

**Pilot's Attention Distributions between Chasing a Moving Target and
a Stationary Target**

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1 **ABSTRACT**

2 **Introduction:** Attention plays a central role in cognitive processing;
3 ineffective attention may induce accidents in flight operations. The
4 objective of current research was to examine military pilots'
5 attention distributions between chasing a moving target and a
6 stationary target. **Method:** Thirty-seven mission-ready F-16 pilots
7 participated in the current research. Subjects' eye movements were
8 collected by a portable head-mounted eye-tracker during tactical
9 training in a flight simulator. The scenarios of chasing a moving
10 target (air-to-air) and a stationary target (air-to-surface) consist
11 of three operational phases; searching, aiming and lock-on to the
12 targets. **Results:** The findings demonstrated significant differences
13 in pilots' percentage of fixation during searching phase between
14 air-to-air ($M=37.57$, $SD=5.72$) and air-to-surface ($M=33.54$, $SD=4.68$).
15 Fixation duration can indicate pilots' sustained attention to the
16 trajectory of a dynamic target during dog-fight manoeuvres. Aiming
17 for the stationary target with larger pupil size ($M=27105 \text{ pixel}^2$,
18 $SD=6565 \text{ pixel}^2$) reflects higher cognitive loading than aiming to the
19 dynamic target ($M=23864 \text{ pixel}^2$, $SD=8762 \text{ pixel}^2$). **Discussion:** Pilots'
20 visual behavior is not only closely related to attention distribution,
21 but also significantly associated with task characteristics. Military
22 pilots demonstrated various visual scan patterns for searching and
23 aiming to different types of targets based on the research settings
24 of flight simulator. The findings would facilitate system designers'
25 understandings of military pilots' cognitive processes during
26 tactical operations. It will assist human-centered interface design
27 to improve pilots' situational awareness. The application of an
28 eye-tracking device integrated with a flight simulator is a feasible
29 and cost-effective intervention to improve efficiency and safety of
30 tactical training.

31
32 **Keywords:** attentional processes; eye movements; mental workload;
33 simulation and training; situation awareness

1 INTRODUCTION

2 Pilots have to process information based on interior cockpit
3 indicators and the exterior environmental stimuli by visual search
4 during flight operations. Compared with commercial flight, exterior
5 stimuli for military pilots also include either the moving target of
6 a foe or a stationary surface target. Lavine, Sibert, Gokturk, and
7 Dickens (12) suggest that visual attention is a precursor to initiate
8 the cognitive process and information acquired from pilot's visual
9 scan is closely associated with a pilot's attention allocation.
10 Ineffective attention distribution may induce accidents (e.g., Asiana
11 Airlines Flight 214 which crashed on final approach), as pilots' lack
12 of situation awareness to the airspeed indicator was a critical human
13 factors issue in the accident (17). Attention plays a central role
14 in cognitive processing. How and where pilots distribute attention
15 is critical to the quality of situational awareness (SA) and links
16 to the features of individual's expectations (7). Therefore, eye
17 movements may serve as a window to illustrate pilots' attention
18 distribution and mental state during flight operations (13). The
19 pattern of pilots' eye movement is one of the methods for assessing
20 pilots' cognitive processes, based on real-time physiological
21 measures (1). Therefore, pilots' visual behaviors are indicators to
22 reveal attentional distributions during flight operations (9, 21).

23 Fixation is defined typically as the eye movement pausing over
24 informative regions of interest. Human beings usually retain
25 fixations on the objects to acquire the most essential information
26 to support the task in hand (21). The patterns of fixations on the
27 indicators or the areas of interest (AOIs) can reveal a pilot's visual

1 trajectory of attention (23). Moreover, the percentage of fixations
2 on the relevant AOIs is deemed as the predictor of the overall SA
3 performance (15). In addition, the length of fixation duration is the
4 total time fixating on an AOI, which can reflect the level of
5 importance or difficulty in extracting information (2). Fixation
6 duration might reveal how long pilots sustain attention whilst
7 scanning the visual fields in order to complete the mission. On the
8 other side, fixation duration might be an index of cognitive capture
9 or over-concentration on a specific indicator, which will slow down
10 attention shifts to the tactical situation (7).

11 Pupil dilation is known to quickly respond to changes in the
12 illumination in the visual field and to a human being's perceived
13 workload while performing a visual task. Under controlled
14 illumination, the pupil size is an effective and reliable indicator
15 of mental workload. The increasing in pupil size is correlated with
16 the increasing in mental workload (6). Attention is critical to pilots
17 filtering the stimuli to the perceptual system. However, workload
18 usually has negative impacts to the effectiveness of visual attention
19 (14). The increasing pupil size is a physical feature of cognitive
20 load (19), as it can be an important indicator of a pilot's cognitive
21 process and visual attention (23).

22 Saccadic eye movements are controlled by top-down visual processes,
23 which are coordinated closely with perceptual attention (24). It
24 indicates that saccadic paths are intentional and meaningful based
25 on the requirements of the task in hand and the trajectory prediction
26 in the near future (11). Therefore, the path of saccades is associated
27 with selective attention and accurate judgments for perceptual

1 targets (4, 16). Saccade duration is the total time taken to make a
2 saccade, which is recognized as one of indexes to assess operator's
3 workload; e.g., increase in workload has been found to decrease
4 saccade duration (20). Saccade velocity is how fast the eyes move
5 between fixations, which are associated with rapid deployment of
6 attention. Thus saccades might be an effective indicator of attention
7 distribution.

8 The information provided in the cockpit is mostly acquired by
9 pilots' visual scans among cockpit interfaces, and previous research
10 has shown that 75% of pilot errors result from poor perceptual encoding
11 (3, 8). It highlights the importance of the interactions between
12 pilots' visual scan and the characteristics of cockpit interface
13 design. It is obviously that attention is a critical precursor to
14 in-flight SA performance and decision-making (18). Eye tracking has
15 been gaining in popularity over the past decade as a window into
16 participants' visual and cognitive processes. Therefore, analysis
17 metrics of current research include five parameters of visual behavior:
18 the percentage of fixations, fixation duration, pupil size, saccade
19 duration, and saccade velocity among three operational phases
20 composed with searching for visual contact with a target, aiming at
21 a target, and lock-on for pick-off (press the trigger to launch weapon)
22 between air-to-air for a moving target and air-to-surface for a
23 stationary target. Based on the above literature review, there are
24 four fundamental hypotheses will be investigated as followings:
25 (1) there is no significant difference in pilots' fixation duration
26 between chasing a moving target and a stationary target; (2) there
27 is no significant differences in pilots' fixation duration among three

operational stages; (3) there is no significant difference on pilots' pupil dilation between chasing a moving target and a stationary target; (4) there is no significant differences on pilots' saccade velocity among three operational stages.

METHODS

Aims

The research aims were (1) to investigate pilots' visual characteristics between pursuing a moving and a stationary target; (2) to explore pilots' eye movement patterns and attention distributions on three operational stages, searching, aiming and lock-on a target; (3) to evaluate pilots' pupil dilation and cognitive process on three operational stages between the pursuit of a moving and a stationary target; and (4) to apply the findings to benefit military pilot training and cockpit interface design.

Subjects

A total of thirty-seven qualified mission-ready F-16 pilots participated in this research. The subjects' flying experience varied between 372 and 3,200 hours ($M=1280$, $SD=769$). The ages ranged between 26 and 45 years old ($M=33$, $SD=5$). All of the subjects were male volunteers and informed that they had the right to cease the experiments and withdraw information they provided without any reason. Subjects signed an informed consent form and reported normal levels of visual function. The treatment of all subjects complied with the ethical standards required by the Research Ethics Regulations of Cranfield University.

1

2 *Equipment*

3 *Flight Simulator:* The flight simulator used in the experiment is
4 a formal F-16 trainer. It is a high-fidelity and fixed-base type flight
5 simulator. It consists of identical cockpit displays to those in the
6 actual aircraft to supports pilots' routine flight training and combat
7 planning. It is integrated with high-definition databases, image
8 generation systems and physics-based processing technology which
9 enable pilots to detect, judge the orientation of, recognize and
10 identify targets as they would in the real world of tactical
11 operations. The instructor can install scenarios and observe the
12 trainee pilot's performance via a console with three monitors.

13 *Eye Tracking Device:* Pilots' eye movement data were collected by
14 a mobile head-mounted eye-tracker which is designed by Applied Science
15 Laboratory (ASL Series 4000). It is portable and light (76 g) so
16 participants can move their head without any limitations. The sampling
17 frequency of this type of eye-tracker is 30 Hz. Video recordings of
18 eye movements and the related data were collected and stored using
19 a Digital Video Cassette Recorder (DVCR) and then transferred to a
20 computer for further analysis. The definition of an eye fixation in
21 the present study was as three gaze points occurred within an area
22 of 10 by 10 pixels with a dwell time more than 200 msec (21).

23

24 *Scenarios*

25 *Air-to-Air Task for Pursuing a Moving Target:* The scenario-1 is
26 an air-to-air (A-A) manoeuver to pursue a dynamic target. The altitude
27 of the interceptor (participant) at the patrol area was 20,000 feet

1 with a cruise speed of 300 knots indicated airspeed (KIAS). The heading
2 was 050° under the weather conditions of 7-mile visibility and
3 scattered clouds. A foe unexpectedly appears at the same altitude as
4 the target moving from left to right with heading of 090° and air speed
5 of 300 KIAS. The participants have to search the airspace for the
6 target, and intercept the target immediately by tactical manoeuvres.
7 At the same time, the target would change its heading, altitude and
8 speed in order to escape from the interceptor's pursuit (figure 1a).

9
10 [Figure 1 here]

11
12 *Air-to-Surface Task for Aiming at a Stationary Target:* The
13 scenario-2 is an air-to-surface (A-S) manoeuvre to pursue a stationary
14 target. Participants were dispatched unexpectedly to attack one
15 stationary target, where they not only needed to execute tasks
16 precisely by operating the aircraft, but also to follow the navigation
17 system, entering appropriate codes by using various cockpit
18 interfaces. Participants had to intercept the proper route and turn
19 toward the target at an altitude of 500 feet with a speed of 500 KIAS
20 simultaneously, then performed a steep pop-up manoeuvre to increase
21 altitude abruptly for appropriate target reconnaissance, followed by
22 a dive and roll-in toward the surface target to avoid hostile radar
23 lock-on. When approaching the target, participants have to roll-out,
24 level the aircraft, aim at the target, lock-on and pick-off the target
25 (figure 1b).

26
27 *Research Design*

1 *Procedures:* All participants undertook the following procedures;
2 (1) complete the demographical data including rank, job title, age,
3 education level, qualifications, type hours and total flight hours
4 (5 minutes); (2) a short briefing explaining the purpose of the study
5 and the introduction of the air-to-air and air-to-surface scenarios
6 without mentioning any potential aircraft equipment failure (20
7 minutes); (3) participants were seated in the F-16 simulator and then
8 the eye-tracker was put on for calibration using three points
9 distributed over the cockpit display panels and outer screen (15-25
10 minutes); (4) perform the air-to-air task for aiming at a dynamic
11 target (5 minutes); (5) perform air-to-surface task for aiming at a
12 stationary target on the ground (5 minutes); simultaneously the
13 instructor pilot in the simulator console evaluated participants'
14 performance. It took around 60 minutes for each participant to
15 complete the experiments.

16 *Analysis of Eye Movements Data:* The eye movement data of both
17 air-to-air and air-to-surface tasks in this study were analyzed by
18 three phases of visual behavior during tactical operations: searching
19 for the target with eye contact (Searching), pursuing the target for
20 aiming (Aiming), and lock-on to the target for pick-off (Lock-on).
21 The length of time for analyzing each operational phase was 6 seconds
22 (18 seconds in total for three phases). It was grounded by the
23 consensus of experienced instructor pilots based on the most critical
24 decisive time to process tactical information during performing both
25 air-to-air and air-to-surface tasks. The variables of eye movement
26 data were analyzed by percentage of fixation, fixation duration, pupil
27 size, saccade duration and saccade velocity.

1

2 **RESULTS**

3 The demographical information of participants' age, rank,
4 qualification and total flight hours are shown as table I. As
5 percentage of fixation is proportional data, it is necessary to
6 perform an arcsine transformation in advance to enable further
7 statistical analysis (5). Based on the research design of current
8 study, a paired T-test and ANOVA were applied to analyze the
9 differences of eye movement data between air-to-air and
10 air-to-surface during three operational phases of searching, aiming
11 and lock-on (dependent variables). The analysis for this study is a
12 within subjects test, as all participants were performing both
13 tactical tasks of aiming at a dynamic target (air-to-air) and a
14 stationary target (air-to-surface).

15

16 [Table I here]

17

18 There were five dependent variables related to pilots' eye movement
19 characteristics between air-to-air and air-to-surface tasks among
20 three operational phases, which are fixations/ percentage of fixation,
21 fixation duration, pupil size, saccade duration, and saccade velocity.
22 The results demonstrated that there were significant differences in
23 pilots' fixations ($t=-2.52$, $p<.05$, $d=-.624$) and fixation duration
24 ($t=3.26$, $p<.005$, $d=.748$) between air-to-air and air-to-surface task.
25 Therefore, the null hypothesis 'there is no significant differences
26 on pilots' fixation duration between chasing a moving target and a
27 stationary target' was rejected. Also, there were significant

differences in pilots' saccade duration between the two tasks, $t=-2.30$, $p<.05$, $d=-.372$. However, there were no significant differences in pilots' pupil size ($t=-1.92$, $p>.05$, $d=-.252$) and saccade velocity ($t=-1.31$, $p>.05$, $d=-.214$) between two tasks (table II).

[Table II here]

Significant differences among three operational phases were observed in terms of percentage of fixation during air-to-air, $F(2, 36) = 5.75$, $p<.01$, $\eta^2p = .138$, and air-to-surface, $F(2, 36) = 6.29$, $p<.01$, $\eta^2p = .149$. Further comparisons by post-hoc Bonferroni adjusted tests showed that during air-to-air task, searching (37.57) has a higher percentage of fixations than aiming (35.11), and lock-on (32.94); the highest percentage of fixations was occurred at aiming phase during air-to-surface. There were significant differences in pilots' fixation duration among three operational phases at air-to-air, $F(2, 36) = 5.39$, $p<.01$, $\eta^2p = .130$, and also at air-to-surface, $F(2, 36) = 18.48$, $p<.001$, $\eta^2p = .339$. Further comparisons by post-hoc Bonferroni adjusted tests showed that lock-on (938 msec) has significantly longer fixation duration than aiming (702 msec) and searching (612 msec) during air-to-air task; the patterns showed at air-to-surface was same as air-to-air, lock-on the longest fixation duration (580 msec), then aiming (462 msec) and searching (332 msec) (table III). Therefore, the null hypothesis 'there is no significant differences on pilots' fixation duration among three operational stages' was rejected.

[Table III here]

1
 2 There were significant differences in pilots' pupil dilation among
 3 three phases during air-to-air, $F(2, 36) = 7.57, p < .01, \eta^2_p = .174$,
 4 and air-to-surface, $F(2, 36) = 38.82, p < .001, \eta^2_p = .519$. Further
 5 comparisons by post-hoc Bonferroni adjusted tests showed that pilots'
 6 largest pupil size at air-to-air was in the phase of lock-on (26147
 7 pixel²); the largest one at air-to-surface was occurred in aiming
 8 (27105 pixel²). Therefore, the null hypothesis 'there is no
 9 significant differences on pilots' pupil dilation between chasing a
 10 moving target and a stationary target' was rejected.

11 There were significant differences in pilots' saccade velocity
 12 among the three phases during air-to-surface tasks, $F(2, 36) = 7.87$,
 13 $p < .01, \eta^2_p = .179$. Further comparisons by post-hoc Bonferroni adjusted
 14 tests showed that pilots' saccade velocity during air-to-surface task
 15 at the phase of lock-on (1148 pixels/sec) was significantly longer
 16 than at aiming (1045 pixels/sec) and at searching (829 pixels/sec).
 17 However, there were no significant differences in pilots' saccade
 18 velocity among three phases during air-to-air task, $F(2, 36) = .68$,
 19 $p > .05, \eta^2_p = .019$ (table III). Therefore, the null hypothesis 'there
 20 is no significant differences on pilots' saccade velocity among three
 21 operational stages' was partially rejected.

22

23 **DISCUSSION**

24 The characteristics of the air-to-air task in current study are
 25 engaging a dynamic target by visual searching to aim and lock-on the
 26 moving target. On the other hand of air-to-surface, pilots have to
 27 perform a steep pop-up manoeuvre to search for the target, followed

1 by a rapid dive and roll-in to aim and lock-on the stationary target.
2 The results showed the significant differences in pilots' fixations
3 and fixation duration between the pursuit of a moving and a stationary
4 target (table II). Pilots did demonstrate different patterns of
5 fixations and fixation duration between chasing a moving target and
6 stationary target. Furthermore, pilot's in-flight cognitive process
7 is extremely dynamic, which needs to be explored by the contexts of
8 operational environment.

9 Two different tactical tasks in current study are composed with
10 three operational phases; each phase has specific tactical
11 requirements and threats. Table III shows pilots distributed the
12 highest percentage of fixations on aiming at the surface target (37.62
13 arcsine values). It reflects the tactical standard operating
14 procedures that pilots have to precisely aim at the surface target
15 within the time frame (between 3-5 seconds), otherwise the mission
16 would be aborted. On the other side, searching a moving target at
17 air-to-air task represents the highest percentage of fixations (37.57
18 arcsine values), which demonstrates that the uncertain trajectory of
19 a moving target might increase pilots' cognitive load in searching
20 for the unknown airborne target.

21 Pilots' fixation duration during the air-to-air task was
22 significantly longer than the air-to-surface task across all phases
23 (table III). It might indicate that pilots have to sustain substantial
24 attention to avoid missing the trajectory of a dynamic target during
25 the high kinetic manoeuvres. Especially the interval (236 msec) from
26 aiming to lock-on, pilots' fixation duration increased 2.6 times
27 compared to the interval from searching to aiming (90 msec). It reveals

1 that pilots have to keep tracking and precisely project the target's
2 probable trajectory movement in the vast airspace while aiming and
3 locking-on a dynamic target.

4
5 [Figure 2 here]

6
7 Figure 2 indicates that pilots' pupil size in the phase of lock-on
8 ($26,147 \text{ pixel}^2$) is the greatest at the pursuit of a moving target. Also,
9 the tendency of increasing pupil dilation along task performance might
10 reveal pilots' increasing cognitive load from searching to lock-on.
11 However, the pupil size at the pursuit of a stationary target is
12 averagely greater than at the moving target. Figure 2 also shows the
13 greatest pupil size was occurred at the aiming phase. The results did
14 reveal there are significant differences on pilots' pupil dilation
15 among three operational stages. Also, the increasing in pupil dilation
16 from searching to aiming during the air-to-surface ($3,108 \text{ pixel}^2$) is
17 significantly greater than air-to-air ($1,904 \text{ pixel}^2$). It shows that
18 pilots might have tremendous cognitive workload during the
19 air-to-surface task compared with air-to-air. The findings are
20 constructive to comprehend pilots' cognitive processes regarding the
21 aspect of workload objectively while chasing a stationary target with
22 potential accident of control flight into terrain (CFIT) (10).

23
24 [Figure 3 here]

25
26 The significant difference in pilots' saccade duration was
27 observed between the air-to-air and air-to-surface tasks (table II).

1 Figure 3 reveals that pilots significantly decreased time to make a
2 saccade while searching a dynamic target (239 msec) than searching
3 for a stationary target (457 msec). It illustrated that pilots shifted
4 attention with shorter time to search for an almost unknown and moving
5 target than for a stationary target with awareness of approximate
6 location. As a result, the level of knowledge of the target influences
7 pilot's saccade duration. In addition, the saccadic duration is
8 accompanied by a shift of attention to the selected target (11).
9 Searching for the stationary surface target seems to reflect higher
10 cognitive load than searching for the dynamic target (20). Pilots
11 operating fighter aircraft towards a surface target must fly so
12 precisely in order to avoid the accident of CFIT. Simultaneously, they
13 also have to be aware of hostile threats while assessing appropriate
14 timing for lock-on and pick-off. It was found that the decreasing rate
15 at saccade duration from searching to aiming during the air-to-surface
16 task is 55.36% (figure 3).

17

18 [Figure 4 here]

19

20 There was no significant difference between two tasks although
21 table II reveals average saccade velocity at the pursuit of a
22 stationary target (1007 pixels/ sec) is faster than the pursuit of
23 a moving target (948 pixels/ sec). However, there were significant
24 differences among three phases during the air-to-surface task (table
25 III). Figure 4 reveals the fastest saccade velocity was occurred at
26 the lock-on phase (1148 pixels/sec). In contrast, the slowest saccade
27 velocity is at the searching phase (829 pixels/sec) which is the stage

1 of collecting relevant navigation and target information for further
2 operations. Processing massive amounts of information inducing high
3 cognitive load might be the reason to make the searching phase
4 demonstrating the slowest saccade velocity and the longest saccade
5 duration. In addition, the fastest saccade velocity reveals the
6 lock-on phase requiring quick attention shifts to enhance situational
7 awareness as flying at extreme low altitude for air-to-surface task.
8 The findings of saccade duration and saccade velocity reveal pilots'
9 top-down visual scan patterns in tactical operations based on pilots'
10 expectations (projection of the course of action) associated with
11 specific objectives which are matched with the previous research (4,
12 22).

13

14 **CONCLUSION**

15 Current research found that pilots would apply different
16 approaches of visual scan patterns for searching and lock-on to
17 different types of targets. Eye tracking devices can aid in capturing
18 a pilot's attention allocation where traditional flight simulators
19 training were lacking. Additionally, the analysis of eye movement
20 parameters in real-time tactical manoeuvres could provide system
21 designers with a better understanding of the tendency of pilots'
22 cognitive process to optimize interface design and alleviate pilots'
23 workload. The findings of current research also could facilitate the
24 development of tactical training syllabi for air-to-air and
25 air-to-surface tasks to improve pilots' attention distribution and
26 situational awareness. However, the present findings were based on
27 experiments conducted in a ground-based flight simulator. In order

1 to reflect military pilots' in-flight cognitive process, next step
2 is to develop a cockpit eye tracker to further study pilots' eye
3 movement patterns and attention distributions in real tactical
4 operations.

5

6

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1 **TABLE I**

Variables	Groups	Frequencies
Age	25-30	13 (35.1%)
	31-35	11 (29.7%)
	36-40	7 (18.9%)
	41-45	6 (16.2%)
Rank	Lieutenant	1 (2.7%)
	Captain	16 (43.2%)
	Major	9 (24.3%)
	Lieutenant Colonel	10 (27%)
	Colonel Above	1 (2.7%)
Qualification	Combat ready	13 (35.1%)
	Two fighter team leader	4 (10.8%)
	Four fighter team leader	9 (24.3%)
	Daytime back seat instructor	2 (5.4%)
	Training instructor	9 (24.3%)
Total Flight Hours	500 and less	3 (8.1%)
	501-1000	13 (35.1%)
	1001-1500	11 (29.7%)
	1501-2000	4 (10.8%)
	2001 and above	6 (16.2%)

2
3 **TABLE I. SUBJECTS' DEMOGRAPHIC VARIABLES.**

1 **TABLE II**

Variables	Tasks	M	SD	N	<i>T-Test</i>				
					<i>t</i>	<i>df</i>	<i>p</i>	<i>SE</i>	<i>Cohen's d</i>
Fixations	AA	8.0	2.2	37	-2.521	36	.016	0.44	-0.624
	AS	9.2	1.6						
Fixation duration (msec)	AA	751	543	37	3.263	36	.002	89.67	0.748
	AS	458	111						
Pupil size (pixel ²)	AA	23990	7703	37	-1.922	36	.063	913.33	-0.252
	AS	25746	6173						
Saccade duration (msec)	AA	196	215	37	-2.297	36	.028	30.82	-0.372
	AS	267	163						
Saccade velocity (pixels/sec)	AA	948	319	37	-1.308	36	.199	45.60	-0.214
	AS	1007	224						

2
3 **TABLE II. T-TEST of EYE MOVEMENT VARIABLES between AIR-to-AIR (AA)**
4 **and AIR-to-SURFACE (AS) .**
5

1 **TABLE III**

Variables	Tasks	Phases	<i>M</i>	<i>SD</i>	<i>df</i>	<i>F</i>	<i>p</i>	$\eta^2\rho$
Percentage of fixations (arcsine values)	AA	S	37.57	5.72				
		A	35.11	2.96	36	5.75	.005	.138
		L	32.94	5.37				
	AS	S	33.54	4.68				
		A	37.62	3.93	36	6.29	.003	.149
		L	34.23	4.35				
Fixation duration (msec)	AA	S	612	487				
		A	702	515	36	5.39	.007	.130
		L	938	881				
	AS	S	332	71				
		A	462	145	36	18.48	.000	.339
		L	580	270				
Pupil size (pixel ²)	AA	S	21960	10132				
		A	23864	8762	36	7.57	.001	.174
		L	26147	6449				
	AS	S	23997	6180				
		A	27105	6565	36	38.82	.000	.519
		L	26136	6152				
Saccade duration (msec)	AA	S	239	332				
		A	167	188	36	1.34	.269	.036
		L	183	270				
	AS	S	457	288				
		A	204	198	36	29.06	.000	.447
		L	141	170				
Saccade velocity (pixels/sec)	AA	S	970	438				
		A	983	438	36	0.68	.510	.019
		L	891	437				
	AS	S	829	368				
		A	1045	328	36	7.87	.001	.179
		L	1148	394				

2
3 **TABLE III. ANOVA of EYE MOVEMENTS at THREE OPERATIONAL PHASES:**
4 **SEARCHING (S), AIMING (A) and LOCK-ON (L) during the TASKS of**
5 **AIR-to-AIR (AA) and AIR-to-SURFACE (AS).**
6
7
8

FIGURE 1

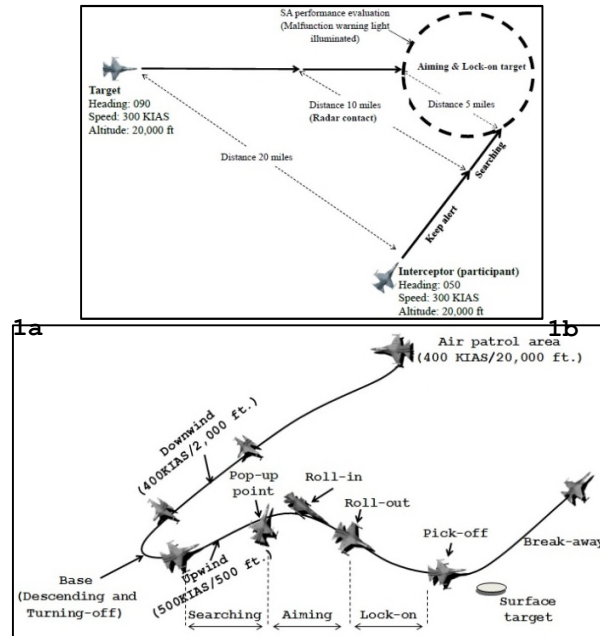


FIGURE 1. ILLUSTRATIONS of AIR-to-AIR (1a) and AIR-to-SURFACE (1b) TASKS

FIGURE 2

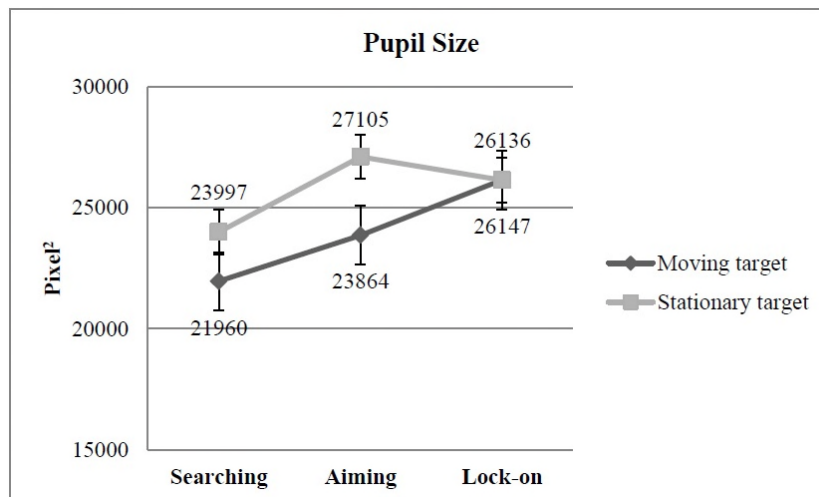
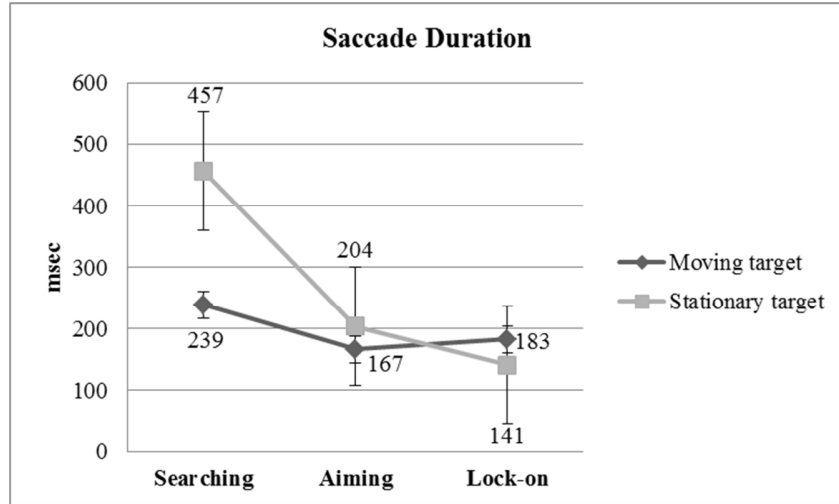
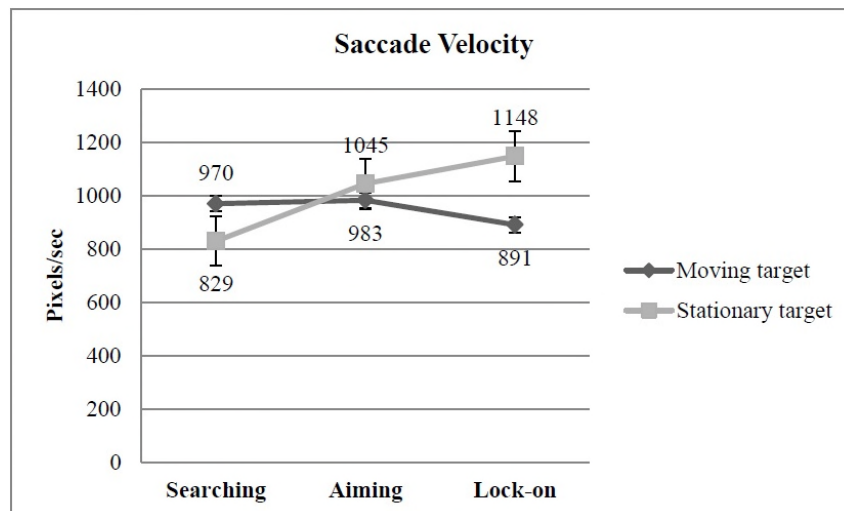


FIGURE 2. PILOTS' PUPIL DILATION among THREE OPERATIONAL PHASES WHILE PURSUING a MOVING TARGET and STATIONARY TARGET. THE BIGGEST PUPIL DILATION IS DURING the AIMING PHASE WHEN PURSUING a STATIONARY TARGET INDICATED the HIGHEST WORKLOAD.

1 **FIGURE 3**

2
3 **FIGURE 3. PILOTS' SACCADe DURATION at THREE OPERATIONAL PHASES WHILE**
4 **PURSUING the MOVING TARGET and the STATIONARY TARGET. SEARCHING PHASE**
5 **SHOWS the LONGEST SACCADe DURATION for BOTH TASKS, and PURSUING**
6 **STATIONARY TARGET DEMOSTRATED SIGNIFICANT LONGER SACCADe DURATION**
7 **THAN MOVING TARGET at SEARCHING PHASE.**

10 **FIGURE 4**

11
12 **FIGURE 4. PILOTS' SACCADe VELOCITY at THREE OPERATIONAL PHASES WHILE**
13 **PURSUING the MOVING TARGET and the STATIONARY TARGET. THE FASTEST**
14 **SACCADe VELOCITY OCCURS at the LOCK-ON PHASE on PURSUING a STATIONARY**
15 **TARGET. IT IS SIGNIFICANTLY FASTER THAN PURSUING a MOVING TARGET.**

16



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Aerospace Medical Association

<https://dspace.lib.cranfield.ac.uk/handle/1826/10704>

Wen-Chin Li, Chung-San Yu, Graham Braithwaite and Matthew Greaves. Pilot's attention distributions between chasing a moving target and a stationary target. *Aerospace Medicine and Human Performance*, Volume 87, Number 12, December 2016, pp989-995