Analysis of Mental Workload during En-route Air Traffic Control Task Execution Based on Eye-Tracking Technique

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Abstract. This text aims to present a study which deals with mental workload evaluation during task execution. It is focused on the Air Traffic Controllers working situation. In this document, we mainly introduce an experiment which has been conducted in a French En-Route air traffic center with the participation of Air Traffic Controllers. Four principal experiment characteristics are detailed: the experiment procedure, the working situation elaborated for our experimentation, the nature of the task achieved by participants, and the technique chosen to analyze mental workload felt by operators. We finally present the main results from our first data analysis which seem to confirm major observations known in the field of air traffic control, as well as, mental workload study field.

Keywords: Mental workload analysis, Air Traffic Controller, Eye-tracking, eye fixations, pupil diameter.

1 Introduction

A researcher group which comes from the University of Toulouse began, in collaboration with the French civil aviation direction (named DGAC, Direction Générale de l'Aviation Civile), a search project which deals with Air Traffic Controllers (ATCo) mental workload variations during task execution. This project is necessary due to major transformations of air traffic control during the 20th century and especially the further adaptations envisaged during the following years. In fact, assessment of mental workload is a way to evaluate HCI performance [1].

A study has been carried out with the participation of a French En-Route Air Traffic Center. This work's objective is to evaluate "realistic" mental workload felt by ATCo during their work activity. This approach allows analyzing correlations between mental workload variations and air traffic sequence events (like conflict presence). Assessing mental workload can refer to two different approaches: subjective and objective analysis. Subjective mental workload evaluation often consists to fulfill a questionnaire after task execution.

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Objective analysis involves task performance or psychophysiological measures. These latter have for principal advantage to offer the capability for continuous data recording [2] and also for real-time mental workload evaluation. More precisely, we refer to eye movements because it is the human physiological parameter which has the most frequent period of update [3]. We choose to use eye data to analyze ATCo mental workload during task execution in order to obtain detailed evaluation.

2 Method

2.1 Experiment Procedure

The experiment consists in asking ATCo to manage a forty-five minutes air traffic sequence in realistic work conditions. No procedure or action constraint was given to the operator before and during task execution. The experiment objective is to obtain an analysis of mental workload characteristics which transposed realistic aspects of operator's activity.

2.2 Participants

Thirty-seven En-Route air traffic controllers volunteers (9 females and 28 males) were recruited as participants. They all possess the qualification to work on the air traffic sector used for our experimentation. Participants were ranged from 26 to 56 years of age, and reported ATC experience from 0.5 to 26 years.

2.3 Experiment Working Position Characteristics

To carry out this experiment the elaboration of an en-route air traffic simulator has been necessary. Special means have been given to optimize realistic aspect of ATC position elaborated. During experiment, ATCo had at their disposal an experiment working position to realize the requested task. This latter is composed of four main tools:

- Radar screen where the air traffic sequence is projected including real time aircrafts position and air traffic sector boundaries. Operator had the possibility to adjust the radar image parameters (like sector position on the screen);

- Paper strips printed exactly five minutes before each aircraft's sector entry. This small piece of paper contains principal flight information and is used as a quick way to annotate a flight;

- Radio frequency allowing ATCo to communicate with each aircraft pilot of the air traffic sequence. Only one pseudo-pilot played the role of all simulation aircraft pilots. To improve task's realism, pseudo-pilot voice has been modified thanks to a voice distortion system.

- Mouse used by the operator to act on the radar vision parameter settings.

The following figure shows the details of experiment working position.

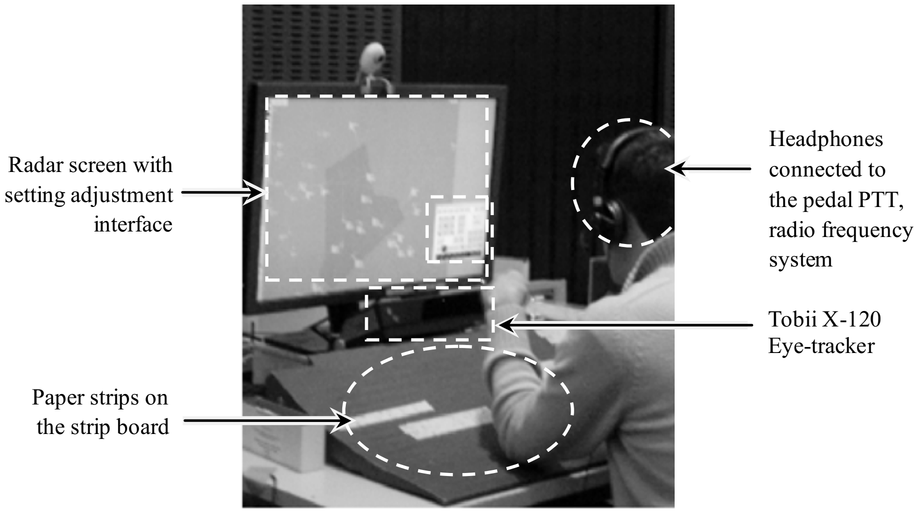

Fig. 1. The simulated air traffic control position including the eye-tracker

2.4 Air Traffic Task Executed

The air traffic sequence used during the experimentation has been built from real air traffic recorded sequences. We can define the experiment sequence as ecologically valid according to air traffic management point of view because it respects all operational rules applied to control airspace.

The air traffic sequence is composed of fifty-one aircrafts crossing the sector managed by the operator during the experiment. It takes about forty-five minutes.

In the air traffic sequence controlled by participants the number of conflicts varies contrary to number of aircrafts on the radar screen which is relatively constant. Three categories of aircrafts can also be defined: Out of Sector aircrafts (OS), Non-Conflict aircrafts (NC) and Conflict aircrafts (C). Moreover, two situations are distinguished in the air traffic sequence: non-conflict phase (named "Phase 0") and conflict phase (called "Phase 1").

2.5 Mental Workload Evaluation

Mental workload felt by ATCo during task execution has been evaluated with an eye-tracker device (Tobii X-120). Tobii X-120 is a binocular eye-tracker composed of two infrared cameras. We used it with a 60 Hz recording rate. For each experiment a calibration phase has been achieved to optimize quality of recording. Moreover, eye tracker has been placed at 70 centimeters of participant's face because this setting is necessary to ensure data quality. This prerequisite has required to constraint participant's seating position which explains the use of an office chair without wheels.

Eye-tracking technique permits to record in real time the point fixation of gaze, blink periods, saccade trajectories and pupil diameter variations. The eye data analysis here is focused on fixations and pupil diameter. With the help of a dwell-time algorithm we linked the position of eye fixation and the location of each aircraft on the radar screen. This function allows the repartition of the number of fixations according to the several aircrafts categories in order to examine differences between fixations amount by category of aircraft (OS, NC, C).

We also compare pupil diameter according to conflict presence (phase 0 and phase 1). This comparison was focused on two pupil diameter variations [4]: the maximum value obtained during fixations and latency duration (time required to reach the maximum value of pupil diameter). To analyze these data with taking into account inter-individual differences operators concerning their pupil diameter value, we standardized the pupil diameter, which explain the scale observed in the following graphics.

3 Results

Two main results issued of the data analysis can be observed.

3.1 ATCo Attention Allocation

The first one deals with ATCo's attention allocation and is derived from fixations count analysis. In fact, an aircraft hierarchy in terms of attention required is suggested according to the category. Actually, OS aircrafts need significantly less attention (so less fixations count) than other type of aircraft. Moreover, C aircrafts get significantly more fixations count which means more attention by ATCo.

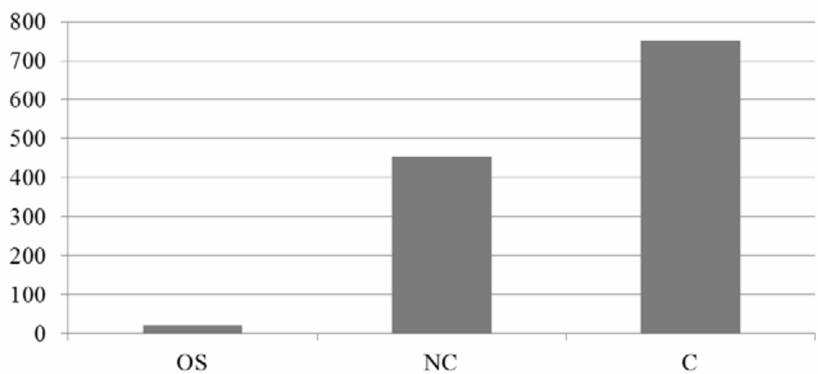

Fig. 2. Changes in fixation count within three several aircraft categories

3.2 Mental Workload Recorded

The second result obtained relates to mental workload. Analysis of maximum pupil diameter shows a significant effect of conflict presence. In fact, pupil diameter is higher when air traffic situation includes conflict (phase 1). This stresses an increase of ATCo mental workload due to conflict presence.

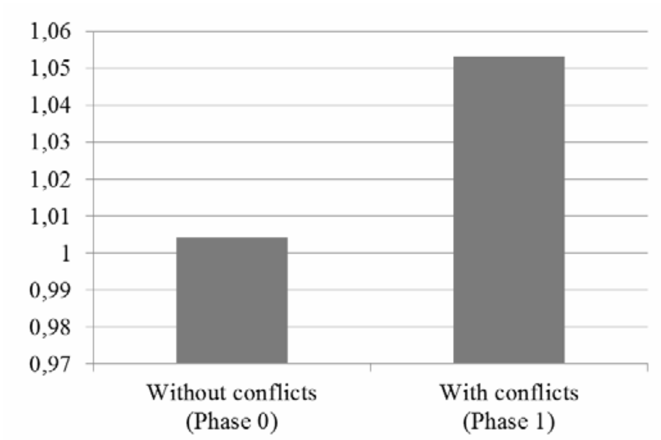

Fig. 3. Changes in maximum pupil diameter according to presence of conflicts (Z score)

Latency analysis allows noting a shorter latency in the presence of conflict, which confirms the effect of conflict presence on mental workload felt by ATCo.

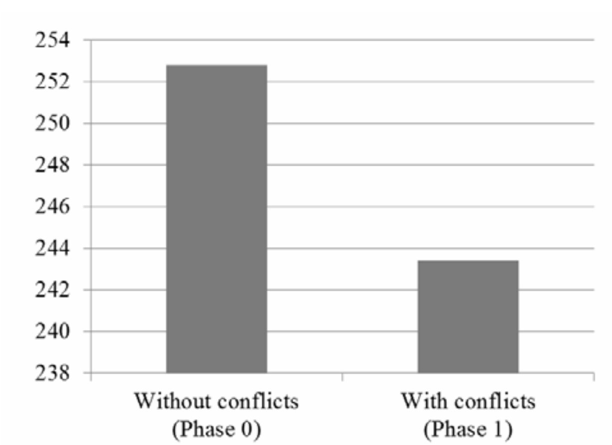

Fig. 4. Changes in latency duration according to presence of conflicts

Currently, complementary data analyses are being carried out. It is focused on the temporal management of workload by ATCo [5]. The objective is to understand the way operators manage their own mental workload level.

4 Discussion

Two limitations of this work have to be highlighted. Firstly, we can consider a limitation in the way mental workload evaluation is achieved because it is focused on only on one physiological source [6]. Indeed, our approach could be completed by another physiological source or by means of a questionnaire/interview with ATCo to obtain ATCo subjective feedback.

Secondly, high frequency of parameter recording wasn't optimally exploited. It could be possible if a temporal data analysis would be carried out. It would allow us to obtain two main signal characteristics: the general trend of pupil diameter value, and the presence of pupil diameter peak, defined as TEPR, Task Evoked Pupillary Response [4]. These findings would allow linking prior mental workload level changes, translating mental workload modification, with events, which happen in the air traffic situation controlled by ATCo.

5 Conclusion

To conclude we can say this study gets hopeful results. Indeed, it allows us to confirm simple hypothesis, which come from ATC field. It particularly highlights the crucial status of conflict in attention and mental workload during ATC task execution.

Results also stress that eye-tracking technique is a powerful approach to study mental workload during a complex activity. Thanks to this experiment we found same results of previous studies carried out with laboratory tasks, especially those showing mental workload growth when task requirements increase. Such results are especially important for guiding design decisions of ATC support systems in the SESAR (Single European Sky ATM Research) project.

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