provide data about the process of visual acquisition of information (e.g. duration and location of fixations not investigated).

Eye tracker devices and their measures of eye movements (e.g. visual efficiency, eye motion workload and pupil motion workload) have been used as indicators of controller behavior. Results showed for example, the impact of task load and expertise on fixations: busier controllers had shorter and more frequent saccades; experienced controllers tended to make more fixations [8]. 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 [5]. The focus on general characteristics of fixations (frequency and duration of scanning) showed that eye tracking techniques could provide a meaningful evaluation of changes in visual scanning behavior induced by automation failures. In a recent study [4] visual information acquisition was included as a measure of team situation awareness. The analysis of fixations as a function of area and object’s type (static versus dynamic) enabled the identification of two visual attention strategies: focused (i.e. looking at a few chunks of information for longer periods) 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 [11]. 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 (radar screen, flight strip bays, radar return and data blocks), but did influence the structure in the visual scanning pattern. Even though eye movement analysis provides an extensive range of data, from workload measurements to scanning patterns identification, few (if any) studies have related the structure of scanning patterns to the structure of the airspace itself or to the controller strategies.

EXPERIMENTAL DESIGN

Objectives
One of the key objectives of the present study is to assess the impact of the spacing instructions on the overall controller activity, using a unique framework to address the tasks of traffic monitoring and flow management.

More specifically, the eye movement analysis aimed to:
- measure general characteristics of fixations (e.g. duration, number);
- relate eye movement to controller activity, in analyzing the geographical distribution of eye fixation over the sector (macroscopic analysis);
- assess the frequency of monitoring per aircraft, potentially pointing out cases of aircraft not fixated during a given period (microscopic analysis)

EXPERIMENTAL SET-UP

Participants
Six European controllers participated in the 3 weeks experiment. Aged between 35 and 51, their experience ranged from 8 to 25 years. Two out of the six controllers had participated in a previous experiment.

Equipment
Two ASL501 eye tracking systems (Figure 1), enabling unrestricted freedom of movement were used during the experiment. This eye tracking systems is designed to measure a subject’s eye line of gaze with respect to the head. In terms of technical features, the system had a 50Hz sampling rate, an accuracy of 0.5 degree visual angle and a resolution of 0.1 degree visual angle. In the present experiment set-up, 0.5 degree angle corresponds to 0.35cm and 0.1 degree angle to 0.07cm.

Airspace and procedure
The airspace (Figure 2) comprised two sectors (AO and AR) derived from four Paris ACC sectors, handling south-east arrivals to Orly (LFPO) and Charles-De-Gaulle (LFPG). Each sector was controlled by an executive and a planning controller.

In the simulated environment controllers received converging flows of aircraft that they were tasked to integrate to build a single flow of aircraft (denoted sequence) to be delivered to the next sector at a given altitude with a minimum inter-aircraft spacing. The task of defining aircraft order in the sequence and setting it up is called the “building of the sequence”. It occurs in areas denoted AO1 and AR1. Once the sequence and the required inter-aircraft spacing have been established, the “maintenance of the sequence” corresponds to maintaining spacing between successive aircraft before transferring them to the approach sector. The maintenance occurs in areas denoted AO2 and AR2. In conventional conditions, the controllers use heading instructions to build sequences and speed instructions to maintain them. With the new instructions, whereas controllers are still in charge of building the sequences, the
tasks of maintaining the sequence are assigned to the flight deck, through speed adjustments.

Eight days of training were provided for six days of measured runs.

![Figure 2. Airspace with main arrival flows and distance from exit points (50 and 100 nm from OMAKO and MOLEK).](image)

**Scenarios and variables**

During the experiment, controllers had to control a high level of traffic (31 arrivals per hour, plus transit). The use of the spacing instructions was at controller’s discretion.

The experimental plan was a $3 \times 2$ (3 types of spacing instructions available $\times$ 2 sectors) within subject design. The three main conditions were:

- **No**: no spacing instruction available (conventional instructions only)
- **Distance**: in addition to conventional instructions, spacing instructions available to acquire and maintain a spacing in distance (8nm);
- **Time**: in addition to conventional instructions, spacing instructions available to acquire and maintain a spacing in time (90s).

All controllers worked as executive controller on the two sectors in all conditions.

**Data collection**

The experiment resulted in 18 measured runs (6 controllers $\times$ 3 conditions) with typically 3 runs per day, each run lasting 1h15 (1h of actual eye tracker recording). This corresponds approximately to 25 hours $\times$ 2 sectors of recordings. Data collection consisted of continuous recording of the position and duration of eye fixations on the controller screen. Each experimental run required the calibration of the eye tracker. Data recorded included, for each fixation: start time, calibration surface, duration, inter-fixation duration (duration between the fixation and the previous one), inter-fixation degree (degree difference, according to the controller position, between the fixation and the previous one), horizontal and vertical position, distance between the head and the control unit, pupil diameter, loss of signal between fixations (e.g. due to blinks). The analysis of fixations distributions and gaze patterns was based on the comparison between eye positions and aircraft positions on the radar screen (extracted from simulator logs).

**RESULTS**

**General characteristics of monitoring**

Subjective feedback from controllers was collected via questionnaires. Five controllers out of the six thought the use of spacing instructions modified their monitoring, typically in reducing its frequency. They all felt their monitoring was more global (as opposed to focused on individual aircraft) and less complex. No difference was felt between the spacing conditions (distance versus time). Spacing instructed aircraft were perceived as less often monitored. Controllers felt they had difficulties to maintain an up to date awareness of the current situation.

![Figure 3. Duration and number of fixations, AO and AR sectors.](image)

In terms of objective data, we first measured the number and the duration of fixations inside the radar screen as opposed to outside. In the three conditions, the controllers spent more than 70% of their time monitoring the radar screen. Note that most of the remaining 30% of fixations were on paper documents used by controllers (paper strips, maps), on workload assessment devices. The mean duration of fixations was similar in the three conditions, whereas their number was higher in the time condition. This can be related to the increased difficulty to assess time visually, requiring the consideration of the aircraft speed in addition to physical distance between them.

**Macroscopic analysis**

In a previous experiment [2] a geographical distribution of instructions consisting in analyzing their location in the sector, helped identifying two strategies of control: strategic versus tactical. The analysis showed that the use of the new instructions led to anticipating the issuing of instructions, supporting a more strategic mode of control. The objectives of the macroscopic analyses of fixations are to relate fixation data to these two strategies of control, in analyzing the areas monitored. To do so, each fixation was plotted over the areas monitored and their distribution analyzed as a function of their distance to the sector exit point (Figure 4). This
geographical distribution showed that the use of spacing instructions modifies the controller areas of attention. With spacing instructions, controllers focus on the building area (56% of fixations) whereas without spacing instructions their fixations are more numerous over the maintain area (56% of fixations). With such a very high level of traffic, whereas in conventional situation the controllers focus on the [20-100nm] area (last part of the sector), the use of the spacing instructions enables them to focus their attention (or at least their fixations) on the earlier part of the sector [100-180nm]. It should be noted that in nominal conditions, the [100-180nm] area corresponds to where sequences need to be built, whereas the [20-100] area corresponds to speed adjustments used to maintain the sequence.

The distribution of fixations supports the assumption that the use of the spacing instructions enables controllers to anticipate the situation instead of reacting to it. Without spacing instructions, the controllers are in a more reactive position, the building of sequences being no longer anticipated. With spacing instructions (distance and time), controllers seem to be focusing upstream, where most of the instructions are issued, that is where sequences need to be focused on their attention (or at least their fixations) on the earlier part of the sector [100-180nm]. It should be noted that in nominal conditions, the [100-180nm] area corresponds to where sequences need to be built, whereas the [20-100] area corresponds to speed adjustments used to maintain the sequence.

The comparison between controllers led us to identify diversity in the monitoring curves. In both sectors, results show cases of positive impact and cases of no impact of the spacing instructions on the monitoring (in terms of focus on early part of the sector). It is interesting to notice that similar patterns were found for each controller, whatever the sector monitored. Typically, when a positive impact of spacing instructions is noticed for a controller on a given sector, it is also observed in the other. Positive impact concerns 3 controllers and the absence of impact the 3 others. Specific metrics developed to assess the controllers’ level of proficiency in using the new instructions confirmed disparity between the two types of controllers. Typically, we obtained two different rates of errors in using the instructions for the proficient and the less proficient sub-groups.

**Microscopic analysis**

To try understanding what triggers controller monitoring, we performed a contextual analysis of fixations. The reduced monitoring in the second part of the sector when using spacing instructions raised the issue of frequency of monitoring per aircraft and ultimately of safety. Typically, the questions to be investigated were: are aircraft still monitored once spacing instructed? Are changes equally impacting all aircraft? To answer them, we analysed the frequency of monitoring of each aircraft, i.e. the interval between two consecutive fixations on the same aircraft.

To tackle limitations encountered in previous experiments [12], we introduced the distinction between directed and peripheral fixations, respectively denoted foveal and parafoveal fixations. Studies on vision [7] showed that visual perception was based on the combination of foveal and parafoveal vision. In the foveal region (1 degree of visual angle to the left and right of fixation, corresponding to 0.7cm on screen and 3.5 nm), acuity is the sharpest. In the parafoveal region (extending to 5 degrees of visual angle on either side of fixation, corresponding on the radar screen to 3.5cm radius around the fixation and 17.5 nm) and in the peripheral region (everything on the line beyond parafoveal region) acuity drops off markedly so that our ability to identify letters is not very good even in the near parafovea. According to [6], the purpose of eye movements in reading is to place the foveal region on the part of text to be processed. Even though eye fixation behavior does not directly indicate the end product of the comprehension process ("looking does not imply seeing, understanding or remembering" [9]), we assumed that in the case of controllers, foveal vision corresponds to active monitoring and parafoveal vision to peripheral monitoring. Previous results [12] suggested that controllers were fixating between groups of aircraft rather than on each of them. We assume that the foveal perception of the area between aircraft corresponds to parafoveal perception of these aircraft.

The microscopic level of analysis required a fine synchronisation between traffic events and eye measures. Spatial and temporal synchronisation was ensured through controller mouse clicks on reference beacons every 15
minutes. The calculation of fixations per aircraft was made by allocating to every fixation one or several concerned aircraft. In addition to analysing the distributions of fixations on the radar screen, we examined the frequency of monitoring of each aircraft, depending on its status:

- N: not involved in a spacing instruction,
- T: having a target selected,
- S: spacing instructed.

For each aircraft, we calculated the mean number of fixations as a function of their type (foveal versus parafoveal) and of aircraft status (N, T, S).

Figure 6 shows that the fixations per aircraft are more numerous in the No condition. In the time condition, we do not notice any impact of the aircraft status on the number of fixations. In the distance condition, aircraft are less fixated during the selection of the target. This can be explained by the fact that this selection is a discrete event, as opposed to the two other statuses which reflect more continuous processes. In the time condition, the absence of differences between the numbers of fixations on the three aircraft status can be explained by the increased complexity of this condition. Indeed, as expressed by controllers, assessing visually a time between aircraft whose speeds are different requires more numerous and more frequent monitoring. Regarding the type of fixation, a similar pattern is observed in all conditions: parafoveal fixations are twice as numerous than foveal fixations.

During the target selection (T), the less numerous fixations (see Figure 6) are however very frequent. No difference is observed between aircraft under spacing (S) and not under spacing (N). The controllers are monitoring with a similar frequency aircraft in all conditions.

The next step consisted in looking at the distribution of the maximum periods (Figure 8). In addition to confirming the mean maximum period, this step enabled us to identify outliers cases of very long inter fixations period. Extremely long periods (>300 seconds in foveal and >150 seconds in parafoveal) could raise safety issues.

Despite the introduction of the foveal/parafoveal distinction, 33 cases of aircraft not monitored during more than 5 minutes were still detected in the three conditions, even though the most frequent were in the no spacing condition. Each case was analyzed by an operational expert, using replay tools.

Three cases could not be analyzed for technical reasons (loss of data). Fourteen cases corresponded to clean situations, when less frequent monitoring is acceptable (e.g. aircraft flying to an adjacent sector and not interfering with own aircraft can be less frequently monitored). Nine cases raised issues in terms of eye tracker data reliability (e.g. no fixation detected on aircraft while receiving instruction - and obviously monitored by controllers-). Only 7 cases were of concern. Five cases, in the three conditions, corresponded to a 5 minutes absence of monitoring that needed to be carefully analyzed. In most of the cases, this reduced monitoring
concerned aircraft not yet transferred but within a chain of already transferred aircraft. It is assumed that the controllers thought the aircraft had been sent. These cases could raise the issue of losses of situation awareness. The two last cases, in the no spacing condition, could be really problematic. These cases, caused by a too high workload, corresponded to risky absence of monitoring of an aircraft, due to a focus on the rest of the traffic.

CONCLUSION
In order to assess the impact of a set of new instructions on controllers monitoring activity, macroscopic and microscopic analyses of eye fixations were conducted. At the macroscopic level, a geographical analysis of fixations confirmed results previously observed: the use of the new spacing instructions enables controllers to focus their attention upstream, where most of the instructions are issued. Microscopic analysis showed that aircraft were still monitored once spacing instructed and that the frequency of monitoring was the same for all aircraft, whatever their status. The distinction between foveal and parafoveal fixations based on the assumption that controller monitoring is mainly peripheral proved to be fruitful: the number of cases of long inter-fixation periods was drastically reduced and the few remaining cases could be analysed and understood by an operational expert. The next step will consist in extending the analysis to the approach control, using the same experimental and analytical framework.

ACKNOWLEDGEMENT
As part of the Air Ground Co-operative ATS Programme, the Cospace project is sponsored by Eurocontrol Experimental Centre (EEC) and European Air Traffic Management Programme (EATMP) of Eurocontrol. The authors would like to thank controllers for their participation in the experimentation and the technical team for their support. Special thanks to the CoSpace team for their support in preparing, conducting and analysing the experiments. Particular thanks to Nathalie Lépy, Anne Pellegrin and Luc Rodet (Novadis Service) for their expertise in conducting the eye tracker data collection, processing and analysis.

REFERENCES