The Research of Eye Movement Behavior of Expert and Novice in Flight Simulation of Landing

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Abstract. The objective of this research is to study the eye movement patterns of pilots in landing process by analyzing and comparing the eye movement data of experts and novices so as to reveal their cognitive process of information processing in the final landing stage. Ten experts who have flown above 1000 h and fourteen novices whose flight hours were between 200 to 400 participated the experiment. All subjects' task was to implement a landing task according visual flight rules in no wind and shinning day and the landing task was completed with a high fidelity flight simulator. Eye movement data and flight parameters data were recorded during the experiment. The result showed that there was obvious difference of flight performance between experts and novices. The course deviation, roll angel and pitch angel of experts were better compared to that of novices. And the land course of experts was also better than that of novices. It could be found by the comparison of eye movement index between experts and novices that there were obvious differences of six eye movement index. Expert showed shorter fixation time, smaller pupil size changes, lager scanning range, faster scan velocity, greater scan frequency and greater fixation frequency. So the conclusion can be made that there is obvious differences between experts and novices not only in flight performance but also in eye movement pattern; the scanning pattern is related to flight performance and effective scanning pattern is related to better flight performance; so the measurement of eye movement pattern can be used to evaluate and forecast flight performance and thus to guide the training.

Keywords: Eye movement · Expert · Novice · Flight simulation · Ergonomics

1 Introduction

The research of eye movement is the most effective means of Visual information processing. The expert-novice paradigm has often been applied by the eye movement researchers in the past more 30 years and it is widely used in sports, traffic, medical,

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text reading, aviation environments, etc. [1–7] In this paradigm the subjects would be divided into experts and novices, and their eye movement data which include the fixation time, fixation count, scanning range and so on were recorded and the comparison was made between the two groups of their eye movement data, so as to find the difference of the eye movement pattern of the two groups. With this comparison, the efficient and practical eye movement mode of experts and the scanning defects of novices could be found which is of great practical significance to guides novices for their skills training.

As early as the late 1940s, Fitts found the scan difference between expert and novice, and noted the scan difference between skilled pilots and novice [8]. He found that experts have shorter fixation time than novices on each instruments and suggested this difference could be used to distinguish the degree of operational maturity of the expert and novice. Eye movement is also used to evaluate the usability of newly developed electric map. Simulated flight according to visual flight rules, Ottati et al. compared the scanning mode of expert and novice in different terrain conditions [5]. It was found that experts have shorter time to search the sign of navigation and fixate to it, while novices are difficult to search navigation signs and have longer time to fixate it. Bellenkes et al. (1997) found that expert pilots make more frequent scanning on speed instrument than novices when the height is in variation [6]. Kasarskis Peter et al. (2001) recorded the eye movements data of 10 novice and 6 expert pilots in the approach and landing phase [9]. It is could be found that experts have shorter fixation time, more fixation count than novices, less attention to the speed meter, more simple and regular sweep mode. In order to improve the novices training efficiency, Sajay et al. recorded the fixation points and scanning path of the experts observation to the cargo in the cockpit, and used the recorded eye movement data as a feed forward to train the novices [7]. They divided the novices into two control groups, one was trained with the experts' search pattern, and the other did not. The results showed that the performance of providing the experts' search mode group was higher than the other. So they think that experts' scanning mode could be used to guide novices to scanning. Through systematic study, the military of American found that eye movement measurement system could significantly improve the effect of training when the system was applied to the air force training and it was obvious when it was particularly used in the initial training phase, and in that condition, it can correct the wrong scan habits at an early stage. In the training course for F16B, there exists 10 courses that use eye movement measurement systems [10].

As could be seen, professional experience and knowledge in the field affects not only the performance also the scanning behavior. In the field of aviation research, as the task situation varies, the choice of performance and eye movement indicators are also different. The manipulation of the landing stage is complex and the information changes rapidly, so the accident rate is higher, but the current research of visual scanning to this phase is still little, lack of detailed and comprehensive studies. So as to further learn the scanning pattern of expert pilots and novice, this paper simulate the final landing phase of the mission to makes an overall comparison based on records of eye movement data between expert and novice glance to obtain quantitative differences in the two scanning mode. The results will provide support for pilot training and for the evaluation of flight performance.

2 Method

2.1 Participants

Twenty-four subjects who are flight simulation amateurs participated the experiment, and their skill came from the PC (personal computer) on the flight simulator games and flight simulators. NASA found that training skills in the PC can be actively transferred to the actual flight, so the choice of subjects is reasonable [11].

After the observation to the performance in the simulator operation and also the interview, it could be found that 10 individuals' simulation flight time is longer and their operation was more skilled, so they were defined as experts. The flight hours of the others were shorter, and their proficiency in operating was poorer, so they were defined as novices. Subjects ages ranged from 20 to 30 years old who all of them were of normal vision or corrected vision with no other eye diseases. All subjects could implement all courses of basic simulation tasks.

2.2 Apparatus

Experimental measurement systems included flight simulators and eye movement measurement system. The prototype of the simulator was a fighter that has been tested with high validity. The simulator could measure and record the flight parameters during the flight. Eye movement measurement system was Eyelink II measurement system which was made by Canada SR Research company. It worked with a way of pupil and corneal reflex and its sampling frequency was 250 Hz, average gaze error was less than 0.5°.

Eye movement measurement system could not only measure eyes numerical data, also could record the video data. The position of the subjects' fixation and the sequence to scan instrument of subjects could be known bye the playback of video. The measured data by Eyelink II system was processed by the software of DataViewer and then many eye-movement indices could be obtained, such as the fixation duration, pupil size, scanning amplitude, blink count and so on.

2.3 Experiment Task

Experiments required subjects to complete the approaching and landing task with simulator according an visual flight rules (VFR, Visual Flight Rule) on a cloudless and sunny day. The diagram of landing task was shown in Fig. 1. When the subjects landing, they were asked to keep a good attitude, and make a smooth land on the runway as accurately as possible. The landing point was near the position of 5400 m from the starting point of landing. Each subject completed 4 landing missions.

2.4 Procedure

Before the subjects made the flight, the background of the experiment task was introduced to them and then they worn the head mounted eye tracking system to make

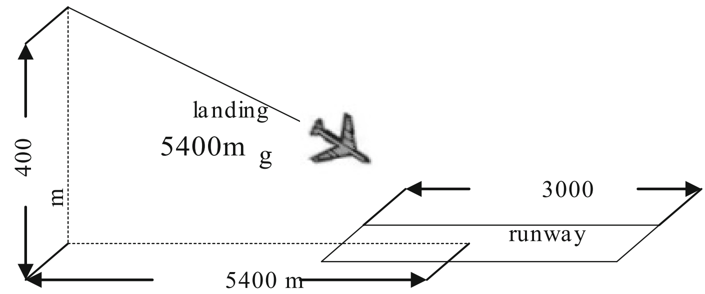

Fig. 1. Experiment pictures

a calibration. After the calibration, the subjects entered the cockpit of the simulator and exercised about 5 to 10 headgear to minutes to adapt simulator and get familiar to the task. Then the experiment started. Each subject would calibrate again before the starting of the task, and performed the same procedure. The experiment scene was shown as Fig. 2.

Fig. 2. Experimental scenario

3 Results

The performance of plane landing at last stage could be evaluated by four indexes, flight gliding angle, yaw angle, tilt angle and falling rate. The first three indicators evaluated the pilots' capabilities of controlling the aircraft attitude while the gliding rate accessed the stability of the aircraft flight. The stability of landing is the key to the safe landing of plane. The "t" test of performance indices of the expert and novice has been carried on and results showed the significant differences (see Table 1). It could be seen that the experts' performance of controlling the attitude in three flight axes was better than that of novices. It was particularly in aircraft directional controlling and tilt angle controlling, there existed significant difference between expert and novice. Moreover expert performed better than novices in landing stability.

Table 1. Comparison of the flight performance between expert and novice (n = 24, $\bar{x} \pm s$)

Subject	Pitch angle (°)	Yaw angle (°)	Roll angle (°)	Gliding rate (m/s)
Expert	2.5 ± 1.5	1.4 ± 1.4	3.5 ± 2.8	11.8 ± 1.6
Novice	3.9 ± 2.9	6.5 ± 3.4	16.3 ± 12.1	15.6 ± 3.0
"t" test	*	***	***	***

Note: *P < 0.05, ***P < 0.001, as compared with expert group

After the processing of the eye movement data, it was found that s there exist obvious differences in six eye movements indices, including average fixation time, average scan amplitude, the average pupil change rate, average scanning velocity, fixation frequency and scanning frequency, the "t" test results were shown in Table 2. Expert have shorter fixation time, smaller average pupil changes, lager scanning amplitude, faster scanning velocity, greater scan frequency and greater fixation frequency. Ottati found that novices pay more attention to out view of cockpit compared with the experts [5] and the similar results were obtained in this experiment. From the video playback, it could be found that the distribution of attention between experts and novices was significantly different. Experts not only paid attention to the external visual, but also intermittently glanced at cockpit instrument. The experts regularly switched vision between cockpit instruments and external scene. The novices just scanned external view of cockpit and particularly focused on the narrow runway. The novices almost didn't pay any attention to the instrumentation.

Table 2. Comparison of eye movement indices between expert and novice (n = 24, $\bar{x} \pm s$)

Subject	Fixation Time (ms)	Saccade amplitude (°)	Pupil Variance (%)	Saccade Velocity (°/s)	Fixation Frequency (min-1)	Saccade frequency (min-1)
Expert	591 ± 43	7 ± 1.3	0.32 ± 0.05	133 ± 21.7	104 ± 6.1	95 ± 19.2
Novice	730 ± 35	5 ± 0.3	0.38 ± 0.01	79 ± 8.4	77 ± 6	65 ± 11
"t" test	**	*	***	***	***	***

Note: *P < 0.05, **P < 0.001, ***P < 0.001, as compared with expert group

4 Discussion

4.1 The Analysis of Differences in Scanning Mode

Seen from the video playback, novice was almost paid all their attention on the runway, while expert not only concentrated on the runway and the horizon but also regularly scanned the speedometer, the altimeter and the attitude instrument in the cockpit. For this reason, more information sources were obtained by experts, and range of the scanning was relatively wide. Expert could more accurately grasp flight parameters information, land more accurately and smoothly and make better flight performance by contrasting the information obtained from visual reference of exterior scenes with instrument information in cockpit. In conclusion, one important reason of different flight performances between novice and expert was that the way they distributed their attention. So the feature of expert's attention distribution should be studied more deeply which could guide novice distribute their attention more reasonably in actual flight training.

The time of landing process was very short. So as to acquire information from more sources within limited time, high-speed and flexibility of experts' eye movement were required. Experts must reasonably allocate time on each information source. They also need to transfer and switch attention quickly. So the scanning speed of expert was faster, and the scanning frequency was greater. Relevant expert held the opinion that the defect of acquisition or processing of information could be remedied by frequent and rapid scanning activity [12]. It was a necessary condition that driver scanned instrument and exterior scenes fast and frequently in the process of training novice to become a skilled pilot. So at the beginning of flight training, novice should be guided to make quick and frequent scanning consciously to develop correct scanning habits.

Relevant research found that expert spent less time on all instruments and had more fixation point compared with novice in flight [13]. Although this experiment task was VFR flight, the same result was obtained. There were two main reasons for this difference between experts and novices. For the first reason, because trained for a long time, Expert had more developed peripheral vision than novice, and expert could use the surrounding visual to access information preferably. In this way, expert did not require to stare at instrument to obtain information, they reduced the time spent on fixating at instrument [3]. The second reason is that expert had more knowledge and experience. Because of long time flight, the information processing and cognition of expert tended to programmed and automation. They processed information with a way of high efficiency of Top-Down that can process information with modularization. They did faster than novice in the process of extracting and encoding information and in decision, so they had the advantage of time [14]. Because of lacking of training, the scanning pattern of Bottom-Up was more used by novice which made novice spend more time on information searching and locating. It was difficult for novice to extracting information and they need fixate on information longer time to perceive it. As the result, expert had the ability to extract information at a shorter fixation time, which provided them plenty of time to adjust the deviation in time when aircraft was flying and made plane landing accurately and stably. Thus, enlightenment was acquired. There were two factors needed to make the driver faster in accessing the target location information in the complex cockpit environment. The first was the well training that automated scanning of top-down was developed. The second was the good design. For example, the alarm display system captured operator's attention in the way of Bottom-Up which cause the efficient distribution of attention.

Changes of the pupil reflected the changes of pilot's mental workload in the information processing. High pupil change rate reflected the heavy information processing task and the high mental workload. Conversely, mental workload was low. A fact could be found from the result that the higher frequency and greater scanning amplitude of scanning of expert haven't raised the mental workload which showed that the improvement of the flight performance is not at the expense of mental workload and efficient and good eye movement pattern not only can improve performance but also release mental workload. Relevant person also made the same opinion [15].

Shapiro found that the performance of subjects adopting high efficient pattern of eye movement was significantly better than that didn't use and after a period of time, the subjects who did not use the high effective eye movement pattern would automatically adopt the effective scanning method when they played video game [16]. The eye movement pattern of the expert pilots should be recorded by the eye movement measuring system when they are training to provide mode that the novice could imitate. The imitating effect should be checked by eye movement system, so as to help novices develop correct scanning habits in the early stage of training, and help them to improve their training efficiency and shorten the training period.

Two characteristics could be found from the above discussion. One was that the flight performance of expert was better than novice; the other was that the scanning mode of expert was different from novice. Analyzing from the aspect of information processed, eye movement reflected the input and processing of information. Flight performance was the result of output information. Although eye movement behavior was not the single factor that produced performance differences, the flight performance could be reflected from the eye movement pattern. A continuous, active and efficient scanning pattern corresponded to a perfect flight performance. Therefore, performance analysis could be judged by analyzing the pattern of eye movement.

4.2 The Relationship Between Scan Pattern and Training

Usually, instructional training could promote the speed of learning. Therefore for the training of instrument scanning in cockpit, instructors generally used the language to guide trainee the method used to read instruments which showed the flight status under specific tasks, the optimal time to read instruments, the type of instrument they should read and the order of scanning. After repeated such training, trainee can master the relationship between instrument and task, they could also extract relevant information when they manipulate flight. For example, in the initial stage of training trainee was required to begin to check the instrument from the level flight indicator and came back to the level flight indicator in the end. I.e. the level flight indicator to climb meter to the level flight indicator; the level flight indicator to speedometer to the level flight indicator; the level flight indicator to heading device (radio compass) to the level flight indicator; and so on. In the middle period of the training, trainee must learn to assign and shift attention to the instrument cluster and do instrument inspection work in an "8" shaped way. The sequence was the level flight indicator-speedometer-altimeter-turn and sideslip indicator. Then the sequence is the level flight indicator-automatic wireless electronic compass-climb meter. Relevant experts believed that this guidance was helpful to the formation of a stable and flexible instrument scanning skill, and it could make trainee gradually raise a good scanning instrument habit [17].

The question whether scanning guidance of expert was effective, whether novice carried out the intention of the instructor was not validated. It was a effective way to use eye movement to check it. Mission in Shapiro's video game belonged to simple mission compared to aircraft manipulation [16]. The environment of cockpit was complex and the flight was difficult to control. The conclusion about pattern of expert scanning hadn't formed. From the perspective of cognition theory, someone held the opinion that the scanning technology of expert would not be formed in a accelerate way, it would only be obtained gradually by practice. In this opinion, the guidance of the scanning strategy was based on expert's knowledge and experience of the Top-Down training strategy. This kind of scanning strategy which was efficient strategy was obtained by the experts after a long time of practice, training and continuous optimization. At the beginning of the training, expert practiced in the Bottom-Up way. With the addition of exercise time, the scanning components of Top-Down way gradually increased, until it was dominant [18]. The report recognized that the guidance of expert scanning patterns may be more effective in the case of relatively simple procedural tasks such as task which need to monitor instrument but didn't need to make control action. In the case of complex operation task in which trainee needed the coordinate eye and hand and make more decision, scanning strategy perhaps mostly relied on trainee daily practice and gradual development. For example, the mental workload of pilot was small in cruising flight when trainee needed to check the instrument according to the procedure, while in stunt training and tactical training, the task was more difficult, and trainee may not scan the instrument according to the intention of the instructor. Since the initial stage of the novice pilot flight training was generally start with a simple primary task. The eye movement measurement equipment could be used to record the expert pilot's scanning mode which was provided to novice to imitate. This can help novice develop a correct scanning habit, improve training efficiency, shorten the training period in initial stage of training.

5 Conclusion

Through the comparative study of expert and novice, the characteristics of the scanning mode of expert and novice were obtained, the relationship between the scanning mode and flight performance was determined. Quantitative differences between expert and novices in the 6 eye movement indexes were obtained. The specific conclusions are as follow:

1. Expert and novice not only have obvious differences in flight performance, but also have significant differences in eye movement patterns.
2. Performance of expert is better than novice. Expert has the shorter fixation time, more fixation point, faster scanning velocity, greater scan frequency and wider scan area than novice. It is also found that eye movement pattern of expert bring lower mental workload than novice.
3. The eye movement patterns relate to the flight performance. High efficiency eye movement patterns relate to better flight performance. Therefore, contrasted with the mode of expert's eye movement, the eye movement measuring instrument could be used in the training to inspect the novice's scanning defect, track and evaluate the training progress, and provide the reference for the flight training plan adjustment and the formulation.

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