# Can Fixation Frequency Be Used to Assess Pilots' Mental Workload During Taxiing?

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**Abstract.** Increased mental workload is often associated with increased risk of pilots' operational errors. Mental workload is a multifactor problem. The paper aims at defining an appropriate indicator for pilot mental workload, under the assumption that vision is the single most important source of information for the pilot. We design a series of experiments about the task difficulty, which have different visibility, taxiing length and turns. The results showed that the fixation frequency did not increase with the task difficulty. Fixation frequency is not sensitive with the mental workload. This study concludes that the Fixation frequency cannot be used as the evaluation criteria of mental workload. But the results may be caused by small sample sizes (three pilots).

**Keywords:** Mental workload · Pilot · Fixation frequency · Fixation · Eye movement

## 1 Introduction

Pilots need to perform various visually demanding tasks in flight, such as monitoring various displays in the cockpit, navigating, and cockpit reconfiguration [1]. The culmination of the required tasks, the difficult operating environment, and the lack of aiding technologies result in a very high-workload of their visual system, which is very likely to induce operational errors [2]. According to the statistical summary of commercial jet airplane accidents reported by Boeing, human errors due to the overloaded visual system accounted for nearly 90% aviation accidents [3]. Thus, there is an urgent need to control pilots' operational errors induced by the overloaded visual system.

Subjective-ratings and Physiological measurements are two traditional methods used to assess inflight pilot workload. Notable Subjective-ratings currently employed are NASA-TLX (subject demand assessment) [4, 5], a Bedford workload scale, SART (a situational awareness assessment analysis questionnaire), and the Modified Cooper-Harper Rating Scale is four generally used subjective method [5]. But Subjective measures have some limitations. The probes of questionnaires confused pilots easily, and they always require a conscious, subjective response from the pilots to ensure the accuracy [6]. Ahlstrom et al. concluded that eye movement activity can


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provide a sensitive measure of controller workload, but subjective ratings might not capture more transient fluctuations in workload levels during system or display interactions [7]. Therefore, objective, physiological measures would be preferable and become a key issue. Results from previous studies report that eye movement activity, heart parameters, and respiration, EEG signals are all sensitive to mental workload.

The blink of the eye is believed to be a good indicator of both fatigue and workload [7–9]. Blink Rate (BR) increases as a function of time on task (TOT), and blink duration (BD) decrease as visual workload increases. Besides eye blink activity, some researchers found that pupil size can also be used to assess workload. Pupil dilates most because of mental effort. Pupil dilation has been successfully used for distinguishing different levels of difficulty of various cognitive tasks.

The paper aims at defining an appropriate indicator for driver visual workload, under the assumption that vision is the single most important source of information for the pilot. Fixation frequency had been proposed to assess mental workload of pilot during taxiing. We design a series of experiments about the task difficulty, which have different visibility, taxiing length and turns. During the experiment, the eye movement data had been collected, and analyzed.

## 2 Methods

### 2.1 Subject

Three aircrews, each consisting of one captain and one FO (the First Officer) from Shanghai Eastern Flight Training CO., LTD. who flew the Airbus320, participated in the study. The participants are all male. The information of the three captains executing the experiment are given in Table 1.

**Table 1.** The information of three captains

| No. | 1 | 2 | 3 |
|---|---|---|---|
| Flight hours (h) | 6500 | 15000 | 20000 |
| Gender | Male | Male | Male |

### 2.2 Tasks

The trial is conducted in Airbus 320 simulator (shown in Fig. 1) in Shanghai Eastern Flight Training CO., LTD. In all scenarios, the pilot is asked to land from the last approach point and taxiing to the gate successfully according to the flight plan established before. Two variables of interest were investigated in the study: visibility and taxiing way.

**Visibility.** Trials were conducted in three different visibilities shown in Fig. 2. First is clear day. Pilot has unlimited visibility and the trial conducted in Visual Meteorological Condition (VMC). Second is night. The airport is under night mode and pilot should flight in Instrument meteorological Condition (IMC). To investigate the visual performance under low visibility, the runway visibility is 200 m, which is the lowest visibility according to the flight rules, and pilot should flight in IMC.

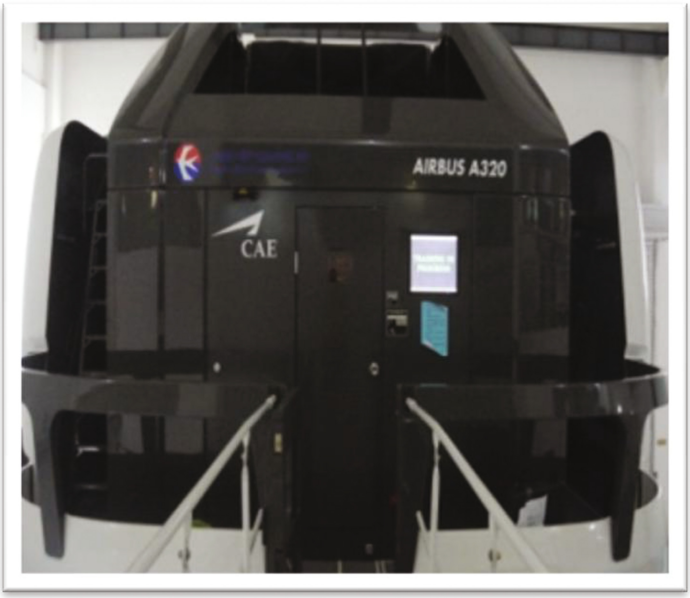
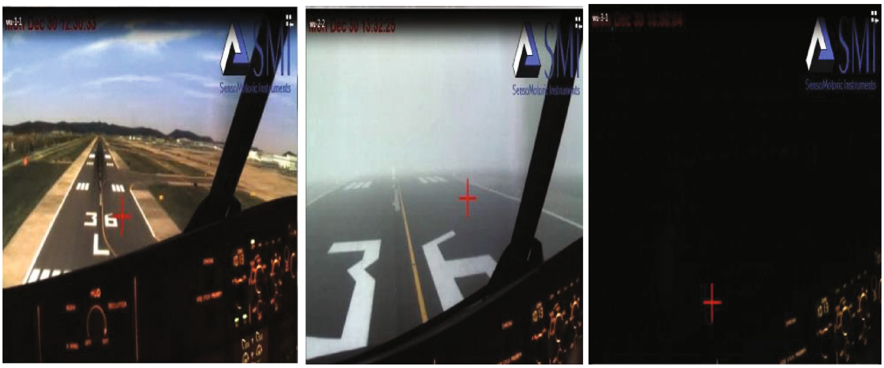


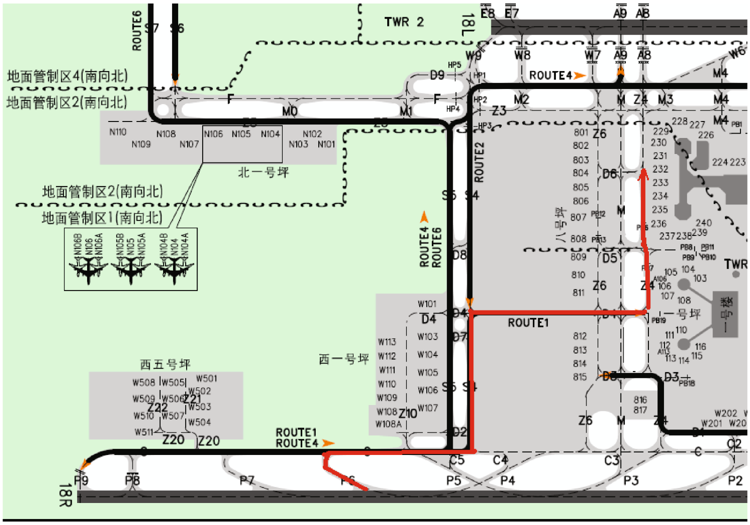

**Fig. 1.** Simulator used in the experiment



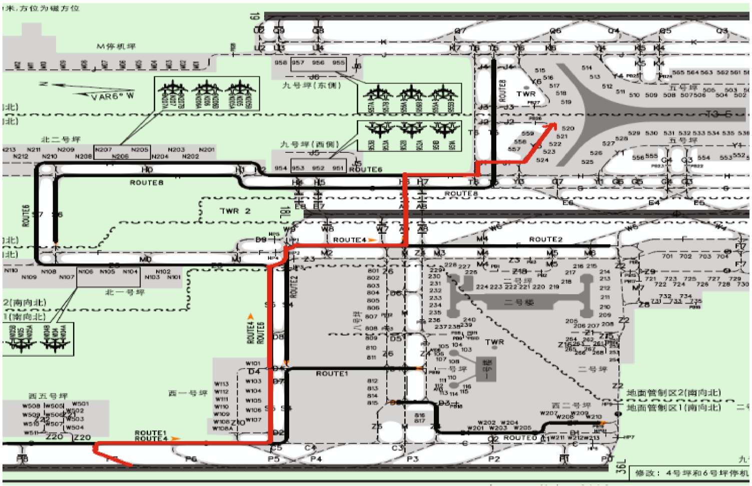

(a) Clear day (b) Low visibility III (c) Clear day, night

**Fig. 2.** Three different visibilities

**Taxiing Way.** There are two different difficulty taxiing ways from Beijing international airport shown in Fig. 3. The two has different number of turns and length. Besides, the difficult taxiing way will across runway, which needs the pilot to wait for a runway clearance from ATC (Air Traffic Control). The two different taxiing ways are shown in Table 2.




(a) Runway 36L to 232 gate (simple one)



(b) Runway 36L to 520 gate (difficult one)

**Fig. 3.** Two different taxiing ways in Beijing international airport

**Table 2.** Two different taxiing ways

| | The number of turns | Length (km) |
|---|---|---|
| Simple | 10 | 10.5 |
| Difficulty | 18 | 19 |

### 2.3 Variable Design

The experiment is in-subject design, and each group should flight six times. The order of the blocks were clear day & simple way(CS)- clear day & difficulty way(CD) -night & simple way (NS)-night & difficulty way (ND)- low visibility & simple way(LS) - low visibility & difficulty way (LD).

### 2.4 Experimental Procedure

In all scenarios, the participants were asked to land from the last approach point and taxiing to the gate successfully according to the flight plan established before.

At the beginning, the flying instructor communicated the flight plan including landing airport, runway, taxiing plan and airport gate with the aircrews as given. And then the instructor set the airplane to the last approach point. The participant's task, then, was to arm the autopilots, set the altitude, and engage landing gear, and altitude settings. After all the configurations done, eye tracker (SMI iView X HED) would be took on by the captain. A five-point calibration was made for each participant. Then the flight instructor activates the simulator, and the trial begins. Pilots should take full manual control during the trial.

### 2.5 Eye Tracker

The eye movement data had been collected by SMI head- mounted eye tracker shown in Fig. 4. The sample frequency is 240 Hz, and accuracy is 0.01.

**Fig. 4.** Pilot with the eyetracker in the experiment

### 2.6 AoI Designs

The definition of Area of Interests (AoIs) was directly connected to the pilot fixation pattern. AoIs were defined throughout the cockpit, namely electronic centralized aircraft monitoring display (EVAM), the navigation display (ND), primary flight display (PFD), and the centerline of taxiing way out of the window (OTWM), the left signs besides the taxiing way (OTWL) and the right signs besides the taxiing way (OTWR). The division of AoI is shown in Fig. 5.

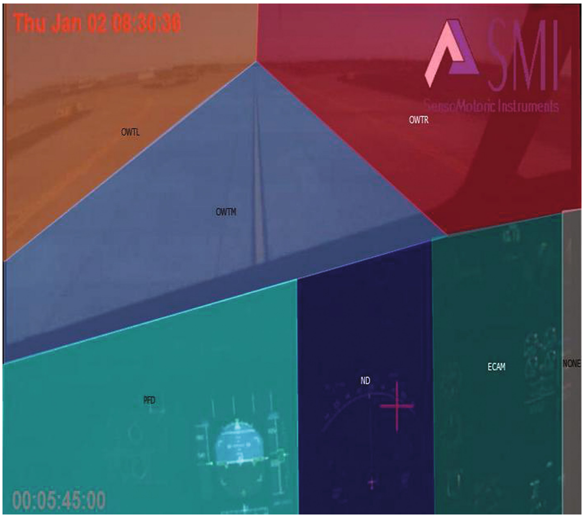



**Fig. 5.** Division of AoIs

## 3 Results

The $F_f$ (Fixation frequency) of different pilots in the experiment is shown in Tables 3, 4 and 5.

**Table 3.** $F_f$ of the pilot No. 1

| Item | Scenario | | | | | |
|---|---|---|---|---|---|---|
| | CS | CD | NS | ND | LS | LD |
| Number of fixations | 473 | 707 | 583 | 832 | 500 | 668 |
| Fixation time(s) | 174.364 | 236.915 | 244.581 | 316.104 | 179.294 | 259.848 |
| $F_f$ | 2.7 | 3.0 | 2.4 | 2.6 | 2.8 | 2.6 |

**Table 4.** $F_f$ of the pilot No. 2

| Item | Scenario | | | | | |
|---|---|---|---|---|---|---|
| | CS | CD | NS | ND | LS | LD |
| Number of fixations | 509 | 674 | 576 | 659 | 560 | 569 |
| Fixation time(s) | 176.662 | 237.538 | 230.793 | 255.806 | 193.267 | 214.546 |
| $F_f$ | 2.9 | 2.8 | 2.5 | 2.6 | 2.9 | 2.6 |

**Table 5.** $F_f$ of the pilot No. 3

| Item | Scenario | | | | | |
|---|---|---|---|---|---|---|
| | CS | CD | NS | ND | LS | LD |
| Number of fixations | 465 | 617 | 540 | 684 | 427 | 615 |
| Fixation time(s) | 175.401 | 205.520 | 190.930 | 256.580 | 147.775 | 235.186 |
| $F_f$ | 2.7 | 3.0 | 2.8 | 2.7 | 2.9 | 2.6 |

A significant effect was found between scenes by different flight experience pilots, $F(5,17) = 5.365$, $P < 0.05$. However, there is not significant effect between different flight experience pilots. The $F_f$ didn't changed regularly with the difficulty of taxiing way or the visibility.

## 4 Discussion

The aim of this paper was to contribute to understanding the pilot's fixation frequency is an effective indicator of mental workload. Due to the difficulty in recruiting professional pilots, the sample size of the present study was relatively small. This could explain why we did not find many significant differences between the experience conditions and visibility conditions.

Besides the statistical significant difference discussed above, we also found some interesting trends for the factors of interests shown in Fig. 6. The result showed that the $F_f$ is significant different among different scenes. But the result can not be used as the evidence that Ff can be used to assess the workload since $F_f$ is not changed regularly. $F_f$ is higher in simple taxiing way than in difficult one, while it is smaller in worse visibility than in better one. Environment factors were also found to have effects on mental workload. McCann et al. (1997) reported that the low-visibility and night conditions contributed to increased workload [9]. Foyle (1996) also reported that a variety of environmental conditions (airport complexity, and visibility) could affect the workload [10]. But $F_f$ did not changed regularly with the environment changed. Besides, experience is one of the factors that may affect mental workload. Some researchers reported that expert and non-expert pilots have different physiological responses to tasks at different difficulty levels [9, 12–18]. The value of $F_f$ has no significant effect among different pilots.

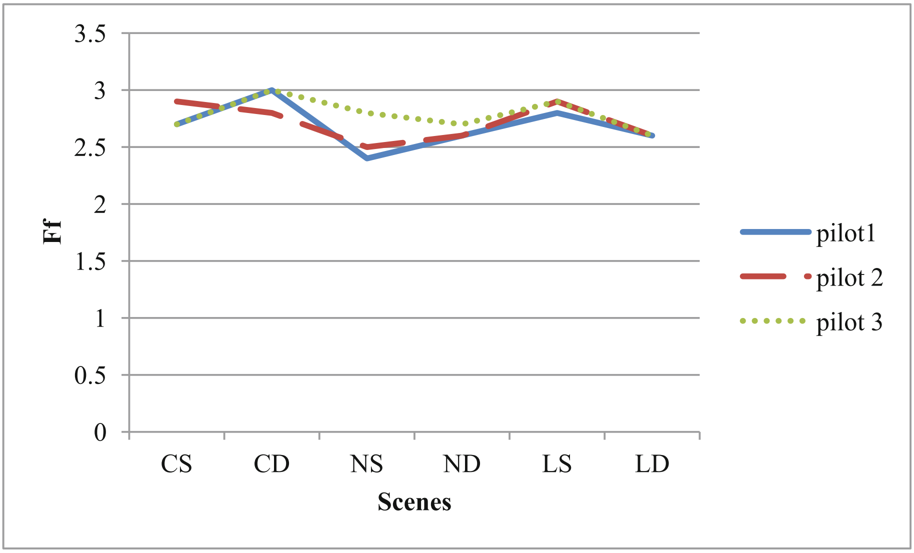



**Fig. 6.** $F_f$ by scene and pilot

## 5 Conclusions

Interestingly, there was no significate effect found in expertise level and visibility condition in fixation frequency. We did not confirmed that the fixation frequency of pilots was an effective method to assess pilot mental workload. Although a significant effect had been found among different scenes, but it changed irregularly. The change of fixation frequency can neither indicate the change of mental workload influencing by the task difficult nor by the pilot experience. The lack of significance in this main effect could be due to small sample sizes (three pilots). For the future study, we should recruit more pilots to validate that whether fixation frequency could be an effective indicator to evaluate mental workload among different pilots or different visibilities.

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