The Comprehensive Evaluation Method of the Human Factors in the Flight Deck Based on the Physical and Behaviour Measurements

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Abstract. There is increasing concern about the design and evaluation of the human factors in the flight deck. The study was to propose a comprehensive evaluation method of the human factors in the flight deck, combing with multiple physiological signals. The proposed comprehensive evaluation method in the flight deck are composed with the evaluation of the operators’ cognition, operational performance, control activities and workload. The cardiovascular signal, eye movement and flight parameters were recorded during task to conduct the evaluation. An experiment about the evaluation of the display elements in the flight deck was conducted to verify the proposed comprehensive method of the human factors. The results revealed the validity of the proposed method, which can give a detailed description of the operator’s workload, operational performance and cognition during the flight task.

1. Introduction

Human factors have become the major cause of aviation accidents and incidents as the development of the technology in the aerospace area. Previous studies of the aviation safety have found that about 70\% of the accidents and incidents were caused by human errors, especially the flight crew errors \cite{1}. From the evidence, one of the major contributing factors to flight crew errors is from the design of the interface in the flight deck \cite{2}. Therefore, there is increasing concern about the design and evaluation of the human factors in the flight deck.

The state of art evaluation of human factors in the flight deck falls into three categories: subjective rating scales, performance measures and psychophysiological measures \cite{3}. As the most common methods, the subjective rating scales, such as NASA-TLX and SWAT, have the advantages of ease of implementation, and non-intrusiveness \cite{4}. However, they have no sufficient time resolution to analyze the process details. The performance and psychophysiological measures can objectively evaluate the human-machine interaction in real time. However, each measure has its applications and drawbacks. It seems that it is necessary to use multiple measures in combination for the accuracy \cite{5, 6}.

The study was to propose a comprehensive evaluation method of the human factors in the flight deck, combing with multiple physiological signals.
2. Evaluation method of human factors
As the main interface between the pilots and the aircraft, the flight deck should be match the pilot’s cognitive process. Otherwise, the design may reduce the pilot situation awareness and induce human errors. Therefore, the design of the human-machine interface (displays and controls) should be examined to accommodate the pilot capabilities and cognition.

In the study, we proposed a method to evaluate the displays and controls in the flight deck from the cognitive state, performance, control activities and workload.

- Cognition, which indicates the pilots’ cognitive process like perception, encoding, decision making, is integrated with fixation and saccade.
- Performance, which indicates the results of the operation, is integrated with the deviation of the flight path and the acceleration of the aircraft.
- Control activity, which indicates the inputs of the pilots, is integrated with the control magnitude, control time and control frequency.
- Workload, which indicates the effort and fatigue of the pilots, is integrated with the heart rate, respiration rate and depth, and pupil diameters.

For each dimension, the parameters are integrated with the linear weighted sum, which weight is depended on the principle component analysis.

3. Experiments
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3.1. Experimental design
The experiment was carried out on the flight simulator with high fidelity. In the flight deck, the arrangements are referred to Boeing 777-20ER. In the study, we modified the design of the airspeed indicator in the primary flight display. In the design A, only the ones of the airspeed reading was rolling in the indicator and the hundreds and tens were jumping. In the design B, the tens and ones of the reading was rolling, that meant it is easier to perceive the change trend of the airspeed. The other display and control was constant.

![Figure 1. The design of the primary flight display. Left: design A; Right: design B.](image-url)
3.2. Experimental apparatus
The Tobii glasses eye tracker (Tobii Technology, Stockholm, Sweden) was used to recording the eye movement of the pilot at a sample rate of 50 Hz. The Bio harness physiological monitoring system (Bio harness, Zephyr Technology Corp., Annapolis, MD) was used to recording the heart rate, respiration and body temperature.

3.3. Procedure
The experiment included the pretest and formal test. In the pretest, the pilot was asked to flight a straight and level flight to familiarize with the simulator and the measuring equipment. In the formal test, the pilot was asked to fly a complete flight, including take-off, cruise, approach and landing. The flight would take off from KSJC 30R and land at KSFO 28R. The task would last about 15min. During the test, the simulator would record the flight data, like airspeed, altitude, heading, position (latitude and longitude) and control inputs. The eye movement and physiological parameters were also recorded.

3.4. Data process
The raw data from the eye tracker was the time stamp and the gaze data. Therefore, the fixation was calculated according to the angular velocity of the eye movements. When the angular velocity was $<$30o∙s$^{-1}$, the eye movement type was defined as fixation. The time that a fixation lasts was defined as fixation duration. When eye speed was $>$30o∙s$^{-1}$, the eye movement type was defined as a saccade. And the number of the saccades per minute was defined as saccade rate.

Blink was calculated according to the change of the pupil diameter. When the pupil diameter became zero, a blink was detected, and the blink rate was defined as the number of the blinks per minute.

4. Results
In the study, two designs about the airspeed display were compared to evaluate the human factors issues, and the indictors about speed were more concerned.

As shown in Fig.2, for the design B, the change of the acceleration was sharper, and value of the acceleration was higher. It meant that the pilot adjusted the speed frequently in the experiment about design B and the control of the speed was worse. The results of the acceleration resulted in the worse performance, presenting the great change of the performance during the whole task.

Since the airspeed indicator on the primary flight display is an important display, the pilot’s cognition was considered as one of the critical ergonomic indictors. In the study, fixation and saccade rate was used to evaluate the cognitive state. Compared with the design A, the average fixation time for the design B was more (1652.057ms vs. 2135.158ms, Fig. 3), meaning that the pilots may need to pay more attention to obtain information.

The saccade rate in the design A was higher than that in the design B during the cruise phase, while in the landing phase, the saccade rate in the design B had an obvious increase (Fig. 4). It suggested that the pilot adjusted the attention on the different displays more frequently to update the information.

Additionally, in the design B, the pilot had a lot of cognitive and control activities during the whole flight task and the value was changed sharply, while in the design A, the pilot had more control activities only at the landing phase (Fig. 5 and 6).

After the experiment, the pilot gave a feedback about the display of the airspeed that for the design B, there was more numbers in the reading frame with the same size, therefore it was more difficulty to get previous airspeed. There was the readability issue in the design B, although it could provide the change trend.

5. Conclusion
The study proposed a comprehensive method to evaluate the human factors in the flight deck, combing with multiple physiological signals and behavior signal. An experiment was carried out in the flight simulator to examine the method. The revealed the validity of the proposed method, which can give a detailed description of the operator’s workload, operational performance and situation awareness during
the flight task. However, the influence of the emotion and the relation between different dimensions were not considered in the study, which would be investigated in the future.

**Figure 2.** The flight acceleration using two design of airspeed indicator. Upper: design A; lower: design B.

**Figure 3.** The fixation number using two design of airspeed indicator. Upper: design A; lower design B.
Figure 4. The saccade frequency using two design of airspeed indicator. Upper: design A; lower: design B.

Figure 5. The cognitive activities using two design of airspeed indicator. Upper: design A; lower: design B.
Figure 6. The control activities using two design of airspeed indicator. Upper: design A; lower: design B.

Figure 7. The performance using two design of airspeed indicator. Upper: design A; lower: design B.

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