Object recognition and detection: Potential implications from vision science for wilderness searching

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Abstract

Field searching relies heavily on human vision and the ability to recognize objects that are out of place in their environment. Searchers seek to continually improve their ability to detect clues. This paper provides an overview of findings from vision science investigations as they relate to the ability to detect and recognize objects. Vision research provides a solid basis for the utilization of the searcher's cube and the walk/stop/search cadence. It provides insights into the psychological factors that inhibit detection of low prevalence clues and means to reduce these barriers. Lastly, investigations from vision science illustrate the key elements needed in training to improve visual search outcomes.

KEY WORDS: *wilderness search and rescue, vision, visual search, foveal field, low prevalence effect*

Introduction

During a search and rescue operation, the goal of both searcher managers and searchers themselves is to rapidly and efficiently bring the search for a lost or missing person to a successful conclusion. Modern search theory is built upon the science of probabilities; in order to maximize the probability of success (POS), it is necessary to individually maximize the probability of area (POA, the probability a lost person or physical clue is in an area being searched) and the probability of detection (POD, the probability of detecting the lost person or clue, assuming these are in the area being searched) as the former is simply the product of the latter two. In the past several years, there have been significant steps forward in addressing the parameters that influence POD. It is known that POD is related to several search variables that can either be controlled during a search or estimated for a specific terrain in which the search is being conducted. These dependencies are best described by their mathematical relationships. Most approaches to search theory use the random search relationship originally developed by Koopman (1946, 1980), specifically:

$$POD = 1 - e^{-coverage}$$

where coverage is defined as the ratio of the area effectively swept (A_s) to the total area assigned to be searched (A_a). In turn, area effectively swept (A_s) is the product of the effective sweep width (W) and searcher effort (the latter being defined as the distance a searcher covers x the average rate of travel x the number of searcher hours involved in the task).

$$Coverage = A_s/A_a = [Effort \times W] \div A_a$$

Thus, in a hypothetical situation where all variables are constant except effective sweep width, the probability of detection would vary with the effective sweep width in an exponential manner.

$$POD = 1 - e^{-KW}$$

where the constant K encompasses all other variables.

The effective sweep width, W, is a statistical parameter; it is derived from the notion that a searcher is passing through an area with a large number of identical stationary objects that are uniformly distributed throughout the area. W has units of length and is a measure of the effectiveness with which a particular sensor can detect a specific object under specific environmental conditions (Koopman 1946). Within the context of this paper, the sensor is a human searcher. As the searcher passes, some objects will be detected, and others missed. The effective sweep width is statistically defined as the search width at which the number of missed detections inside W equal the number of detections outside W, as shown in Figure 1.

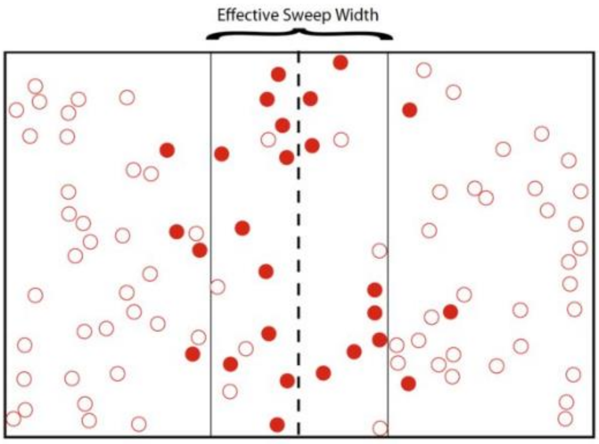

Figure 1: Effective Sweep Width (Banning 2017)

A solid dot indicates a detected object; an open circle indicates a missed detection.

Larger effective sweep widths are associated with situations where detection is greater. Effective sweep is statistically robust. As stated by Frost (1999) and shown by Koester (2014) and Chiacchia and Houlahan (2010), effective sweep width depends on the terrain environment, seasonality and search object characteristics as well as the searcher. In the context of wilderness search and rescue where a human is visually searching for the missing subject as well as physical clues, object detection and recognition by a searcher intuitively underpins effective sweep width and thus the probability of detection. Thus, improving this skill in a significant fashion would be expected to directly lead to more successful search operations, assuming all other parameters constant.

Vision science literature may reasonably be expected to provide insights regarding how significant improvements in searcher performance may be achieved. In this discipline, visual search is defined as the process of locating a target among a set of distractors in a scene, distractors being all other objects in the scene that resemble but are not the target. (Wolfe 1998). Visual science attracts great interest in its own right, but the ability to better recognize objects in the field of view has real-world consequences across a number of distinct disciplines. Whether it is improved luggage screening at airports for guns, bombs or other weapons, enhanced medical interpretation of diagnostic images so fewer cancerous tumors are missed, increased ability to inspect crowds for possible terrorists, patrolling a border, lifeguarding a pool or a variety of other endeavors that involve visual inspection, understanding how objects are viewed by human observers and recognized is critical as it allows for the possibility of improvement of the skill.

This paper provides an overview summary of the rich and emerging literature from vision science investigations that are of relevance to individuals involved in wilderness search and rescue, most of whom are not intimately familiar with this area of scientific research. The goal is to provide an understanding how objects are visually detected and recognized. (It is understood that, in the context of wilderness searching, objects of interest include not only the subject but articles of clothing, footprints, or other visible signs.) As such, this paper briefly reviews central vision, eye anatomy and eye movements involved in object recognition as well as the cognitive drivers that provide for interpretation of mental images of objects. Psychological factors that significantly influence the ability to recognize objects are also reviewed. Patterns of visual search from professional searchers are compared to novices and the impacts of training on real world search performance are discussed. As will be shown, vision science has much to teach regarding how to better perform searches in the wilderness; several areas are suggested for potential improvements.

Central foveal and peripheral vision

As light passes through the cornea, it is focus by the lens onto the retina at the back of the eye where the two types of photoreceptor cells reside (rods, cones, so named for their anatomical features). Rods greatly outnumber cones, approximately 91 million per retina to 4.5 million per retina (Purves 2001). Rods are extremely light sensitive and are responsible for recognizing movement and peripheral vision, among others. Rods are symmetrically distributed around the retina, except for the fovea, a small 1.2 mm diameter, central dimple in the retina located directly behind the lens. Not only are the photoreceptor cones responsible for color vision located within the fovea (with significantly fewer in the surrounding periphery), but light impinging upon the fovea is critical to our ability to recognize objects.

Human vision is an active process; visual information is received during brief periods of stable eye positions (fixations) before the eyes subconsciously move (termed saccades) to focus on another area (Ludwig 2014). Central vision or the foveal field of vision as it is sometimes referred to, is only a few degrees (less than 5°) wide. Carrasco and co-workers (1995) studied the effect of moving the target off center from the fovea (termed an eccentricity effect) by having subjects respond when they identify a specified target in a visual field presented to them. Their work clearly showed that both the time it takes to detect the target and respond, and the detection error rate increase with increasing eccentricity angle;

just a few degrees off center and these effects manifest. These results have been replicated by others (for example, Wolfe 1998, Scialfa 1998).

Wolfe and colleagues (1998) presented experimental evidence that items located near the fixation point receive more mental attention than those in the periphery and that this is a primary driver of the eccentricity effect; said differently, light focused on the fovea receives preferential cognitive processing and provides the sharpest, clearest images to the mind such that objects are most easily recognized when brought into the central or foveal field of vision (Eckstein, 2011). In addition, there is a general decrease in attention given to objects with increasing eccentricity (Staugaard et al 2016). Light impinging the retina at places other than the fovea is not nearly as efficient for object detection and recognition, Visual acuity is reduced 75% for objects just 6 degrees off center from line of sight (Purves et al 2001). Any part of an image that falls outside of the fovea may not be recognized because fine, spatial detail and form recognition occur within the foveal field (for example, Eckstein 2017, Strasburger 1996). Foveal analysis serves to identify the currently fixated object (Ludwid, 2014). Moreover, dependence on foveal vision for object recognition seems to be innate; in studies with subjects who had 10-20 years of lost central vision due to disease (Stargradt disease), no evidence was found of increased ability to use peripheral vision in this capacity (Boucart 2010). In studies of individuals with ophthalmoplegia (paralysis of the eye muscles such that normal eye movements are not possible), saccade-like head movements are made to visually sample the environment via the fovea (Gilchrist 1997).

Peripheral vision is involved in the detection of movement as well as night vision. In addition, peripheral vision does play an active role in visual sampling of the environment by regulating decisions regarding where to fixate next. Research indicates that saccadic eye movements are guided by peripheral vision up to 80-100 msec prior to eye movement (Caspi 2004, Ludwig 2007, Becker 1979, Ludwig 2014) Interestingly, studies have indicated that the cognitive processes involved in foveal analysis and peripheral selection can proceed simultaneously by parallel mental processes. (Ludwig 2014).

Eye Movements and Points of Fixation

Visual searching involves both eye movements and associated attention processes (Van Der Lans 2008). Eyes have a quick and continual motion, known as saccadic movement, that is used to focus on various points and create a mental picture of an image from a given scene. Saccades are extremely fast; the eye can focus on a target within fractions of a second. Measurements indicate between three and five saccadic movements each second (Henderson 2003, Zelinsky 2008). When observing a stationary image, eyes focus on an interesting point before rapidly moving to the next. Each of these points of focus is referred to as a fixation point (Ludwig 2014). Eye movements can be tracked by various means. Figure 2 shows the 1-minute gaze pattern of an air-to-ground searcher as an example of the saccadic movements, measured by eye tracking (Croft 2007).

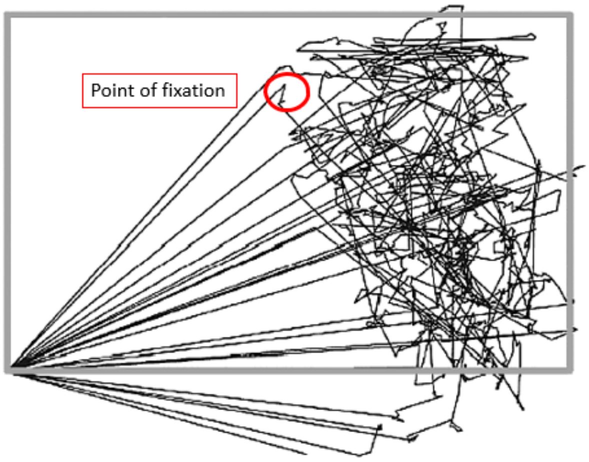

Figure 2: Example gaze pattern (modified from Croft 2007)

As stated above, accurate vision sufficient to recognize objects is largely limited to the fovea. To identify objects that are observed peripherally, the eyes bring it into the foveal field of vision by a saccadic movement (Poth 2015). Furthermore, mental processing of visual information is limited to sensory input gathered during fixations; no information is acquired during the saccadic movement (Martin 1974, Campbell 1978) that would otherwise result in a blurring of the image. Stated differently, pattern information is only acquired during periods of stability (Henderson 2003).

Precisely how the brain subconsciously decides where to point the eyes during a visual search is not completely understood and remains an active area of research (for example, Eckstein 2011, Fluharty 2016). Evidence suggests at least three factors are involved: low-level salient features (regions in a scene that differ locally in some fashion such as color, orientation, etc.), scene context (the relationship of the object to the search scene, e.g., room ceilings are not searched when looking for missing car keys) and target template information (i.e., visual information is compared to mental images of targets to determine if a viewed object is the target of the search) (Malcolm 2010). As a result of the latter, objects that share some characteristics with the target but in fact, are not the target (termed distractors) are more likely to be fixated upon than others (Zelinsky 2008).

It is tempting to inquire about the role of fixations in object recognition, such as the number of fixations needed, their duration, etc.; such factors depend on the complexity of the scene and object. For example, in much of basic vision research, response times (time needed to identify the target or conclude it is absent) are measured; response time is essentially the number of fixations multiplied by the fixation duration (Zelinsky 1995). In studies where the target letter 'Q' must be identified in a field of 'O' distractors, response times are short, and few fixations are needed (Zelinsky 1995). The number of fixations required to locate targets increases as the complexity of the scene increases, forcing the searcher to a serial mental processing mode which slows down the visual search. In addition, there is evidence that searchers spend significantly longer on their initial saccade than subsequent ones

(Zelinsky 1995). In real world visual searches of mammograms, experienced radiologists utilized an average of 30 fixations per image for their diagnosis (Nodine 2001).

Eye movements clearly reflect the attention of the searcher. As stated by Zelinsky (2008), “manual search measures correlate highly with the number (and distribution) of gaze fixations occurring during search”. In studies of everyday activities such as making tea, Land (1999) found that foveal vision was always focused on the object being manipulated, with few fixations unrelated to the task. Fixations preceded the initiation of manipulations by about 0.5 sec and then moved to the next object about 0.6 sec before completion of the current manipulation, the eye thus closely following every step of the process. In a study of walking over an irregular surface, Patla (2003) observed that over 50% of subjects’ gaze patterns were focused on the path of travel. When they did focus on the landing target, they did so approximately 1 sec prior to contact. In a study of walking over a surface that demanded precise footfall, subjects’ eye fixations are essentially completely on the task at hand (Hollands 2001). Galna (2012) measured a 4-fold increase in the frequency of saccadic eye movements when subjects were tasked with walking while approaching a simple turn as compared to walking straight. Foulsham (2015) has summarized several investigations such as these which clearly demonstrate eye involvement in everyday activities, whether intentional or not.

Eye movements also reflect the absence of attention by the searcher. During periods of mind wandering (task-irrelevant internal thoughts), Krasich (2018) measured fewer and longer fixations as compared to periods of attentive scene viewing.

A fuller discussion of the interplay of saccadic eye movements and fixation points is beyond the scope of this paper; the search and rescue reader is referred to the review by Mardell (2013).

Cognitive Processes involved in Vision

Studies in the basic visual search sciences have delved deep into the mental processes involved. A review of those is well beyond the scope of this paper; the reader is referred to a review by Eckstein (2011). There are, however, a few aspects that are of direct relevance to wilderness search and rescue.

The scene itself provides context that guides searches (Wolfe 2011). Search often involves utilizing prior knowledge (referred to covert attention) regarding the relationship of an object with the scene in which it exists to guide the visual examination for that object; such knowledge can greatly improve search success (Eckstein 2017). Thus, tabletops are searched for one’s coffee cup but walls are not. With regards to wilderness SAR, evidence of the physical passage of someone (sign) is searched for on or near the ground.

Vision science has focused on the cognitive processes that guide eye movements; this research indicates two different broad governing mechanisms, so called two modes of attention (Katsuki 2014). In the top-down mode, eye movements are directed according to the goals and desires of the observer.

The top-down attention mode is a voluntary, wilful process. It involves internally selecting a specific location or feature or object upon which to search. This mode is used when searching for specific objects. The bottom-up mode drives eye movements in response to the visual properties of the target. Characteristics of search objects that impact detection and recognition include size, color, shape, angles, lines, orientation and contrast with the background or environment as well as the degree of movement. These characteristics are deeply involved in searches where the background is complex and heterogenous; a potential target must first be separated from the background before recognition can be achieved and segmentation is driven by these object characteristics (Wolfe 2002).

Both mechanisms are in constant use, interact with each other, and involve multiple distinct areas of the brain. In both, visual images of objects are compared to mental representations to determine recognition of the object. Importantly, the research indicates that the top-down mode can be intentionally influenced to improve search success. That is, the observer's mental picture of the target is one of the most important factors in object recognition and this mental picture can be improved upon, often with dramatic improvement in detection performance (Eckstein 2011). Even partial views of objects may still lead to target recognition. When presented with incomplete information, the visual system fills in the blanks (Gold 2000, Chong 2016).

Vision research has shown that there are important psychological influences on object recognition that are of relevance to wilderness searching. These experiments often involve presenting many images to participants where the number of images that contain the target as well as the number of distracting elements in the image can be easily varied. A variety of parameters are measured including the rate of missing the target, the manner in which the eyes fixate on the image and the time participants take to determine if the target is present or absent. From multiple experiments such as these, a psychological influence termed the low prevalence effect has been identified and studied. The <u>rate</u> of missing targets increases substantially when the frequency of images containing the target drops (Wolfe 2007, Rich 2008.); stated succinctly, rare targets are disproportionally missed.

For example, a series of images were shown to participants where, on average, every other image contained the target; under these conditions, participants missed the target at a rate of approximately 10% regardless of whether the target object is embedded in a set of 6 or 12 distractors. Identical experiments conducted, where the prevalence of the target is lowered to 2%, reveal the miss rate rises dramatically to approximately 40%. Research by Wolfe (2007) have explored the nature of the low prevalence effect and have shown it to be robust. The low prevalence effect is characterized by two distinct elements: the first is a marked elevation in the rate of missing targets and the second is a decrease in the participant’s reaction time in determining if the target was present or absent. Experimental evidence reveals this effect is caused by a mental shift on the part of the searcher; when searching under low prevalence conditions, there is a subconscious expectation is that the target is most likely not present. Some research has indicated this effect is due to failures of perception to recognize the target (Hout 2015). A more widely held perspective comes from work by Wolfe and Van

Wert (2010) who have developed evidence that the low prevalence effect reflects a shift in the decision criterion (as to whether a target is present or absent) to one of becoming more conservative; rare targets are judged more likely absent even when present. It reflects an implicit bias.

Wolfe and his co-workers (2007) have published a variety of experiments designed to explore this psychological phenomenon in greater detail. Several experiments were conducted where participants searched for targets in images that mimicked airport screening of luggage. After some initial practice images, participants were then tested for their ability to detect targets. When challenged with low prevalence targets, participants were able to improve their performance when searching was regularly interrupted and participants shown several images where the target was present at high prevalence rates. By providing bursts of training at high prevalence, participants' missed error rate was cut nearly in half, from approximately 45% to 20-25%. The false positive rate also increased. Additional experiments have revealed that low prevalence targets are in fact fixated upon but are missed due to the perceptual failure of the participant to identify the target (Goodwin 2015, Hout 2015). The mental expectation of not finding the target creates the bias that results in not recognizing the target when, in fact, it is present. Yet, as pointed out by Eckstein (2011), enhancing the observer's mental image of the target improved performance.

There may well be evidence of a similar effect in wilderness search and rescue. Koester and co-workers (2014) measured the relationship between effective width and range of detection using three different kinds of search objects: high, medium, and low visibility objects. Effective sweep width and range of detection were highly correlated, but the correlation depended upon the visibility of the search object. For high visibility objects, a correlation of 1.8 was measured. For medium visibility objects, the correlation coefficient was 1.6 and for low visibility objects the correlation was 1.1. The authors noted that the smaller correlation for low visibility objects was not simply due of the difficulty of seeing the objects against the background environment; that effect had already been accounted for in the lower range of detection for those objects. The smaller correlation stemmed from the fact that, psychologically, these objects are less likely to be noticed by the searcher apart from their lower visibility. A similar effect can be shown in independent data from Koester and coworkers (2004) when correlations between effective sweep width (W) and range of detection (specifically AMDR, Average Maximum Detection Range) are calculated; 1.7 for high visibility objects, 1.5 for medium visibility objects and 1.2 for low visibility objects. Such observations lead to the question of whether searching for a low visibility object is psychologically similar to searching for a rare target. That is, because it is difficult to detect, is there a similar subconscious expectation that a low visibility target is most likely not present? In wilderness search and rescue, search objects and clues are often both low in number and difficult to see against the environment, making the psychological influence of substantial importance.

Implications for Search and Rescue

Foveal vision:

Collectively the research summarized above provides valuable insights applicable to wilderness search and rescue. To begin, recognition of the importance of the foveal field of vision is critical. The Civil Air Patrol attempts to incorporate this concept during their training of air-to-ground spotters (Civil Air Patrol, 2017). In their application, visual scanning is the process of investigating or checking an area by training scanners to use a systematic eye movement pattern. Employing their outstretched fist as a visual guide, the spotter attempts to bring a search area of approximately 10 degrees into the foveal field of view, focusing on this area for a few seconds before systematically moving to the next overlapping area. Using this process, a trained spotter can systematically cover an area as the search plane is moving.

It is fair to ask whether such a visual scanning approach provides for demonstrably better search results. Croft (2007) conducted a real-world test where spotters were tasked with identifying known targets as they were flying overhead. Targets, sheets of plastic mimicking a Cessna 180 wing, were planted in the search field. Ten spotters with an average of 5 years-experience each participated in this experiment. Data extracted included the points of fixation, the visual coverage, the distance between fixation points, the visual scan pattern utilized as well as the frequency of finding and identifying the target. Despite training, the vertical scan technique was used only approximately 40% of the time. Visual coverage of the area was low at approximately 25%, assuming a 5 degrees circle around each point of fixation. Search success rates were approximately 30%. Importantly, this research demonstrated that search success was dependent upon 3 factors: the number of fixation points (the more, the better), the Inter-fixation distance and its variability (small and consistent is better). These results indicate that the scanning technique has merit, but it is difficult for searchers to learn and consistently apply this method, particularly while moving at relatively high speed in an aircraft.

To the extent that the wilderness environment demands a searcher to focus on their path as they move through their assigned area, it is important that they stop in order to utilize foveal vision critical for the detection of search objects. Research clearly shows that when moving, eyes are largely fixated on the path, where the next step will fall and hence, not the target (Patla 2003, Galna 2012). In addition, complex 3-D scenes of the wilderness can effectively shield objects from one specific viewpoint, thus requiring multiple views to overcome.

Many within the wilderness search and rescue community are taught the concept of the searcher cube, a hypothetical 6-sided cube whose center is located with the searcher and whose facial dimensions are equivalent to the effective sweep width (Stoffel 2013). The utility of the searcher cube is that it helps define the length a searcher can travel before stopping and, using foveal vision, inspect the surrounding scene via all 6-faces. For the searcher to fully utilize his/her foveal vision in pursuit of the target object, it is critical to stop. In addition, it seems intuitive that searchers should refrain from idle conversation and work to maintain their attention on the search task since eye movements clearly reflect the attention of the searcher. While the concept of using central vision is not foreign to search and rescue (for example Civil Air Patrol, 2017, Stoffel 2013, Illinois Search and Rescue Council, Ontario Search and

Rescue), it is not apparent that it is as widely factored into training as indicated when search tasks require greater thoroughness.

Low Prevalence Effect, Distractors, and other complications

Wilderness searching represents a situation where target prevalence is low and searchers spend most of their time examining terrain that does not contain a target (i.e., clue). Target characteristic such as small size, low contrast with background, low visibility, noncanonical orientations, etc. make detection difficult (Schuster 2013). Target identity is often not known. Search scenes are complex and variable. Environmental conditions are frequently unfavorable to searching. Because of these factors, it is likely searchers are psychologically influenced to some degree into believing, that in any given scene, a target is most likely absent and hence, be quick to conclude no targets (clues) are present. There is no a priori reason for wilderness searchers to be immune from the low prevalence effect; there are, however, some obvious steps that can be taken to offset its impact.

As stated by Eckstein (2011), searchers knowledge of the physical characteristics of a target is one of the most important factors for efficient and improved search. Thus, in the context of wilderness search, enhancing mental images of targets in the minds of searchers is important. It has been suggested that it is possible to increase the probability of detecting clues by showing surrogates of expected clues to searchers during their task briefings (Stoffel 2013), provided these are known from SAR interviews, witness reports, etc. Target uncertainty can be reduced by showing a preview picture of the target; actual pictures reduce the time to find a target more than word clues (Wolfe 2004). Rather than just a verbal or written description of search objects, a physical surrogate should be shown. Research indicates even passive exposure to a stimulus can affect performance (Schuster 2013). Searchers should be allowed to view these objects as they may appear in the environment, lying on the ground in differing orientations. In addition, the individuals performing the briefing can enhance psychological ability of searchers by avoiding such terms as “low probability areas” as these likely create a negative psychological bias. Some search teams have already incorporated these elements into their training; the research summarized here indicates this training should be more widely utilized.

Expert Searchers

Table 1 lists studies that have examined professional expert searchers or compared them to either trainees or novices to learn what differential factors are at play. Inspection of the data in Table 1 reveals that experts are far from perfect; within expert ranks, the performance of some is much greater than others (Schwaninger 2003b). And experts still miss targets such that algorithms that redirect their search improve outcomes (Nodine 1990). Nonetheless, when compared to novices or trainees, experts tend to dwell longer than others (i.e., are slower) while inspecting a scene before reaching a conclusion regarding target present or absent; in addition, their eyes fixated more on targets. Their search technique is more consistent and more accurate. From a study of expert radiologists, Drew (2013) concluded that it was probable their expertise consisted of both hardwired guidance by basic features of targets (color, etc.) as well as learned guidance from their practice. The studies listed in Table 1 span both airport security and radiology; both involve examination of images on a computer screen. Yet the outcomes of these studies are in alignment with predictions of vision science and hence, there is no reason not to expect similar effects in wilderness searchers.

Training

Several studies in the literature have examined the role of training with respect to visual search in real world applications. Some of these are listed in Table 2. (Multiple other studies investigating the effects of various training regimens have focused on a basic understanding of the cognitive processes involved; these are not listed here.) From these investigations, a number of relevant insights can be drawn: 1) training almost always involves multiple short sessions conducted over an extended period of time, 2) training works; improvements in search performance are observed. It is also possible to improve vision itself, 3) a diverse, heterogeneous set of target objects is best to train with, and 4) improvements in vision training is transferrable to novel objects. All these elements are important to wilderness searching.

Conclusion

Vision science provides a solid foundation for understanding key factors of visual search, including foveal field of view and the role of saccadic eye movements. These lower level elements, along with the recognition of both bottom-up and top-down modes of attention involved in object recognition, set the groundwork for insights into improving visual search. Higher level cognitive processes involved in searching for low prevalent objects must be understood and managed, both in training as well as in search briefings. Lastly, the characteristics of training that have been successful in improving visual search should be incorporated into ongoing SAR training programs.

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Abbreviations

SAR: Search and rescue
POS: probability of success
POD: probability of detection
POA: probability of area (same as probability of containment, POC)
W: Effective Sweep Width
AMDR: Average Maximum Detection Range

Table 1: Impacts of Experience on Real World Search Tasks

Visual task targeted	Group receiving training	Test of Performance	Outcomes	Comments	Citation
Airport baggage screening	93 university students and 206 TSA officers	Search task: differentiate single ‘T’ target from multiple ‘L’ distractors. Groups compared across set of 256 images (target present at 50% prevalence).	Experienced TSA officers more accurate but slower (response times longer) to both locate a target and to conclude target absent.	Professional searchers more accurate but slower, suggesting they are performing the search task more diligently (Biggs 2013)	Biggs 2013
Airport baggage screening	72 TSA screeners and 103 university students	Search task: differentiate single ‘T’ target from multiple ‘non-T’ distractors. Groups compared across set of 255 images of varying target salience and prevalence.	Minimal difference in accuracy between professional and non-professional searchers. Professionals slower to respond (response times longer)	More consistent searchers (in terms of amount of time/trial) were more accurate.	Biggs 2014
Airport baggage screeners	80 airport security screeners	Screeners tested for ability to recognize threat items in different orientations, or superimposed by other objects or complex backgrounds	Objects in uncommon orientations or partially hidden or in complex environments more difficult to identify.	Significant differences exist between screeners, with some substantially better than others. Possible to test ability of screeners and identify need for training.	Schwaninger 2003b
Radiological examinations of chest CT scans	3 highly experienced radiologists	Eye movements tracked during examinations of 120 chest x-ray images, each viewed twice. Second reading had highlighted regions of either high dwell time or random location.	Re-examining areas of initial high dwell times that were initially not judged as lesions results in greater finds.	An algorithm that redirects a radiologist to re-examine areas originally dwelled upon but not judged positive effectively doubles the probability of converting a false negative to a true positive.	Nodine 1990
Radiological examination of mammograms	3 experienced mammographers and 6 radiology trainees	40 sets of 2-view mammograms; in 20 cases, at least one malignant lesion visible on at least one view. Other 20 cases are free of lesions. Eye movements tracked as mammograms examined until lesion located.	Eye positions of experienced mammographers fixated more on true lesions than novices. .	Experienced clinicians detected true positive more thoroughly than novices, but dwell times before clinical decisions made were longer compared to novices. Prolonging the search yielded few new lesions and increased risk of error.	Nodine 2002

Table 2: Impacts of Visual Training Real World Search Tasks

Visual task targeted	Group receiving training	Training		Outcomes	Comments	Citation
		Method	Replications			
Airport baggage screening	72 screeners		20-minute sessions repeated weekly for 6 months	Increased detection ability 60% after 20 sessions, 71% after 28 sessions	Training difficulty dependent on viewpoint of prohibited item, superposition by other objects and bag complexity	Schwaninger 2003
Airport baggage screening	16 adults	Computer based study of four sets of 300 practice images	Five experimental sessions of 300 images each over	Small but statistically significant improvements in	Screeners were quicker to fixate on the target but not more likely to do so. Scanning became more efficient but not more effective. Authors conclude that training should not modify the scanning	McCarley 2004

		each; digitally inserted targets present in 20% of images	multiple days; last session presented fresh images only	sensitivity; faster response times for both target present and target absent trials	behavior but should focus on developing ability to perceptually recognize objects in security imagery. Training materials should be maximally heterogeneous ensure skill generalization.	
Airport luggage screening	36 university students	Computer-based images containing 1 of 5 distinct prohibited items.	Group 1: Memorize a set of 1 of 5 possible targets. Group 2: Memorize sets of all 5 possible targets. Training for each consisted of 4 sessions of 100 images each with targets present at 50% prevalence. Feedback provided after each image.	Day after training, Groups shown images containing novel target for test of performance. Group 1 (trained on higher diversity of targets) exhibited significantly higher hit rate on novel target than Group 2 or control group.	The higher diversity of target search objects during training resulted in higher hit rate against a novel target.	Gonzalez 2011
Airport baggage screening	40 university students	Computer-based discrimination testing; two images presented simultaneously; searchers tasked with identifying if IED threat items were identical across images	On average, 377 trials of images during a 30 min session	160-item test (63 with target, 97 without target) of performance with novel targets. Versus control group without training, authors report increases in speed and accuracy.	Impact of training was transferred to the detection of novel targets.	Schuster 2013
Baseball performance	19 players	Perceptual computer-based learning program consisting of training with a diverse set of stimuli, optimized stimulus presentation, multisensory facilitation, and reinforcing training stimuli	Thirty 25-minute sessions over course of 8 weeks, averaging 4 sessions per week.	Improved contrast sensitivity and visual acuity. Improved baseball performance versus previous year and league averages	Details of training available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3932179/	Deveau 2014
Radiological exam of chest CT scans	10 novices and 10radiologists	Multiple sessions viewing CT scans with 1 of 3 known lesions	4 sessions of 500 trials each	Novices improved sensitivity to lesion detection (via reduction of false positives) equal to that of experienced radiologists	No overt training per se; experience gained because of participation in study	Nakashima 2013

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