Visual Pattern and Search Behavior

By

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A complete visual search consists of both cognitive and physical activities. Physical activity includes eye movement and fixations. Cognitive activity includes perception and information processing. The physical search behavior is the result of cognitive activities. Previous studies of visual inspection mainly focused on analysis of final search performance rather than the mental process. This study intended to thoroughly analyze search behavior and explain how a search strategy is generated.

The goal of this study was to evaluate this model of pattern-driven search and to study what the prerequisites are. A visual inspection task was designed, according to Gestalt's laws, to search on the simulated circuit boards in this study. Eighteen subjects, nine females and nine males, participated in this test.

The results of this study have verified the existence of pattern-driven search behavior. However, the results also indicate that there are certain prerequisites for such pattern-driven search. The main findings and conclusions of this study are summarized below:

- Pattern-driven search is applied if the whole search target can be perceived.

- Pattern-driven search strategy is applied when self-termination search, rather than exhaustive search, is the goal.
- Subjects strive for the accuracy of defect detection during pattern-driven search, whereas during random visual inspection subjects usually strive to improve speed.
- Training and practice are helpful in developing pattern-driven search behavior.
- The pattern-driven search model can be used to improve visual interface design.

This study is the first step in verifying the validity of pattern-driven search. More thorough cognitive studies are recommended to develop the complete model of pattern-driven visual search.

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1. Introduction

Goal

Visual inspection is a complex process involving information processing and physical activities. Previous studies have indicated that visual inspection consists of two main phases -- visual search and decision-making, that most of inspection effort is spent on visual search. Most previous studies of visual search studied the effect of physical factors to the search performance. For that reason, this study mainly focuses on the search process rather than the final performance. The goal of this study is to learn how an inspector generates the search strategy in a complex inspection task.

Issues

Different models of visual search have been developed in previous studies. However, controversies and questions still remain:

Are fixations randomly distributed in the search field? How does an inspector determine the sequence of fixations? Does each fixation receive the same level of attention? All of these questions are related to search strategy. Therefore, in addition to performance analysis, which has been commonly used in previous studies, cognitive analysis was applied in this study.

Approach

The approach used to conduct this study and the process of developing a pattern-driven search model are introduced in the following chapters.

In order to learn how a search strategy is generated, a literature review was conducted, targeting on the physical factors that affect search performance and theories in cognitive psychology related to search behavior. The summary of the literature review is given in Chapter 2.

Based on the literature review, a model of pattern-driven visual search was generated. To evaluate the hypothesis defined of this visual pattern search model, a pilot study was designed to verify task design and analysis in advance. The test plan and experimental design are described in Chapter three.

Chapter 4 details the detail the Analysis of Variance (ANOVA) of search performance. Two dependant variables were applied in this study: overall performance and search performance on each image pattern.

In Chapter 5, the detailed interpretation of results introduced in Chapter 4 is addressed. The search behavior in different tasks is also discussed in detail.

Quantitative analysis in this study confirms the existence of patter-driven search. Verbal protocol analysis and field surveys are recommended in order to complete this search model. Conclusions of this study and application of this search model are discussed in Chapter 6.

2. Literature Review

In section 2.1, previous studies of visual search are reviewed and most physical factors affecting search performance are also discussed. In section 2.2 and 2.3, related theories and research in the psychology field are introduced.

2.1. Visual Inspection

Many factors influencing inspection performance have been studied in various tasks. Colquhoun (1964) provided a framework of visual inspection that included three kinds of physical and mental work:

1. Detection of a discrepancy in the material being examined
2. Judgment of whether the discrepancy as perceived exceeds specified standards
3. Decision as to whether an item judged as being faulty is rejected

This framework emphasizes a dynamic process before decision-making. In the whole inspection task, detecting a discrepancy needs most of time in inspection. In the process of discrepancy detection, the physical eye movements and mental information processing are influenced by physical restrictions of task design. Previous physiological studies indicated that the area of fovea vision subtends an angle at the eye of about 2 degrees (Llewellyn-Thomas and Lansdown, 1963). Any item for inspection that subtends a larger view angle would usually require physical eye movements to cover the whole search target. Therefore, the visual inspection can be seen as a series of visual searches with

different fixations or focal points. Each single visual search with a sole fixation constitutes a single task, which consists of the following subtasks (Gallwey, 1982).

1. Choose an area to fixate
2. Examine the area fixated
3. Decide what is likely fault
4. Select an appropriate visual image from memory
5. Compare this image with that from iconic storage
6. Judge their similarity
7. Recall the inspection standard
8. Decide if this discrepancy is serious enough for rejecting the inspected item -- If reject, cease the inspection process for this item.
9. If this discrepancy is waived, decide if there is enough time to examine more area.
   - 9.1. If there is not enough time, accept the item.
   - 9.2. If there is enough time, select another fixated area to examine and move eyes to it, then repeat all above.

These nine steps have clearly divided the inspection work into different physical and mental work. It is also important to know which steps in an inspection task would be affected by physical factors and what the influence would be. Then, the correlation between those factors and inspectors' performance can be studied. In the engineering field, most studies have focused on effect of physical factors to performance rather than

the influence to search behavior. In order to studying the effect to search behavior , physical factors were thoroughly reviewed for a complete task design.

From the review of previous studies, three major categories of physical factors were identified; 1) capability of inspectors, 2) physical factors, and 3) environmental factors.

2.1.1. Physiological and Psychological Capability

There is consensus that the individual difference plays an important role in visual inspection, though the study of individual differences in inspection has not proven particularly fruitful. Wiener (1975) showed that although strong individual differences exist, they are not readily predicTable from the typical pretests. For the reason, many researches attempt to classify them with more detailed factors. For example, various factors such as gender, age, experience, and anthropometric factors have been studied separately to compare their effect to search performance. To summarize from previous studies, the typical physical and mental factors are listed and discussed as follows:

Eyesight

From selection tests conducted at early age, it has been found that certain visual functions were essential requirements for screening prospective inspector (Tiffin and Rogers, 1941). In general, visual acuity and the way to distributing fixations are two main aspects in studies of eyesight.

Visual acuity. Acuity is seen as a measure of the minimum angle, which is subtended by the test object at the eye. If the same visual discrimination is required in tasks, the inspection performance is highly correlated to inspectors' peripheral visual acuity (Bloomfield, 1975). It was also reported that peripheral visual acuity was independent of viewing distance when the viewing distance was farther than 6 feet. Bloomfield (1972) reported that there was no appreciable difference in inspection performance when viewing distance was increased from 7 to 47 feet. Gillies (1975) had similar finding and reported that visual acuity would keep the same when the viewing distance was increased from 2.4 to 4.8 meters.

McCormick (1950) found nonlinear relationship between accuracy of inspection and static acuity. He emphasized that static acuity was not the only factor to visual performance of inspection although it was confirmed with significant effect on inspection performance. Therefore, it is uncertain whether the peripheral vision has a positive effect to search performance. Although this viewpoint has been supported by results from laboratory studies, but inconsistent results have also been found in industrial tasks. Such difference might be due to a wide variety of task designs. However, the possession of good acuity (equivalent to one minute of angle or less) does not guarantee that a person can be a good inspector. It merely indicates that persons with good acuity are more likely to be a good inspector.

Eye fixations. People move their eyes and search for information they need. They try to acquire necessary information particularly by saccadic eye movements (saccades). Because inspectors can only fixate on a limited area, eye-movement for fixations in a large

target is needed in inspection (Llewellyn-Thomas and Lansdown, 1963). The scanning strategies with effective eye movements have been considered important in determining accuracy of inspection. Several eye-movement parameters must be taken into account in the analysis of eye fixations.

During a series of eye fixations, inspectors would continue visual search until they find a target or a decision is made with no target presented. Thus, visual search is thought to be self-terminating. For each fixation, the inspector needs to compare focused items with image stored in memory. Therefore, memory search during each fixation is thought to be serial and exhaustive because fixed items need to be compared with every item in memory. Sternberg (1967) inferred that memory search consists of two successive stages: an encoding stage, in which the fixated item is coded into a mental representation, and comparison stage, in which the newly encoded item is compared successively with each of the previously encoded memory set items.

Previous studies concluded that fixation time and the number of fixations are the most crucial parameters. A number of researches have studied them from different views. Gould and Dill (1969), and Bloomfield (1975) found that fixation times were determined by task difficulty. Boynton (1975) indicated that fixation time were shorter when inspectors were experienced. In previous studies, fixation time was also found around 200 to 300 ms in most inspection. Longer fixations were associated with the confirmation of presence of a potential target (Bloomfield and Modrick, 1976). In letter search tasks, Gould (1973) also found that fixation duration on target characters was about 250 msec and it was longer than searching on non-target characters.

If the task of visual search is composed of a series of visual fixations, the effect and interactions of the number of fixations and fixation time would be the main issues in studies. The review of previous studies suggests that the number of fixations seemed to affect the total search time more than fixation time. Gould (1973) and Boynton (1975) both found the fixation time was likely to be constant or within a specific range. Schoonard, Gould and Miller (1973) investigated eye-movement in searching circuit chips and found that fast inspectors had fewer fixations. The study also found that the fastest inspectors also had higher accuracy in inspection. Kundel and La Follette (1972) also found that experienced radiologists detected abnormalities in X-rays with fewer fixations than inexperienced examiners.

Distribution of fixation Area coverage of stimulus has been studied by measuring the frequency of fixations falling in specific areas over the display. Williams (1967) found that the frequency of fixations was affected by specific features shown on the display. When two or more target characteristics were specified, fixations were generally based on only one single characteristic. The same study also suggested that the specification of the target creates a perceptual structure of which subjects explored, and allocation of fixations is determined by such structure. Enoch (1959) and Ford, White, and Lichtenstein (1959) found that inspectors paid more attention to the center of search field rather than to the outer parts of the display. Moreover, Enoch (1959) has postulated a quadrant since fewer fixations were given to the upper left-hand quadrant of the field than any other three quadrants.

Sequential indications. The most common sequential indication is the scan-path.n In most studies, a eye tracking device was employed to record the scan-path composed by a series of fixations (Schoonard and Gould, 1973; Schoonard, Gould and Miller, 1973; Megaw and Richardson, 1979). Inconsistencies were usually found in the analysis of scan-paths because of variability. Since search patterns are influenced by the type and structure of the visual field (Williams, 1967), such high variety may have obscured the consistency of the scan path. Another possibility is that same image pattern might not affect attention to different inspectors.

Two models of visual searches have been postulated in the past. The random search, Larmar (1960), and Krendel and Wondinski (1960) assumed that fixations in visual search were independent and random. Therefore, any fixation point is equally distributed on any scan. This means that selection of fixation points can be anywhere of the search area, and such selection is independent of the previous selection within fixations. On the other hand, Williams (1966) postulated a model of systematic search, in which fixations are sampled from the search field without replacement. In Williams's postulate, systematic search does not necessarily follow a regular pattern as long as each fixation is constrained to fall only on an unselected area in previous glimpses. In another study, Tsao and Drury (1979) reported that systematic visual search was highly correspondent to the stop policy in self-paced inspection.

Other parameters, including inter-fixation distances and direction of eye-movements were also found to cause individual difference in inspection. Mackworth and Bruner (1970) found that young children exhibited shorter distance between two

successive fixations than adults did when examining pictures of familiar scenes. this might account for the lower speed rate of information processing of the children. The same study also suggested that horizontal saccades occurred more frequently than vertical ones. They also emphasized that this phenomenon was not due to the structure of distribution of the stimulus material. In the same study, the elliptical shape of field view was found most effective for visual inspection.

Experience

Experience is recognized as being an important variable in inspection but it may have both positive and negative effects. After practice or work on similar tasks for a while, the main influence of an inspector will be reflected in two things, the comprehension of specification, and expectancies. Baker, Morris and Steedman (1960) and Bloomfield (1975) have found that observers were able to search faster with fewer errors after practice. Practice repeats the coding process of specification to the memory system. The understanding of specification is helpful in matching iconic images to failure images stored in the working memory.

Usually, inspectors were given inspection standards or samples defects before inspection. Sometimes, it is difficult for inspectors to tell the difference between standard sample and inspection targets due to lack of experience. In other words, inspectors may not have enough practice to keep a clear image of standard sample in memory in order to compare with search targets. In Gibson's (1953) conclusion, such difficult discrimination can show how the importance of practice was. Another important concern is that experience gained through training or practice helps trainees to establish a mental model of

the characteristics of an accepTable product (Embery, 1979). The effect of a mental model in visual inspection will be discussed later.

With experience, an inspector will develop an expectation of defects occurrence. According to experience, inspectors will pay more attention on the specific area where defects are likely to occur more frequently. Similarly, the specific failure that occurred frequently in inspectors' previous experience will also easily gain more attention. Accordingly, with a time constraint, inspectors would rather spent little time on those areas where no failure has been found before. For the same reason, inspectors also tend to ignore failure types that rarely occurr. Expectation will also affect inspectors' visual search pace. Tsao and Wang (1984) have investigated inspectors' stop policy in self-paced inspection tasks. They found that in continuous search, the searching time decreased for the following second and third items after detecting a defect, then the search time increased for the sixth and seventh items.

Experience facilitates visual search if the product quality keeps consistent. However, previous experience may mislead the visual search and cause some failures to be undetected if inspectors are unaware of the change (Bloomfield, 1975).

Personality

Cognitive style has been widely recognized as a main factor influencing inspection behavior. Different personalities result in different cognitive styles of processing information. Wiener (1975) reported that although strong individual difference existed. They are not readily predicTable from typical pre-tests employed to date. Many tasks or

scales have already been applied in military service for personnel selection, but Weiner's investigation on evaluating the validity of those tasks and scales still founded disappointing results. He indicated that the potential of Minnesota Multiphasic Personality Inventory (MMPI) and other personality scales were not reliable and should be reviewed and examined.

Schwabish and Drury (1984) followed the idea and thought that the cognitive styles were a potentially useful dimension to predicting inspectors' performance. In their studies, subjects were pre-tested and classified as reflective (longer times, fewer errors), impulsive (shorter times, more errors), fast-accurate (shorter times, fewer errors), and slow-inaccurate (longer times, more errors). They concluded that the reflective and fast-accurate were faster than the other two groups but the faster groups made more mistakes. The cognitive styles were significantly related to decision errors only if flaws are very small or very big. Overall, anxiety caused by time pressure is the main reason to result in the rapid search; however, the reflective cognitive style maintained superior performance.

Age, Gender, and Intelligence

There are numerous other factors that have been studied and are important in explaining individual differences. But they seem to be more tasks-dependent and do not always show significant effects.

As to age, Erickson (1964) designed a search task, in which 16 observers with age between 23 and 41 years searched for a Landolt 'C' placed among rings of similar size and color contrast. The result showed no correlation between age and search performance in

both static and moving displays. Contrary to this finding, Sheehan and Drury (1971) reported a decrease in inspection performance as a function of increasing age. An important difference is that the larger age range (30 to 65) was employed in Sheehan and Drury's study. In Jamieson's (1966) electronics inspection tasks, a larger age range (age to 60) of subjects was used, and the result showed that a smaller rate of inspection errors in older subjects groups. Jacobson (1953) found increasing accuracy among electronics inspectors up to age of 34, which the declined until age of 55.

Gender effect is also confusing after reviewing previous researches. In different inspection tasks, no significant effect of sex was reported (Wagg et al., 1973, Kirk and Hecht, 1963). But Neal and Pearson (1966) claimed that male inspectors were normally superior to female inspectors in their studies. In some other studies, there was no significant effect of gender on search performance but significant interactions with other variables were found (Bakan and Manley, 1963).

Another factor of individual difference is intelligence. A stereotype of people's belief suggests that inspectors with low intellectual capability have better performance in the monotonous task than in other more complicate tasks. Intelligence may influence the decision-making process and the determination of appropriate strategies, but only a few studies have examined the effect of intelligence in inspection performance. In vigilance tasks, Kappauf and Powe (1959) reported a significant effect of intelligence with positive correlation to the performance. But other studies did not report the same findings (Wilkinson, 1961; Ware, 1961). It is unknown whether the intelligence in different studies were similar or not. In fact, the definition of intelligence is still ambiguous and diverse IQ

tests applied in different studies might also have caused the inconsistent conclusions. Additionally, the different task designs could also have contributed to the contradictory results. Furthermore, most laboratory experiments were in very short period of time. Whether or not the intelligence difference would be maintained after a long period practice has not been evaluated. Therefore, intelligence has not yet been shown to be still not a promising basis by which to select inspectors. But the individual difference caused by intelligence difference should not be ignored.

2.1.2. Physical Factors

In addition to individual differences, the physical conditions in each task are also major factors affecting inspection behavior and performance. The reason why inspectors determine different search strategies for different tasks is usually based on various restrictions caused by task design. Moreover, the system designers can somewhat influence inspectors' behavior through task design. Most of physical factors are measurable and controllable during inspection.

Presentation of Targets

There are several parameters related to this issue: Dynamic or static; single defect or multiple defects; target uncertainty and others. Many studies have examined various factors pertinent to the presentation of searching targets.

Dynamic inspection In dynamic inspection, inspectors usually focus on a fixed area through which where the inspected targets will automatically pass through. In