Effect generated by the use of a new all-electronic Air Traffic Control position on the level of mental workload

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Abstract

Currently, Air Traffic Control system is facing a period of transition justified by the context which surrounds it (Cegarra, Dehais, Causse & Martin, 2010). Indeed, the level of air traffic is predicted to increase significantly in the next twenty years (Eurocontrol, 2007). The need of technical and organizational solutions definition is therefore drawn to avoid the saturation of the existing air traffic control system. One of them would consist to propose a new working position including a new way of interaction with the air traffic control interface. The study described in this article aims to evaluate this modification in terms of processing capacity of the air traffic control system. More precisely, the level of mental workload felt by operators was assessed for two comparative situations, through a technique of eye-tracking. Analysis of eye gaze fixations and pupil diameter value shows that attention and cognitive resources continue to be allocated on the same way, despite the use of an all-electronic interface. It also highlights that a significant part of operators' resources are dedicated to the information and the consultation of the interface.

Introduction

Technological advances, as significant changes in an activity sector, can generate or at least push for change. The change mentioned here has for objective to guarantee consistently high level of performance, despite a complexity increase in terms of task requirements. In this case, change can take many forms and may equally cover the procedures and rules respected by operators, the tools they use, the support systems available, or as well the entire working position…
Currently, this is occuring in the field of Air Traffic Control (ATC). As a brief description, the ATC system has three principal missions to undertake: a security mission, which principally consists in avoiding collisions between aircraft, a mission concerning respect for the environment and aims to limit the kerosene consumption, and finally an information mission provided to the aircraft's pilots. The operators in charge of these missions are the Air Traffic Controllers (ATCo).

In practice, the operators are, during each work cycle, responsible of a portion of airspace called air traffic sector. They have to guide aircraft through the airspace

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under a set of rules and procedures in order to reach their mission's objectives. To make possible interactions with the aircraft of their sector, ATCo communicate with aircraft's pilots thanks to a radio telephony system.

The actual context of ATC requires change to increase the ATC system's capacity. This study aims to analyze one of the most important changes to anticipate concerning the air traffic control situation and which concerns the working position. In detail, we propose to evaluate mental workload felt by ATCo during the use of two working positions in order to anticipate what would be the consequences on the operators when the ATC working position will change.

The air traffic control situation from today to tomorrow

The elaboration of the tomorrow's ATC system is currently studied through the SESAR (Single European Sky Air traffic management Research) program. Many axes of evolution are being explored; one of them is focused on tools used by controllers during the control task execution.

As a starting point of this research focus, previous applied researches have demonstrated that the task of conflict resolution is the most expensive part of control task for the controllers (Laudeman et al., 1998; Hilburn, 2004). Limiting the number of conflicts to be resolved by ATCo has therefore been defined as a way to increase the capacity of treatment, in terms of aircraft number. In detail, the integration of a conflict solver, able to resolve automatically conflicts by low speed adjustments, is expected to decrease task cost. This solution would have as a major consequence the decrease of the conflict number to be resolved by ATCo and is hence expected to limit the mental workload felt.

Actually, a problem arises. The actual ATC working position, functioning with an old level of technology, makes the integration of this type of tools impossible. This implies that a new generation of ATC working position is expected to consider the integration of a conflict solver for controllers.

Figure 1. Picture of an air traffic control working position in a French En-route ATC centre

The study issues

This study is carried out before the evaluation phase of an automated system, such as conflict solver. It is a preliminary work, which aims to assess the impact generated by the introduction of a new working position on controllers. More precisely, the new working position tested is an all-electronic position including a computerized system to which the operator has to give information (principally the Air Traffic Control clearances given). To provide responses to the main study questions, three assumptions have been made:

- Despite the use of a new working position, controllers' attention repartition between aircraft's categories is not altered.
- Computerized system of an all-electronic requires significant part of the controllers' attention, as important level of mental workload.
- The use of an all-electronic position, without significant training, generates a higher level of mental workload.

In order to evaluate hypotheses, an experimentation composed of two experimental conditions has been designed.

Method

The experiment objective

The principal objective of the experiment is to compare mental workload felt by air traffic controllers according to the type of air traffic control working position they use during the same tasks. To make possible this comparison an experiment composed of two conditions was designed.
To reach the experimental objective, it was essential to limit differences between the situations compared, that is why the only distinction between the two conditions concerns the experimental position. The experimental task, the procedure and the mental workload evaluation were identical.

The experimental task

The experimental task aims to reproduce a real air traffic control task. The principle consisted in asking qualified Air Traffic Controllers to manage an air traffic sequence as they would do in real life. In practice, participants had to communicate with aircraft on their sector (messages "hello" and "goodbye"), to detect, define a solution and resolve conflicts between sector aircraft (by initial trajectories change through heading, flight level or speed adjustment).
Before the beginning of the experiment, participants were briefed about the working position and the tools available to achieve the experimental task. This phase was more important for the second experimental conditions because participants were not familiar to the ATC platform before the experiment.

Participants

Thirty-seven persons participated in the first experimental condition and thirteen in the second experimental condition. The first group of participants were between 26 and 56 years, and 24% of them were female and 76% male. The second group of participants were between 25 and 51 years, and 23% were female and 77% male.
All participants were selected from a pool of air traffic controllers from a French air traffic control centre (CRNA S/O) and were voluntary and unpaid. The participants have the same level of basic training, because they all graduated as Engineers of the air navigation control. Moreover, they all have the qualification to work on the air traffic sector used during the experimentation. Nevertheless, there is one principal difference distinguishing the participants from each other: the level of experience in air traffic control room ranging from 0.5 to 26 years for the population of the two experiments.

Air Traffic scenario

During the two experimental conditions, air traffic controllers were invited to manage, as they do usually, the same sequence of air traffic. The scenario took place on the air traffic sector called sector T, for which all participants have the ability to control the air traffic. The air traffic sequence of the experimentation lasted forty-five minutes, and had been built from real air traffic recorded sequences. This air traffic may be defined as ecologically valid according to the air traffic management point of view because it respects all operational rules and procedures, which have to be applied.

In the scenario, the number of aircraft instantaneously present on the radar picture was relatively constant (around 14 aircraft). However, the presence of conflict situations, defined as an indicator of air traffic complexity (Averty et al., 2004), was varying. This defines three kinds of aircraft status: out of sector aircraft, on sector and non-conflict aircraft, on sector and conflict aircraft.

Experimental positions

The principal difference of the two experimental conditions was the experimental position used, which were Air Traffic Control simulators. Indeed, this variable aimed to illustrate the transition of the air control situation expected. Therefore, the Air Traffic Control simulator used during the first experiment reflected the actual air traffic control position (present in the French air traffic control centres); whereas that of the second experiment represented one perspective of what could be the tomorrow’s air traffic control position.

The Air Traffic Control simulator used during the first experimental condition was composed of four main parts, each supposed to represent a tool used by the air traffic controller during his daily working activity:

- A radar screen corresponding to a 30” LCD screen and where the air traffic scenario was graphically represented.
- A mouse to interact with the “radar screen”.

- A set of “paper strips” and a paper strips’ board. For each aircraft of the simulation, one paper strip was printed before its entry in the air traffic sector managed by the participant.
- A radio telephony system which allowed the experiment’s participant (playing the role of the air traffic controller) to communicate with the pilots of the simulated aircraft (managed in a pseudo-pilot position). In order to improve the realistic aspect of the experiment, a system of voice transformation was integrated to the experimental position. With this system, the pseudo-pilot’s voice varied during the experiment. For each aircraft, a different voice (characterizing by a tune of voice) was associated.

During the second experiment, the Air Traffic Control simulator used was composed of two main parts:

- The radar screen composing the upper part of the simulator. That 30’’ screen displayed the radar picture and the scenario of the experiment. In this graphical representation of the air traffic situation, four main types of information were displayed: the clock, the list of flights, aircraft illustrated by a radar plot associated to a label, menus and functions (displayed on demand).
- The lower part of the platform, a cintiq interactive pen display, was the interaction interface. It was composed of two areas: The first was the input zone to act on the objects of the radar picture (move the pointer, make a data entry) through the stylus. The second area gathered the rest of the platform’s lower part providing the access to the settings of the radar picture (zoom in, zoom out, change of the sector position, display of the radar beacons). It permitted as well to display additional information (velocity vectors, information on flights…).

During the second experimental condition, the same system of radio telephony was used.

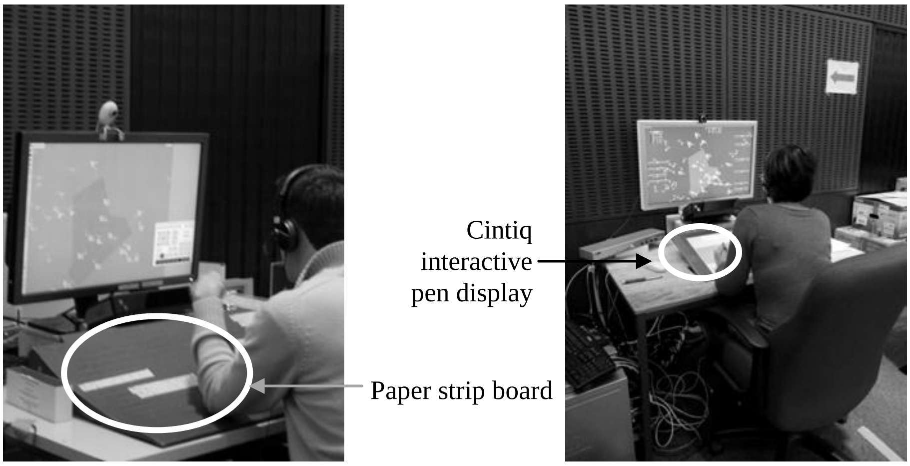

Figure 2. Air traffic control simulators used during the two conditions of the experiment.

To resume we can say that three principal differences distinguished the two air traffic control simulators used during the experiment of the study:

- The first deals with the way to interact. Indeed, the first simulator used a mouse whereas the second used a stylus.
- The second difference is focused on the working method implemented during the air traffic control task. During the second experimental condition, air traffic controllers had to provide information to a computerized system, while they annotated the same information on the paper strips during the first condition.
- The last principal difference between the two ATC simulators concerns the duration of the use that the participants had with each platform at the time of the experiment. The first simulator reflects the actual air traffic control working position that the participants use since the start of their career. Concerning the second simulator the participants had only a brief training session which not exceeded 30 minutes.

Mental workload evaluation

The impact generated by the use of a new interface is studied through the assessment of mental workload felt by operators. The mental workload evaluation carried out in this study aims to obtain an operator's feedback without a subjective approach. One complementary objective is focused on the scope of the analysis. The method of mental workload evaluation used has to make possible a time assessment in order to take into account dynamic aspects of the air traffic situation managed by the participants (Niessen et al., 1998).

The method of mental workload assessment chosen for the study is the eye-tracking technique. More precisely, eye gaze fixations and pupil diameter value have been the objects of the analysis carried out. To record eye movements and characteristics, a deported and binocular eye-tracker (the Tobii X-120 model) was integrated to the two experimental working positions.

This apparatus was placed under the radar screen and at approximately 70 centimetres from the participant's face in order to optimize data quality. The eye-tracker has been used with a frequency of 60 Hz, which corresponds to one record every 16.7 milliseconds. Before each experiment, a calibration phase was carried out. This phase consists in recording for nine points of the screen the value of eye gazes. The eye-tracker uses theses values to fix benchmarking for the recording. This phase has consisted for the participant to fix a blue target and to keep watching it during movements.

Ocular data analysis

Before thinking of ocular data analysis, a work of pre-analysis of raw data was necessary to filter incorrect data. In a first time an eye fixations data sorting has been carried to in order to delete, all the non-significant fixations defined by duration value less than 150 milliseconds (Sereno & Rayner, 2003). Once this first sorting out done, the ocular data were linked to the air traffic scenario data. Thus, the number of eye fixations for each AOI, Area Of Interest, was determined (as the aircraft on the radar screen, parts of the interface…).

Moreover, fixations have been divided between the three aircraft categories distinguished (out of sector aircraft, on sector and non-conflict aircraft, on sector and conflict aircraft).
The analysis carried out is focused on two ocular parameters: the eye fixations and the pupil diameter value. This is justified by the fact that eye fixation is defined as an indicator of attention repartition (Recarte & Nunes, 2003) and the pupil diameter as a reflector of mental workload felt (Beatty, 1982; Klingner, 2002). Eye fixations have been analysed in two ways: in terms of number and of duration, while pupil diameter has been studied through the maximum value reached during eye fixations. In order to avoid effects of individual differences, the pupil diameter data analysed are baseline-corrected value.

Results

The study of eye fixations

The analysis of the repartition of eye fixations according to Areas of Interest shows two principal results (see figure 2 and 3). Despite the use of a new all-electronic interface, the same repartition between aircraft categories is observed with a significant lower number of eye fixations on "out of sector" aircraft, while the highest number of eye fixations is on "on sector and conflict" aircraft. In condition 2, there are more eye fixations for each Areas Of Interest category.
As a complementary result, it has to be pointed out that Interface (Condition 2) requires a number of eye fixations significantly higher than "out of sector" aircraft but lower than "on sector and non-conflict" aircraft.

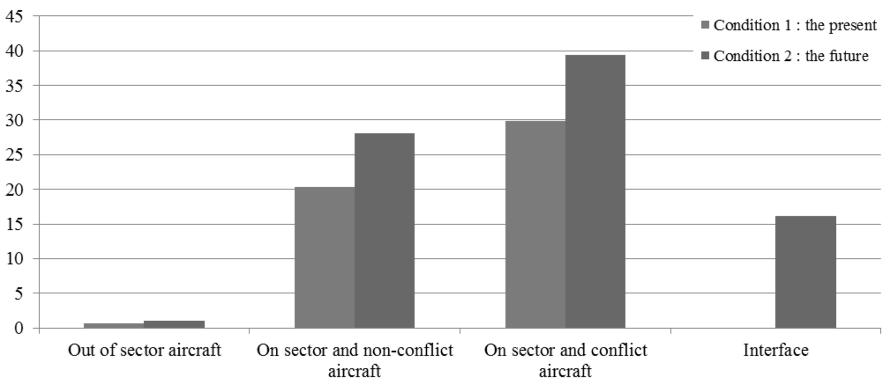

Figure 2. Average number of eye fixations allocated between the different Areas Of Interest.

The study of the cumulative duration of eye fixations confirms previous results with the same hierarchy between AOI. Moreover, in condition 2, it can be observed that eye fixations cumulative duration on interface and on "on sector and conflict" aircraft are in the same order of eye fixations duration.

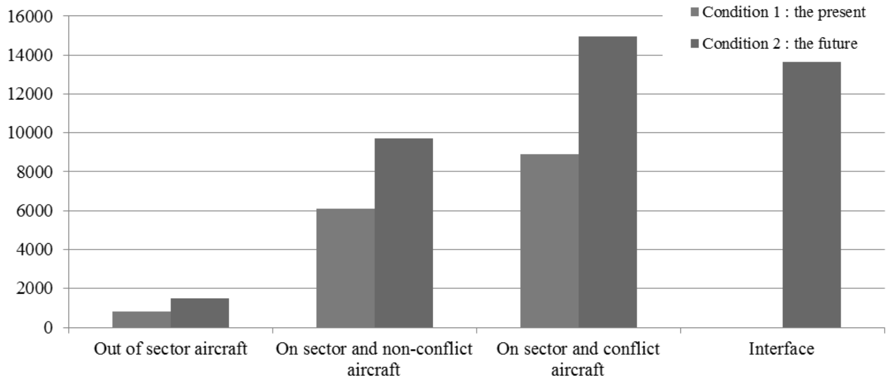

Figure 3. Cumulative duration of eye fixations allocated between the different Areas Of Interest.

To resume about controllers' attention, it is shown that attention repartition does not seem to be altered by the use of an all-electronic interface, which confirms the first assumption initially defined. Results illustrate that conflict aircraft need more attention from controllers. Finally, as expected, all-electronic interface seems to require a significant level of attention which is almost equivalent to attention required by "on sector and conflict" aircraft.

The pupil diameter analysis

To analyse pupil diameter data, the maximum values reached during each significant eye fixations has been filtered out. The choice of analysis of pupil diameter through the maximum reached during eye fixations is justified by two pupil characteristics: pupil is constantly varying and reaching extreme value which makes irrelevant the study of average (Martin et al., 2011). Significant increase in pupil diameter is defined as a sign of mental workload rise (Beatty, 1982).

Results obtained show that, in each experimental condition, a higher value of pupil diameter maximum for "on sector" aircraft is observed than "out of sector" aircraft (see figure 4). Furthermore, the value of pupil diameter is the highest for the "conflict" aircraft.

It is also noticeable that the pupil diameter values recorded during the condition 2 are lower than condition 1 data. Here, it has to be recalled that the sample of participants was different during the two experimental conditions, which induces physiological differences. Therefore pupil diameter values between experimental conditions are not comparable.

As was the case in the eye fixations results, the value of pupil diameter for the interface (condition 2) is shown as almost equivalent to the value recorded for "on sector and non-conflict" aircraft and significantly higher than "out of sector" aircraft.

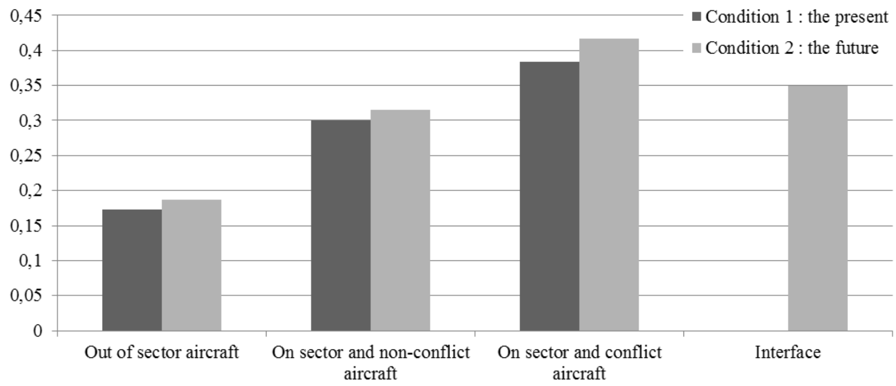

Figure 4. Maximum of pupil diameter during eye fixations on different categories of Areas Of Interest

The analysis of the maximum of pupil diameter reached during eye fixations identifies two principal results concerning mental workload felt by participants. The hierarchy between aircraft categories in terms of mental workload dedicated is not altered by the use of a new all-electronic interface. Indeed, “out of sector” aircraft are defined as significantly less costly from a cognitive point of view than “on sector” aircraft, while “conflict aircraft” as the costliest.
The second principal result deduced from the maximum of pupil diameter analysis deals with the interface. In fact, the information of interface requires a significant level of mental workload as confirmed by the almost equal of pupil diameter maximum recorded between the eye fixations on “on sector” aircraft and on the interface.

Conclusion

The experiment carried out in this study shows that the use of a new all-electronic interface without a significant preliminary training does not alter the repartition of cognitive resources of controllers during a realistic ATC task achieving. Indeed, the repartition of eye fixations and pupil diameter value (reflecting attention allocation and mental workload felt) between the several aircraft categories, composing air traffic to be managed by the controllers, does not change. However, the level of visual attention in this situation is observed to be higher which is illustrated by a larger number of longer eye fixations recorded. The difference between the participants of the two experimental conditions makes impossible comparison of pupil diameter data recorded and therefore of mental workload felt by operators.

The analysis of cognitive resources allocated to the interface is shown to be significant. This observation may partially be linked to the fact that controllers have to inform interface, while he has to inform paper strips in the actual ATC working position. Nevertheless, the part of attention required by the all-electronic interface is expected to decrease with a sustained training dedicated to the use of that new tool.

As a conclusion, the analysis of eye parameters appears to be a very promising approach in the evaluating of a new tool as a graphical interface. In the context of the SESAR project, such an approach could present a way to analyse operators' feedback concerning the use of new tools after a sustained and sufficient training. This observation draws the perspective of this work, which will consist to compare, for the same ATCo sample, the level of mental workload felt according to several levels of automation.

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