AFRL-RH-WP-TR-2010-0009

An Examination of SAR Image Interpretation Aids: Magnification and an Information Window

Pe'erly Setter
Hadas Marciano
Maya Lipkin-Goldberg
Joel Norman

Ergonomics and Human Factors Unit
Institute of Information Processing
and Decision Making
University of Haifa
Haifa Israel

January 2008

Interim Report for February 2007 to January 2008

Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Cognitive Systems Branch
Wright-Patterson AFB OH 45433-7022

NOTICE

Using Government drawings, specifications, or other data included in this document for any purpose other than Government procurement does not in any way obligate the U.S. Government. The fact that the Government formulated or supplied the drawings, specifications, or other data does not license the holder or any other person or corporation; or convey any rights or permission to manufacture, use, or sell any patented invention that may relate to them.

This report was cleared for public release by the 88th Air Base Wing Public Affairs Office and is available to the general public, including foreign nationals. Copies may be obtained from the Defense Technical Information Center (DTIC) (http://www.dtic.mil).

AFRL-RH-WP-TR-2010-0009 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

//SIGNED//
GILBERT G. KUPERMAN
Work Unit Manager
Cognitive Systems Branch

//SIGNED//
DANIEL G. GODDARD
Chief, Warfighter Interface Division
Human Effectiveness Directorate
Air Force Research Laboratory

This report is published in the interest of scientific and technical information exchange, and its publication does not constitute the Government's approval or disapproval of its ideas or findings.

REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
January 2008	Interim	February 2007 – January 2008

4. TITLE AND SUBTITLE

An Examination of SAR Image Interpretation Aids: Magnification and an Information Window

5a. CONTRACT NUMBER
FA8650-04-D-6405

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62202F

6. AUTHOR(S)
Pe'erly Setter, Hadas Marciano, Maya Lipkin-Goldberg, Joel Norman

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
7184X03C

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Ergonomics and Human Factors Unit
Institute of Information Processing and Decision Making
University of Haifa
Haifa Israel

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Materiel Command
Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Cognitive Systems Branch
Wright-Patterson AFB OH 45433-7022

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/RHCS

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

AFRL-RH-WP-TR-2010-0009

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

88 ABW/PA cleared on 17Mar10, 88ABW-2010-1246.

14. ABSTRACT

This study examined the image interpretation performance of Synthetic Aperture Radar (SAR) imagery analysts on images that contained Assisted Target Recognition (ATR) designations. The purposes of the study were: 1) to compare the performance of the analysts using one of two magnification methods, a moving magnifier (simulated magnifying glass), or a magnification window at the side of the display; 2) to examine the benefit of adding an information window at the side of the display which included an optical image, a SAR image, and sketches of the vehicles used in the study. These two purposes were combined in the study's design. The design consisted of two parts: in the first part, 25 analysts interpreted 72 images; and in the second part, the eye-movements of 9 analysts were monitored as they carried out the same task.

15. SUBJECT TERMS Synthetic Aperture Radar (SAR), Assisted Target Recognition (ATR), Eye Tracker, Ancillary Data

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Gilbert G. Kuperman
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	SAR	42	**19b. TELEPHONE NUMBER** *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED			

i

THIS PAGE LEFT INTENTIONALLY BLANK

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

THIS PAGE LEFT INTENTIONALLY BLANK

Executive Summary

Synthetic Aperture Radar (SAR) is an important means of acquiring information from afar. Flown by plane or satellite it simulates a huge radar antenna and yields many advantages, but it also raises certain problems. One of these occurs when analysts attempt to interpret the SAR images. In order to provide the analyst with an image that presents a larger general picture, the scale is decreased and the targets appear quite small. To overcome this difficulty it is necessary to magnify parts of the image to allow the examination of suspected targets. This magnification can be implemented in several ways.

Research on such computerized magnifications has yielded inconsistent results as to which method of magnification is superior. One method of magnification presents two separate images in windows next to each other. One window displays the entire image, while the second window displays relevant details. Parameters that vary are the exact size and placement of the windows. An alternative method utilizes a digital simulation of a magnifying glass that appears over and within the borders of the original image. The area of magnification is controlled by the computer mouse and covers the area of interest of the analyst.

Automatic Target Recognition (ATR) utilizes computer algorithms to try and recognize targets in images obtained from a variety of sensors. One of the possible advantages of ATR is that it might lighten the load of the analysts who are inundated by an excess of images that are supplied by today's technologies. The ideal goal of ATR systems would be to designate all the targets in an image (maximal hits) without producing false alarms. In such a case the ATR could replace the human analysts. However, present day ATR systems are far from perfect and the analysts have to check and determine which ATR designations are correct and which targets were not designated by the ATR.

The participants in both studies reported below were expert analysts with a military background. The first study included four blocks of images, each block consisting of one of the combinations of the two independent variables: moving magnifier/side-window magnifier; information window available/not available. The analysts were allowed to use the magnification aids and information window whenever they wished. Each block consisted of 18 images. Each image consisted of a SAR image of an area with 10 to 18 vehicles in it. Some of these vehicles were designated as targets by the ATR with a red ellipse. The reliability of the ATR system was approximately 80%, and the recognition rate of the ATR was also 80%. The analysts were instructed to examine all the vehicles in the image, whether designated by the ATR or not, and to mark all the vehicles s/he recognized as targets. There were three "targets", T62, BMP2, and BTR60, and two "distractors", D7 and ZIL131. The analysts marked each suspected target with a red "X" by pressing the left button of the mouse. After the analyst finished marking all the suspected targets s/he moved on to the next image. At the end of the experiment the analysts were given feedback as to how many points they had accumulated after which they filled out a post experimental questionnaire on the computer.

The analysis of results of the first part of the study, the large experiment, indicated that there were no significant differences in performance among the various conditions. In other words, hit rates and false alarm rates were the same for the four combinations of the two variables, type of magnification and availability of information window. On the other hand, the analysis of the post experimental questionnaire indicated that the majority of the analysts preferred working with the

moving magnifier as compared to the side-window magnifier. They expressed the feeling that the moving magnifier is helpful in focusing one's attention on the vehicle, that it is more intuitive and convenient, and that it best serves their needs. Most of the analysts noted that they only used the information window when they felt unsure about the suspected target. It seemed that they did not see the information window as an important and helpful aid and did not use it very often. While the statistical analysis did not yield any differences in performance as a function of the information window, there was a trend indicating that the information window slowed down their performance. The analysts also provided ideas for improving the effectiveness of the information window.

In the second part of the study, the eye-movement monitoring part, nine analysts performed a shortened version of the big experiment while their eye-movements were monitored. Many studies have indicated that a great deal can be learned about visual processes by studying eye-movements. In this experiment the analysts were presented with two exemplars of the four combinations of the two variables that served in the large experiment.

The analysis of the eye-movement data indicated that the analysts examined each vehicle for longer periods of time when the moving magnifier was used than the side-window magnifier was used. This was evidently due to the analysts diverting their attention to the side-window. However, the number of fixations was the same under both conditions. These findings indicate that the moving magnifier is the more comfortable as it helps in focusing ones attention on the source of information during image interpretation.

We found that the analysts were affected by the ATR and examined the designated vehicles more extensively than those not designated. In other words, the analysts devoted more attention to vehicles that the ATR system designated as suspect. This indicates that the analysts utilized the ATR system in order to reach their decisions.

A further finding was that little use was made of the information window; the analysts did not gain much benefit from it, and its usage declined with practice. If the information window was used it appears to have slowed down the analysts. As for the different types of information in the window, it was found that the analysts focused mainly on the upper part of the window that included an optical picture of the vehicle, and less with the other parts of the window, that included a SAR image and sketches of the vehicle. The analysts raised the possibility of adding other information should be examined, such as SAR views from several angles. Their varied suggestions for adding information need to be examined to see if they are indeed helpful.

The eye-movement study also provided video strips showing exactly how the eyes scanned each image. The analysis of these strips indicated that the analysts did not all use the same scanning patterns, with some being systematic and others rather random in their approach to the images. A surprising and somewhat troubling finding in the analyses of the strips was the fact that not all the vehicles in the images were examined. About 6% of the vehicles were not examined. What is more some of vehicles that were not marked as targets in the first run were examined a second time. In other words, it would seem that the analysts were not able to keep track of which vehicles they had inspected and which not. This problem can be alleviated by either teaching the analysts to use a systematic scanning method which would not allow missing items in the image or by giving them the possibility of marking vehicles that appear to them to be distractors with a mark of a different color than that of the marked targets by pressing, say, the right button on the mouse.

To sum up the eye-movement study:

- The moving magnifier is superior to the side-window magnifier.
- The information window, as conceived in the present study, does not yield any benefit and appears to slow down the analysts.
- Means must be developed to prevent the analysts from skipping items in the image or examining them twice.
- The analysts made suggestions both concerning the magnification and the information window and these should be examined.

<center>**1.0 INTERPRETING SAR IMAGES**</center>

1.1 General Background

The extensive technological advancement in image acquisition techniques has provided image analysts with an ever growing array of images for interpretation. One of the means for easing this plight has been the addition of Automatic Target Recognition (ATR) computer algorithms that recognize images from a variety of sensors. Ideally an ATR system that makes no errors (misses or false alarms) would be ideal, but current day ATRs are far from perfect. This is mainly due to the inability to create a bank of images that would cover all the possible targets for all the possible viewing angles. This is true for images in the visible spectrum, infra-red images, as well as Synthetic Aperture Radar (SAR) images (Setter, Norman, Lipkin-Goldberg, & Marciano, H., 2006; Setter, Norman, & Marciano, 2004).

SAR uses planes or satellites to simulate a radar system with a very large antenna yielding high resolution imagery from relatively great distances. This imagery differs from normal visible imagery making both human interpretation and ATR analysis quite difficult. There are several types of distortions in SAR imagery, such as a lack of similarity between an object's true physical size and its relative size in the image, or various types of occlusion, or added speckles (smooth surfaces may contain many dots of varying brightness), or distortions of the distances between objects, as well as many other distortions. It should be emphasized that in spite of these distortions in SAR images, they still remain a very important source of information, especially because of the SAR's ability to function at very large distances and in all weather conditions.

In addition to the technical difficulties stemming from the special characteristics of SAR imagery and the general limitations of ATR, there is a further aspect that demands an examination of the system as a whole. The system also includes a person in the process – the image analyst, who has to make the final decision about the object in the image: Is it really a target, and if it is what is it? The analyst has to examine objects that were designated by the ATR and decide if those designations are correct or not, while also examining objects not designated by the ATR to make sure that they are really not targets. This task is not at all simple, and the analyst is liable to make errors (see Setter, Norman, & Marciano 2004, for an analysis of the different types of errors).

One of the problems facing analysts interpreting SAR imagery is the size of the items in the display. Often the image or parts of it are presented at relatively small scale sizes, due to the need for a relatively wide field of view allowing the analyst to utilize the deployment of the targets to help in the target recognition process. On the other hand, the wide view limits the analyst's ability to discern the exact details of the target, its identity, and the layout of the terrain. This problem can be eased by allowing the analysts to use some computerized magnification tool. With the aid of magnification the analyst can study a given area of the image and discriminate relatively small details. There are several methods of magnification used today. In what follows we will survey some of these methods, two of which were compared empirically in the present study.

1.2 Magnification Methods

Many computer applications utilize magnification of an area of interest in an image, map, or document. The magnification of an area of interest in an image allows

<center>4</center>

the inspection of a close-up of a part of the larger image and is implemented with the aid of several possible methods. In the military setting, this can serve to ease the task of the analyst in examining in detail the area of interest in an image. For example, Rimey, Klarquist, & Debrunner (1998) describe the development of a technology that allows the magnification of areas of interest in the interpretation of SAR images. The program is called Interactive IMage EXploitation (INIMEX), where the interface is based on a zoomable user interface where the objects can be presented in any scale standard. One of the functions of this program is the provision of a magnifier that allows selective viewing and magnification of specific areas. In addition the INIMEX system allows the zooming out to a bird's-eye view and the shifting of the close up from place to place allowing the comparison of two targets. What is more, the system enables the presentation of a close-up at the desired scale with additional relevant information. (see Finegold, Withman, & Kuperman, 2001)

There are several accepted ways of presenting computer magnifications. Here we will review three of these, two of which were examined in the present study.

1.2.1 Zooming and Panning

The most common approach to presenting two or more images is to switch between one image and the second image. This solution is in common daily use in the zoom mode of various imaging programs, in maps, in global positioning systems (GPS), and online navigation resources. This approach requires that the user continuously shifts between the two displays to carry out the task. It allows magnification and maximal use of the screen for each image. However, it does not allow viewing two images simultaneously, and the transitions between pictures causes confusion, disorientation, and loss of the context.

1.2.2 Using Windows

In this approach the two images appear in separate windows, next to each other. Variations can occur in the size of each window or its location in the display screen. Applications using this approach are video monitoring, video editing, geographic information systems (GIS), and others. Another version is the Overview plus detail (O + d) approach (see Baudisch, Good, Bellotti, & Schraedley, 2002). Many windows are displayed, but one always contains the entire image while other windows present detailed views of part of the image.

1.2.3 Magnifying Glass

A third common approach is the digital implementation of a magnifying glass that covers a given area of the display. In this approach the enlarged image appears directly above the original image within its borders and occludes part of it. Usually the location of the enlarged image is not fixed but is controlled by the user with the aid of the mouse, thus placing it directly above the enlarged zone. The user can often vary many parameters to make the task easier. These include the size, contrast and color of the magnified area, a fixed or variable location of the magnified area, the relation between the movements of the mouse and those of the magnified area, and others. The main disadvantage of this approach is the occlusion of part of the original image, which at times causes a loss of important information needed to carry out the task and maintain the context. This problem is especially critical when the enlarged area is large relative to the original image.

Several studies have compared different magnification techniques or focused on specific methods within a given technique. In general these studies reported contradictory results, making it difficult to decide which is the preferred technique. The contradictory results stem from the use of different research methodologies or from the large differences in the tasks used in the studies. However, the findings do appear to indicate that the relative efficiency of the methods depends on the specific task studied. In other words, one task will benefit from one magnification method while another from a different method. Thus, it would be best to carry out a human factors study on the specific application required and carry out a comparative test to determine which method is best for that specific application. The present study is aimed at comparing two magnification methods for the task of interpreting SAR images that also contain ATR information. The aims and method of the study follow herein.

1.2.4 The Aims of the Study

The aims of the study were:

1. To compare the effects of two magnification methods, a moving magnifier (magnification glass) and a magnification window at the side of the display, on the performance of image analysts.
2. To examine the benefits of adding an information window at the side of the display.

A working assumption of the present study was the understanding that presenting analysts with an enlarged high-resolution version of the target would improve their performance. In addition, we examined the hypothesis that the presentation of further information about the items (including an optical image, a SAR image, and sketches) would improve performance. The contribution of the information window was examined together with the two magnification methods in order to determine which combination yielded the best interpretation performance.

1.3 Method

1.3.1 Preparation of Images

In preparing the images we utilized the Moving and Stationary Target Acquisition & Recognition (MSTAR) SAR sensor database. This database contains backgrounds and vehicles viewed from very many different angles, accompanied with detailed data about the relevant parameters (such as resolution, depression angle, and others). Every vehicle in the database appears at all possible angles. Three types of vehicles were chosen to serve as "targets", and two as "distractors". The vehicles chosen to serve as targets were: T-62, BMP-2, and BTR-60. The vehicles chosen to serve as distractors were: ZIL-131 and D-7, a truck and bulldozer, respectively. The latter were not necessarily military vehicles.

The SAR objects were embedded in backgrounds with the aid of a graphic program and their deployment followed well-known combat doctrines. After embedding the targets the distractors were embedded as well. Their deployment was somewhat arbitrary, depending on the specific situation in each image. We assumed that a bulldozer or a truck could be found in all kinds of places and their position is not determined by combat doctrines. We took care that the distractors were

embedded in a sensible manner, where a truck or bulldozer could not appear in the middle of an array of military vehicles or on the roof of a house, or on trees buses, etc. What is more, while embedding the vehicles we carefully matched all the shadows so that they would be in the same direction as the images in the background image.

1.3.2 Participants

The participants in the experiment were 25 analysts (23 males and 2 females) with a background in the interpretation of SAR images. Some were soldiers and officers, while others students in the military reserves who had been analysts during their military career. The students were paid for their participation in the experiment. Five of the analysts performed quite poorly and it was clear that their knowledge of SAR targets was very superficial. Therefore, the statistical analyses were carried out only on the other 20 analysts. The analysis of the post experimental questionnaires was carried out on all 25 analysts.

1.3.3 The Experimental Procedure

Two independent variables were examined in the experiment (see Figure 1), each having two levels: Type of magnification – moving magnifier or side window magnification; Information window – with or without such a window.

Type of Magnification Information Window	Moving Magnifier	Side-Window Magnifier
With information window	1	2
Without information window	3	4

Figure 1. The general plan of the experiment

The design was a within subject design where each analyst underwent all four blocks created by crossing these two dichotomous variables. Thus, each analyst encountered the following four types of blocks:

1. Moving magnifier with information window.
2. Side window magnifier with information window.
3. Moving magnifier with no information window.
4. Side window magnifier with no information window.

1.3.4 Apparatus

In the laboratory the images were presented on a 17" PC CRT display with a resolution of 1024X768. In the field the images were presented on IBM Thinkpad T20 PC42 laptop computers with a 15" screen and a resolution of 1024X768.

1.3.5 Images

The images used in the experiment were SAR images that contained various vehicles (10 to 18 in each image). The images were created from the MSTAR database (see 1.4.1). The military vehicles served as targets were: T-62, BMP-2, and BTR-60. The distractors were two non-combat vehicles: ZIL-131, and D-7. Some of the vehicles were designated with a surrounding red ellipse simulating an ATR system. The reliability of the ATR system was set at 80% (out of all the designated vehicles 80% were targets and 20% were distractors). Furthermore, the recognition rate of the ATR was 80% (out of all the targets in the image the ATR designated 80% of them).

1.3.5.1 Two Modes of Magnification

1. *Moving magnifier*. The magnification appeared on the display in the form of an 80X80 pixel square (see Figure 2). The location of the magnification was determined by the locus of the mouse. The exact location of the mouse was the middle of the magnification square, and it moved with mouse movements and was updated immediately and continuously.

2. *Side-window magnifier*. It appeared at the upper right side of the SAR image, in the shape of an 80X80 pixel square, and magnified the area around the mouse cursor. The exact location of the mouse served as the center of the magnification, and was updated immediately and continuously with each mouse movement. The large image never changed, except for a green square that demarcated the area of magnification and served to give the analyst an indication of its position (see Figure 3).

Figure 2. An example of a moving magnifier image. The green square at the left is the magnification, where the vehicle within it is magnified by 2 compared to the other vehicles in the image. The red ellipses are a simulation of the ATR designations

Figure 3. An example of a side window magnifier. The green square at the left is the area that is magnified in the window on the right

1.3.5.2   *Information Window*

The information window was located at the bottom right side of the image (see Figure 4 and Figure 5). When the analyst moved the mouse to any spot on the image and pressed the right button of the mouse information was displayed in the information window which could be of help in the task. By scrolling the mouse wheel the analyst could go through all five vehicles used in the experiment. The information in the window included: 1) An optical image of the vehicle; 2) A SAR image of the vehicle; 3) Sketches of the vehicle from different viewing angles (the types of information can be seen in Figure 6).

Figure 4. An example of a display with a moving magnifier together with an information window. In addition to the green square on the left where the magnification occurs, on the left we see the information window with information about the enlarged vehicle. This vehicle was designated by the ATR so that a press of the right button displayed information about it

Figure 5. An example of a window magnifier together with an information window. The green square at left is the enlarged area, seen in the window at the top right. At the bottom right one can see the information window
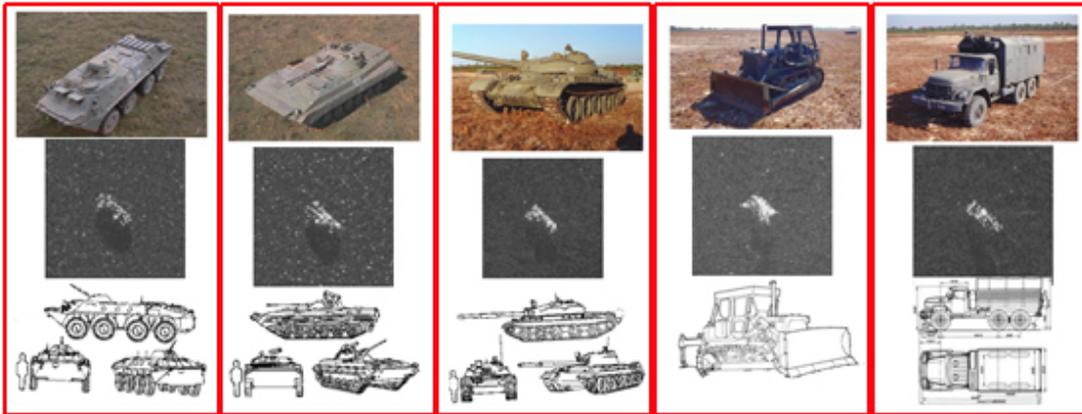
Figure 6. All the information displays that could appear in the information window. From left to right: BTR-70, BMP-2, T-62, D-7, ZIL-131

Pressing the right button of the mouse was possible in all locations in the image, and this yielded three possible information presentation situations:

1. *Pressing on a target designated by the ATR (an ATR "hit").* The correct target appeared in the information window, and the four other vehicles could be called up by scrolling the wheel.
2. *Pressing on a distractor designated by the ATR (an ATR "false alarm").* One of the three targets was randomly chosen by the computer and displayed in the window, and the four other vehicles could be called up by scrolling the wheel.
3. *Pressing on a vehicle not designated by the ATR (an ATR "miss" or a distractor vehicle).* The information window remained blank and the five vehicles could be called up by scrolling the wheel.

1.3.6 The Experimental Procedure

The experiment included practice followed by four experimental blocks as described above. The order of the experimental blocks was balanced over the participants. The practice was meant to give the analysts some experience with the vehicles that s/he would have to recognize in the experiment. The instructions for the practice (see Appendix 1) were read aloud by the experimenter and presented to the analyst in print together with rather large optical photographs of the vehicles accompanied by SAR versions of the same vehicles (see Appendix 1). These pictures were available to the analysts throughout the practice block to allow them to check themselves when this was needed. The practice was made up of four short blocks with 5 trials in each during which a single SAR image was presented (see Figure 7). The analysts saw each vehicle four times, once in each of the short blocks. Presentation time was unlimited and when the analyst decided whether the vehicle was a target or distractor s/he used the mouse to press one of the two buttons. If the analyst committed a mistake a tone informing her/him of such was heard. It both served as feedback and as an incentive to be accurate.

Figure 7. An example of a display used in the practice. In the center a SAR image of a vehicle appears and the analyst had to decide if it is a target (right button) or distractor (left button) and press the appropriate button

At the end of the practice the instructions for the experiment were read to the analyst (see Appendix 1). When the analyst was ready the experiment started. The 18-image block was self-paced. At the beginning of each block the analyst was informed what type of block it would be (magnifier type and with or without the information window). The analysts were given a preliminary demonstration of the aids that would be available during the course of the experiment. The images for each block were chosen so as to balance as best possible the difficulty of the four blocks. Each block consisted of four images containing 10 vehicles, four images containing 12 vehicles, two images with 13 vehicles, four images with 15 vehicles, and four images with 18 images. All 72 images used in the experiment were different. The presentation order in each block was random. On each trial the analyst saw a 465X384 pixel image. The vehicles were distributed in the image, and some of them were enclosed by an ellipse simulating the ATR.

The analyst was instructed to scan all the vehicles found in the image – including both those designated and not designated by the ATR – and mark each vehicle that was a target. The analysts marked each suspected target with a red X by pressing the left button on the mouse. They were not allowed to make corrections or changes after they marked a target, and, thus, were instructed to be careful and meticulous. They were not given any feedback about the accuracy of their responses. The analyst could use all the aids available, the magnification and the information window when available. When the analyst finished scanning the entire image s/he moved on to the next image.

When one block was finished the analyst could move on to the next block. However, since the experiment was quite lengthy (one-and-a-half to two hours), the analysts were instructed to take a break between the blocks. At the end of the entire experiment they were given a score that they had accumulated. It was equivalent to the percent of correct response they had made; correctly marking true targets and not marking distractors. These scores served as significant incentives, as the analysts

compared scores with each other and competed to see who would get the highest score.

1.3.6.1 Post-Experimental Questionnaire

At the end of the experiment each analyst filled out a questionnaire on the computer. The following questions appeared in the questionnaire (in Hebrew):

1. Which magnifying aid was easier to work with?
   - The moving magnifying glass.
   - The window magnifier at the side.
2. What made it easier?
3. What was less convenient in the other magnifier?
4. How could each of the magnifiers be improved?
5. When did you use the information window?
   - Every time I examined a vehicle.
   - Only for vehicles designated by the ATR.
   - Only for vehicles not designated by the ATR.
   - Only for vehicles that I was indecisive about.
   - I did not use it at all.
   - Other _____
6. Can you think of any other information that would have been helpful? If yes, what would it be?

1.4 Results

1.4.1 Statistical Analyses

The measures of performance were hit rate, false alarm rate, and response times. The hit rate was the proportion of targets that the analyst marked out of all the targets in the image. The false alarm rate was the proportion of distractors that the analyst marked. The response time (RT) was the mean time of analysis of each of the vehicles in the SAR image measured in seconds (s). Table 1 presents a summary of all the results. A two-factor analysis of variance (ANOVA) was carried out on the variables, type of magnifier and information window (present or absent).

As can be seen in Table 1, the effects of magnifier type yielded very small differences between the hit rates, and these were statistically not significant, $[F(1,19)=0.00, ns]$, as was the case for the false alarm rates $[F(1,19)=0.01, ns]$ and the response times $[F(1,19)=0.09, ns]$. In other words, no differences were found between the performance with two types of magnifiers, moving and side window.

Table 1. Means of hit rates, false alarm rates, and response times as a function of the experimental condition

Experimental Condition	Mean Hit Rate	Mean False Alarm Rate	Mean Response Time (s)
Moving magnifier with information window	0.78	0.27	3.70
Side window magnifier with information window	0.80	0.26	4.60
Moving magnifier with no information window	0.79	0.27	4.00
Side window magnifier with no information window	0.79	0.26	4.70

No differences were found between the conditions where an information window was available and when it was not, both for the hit rates [$F_{(1,19)}=0.38$, ns] and the false alarm rates [$F_{(1,19)}=0.23$, ns]. In other words, the information window did not contribute to the performance of the analysts. The response times with the information window (4.65 s) were found to be longer than without it (3.85 s), but this trend was also not statistically significant [$F_{(1,19)}=2.90$, $p<0.10$] probably due to the large inter-individual variance. Thus, the information window did not improve performance but did slow it down somewhat.

From the pattern of results depicted in Table 1 it can be seen that the hit rates and false alarm rates of the analysts were similar to those of the ATR system. This raises the possibility that the analysts did not make an effort to analyze the images but simply followed the ATR designations and marked those items that were designated by the ATR system. To check this possibility we examined the congruence between the designations and the analysts' responses. We did this by calculating the hit rates only for true targets that the ATR designated, and also calculated the false alarm rates for those items. If the analysts had marked all the items designated by ATR, then their performance on these items should be near perfect (i.e., hit rate near 1.0). This was not the case; the analysts marked 84% of the vehicles designated by the ATR and about 40% of the distractors designated by the ATR. This finding allows us to infer that the analysts did not automatically follow the designations of the ATR system, but rather attempted to interpret the images.

1.4.2 Responses to the Post-Experimental Questionnaire

1.4.2.1 *Type of Magnification*

The majority of the analysts (19 out of 25) preferred the moving magnifier over the side-magnification window. They claimed that the magnification on the image was more efficient as there was no need to divert one's gaze to the side allowing one to concentrate on the central image. This allowed them to focus their attention on the central image, and not split it between the central and side images. What is more, the possibility of shifting the magnifier from place to place on the image is helpful to the analyst, and marking the targets is made easier and more accurate.

The few analysts, who preferred the side window magnifier, explained that the fact that the ATR designation was not seen in the moving window disturbed them in the image interpretation. They also claimed that the moving magnifier prevented them from simultaneously seeing both the magnification and the actual image, while the side magnification did not occlude the image, making the task of comparing elements much easier.

1.4.2.2   Suggestions for Improving the Magnification

The analysts suggested improving the magnification in the following ways:

- To allow a greater magnification (more than two times), allowing the analyst to change the extent of the magnification in accordance with his needs.
- To enable zoom in and zoom out to help in understanding the size scale.
- To enable magnification with the aid of the mouse wheel and to move on the image by the pressing the button (as in the AutoCAD program).
- A larger window in the side magnifier.
- To be able to "paste" the magnification near another SAR vehicle to allow comparison.
- To allow the magnification of two elements at the same time (such as two magnifying glasses).
- To combine the two magnification methods, with both a moving magnifier and a side-magnification window.
- To have both magnifiers available and let the analyst choose the one s/he wants to use.

1.4.2.3   Information Window

Eleven analysts noted that they used the information window only when they were not sure about the specific vehicle. Three analysts claimed that they used the information window every time they examined a vehicle. Six stated that they used it only when the vehicle was designated by the ATR. None of the analysts reported never using the information window.

1.4.2.4   Suggestions for Improving the Information Window

Data which should be added to the information window: A picture of the typical deployment of the vehicles, both in normal and combat conditions; statistical data such as the average number of vehicles in a certain area; information about the dimensions of the vehicles (height, length, and width); the hour when the image was photographed; and SAR images from several viewpoints, yielding a databank for each vehicle.

1.4.2.5   General Recommendations about the Interpretation Aids

The analysts raised the following suggestions:
- Add the ATR ellipse to the moving magnifier.
- The red color used to mark targets is the same color as that used for the ATR designations, and that is liable to produce errors. It is recommended that a

different color be used, for example, blue for the ATR and the analysts markings in red.

- When the analyst marks target the red X occludes it and then there is no way to compare that target with another one. It is suggested that this be changed.
- It would be helpful if some other SAR images were also available for comparison. For example, a SAR image of the same area that was photographed at a different time, an optical image of the area, an optical display of the same area, an aerial photograph by a different system and at a larger scale.
- The ability to process the image (contrast, luminance, histograms, etc.).

1.5 Discussion

In the present experiment we examined the performance of expert SAR analysts when some of the vehicles were designated by an ATR system. The task of the analysts was to recognize the vehicles (categorize them as "target" or "distractor"). Their performance was assessed under four display conditions:
1) With a magnifying glass-like moving magnifier; 2) With a magnification window at the side of the display; 3) The first condition with an added information window; and 4) The second condition with an added information window.

The results of the experiment indicated that none of the variables – type of magnification and the information window – influenced the analysts' level of performance. The hit rates and false alarm rates were very similar in all the conditions of the experiment: the two types of magnification with or without an information window.

The post-experimental questionnaires indicated that the majority of the analysts preferred working with the moving magnifier as compared to the side-window magnifier. They explained this preference as stemming from the greater ability to focus their attention on the target and from its ease and intuitive nature. The analysts recommended several changes in order to improve the magnifications. For example, to enable the analyst to magnify several vehicles simultaneously and to paste them in different locations on the image, or to allow changes in the scale of magnification and include the ATR designation in the magnification window. In addition, the analysts recommended combining the two magnification methods, in a moving magnifier and in a side-window, or to allow the analyst to choose at each stage the method which was most appropriate at the moment.

Most of the analysts noted that they used the information window only in cases where they had some doubts about the vehicle. The general impression was that the analysts did not find the information window to be an important tool and did not use it often. It should be emphasized that the statistical analyses did not find significant differences between the conditions where the information window was available and when it was not, for both the hit rates and the false alarm rates, but, on the other hand, a trend was found indicating that the response times were longer when the information window was available. This finding together with the responses to the post-experimental questionnaire appears to indicate that an information window, like the one used in the present study, does not improve performance and is even likely to slow down performance. It would seem that an information window like the one used in the present study is not necessary. However, the analysts suggested a number of means to make the information window more helpful. They suggested

presenting information on typical deployments in routine and combat situations, adding information about the dimensions of the vehicle, adding maps, exact time of photographing, and to make a bigger databank of information and images taken from varying angles. It might be fruitful to contemplate a further study where a more informative and interactive information window, like those suggested by the analysts, will be examined.

2.0 STUDYING EYE-MOVEMENTS DURING IMAGE INTERPRETATION

2.1 Background

Many studies indicate that much can be learned about visual processes from the analysis of eye-movements occurring during the performance of various visual tasks (see review in Rayner, 1998). The monitoring of eye-movements can serve as a window on the visual and cognitive processes occurring during the scanning of any scene. Examples are during driving a car, reading, etc. (Maltz & Shinar, 1999; Setter, Marciano, Lipkin-Goldberg, & Norman, 2007; Setter & Norman, 2006). The function of eye-movements is to bring the retinal projection of the area of interest to the fovea, the most sensitive part of the retina. Eye-movements have two major components: the first are the fixations that stabilize the eyes on an area of interest. The second component is the saccades, which are quick ballistic movements between fixations. They can be either reflexive or volitional, and move the gaze to a new fixation point (Duchowski, 2002).

The output of monitoring eye-movements consists of a continuous recording of x,y coordinates of the position of the eyes at all instances. By analyzing the fixations and saccades during the viewing of an image, one can get a complete description of the trajectory of the eyes and the location of fixations yielding a picture of what the areas of interest in the image were.

2.2 Aims of the Study

In the present study we monitored analysts' eye-movements as they interpreted SAR images where some of the vehicles were designated by the ATR system. The interpretation was aided by one of two magnification methods, moving magnifier or side-window magnifier. The analysts also had another aid, an information window at the side, which was available in half of the trial blocks. The monitoring of the eye-movements was carried out in order to examine the methods the analysts used to scan the images, to pinpoint an efficient means of scanning, and to check the extent to which the analysts utilized the various aids that were available.

2.3 Method

2.3.1   Participants

Nine analysts with an expertise in SAR interpretation participated in the experiment (see Appendix 2 for instructions). They were part of the sample of 25 analysts used in Experiment 1. Only analysts with perfect vision participated, without glasses or contact lenses. This was because we found that the eye-movement monitor did not enable us to accurately calibrate the system when the analyst had corrected vision. Some were soldiers and officers, while others students in the military reserves who had been analysts during their military career. The students were paid for participating. All the analysts also participated in the big experiment described above; some of them had their eye-movements monitored before and the others only after the experiment. This was done in order to balance between the learning and fatigue variables.

2.3.2   Apparatus

Eye-movement monitoring was carried out with the aid of an EyeLink II monitor (made by SR Research, Osgoode, Ontario, Canada). The system is worn on the head where a side camera monitors the movements of one eye as the analyst works on the SAR image on the computer screen in front of her/him (see Figure 8). A second PC computer serves the experimenter for processing and storing the data collected by the camera. The data collected by the system are x,y coordinates of the location of the fixations on the screen, at a rate of 500 Hz. These coordinates allow one to calculate the location of the fixations, their duration, and the duration and speed of the saccades.

Figure 8. A participant sitting opposite the screen with an eye-movement monitor on her head and a second computer in the background for gathering the eye-movement data

2.3.3   Procedure

Four of the analysts participated in the eye-movement study before Experiment 1 and the other five after it. This was done for two purposes: 1) to examine the effects of learning the task on the eye-movements; and 2) to balance the effects of fatigue and learning on the results.

In the present experiment the analysts underwent the same exact procedures as in Experiment 1, but here each block included only two SAR images. This experiment was much shorter than Experiment 1 because of the difficulty of sitting with the head mount for extensive periods. For each block we chose one cluttered image with 18 vehicles and one less cluttered image with either 10 or 12 vehicles. The image blocks were presented in the same order, as were the images within a

block. The analysts were presented with 10 SAR images, two for training, and two each for the four blocks.

Each experiment began with a calibration procedure, where the participant had to fixate on nine fixation points in a 3X3 matrix. The calibration was repeated when there was an error greater than 1° for any of the 9 points, or if the average error was greater than 0.5^o.

2.4 Results

The eye-movement monitor recorded the analysts' eye-movements as they interpreted the SAR image, and calculated the number of fixations and the dwell times at each area of interest. The areas of interest were predefined and included each of the vehicles in the image, both those designated by the ATR and those not, and the magnification and information windows at the side of the image (when these appeared). Since the information window included three types of information, one above the other, we divided the information window into three separate areas of interest.

The dependent variables in the statistical analysis were the number of fixations and the dwell times in each area of interest. In addition to the statistical analyses we recorded video strips detailing the exact eye-movements of the analysts as they scanned each image (see the attached disk).

A three-way analysis of variance (ANOVA) was used to examine the effects of the following variables: type of magnification (moving vs. side-window); availability of information window (available vs. not available); and type of area of interest. The dependent variables were the mean number of fixations and dwell times on an area of interest. The following is a list of the independent variables that were included in the statistical analysis followed by Tables 2 and 3 which present the data.

- **Type of magnification**: moving window/side window
- **Information window**: available/unavailable
- **Type of area of interest**:
  Target designated by the ATR
  Target not designated by the ATR
  Distractor designated by the ATR
  Distractor not designated by the ATR
  Information window (top – optical image; middle – SAR image;
      Bottom – sketches)
  Side magnification window

Table 2. Mean number of fixations in the different areas of interest in all the experimental conditions

Type of Area of Interest	Moving Magnifier		Side-Window Magnifier	
	With Information window	Without Information window	With Information window	Without Information window
ATR designated Target	5.45	5.21	5.86	4.78
Non-designated Target	3.74	4.14	7.25	4.11
ATR designated Distractor	5.88	4.92	4.51	3.72
Non-designated Distractor	3.85	3.33	4.73	2.55
Side-Window Magnifier (Over all vehicles in the image)			54.16	39.88
Information Window (Over all vehicles in the image)	3.63		11.55	

Table 3. Mean dwell times (in s) in the different areas of interest in all the experimental conditions

Type of Area of Interest	Moving Magnifier		Side-Window Magnifier	
	With Information window	Without Information window	With Information window	Without Information window
ATR designated Target	4.83	5.47	2.29	1.64
Non-designated Target	3.39	3.65	2.51	1.32
ATR designated Distractor	4.75	5.25	1.70	1.56
Non-designated Distractor	2.95	3.00	1.69	1.01
Side-Window Magnifier (Over all vehicles in the image)			37.18	26.77
Information Window (Over all vehicles in the image)	1.24		4.60	

2.4.1 Analysis of the Number of Fixations on the Vehicles in the Image

We assumed that in the side-window magnification the analysts would look at the vehicle for only a brief period and then move on to the side magnification, and that this would cause the analysts to execute fewer fixations on the vehicles in the image compared to the moving magnifier. This hypothesis was not supported by the results as we did not find an effect of the kind of magnifier on the mean number of fixations on the vehicles. We did find a marginal effect of the information window on

the number of fixations [$F_{(1,8)} = 4.39$, $p<0.06$] (see Figure 9). In the images with an information window the mean number of fixations (5.16) was greater than without an information window (4.10). In addition, an effect was found for the type of vehicle (with or without ATR) on the mean number of fixations [$F_{(3,24)} = 4.72$; $p<0.01$]. The mean number of fixations on a distractor that was not designated by the ATR was significantly less than the other three possibilities (see Figure 10).
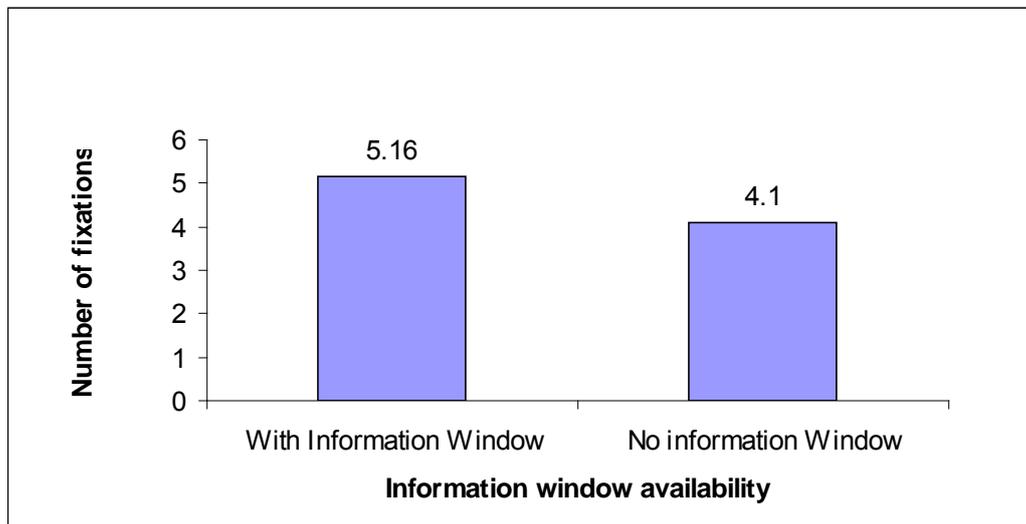

Figure 9. Mean number of fixations per vehicle as a function of the presence of an   information window
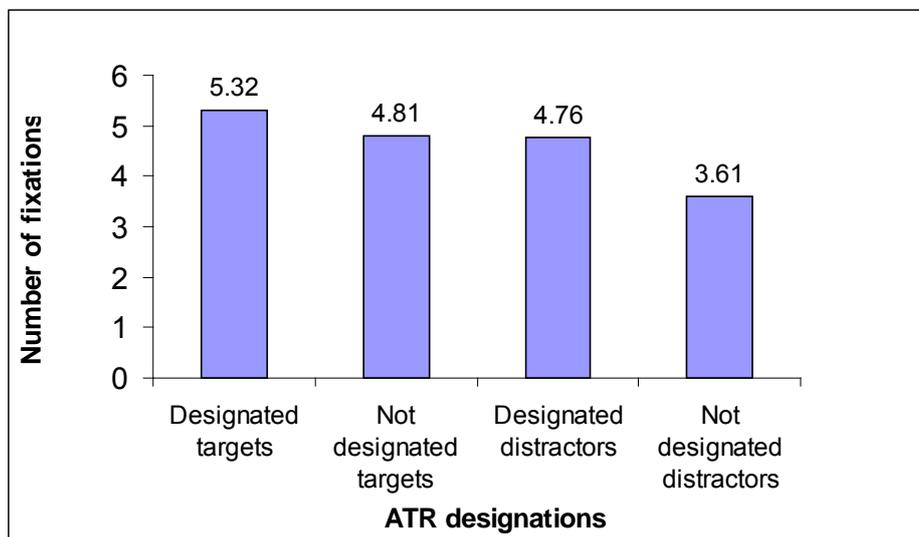

Figure 10. Mean number of fixations per vehicle as a function of the ATR designation

2.4.2   Analysis of Dwell Times for the Vehicles in the Image

The type of magnification had an effect on the dwell times on the vehicles [$F_{(1,8)} = 13.86$, $p <0.05$]. These were considerably longer (4.16 s) with the moving

magnifier than with side-window magnifier (1.72 s) (see Figure 11). This was due to the fact that they spent much of the time inspecting the vehicle in the side magnification window. When the mean dwell time on the side window (2.91 s) is added to that of the vehicle itself we obtain 4.62 s, a value that is similar to the moving magnifier. The dwell times were also different for vehicles that were designated by the ATR and for those that were not designated by the ATR [$F(3,24) = 8.00$, $p<0.01$]. These were longer for vehicles designated by the ATR than for those not (see Figure 12).
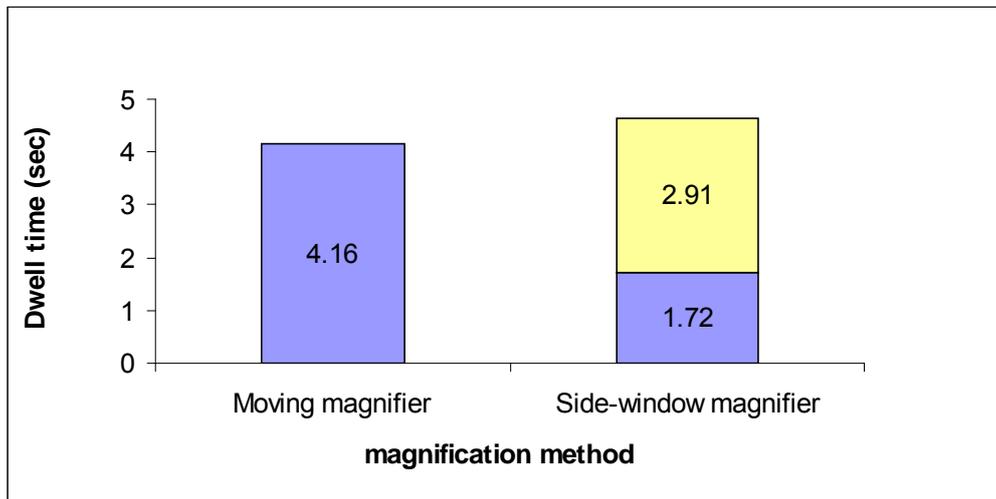
Figure 11. Mean dwell time as a function of magnification methods (blue = fixating on the image; Yellow = fixating on the side-window)
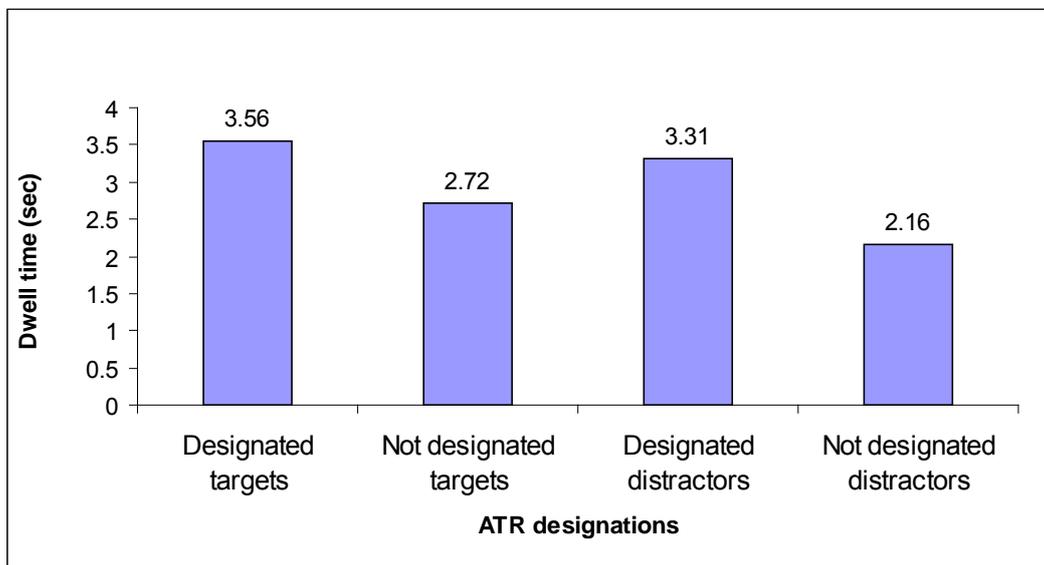
Figure 12. Mean dwell time as a function of ATR designation for targets and distractors

23

2.4.3 Analysis of Number of Fixations and Dwell Times for the Information Window

We analyzed the fixations and dwell times for those series that contained a side-information window. The purpose of this analysis was to examine whether there was a specific type of information that the analysts made more use of than the other types of information. As was described above the information in the window consisted of three parts (see Figure 6), the upper part an optical photograph of the vehicle, the middle part an SAR image of the vehicle, and the lower part sketches of the vehicle from different viewing points.

Significant differences were found between the mean number of fixations in the three parts of the information window [$F_{(2,16)} = 6.91$, $p<0.006$]. The greatest number of fixations were found for the upper part of the window with the visible spectrum photograph (14.7 fixations), followed by the SAR image in the middle (7.6 fixations), and very few fixation for the sketches at the bottom (0.6 fixations) (see Figure 13).
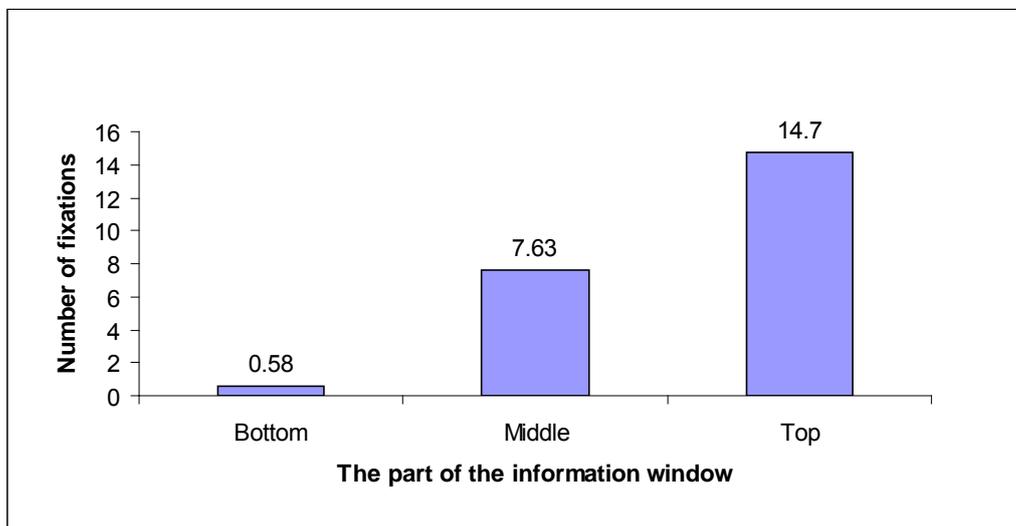
Figure 13. Mean number of fixations as a function of the part of the information window

A significant difference was found between the mean dwell times for the three parts of the information window [$F_{(2,16)} = 4.58$, $p<0.02$]. The longest dwell times were for the upper part (4.93 sec), then for the middle part (3.70 sec), and extremely short for the lower part (0.18 sec) (see Figure 14).
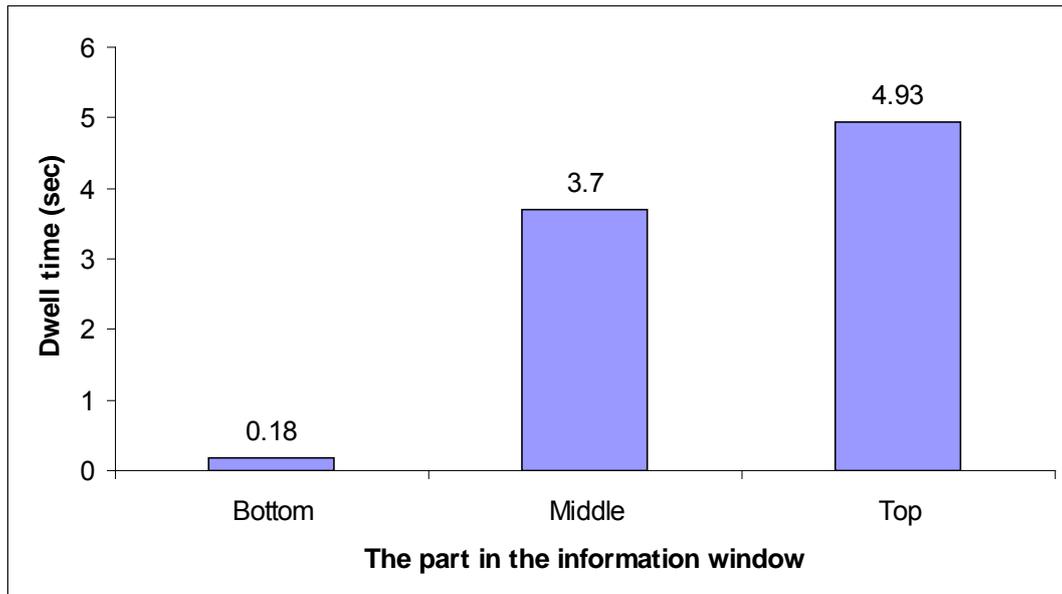
Figure 14. Mean dwell times as a function of the part of the information window

2.4.4 Previous Experience and the Usage of the Information Window

Four of the analysts who participated in the eye-movement study carried it out before participating in the big experiment (Experiment 1), while the other five carried it our after the large experiment (see 2.3.3). This procedure allowed us to compare the usage of the window by analysts who had no experience with the study to those who had had about two hours previous experience. We hypothesized that the inexperienced analysts would utilize the information window to a greater extent as part of their learning the system as a whole.

The inexperienced analysts did indeed utilize the information window to a greater extent. This was true both for the mean number of fixations which was considerably greater for the inexperienced analysts (14.99) than for the experienced analysts (1.65) $[F(1,7) = 12.22, p<0.01]$, and the mean dwell times, 6.11 sec for the inexperienced analysts and 0.4 sec for the experienced analysts $[F(1,7) = 15.71, p<0.005]$.

2.4.5 Image Scanning Patterns

The Eye-Link eye-movement monitor yields a real-time gaze position overlaid on the static computer display image. We recorded video strips for each SAR image the analyst saw, giving us the exact sequence of eye-movements that the analyst made as s/he examined each image. Comparing these video strips allowed us to examine the scanning patterns of the analysts and determine if there were differences among the analysts in these patterns.

Several features of the scanning patterns were examined:

- The initial point of starting the scan (middle, top, bottom, right, or left).
- The order in which the vehicles were scanned (orderly or random).

- The scanning of individual items: scanning a specific vehicle, or the information window, or the side magnification window.
- Were vehicles scanned more than once?
- Did the analyst scan all the vehicles in the image?

Comparing the video strips for different analysts we learned that different analysts have different methods of scanning the images. It was not possible to find a singular scanning pattern among the analysts. However, some of the features listed above did yield consistent findings. There were, for example, analysts who used the information window and the side-magnification window to a greater extent than other analysts. There also were analysts who consistently initiated the scanning of the image from the center and those who started from the margins of the image. Some of the analysts scanned the vehicles in the image in an orderly manner, while others appeared to scan them in a rather haphazard manner. It should be emphasized that a given analyst would switch between scanning patterns from image to image or when the type of image was changed.

An interesting and surprising finding that is somewhat disturbing was that we noticed that the analysts would completely miss a vehicle in the image and not scan it at all. Summing over all the images viewed we found that 52 vehicles were not scanned at all, about 6% of all the vehicles presented. We found that there were no differences between ATR-designated vehicles and undesignated vehicles in the number missed. In other words, the analysts did not miss fewer designated vehicles as might be expected. On the other hand, we found that more vehicles were missed when there was an information window at the side than when there was none. One might speculate that the shifting on the gaze to the side information window disturbed the vehicle scanning sequence making it more difficult for the analysts to recall which vehicles had been scanned. A complementary finding was the fact that we noted that the analysts scanned several vehicles that they had not marked more than once. In other words, the analyst examined a vehicle then moved on to other vehicles and then returned to the first vehicle as he continued scanning. The present study does not avail us with information which would let us know if the second look was intentional, returning on purpose for a second look or whether the analyst simply forgot that he had inspected that vehicle.

2.5 Discussion

Monitoring the analysts' eye-movements while they interpreted the SAR images allowed an in-depth analysis of their scanning patterns. These provided information about the way they examined the images, what their areas of interest were, and their utilization of the additional aids.

The analysis of the eye-movement data indicated that the analysts dwell times on the SAR images <u>in the image</u> were considerably longer with the moving magnifier than with the side-window magnifier. This finding makes sense since with the side-window magnifier there was a need to examine the enlargement in the window. However, a very surprising finding was that the number of fixations in both cases was not significantly different. This finding appears to indicate that the analysts did a lot of looking at the original (smaller) image when they used the side-window magnifier, but their fixations were obviously much shorter in this case. One possibility is that these short fixations allowed the analysts to better orient within the larger image and pick up the relative locations of the vehicle being inspected and all the other vehicles

in the image. However, they seem to have made their decisions based on the inspection of the enlarged image in the side-window magnifier. Overall the data indicate that the analysts fixated on both the smaller vehicle in the large image and on the enlarged version in the side-window. This undoubtedly burdened their attentional mechanism, having to split it between the two images. In contrast, with the moving-window magnifier, the analyst was able to fixate on a single spot, receiving information on the vehicle and its location simultaneously.

Another finding was that the analysts tended to rely on the ATR designations and inspected the designated vehicles for longer durations than the vehicles that were not designated. In other words, the analysts devoted more time on vehicles designated by the ATR. On the other hand, the fact that the analysts devoted a fairly considerable amount of time on the vehicles not designated indicates that they did not totally follow the ATR designations.

The eye-movement data indicates that the presence of an information window increased the number of fixations on vehicles in the image. It is possible that the examination of the vehicle while making comparisons with the information window caused the increase in the number of fixations, even though the dwell times were not greater. The part of the information window that was utilized the most, was the photograph of the vehicle in the visible spectrum and not the SAR image or the sketches. An interesting finding was that the analysts used the information window to a much lesser extent when they had previously performed the large experiment than when they were tested before the large experiment. It would seem that the information presented in the information window was too meager and it would seem that it might be considerably broadened.

Inspection of the video recordings of the exact sequence eye-movements for each image indicated that it is not possible to point to a unique pattern of image scanning by the different analysts. However, it was possible to discern a somewhat idiosyncratic pattern for each analyst. An important finding of this analysis was that the analysts completely missed some vehicles, and did not examine them at all. The presence of the information window increased this trend, although it did occur without the information window as well. A related finding was the fact that in some cases the analysts inspected the same vehicle more than once, but we cannot tell if this was because the analyst forgot that s/he had inspected the vehicle or that the analyst wanted to reexamine the vehicle.

3.0 GENERAL DISCUSSION

The present study examined the effects of the type of magnification, moving magnifier (simulating a magnifying glass) or side-window magnifier, on the interpretation of SAR images with added ATR designations. In addition, we examined the effects of an added information window at the side of the SAR image. This window presented an optical image, a SAR image, and sketches of the vehicle. These effects were examined with the aid of a number of variables: 1) Performance variables – Hit Rate, False Alarm Rate, and Response Time; 2) Analysis of eye-movements; and 3) A post-experimental questionnaire filled out by the analysts.

Magnification Aids: The overall analysis of all the results indicates that the moving magnifier is superior to the side-window magnifier. This appears to be the case in spite of the fact that no differences in performances were found with the two methods of magnification. A detailed analysis of the eye-movements indicated that with the side-window magnifier the analysts divided their attention between the image and the side-window. The rather surprising finding was that with the side window the analysts made the same number of fixations on the vehicles in the image as with the moving magnifier. These fixations are indeed much shorter than with the moving magnifier, but their large number indicates that the analysts are dividing their attention. This division of attention ultimately yields longer response times, and it seems safe to conclude that while the side-window magnifier does not impair performance compared to the moving magnifier it does slow down the performance. What is more, the responses to the post-experimental questionnaire indicated that the majority of the analysts preferred the moving magnifier. They noted that shifting their gaze to the side window disturbed their concentration and forced them to divide their attention between the magnification and the image. The few analysts who preferred the side-window magnifier stated that the moving magnifier occluded part of the image and did not allow viewing the entire image. The analysts made some suggestions for perfecting the magnification, and they are worth consideration:

1. To develop a magnifier that allows more than one level of magnification that could be changed with the mouse wheel.
2. To enable the magnification of two or vehicles simultaneously.
3. To allow the "pasting" of the magnified image of one vehicle near another magnification allowing comparisons.

The Information Window: Summing up all the results indicates that the information window that we made available to the analysts did not yield any benefit. The information window did not affect their performance as measured by hit rates and false alarm rates. On the other hand, the response times with the information window were longer than without one. The analysis of eye-movements indicated that the analysts made more fixations per vehicle when the information window was available, without any contribution to their performance. In other words, the information window slowed down the performance without improving it. The eye-movement data also indicated that after having performed the large experiment (Experiment 1) the analysts showed much less interest in the information window than did analysts whose eye-movements were studied before the experiment.

The analysts made several suggestions for improving the information window. They suggested adding additional information such as: displaying the same area at an earlier time; displaying an optical image of the same area; information about the

typical deployments of the vehicles in the image; the addition of statistical information such as the average number of vehicles in the area; information about the vehicles' dimensions; the time of photography; and presenting a set of SAR images of the vehicle from different angles. The information window contained three types of information: an optical picture of the vehicle; a SAR image from one angle; and several sketches of the vehicle. The eye-movement data indicated that the analysts mainly utilized the optical image, but this did not improve their performance. It is possible that a set of SAR images from different angles would improve performance. We believe that it would be worthwhile examining the effectiveness an information window that would function like an interactive search engine and not simply supply a few fixed items. In other words, the window would serve as a contact to a very large data base that could be searched according to various criteria.

ATR Designations: The analysis of the eye-movements raised several interesting points that are not directly related to the original aims of the study. The analysts made more fixations when the vehicle was designated by the ATR than when it was not, and the dwell times on a designated vehicle were longer than on one that was not designated. This can be interpreted as indicating that the analysts indeed paid heed to the ATR designations. However, the data also indicate that the ATR designations did not cause the analysts to be overly trustful and they did not mark all the vehicles that were designated and were able to divert their attention to vehicles not designated.

Image Scanning Patterns: The video strips depicting the sequence of eye-movements as the analysts inspected the SAR images were examined. It was seen that the analysts did not all use a common scanning method, but we were able to distinguish several idiosyncratic methods. Some analysts inspected the images in a systematic manner, while others were quite random in their scan. Some analysts began at the middle of the image while others at one of the sides. What is more, we came upon a somewhat surprising and distressing finding that some of the vehicles in the image were not inspected at all! The nine analysts whose eye-movements were examined did not inspect 52 vehicles (about 6%). What is more, we found many cases where the analysts returned and inspected unmarked vehicles for a second time. While it is not sure whether this second inspection was done on purpose or was a case of not knowing which vehicles has been inspected, taken together with the fact that vehicles were completely missed it would seem that this can be seen as evidence that the analysts were not able to keep track of which vehicle they had or had not inspected. It would appear that two methods of overcoming this problem might be adopted: to teach the analysts a very systematic scanning method which will make it much simpler for them to trace their scanning pattern; and to add another small graphic to the process, say a small green star, which would allow the analysts to indicate those vehicles they scanned and decided not to mark as "targets". These two suggestions should be put to an empirical test in some subsequent study.

To sum up, the type of magnification did not influence the performance of the analysts, however after taking the subjective evaluations of the analysts and the eye-movement data into account, the moving magnifier (simulated magnifying glass) appears to be the better tool. The information window that was adopted in the present study was of little help; it lengthened the time needed to interpret the image without improving performance. We would suggest examining an interactive information window that would provide access to various sources of information and to specific details required by the analyst. A surprising and distressing finding in the eye-movement data was that the analysts did not inspect all the vehicles in the image, and

at times appear not to have been aware that they had already inspected a vehicle and inspected it again. We believe that it would be worthwhile examining the possibility of both training the analysts to be more systematic in their scanning of the image and also allowing them to mark vehicles that they inspected but did not mark as targets with a different marking.

REFERENCES

Baudisch, P., Good, N., Bellotti, V., & Schraedley, P. K. "*Keeping things in context: a comparative evaluation of focus plus context screens, overviews and zooming.*" ACM Conference on Human Factors in Computing Systems (CHI 2002); 2002 April 20-25; Minneapolis; MN. NY: ACM; 259-266, 2002.

Duchowski, A. T. "*Eye Tracking Methodology: Theory and Practice.*" London: Springer-Verlag, 2002.

Finegold, L. S., Withman, R. L., & Kuperman, G. G. "*Preliminary operability assessment of the Interactive Imagery Exploitation (IMIMEX) imagery analyst.*" Technical Report, Crew System Interface Div., Human Effectiveness Directorate, Wright-Patterson AFB, OH, (ADA399544)., 2001.

Maltz, M., & Shinar, D. Eye movements of younger and older drivers. *Human Factors, 41*(1), 12-25, 1999.

Rayner, K. Eye movements in reading and information processing: 20 years of research**,** *Psychological Bulletin, 124*(3), 372-422, 1998.

Rimey, R.D., Klarquist, W.N. & Debrunner, C.H. "*Design of zoomable user interfaces and lens tools for intelligence analysis.*" 27th AIPR Workshop: Advances in Computer-Assisted Recognition, Proceedings SPIE, Volume 3584, 1998, pages 17-28, 1998.

Setter, P., Marciano, H., Lipkin-Goldberg, M., & Norman, J. "*A study of the eye-movements of military observers.*" Research Report, Ergonomics and Human Factors Unit, Institute of Information Processing and Decision Making, University of Haifa, (in Hebrew), 2007.

Setter, P., & Norman, J. "*A study of human stereoscopic eye-movements to provide data for stereo computer vision models.*" Research Report, Ergonomics and Human Factors Unit, Institute of Information Processing and Decision Making, University of Haifa, 2006.

Setter, P., Norman, J., Lipkin-Goldberg, M., & Marciano, H. "*Encoding and displaying ATR designations in SAR images.*" Research Report, Air Force Research Laboratory, Human Effectiveness Directorate, Wright-Paterson AFB, OH, AFRL-HE-WP-TR-2006-0157, (ADA465163), 2006.

Setter, P., Norman, J., & Marciano, H. "*The effects of ATR on the interpretation of SAR images.*" Ergonomics and Human Factors Unit, Institute of Information Processing and Decision Making, University of Haifa, (in Hebrew), 2004.

APPENDIX 1. Instructions for the First Experiment (translated from the Hebrew)

In the present experiment you will be presented with SAR images of a sector with vehicles in it. Some of the vehicles will be targets and other distractors. <u>Your task will be to distinguish between targets and distractors and mark the targets with the aid of the mouse.</u>
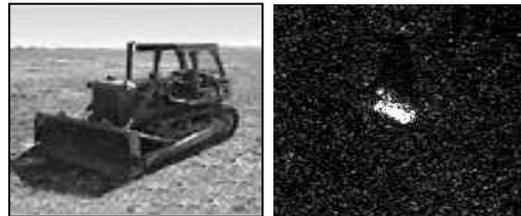
The targets in the experiment will be one of the following vehicles: T62, BMP2, and BTR60.

The distractors in the experiment will be one of the following vehicles: D7 and ZIL131.
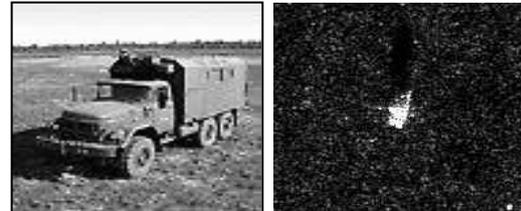
Instructions for the practice:

Before the experiment proper we will have a session in which you will get a chance to practice distinguishing between targets and distractors. On each trial you will be shown a SAR image of a single vehicle and you will have to press on the appropriate button with the aid of the mouse: on "target" if the image is a target and on "distractor" if the image is a distractor. If you make a mistake you will hear a tone.
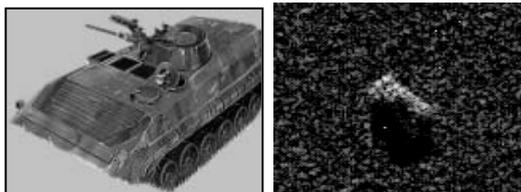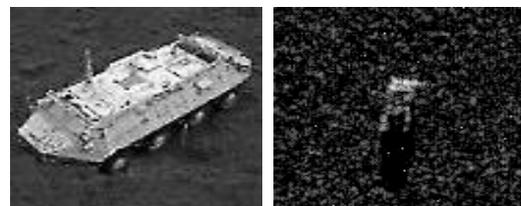
D7 – Distractor

ZIL131 – Distractor

T62 – Target

BMP2 – Target

BTR60 - Target

Instructions for the experiment:
On every trial you will be presented with a SAR image in which some of the vehicles will be surrounded by a red ellipse. The meaning of the red ellipse is that the ATR system identified the vehicle as one of the targets. ATR (Automatic Target Recognition) is a system for automatic recognition of targets by a computer. Ideally the ATR should designate all the targets and only the targets, but for various reasons the system is liable to make mistakes: to designate distractors as "targets" and to miss true targets. In other words, due to the inaccuracy of the ATR system, it is likely that some of the targets will not be designated while some of the distractors will be designated as "targets". The reliability of the ATR system in the present study is about 80%. The reliability of the ATR system indicates how many of the vehicles designated by the ATR are true targets.

Your task is to examine all of the vehicles in the image and decide which of them is a true target and mark these with an X by pressing the left button on the mouse. In other words, in each image you should mark the three target vehicles, T62 or BMP2 or BTR60 and only these three. Before marking a vehicle make sure that it is indeed a target, as you will not be able to erase the mark. After marking all the targets in the image move on to the next image by pressing the space bar on the keyboard.

The experiment will consist of four blocks of trials in which SAR images will be presented, and your task will be to mark all the targets in those images.
In each of the blocks you will have a magnification aid at your disposal allowing you to magnify a specific part of the image. In two blocks you will have a moving magnifier that simulates a magnifying glass moving over the image, which can be moved with the aid of the mouse. The magnification is 2x in the square demarcated by green sides. In the two other blocks the magnification appears in the upper window at the right side of the image, while the area magnified is demarcated on the image by the moving green square.
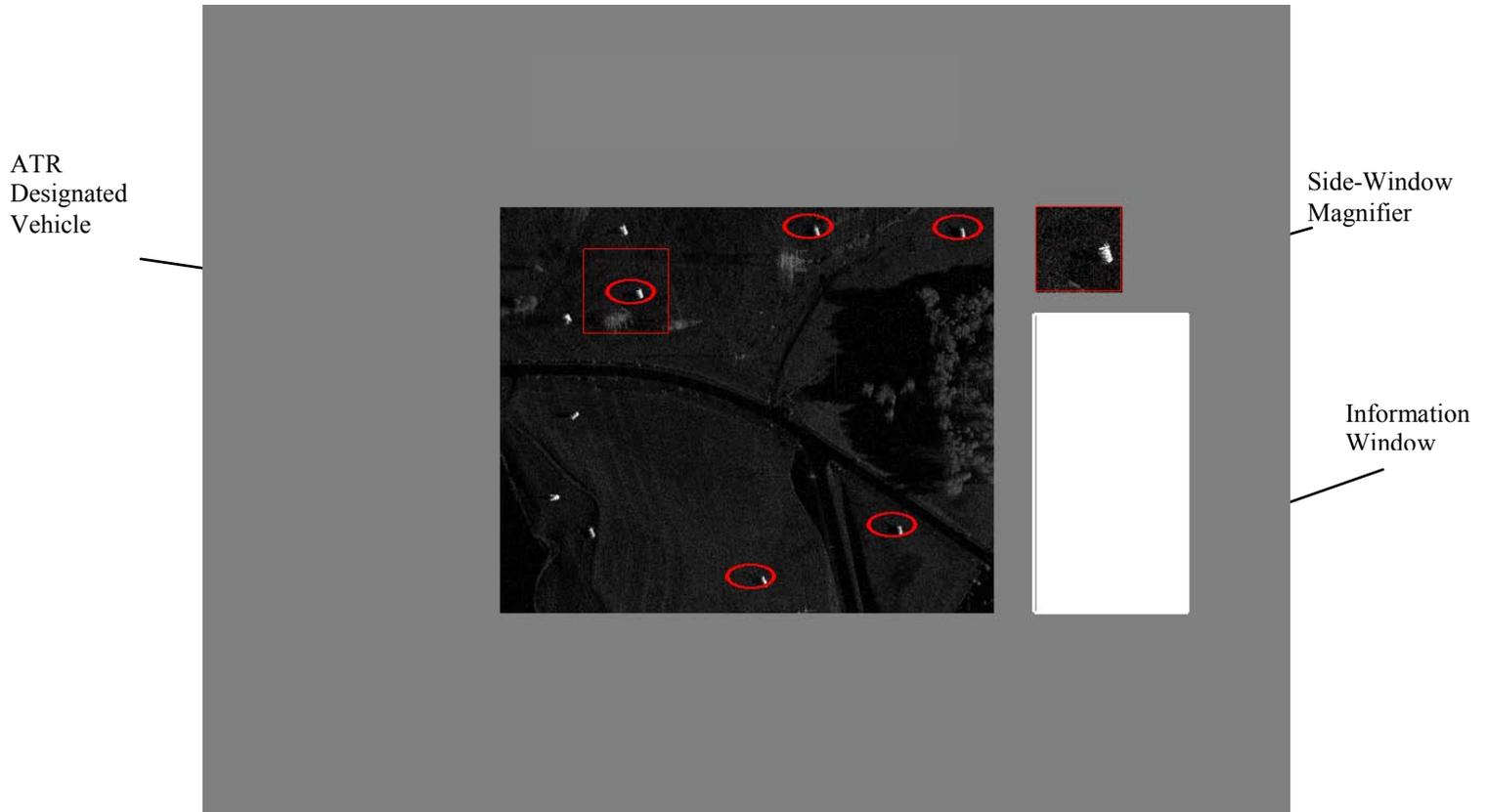
Important: When you decide that a vehicle is a true target, locate it as near as possible to the center of the square so that your response will be recorded by the computer. To make this easier we have added little dots on the diagonals of the square.

In addition, in two trial blocks (one with each type of magnification) an information window will appear at the lower right side of the image. This window will appear empty at first, but if you press the right button on the mouse you will get the information. If you press the button when the mouse is on a vehicle designated by the ATR (target), then you will get information on the specific target that the ATR identified. The information in the window includes an optical image, a SAR image, and sketches of the specific vehicle. The information in the window will be surrounded by a red square, and if you scroll the mouse wheel you will be able to get similar information on all the vehicles in the arena. If you press the right button when the mouse is not on a vehicle designated by the ATR you will see an empty red square but you will be able to see all the vehicles by scrolling the mouse wheel.
Before each block of trials you will get an example and be able to try out all the aids and learn how to use them.

Two aids – magnification and the information window – will serve you in carrying out your task. You can use them when you wish. Remember, it is important that you be as accurate as possible. For each target that you mark correctly you will get one point and every erroneous marking will lessen your score by one point. At the

end of the experiment you will get your point total which will serve as an assessment of your performance.

An example of a display with a side-window magnification and an information window:

ATR Designated Vehicle

Side-Window Magnifier

Information Window

APPENDIX 2. Eye-movements - Instructions

As part of the experiment we will want to examine the way you search for targets by monitoring your eye-movements. During the experiment you will wear head gear with miniature cameras that record your eye-movements. It should be noted that this causes no harm and is not in any way dangerous to your health. These are simple cameras that are photographing your eyes.

Before the start of the experiment we will calibrate the system. The calibration focuses the cameras on the eyes. It is important that you try not to move so as not to disturb the calibration. Your task during the eye-movement monitoring is exactly the same as in the main experiment.

LIST OF ACRONYMS

ANOVA   Analysis of Variance

ATR   Automatic Target Recognition

GIS   Geographic Information System

GPS   Global Positioning System

INIMEX   Interactive Image Exploitation

MSTAR   Moving and Stationary Target Acquisition & Recognition

SAR   Synthetic Aperture Radar