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A comparison of three levels of training designed to promote systematic search behavior in visual inspection

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Abstract

Three levels of training, intended to improve visual search proficiency during inspection by promoting systematic search, are investigated. The three levels of training are verbal instruction on systematic search, verbal instruction with a static diagram of a systematic search, and verbal instruction and a diagram with practice using a dynamic visual stimulus tracing a systematic search. The levels are compared using both performance and process measures in order to identify the least complex means of improving search behavior. While all the training levels improved visual search proficiency, none did so more than any other. Evidence suggests that the levels were not differentiated due to the search task employed—a task that inherently lent itself to systematic search. Thus the least complex level is preferred for this task and those with similar attributes.

Relevance to industry

Human visual inspection is necessary to many industrial processes. Verbal instructions on how to perform a systematic search can be an effective method of training to lower inspection time under the conditions used in this study.

Keywords: Visual search; Training; Inspection; Systematic search; Training aid

1. Introduction

With competition creating an emphasis in industry on higher quality goods, there is a greater demand for quality assurance to ensure that fewer defective products are delivered to the customer. Also, the risk of product liability litigation over defective products has caused quality assurance to be crucial in manufacturing industries. Product inspection is one dimension of a comprehensive quality assurance program. While there are many forms of inspection, visual inspection is predominant. Humans are regularly assigned to visual inspection tasks even though it has long been established that their performance is not entirely satisfactory (Juran, 1935).

Visual inspection has been divided into two primary functions: visual search and decision making (Drury, 1975). These functions are the main determinants of inspection performance and

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must be executed reliably for inspection to be successful. In general, humans tend to perform worse than automated inspection systems at the visual search component (Drury and Sinclair, 1983; Hou et al., 1993). This is largely due to the fact that human visual search behavior tends to be less systematic, which leads to incomplete visual coverage. However, the superior decision making ability of humans, along with their inherent flexibility, make them desirable inspectors. Thus, due to these and other shortcomings of automation (Bainbridge, 1983; Parasuraman, 1997), methods to improve the search behavior of human inspectors are sought.

1.1. Visual search behavior

Visual search consists of a series of eye fixations followed by saccades, or brief eye movements, from one fixation area to another. The pattern of fixations and saccades made by the inspector when examining the inspection area define the eye movement scanning strategy. Individual characteristics, known as subject factors, affect visual search performance (Megaw, 1979). Most of the subject factors such as visual acuity, age, experience, and personality are not easily altered. However, some studies (Gramopadhye et al., 1997b; Kundel et al., 1990; Wang et al., 1997) suggest that one particular subject factor, eye movement scanning strategy, can be improved.

There are two extremes on the spectrum of eye movement behavior: random and systematic. Random behavior assumes a memoryless search, so any particular fixation area is as likely to be viewed as any other, regardless of how many times it has already been viewed. Systematic behavior assumes perfect memory where each fixation area will be viewed only once per scan of the search area (Williams, 1966). True human search patterns lie somewhere between random and systematic (Morawski et al., 1980). Inspection studies have shown that humans will attempt a more systematic search, but will still suffer from imperfect memory (Gottsdanker, 1960; Morawski et al., 1980; Noton and Stark, 1971; White and Ford, 1960). It has been shown both in theory (Arani et al., 1984) and in practice (Wang et al., 1997) that systematic behavior produces better inspection performance. Thus, efforts to make inspectors follow a more systematic search pattern can potentially improve search performance.

1.2. Evaluating human visual search performance

Visual search behavior has been evaluated in two ways: the performance measures of inspection speed and defect detection accuracy (Morawski et al., 1980) and the process measure of eye movements (Megaw and Richardson, 1979). Speed and accuracy are often the sole or principal measures of inspection performance in industrial practice. Eye movement data may serve to reveal changes in underlying search behavior, resulting from the introduction of training interventions for example, which may have led to changes in performance. Megaw and Richardson (1979) list several parameters to quantify eye movements including: number of fixations, fixation times, saccade distance, and number of eye movements in the horizontal, vertical or diagonal directions.

1.3. Methods of improving visual search

Training has been shown to significantly improve visual inspection performance. Embry (1979) provides some practical guidelines and examples of inspection training. Gramopadhye et al. (1997a) have surveyed some training methods that have been successful. These include active training (Czaja and Drury, 1981) and knowledge of results (Kleiner and Drury, 1993) among others. Recently, a study by Wang et al. (1997) showed empirically that search behavior does affect inspection performance and can be improved through training.

The introduction of static aids has also been shown to be useful in improving inspection performance, particularly relating to the visual search component. Harris and Chaney (1969) describe the use of static aids such as magnification, overlays, and physical standards to improve industrial inspection performance. Also, an eye position feedback aid for inspection of chest radiographs proved to significantly increase accuracy (Kundel et al., 1990). A study by Lovie and

Lovie (1968) showed that detection times were reduced for low target contrast conditions by a structured visual field. The purpose of that study was to make the subjects' search strategies more systematic by superimposing a static structured field on the inspection surface.

In a similar vein, a dynamic stimulus in the visual field can affect the search pattern. An example of this effect is a study of eye movements during radar search by White and Ford (1960). They noted that the subjects' search patterns generally followed the scan-line of the simulated radar, even though no instructions were given to the subjects concerning it. The authors observed that the free search patterns from their previous study without the scan-line (Ford et al., 1959) were very different from the simulated radar search. Also, Smit et al. (1987) tested three types of saccade stimuli: visual target (saccade to a target already displayed), remembered target (saccade to a remembered target location), and anti-target (saccade away from a visual stimulus). Performance on the visual target condition was superior to the other two conditions. Thus, a dynamic stimulus is most effective when it is not contrary to the desired saccade direction and does not require memory. In the two studies described above, the stimulus effectively directed saccades to a location in the visual field. Thus, it is conjectured that a dynamic visual stimulus may also be used to induce a systematic search if applied properly.

Training, both with and without the benefit of aids, can bring about an improvement in search behavior. The purpose of this investigation is to identify differences between levels of training in terms of performance and process measures to identify the least complex means of significantly improving search behavior. Three levels of training that build on each other successively are considered in this study. The first training level entails only the verbal communication of guidelines for an effective systematic search during a training session. The second level will present a static training aid in the form of a diagram depicting a systematic search (Fig. 1) along with the verbal instructions mentioned previously. The third level will employ a dynamic visual stimulus in addition

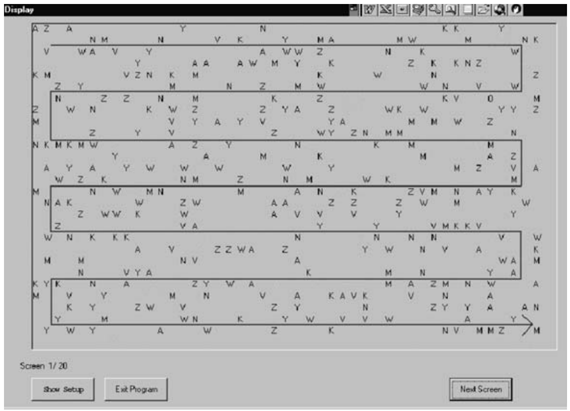

Fig. 1. The systematic inspection pattern.

to both the aforementioned instructions and diagram during the training session.

Clearly, these levels of training progressively increase training content, with commensurate increases in the complexity of both development and implementation. However, it remains to be seen if either of the latter two levels, which are relatively more complex, will bring about a significant improvement in search performance.

2. Methodology

The section below outlines the subjects, experimental procedure, and methods of analysis for this study.

2.1. Subjects

Twenty-four subjects, 13 males and 11 females, were drawn from undergraduate and graduate students at Clemson University. All subjects had natural or corrected 20–20 vision. The subjects were compensated for their participation.

2.2. Experimental groups

Three different modes of training were employed: (1) verbal instructions, (2) a static diagram illustrating a systematic search pattern for this task (Fig. 1), and (3) a dynamic visual stimulus which traced a systematic search pattern across the field.

Each subject was assigned to one of three groups. The subjects in the group designated V were exposed only to the first mode of training support in an unpaced practice session. The subjects in group S were exposed to the first and second modes in an unpaced practice session. The subjects in group D were exposed to all three modes during paced training. Paced training was employed in group D because the rate of movement of the dynamic stimulus was fixed.

2.3. Test equipment

The simulated inspection task was run using an IBM-PC compatible computer with a 15-in color monitor viewed from a distance of approximately 20 in. The ASL Stationary Optics Eye Tracking System, model 504 (stationary pan/tilt camera system) with a scene camera, was used to record the eye movements of the subjects. The VisInS software program was used to implement the task and record inspection performance data (Koenig et al., 1998).

2.4. Stimulus material

The search task consisted of finding a target character, an "X," in a field of other background characters. The subject used the mouse to click on the target character once it was found. Each field was randomly generated and 30% filled with the background characters A, K, M, N, V, W, Y, and Z. The target character was present in 24% of the generated fields. These parameters were used throughout the experiment.

2.5. Description of dynamic visual stimulus

The dynamic visual stimulus is a red cursor consisting of three asterisks (Fig. 2) that moves over the field tracing the same systematic search pattern as delineated in the training aid diagram (see Nickles et al. (1998) for discussion of the dynamic visual stimulus and preliminary findings). The cursor moves at a rate of 22 characters per second, which is derived from Koenig (1998).

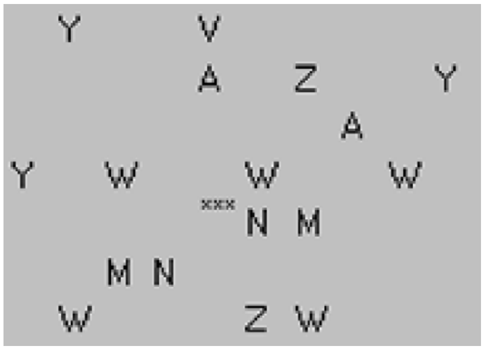

Fig. 2. The dynamic visual stimulus cursor.

2.6. Experimental design

The experiment used is a two-factor design with the factors trial and group. Repeated measures were made on the trial factor before and after training.

2.7. Procedure

Initially, the subjects signed a consent form. Following this, the subjects were given a practice session of ten inspection screens to familiarize them with the task (see Table 1 for a summary of the experimental procedure). No measurements were recorded during the practice session. At this time, the eye-tracking equipment was set up for each of the subjects and calibrated. The eye tracking equipment was recalibrated between sets as necessary during the experiment. Eye movement data was recorded for the duration of the experiment, as was inspection time per screen and defect detection rate.

All groups then performed the before-training session consisting of two sets of 25 screens, which were unpaced. Next, all groups went through their assigned level of training. Following this, the V and S groups practiced the task on two sets of 12 unpaced screens and the D group practiced on two sets of 12 paced screens aided by the dynamic visual stimulus. No feedback on performance was given to subjects during the training session. A rest period of up to 2 min was provided (if desired) immediately before and after the training session. Lastly, all groups performed the after-training

Table 1
Experimental sequence

Groups	Practice	Before training	Training level	Practice session	After training
Verbal instruction	10 screens	2 sets of 25 screens	Verbal instruction	2 sets of 12 screens	2 sets of 25 screens
Static aid	10 screens	2 sets of 25 screens	Verbal instruction + static aid	2 sets of 12 screens	2 sets of 25 screens
Dynamic visual stimulus	10 screens	2 sets of 25 screens	Verbal instruction + static aid + dynamic visual stimulus	2 sets of 12 screens	2 sets of 25 screens

session, consisting of two sets of 25 unpaced screens. On completion of the study, the subjects were debriefed and thanked for their participation.

2.8. Data collection

Data were collected on both performance measures and process measures. Specifically, the performance measures employed were inspection time, mean search time, mean stopping time, and defect detection rate. The performance measures were recorded by the simulator data capture utility. The process measures collected were number of fixations, fixation time, saccade distance, and the number of eye movements in the horizontal direction (horizontal sweeps). The eye tracking system automatically recorded all process measures except for the number of eye movements in the horizontal direction. This measure was collected manually from plots of the fixations and saccades.

2.9. Method of analysis

Plots of eye movements for each screen after both the training and practice sessions were analyzed to determine the number of horizontal sweeps made across the inspection surface. This process measure was analyzed between the three groups by a single ANOVA. Two ANOVA's were performed on all other measures. One ANOVA accounted for the full repeated measures design, while the other ANOVA compared the three groups on the percent differences between the before and after training conditions.

Table 2
Significant results from ANOVA

Measure	Effect	F	p
Inspection time	Trial	37.02	<0.0001
Mean search time	Trial	27.25	<0.0001
Mean stopping time	Trial	28.95	<0.0001
Defect detection	Group	4.20	0.0293
Number of fixations	Trial	38.07	<0.0001

3. Results

The section below outlines the analysis of the data divided into performance measures and process measures.

3.1. Performance measures

The trial $\times$ group interaction was not significant in any of the four performance measures recorded. The trial effect was significant for inspection time, mean search time, and mean stopping time, whereas the group effect was significant for defect detection rate (Table 2). Averaging across all subjects for the significant effects, inspection time dropped 49.9% after training (Fig. 3), mean search time dropped 59.6% (Fig. 4), and mean stopping time dropped 46.1% (Fig. 5). None of the percent difference tests on the performance measures proved significant.

3.2. Process measures

The three process measures of number of fixations, duration of fixations, and saccade

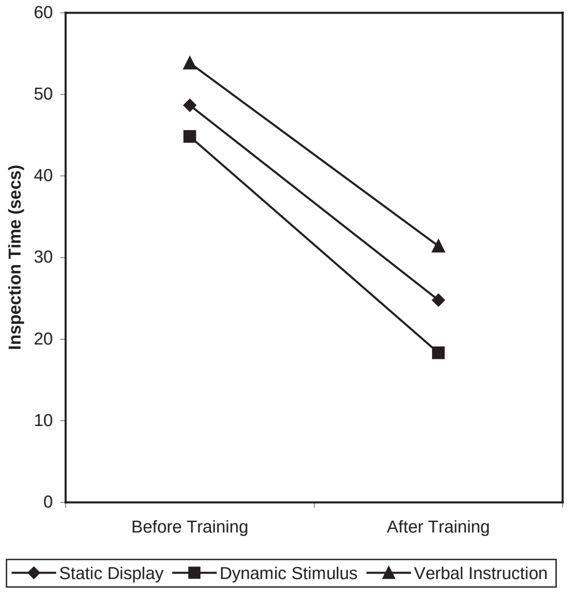

Fig. 3. Mean inspection time before and after training.

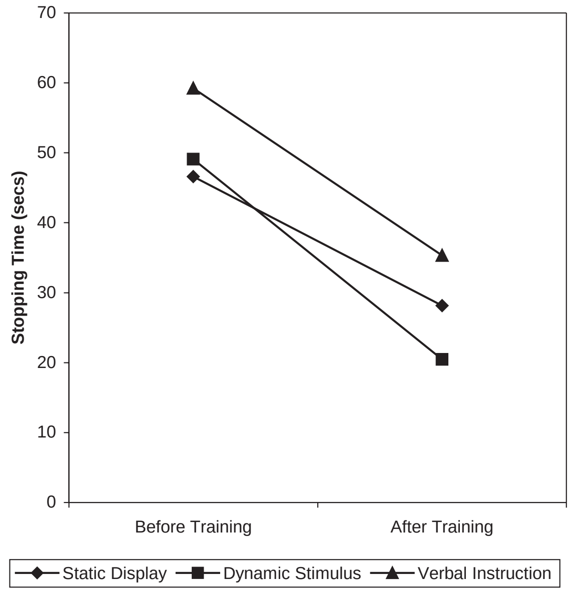

Fig. 5. Mean stopping time before and after training.

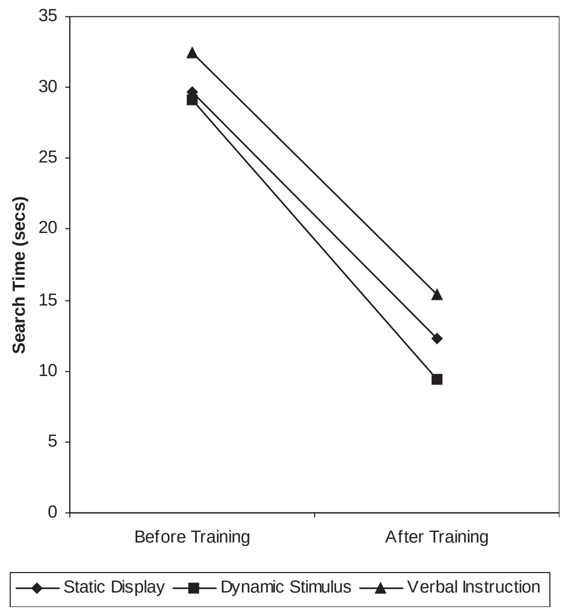

Fig. 4. Mean search time before and after training.

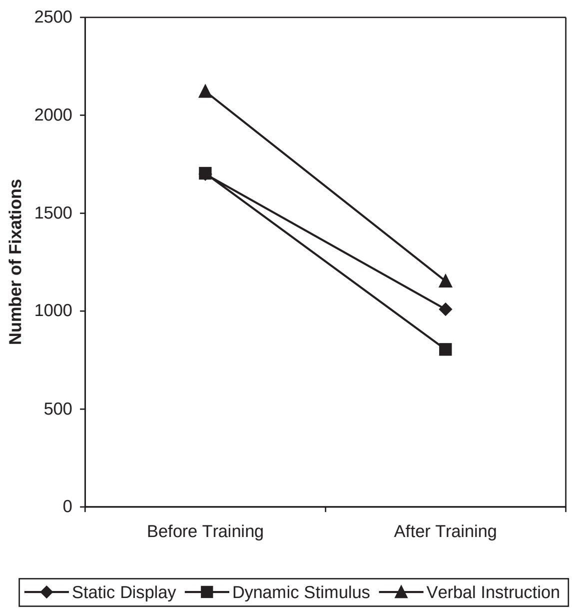

Fig. 6. Number of eye fixations before and after training.

distance were analyzed similarly to the performance measures. The trial × group interaction was not significant for any of the three measures. The only main effect that proved significant was the trial effect for number of fixations (Table 2). Averaging across all subjects, the number of fixations dropped 46.3% after training (Fig. 6). None of the percent difference tests on the process measures proved significant. Lastly, the average number of horizontal sweeps made by each subject was also analyzed between the three groups, but did not prove significant.

4. Discussion

All of the speed related performance measures and one process factor, number of fixations, point to all three training levels as having improved inspection performance in terms of speed. Defects detected, the measure of accuracy, did not prove significantly different between the training levels (Fig. 7). This lack of change in defect detection accuracy may be due to relatively high target conspicuity. Only two subjects out of the 24 found less than 80% of the defects before training. Five subjects found 100% of the defects through the entire experiment. Less conspicuous targets would lower baseline detection rates in the before-training condition, which could potentially result in different levels of defect detection accuracy after training.

While all three levels of training significantly improved inspection speed, none made an improvement that was significantly different from the others in this regard. Accuracy and eye movement behavior also failed to differentiate levels of training, as evidenced by the absence of a significant trial $\times$ group interaction. This lack of difference between levels of training may be due to a lack of inspection task factors that inhibit a systematic search. Potentially, one such factor is a large search field. The entire search field was contained on the computer screen, making the total area very limited. If it were larger, the difficulty of remembering the areas already inspected increases, making systematic search more difficult. It is conjectured that no matter which training level from the three tested is chosen, visual search will show similar improvement given an inspection task of similar complexity.

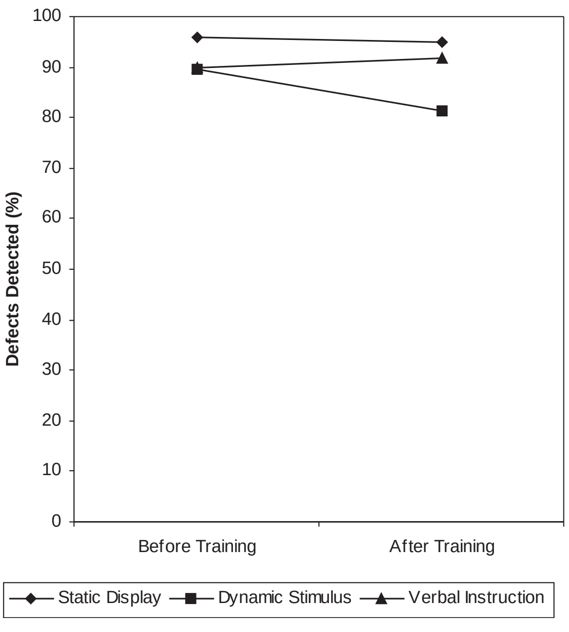

Fig. 7. Defect detection rate before and after training.

In support of this conjecture, eye movement patterns were examined for the before-training condition to determine how systematic they were. Eighteen subjects generally followed a regular pattern before training. Of the rest, three subjects had methodical patterns, however the pattern would vary from screen to screen; two subjects started with random search patterns but converged towards a methodical pattern; and one subject consistently exhibited a random pattern before training. None of these methodical patterns matched the one used in training but typically did consist of overlapping horizontal sweeps moving from top to bottom in the visual field.

While the different levels of training did not appear to differentiate the groups, it did appear to affect the performance of certain individuals. Note the drop in defect detection accuracy for group D (the group exposed to all three modes of training) as seen in Fig. 7; it was not expected and hence was investigated further. After examining the data, it was found that one subject in group D dropped in defect detection accuracy from 100% before training to 50% after training. In between sets of screens after training, this particular subject mentioned finding it difficult to concentrate on finding defects while trying to imitate the dynamic aid presented during training. It would appear that this subject was focused on following the search pattern and pace presented during training rather than finding defects.

One possible explanation stems from the fact that training received by group D was paced due to the nature of the training aid. Paced training with verbal encouragement to use the dynamic stimulus may have led this subject to place greater importance on the task of executing a systematic search with the pattern and pacing demonstrated during training than on detecting defects. Also suggesting the subject's focus on visual search, and particularly on the speed of the inspection process, was this subject's inspection time and number of fixations, which showed the highest percent drop of all subjects (79.5% for inspection time, 76.3% for number of fixations) from before to after training. The subject's average inspection time after training was 16.74 s per screen while the dynamic stimulus was paced to a time of 25.71 s per screen. Thus, the subject may have consciously placed too much emphasis on speed in the speed-accuracy trade off (SATO).

Another possibility is that the subject subconsciously attempted to divide attention between the pace and pattern learned during training and defect detection, but did not allocate sufficient cognitive resources to the defect detection task. These possibilities raise concerns for future use of the dynamic stimulus as a training aid for unpaced tasks in that it may prove effective at producing systematic search, but may direct some trainees to place too much emphasis on inspection speed at the expense of defect detection accuracy. Thus, the dynamic stimulus may be better suited for paced tasks. This training method may also need to be augmented by instruction on the SATO in inspection and more feedback on speed and accuracy performance. Other subjects did not appear to have difficulty with the SATO.

Also, the trained search pattern and pacing were predetermined, but instead may need to be adapted for each individual based on distinctive subject factors such as visual lobe area. If the subject's visual lobe were very small, for example, then the trained search pattern would produce poor performance as it was designed assuming a larger visual lobe. Thus, refining certain aspects of the training that are applicable to all inspectors and incorporating adaptive training for selected subject factors may serve to enhance performance.

5. Conclusions

Three different modes of training for systematic search during inspection were considered here: verbal instruction, a static diagram, and a dynamic training aid. These were combined into three training levels: verbal instruction only, verbal instruction and a static diagram, and all three modes together, which were compared with respect to both performance and process measures. While certain performance and process measures provided evidence that the training levels universally improved inspection proficiency, there were no demonstrable differences in the degrees of improvement between the levels. Therefore, verbal instruction would be the preferred training method in practice as it is the least complex to implement.

Conspicuous targets imbedded within a small, homogeneous search field characterized the pure visual search task selected for this comparison. It is conjectured that verbal instruction would also be the preferred training intervention for any visual search task with characteristics similar to the task employed herein; broadly speaking, one that does not appreciably hinder systematic search. Clearly, further experimentation is warranted with diametric tasks to confirm this conclusion. However, it may be necessary to first conduct a study for the purpose of grading various task characteristics (e.g., field size) with respect to the degree to which they hinder systematic search. If the terminal experiment confirms the conjecture, it is reasonable to believe that it may also indicate the use of more complex training levels for tasks for which systematic search is inherently difficult.

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