Evaluation of strategies to train visual search performance in professional populations
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Visual search, the act of finding targets amongst distractors, is central to many professions with life-or-death implications including aviation security, radiology, lifeguarding, military, and more. As such, every effort should be taken to improve visual search performance. One potential path to improvement is to ensure that workforces are optimally trained. Broadly, there are three general components to train: (1) specific use of the machinery and user interface (i.e. ‘knobology’), (2) target and distractor identification, and (3) search strategy. The current review considers the cognitive psychology aspects of these three components; each is evaluated in light of short-term and long-term training goals, as well as profession-specific constraints.

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Visual search training can broadly be divided into three components (Table 2): (1) ‘knobology’ —learning how to use the necessary equipment/technology, (2) object identification—learning what are and are not targets, and (3) search strategy—learning how to look for targets. Generally, knobology and object identification components have the potential to train a workforce on how to use the provided equipment and identify specific targets, while the search strategy component provides generalized training that can potentially transfer across professions and settings. Some situations may favor the more circumscribed nature of knobology and object identification (e.g. pathologists tasked with finding a specific set of targets using a specific set of tools) while other situations will benefit more from general search strategy training (e.g. aviation security officers tasked with finding an unknown array of threats in an undefined range of search arrays with frequently changing technology).

It is natural to compare the effectiveness of different training components, but it is important to ensure the comparisons are valid and aligned with the training goals. For example, a recent comparison of training protocols found that object identification training was more effective than strategy training [9**]. However, if the study participants had been given multiple days of training instead of one 90-min session [9**], it is conceivable that the harder-to-learn search strategy protocol could have become the more effective tool. That is, more complex...
training procedures (like learning to use a new strategy) may require more time for the trainees to master before the benefits are realized. In line with this, in a non-training study, use of a particular search strategy—searching consistently from trial to trial—was found to be a better predictor of search accuracy for experienced than for early career professional aviation security officers [10]. This may be because the early career searchers were still learning the consistency strategy, which presented them with an added cognitive burden.

In the current review we will briefly discuss knobology and object identification training, then focus more extensively on search strategy training. We will discuss each with respect to potential short-term and long-term training goals from an applied perspective.

Visual search training component 1: ‘knobology’

Nearly every workforce tasked with critical visual searches interacts with technology. As such, workforce performance is maximized when the employees are trained to best use the technology, including the different functions and controls of the imaging machines. For example, aviation security screeners use X-ray machines that allow for multiple viewpoints and various image filters (grayscale, highlighting metals only, etc.). For these features to aid target detection, the workforce must be trained on how to effectively switch between different viewpoints [11], what each image filter does, and when best to employ each. Otherwise, the presence of image enhancement options can actually deteriorate performance [12,13]. Beyond the technical knowledge of

| Table 1 |
|-----------------|-----------------|-----------------|-----------------|
| Search Profession | Examples | Target nature | Environment | Technology changes |
| Checkpoint Security | Aviation, Border crossings, Building entrances and rescue, Border crossing monitoring, Coast Guard search and rescue | Highly variable, Highly variable | Highly variable | Frequent, Frequent |
| Border Protection and Safety | Radiology, Cytology, Pathology | Stable and known | Stable | Frequent |
| Medical Imaging | Radiology, Cytology, Pathology | Stable and known | Stable | Frequent |
| Military searches | Checkpoints, Room clearing, Manufacturing plants, Product quality control check | Highly variable, Stable and known | Highly variable, Stable | Frequent, Frequent |
| Product Inspection | Aircraft integrity | Stable and known | Stable | Infrequent |
| Physical Inspection | Termite Inspection | Stable and known | Stable | Infrequent |
| Pest Control | Pool/beach monitoring, Fossil discovery | Variable, Stable and known | Variable | Infrequent |
features, it is also critical to train for human–computer interaction. Accurate use relies on the ability to trust but also question the technology at hand [e.g. in Ref. 14]. Thus, it is necessary to train for potential technology failures and their fixes [15*].

A hallmark of knobology training is its specificity to particular machines and protocols. From a short-term perspective where quick learning is needed, or in a relatively closed-system search environment (where new target types or new environments rarely occur), knobology training can be highly effective; for example, studies that have looked to train the use of electrocardiography (ECG) and ultrasound technology have found that brief training sessions (~2 hours) are sufficient to provide machine-naïve medical students and professionals with basic diagnostic skills [16,17]. However, there are drawbacks. First, retraining is necessary with each new vendor and technological advance. Second, the specific nature of the training does not promote generalized learning, so the potential for carryover to other tasks or stimuli is limited. In sum, knobology training is effective for the short-term goal of ensuring the workforce can operate their current technology, but the need to retrain with each change may limit the long-term payoff.

**Visual search training component 2: object identification**

Radiologists need to know the visual characteristics of cancerous nodules, aviation security officers need to know how guns, knives, and explosives appear in the X-ray image [18], and lifeguards need to know the signs of a distressed swimmer [19]. Some searches involve a relatively constrained target set (e.g. breast cancer detection), while others have novel and unknown targets in variable environments (e.g. aviation security). These latter cases with varied-targets pose a difficult challenge from an object identification perspective. Specific search templates aid search [20,21], so the more varied and dissimilar potential targets are, the more search performance may suffer [22,23].

Object identification training has taken a variety of forms, including training to identify targets in canonical and non-canonical orientations [24], under conditions of clutter [25], with occlusion or camouflage [26], and through learning the background environment [27]. Similar to knobology training, object identification training can be limited in transfer. For example, in a study where participants searched for four different knives in simulated X-ray images of bags over multiple training sessions [28], the ability to detect those four knives improved. However, when four new knives were introduced at the final testing, the performance improvement did not transfer to the novel, but similar, targets. Furthermore, much of the cognitive research on object identification has been done at 50% target prevalence [e.g. in Ref. 27], but this is not representative of many applied search settings. Instead, many professional searches involve looking for rare targets, and it is unclear how these training techniques would transfer [29].

If the goal is to train a workforce to identify a circumscribed set of known targets (e.g. cancerous nodules that are generally known and unchanging), object identification training can be immensely useful for both short-term and long-term periods. However, if the goal is to be able to identify any target, including new ones that the workforce has not been trained on (e.g. new contraband developed to sneak through airport security), object identification training will ultimately fall short.

**Visual search training component 3: search strategy**

While search strategy training arguably has the most potential for broad and long-term payoffs, it is also the most complicated. Moreover, the optimal strategy will vary with each searcher’s goals and environment, leading to differential solutions. For example, a lifeguard searching for distressed swimmers on a bustling beach will likely have to adopt a different search strategy than an aircraft inspector looking for cracks on a plane’s fuselage. Broadly, there are two steps of visual search that we will discuss in turn: 1) searching the array and 2) deciding if a target is present [30–32].

**Training search strategy—where to fixate**

In general, experts search differently than novices, as seen across a number of realms from chess [33] to driving [34,35]. One key distinction is that experts generally use more consistent and systematic scan paths than novices [8]. This promotes more efficient coverage of the search
field, increasing the probability that a target will be fixated, while also decreasing cognitive load [36,37]. As such, several forms of search strategy training have focused on training novices to use systematic scan paths.

One method for training search strategy is to highlight probable regions of interest. For example, novice drivers are taught where to look for potential hazards in simulated scenarios [38,39]. Likewise, in radiology, training may involve using a list of anatomic structures to check in a consistent order [40,41,42], or superimposing other radiologists’ search patterns [43–45]. In addition to displaying an expert search path, evidence from Marines suggests that simply providing feedback that compares an individual’s search path to that of an expert can help [46]. Inspection industries have sometimes taken a direct approach, training with a dynamic stimulus to promote searching in a consistent order such as across, down, and back across [47–49].

The most important outcome of training the workforce is to improve accuracy and/or efficiency. As such, the critical question is whether search strategy training can not only improve coverage of key areas, but also detection rates. Despite the widespread existence of training programs, it is difficult to adequately test the effectiveness and generalizability of any such program. With no set ‘gold-standard’ of search strategy training, different studies implement different training techniques. Thus, there are varied results, and it is difficult to draw comparative conclusions. There is some evidence in favor of detection improvements [38,39], but this is not always the case. Often times, the improvement in coverage does not necessarily translate to an improvement in target detection or sensitivity [42*], or it comes at the expense of a speed-accuracy tradeoff [43,44]. In the cognitive psychology literature, there have been several attempts to use eye-movement feedback to encourage a full-coverage search pattern, but these attempts have failed to improve target detection [50*,51**]. A likely explanation is that you can train someone to alter their search pattern, but if that search pattern is effortful, their attentional demands will be too high for search to be successful. That is, even if you get a person to fixate (i.e. directly look at) a target, they might still fail to identify it as a target. It is an open question whether more extensive training combined with eye-movement feedback could eventually produce positive benefits, but speed-accuracy tradeoffs must be considered.

**Training search strategy—improving decision making**

Successful visual search requires searchers to not only locate targets, but to also correctly determine what are targets and what are not. In radiology, this distinction has been delineated in three forms of search errors [52,53]: (1) scanning errors—not fixating the target, (2) recognition errors—fixating a target but not for a sufficient amount of time to successfully process the item’s identity as a target, and (3) decision errors—fixating a target for a sufficient amount of time but incorrectly concluding that the item is not a target. The focus of this section is on training to reduce decision errors—those created by incorrect decisions despite all necessary information being available.

The decision component of search involves information extraction—searchers must pull the appropriate information from visual search before making their decision [e.g. in Ref. 54]. Experts generally extract information and make decisions more accurately and efficiently than novices [e.g. in Refs. 55–57]. In some cases, the differences in information extraction are reflected in search pattern differences; for example, novice drivers typically have longer fixations and less horizontal scanning than expert drivers [34,35]. Information extraction differences have also been observed via non-search pattern metrics; for example, although expert badminton players [56] and squash players [57] were found to extract information earlier and more efficiently than novices in an anticipatory task, there were no differences in their fixations. Similarly, expert soccer players had no consistent differences in fixations from novices but were more sensitive to peripheral information [58], again suggesting an advantage in information extraction.

Training the decision component has great promise, but it takes time. Systematic search patterns can be trained, but improvements may not materialize until decision making skills are also developed. While information extraction and decision making improve with experience, there is limited research to date on how to actively train these aspects of search. Although training search strategy should have the most generalizable and long-term benefit to the workforce, further research is needed to understand how best to implement the training and realize the greatest benefits.

**Discussion and conclusion**

The goal of the current review is to provide a brief overview of the pros and cons of various forms of visual search training as it applies to professional settings. Building on basic research principles, there may be ways to improve industry operations by helping a workforce perform more efficiently and/or effectively. Broadly, ‘knobology’ and object identification training are seemingly best suited for short-term goals when it is critical to quickly teach the workforce how to use the technology and what to look for. However, technology and potential targets can change and such specific training is not likely to transfer. As such, these methods provide short-term gains but may be costly in the long run. Alternatively, search strategy training seems best suited for long-term goals, where learning should generalize across realms and be resistant to many workplace changes, as it is rooted in
cognitive principles of decision making and systematic search patterns. The downside, however, is that it takes the longest amount of time to learn, and there is no clear evidence yet pointing to the ideal training strategy.

Each professional visual search environment comes with its own constraints, and there is no ‘one-size-fits-all’ approach to search training. However, the cognitive psychology literature suggests that search strategy training will likely lead to the most robust benefits for each individual employee and for the organization. The easiest path to the quickest wins in learning is to use circumscribed methods that are highly specific to the search task. However, it is important to consider both short-term and long-term goals when training a workforce for professional search. While training for long-term benefits on a short time scale is the ideal in applied realms, effective and lasting training often takes time and should be carefully designed.

Conflict of interest statement
M.R. Kramer and C.L. Porfido have no conflicts of interest to declare. S.R. Mitroff is the Chief Science Officer of Kedlin Screening International—a small business that uses software solutions to help improve security screening operations. The company is currently focused on issues related to pre-hire assessments and current workforce assessments, but may explore training in the future. None of the work presented here is related to the company, but it may be possible that the company could indirectly benefit from some of the research suggestions laid out here if future research were to prove fruitful.

References and recommended reading
Papers of particular interest, published within the period of review, have been highlighted as:

● of special interest
** of outstanding interest

This paper highlights that an operator’s trust in automation and performance depends on the technology failures that they are exposed to during training. This emphasizes the importance of proper and comprehensive training on how to best interact with the technology available.


38. Pradhan AK, Pollatsak A, Knodler M, Fisher DL: Can younger drivers be trained to scan for information that will reduce their risk in roadway traffic scenarios that are hard to identify as hazardous? Ergonomics 2009, 52:657-673.


This paper shows that, while experts have a more systematic search pattern and perform better than students, there were no performance improvements found in students that underwent a systematic search training. This highlights the challenges in finding effective training strategies, as the practices of the experienced may be too effortful to be effective for the less experienced.


50. Drew T, Williams LH: Simple eye-movement feedback during visual search is not helpful. Cogn Res Princ Implic 2017, 2:44. The authors sought to use eye-movement feedback to improve target detection and efficiency, but did not find any reliable improvements in performance. This paper highlights the challenges with search strategy training—which is much to be learned about how to improve search performance beyond improving coverage.

51. Peltier C, Becker MW: Eye movement feedback fails to improve visual search performance. Cogn Res Princ Implic 2017, 2:47. Similar to Drew & Williams [50], here the authors attempted to use a variety of eye-movement feedback methods to improve search performance in rare target search. Again, they failed to find reliable improvements in performance with this training method. While seemingly intuitive that increasing coverage would improve search performance, failures in decision making seem to remain.


