Analysis on Eye Movement Indexes Based on Simulated Flight Task

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Abstract. To probe pilot's attention allocation, workload and cognition by eye movement indexes analysis. Six subjects participated the experiment. They were asked to fly three simulation scenarios: landing, climbing and cruise flight. Five eye movement indexes which they were the percentage of fixation point, the percentage of dwell time, average fixation duration, average pupil size and average saccade amplitude were recorded and analyzed. The result indicated that eye movement data was obviously different in out view and instrument panel; also it was different among three tasks. Conclusions can be made from the result: subjects spent most time on outside view while leaving small time to make quick crosschecking to the instrument; Subjects show different pattern of attention allocation through three flight tasks; the recorded eye movement indexes are the good indicators to pilots' attention allocation, workload and cognition.

Keywords: Eye movement, Flight simulator, Attention, Workload, Cognition.

1 Introduction

It is well known that aircraft driving is a highly visual task during which pilots must fixate objects finely to finish accurate control and scan the environment quickly to acquire the situation awareness of flying aircraft. Eye movements indexes are the indicator of human mental activity. Pilots' attention allocation, the change of their workload and fatigue will all be clear by analyzing eye movements. The cockpit's design and instrument layout can be reached from eye movements' analysis. Consequential result is the best man machine interaction and the alleviation of pilot's workload. Fitts, etc. conducted a series of researches to pilots scanning behavior at the end of 1940s, and the result was the establishment of typical "T" of cockpit's instrument layout[1]. After Fitts' work, more and more researchers have researched on pilot's eye movement and eye tracking has been widely applied in aviation field. Eye tracking can be used to[2]: (1) compare eye scanning behavior of pilots using conventional displays and new display; (2) do behavioral assessment of pilot visual attention under

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various levels of visibility;(3) measure performance based on fixation duration and number of fixations;(4) evaluate pilot workload;(5) evaluate situation awareness (6) measure attention and fatigue, et al. To meet operational needs over the next 20 to 30 years, American Air Force introduced a revolutionary virtual crew station concept titled the "Super Cockpit"[3]. The pilot can interacts with the display spatially by pointing his eyes at objects in the display and giving verbal commands. Functions can also be activated by merely looking at a displayed switch and saying "select," or "on, or "off," or "go there," or "stop here," etc.

The purpose of this study is to explore the characteristics of pilots' attention allocation, workload change, and cognition by eye tracking of pilots' scanning behavior and the analysis of pilots' eye movement indexes. The work will provide some valuable reference to the design of aircraft cockpit.

2 Method

2.1 Subjects

Six young males participated the experiment. They have been trained proficiently enough to implement the basic tasks with the military flight simulator. Their age was form 22 to 31 and averaged 26. All of them had normal visual acuity with binocular acuity of 1.2 or better.

2.2 Apparatus

The study was conducted at a cockpit-based simulator with a high fidelity. Prototype of the simulator was a military fighter cockpit that replicated actual aircraft performance, navigation and dynamic system. The interior cockpit has a set of instrument panel, The real stick, rudder pedals and a throttle lever. Outside visuals were provided by a forward projection screen at a total field of view with 90 degrees.

Fig. 1. Helmet of Eyelink II System

Eye movement measurement was collected with an Eyelink II head-mounted eye tracking system which pilots could move their heads freely in flight simulation(Fig 1). The eye tracking system utilizes both pupil and corneal reflection and the data was sampled at 250Hz. The system's average gaze position error was less than 0.5°. There is a scene camera on helmet of the Eyelink II system that can record the video of the scene. Playback of the video can know the pilots' line of sight to any instrument and the sequence of instrument scan in the cockpit.

2.3 Flight Tasks

Participants were asked to fly three scenarios in visual flight rules(VFR) condition in a sunny day without wind with simulator. Scenario 1 involved landing phases and lasted approximately 50 seconds. Scenario 2 involved a level fly that lasted approximately 1 minute. Scenario 3 was a climbing phase and lasted approximately 40 seconds. The beginning place of three scenarios was the same. It was 400 meters high and 5400 meters away from the centre of the runway (Fig 2).

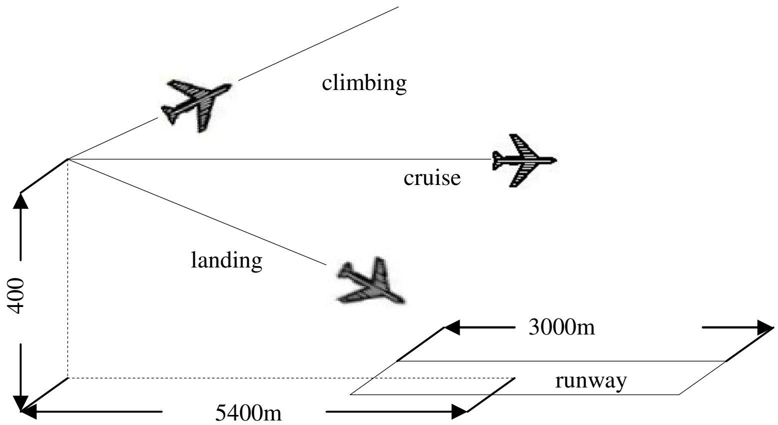

Fig. 2. Flight simulation task sketch map

2.4 Procedure

The actual experiment scene was shown as figure 3. At the beginning of each session, every participant received a brief introduction about the background of the study and experiment tasks. Before sitting into the cockpit, the helmet of the eye tracking system was put on the participant's head and calibrated. Each participant was allowed a five-minute familiarization to the flight and simulator. The simulator was then initialized to the position for flying.

Fig. 3. Actual experiment scene

3 Results

When pilots perform a flight mission, they should have different eye scanning mode and attention allocation strategy on out view(OV) and instrument panel(IP) of the cockpit. To study this difference, the vision information source was divided into two parts: area of interest(AOI) of out view, and area of interest of instrumentation panel of the cockpit. Five eye movement indexes which they were the percentage fixation point(PFP), the percentage dwell time(PDT), the average fixation duration(AFD), the average pupil size(APS) and the average saccade amplitude(ASA) were finally recorded and analyzed.

3.1 The Percentage Fixation Point

PFP is the ratio of fixation point number in each AOI to the total fixation point in each trail. The index was related to the fixation frequency to OV or IP. The result of PFP of three fly scenarios could been seen in table 1. The t Test showed that PFP spent on IP of cruise and climbing task had obvious difference($P<0.05$) to that of landing task. on instrument PFP. The difference between cruise and climbing phase was not significant ($P>0.05$).

Table 1. PFP in each AOIS of three flying stages(%)

AOI	Landing	Cruise	Climbing
OV AOI	82	69	66
IP AOI	18	31	34

3.2 The Percentage Dwell Time

PDT was a measure of the percentage of time that subjects looked at each AOI. PDT can quantitatively measure vision attention allocation to each information sources. PDT data (Table 2) showed that there exit great difference between OV AOI and IP

AOI. Compared to cruise and climbing phase, the time that subjects looked at OV AOI was more($P<0.05$) in landing phase. The time difference between climbing and cruise phase was not obvious ($P>0.05$).

Table 2. PDT in two AOIS of three flying stages(%)

AOI	Landing	Cruise	Climbing
OV AOI	97	84	80
IP AOI	3	16	20

3.3 The Average Fixation Duration

AFD was a ratio of dwell time in each AOI to the fixation point number in this research. Data (Table 3) shows that AFD in OV AOI was far more than that in IP AOI and was almost twice as much as that in IP AOI. AFD difference in OV AOI also exited between landing and cruise phase ($P<0.05$) and between climbing and cruise task ($P<0.05$) while the difference between landing and climbing task was not significant ($P>0.05$).

Table 3. AFD in two AOIS of three flying stages(ms)

AOI	Landing	Cruise	Climbing
OV AOI	594	501	586
IP AOI	250	220	276

3.4 The Average Pupil Size

APS data of three flying tasks was in table 4. T test results showed that APZ between OV AOI and IP AOI was of significant difference ($P < 0.05$).

Table 4. APS in two AOIS of three flying stages

AOI	Landing	Cruise	Climbing
OV AOI	1031	991	958
IP AOI	1085	1063	1012

3.5 The Average Saccade Amplitude

ASA of three scenarios was shown as figure 4. T test showed that ASA of landing stage and climbing stage were of significant difference($P < 0.05$) to cruise stage while there was no difference ($P > 0.05$) between landing stage and climbing stage.

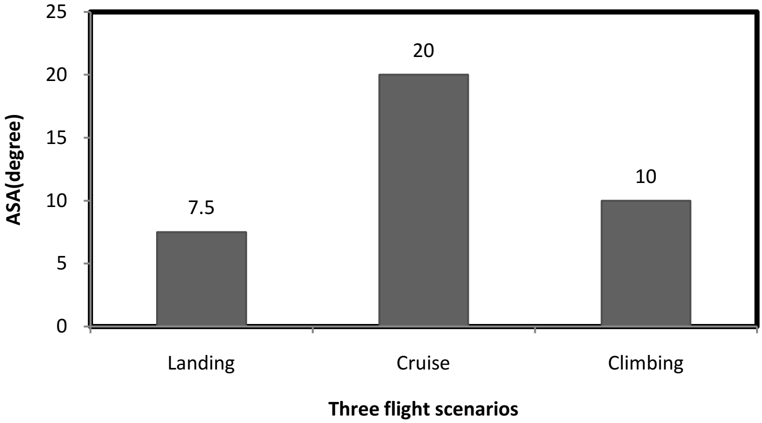

Fig. 4. ASA of three flight scenarios

4 Discussion

4.1 The Percentage Fixation Point

Two characteristics could be seen obviously from Table 1: the first was that the times which subjects fixated on out view was much more than they fixated on instrument panel; the second was that the fixation times to the instrument in cruise and climbing phase was more than that in landing phase. It also could be seen from the video playback that only the air speed indicator was viewed during the landing stage. The vertical speed indicator and altitude instrument were viewed more frequently during level flight stage while the vertical speed indicator, air speed and direction instrument were viewed more frequently during climbing stage. Some researchers found that the pilot viewed the altimeter more frequently during stages when heading was changing, And while heading and altitude were changing, the airspeed indicator was visited more frequently[4]. Their results were in the instrument flying rule (IFR) condition. The difference of fixation times indicated the change of scanning pattern on tasks and importance degree of the information sources to pilot's tasks. The optimal instrument layout or design can be reached by this important degree. For example, according to the times and direction of pilot's scanning, air speed indicator could be placed to the left side of the attitude indicator and altitude indicator is to the right while other indicator can be laid around them[1].

4.2 The Percentage Dwell Time

Data (Talble2) showed that there exit great difference between OV AOI and IP AOI. Subjects spent most of their time looking outside, which meant that subjects got information mainly from the out view, their attention was mostly allocated to out view. In realistic flights, aircraft controlling information mainly comes from speed, altitude, direction and attitude instrument. In VFR condition, pilots can acquire the most flying information from the runway, the skyline, buildings and terrains, so they need not to pay more attention to instrument. Especially in the landing task, outside scene of the cockpit is so clear and change so quickly that the pilots are not able to look at instrument for much time. The data (Table2) showed a ratio of above 80% of the time allocated to the outside. In comparison, Wickens and colleagues found that pilots spent about 40% of their time attending to the outside world in cruise[5]. But it was in a general commercial aviation task and commercial pilots generally have more emphasis on instrument interpretation and rely much less on outside visual references than their military counterparts[6]. Similar to the data (Table 2), Peter Kasarskis found that roughly 13% of the time was spent on the instrument panel (87% outside) during landing phase[4], but the scenario is some different in the sort.

4.3 The Average Fixation Duration

The longer time of AFD attributed to two factors: the information was difficult to extract that required greater cognitive efforts, or that information was rich that need to spend greater time to read the various sources. Because there are skyline, runway and much more other visual reference information which pilot's fly needs, the longer dwell time might be a combination of both. The result of the longer time of AFD was the increasing cognitive workload. Landing and climbing task is more complex than cruise and workload during two phases is highly, so it was reflected on AFD. Especially during landing phase, pilots must get enough information and make accurate and complex information process for the precise landing. So this AFD difference may be the represent of the difficulty and complexity of the task. So it can be concluded that AFD is an index of task difficulty and workload and it will be longer with the increasing of the task difficulty and increasing of workload. This index also can be used to diagnose the readability of the cockpit display information; the well-designed display may need a shorter AFD.

4.4 The Average Pupil Size

Researchers believed that the pupil size was a sensitive indicators of workload. When participants tried to look at a target, the pupil size increased. In this experiment, there were two possible reasons with the increasing of pupil size: first, the position of the cockpit instrument was under the horizontal line of sight of subjects, they must make a downward looking to read the instrument; the second, Dark cabin environment made subjects increase the pupil size to obtain the instrument information. In addition, it was also a reason that subjects need to make continually fast instrument inspection and monitoring workload was improved. So it was suggested that the instrument should be tried to put in the optimum field of vision when make a layout design. The display form of instrument and ambient lighting should also make a reasonable design.

4.5 The Average Saccade Amplitude

It could be found that ASA had the relation to task difficulty. It agreed with the related study that ASA decreased with the increase of task difficulty[7]. A certain relationship existed between vision field and task difficulty. When task difficulty increased, the information content increased, then the vision angle of vision cone decreased, effective attention field of vision decreased, and the phenomena was named as "Tunnel Vision", so the ASA decreased. In landing phase, the pilot's visual scanning range was mostly on the narrow strip runway. Especially before the final earthing short moment, the pilot's vision was highly concentrated in a short runway of the front end of the airplane. The reason of Pilots' feeling of the task difficulty was that attention mechanism limited its access to more information, so as to protect the visual system overload.

4.6 Attention and Eye Movement

Other researchers have studied pilots scanning behavior with recollection report[8], however, since it reflected only what the observer remembered and most people were not always aware of where their eyes are looking at any given instant time. The measurement of eye movement provides a detailed history behavior of scanning patterns; eye movement is likely to be a more sensitive measure of the observers' intentional state. The fixation durations reveal sensitivity to stimulus changes that could not be reported verbally. Subjects can easily distribute their attention covertly across the visual field in the absence of eye movements. However, many studies supported the idea that the shifts in attention made by the observer were usually reflected by fixations[9]. In aviation domain, the eye movement behavior is task-driven and eye movement is mostly controlled by top down mechanism, so the fixation locus and focus of attention are tightly linked. The tight link between fixations and task performance in landing task also lends credence to the idea that fixations reflect the primary distribution of attention[4].

From above analysis, it can be thought of that eye movement indexes can measure pilots' attention quantitatively; different task difficulty and different dimension workload can also be indicated by eye movement measure. The index of the average fixation time can probe the state of cognitive workload. The pupil size is a sensitive index of visual monitor workload. The average saccade amplitude will change with the task difficulty. The increasing task difficulty improve the workload, the further increasing workload may lead to "vision tunnel" and reduce the attention extent. So the relation of task difficulty, attention and workload can be revealed by the measurement of eye movement.

5 Conclusion

Eye movement technology is an accurate and objective means of providing a window into a pilot's cognitive process. Through the analysis of this study, some conclusions can be made as follows: (1) Eye movement indexes are good indicators of quantitatively measuring pilot's attention, the pilot's attention keeping, switching and allocation can be known by integrating multiple eye movement indexes. (2) Eye movement measures can reflect the different dimensions of workload and can make good diagnosticity to multiple dimensions workload. (3) The pilots' scanning mode to the out view and cockpit instrument is different. (4) In VFR condition, pilots' attention is mainly focused on out view. The information that they make decision to fly an airplane is mainly obtained from out view while they only have a quick crosscheck to the cockpit instrument.

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