Pilots' Latency of First Fixation and Dwell Among Regions of Interest on the Flight Deck

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Abstract. The purpose of this pilot study is to investigate the differences of eye movements among three different flight backgrounds. There were eleven participants (2 military pilots with average 2,250 flying hours, 6 commercial pilots with average 5,360 flying hours, and 3 novices). All participants wear a mobile eye tracker during the experiment operating a Boeing 747 flight simulator for landing. The eye tracker recorded all participants' eye movement data automatically. The average values of the latency of first fixation (LFF) and the total contact time (TCT) for five regions of interest (ROIs) are used to examine proposed hypotheses. The findings include: (1) participants of different flight backgrounds have different sequences of viewing ROIs; (2) participants of military pilots and novices spent most of time viewing the outside of cockpit (ROI-3); however, participants of commercial pilots spent most of time viewing the Primary Flight Display (ROI-1). Current research findings might be applied for developing conversion training for military pilots conversed to civil airlines pilots. The fundamental reasons of why pilots viewing ROIs in different sequence and spending significant different time on the ROIs needed to be studied further in the future.

Keywords: Attention distribution · Eye movement · Fixation duration · Flight deck design

1 Introduction

Landing is one of the most dangerous stage related to high accident rate (56 %), followed by take-off (27 %) and approach (15 %) phases [1]. With such huge number of accidents occurring during landing, it is important to enhance training methods for pilots. Pilots operate aircraft mainly by visual perception to process symbols, number, texts and flashing warning signals present on interface displays on the flight deck. Pilots process information through vision, eyesight is often more directed and attracted to texts, pictures, and animation [2]. Therefore, eye-tracking technology has been used to conduct various studies, such as visual and content design [3], reading strategy [4] and dashboard design [5]. In this study, researchers used eye gaze data to analyze

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participants' eye movements in order to find out whether or not there are differences between the novice and expert viewing the flight deck during the airplane landing.

Eye movements consist of a series of fixations and saccades [6]. When a pilot performs visual search, the eyes move rapidly from one gaze point to another. Most visual information is obtained through fixations which are formed when a pause exists between gaze points. The previous study indicated that eye movements can be useful cues to indicate a pilot's current cognitive state and to explore their operational behaviour [7]. The eye movement pattern and cognitive process are closely related to interface design and the development of training syllabus [8], e.g., it was found that expert pilots had significantly shorter fixation duration and more total fixations [9] than novice. Also, experts had more fixations on airspeed and fewer fixations on altimeter than novices. Experts were also found to have better defined eye-scanning patterns [10]. However, due to the limited capacity of a human's working memory, it is necessary to distribute attention on the most critical task at hand when selecting the visual channel to be attentive to [11, 12]. Two of eye movement variables, the latency of first fixation (LFF) and total contact time (TCT), are usually used to assess participants' attention distribution. For examples, the shorter the LFF paid on a region of interest (ROI), the more attractive it is to the participant; the longer the TCT, the more attractive the ROI is to the participant [13].

Previous research indicated that operator's performance is impacted by the tools, tasks and environments in which they operate [14]. Pilots' attention distribution could be influenced by the types of aircraft, the features of operational context, and the specific organization where they come from. Hence, to investigate visual scan patterns not only benefits the understandings of pilots' attention distribution, but also can be applied to improve the safety and efficiency of pilot's conversion training. Based on the literature review, two null hypotheses were generated as followings.

H_1: There are no differences of viewing sequences among pilots.
H_2: There are no differences of the total contact time of eye movements among pilots.

2 Methodology

2.1 Participants

There were eleven participants (2 military pilots with average 2,250 flying-hours, 6 commercial pilots with average 5,360 flying-hours, and 3 novices). Due to the number of participants in this pilot study was small, the arithmetic mean was chosen instead of the statistics analysis.

2.2 Apparatuses

All participants operated the landing procedure by using a Boeing-747 flight simulator following visual flight rules (VFR) scenario. The eye movement data was recorded by a headed mounted eye tracker (ASL-4000) (Fig. 1).

Fig. 1. Research apparatus including eye tracker and Boeing 747 flight simulator

Boeing 747 simulator is a high fidelity and fixed-base type for the purpose of routine flight training. It utilizes a simplified cockpit with identical display panels, layout and controls to those in the actual aircraft. The instructor sat at right seat and installed experimental scenarios in advance via a normal operation procedures. Participants can get the required information from the cockpit instruments, such as Altimeter, Attitude, Airspeed, and etc. In addition, the sampling rate of the mobile eye tracker ASL 4000 is 30 Hz. It recorded the position and radius of participants' pupil, the view from the angle of participants, and the spot point in the scene.

For the eye movement analysis, EyeNTNU-120p analysis system was applied in this study. Researcher not only define those ROIs with frame by frame, but also analyze more than twenty-three variables of eye movement provided, e.g., LFF, TCT, First Fixation before First Arrival, and etc.

2.3 Experimental Design

The present study is a single independent variable experiment. The independent variable is the backgrounds of participants (military pilot, commercial pilot, and trained novices) and it is a between-subject variable. Dependent variables include the latency of first fixation and the total contact time of fixations of eye movement for each region of interest (ROI). In the definition of ROIs, ROI-1 indictaes the region of Primary Flight Display (PFD); ROI-2, Engine and Alert Display (EAD); ROI-3, Outside of Cockpit; ROI-4 Navigation Display (ND), and ROI-0, the region of others (Fig. 2).

2.4 Procedures

All participants undertook the following procedures; (1) the participant completed the demographical data including gender, working backgrounds, type ratings and total flight hours (3 min to complete); (2) a short briefing explained the purposes of the

Fig. 2. The definition of ROIs: ROI-1(PFD-Primary Flight Display); ROI-2 (EAD-Engine and Alert Display); ROI-3 (Outside of Cockpit); ROI-4 (ND-Navigation Display), and ROI-0 (Other regions).

study and introduced the landing scenario (5 min); (3) the participant was seated at left seat in the simulator and the eye tracker was put on for calibration by using three points distributed over the cockpit instrument panels and outer screen (5-10 min); (4) the participant performed the landing task and simultaneously the instructor pilot sitting at the right seat (6 min). The eye tracker recorded both the scene video and corresponding eye movement data during the flight operations.

After the experiment, two types of data would be observed. One was participants' eye movement data; and the other was the scene video. EyeNTNU-120p analysis system only supported eye movement data saved in txt format. The eye movement in ASL 4000 was saved in csv format. Hence, the format of data should be transformed first. Secondly, using the ROI define tool in EyeNTNU-120p analysis system to define ROIs for each scene videos. After the analysis, the results (LFF and TCT) would be saved in txt format.

3 Results and Discussions

The results show that different background pilots' have different sequences of viewing ROIs; military pilots and novices spent more time viewing outside of cockpit compared with commercial pilots spent more time viewing the Primary Flight Display (ROI-1). The viewing sequences of military pilots is ROI-0, ROI-3, ROI-2, ROI-1, and ROI-4, the viewing sequence of commercial pilots is ROI-1, ROI-0, ROI-3, ROI-4, and ROI-2, and the viewing sequence of novices is ROI-0, ROI-4, ROI-1, ROI-3, and ROI-2. Therefore, the first null hypothesis (H_1) was rejected due to the significant differences of viewing sequences among different background pilots (Table 1).

The percentage of total contact time of pilots' first fixation indicated significant differences that military pilots spent most of time on ROI-3 (Outside of Cockpit),

Table 1. The latency of first fixation for all ROIs (milliseconds)

Participant code	ROI-0	ROI-1	ROI-2	ROI-3	ROI-4
1	456	7180	4123	0	16388
2	2388	0	36508	22360	9238
3	3862	0	*	44146	4027
4	236	0	*	7759	89255
5	0	1789	*	297	9194
6	0	759	9581	7923	7395
7	3254	0	*	18491	2043
8	0	*	*	3828	*
9	1039	7320	*	15285	0
10	100	1899	*	7353	0
Military	278	4540	4123	3677	8194
Commercial	1948	358	36508	18611	22751
Novices	346	4040	9581	9012	3698
Mean	1134	2105	16737	12744	34643

* denotes the ROI never been fixated.
0 denotes the ROI had been fixated at the very beginning.

commercial pilots on ROI-1(PFD), and novice pilots focus on ROI-0 (Others). The result rejected the second null hypothesis (H_2). Hence, there are differences of the total contact time of eye movements among different background pilots (Table 2).

Table 2. The percentage of total contact time of fixations for all ROIs

Participant code	ROI-0	ROI-1	ROI-2	ROI-3	ROI-4
1	34.42 %	2.64 %	0.35 %	61.74 %	0.84 %
2	36.60 %	42.87 %	0.65 %	3.72 %	16.15 %
3	7.09 %	79.05 %	0.00 %	5.13 %	8.73 %
4	61.90 %	31.48 %	0.00 %	6.33 %	0.29 %
5	44.91 %	9.69 %	0.00 %	16.78 %	28.62 %
6	59.19 %	2.41 %	2.85 %	26.10 %	9.45 %
7	3.93 %	83.20 %	0.00 %	0.23 %	12.64 %
8	70.16 %	0.00 %	0.00 %	29.84 %	0.00 %
9	39.17 %	3.07 %	0.00 %	37.73 %	20.04 %
10	18.25 %	4.95 %	0.00 %	59.73 %	17.07 %
Military	26.34 %	3.80 %	0.18 %	60.73 %	8.96 %
Commercial	30.88 %	49.26 %	0.13 %	6.44 %	13.29 %
Novices	56.17 %	1.83 %	0.95 %	31.22 %	9.83 %
Mean	37.80 %	18.30 %	0.42 %	32.80 %	10.69 %

Flying an aircraft is comprised of a series of cognitive processes. Visual scan sequence and time could outline pilots' patterns of attention distribution in the cockpit which relate to pilot's situational awareness and decision-making process [11]. The results of present study indicate the flight background, e.g., experience and training, impacts pilots' visual scan patterns. Table 1 shows the first two ROIs where military pilots viewed are Others and Outside of Cockpit; commercial pilots' sequence is PFD and then Others. Table 2 demonstrated the scan sequences and the time distribution by the military and commercial groups are compatible, for both of military and commercial pilots relied on what they learned from previous training experiences to acquire necessary information supporting their task in hand. Furthermore, novices' attention sequence and visual time distribution do not match each other. However, it seems to be rational that novice pilots scanned ROI-0 (Others) as the first priority with the highest percentage time (56.17 %) due to the unfamiliar of cockpit instruments. After knowing where he/she could acquire the necessary information, novices shifted attention to the secondary ROI (Outside of Cockpit). However, even the latency of first fixation is meaningful, it is necessary to interpret pilots' cognitive process combined with the total dwell time distributed on those ROIs.

In addition, at the very beginning phase during fundamental training, military pilot was required to control the aircraft by scanning the horizon only, not by using the instruments while flying with VFR condition, for military pilots have to pay more attention on tactical manoeuvres and engagement. This might be the reason why the participants with military background spent the highest percentage of visual time (60.73 %) viewing outside of cockpit (ROI-3). In contrast with military pilots, the participants having commercial flight experience distributed most time (49.26 %) on the instrument, PFD. In fact, the total percentage of time that commercial pilots distributed on PFD and ND summed up as 62.55 %, which is very equivalent to the time on outside cockpit distributed by military pilots. It is reasonable that the information provided by PDF an ND can be acquired from outside of cockpit, such as runway direction and terrain features. On the other side, the ROI where novices spent most time is the other regions. This phenomenon could tell novice pilots' scanning strategy during the landing task is not well organized and even unfamiliar with the functions of PFD and ND, they might not be able to control the aircraft by using the horizon which military pilots were familiar with (Table 2).

Pilots' visual scans patterns among ROIs are related with selective attention. It is a critical skill for improving situational awareness and decision-making in the cockpit [15]. The findings of current research indicate the factors impacting pilots' cognitive processes of selective attention are reinforced by pilot's previous training background, e.g., knowledge and experience, which also could be observed and identified by specific LFF and TCT patterns. Therefore, with real-time visual scan patterns distributed on the control panel, the performance level of trainee's attention distribution can be understood at very early training phase. It should be able to apply for improving the effectiveness of conversion training.

4 Conclusion and Future Work

Flying an aircraft is comprised of a series of cognitive processes. Visual scan sequence and time could outline pilots' patterns of attention distribution in the cockpit relate to pilot's situational awareness. The results of present study indicate the flight background, e.g., experience and training, impacts pilots' visual scan patterns. The fundamental reasons of why pilots viewing ROIs in different sequence and spending significant different time on the ROIs needed to be studied further in the future. However, the findings might be applied for developing conversion training for military pilots conversed to civil airlines pilots. The application of eye tracking devices could be a suitable tool for investigating pilot's fixation distributions between the surrounding operational environments. Pilots with different flight experience have different strategies of viewing ROIs and pay attention on different interface displays. According to the findings of current small scale of piloting, a formal experiment why pilots were viewing ROIs in different sequence and pay attention in different ROIs are critical issues to aviation training and flight deck design, and needed to be studied further in the future for improving aviation safety.

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