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Pilots' Visual Scan Pattern and Situation Awareness in Flight Operations

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ABSTRACT

Introduction: Situation awareness (SA) is considered an essential prerequisite for safe flying. If the impact of visual scanning pattern on a pilot's situation awareness could be identified in flight operations, then eye-tracking tools could be integrated with flight simulators to improve training efficiency. **Method:** Eighteen qualified mission-ready fighter pilots participated in this research. The equipment included high-fidelity and fixed-base type flight simulators and mobile head-mounted eye-tracking devices to record a subject's eye movements and SA whilst performing air-to-surface tasks. **Results:** There were significant differences in pilots' percentage of fixation in three operating phases including preparation (M=46.09, SD=14.79), aiming (M=24.24, SD=11.03), and release and break-away (M=33.98, SD=14.46). Also, there were significant differences in pilots' pupil sizes of which aiming phase was the largest (M=27621, SD=6390.8), followed by release and break-away (M=27173, SD=5830.46), then preparation (M=25710, SD=6078.79) was the smallest. Furthermore, pilots with better SA performance show lower perceived workload (M = 30.60, SD = 17.86), and pilots with poor SA performance show higher perceived workload (M = 60.77, SD = 12.72). Pilots' percentage of fixation and average fixation duration among five different areas of interest show significant differences as well. **Discussion:** Eye-tracking devices can aid in capturing pilots' visual scan patterns and SA performance unlike traditional flight simulators. Therefore, integrating eye-tracking devices into the simulator will be a creative method for promoting SA training in flight operations, and will provide in-depth understanding of the mechanism of visual scan patterns and information processing to improve training effectiveness in aviation.

Keywords: attention allocation, aviation safety, fixation duration, training evaluation

INTRODUCTION

Situation awareness (SA) has been highlighted as an essential prerequisite for safe flight operations. Aviation psychologists have focused on the cognitive components of SA because of the increasing demands that performing the multi-tasks in the automated cockpit place on pilots' information processing (4). Flying an aircraft is comprised of a series of cognitive processes. Pilots not only have to follow procedures to ensure appropriate monitoring, command, control and communication, but also have to problem-solve in dynamic and ambiguous situations. The information processed by pilots is mostly acquired by visual scans of the displays in the cockpit and research has shown that 75% of pilot errors result from poor perceptual encoding (12). Consequently, visual perception underpins a pilot's SA and decision-making. For example, the accident involving Flight SQ006 which occurred at Taipei Airport in 2001 largely resulted from the lack of SA by the pilots and an incursion onto a closed runway due to poor visual perception of the airport environment. SA is a key component in human information processing, and as the basis for a pilot's decision-making (23). SA ensures that dynamic changes within environment are identified by pilots. Theoretically, SA operates at three levels: the perception of the cues, the comprehension of their meaning, and the projection of their status in the near future (5).

Attention is usually allocated to the area where the eyes are focused, though Posner (18) found pilots could shift their attention without moving their eyes. Lavine et al (14) suggested that visual attention is an initial step prior to the cognitive process and that information from the visual senses is closely associated with a

pilot's attention allocation. Furthermore, as attention plays a central role in cognitive processing, eye movements may serve as a window into the visual scan pattern for acquiring SA and for reflecting the mental state of pilots. Previous studies have observed that human visual behavior is tightly linked with attention (7, 22), which is influenced by the environment in which the pilot is operating (23). It has also been proposed that more experienced pilots could apply peripheral vision to process the objects within their visual field (13, 24). Furthermore, due to the limited capacity of a human's working memory, it is necessary to focus attention on the most critical task at hand and ignore stimuli from the environment when selecting the visual channel to be attentive to (10). If a pilot distributes attention across complex interfaces of displays in the cockpit, it will severely influence his/her holistic SA performance (5). It has been observed in a previous study that pilots' experience and knowledge determine where to focus their attention and what information to acquire. Expert pilots are not only able to quickly shift attention to acquire significant information efficiently, but can also decide faster than novice pilots which are the higher priority tasks on which to focus (1, 24).

Eye movements are associated with attention allocation (8, 18). There are three states of eye movements within the human visual field in which objects can be identified with or without the need for an eye or head movement (20). One argument concerning eye movement has focused on two approaches: top-down and bottom-up visual processes. Nevertheless, eye movements can be useful cues to indicate a pilot's current cognitive state and to explore their operational behavior (7).

For instance, fixations distributed on relevant areas of interest (AOIs) can be not only appropriate indicators to evaluate a pilot's expertise level, but can also be critical elements of a pilot's SA performance (2, 19). Furthermore, the percentage of time fixating on the relevant AOIs is also an index to predict a pilot's overall SA level and error detection (15). Hence, the distribution of their fixations and visual time on interesting and informative regions is related to attention allocation; and this can support mechanisms for those factors that will be considered to help build a pilot's SA (11). On the other hand, if a pilot over-concentrates on some AOIs or information displays it can result in tunnel vision and poor SA (16). Therefore, it is necessary to observe a pilot's visual traces at the very early phases of flight training in order to correct inappropriate scan patterns to avoid loss of SA in time-limited situations.

Lack of visual attention is an indicator of missing SA, and missing SA awareness is a known contributing factor in aviation accidents (4). Pilots have to recognize and interpret the visual cues based on displays of instruments (AOIs), and predict the subsequent impacts on the task and safety in constantly changing situations (3). Those cognitive processes produce the amount of mental loading that probably affects a pilot's holistic SA of environmental cues (25). Furthermore, pupil size has been noted as one of the psychological indicators that can help to explore a pilot's mental process objectively, and pupil dilation is known to quickly respond to illumination and cognitive workload while performing a visual task (17, 21). Compared with the issues of fixation and dwell duration, pupil size has rarely been studied, probably due to the impact from multiple factors such as

cognitive workload, context complexity, environmental illumination and gaze angle. However, it has been noted as one of the psychological indicators that can help explore a pilot's mental process objectively (17). Through the combination of an eye-tracking device and flight simulator, pupil size data can be collected for further analysis of pilots' cognitive processes for attention allocation and SA performance at certain phases of flight operations. This can then be correlated with training and evaluation in the future.

Most eye-tracking experiments are performed in the laboratory and restrict subjects' head and body motion, which differs from the naturalistic setting and limits the application (6). This study uses a specific flight simulator and a portable eye-tracking device to capture the pilots' visual scan patterns and SA performance during flight operations. If the percentage of fixation, average fixation duration, pupil size and perceived workload related to SA performance could be identified in flight operation, then eye-tracking tools could be considered for use in combination with flight simulators to improve training effectiveness in the future.

METHODS

Subjects

Eighteen male military pilots who were qualified as mission-ready participated in this research. Their flying experience varied between 310 and 2,920 hours (M=851.3, SD=585.3). The ages of subjects ranged between 26 and 44 years old (M=29.7, SD=4.0). The treatment of all subjects in this study conformed to the ethical standards required by the Research Ethics Regulations of National Tsing Hua University.

Equipment

1. Flight Simulator: The research equipment was a high-fidelity and fixed-base type flight simulator. It consists of an actual cockpit with display panels, layout and controls identical to those in the actual aircraft, which is the Indigenous Defence Fighter (IDF). The simulator is equipped with a 2-D and 1:1 image screen. It has a console with three monitors to support pilots' routine flight training and combat planning.

2. Scenario of Simulator: The scenario was designed to replicate an air-to-surface task. It represented a challenging situation for subjects from hostile threats integrated with the high cognitive demand of a difficult task and uncertain levels of risk associated with an activated warning light indicating generator failure. Subjects not only had to execute tasks precisely by operating the aircraft, but also had to follow the navigation system and enter the appropriate codes by using various flight deck interfaces. Simultaneously, subjects 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 (KIAS). They then performed a steep pop-up manoeuver 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, subjects had to roll-out, level the aircraft, aim at the target, release the weapon, and finally pull-up with a 5～5.5 G-force to break-away from the range.

3. Eye Tracking Device: Pilots' eye movements were recorded using

a mobile head-mounted eye-tracker (ASL Series 4000) which is designed and built by Applied Science Laboratory. It is light (76g) and portable so it is easy for subjects to wear and allows them to move their head without any limitation during the air-to-surface manoeuvers required in the flight scenarios. Video records of the pattern of eye movements and the related data were collected and stored using a Digital Video Cassette Recorder (DVCR) and then transferred to computer for further processing and analysis. The sampling frequency for eye movements was 30 Hz. The definition of an eye fixation point was as three gaze points occurring within an area of 10 by 10 pixels with a dwell time (the time spent per glance at an instrument) of more than 200 msec. There were five AOIs set up to collect subjects' eye movement data. Those AOIs were selected after discussions with senior instructor pilots and following the requirements of the standard operating procedures (SOP) of air-to-surface training. 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. The eye movement data were collected for the critical period of time performing the air-to-surface task including preparation and planning for 30 seconds before leveling the aircraft, 10 seconds for aiming, and 20 seconds for releasing weapons to the target and breaking away. All subjects' eye movement data were analyzed for the same period of time based on those critical 60 seconds of the air-to-surface task, although subjects took between 185 and 293 seconds to complete the total task in the flight simulator.

Procedures

All subjects undertook the following procedures; (1) the subject completed the demographical data on the performance evaluation form including rank, job title, age, qualifications, type ratings and total flight hours (5 minutes to complete); (2) a short briefing explained the purposes of the study and introduced the air-to-surface scenario, without mentioning any potential aircraft equipment failure (10 minutes); (3) the subject was seated in the simulator and the eye tracker was put on for calibration by using three points distributed over the cockpit display panels and outer screen (10-15 minutes); (4) the subject performed the air-to-surface task and simultaneously the instructor at the simulator console panel was not only evaluating the subject's performance, but also recording their situational awareness by activating the 'generator malfunction light' during the highest workload phase (from roll-out to break-away). If the subject subsequently pushed the master caution light button and called 'Generator out', it was considered to indicate the subject's awareness of the potential risk and recorded as 'high SA'; if not, it was recorded as 'low SA' (3-5 minutes); (5) as soon as the subject completed the air-to-surface task, they were asked to evaluate their perceived workload by recording mental demand and perceptual activities such as thinking, decision, memory, observation and target searching for the air-to-surface task, using marks between 0 (no mental demand) and 100 (extremely high mental demand) (3-5 minutes). Approximately 40 minutes was required for each subject to complete the experiment.

RESULTS

Table I gives the data for percentage of fixation and average

fixation duration in the five AOIs for eighteen subjects. The data for SA, perceived workload, percentage of fixation and average fixation duration in three critical phases including preparation, aiming, and release and break-away are shown as Table II.

[Table I here]

The 'percentage of fixation' variable is proportional data, and it is necessary to perform an arcsine transformation (9). Therefore, the data of pilots' percentage of fixation on five AOIs, and percentage of fixations on three operating phases were transformed into arcsine values before conducting analysis of variance. There were significant differences in pilots' percentage of fixation among the five different AOIs, $F(4, 85) = 150.54$, $p<.001$, $\eta 2\rho = .90$. Further comparisons using post-hoc Bonferroni-adjusted tests showed that AOI-1 has a significantly higher percentage of fixation than AOI-2, AOI-3 and AOI-4. Similarly, AOI-5 has a significantly higher percentage of fixation than AOI-2, AOI-3 and AOI-4. There were also significant differences in pilots' average fixation duration among the five different AOIs, $F(4, 85) = 29.47$, $p<.001$, $\eta 2\rho = .63$. Further comparisons using post-hoc Bonferroni-adjusted tests showed AOI-1 has significantly higher average fixation duration than AOI-2, AOI-3 and AOI-4 and that AOI-5 also has a significantly higher average fixation duration than AOI-2, AOI-3 and AOI-4 (table I).

There were significant differences in pilots' percentage of fixation in three operating phases, $F(2, 51) = 115.44$, $p<.001$, $\eta 2\rho$

= .87. Further comparisons using post-hoc Bonferroni-adjusted tests showed that pilots' percentage of fixation in the phase of preparation was significantly higher than in aiming and in release and break-away. Also the pilots' percentage of fixation during the phase of release and break-away were significantly higher than during aiming. There were no significant differences on pilots' average fixation duration in three operating phases, $F(2, 51) = 1.25$, $p>.05$, $\eta 2\rho = .07$.

There were significant differences in pilots' pupil size across the three operating phases, $F(2, 51) = 10.07$, $p<.001$, $\eta 2\rho = .37$. Further comparisons using post-hoc Bonferroni-adjusted tests showed that pilots' pupil size during the phase of preparation were significantly smaller than during aiming and during release and break-away. Also, a negative partial correlation was observed between pilots' SA performance and perceived workload when controlling for the pilots' experience (total flight hours), $r=-.574$, $p<.05$. Pilots with better SA performance show lower perceived workload ($M = 30.60$, $SD = 17.86$); pilots with poor SA performance show higher perceived workload ($M = 60.77$, $SD = 12.72$).

[Table II here]

DISCUSSION

This research demonstrated that pilots distributed 59.92% (arcsine value=50.72) of their fixations on the HUD (AOI-1) and 39.18% (arcsine value=38.75) outside of the cockpit (AOI-5) respectively whilst performing the air-to-surface task. Also the average fixation durations on the HUD and outside of the cockpit are significantly

higher than on the ICP (AOI-2), RMFD (AOI-3) and LMFD (AOI-4). The results showed that information provided by the HUD and outside of the cockpit are the main supports for completing the task successfully (table I). This indicates a critical threshold to evaluate a military pilot's capability to capture the integrated information from these two AOIs in a time-limited tactical mission. Although pilots have to key different codes into the ICP for aiming and releasing the weapon to target, only 0.79% of fixation (arcsine value=5.09) is on the ICP. This phenomenon can be observed by analyzing eye-tracking DVCR data, which showed pilots keying the codes into ICP whilst simultaneously searching for the surface target. Each AOI provides a variety of information and, as a result, pilots have to cross-check between ICP and RMFD depending on the specific operating requirement for entering the navigation data at different stages. For performing the air-to-surface task, pilots' priority information is altitude, speed and vertical speed while the target is in sight. Because of this, pilots did not allocate their attention to the LMFD which provides radar information of distance measurement. Table I demonstrates that both the percentage of fixation and the average fixation duration on the LMFD are zero.

Searching for information and the target are the major activities involved in the pilots' attention allocation and are related to SA performance. Pilots have to be able to 'see and perceive' the information, then to 'understand' the information perceived to comprehend the situation, and to 'project' the situation in the near future (5). Pilots paid attention to the relevant instruments by shifting their fixation according to the requirements for completing

the air-to-surface task; it is a series of cognitive activities in a dynamic situation. Although there is debate concerning bottom-up or top-down visual processes in the eye-tracking literature, it is observed through this research that pilots integrated both bottom-up and top-down visual processes based on their experience or salience of information. The bottom-up eye movement is a stimulus-based visual process. The salient cues attract the pilot's gaze to pay attention to the warning light, demonstrating they applied a bottom-up visual scan at the initial stage of SA, as the pilots moved their fixation from the HUD to the activated warning light panel (WLP), reset the master caution, then returned to the HUD (figure 1). The analysis of frame-by-frame DVCR data from the eye-tracker found that pilots also frequently employed a top-down visual process in the air-to-surface task. Figure 1 could illustrate the integration of bottom-up and top-down visual processes with three-levels of SA model proposed by Endsely (4): pilots perceived the warning light (level-1); realized which system was malfunctioning (level-2); and then predicted that the malfunctioning of this system did not affect the task in hand and immediately directed their attention back to the main mission (level-3). The level-1 of SA is a bottom-up approach for perceiving the stimulus of activated warning light whilst level-2 and level-3 are top-down visual processes for understanding the stimulus by cross-checking the information from HUD, RMFD and outside the cockpit, then projecting the future situation by entering the codes to the ICP for carrying out the tactical manoeuver.

The top-down visual process indicates that the pilot recognized the subsequent engagement, and planned the tactical strategies of the

air-to-surface manoeuver by inputting navigation data into the ICP interface. The pilot has to move his fixations, shifting to the buttons of the ICP in order to guide his fingers to the specific button. When the processes of directing attention allocation are completed, the pilot relocates his fixations to the RMFD to determine if the waypoints are precisely displayed (figure 1). However, the key-in activities using peripheral vision last 2.5 seconds on average, which indicates that fixation and attention certainly aren't either overlaying at the same location nor at the same time. This finding was not consistent with previous research which proposed that when visual fixation focuses on a certain location, attention is also paid to this specific location (22). In this study, pilots have a potential of 1,800 gaze points recorded by the eye tracker at the frequency of 30 Hz lasting for 60 seconds of flight operation. However, the average number of pilot fixations was only 92 (N =18, SD =12.70). This finding supports previous research proposed by Henderson (7) that most of the gaze points are ignored due to the condition of forming a fixation. This research defines fixation as three gaze points occurring within an area of 10 by 10 pixels with a dwell time of more than 200 msec. Fixation point is meaningful and is closely linked to attention allocation and SA. However, gaze point is the foundation of fixation and it triggers pilots shifting attention to different AOIs for performing multi-tasks simultaneously, such as searching information, keying information, analyzing information, and operating the aircraft. There is a close relationship between peripheral vision and gaze points observed while pilots rapidly shift their gaze from buttons within the ICP as their fingers can precisely key-in a series of codes without

forming a fixation. Pilots didn't fixate on the buttons of ICP whilst entering a series of codes and simultaneously searching for the outside target. It is the evidence that gaze might be the precursor of fixation and enable the peripheral vision processing information promptly.

[Figure 1 here]

Pilots have large amounts of fixation on the HUD. This demonstrated a phenomenon of focusing on a particular cockpit display which might result in tunnel vision or overlooking the aircraft's dynamic status and missing the target. This is the main reason for pilots' basic flight training requiring them to level the aircraft by scanning the horizon, not by using the instruments while operating in visual flight rules (VFR). The limitation of simulator training is that the instructor cannot identify which AOIs the trainee is looking at for information. If a trainee's real-time visual scan pattern can be recorded and displayed on the control panel simultaneously for the instructor, he/she can diagnose the trainee's attention allocation and hence improve the training effectiveness in increasing a pilot's SA performance.

Under conditions of controlled illumination in the training simulator, pupil size is an effective and reliable measure of mental workload. Pupil size can reveal the condition of cognitive load, and increases in pupil size correlate with increases in mental workload (21). The findings of this research are consistent with previous research; pilots' workload at the aiming stage is the highest,

followed by the stage of release and break-away; the lowest workload is the stage of preparation during the air-to-surface task. Accordingly, Table II shows that pilots' pupil size at the phase of aiming is the largest, followed by release and break-away, and then preparation. On approaching the target, pilots have to roll-out, level off the aircraft, with only few seconds to aim at the target, release the weapon and pull-up with a 5～5.5 G-force to break-away from the range otherwise aircraft will be exposed to a hostile environment (such as anti-aircraft fire). Pilots conduct lots of tactical manoeuvers to level-off the aircraft under hostile and time-limited situations to aim at a target. If they can't be successful in aiming and locking on to the target, the mission has failed. It is for this reason that the pupil size during the stages of aiming and release and break-away was significantly larger than during the stage of preparation (figure 2).

[Figure 2 here]

Almost 72% (14) of the pilots in the study showed poor SA by failing to identify the activated generator warning light during the challenging stage of aiming the target. The understanding of SA component processes is important in understanding failures in SA (4). Component level analysis by eye-tracking tools could identify practical problems in developing SA and also analyze failures in SA in flight operations. This research found that pilots who were able to identify the activated warning light have better SA performance and show significantly lower workload (table II). It demonstrates that

pilots' SA performance is correlated with the perceived workload. To clarify the further correlation between SA performance and workload might be a necessary subject of research in the future. The analysis of pilots' responses to the warning light recorded using the eye-tracker can certainly be used to evaluate pilots' SA performance, and is also valuable for the instructor's task debriefing in order to improve training effectiveness. Also, eye movement data can be used to identify specific system display components for crucial information that might reduce a pilot's perceived workload and increase a pilot's SA performance.

Understanding a pilot's visual scan patterns for attention distribution in order to achieve a high level of SA will allow aviation professionals to move beyond the retrospective diagnosis of SA failures. The weakness of traditional simulator training is that there is no specific feedback of the trainee's visual scan pattern provided for the instructor to address the critical timing of attention distribution to achieve a high level of SA, as a trainee pilot's visual scan patterns, attention distribution and SA cannot be observed and analyzed simultaneously by instructor. Based on the results of this research, eye tracking devices can aid in capturing a pilot's attention allocation. Therefore, if the simulator is integrated with eye-tracking devices, it will be a creative method to promote SA training in flight operations, and provide an in-depth understanding of the mechanism of visual scan patterns and information processing. The limitation of current research is the small sample size of eye-tracking data which lacks the power to justify generalization of the result outside the aviation domain. There is a rising need to

conduct large scale research to investigate pilots' eye movement patterns in the cockpit in the future.

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TABLE I

Subject	Age	TH	Percentage of Fixation (arcsine values)					Average Fixation Duration (msec)				
			AOI-1	AOI-2	AOI-3	AOI-4	AOI-5	AOI-1	AOI-2	AOI-3	AOI-4	AOI-5
1	29	310	63.04	0	0	0	26.96	420	0	0	0	560
2	27	400	58.19	0	0	0	31.81	390	0	0	0	290
3	26	420	52.68	8.53	5.65	0	35.41	490	300	450	0	500
4	26	470	63.01	0	0	0	26.99	480	0	0	0	320
5	32	500	59.28	0	0	0	30.72	540	0	0	0	430
6	28	580	52.56	8.49	0	0	36.14	330	470	0	0	280
7	28	600	44.38	0	5.99	0	45.00	470	0	0	0	470
8	27	638	53.58	12.60	0	0	33.51	460	340	500	0	330
9	30	650	33.14	0	0	0	56.86	540	0	0	0	340
10	29	750	56.31	5.62	0	0	33.09	480	220	0	0	430
11	30	950	51.67	0	0	0	38.33	510	0	0	0	390
12	29	930	52.56	0	0	0	37.44	390	0	0	0	340
13	30	823	25.09	0	0	0	64.91	590	0	0	0	450
14	28	850	45.00	11.61	0	0	42.68	640	290	1340	510	360
15	29	1133	59.47	0	0	0	30.53	530	0	0	0	340
16	30	1100	28.71	0	0	0	61.29	490	0	0	0	420
17	33	1300	54.98	0	0	0	35.02	580	0	0	0	550
18	44	2920	61.79	0	0	0	28.21	490	0	0	0	310
Mean	29.7	851.3	50.72	5.09	1.94	0	38.75	490	90	130	30	400
SD	4.0	585.3	25.75	7.04	3.31	0	25.79	80	160	340	120	90

TABLE I. SUBJECTS' AGE, EXPERIENCE AND EYE MOVEMENT DATA ACROSS AOIs

TH: TOTAL HOURS; 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); AOI-5: OUTSIDE OF COCKPIT

TABLE II

Subject	SA	WL	Pupil Size ($pixel^2$)			Percentage of Fixation (arcsine values)			Average Fixation Duration (msec)		
			PRE	AIM	REL	PRE	AIM	REL	PRE	AIM	REL
1	0	50	23202	25928	25497	46.12	23.25	34.74	400	380	540
2	0	70	20936	21244	20434	45.95	24.79	33.69	390	390	330
3	0	75	30719	32432	32708	54.74	25.07	23.09	550	390	470
4	0	50	34279	38461	35492	45.80	21.99	36.02	370	510	600
5	0	70	28272	31150	30668	44.09	25.81	34.84	440	540	670
6	0	50	33065	37305	35584	47.67	19.94	35.50	320	320	340
7	0	85	19169	24697	25726	46.91	24.10	33.21	510	450	410
8	0	50	22920	24532	27408	47.21	27.19	30.18	440	390	450
9	0	60	32139	34002	32353	44.36	28.12	32.51	480	320	490
10	0	60	24664	26407	25449	47.73	21.22	34.54	490	370	460
11	0	60	23029	23243	26173	46.65	23.85	33.69	530	440	450
12	1	40	19920	22621	21864	45.28	27.24	32.31	350	440	380
13	0	70	19192	20100	19631	46.91	20.46	35.93	410	540	560
14	1	30	22426	23971	23260	37.24	29.29	38.90	560	380	700
15	0	40	34523	34680	30282	47.90	25.91	30.55	310	640	350
16	1	25	31197	32917	32773	46.69	20.06	36.45	480	370	480
17	1	50	14121	15317	14255	38.58	23.48	42.27	580	710	520
18	1	35	29006	28168	29549	49.85	22.47	31.29	450	310	510
Mean		53.89	25710	27621	27173	46.09	24.24	33.98	450	440	480
SD		16.32	6078.79	6390.80	5830.46	14.79	11.03	14.46	80	110	110

TABLE II. SA, WORKLOAD, PUPIL SIZE AND EYE MOVEMENT DATA IN THREE CRITICAL PHASES OF AIR-TO-SURFACE TASK

SA: SITUATION AWARENESS PERFORMANCE (1: HIGH; 0: LOW); WL: WORK LOAD (1: VERY LOW WORKLOAD—100: EXTREMLY HIGH WORKLOAD); PRE: PREPARATION; AIM: AIMING; REL: RELEASE AND BREAK-AWAY

FIGURE I

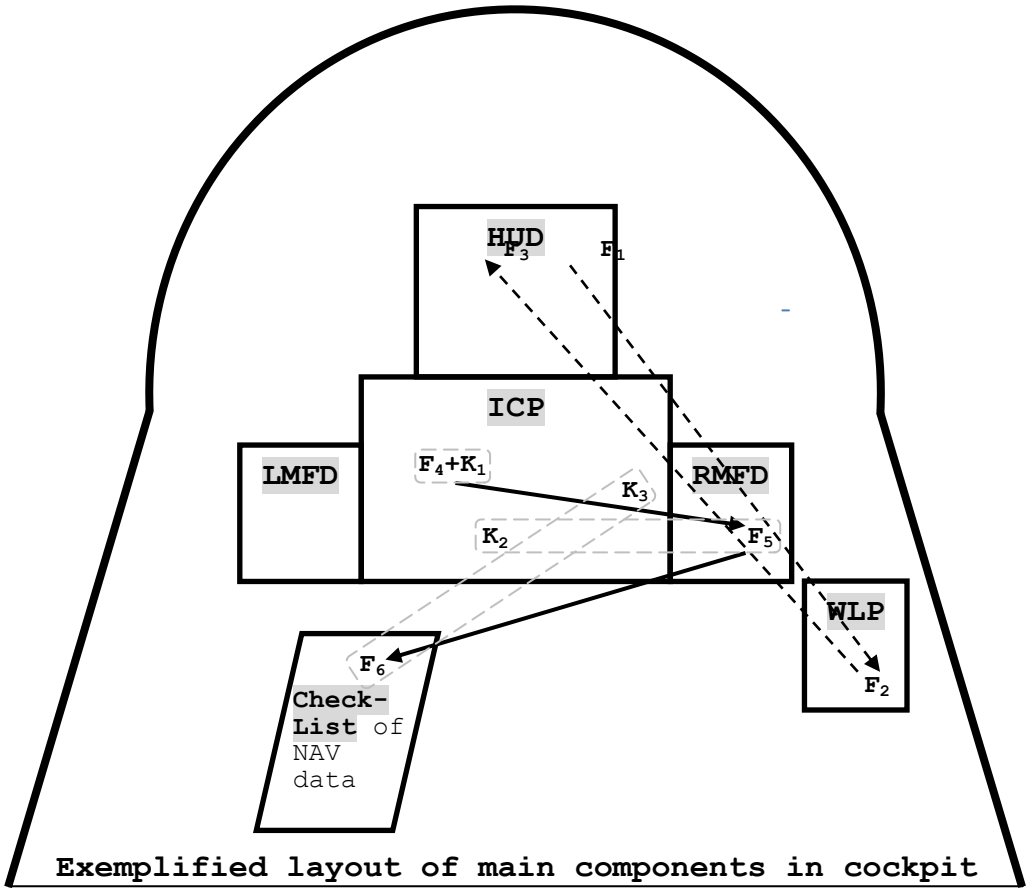


FIGURE I. ILLUSTRATED PROCESSES OF BOTTOM-UP, TOP-DOWN AND PERIPHERAL VISUAL SCAN IN FLIGHT OPERATIONS

WLP: WARNING LIGHT PANEL; F_{1-6}: LOCATIONS OF FIXATIONS; K_{1-3}: THE BUTTON POSITIONS KEYING IN NAVIGATION DATA WITH LEFT FINGERS.

- - - → : BOTTOM-UP VISUAL BEHAVIOR (FROM F_1 TO F_2, THEN F_2 TO F_3)

——→ : TOP-DOWN VISUAL BEHAVIOR (FROM F_4+K_1 TO F_5, THEN F_5 TO F_6)

: FIXATE AND KEY-IN DATA SIMULTANEOUSLY BUT DIFFERENT LOCATIONS (F_5 & K_2 OCCURRED SIMULTANEOUSLY, THEN F_6 & K_3 OCCURRED SIMULTANEOUSLY)

FIGURE II

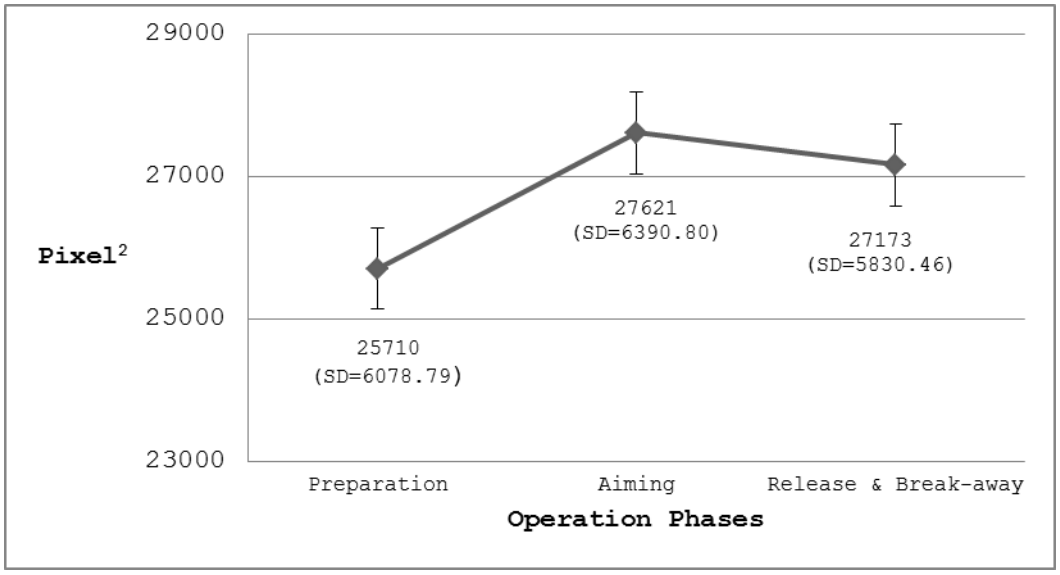


FIGURE II. PUPIL SIZES AT THREE OPERATIONAL STAGES IN AIR-TO-SURFACE TASK (N=18)

Footnote 1

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