Pilots' Scan-path and Attention Shifts during Tactical Manoeuvres

Wen-Chin LI[1], Chen-Kai HSU[2], Graham BRAITHWAITE[1] and Matthew GREAVES[1]

[1]Safety and Accident Investigation Centre, Cranfield University, Bedfordshire MK43 0AL, UK. [2]Department of Industrial Management, National Taiwan University of Science & Technology, Taipei 106, Taiwan

Abstract: Understanding the cognitive processes of pilots' fixation shifts and attention distributions can facilitate training of tactical maneuvers and improve both performance and flight safety. Thirty-five military pilots participated in the current study. By analyzing eye movement data, it is possible to identify what the military pilot was looking at during particular moments in the flight. A pilot's attention is likely to remain one of the critical and limited resources that will need to be confronted in the development of new technology. It is important that the nature of pilots' attention and fixation distributions is understood in order to assess and manage the implications of new technology in the cockpit.

Keywords: Attention Distribution, Control Flight Into Terrain, Fixation, Scanpath

1. Introduction

Pilots' cognitive processes may have impacts on the pattern of cue acquisition which is associated with situation assessment and monitoring. Pilots may sometimes experience cognitive complexity for example through symbols on a head-up display (HUD) and mission management systems, and their attentional resources are almost entirely engaged in solving such conflicts (Dehais, Causse, & Tremblay, 2011). A phenomenon known as attentional tunnelling (Wickens & Alexander, 2009) may explain the cause of controlled flight into terrain (CFIT) events that occur during air-to-surface missions. Eye tracking research revealed that excessive focus is associated with decreased saccadic activity, long concentrated eye fixation durations (Tsai, Viirre, Strychacz, Chase, & Jung, 2007), and narrowing of visual scene, inducing attentional shrinking on particular interfaces (Thomas & Wickens, 2004). Furthermore, eye tracking techniques provide clues not only regarding the timing of attentional tunneling, but also the location on the user interface where it took place. These indications could be used in an adaptive system to decide when and where to switch information from the HUD (Wiggins, 2006). The principle of cognitive countermeasures relies on the temporary removal of information on which pilot is focusing, for it to be replaced by an explicit visual stimulus to change the attentional focus. The user interface acts as a cognitive prosthesis as it performs the attentional engagement and stimulates attentional shifting. The principle of information removal would not be critical as the displayed information on the HUD is, at least at that moment, redundant (Dehais, Causse & Tremblay, 2011).

Pilots' visual search tracks are affected by the surrounding environment and current operating tasks. Thus, knowledge accumulated leads to visual search behaviour, which is crucial and practical for pilots in operating aircraft (Sarter, Mumaw, & Wickens, 2007). An eye-tracking system can clearly record the eye-movement states of pilots and provide feedback during training as an empirical reference for attention allocation and improving search models, thereby elevating the training effectiveness. Hoffman and Subramaniam (1995) proposed that places allocated with increased time and fixations are places receiving concentrated attention.

Fixation shifts demonstrate the attention distribution and scanpath of pilots (Ratwanti, McCurry, & Trafton, 2010). Katoh (1997) found that pilots exhibited the shortest dwell times and the smallest saccade amplitude during landing. This finding suggests that visual scan patterns during landing are distinctly different to other periods of flight, as landing requires attention of both instruments and outside the aircraft. Hence, pilots must conduct more visual scan activities, especially during final approach to the runway. Similarly, Bellenkes, Wickens, and Kramer (1997) found differences in visual scanning during various phases of instrument flight where pilots exhibited different scanning patterns when turning than when climbing or descending. The factors manipulating visual attention distribution include the scheme for presenting information, identification difficulties, complexity of interface design, and operating environments. When information is complex or incomprehensible, the corresponding eye movement will be different, such as increased fixation duration, and reduced saccade distance (Rayner & Pollatsek, 1989). When a pilot gazes at a specific region, vision and attention is focused on the region (Hoffman & Subramaniam, 1995; Shinar, 2008). These arguments provide a compelling explanation that eye movement is highly correlated with attention, indicating a substantial correlation between the fixation point and spatial distribution of attention between cockpit instruments and surrounding terrain.

2. Methods

2.1 Participants

A total of 35 male F-16 pilots participated in this study. All of the subjects were informed that there was no incentive to secure participation and they had the right to cease the experiment and withdraw provided information without any reason.

2.2 Apparatus

1. Eye Tracker: A head-mounted eye tracker, ASL Series 4000 weighing 76g was used to collect pilots' eye movement data. This system applies the principle of reflection from the pupil to the cornea and records eye movement parameters and cockpit settings by eye camera and scene camera. The obtained data were stored using a digital video cassette recorder and computer. The sampling frequency was set at 30 Hz, and the resolution was set at 640 × 480 pixels. The definition of a fixation in the present study was three gaze points occurred within an area of 10 by 10 pixels with a dwell time being more than 200 ms (Salvucci and Goldberg, 2000).
2. Flight Simulator: The flight simulator is a formal F-16 trainer. It consists of identical cockpit displays to those in the actual aircraft, and integrated with high-definition databases, image generation systems and physics-based processing technology, all enable pilots to detect, judge the orientation of, recognize and identify targets, as they would in tactical operations. There are five Areas of Interest (AOIs) in the cockpit to observe participants' eye movement during tactical operations. Those AOIs were selected based on the requirements of the standard operating procedures (SOP) of the tactical manual. They are AOI-1: Head-up Display (HUD); AOI-2: Integrated Control Panel (ICP); AOI-3: Right Multiple Function Display (RMFD); AOI-4: Left Multiple Function Display (LMFD); and AOI-5: Outside of cockpit (OC).
3. Scenario: The scenario was designed to replicate an air-to-surface task – where a weapon would be aimed and released from the air at a target on the surface. Participants had to intercept the proper route, and turn toward the target at an altitude of 500 feet with a speed of 500 knots indicated air speed, then perform a steep pop-up manoeuvre to increase altitude abruptly for appropriate target reconnaissance, followed by a dive and roll-in toward the surface target to avoid hostile radar lock-on. When approaching the target for roll-out and level, the aircraft needed to aim at the target precisely in order

to release the bomb, and finally pull-up with a 5-5.5 G-force to break-away from the range of the target (figure 1).

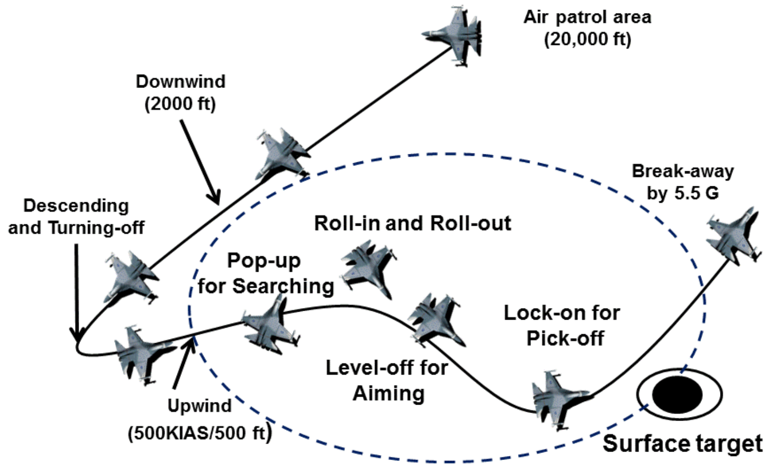

Figure 1. The critical phases of pilots' cognitive processes during an air-to-surface task

2.3 Research Design

All participants undertook the following procedures; (1) complete the demographical data including rank, age, education level, qualifications, type hours and total flight hours (5 minutes); (2) a short briefing about the purpose of research and introducing the scenario of an air-to-surface task without mentioning any target information (10 minutes); (3) participants were seated in the F-16 simulator for eye tracker calibration by using three points calibrated over the cockpit instrument display panels and the screen of image projector (10-20 minutes); (4) participants performed an air-to-surface task involving a stationary target on the ground. Simultaneously, an instructor pilot on the control console appraised participants' performance (between 1 and 50) based on the evaluation form of F-16 tactical training manual for air-to-surface (5 minutes); (5) and a debriefing and feedback to participants (5-10 minutes). It took approximately 50 minutes for each subject to complete the experiment.

3. Results

All 35 participants were qualified F-16 pilots with different levels of flight experience. The age of participants ranged between 26 and 45 years (M = 33.43, SD = 5.64). The total flying hours ranged between 372 and 3,200 hr (M = 1302.71, SD = 839.42). The type rating of F-16 flying hour were between 89 and 2,270 hr (M = 792.91, SD = 573.97). The qualifications of pilots included fourteen combat ready (40%), three two-ship leaders (8.6 %), seven four-ship leaders (20 %), and eleven instructors (31.4%). The threshold of pilots' tactical performance was defined as a rating score above 30 equating to high performance, below 30 as low performance.

Pilots' eye movement data consisted six variables of eye movement which were analyzed among five AOIs during the air-to-surface task. The distributions of gaze-points, fixations and percentage time spent in each zone were mainly on both HUD and OC, with only small amount on ICP and L/RMFD. There were significant differences of gaze-point count, $F(1.16, 39.49)=682.77$; $p=0.000$, fixation count, $F(1.40, 47.43)=601.01$; $p=0.000$, percentage time in zone, $F(1.03, 34.84)=560.62$; $p=0.000$, percentage of total fixations, $F(1.05, 35.56)=779.93$; $p=0.000$, and average fixation duration, $F(2.32, 78.80)=100.87$; $p=0.000$. For example, pilots' fixation were mainly focused on HUD (70.29%) and OC (28.47%), with only 0.96%, 0.28% and 0.08% of total fixation on ICP, LMFD and RMFD respectively. It is clear that pilots' cognitive processes and attention allocation is significantly concentrated on the HUD and OC for critical information required to complete the task compared with the other three AOIs. The longest average fixation duration of pilots is on the HUD, followed by OC, ICP, LMFD and RMFD.

Of the 35 combat-ready participants, 19 were rated as high performance and 16 were rated as low performance. Therefore, the t-test is applied to examine the differences between high performance and low performance groups for the eye movement patterns on both HUD and OC. The results show that pilots within the high performance group had significantly less gaze-points, fixation points, percentage time spent in zone, and percentage of total fixation on HUD, and have significantly more gaze-points, percentage time spent in zone and average fixation duration on OC compared with the low performance group (table 1).

Table 1: Pilots' Tactical Performance and Eye Movement Pattern between HUD and Outside of Cockpit (OC)

	AOI-1 (HUD)		**t**	**AOI-5 (OC)**		**t**
	TP＞30 (N=19)	TP≦30 (N=16)		TP＞30 (N=19)	TP≦30 (N=16)	
Gaze-point count	1079.31 (SD=176.47)	1225.53 (SD=163.39)	**-2.54***	563.25 (SD=156.46)	423.16 (SD=91.62)	**3.29****
Fixation count	55.56 (SD=9.32)	64 (SD=9.47)	**-2.65***	26.81 (SD=9.93)	22.42 (SD=6.6)	1.56
Percent time spent in zone	59.46 (SD=10.7)	69.05 (SD=8.08)	**-3.02****	39.41 (SD=10.33)	29.94 (SD=7.44)	**3.14****
Percentage of total fixations	66.71 (SD=10.33)	73.31 (SD=7.2)	**-2.22***	31.71 (SD=9.98)	25.74 (SD=7.14)	2.06
Average fixation duration (seconds)	0.54 (SD=0.1)	0.55 (SD=0.08)	-0.33	0.42 (SD=0.08)	0.36 (SD=0.07)	**2.54***

Note: 1. TP= Tactical Performance
2. p＜.05= *, p＜.01= **

4. Discussion and Conclusion

The results showed that military pilots distributed a high percentage of fixation on the HUD and outside of the cockpit. It also showed that pilots' eye movement patterns were significantly different between high performance and low performance groups (table 1). The phenomenon that high performance pilots having longer average fixation duration (420 ms vs 360 ms) on outside of cockpit (OC) compared with low performance pilots is probably due to the analyzing the target and terrain information in order to avoid CFIT. In addition, the fixation distributions and scan path of high performance pilots were more diversely spread between HUD and outside of the cockpit compared with low performance pilots who mainly focused on the HUD for an air-to-surface task. The variable of gaze-point is related to fixation, based on the definition of a fixation in the present study as three gaze points occurring within an area of 10 by 10 pixels with a dwell time of more than 200 ms (Salvucci and Goldberg, 2000). There were 1,158 and 487 gaze-points on the HUD and OC, but only 60 and 24 fixations respectively. The orders of fixations demonstrate pilots' attention distribution and scanpath (Ratwanti, McCurry, & Trafton, 2010). Figure-2 (a) demonstrated that high performance pilots do not just distribute a wider attentional field during the air-to-surface task, but also prioritize the tasks. It can be seen that number 8th and 12th fixations localized on the target. The 3rd, 6th, 8th and 12th fixations were distributed across four quadrants which revealed that pilots shifted their attention starting from the target to surrounding cues and back immediately to the HUD again. On the other hand, the pilots with low performance showed a very narrow scope of fixation distribution on the HUD only shown as figure-2 (b). Low performance pilots might focus on aiming the target by superimposed the symbol on the HUD resulting in attentional tunneling (Tsai, Viirre, Strychacz, Chase & Jung, 2007). Eye movement measures provide a valuable source of information, and parameters such as gaze-points, fixations, average fixation duration, number of fixations before first arrival, and percentage time spent in each zone to measure pilots' tactical performance. Some indicators of eye movement variables did show significant differences between high and low performance pilots.

(a) High Performance (b) Low Performance

Figure 2. Different scanpaths of pilots demonstrated a difference in tactical performance

The principle of cognitive countermeasure could explain the competition of resources related to attended visual attention between complex information present on a HUD and outside of cockpit (Wickens & Alexander, 2009). Eye movement characteristics cannot only detect differences of cognitive processes related to attentional distributions, but also can be used to identify specific system display components (e.g. data fields, text, symbols, and graphics on AOIs). By analyzing eye movement data, it is also possible to identify what the military pilot was looking at (texts, numbers, symbols or graphics) within an AOI when it happened. Furthermore, pilots' attention is likely to remain one of the critical limited resources that will be challenged by new technology. As a consequence, it is important that the nature of pilots' scanpaths and attention shifts can be modeled so as to allow the evaluation of the implications of new technology installation in the cockpit.

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