Human search with a limited Field of View: the effect of scanning parameters and scene content

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ABSTRACT

In order to find an optimal scanning strategy we determined the relationship between search performance and several scanning- and scene parameters in human observer experiments. The observers searched with a limited field of view (FOV) through a large search sector for a target (a camouflaged person) on a heath. From trial to trial the target appeared at a different location. Predefined (horizontal) scan paths were used with constant speed. The subjects hit a button as soon as the target was spotted. We determined the effect of scanning speed, zoom factor, FOV width and target location on search performance (detection time and -probability). We also obtained estimates of target conspicuity for all targets and determined the relationship between conspicuity and search performance. We found that search performance was largely determined by the angular scanning speed of the simulated camera, and largely independent of zoom factor. The results show that conspicuity can be used to predict search performance in search with a limited FOV (this was previously shown for unrestricted search). Target conspicuity decreased when the targets appeared closer to the horizon (and where therefore more distant). Such a systematic dependency between target conspicuity and target location can be (and is probably) used by the observers to optimize search performance. The results further show that a reduction in the FOV width affects search performance when the time that a target is visible falls below a certain value (in our case about 1 sec). These findings can be used in future models of search performance with a limited FOV.

Keywords: Search performance, Field of Regard, Field of View, Modeling, Conspicuity, Scan path, Zooming, Target, Detection time, Detection probability

1. INTRODUCTION

A large and important part of military practice consists of surveying a designated area (FOR: Field of Regard). Military personnel is trained to scan an area in a specific manner, with scanning procedures depending on the task and function of the scanner. The question is whether these procedures are actually used in practice. That this is not (always) the case was shown in a large scale field experiment organized by the NVESD (Night Vision & Electronic Sensors Directorate, Ft. Belvoir, Virginia) in June 1995 called DISSTAF[1]. In this experiment scan patterns of experienced gunners were recorded while performing a realistic search task. The scan patterns were very different from the predescribed procedure. In 90% of the time the Narrow FOV was used instead of the overview image. Search strategy and search performance differed largely from person to person. The question arises whether the predescribed scanning procedure is optimal. It can also be questioned whether an optimal scanning strategy exist at all (if it does, what does it look like?). In the current study we investigated how search performance depends on basic scan parameters such as scan speed, zoom factor, target location and conspicuity of the target. Once it is known how search performance depends on these basic parameters, search performance for a given scan path can be estimated. This “model” can then be used to search for the optimal scan path for a given scene, and derive good scanning strategy and good scanning heuristics.

2. METHODS

We ran a series of experiments in which observers searched for a target (a camouflaged person) in a natural environment. The observers searched with a limited FOV through a large panoramic image displayed on a 21 inch computer monitor, with a resolution of 1024 x 768 pixels (pixel depth 16 bits). We simulated a situation in which an EO-sensor with a limited FOV scans with constant angular speed over the Field of Regard.

The panoramic images (covering in reality an area of 75 deg x 20 deg) consisted of a series of high resolution images obtained in the visual domain with a photographic camera with 300 mm lens. Whenever possible, at each viewing direction of the camera an image was taken with and without a camouflaged person somewhere in the image (see Figure 1). The slides were digitized to images of 1536 x 1024 pixels, and were made into one large panorama of 16384 x 1536 pixels. The fact that the same scene was shot with and without target allowed us to make panoramic images with a target at various locations in the panorama. The scene consisted of a heath scattered with trees. The weather was misty (see Figure 1).

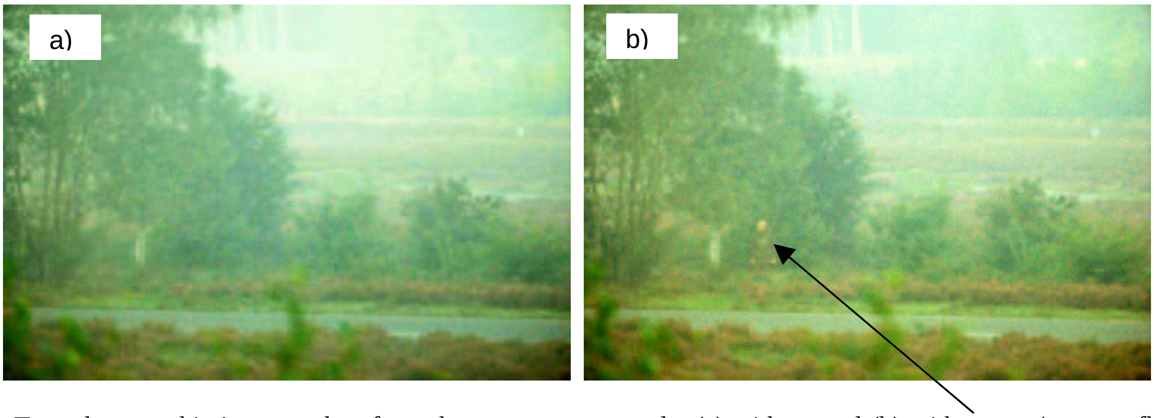

Figure 1. Two photographic images taken from the same camera angle, (a) without and (b) with target (a camouflaged person).

Copies of the panorama were made, each with the target in one out of 45 different locations. We also made scaled versions of the panoramas, with panoramas that were 2x and 4x smaller than the original, i.e. with 8192 x 768 pixels and 4096 x 384 pixels respectively. Figure 2 shows which parts are shown when the different zoom factors are used.

In experimental sessions the panoramas were viewed with a limited FOV of 1024 x 768 pixels and predefined scan paths were used. The scan paths were horizontal and had constant speed (see Figure 3 for an impression of a scan path). Each panorama was extended with empty black images on both sides of the panorama and scanning started with the FOV centered on the black image on the left side of the panorama. After the forward scan (from left to right) was finished the black image on the right came into view. This image was shown for a few seconds before the return scan (from right to left) was started.

The task of the observer was to press the fire button on a joystick as soon as he/she detected the target. After this a black empty screen appeared and the observer indicated where the target was seen at the time of detection, by moving a white cross over the screen (using the joystick) to the target location and pressing the fire button again. Whenever the target had disappeared from the window at detection, the observer was asked to put the cross at the side of the screen at the correct vertical location where the target had disappeared. This indication was used to check whether the target was found correctly. The observer was free to choose a suitable distance to the PC-monitor (around 45 cm).

Detection times and target locations were recorded for predefined scan paths with
- zoom factor: 1, 2 or 4
- scan speed: 5, 10 or 20 pixels per frame at a frame rate of 75 Hz
- horizontal FOV width: 1024 (full) or 512 (half) pixels

In total 4 sessions were run with

1. zoom factor 1, scan speeds 5, 10 and 20 pixels per frame, full window size (1024)
2. zoom factor 2, scan speeds 5, 10 and 20 pixels per frame, full window size (1024)
3. zoom factor 4, scan speeds 5, 10 pixels per frame, full window size (1024)
4. zoom factor 1, scan speeds 5, 10 and 20 pixels per frame, window size halved (512): in this case the left and right sides of the screen were covered with cardboard.

From trial to trial the speeds were randomized (so, the observer did not know the speed of the next trial). Only targets found during the forward scan (from left to right) were treated as hits (correct detections).

Four observers, with initials MH, MR, LB and SK, participated in the experiment. In each session each target was shown once for each scan speed. All observers performed each session once.

Figure 2. The FOVs for zoom factors of 1 (most central part), 2 (middle) and 4 (the whole image). For a zoom factor of 2 a panorama was used that was half the size (in pixels) of the original image. For a zoom factor of 4 a panorama was used that was a quarter the size of the original image. In the latter case, the top and bottom parts of the screen were black (as in the image). The PC monitor always displayed an image of 1024 by 768 pixels.

Figure 3. Impression of a scan path with a zoom factor of 1 showing the change in FOV over time (t1..t5). Note that in reality the FOV (PC-monitor) was fixed and the panorama moved.

3. RESULTS OF THE SEARCH EXPERIMENTS

3.1 Raw data

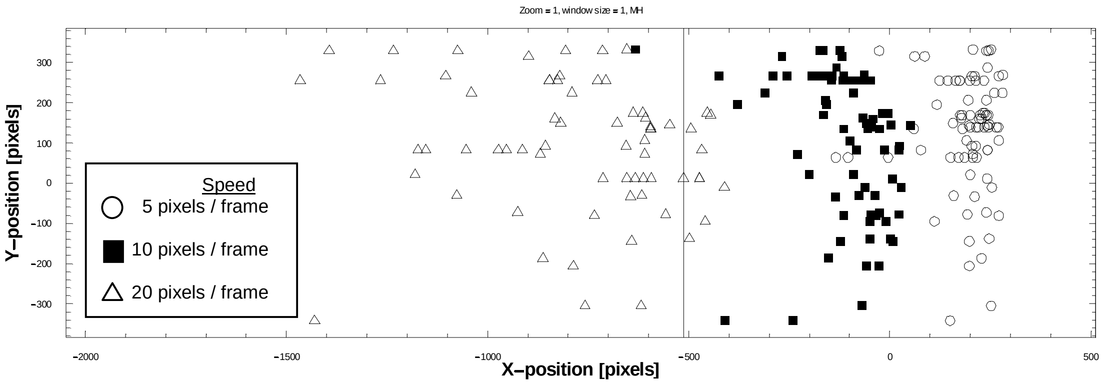

Figure 4. An example of the target locations at the time of detection (only the correctly detected targets are shown) relative to the center of the FOV (center of the screen, at (0,0)), with the x and y location measured in pixels. The different scan speeds are represented by different symbols: open circles for 5 pixels / frame, closed squares for 10 pixels / frame, and open triangles for 20 pixels / frame. The example shows the data of observer MH for a zoom factor of 1 and full FOV (condition 1).

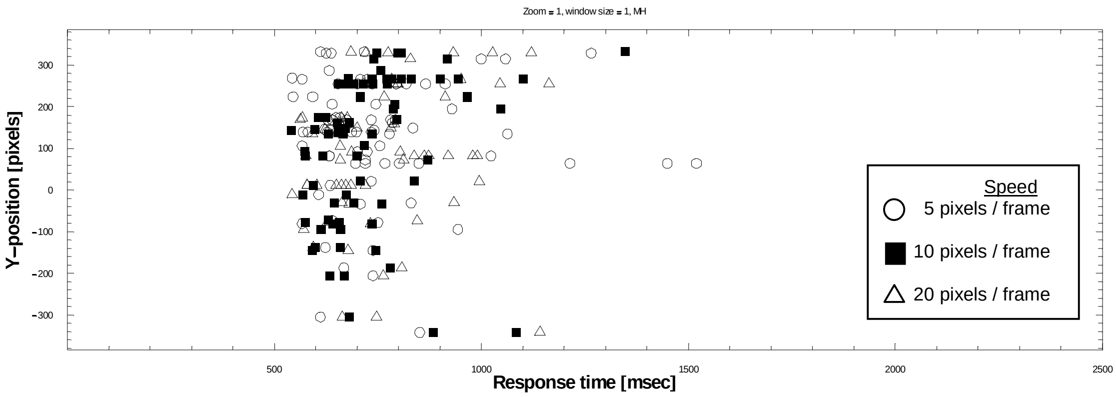

Figure 5. The data of Figure 4 shown with vertical position (relative to the center of the screen) versus the response time: the time between the point at which the target came into view and the time of detection. The different scan speeds are represented by different symbols: open circles for 5 pixels / frame, closed squares for 10 pixels / frame, and open triangles for 20 pixels / frame. The example shows the data of observer MH for a zoom factor of 1 and full FOV (condition 1).

Figure 4 shows an example (data of condition 1, observer MH) of the locations of the (correctly detected) targets at the time of detection relative to the center of the screen for different scan speeds. The distance between the targets and the edge where the targets first appeared (the right side of the Figure 4) appears to scale with scan speed: the targets with speed 10 pixels per frame are about twice as far from the edge as the targets with speed of 5 pixels per frame, and the targets with speed 20 pixels per frame are again twice as far from the edge as the targets with speed of 10 pixels per frame. Figure 5 shows the same data but now with the response time, i.e. the time between appearance and detection on the horizontal axis. The distribution of data points for different scan speeds are very similar. This means that the pattern of response times is largely independent of the scan speed. The data from the other conditions and observers show a similar pattern.

3.2 Detection time distributions

In Figure 6, the figures on the left-hand side show the cumulative fraction of detected targets as a function of the time that a target is in the FOV (Figures a, c, e and g) for all four conditions and for all scan speeds (different curves). The figures on the right-hand side of Figure 6 show the derivatives of the cumulative functions. These graphs show the fraction of targets detected at a certain time. The data of all observers is used in these figures. Hardly any responses are recorded in the first 500 ms. This suggests that the reaction time is about 500 ms. After 500 ms the fraction of detections increases and then saturates. After 2500 ms hardly any additional targets are found. Figure 6 shows that the total number of detected targets decreases with increasing speed, e.g. the final fraction detected (at 2500 ms) in Figure 6c decreases with an increase in speed. The final fraction of detections also decreases with increasing zoom factor (compare Figures 6a, 6c and 6e).

The figures on the right show that the distribution of detection times is remarkably similar across speeds and zoom factors. The peak remains at the same position (around 750 ms). This invariant property can be used in a future model of search performance. The peak height decreases with increasing speed and zoom factor reflecting the decrease in overall detection probability with increasing speed and zoom factor.

When the data of condition 4 (FOV width halved, figures g & h) are compared with the data of condition 1 (full FOV width, figures a & b) it appears that only performance for the fastest speed is affected by the reduction in FOV width. Apparently, good detection requires the target to be visible for at a minimum amount of time. The largest possible response time corresponds to the time a target is visible plus the reaction time (approximately 500 ms). With a full FOV width, the time that the targets are visible is 2410, 1205 and 602 ms for speeds (S) of 5, 10 and 20 pixels per frame respectively. Therefore, hardly any more targets will be found after 2910 (S = 5), 1705 (S = 10) and 1102 ms (S = 20). Figures 6b, 6d and 6f show that all (correctly) detected targets are found within the maximum time derived above plus an additional 200 ms (possibly due to fluctuations in reaction time). When the FOV width is halved hardly any targets will be found after 1705 (S = 5), 1102 (S = 10) and 801 ms (S = 20). Figure 6h shows that all detection times fall within this time span plus an additional 200 ms. This property can be used in a future model of search performance with a limited FOV.

3.3 Hit rate

Figure 7 shows the fraction of targets that are detected as a function of the vertical target position for the different scan speeds for all 4 conditions. The fraction of detected targets decreases with increasing vertical position. This is likely to be due to the fact that targets closer to the horizon are further away, and therefore smaller in the image. In general, smaller targets will be more difficult to detect (this issue will be discussed in more detail later). The detection rate also decreases with increasing zoom factor (compare Figures 7a, 7b & 7c). As noted in the previous section, halving the FOV width only affects performance for the largest speed (Figure 7d vs. 7a).

Figure 8 shows the data from Figure 7a, 7b and 7c in a single graph (leaving out the data of condition 4). The different zoom factors are indicated by different line dashings. The gray level indicates the *real scan speed*, i.e. the angular scan speed of the simulated EO-camera in the field. For example, a zoom factor of 1 and scan speed of 20 pixels/frame simulates a situation in which a camera scans over the Field of Regard with an angular scan speed of 7.3 deg/sec. The same *real scan speed* is simulated by a zoom factor of 2 and a scan speed of 10 pixels/frame, as well as a zoom factor of 4 and a scan speed of 5 pixels/frame. The difference between the three cases is the zoom factor. (The product of scan speed and zoom factor relates to the real scan speed.) Curves with different zoom factors but with the same *real scan speed* are similar. This means that in the simulated situation, *performance deteriorates with an increasing in the angular scan speed of the EO-camera.* However, *performance is largely independent of the zoom factor* of the simulated EO-camera.

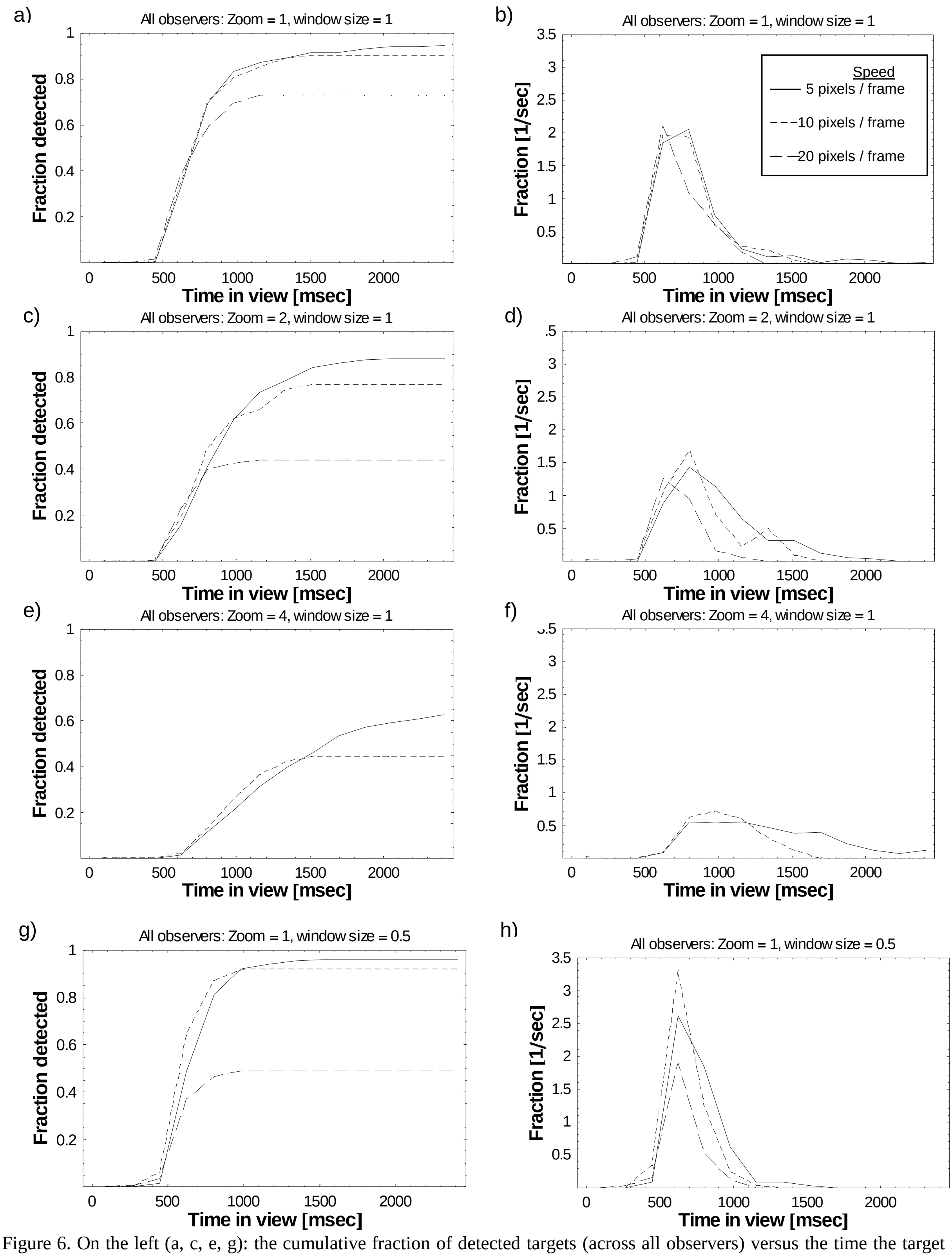

Figure 6. On the left (a, c, e, g): the cumulative fraction of detected targets (across all observers) versus the time the target is within the FOV for different speeds (solid line: 5 pixels / frame, short dashes: 10 pixels / frame, long dashes: 20 pixels / frame) for all 4 conditions. On the right (b, d, f, h): the derivatives of the functions on the left. The latter figures more clearly show how the detection times are distributed.

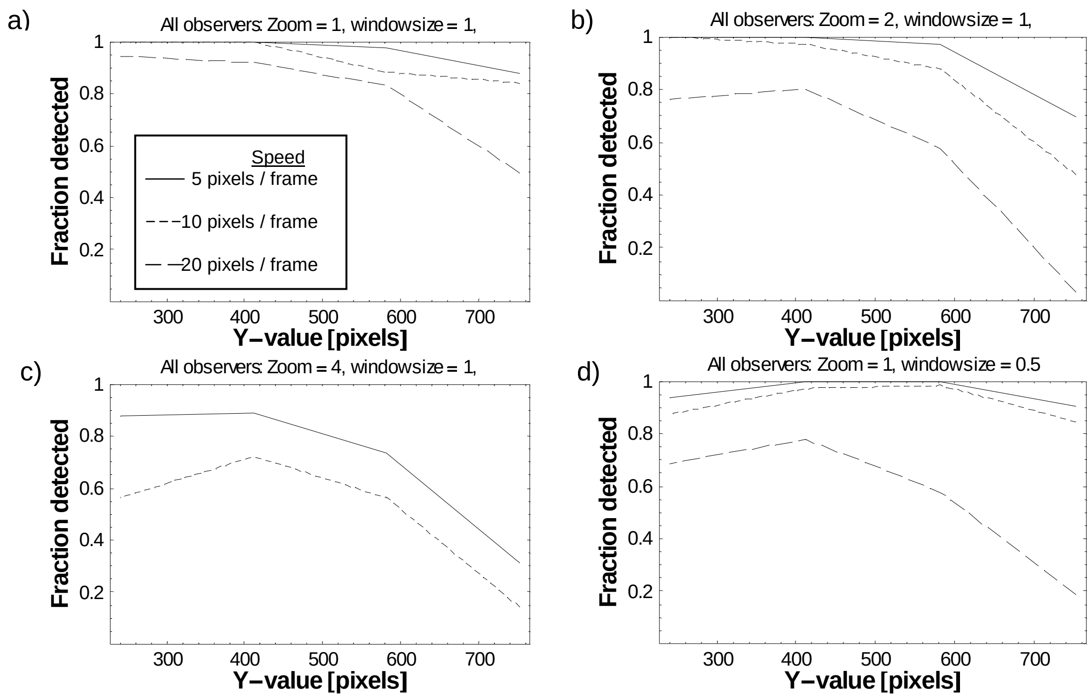

Figure 7. The fraction of detected targets as a function of the vertical position of the target for the 4 conditions with separate curves for the different speeds: solid line: 5 pixels/frame, short dashings: 10 pixels/frame, long dashings: 20 pixels/frame. The vertical target position is measured in pixels in the original image (zoom = 1). Zero coincides with the bottom of the panorama.

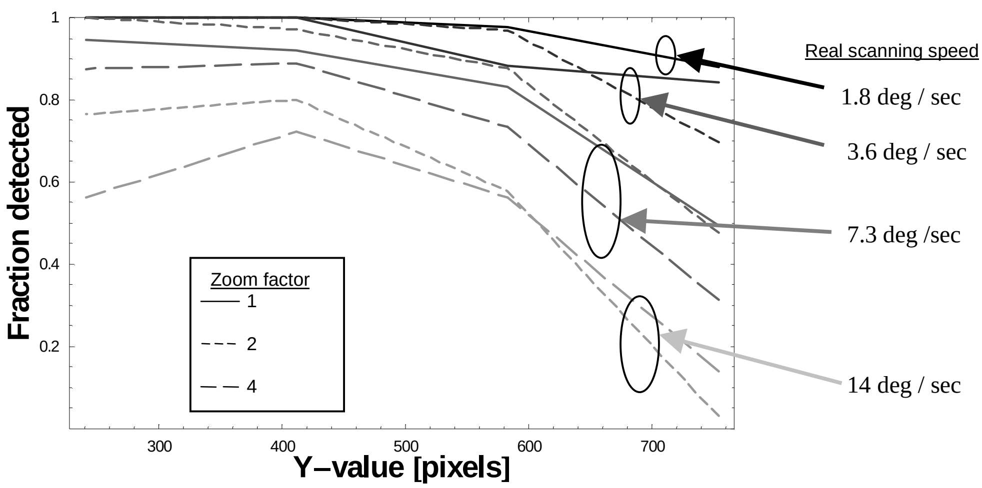

Figure 8. The data from figure 7a, b, & c (different zoom factors) in a single graph with the zoom factor indicated by the dashing type. Instead of the scan speed on the PC monitor, the scan speed is expressed in the *real scan speed*, i.e. the angular scan speed of the simulated situation in which an EO-sensor scans over the Field of Regard (the heath). The scan speed is indicated by the gray level. The graph shows that the fraction detected in the simulated situation decreases with increasing angular scan speed, but is largely independent of the zoom factor of the EO-sensor.

3.4 Reproducability

To determine whether certain targets are missed more often than others, we calculated for each target the total fraction detected over all zoom factors and speeds (11 measurements per target), as well as the average detection time (averaged over the times the target was detected) for all four observer. We plotted the fraction detected and average detection time for one observer versus that of another observer to see whether different observers found the same targets difficult to detect. Figure 9b shows an example in which the fraction detected (top) and the average detection times (bottom) per target are plotted for observer MH versus the values for observer LB. Figure 9a shows the magnitude of the correlation in the data of different combinations of observers.

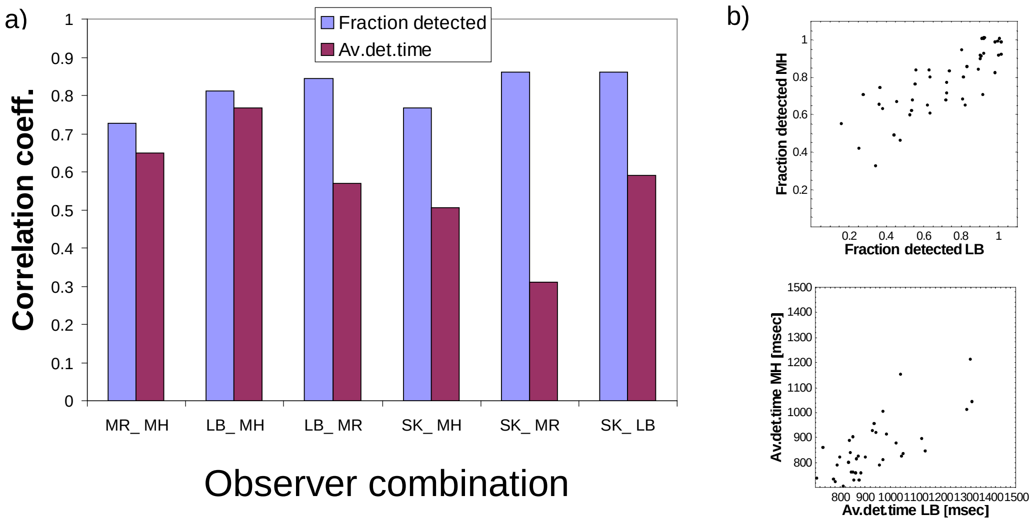

Figure 9. a) The correlation in the total fraction of detections per target (average over all zoom factors and speeds) between different observers, and the correlation in the average detection time (of the targets that were detected) per target between different observers. On the right hand side (b) example showing the correlation in the fraction detected (top)* and average detection times (bottom) per target between observers MH and observer LB.

The fraction of the conditions in which a target is detected is highly similar across observers, with correlation coefficients ranging from 0.73 to 0.86. Average detection times are also correlated (but somewhat less), with correlation coefficients ranging from 0.31 to 0.77. This shows that for different observers the same targets are more difficult to detect (and they also agree on which targets are easy to detect), i.e. certain targets are inherently more difficult to detect.

4. CONSPICUITY

TNO Human Factors has developed a psychophysical method to quantify the visual conspicuity of a target in a complex scene[2]. This measure can be obtained quickly and only a few observers are needed to achieve a reasonable accuracy. The measure is directly related to the conspicuity area defined as the area around the point of fixation within which the target can be distinguished from its background[3-5]. It has been shown that the conspicuity measure developed at TNO correlates well with search performance (mean search time, detection probability) in situations with a static FOV[6-7]. Therefore, we assume that this measure can also be used to predict search performance in situations in which one scans over a larger Field of Regard (FOR) with a limited FOV.

4.1 Method

The conspicuity area of a target is defined as the region around the center of the visual field where the target is capable of attracting visual attention, because it is perceived as significantly distinct from its local background. Figure 10 illustrates the concept of the conspicuity area. The circle represents the extent of the conspicuity area of the target and corresponds to the maximal separation between eye fixation and the target at which the target can still be distinguished from its local background. The conspicuity measurement procedure introduced here is as follows. First, the observer visually inspects (foveates) the target. Next, the observer fixates a point in the scene that is at a large distance from the target location. When the observer fixates this point, the target should be positioned so far in his peripheral visual field that it can not be distinguished. The observer then successively fixates locations in the scene that are progressively closer to the target location, until he can perceive the target in his peripheral FOV. The successive fixation points are along a line through the initial fixation point and the center of the target. The distance between the fixation location at which the target is first noted and the center of the target is then recorded (measured in pixels on the screen). We obtained (static)

* Some random jitter was added to the data points to make all points visible.

conspicuity estimates from 3 experts (MH, PB and JV) for all 45 targets using the large panoramic image (zoom factor of 1) and determined its relation to search performance.

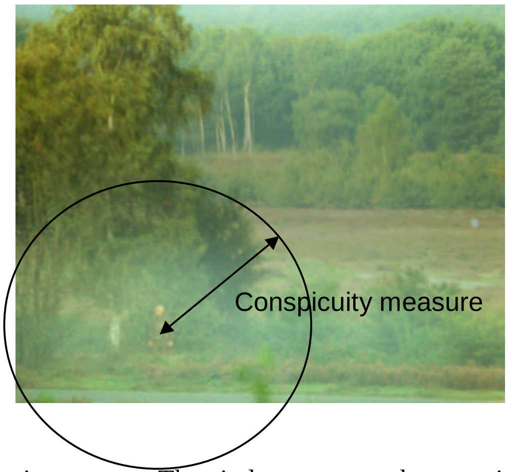

Figure 10. Illustration of the conspicuity concept. The circle represents the conspicuity area of the target (located in its center), and the radius (the conspicuity measure) corresponds to the maximum separation between eye fixation and the target at which the target can still be distinguished from its background.

4.2 Results

The conspicuity estimates from the three experts were found to be correlated, with correlation coefficients of 0.66 (JV vs. MH), 0.73 (JV vs. PB) and 0.76 (MH vs. PB). The fact that these correlation coefficients are relatively low is probably related to the fact that for each target only one estimate was obtained. We will use the geometric average of the conspicuity estimates of the 3 experts as our best estimate of the conspicuity of the target.

Figure 11 shows the relationship between search performance and target conspicuity. Figure 11a shows the fraction of detection and Figure 11b shows the average detection time versus target conspicuity for all 45 targets. The fractions detected and the average detection times are average over all zoom factors, speeds and observers. On average, the fraction detected increases with an increase in target conspicuity. Also, the average detection time (of the targets that are detected) decreases with increasing target conspicuity. The correlation between the fraction of detection and conspicuity is 0.72 and the correlation between the average detection tine and target conspicuity is -0.71. *Therefore, conspicuity can be used to predict search performance* (along with other factors).

That search performance and target conspicuity are not perfect is partly due to experimental error in the measurements. Using the observer-to-observer variation we obtained estimates for the uncertainty in the conspicuity (about 15%), the fraction detected (about 3.5%) and the average detection time (the standard error increases from 8 ms for the lowest detection time to 200 ms for the highest detection time). Taking these errors into account, a perfect linear relationship between target conspicuity and fraction detected yields a correlation coefficient of $R = 0.94 \pm 0.01$ (R values calculated from MonteCarlo simulations). This is still much higher than the correlation in the data ($R = 0.72$). The fact that the correlation coefficient is lower than 1 is therefore not entirely due to experimental error. Also, due to the errors even a perfect linear relationship between target conspicuity and average detection time would result in a correlation coefficient of $R = -0.79 \pm 0.07$. This is close to the correlation in the data we obtained ($R = -0.71$). The correlation coefficient is therefore not significantly different from –1 (given the variance in the data). Still, the main reason why the correlation between search performance and target conspicuity is not perfect is that other factors, such as where the eyes fixate, are likely to have a large impact on performance.

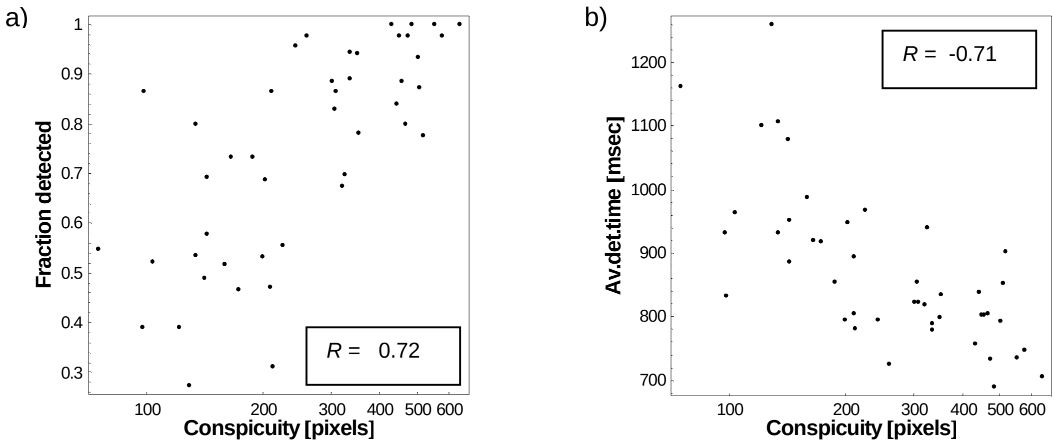

Figure 11. Relationship between search performance and target conspicuity. In a) the fraction detected is plotted against target conspicuity for each target, and b) shows the average detection time (of the detected targets) versus target conspicuity for each target. The fraction of detected targets and the average detection time are averages over all conditions, speeds and observers. The fraction detected generally increases with increasing target conspicuity. The average detection time decreases with increasing target conspicuitv.

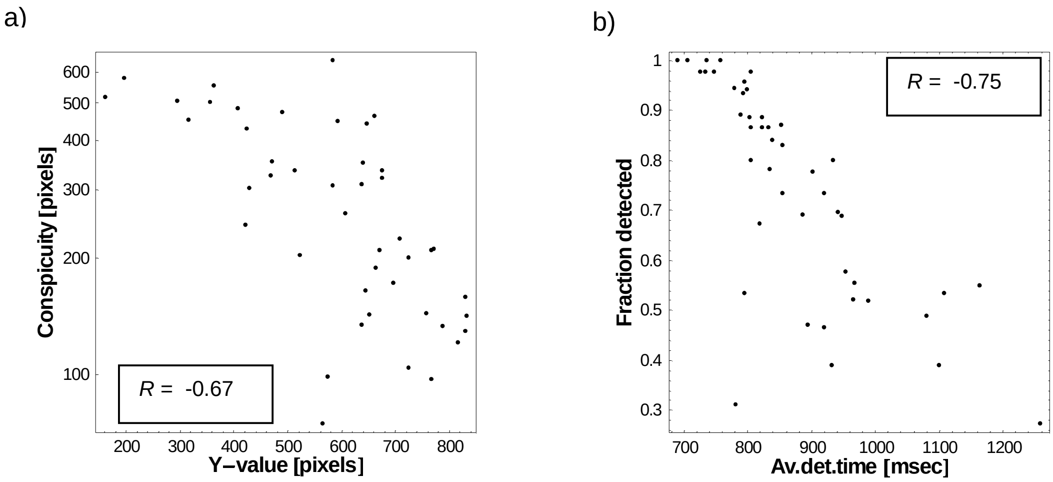

Figure 12. a) Relationship between target conspicuity and vertical target position (y-value). b) Relationship between average detection time (of the detected targets, average over all zoom factors, speeds, and observers) and the fraction detected. The conspicuity decreases with increasing vertical position (when targets get closer to the horizon, and therefore more distant). Average detection time and fraction detected are correlated: the targets with large average detection times have a low detection probability.

There is also a relationship between target conspicuity and the vertical position of the target, as indicated by Figure 12a. As mentioned before (section 3.3), targets that are higher up in the image are closer to the horizon and therefore smaller. Therefore, *targets that are closer to the horizon targets will generally be less conspicuous.* This systematic relationship between vertical position and conspicuity can be used by the observer to optimize search performance (see Summary & Discussion section). Given the relationship between conspicuity and vertical position it will not be surprising that the fraction detected and average detection time are also correlated to vertical target position: the correlation coefficients *R* are –0.69 and 0.48 respectively.

Figure 12b shows the relationship between the average detection time (average over those trials for which the target was detected) and fraction detected per target. As expected, *the average detection time decreases when the detection probability increases*.

5. SUMMARY & DISCUSSION

Main findings of this study

We have used a predefined scan path and determined the effect of several parameters on search performance. We plan to use these findings to construct a model of search performance for a given scan path. Such a model can then be used to predict search performance for a given path (scan path, zoom factor, scan speed). The final goal is to compare different search strategies and determine which strategy is best. A more general goal is to derive general heuristics for good scanning behavior.

The main findings of our study are:

1. Search performance was found to be largely determined by the angular scan speed and largely independent of the zoom factor in the simulated situation in which an EO-sensor scans over a FOR with a limited FOV.
2. Search performance improved with increasing conspicuity. Conspicuity can therefore be used (along with other factors) to predict search performance.
3. Conspicuity and vertical position were correlated. This is due to the “horizon effect”, i.e. targets closer to the horizon (higher up in the image) are more distant and therefore smaller in the image. This systematic relationship can be used to optimize performance, since conspicuity can (partly) be predicted based on target location.
4. Performance deteriorates when FOV width becomes too small. This indicates that the target has to be visible for a minimum amount of time to obtain good performance. When the time that a target is visible exceeds this minimum, performance does not improve much more. This is probably due to the fact that the region far removed from the edge at which targets appear is not inspected.

Regarding the minor role of the zoom factor

We found that search performance was largely independent of the zoom factor. Instead, it was largely determined by the angular scan speed (of the simulated EO-device). We think that this was the case because the *region of interest*, i.e. the region in which targets could be expected, scaled with the zoom factor. If one zooms in further (e.g. zoom factor = 0.5) it can be expected that targets that fall within the scan path will be easier to detect and search performance for these targets will improve. (Those targets that do not become visible will of course not be detected). In the future we plan to examine this issue further.

Regarding the role of conspicuity in search modeling

In previous studies it was found that target conspicuity correlates well with search performance in unrestricted search[6-7]. We have shown that also in restricted search (with a limited FOV) search performance correlates well with target conspicuity (as measured by a method developed at TNO). This suggests that conspicuity supplies the means of predicting search performance for different scenes, circumstances (e.g. weather conditions) and imaging systems (thermal, image intensified, visible, image fusing systems, color, black & white etc.). In the future we plan to investigate search performance for different scenes (forestry, urban, etc), weather conditions, and with different types of imaging systems.

Regarding the relationship between conspicuity and vertical position

We found that conspicuity and vertical position were strongly related, due to the fact that targets closer to the horizon are further away and appear therefore smaller in the image. Optimal search performance will probably mean that the observer gradually builds up an expectation of target conspicuity and likely location areas. This expectation is then used in planning the scan path (trace, scan speed, zoom factor). The “horizon effect” partly predicts what the target conspicuity will be. In mountainous regions the relation between distance to the target and target location in the image will be less simple. Still, the distance will vary (relatively) smoothly with changes in target location.

Subjective reports show that the relationship between target conspicuity and vertical position is used to optimize search performance. The observers reported that they tended to fixate close to the horizon. Thus, targets with the lowest conspicuity can be detected. Targets lower in the image are generally more conspicuous and will be detected anyway. Such a strategy will lead to better search performance. It also will reduce the effect of conspicuity on search performance. Therefore, we think that a model of search performance that incorporates (likely) eye movements will be much more successful than one that doesn’t. This is one of the reasons to study eye movements in the future.

Regarding the minimum time a target needs to be visible for good performance

When the FOV width was reduced this affected performance only for the highest speed. This suggests that each target should be into view for a minimum amount of time. The distribution of detection times (the time between appearance of the target and detection) turned out to be largely independent of scan speed and zoom factor. Above a detection time of about 1500 ms hardly any additional targets were found. Taking a reaction time of about 500 ms into account, this means that (in our case) a target should remain visible for at least about 1000 ms to reach good search performance.

What is optimal?

In order to optimize search strategy one needs to define what is meant by optimal. There will for instance be a trade-off between detection time (which in this context means the time between starting the search and detection) and detection probability. This means that one needs to minimize a certain cost function, e.g. that a tank is detected at least when the observer becomes within its shooting range.

Using predefined scan paths

In this study predefined scan paths were used. We determined effect of different scanning parameters on search performance. We plan to use these results to build a model of search performance. To construct a good model of search performance it is required to investigate free search as well. In most practical situations the observer will be free to choose a scan path. In that case a region can be inspected more than once. Several questions arise that cannot be answered by using experiments with predefined scan paths alone. For example, how well does the observer know which part was already inspected (and to what degree)? Also, how well does he/she know whether all parts (that can contain a target) were inspected and how much overlap is there? Does he/she know which part is under inspection at each moment in time (how good is his/her "situational awareness")? The advantage of using predefined scan paths is that in a short period of time and with a limited number of observers, reliable data can be obtained from with firm conclusions can be drawn.

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