

The use of advanced technology for visual inspection training

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In the past, training with traditional methods was shown to improve inspection performance. However, advances in technology have automated training and revolutionized the way training will be delivered in the future. Examples of such technology include computer-based simulators, digital interactive video, computer-based training, and intelligent tutoring systems. Despite the lower cost and increased availability of computer technology, the application of advanced technology to training within the manufacturing industry and specifically for inspection has been limited. In this vein, a case study is presented which shows how advanced technology along with our basic knowledge of training principles, can be used to develop a computer-based training program for a contact lens inspection task. Improvements due to computer-based inspection training were measured in an evaluation study and are reported. © 1998 Elsevier Science Ltd. All rights reserved.

Introduction

Modern manufacturing demands extremely low defect rates, often measured in parts per million. Furthermore, customer awareness regarding product quality and increased incidences of product liability litigation have caused inspection process to become an important factor in manufacturing industries (Moll, 1980). This situation requires a better trained inspection workforce whose training can withstand legal scrutiny. Stated, simply, the inspection process is a careful search for non-conformities in an item. The two functions that are central to all inspection tasks are visual search and decision making (Drury, 1978). These functions have also been shown to be important determinants of inspection performance (Sinclair, 1984; Drury, 1992). If inspection is to be successful it is critical that these functions be performed effectively and efficiently.

Inspection tends to be less than 100% reliable with human inspectors (Chin, 1988; Drury, 1992). To overcome this deficiency, many companies have resorted to automated inspection in an effort to eliminate error from the inspection process. Automated inspection systems (e.g. Ahlers, 1986; Batchelor *et al.*, 1986; Hou *et al.*, 1993) automate various functions of the inspection task. Although automation is considered to be a solution, it does not surpass the superior decision-making abilities of the human inspector as evidenced by both laboratory and field studies of inspection (Hou *et al.*, 1993; Thapa *et al.*, 1996). Furthermore, the superiority of human inspectors is more pronounced when complex decision making is involved (Drury and Sinclair, 1983). Humans are desirable for examination types of inspection tasks wherein the inspector has to search

and later decide whether the item is to be accepted or rejected based on single or multiple attributes (Czaja and Drury, 1981). Since humans will continue to be a part of the inspection process for the foreseeable future, they need to be trained to be effective and efficient as inspectors.

Training has been shown to have a powerful effect on inspection performance even when applied to experienced personnel, i.e. retraining. Yet studies of inspection training are limited. The lack of extensive studies in the application of training to inspection can be attributed to the fact that both training and inspection are often considered as necessary evils and basically non-productive activities (Embrey, 1979). A wealth of laboratory data has been gathered on training and learning (e.g. Salvendy and Seymour, 1973; Goldstein, 1974; Gagne *et al.*, 1992), but again, the application of this knowledge in industry, and specifically in inspection, is the exception rather than the rule. Analytically based training techniques are confined largely to the military, where they have proven to be cost-effective and have been shown to improve performance (Johnson, 1981; Goettl *et al.*, 1996). Embrey (1979), Czaja and Drury (1981) and Drury and Gramopadhye (1990) noted the lack of application of analytically based training techniques in industry, while detailing the principles on which inspection training should be based. The lack of application of training principles to inspection training is not the only issue which needs attention. Advances in technology have led many researchers to concentrate on the training delivery system as the means for improving training. With computer technology becoming less expensive, the future will bring an increased application of advanced technology in training. Over the past decade, instructional technologists have offered

numerous technology-based training devices with the promise of improved efficiency and effectiveness. These training devices are being applied to a variety of technical training applications. Examples of such technology include computer-based simulation (e.g. Johnson, 1990) interactive videodiscs (Gordon, 1994) and other derivatives of computer-based applications (White, 1993). Compact disc read only memory (CD-ROM) and Digital Video Interactive (DVI) are two other technologies which will provide us with the 'multi-media' training systems of the future. Training delivery systems such as computer-aided instruction (Fletcher, 1988), computer-based multi-media training (Wilcocks and Sanders, 1994) and intelligent tutoring systems (Psotka *et al.*, 1992; Shutke and Psotka, 1996) are already being used today, thus ushering in a revolution in training. In the United States, the Department of Defense has taken a leadership role in applying advanced technology to training (Fletcher, 1995). Examples of these applications currently used by the United States Air Force are (Regian *et al.*, 1996): the KG 194 Trouble Shooting Tutor, the F-15E Armament Maintenance Trainer, and the Undergraduate Navigator Training Tutor (all of which use the Intelligent Computer Aided Instruction approach to training). Studies conducted by the United States Department of Defense in the use of Intelligent Computer Aided Instruction have revealed a 34% increase in outcome performance measures and 55% reduction in learning time (Fletcher, 1995).

In the domain of visual inspection, the earliest efforts to use computers for off-line inspection training were reported by Czaja and Drury (1981). They used keyboard characters to develop a computer simulation of a visual inspection task. Similar simulations have also been used by other researchers to study inspection performance in a laboratory setting (e.g. McKernan, 1989). Since these early efforts, Latorella *et al.* (1992) and Gramopadhye *et al.* (1994) have used low fidelity inspection simulators using computer-generated images to develop off-line inspection training programs for airframe inspection tasks. More recently, Blackmon and Gramopadhye (1996) have reported the development of an inspection simulator using scanned images of airframe structures for aircraft inspection training. Similarly, Drury and Chi (1995) studied human performance using a high fidelity computer simulation of a printed circuit board inspection. Another domain which has seen the application of advanced technology is that of inspection of X-Rays for medical practice (e.g. Kundel *et al.*, 1990). In summary, most of the work in the application of advanced technology to inspection training has focussed on developing low-fidelity simulators for running controlled studies in a laboratory environment (e.g. a computer-simulated line judgement task — Micalizzi and Goldberg, 1989) or has found application for off-line training in non-manufacturing areas (e.g. the aircraft inspection domain). Advanced technology has found limited application in industrial tasks, specifically inspection tasks that exist in today's manufacturing industry. The primary exception is the use of simulators (Fletcher, 1995; Johnson, 1990) which have moved beyond the aviation industry and military applications to chemical and nuclear plants. The message is clear: we need more examples of the application of advanced technology to training for inspection tasks that draw upon the principles of training which we

already know will work. In this vein, a case study is presented which demonstrates the application of advanced technology to inspection training for a contact lens inspection task. Initially, this paper outlines a systematic methodology for developing an inspection training program which is then used in the development of a computer based inspection training program. Finally, the results of a study conducted to determine the effectiveness of the computer-based inspection training system are reported.

Systematic approach to the development of an inspection training program

Researchers and training practitioners have proposed various methodologies for developing training programs (Goldstein, 1974; Gordon, 1994; Embrey, 1979; Kleiner and Drury, 1993). *Figure 1*, adapted from Gramopadhye *et al.* (1997), outlines a step-by-step methodology to design an inspection training program. The figure shows the organizational inputs and objectives/goals at each step of the training program development methodology. Having defined the training program development methodology, any training program consists of the training content, training methods and the training delivery system. The specific methods and delivery systems which can be used for inspection training are detailed below.

Training methods for inspection

The specific training methods which can be used for inspection training (Drury and Gramopadhye, 1990; Gramopadhye *et al.*, 1997) are described below:

(1) *Pre-training*: Pre-training provides the trainee with information concerning the objectives and scope of the training program. During pre-training, pretests can be used to measure (a) the level at which trainees are entering the program and (b) cognitive or perceptual abilities that can later be used to gauge training performance/progress. Advanced organizers or overviews, which are designed to provide the trainee with the basics needed to start the training program, have been found to be useful. The elaboration theory of instruction (Reigeluth and Stein, 1983) proposes that training should be imparted in a top-down manner wherein a general level is taught first before proceeding to specifics. Overviews can fulfill this objective by giving the trainee an introduction to the training program and facilitating assimilation of new material.

(2) *Feedback*: A trainee needs rapid, accurate feedback in order to know whether a defect was classified correctly or a search pattern was effective. Feedback with knowledge of results, coupled with some attempt of performing the task, provides a universal method of improving task performance (Wiener, 1975). This applies to learning facts, concepts, procedures, problem solving, cognitive strategies and motor skills (Annett, 1969; Adams, 1987). The training program should start with rapid feedback which should be gradually delayed until the 'operational level' is reached. Providing regular feedback beyond the training session will help to keep the inspector calibrated (e.g. Drury, 1989). Gramopadhye *et al.* (1997) classify feedback as performance and process

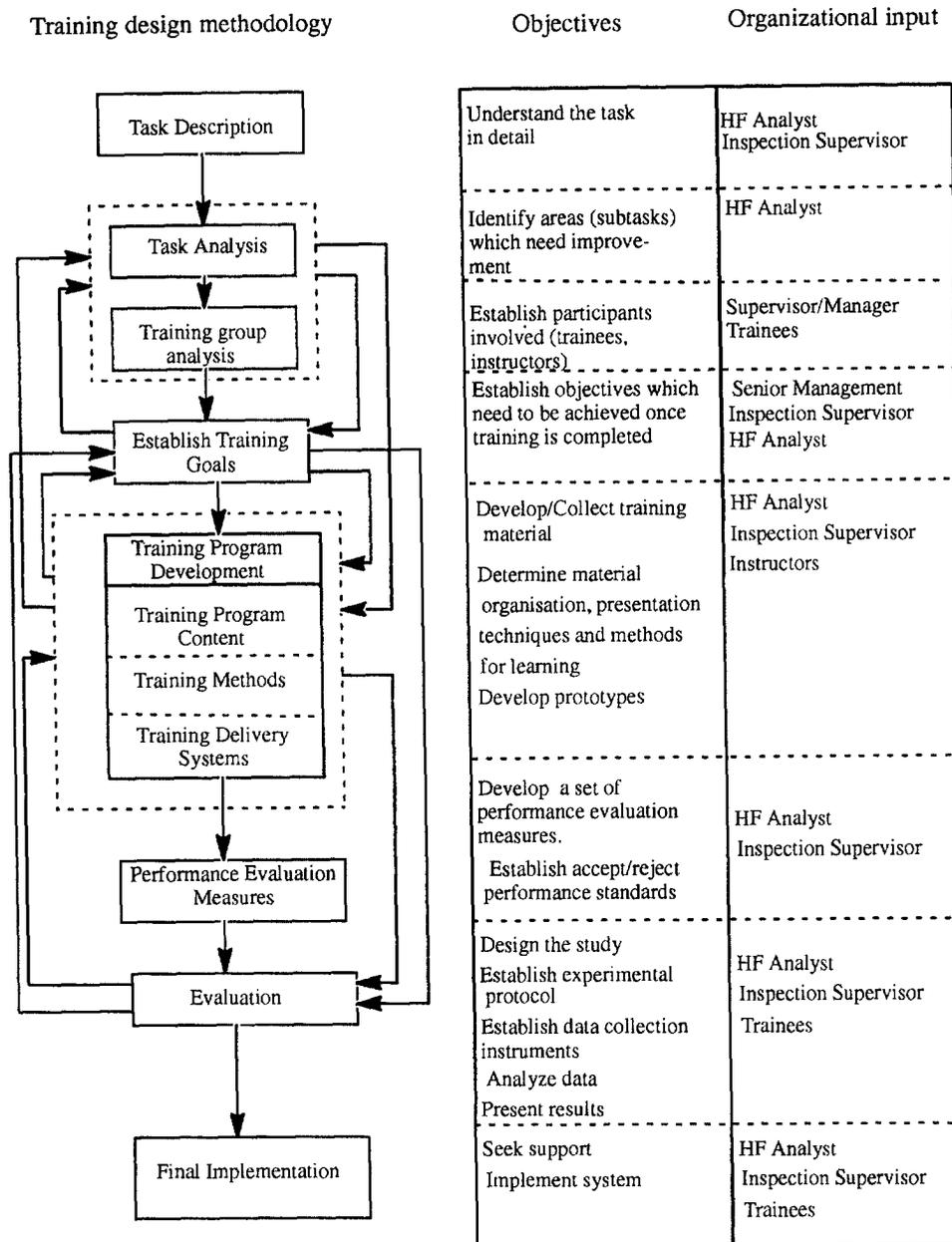


Figure 1 Step-by-step training methodology

feedback. Performance feedback in inspection typically consists of information on search times, search errors and decision errors. Process feedback, on the other hand, informs the trainee about the search process, such as areas missed. Another type of feedback called 'cognitive feedback' has emerged from the area of social judgement theory. Cognitive feedback is the information provided to the trainee on some measure of the output of his or her cognitive processes. For inspection tasks, process feedback is the same as cognitive feedback (Gramopadhye, et al, 1997).

(3) *Active training*: In order to keep the trainee involved and to aid in internalizing the material, an active approach is preferred. In active training, the trainee makes an active response after each piece of new material is presented, e.g. identifying a fault type. Czaja and Drury (1981) used an active training approach and

demonstrated its effectiveness for a complex inspection task.

(4) *Progressive part training*: Several researchers have successfully used a progressive parts training methodology for inspection training (e.g. Czaja and Drury, 1981; Blackmon and Gramopadhye, 1996). In the progressive part methodology, parts of the job are taught to criterion and then successively larger sequences of parts are taught. For example, if a task consists of four elements E1, E2, E3 and E4, then the following would follow:

- Train E1, E2, E3 and E4 separately to criterion.
- Train E1 and E2; E3 and E4 to criterion.
- Train E1, E2 and E3 to criterion and E2, E3 and E4 to criterion.
- Train the entire task to criterion.

This method allows the trainee to understand each element separately as well as the links between the

various elements thus representing a higher level of skill. On the other hand, reviews of literature reveal that part task training is not always superior. The choice of whether training should be part or whole task training depends on the 'cognitive resources' imposed by task elements and the 'level of interaction' between individual task elements (Gordon, 1994). Thus, there could be situations in which one type of task training is more appropriate than the other. Naylor and Briggs (1963) have postulated that for tasks of relatively high organization or complexity, whole task training should be more efficient than part task training methods.

(5) *Schema training*: The trainee must be able to generalize the training to new experiences and situations. For example, it is impossible to train the inspector on every site and extent of scratches on a contact lens so that the inspector is able to detect and classify a scratch wherever it occurs. Thus, the inspector will need to develop a 'schema' for scratches which will allow a correct response to be made in novel situations. The key to the development of schema is to expose the trainee to controlled variability in training (Kleiner and Catalano, 1983).

(6) *Feedforward training*: It is often necessary to cue the trainee as to what should be perceived (Thapa *et al.*, 1996). When a novice inspector tries to find defects in a contact lens, the indications may not be obvious. The trainee must know what to look for and where to look. Specific techniques within cueing include match-to-sample and delayed match-to-sample. Feedforward information can take different forms such as physical guidance, demonstrations, and verbal guidance. Feedforward should provide the trainee with clear and unambiguous information which can be translated into improved performance.

Training delivery system

Training delivery systems can be classified as Classroom Training, On-the-Job Training and Computer-based training (Gramopadhye *et al.*, 1997). Gordon (1994) goes

on to develop a more detailed taxonomy of delivery systems, listing the advantages and disadvantages of each training delivery system. Gordon stated that the choice of the specific delivery system depends on various factors, some of which include the nature of the task, the type of knowledge that needs to be transferred, user background and experience, implementation and development costs, time available and flexibility. *Table 1* adapted from Drury (1992) summarizes reported work on practical applications of inspector training programs and identifies the different delivery systems used. Having described a systematic approach to development of a training program, the following section describes the use of the methodology in developing a computer-based inspection training program.

Case study—contact lens inspection

Task description

Contact lenses are FDA-regulated Class II medical devices, and inspection in such an industry may exist for a long time due partially to the mind set of the industry and its view of complying with FDA regulations (Kimble and Gramopadhye, 1994). A company manufacturing contact lenses employed a large number of inspectors, and the inspection process was critical to ensure product quality because it helped weed out defective lenses before they reached the customer. Thus, any changes made to the inspection process to make it more effective and efficient could potentially have a large impact on quality and costs.

Briefly stated, the contact lens inspection task consisted of visual inspection of contact lenses of 10 mm in diameter for cosmetic defects (refer to *Table 2* for the task description). The company's Standard Operating Procedure (SOP) required the inspector to look for single as well as multiple cosmetic defects in a contact lens. These defects, which could occur in the central optic area or

Table 1 Practical applications of inspection training programs

Researchers	Training			Results
	Methods	Delivery system	Content/task	
Evans (1951)	Knowledge of results	Classroom training with 30 mins of instruction	Micrometer inspection gage	50% reduction in error
Chaney and Teel (1967)	Knowledge of results	Lecture and demonstrations	Inspection of machine parts	32% improvement in defect detection
Parker and Perry (1972)	Knowledge of results	Demonstrations using photographs	Inspection of glass bowls	50% increase in faulty detection and 50% increase in faulty rejections
Steven and Gale (1970)	Knowledge of results	On-the-job training with known sample in production	Inspection of apples	Number of errors decreased with increased time
Kundel, Nodine and Krupinski (1990)	Feedback	Computer-based training system	Reading chest radiographs	16% improvement in detection
Kleiner and Drury (1993)	Progressive part, cueing, knowledge of results	Administered in classroom using task cards	Inspection of small steel cylinders	Repair and scrap rate reduced by 50%
Blackmon and Gramopadhye (1996)	Progressive part, knowledge of results	Computer-based training system	Aircraft inspection	Improvement in fault detection and reduced inspection times

Table 2 Task description: contact lens inspection task

Tasks	Description
1. Initiate	Set the optoscope magnification and use vacuum pickup to pick contact lens from the tray.
2. Orient	Locate and orient the contact lens under the eye-piece.
3. Focus	Focus the optoscope so that contact lens is clearly visible on the screen.
4. Search	Search for a defect beginning with the optic area progressing towards the lenticular area.
5. Decision making	Examine potential defect against standard and classify lens as conforming or non-conforming.
6. Dispatch	Place the contact lens back into the tray if it is conforming, else discard it.
7. Record	If the lens is defective, record the defect type.

peripheral lenticular area, included: holes, mold flashes, pre-releases, inclusions, cup handling defects, irregular edge/chips, cracks, scratches, discoloration, air bubbles and engraving defects. The inspection was conducted on a projection unit (optoscope) similar to a microfiche reader wherein the contact lens was placed on a glass dish using a pneumatic holder and the projection unit was used to focus the lens which was magnified 17 times and displayed on the optoscope screen. The inspector then visually searched the optic and lenticular area for different defects. Based on the defect type and its severity, the number of defects of each type and the location (optic area or lenticular area), the inspector classified the lens as conforming or non-conforming. Non-conforming lenses were placed on a separate tray, recorded according to the defect type and later discarded.

Task analysis

A detailed task analysis of the entire inspection operation was conducted. A number of points became evident during the task analysis which had a direct impact on the training scheme. The most important among them are:

- A lack of consistency/standardization amongst experienced and inexperienced inspectors in using search and decision criteria to classify defects and lenses.
- A significant difference in the names of defects given by the inspectors even though the SOP clearly specifies each defect type by a specific defect name.
- Difficulty in applying the appropriate defect rules to classify the lenses as conforming or non-conforming based on defect location, defect severity, defect type and number of defects.

The present system used to train inspectors mostly relied on one-on-one interaction between the trainer and the trainee, conducted off-line using actual defect samples. Although this method of training is highly flexible and adaptive, it is limited by the knowledge of the trainer and the time available for the trainer to conduct training. A major drawback of the current method of training is that inspectors are trained by different trainers, resulting in inconsistency and non-standardization of instruction.

Thus, the method suffers from all the drawbacks from which typical tutoring systems suffer (Gordon, 1994). Furthermore, training is conducted using actual samples of conforming and non-conforming lenses. The lenses degenerate rapidly over time in storage by changing in shape and form and hence cannot be used as test samples over extended time periods. Substitutions may also be necessary for lenses that are discovered by the inspector undergoing training to have new defects which were not present when the original sample was developed or which were overlooked by the team screening and assembling the test sample. In addition, handling damage can occur with each inspection and each storage of the sample, leading to more defects. Therefore, it may be necessary to substitute new items for those damaged. The greatest difficulty (or virtue) in using the 'test sample method' for training is the assembly of the test sample itself. Before it is assembled, the trainers must have a detailed knowledge of the various defects possible, their ranges of severity, their standards and the overall defective rate. However, incorporating realism into the test sample implies a 'batch size' problem which the trainers have to tackle.

Task analysis identified the training as the most cost effective and efficient strategy for improving inspection performance. The training system designed to improve contact lens inspection performance needed to address the problems resulting from non-standardization and those resulting from using actual defect samples. To alleviate some of the problems resulting from the use of actual defect samples and the tutoring method of training, a computer-based inspection training system which uses computer-simulated images of contact lenses was developed.

The computer-based inspection training system

System description

The computer-based training program was developed using Asymetrix's - Multimedia ToolBook Kit and DBASE III plus. It operates on a 486 DX2 66 MHz platform with a 17" high-resolution monitor (0.28 mm dot pitch, non-interlaced), 32 Mb RAM, 2 Mb video RAM, ATI Mach 32 VLB advanced graphics accelerator card, 810 Mb hard drive, multi-speed CD drive, 210 Mb Bernoulli drive and a Reveal Multi-Media Kit. The training program uses text, graphics, animation and audio. The inputs to the system are entered through a keyboard and a two button mouse.

Development of computer-simulated lens images

The computer-simulated images of contact lenses were developed by capturing images of good and defective lenses using a high-resolution CCD camera. The setup used to capture the images is shown in *Figure 2*. It uses embedded frame grabbers that transfer images over the CPU bus. The use of a bus-transfer based board which has its own memory and typically provides both input and output facilities allows for maintaining true 24 bit RGB color throughout acquisition and display with superior Analog to Digital Converter (A/D) sensitivity for very accurate results. The CCD camera captures the image of a lens and displays it on a local monitor.

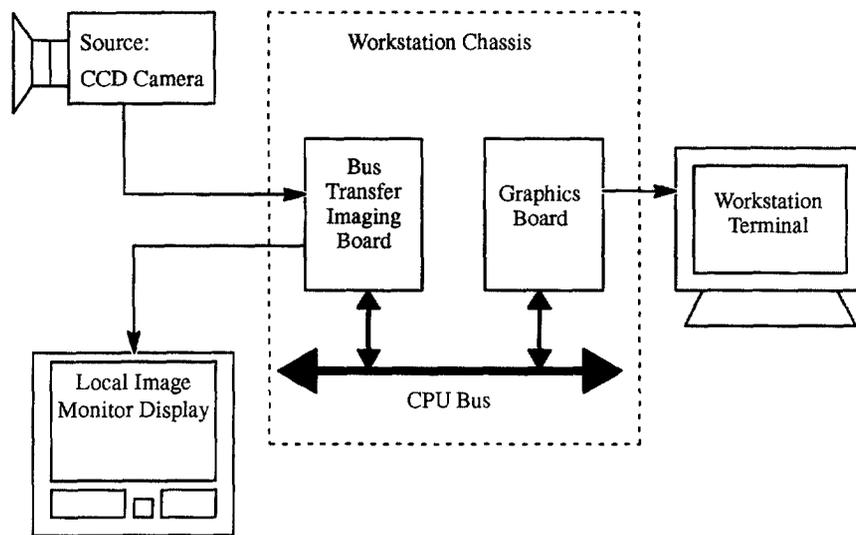


Figure 2 Setup for generating computer simulated images

The image, once displayed on the local workstation terminal is mapped to a 256 color palette and later enhanced and edited using commercially available image editing software (ADOBE Photoshop and COREL Draw) so that the lenses and defects closely match those viewed by the inspectors on an optoscope screen. Thus, a library of contact lens images was developed which consisted of conforming and non-conforming lenses having different types of defects at varying severity levels and locations. All of this could not have been achieved without closely interacting with the supervisors, trainers and quality assurance personnel to ensure that the computer-generated images were a realistic representation of what the inspector actually observes on an optoscope screen. Each image was viewed independently by six evaluators (three trainers and three experienced inspectors) and closely matched using a color swatch system before being included in the library of final images. The images were viewed simultaneously on the computer and the optoscope screen so that the evaluators could perform a relative comparison of each computer image. As each image was viewed on the computer screen it was compared with its equivalent image on the optoscope and rated on a seven-point scale (1 being not acceptable and 7 being acceptable). Only those images which had a mean rating of six or higher were included in the library of final images. The evaluators also supplied detailed verbal information on unacceptable images. This information was used by the developers to enhance the images.

System structure

The system consists of four major modules: the inspection training module, the help module, the instructor's utilities module and the startup module (Figure 3). All system users interacted through a user-friendly interface. The user interface capitalizes on graphical user interface technologies and human factors research on information presentation (e.g. color, formatting, layout, etc.), ease of use and information utilization (Smith and Mosier, 1984; Helander, 1990; Eberts, 1994).

Inspection training module

This is the primary module of the training program through which the trainee inspector interacts with the system. The training module is further divided into four major sub-modules: introduction, search training, decision training and testing. Each of these sub-modules uses computer-generated images of the contact lenses. The layout of the simulated inspection task is shown in Figure 4. The contact lens is displayed on the left side of the screen and associated information is shown on the right side of the screen.

Introduction: The introduction is an animation that provides the trainee with an overview of the various facets of the program. It consists of the following:

1. *Lens terminology:* This section provides basic information on contact lens terminology and identifies the different parts of the contact lens. It also identifies for the trainee the associated information which he/she should look for.
2. *Defect standards:* This section provides the trainee with a graphical representation of each fault. Information associated with the fault is shown on the right side of the screen (Figure 4). The trainee is provided the following information on each defect: defect name, defect location, and rules for accepting or rejecting the lens (based on defect severity, number of defects and defect location).
3. *Overview:* This section introduces the trainee to the search and decision making aspects of the inspection task. Each section is followed by a question and answer session wherein the trainee has to make an active response as each piece of new material is presented. The trainee is provided with immediate feedback as to its correctness. If an error is made, it is identified and the correct answer is supplied.

Search training: This module trains the inspector only on the search component of the inspection task. The objective is to train inspectors to correctly identify and locate cosmetic defects that may exist in a contact lens. This

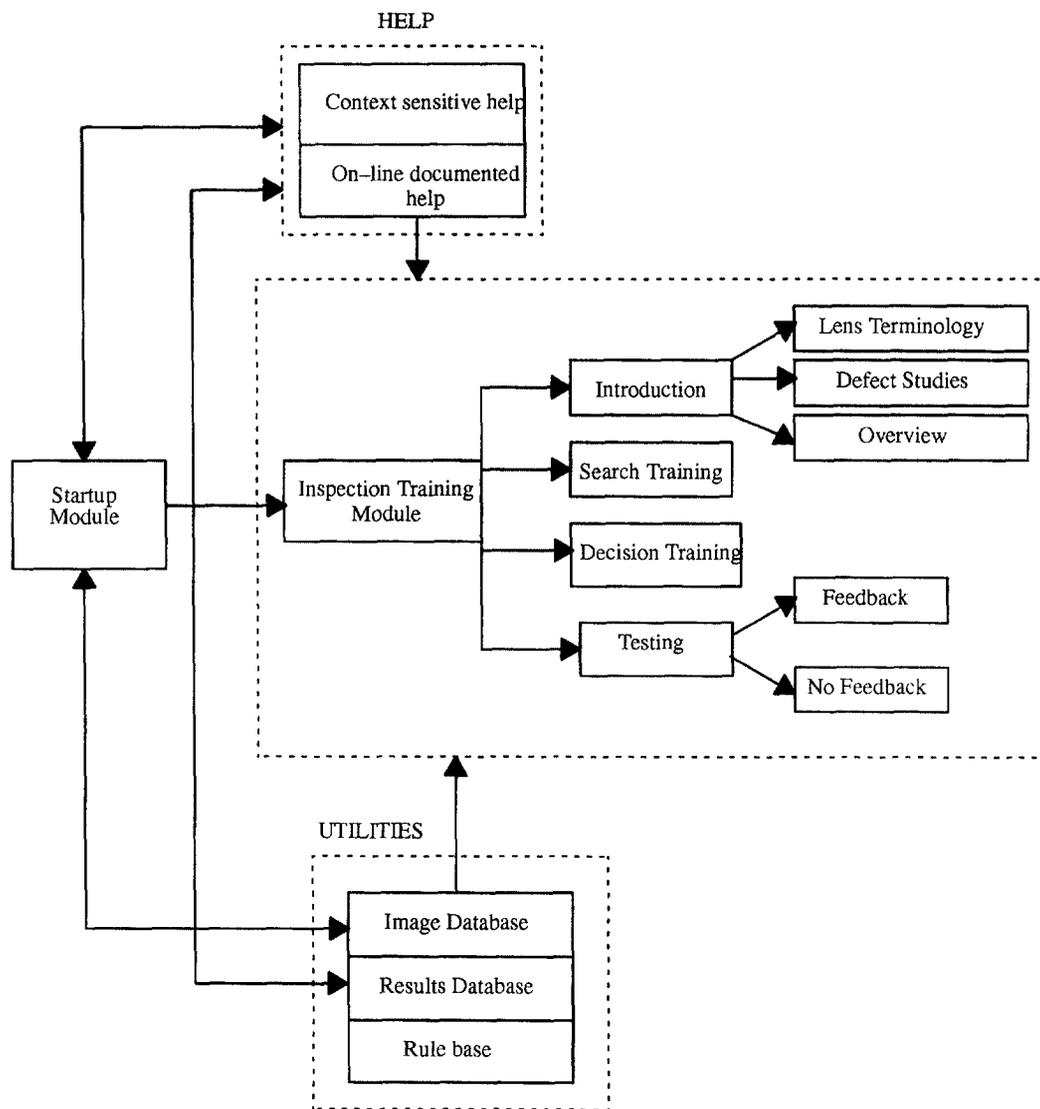


Figure 3 Structure of the computer-based inspection training system

type of training is aimed at developing cues and knowledge of where specific defects occur. A series of contact lenses with and without defects is displayed to the inspector. After each lens is displayed, the inspector locates the defect by clicking the mouse on the fault. The trainee is provided with immediate feedback on the following speed and accuracy measures:

- The time to locate the defect (search time)
- The accuracy of the search process (the program lets the inspector know whether he/she correctly identified the defect and marks the defect on the computer screen)

Decision training: This module trains the inspector on the decision-making component. A series of contact lenses is displayed with the faults marked. After each lens is displayed, the inspector makes an active response on the defect type and the lens type. First, the trainee classifies the defect by defect name. Following defect classification, the trainee classifies the lens based on the number of defects, defect type, severity and location as conforming or non-conforming. The inspector is

provided with immediate feedback on his or her decision making performance. Feedback is provided on defect classification performance, lens classification and decision time. The general objective of this module is to train the inspector on both the rule-based and knowledge-based aspects of the decision task. The specific objectives of this module are to train the inspectors on defect naming, to assist in schema development and to train on defect and lens classification rules.

Testing module

The testing module can be run in two separate modes, with and without feedback. The no-feedback mode simulates the actual inspection task. In either mode, the inspector first locates the defect and indicates this by clicking on the fault. Following search, the inspector classifies the defect and later classifies the lens as acceptable or rejectable. In the feedback mode, the inspector is provided with immediate feedback on his/her performance on the search and decision making components of the inspection task. The trainee is also provided with end-of-session performance feedback. The

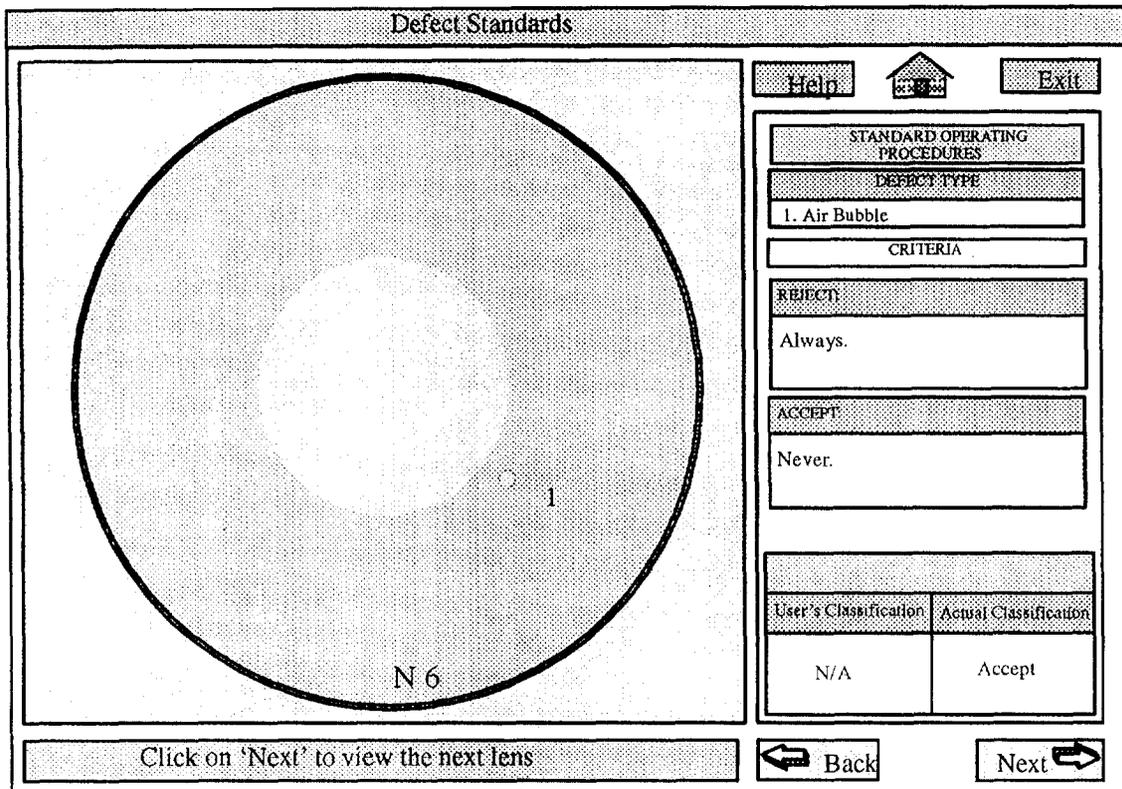


Figure 4 Layout of a typical inspection screen

performance feedback consists of the following:

- Location of the defects present in the contact lens.
- Mean inspection time per lens.
- User defect classification and the correct defect classification.
- User lens classification and the correct lens classification.

In addition to the above measures, the system records performance on various speed and accuracy measures as outlined in the following section. *Figure 5* depicts a prototypical screen viewed by the trainees after inspecting a single lens in the feedback mode.

Instructor's utilities module

This module allows the supervisors to access the results database (*Figure 6*), the image database (*Figure 7*) and the faults rule base modules (*Figure 8*). The module has been designed as a separate stand-alone tool that is linked to the other modules of the system. The results database allows the instructors to review the performance of a trainee who has taken several training and/or testing sessions. Performance data are stored on an individual image basis and summarized over the entire session so that results can be retrieved at either level. The utility allows the instructor to print or save the results to a file. Data are collected on the following speed and accuracy measures:

Speed measures:

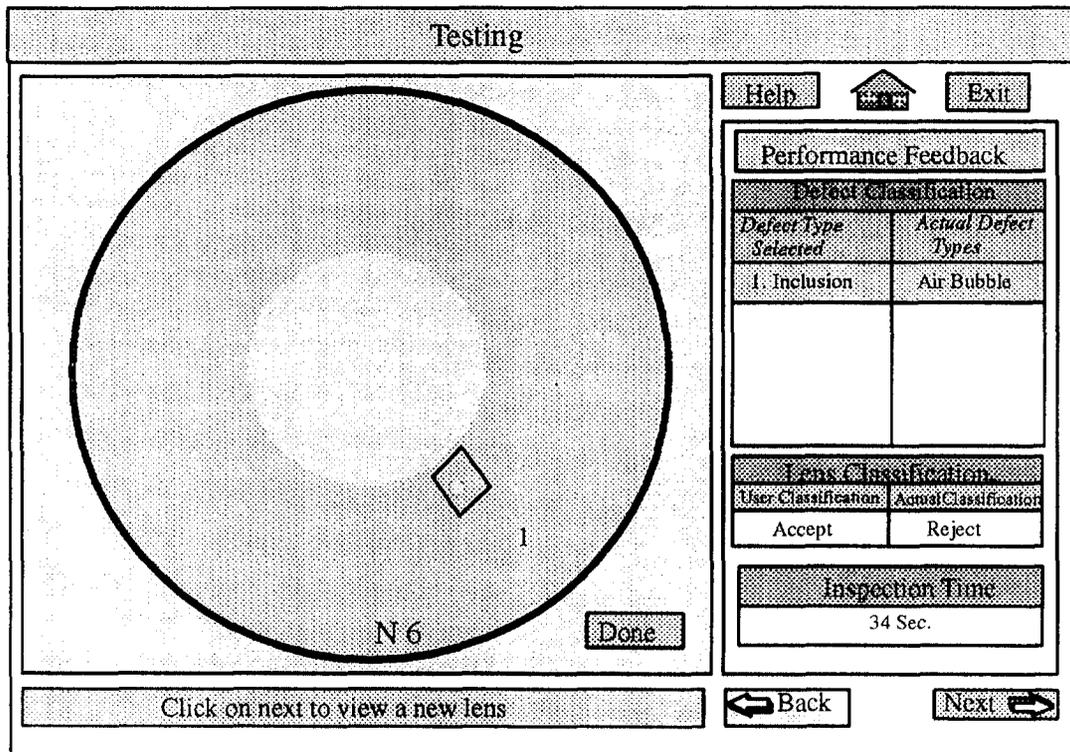
- (1) Search time: the time in seconds for detecting a defect.

- (2) Stopping time: the time in seconds at which the trainee terminates search and moves to the next image.
- (3) Decision time: the time in seconds for classifying a defect and the lens.
- (4) Inspection time: the mean time in seconds spent per lens.

Accuracy Measures:

- (1) The number of faults correctly detected.
- (2) The number of false alarms.
- (3) Defect classification: The trainee's classification of defects.
- (4) Lens classification: The trainee's classification of lenses categorized as hits, misses, correct accepts and false alarms

The objective of the image database module is to provide the instructor with a utility wherein a specific lens image along with its associated information can be viewed on the computer screen. Instructors can use this utility to identify images that result in unusually high numbers of errors (false alarms or misses) and may use the utility to deactivate those images. Such images can be reactivated so that they can be used in the future. Also, as additional clinical studies are conducted and the results of these studies become available, it is anticipated that the rules which are currently used to classify the lenses as conforming or non-conforming may need modification. The faults rule base module allows instructors to make changes to the rules which are used to classify lenses as conforming or non-conforming based on defect size, defect location, defect severity and number of defects



Feedback mode: Performance feedback is shown on the right part of the screen, defect is marked out.

Figure 5 Inspection screen: feedback mode

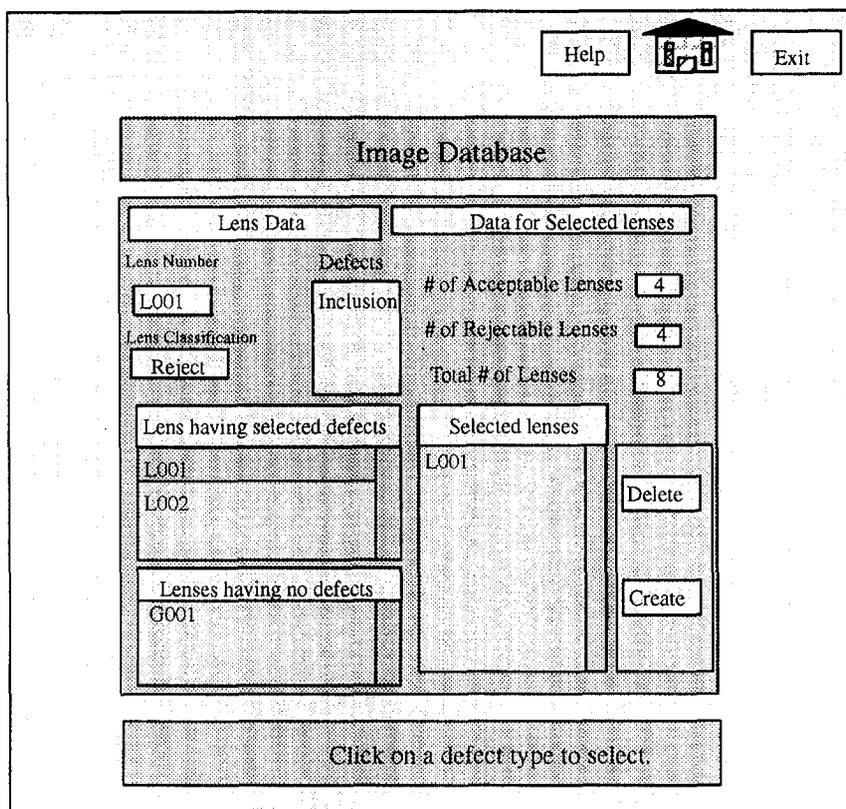


Image database

Figure 6 Results — summary

The screenshot shows a software interface titled "Results - Summary". At the top right are buttons for "Help", a home icon, and "Exit". The main content area is divided into several sections:

- Session Information:** Includes fields for "Enter SS #", "Session ID", and "OK" button. A note says "For complete information on user performance, click on the 'Details' button." There is also a "Save to File" button.
- User Information:** Displays "User # 999-99-9999 on 08/18/94 at 09:45", "MODULE: Active-II", "Seed: 43", and "File: C:\Programs\TEST1.tbk Suggested Inspection Time: 0min. 45sec".
- Session Data and User Classification Performance:**

Session Data		User Classification Performance		
LENS	No. of Lenses Inspected	10	No of Lenses classified correctly	6
	No of Acceptable Lenses	6	No of acceptable lenses classified as accepts	3
	No of Rejectable Lenses	4	No of rejectable lenses classified as rejects	3
DEFECT	Total No. of Defects	11	No of Defects Identified	7
			No of Defects Classified correctly	5
			No of False alarms	2
- Performance Time Data:**

Mean search time (sec)	7.0	Mean stopping time (sec)	20	Mean Inspection time per lens (sec)	12.0
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- Footer:** A text box asking "Please enter the social security number of the user whose performance you wish to see....."

Results database- summary of results

Figure 7 Image database

so that the changes reflect the results of the clinical studies.

Startup module

The startup module allows the instructor to select lens images (both conforming and non-conforming lenses) from the image database and store them in a batch file. The instructor can create several batch files of lens images which can be used with the training and testing modules.

Help module

The help module provides on-line help on the different modules available in the training system. This help basically consists of explanations of the operational aspects of the software. In addition, trainees can access 'context-sensitive' help at any point simply by clicking on the 'Help' icon available on each screen.

Training programme

The training program was designed to use the general principles listed earlier in the context of this particular inspection job as derived by the task analysis. A major prerequisite was that it be a progressive part training scheme which enabled the inspectors to build their repertoire of knowledge and skills in an orderly manner. A typical training session proceeds as follows:

1. *Initial overview:* Initially the subjects use the introduction module and are introduced to basic lens terminology and familiarized with the computer program. Following familiarization training, subjects are quizzed on their knowledge of the operation of the computer program and correct answers are supplied for incorrect responses.

2. *Standards training:* Since a progressive parts training approach is used, the subjects are initially trained on

Figure 8 Faults - rule base

only two types of defects. Subjects are shown different instances of each defect with their names and probable locations (cueing).

3. *Defect naming*: Lenses with a single defect are displayed on the screen and trainees classify the defects by defect name (active response). Trainees are provided with immediate feedback after each response.

4. *Search training*: Trainees are shown lens images with and without defects. The inspectors search for the defect and respond by clicking on the defect. Subjects are provided immediate and end-of-session feedback on search performance.

5. *Decision training*: Initially, training is provided on the rules which are used to classify the lenses as conforming and non-conforming. Trainees are shown lens images with single defects marked. Trainees classify the defects and, based on the defect type, severity and location, classify the lens. Trainees are provided immediate feedback on decision performance.

Thus, the trainees are trained on the search and decision aspects separately. Later, defects are combined progressively and steps 2-5 are repeated. Then subjects are trained on the search and decision aspects for different combinations of defects. At each step, immediate feedback is provided on search and decision making performance.

6. *Training on the whole task*: All defects are considered in developing representative batch files of conforming and non-conforming lenses. The percentage non-conforming in each batch file is the same as that which would exist in the actual production environment. In this type of training, the trainees have to first visually search for all the defects in a single-lens image and name the defects. On location of defects, the subjects classify the lens as conforming or non-conforming based on the defect severity, number of defects and the location. Trainees are provided with both immediate performance feedback after inspecting each lens image and end of session feedback. The feedback is reduced as the desired proficiency level is reached.

Evaluation

A detailed evaluation was conducted to determine the effectiveness of the computer-based training program using real world inspectors. The company management wanted to compare the two training programs — the computer-based training program and the existing training program — and a controlled study was conducted to facilitate such an assessment. In addition, the training system was also evaluated by the inspectors on various usability issues.

Subjects

The study used 24 naive subjects (i.e. new recruits with minimal inspection experience) provided by the company, in the age group of 20–30 y. They were tested for 20/20 vision (corrected if necessary) and were randomly assigned to two equal size groups. They are:

Control group: Subjects in this group were trained using the company's existing training program (on-the-job training).

Computer group: Subjects were trained using the computer-based training program.

Procedure

Initially, the subjects performed the criterion inspection task in a production environment with a representative sample of lenses (300 lenses with 20% defective) using an optoscope. The sample used six different defect types (mold flashes, pre-releases, inclusions, irregular edge/chips, scratches, and air bubbles) with lenses having both single and multiple defects occurring at varying severity levels and locations. Subjects were not provided with any feed-forward information. Subjects were instructed that both speed and accuracy were equally important. No feedback was given to the subjects on their performance on the criterion inspection task. Following the completion of the criterion task, both groups were trained on the search and decision making components of the inspection task using the appropriate training program. After a 15 min rest period, the subjects were re-tested on the same criterion inspection task wherein they repeated the inspection task using an optoscope. On completion of the study the subjects were debriefed and thanked for their participation.

Result and discussion

To evaluate the effects of the two training methods, inspection performance was analyzed separately for the

search and decision making components of the inspection task (averaged across all the defects). The results of the various ANOVAs are summarized in *Table 3*. The means and standard deviations are summarized in *Table 4*. Analysis of variance on the mean inspection time per lens showed a significant Group x Trial effect and a significant Trial effect. Since the Group x Trial interaction was found to be significant, a simple effects test of the Group factor was done at both levels of trials revealing that the Group effect was significant for the Post-Training Trial. A Newman-Keuls test on the group means on the Post Training Trial revealed that the mean inspection time per lens was significantly lower for the computer group. Similarly, ANOVAs on mean search time and mean stopping time showed a significant Group x Trial interaction effect and a significant Trial effect. The simple effects test revealed a significant Group effect for the Post Training Trial. A Newman-Keuls tests on the group means showed significantly lower search times and stopping times for the Computer Group (refer to *Figures 9(1), 9(2) and 9(3)*). Similarly, analysis of search errors showed a significant Group x Trial interaction effect. Newman-Keuls test revealed that the subjects in the computer group detected a significantly larger number of defects on the post-training trial compared with those who underwent training under the existing program (*Figure 9(4)*).

Significant Group x Trial interaction effects and Trial effects were also found for decision making performance. Newman-Keuls analyses conducted on the Post-Training Trial group means showed that the computer group made significantly fewer defect classification errors and lens classification errors than the control group (*Figures 10(1) and 10(2)*). Although, the Trial effect for false alarms was significant, the analysis did not reveal any significant Group x Trial interaction effect.

To test whether the software met usability goals, all subjects in the computer group completed a questionnaire that addressed usability issues related to the computer training software. The results of a questionnaire administered to the subjects in the Computer Group were analyzed using a Wilcoxon test. The test compared whether the subjects preferred the system on each of the seven different usability issues. The test compared the actual mean scores versus expected mean scores (of 3.5). The results revealed that the subjects favored the computer system on all the dimensions investigated (refer to *Table 5*).

On comparing the performance of the Training group with the Control group, the benefits of a computer-based training program are obvious: the training group outperformed the control group on both the visual

Table 3 Summary of ANOVAs showing the F-values

Search performance					Decision making performance			
Source	df	Time per lens	Search time	Stopping time	Search errors	Defect classification	Lens classification	False alarms
Group (G)	(1,22)	ns	ns	ns	ns	ns	ns	ns
Trial (T)	(1,22)	7.62 [†]	10.11 [‡]	11.35 [‡]	5.38 [†]	8.90 [‡]	7.71 [†]	4.95
GxT	(1,22)	5.11 [†]	5.97 [†]	8.01 [‡]	5.01 [†]	6.88 [†]	5.11 [†]	ns

Significance level:

[†]p < 0.05

[‡]p < 0.001

ns: Not significant

Table 4 Means and standard deviations for the various performance measures

Performance measures	Control group		Computer group	
	Trial 1	Trial 2	Trial 1	Trial 2
Time per lens (s)	12.6 (4.2)	10.8 (3.3)	14.3 (4.8)	7.8 (3.2)
Mean search time (s)	14.8 (4.3)	11.6 (3.9)	13.1 (5.1)	6.9 (4.2)
Mean stopping time (s)	18.9 (5.9)	15.4 (5.0)	17.7 (4.6)	8.25 (4.6)
Percentage detected	75.1 (11.5)	81.3 (8.0)	67.0 (9.5)	94.2 (7.8)
Percentage defects classified correctly	60.2 (9.5)	70.1 (9.0)	55.2 (8.2)	93.9 (6.0)
Percentage lens classified correctly	66.1 (9.2)	79.9 (8.3)	69.8 (10.1)	96.8 (6.2)
Number of false alarms	69 (9.7)	34 (6.1)	76 (8.1)	29 (4.5)

search and the decision making measures. The study clearly demonstrated that:

- (1) the subjects in the computer group were performing at a higher level of speed and accuracy than the subjects in the control group, and

- (2) training using computer-simulated images transferred to the criterion inspection task performed on an optoscope.

The study demonstrated the usefulness of computer technology and specifically the use of computer simulated images for inspection training. What has really been done by such a training program is to prepare the trainees carefully to make the maximum use of what they see on the job rather than leaving the learning process to trial and error in an uncontrolled environment. Because the training experience is so controlled, it is concentrated and trainees can progress to the level of experienced inspectors within a shorter time. In addition to improving the quality of outgoing products as a result of improved inspection performance, other potential advantages identified in using the computer-based training system over the original system are listed below:

Standardization: Use of a computer-based inspection training system alleviates the problems resulting from

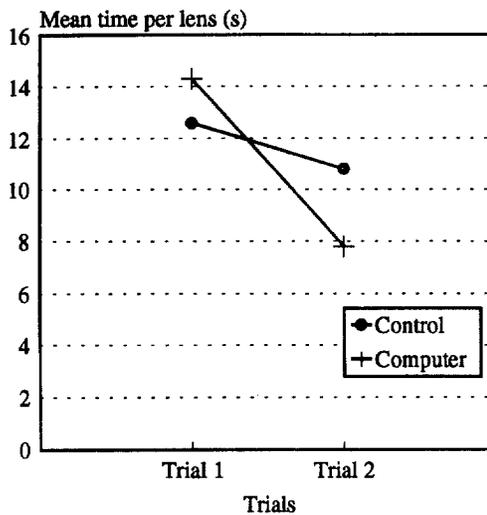


Figure 9.1 Search performance (time per lens)

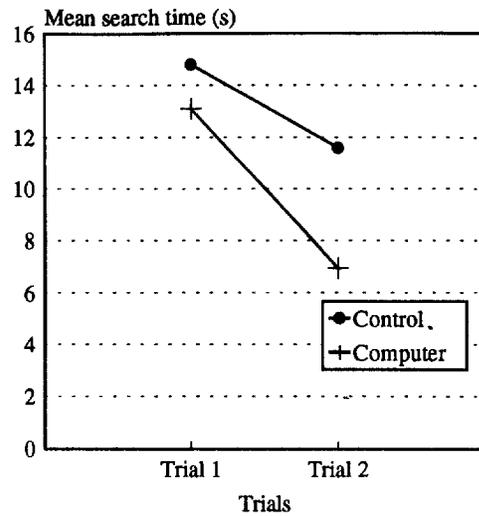


Figure 9.2 Search performance (search time)

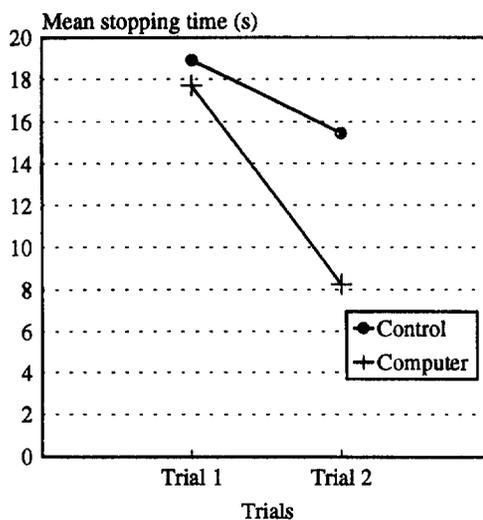


Figure 9.3 Search performance (stopping time)

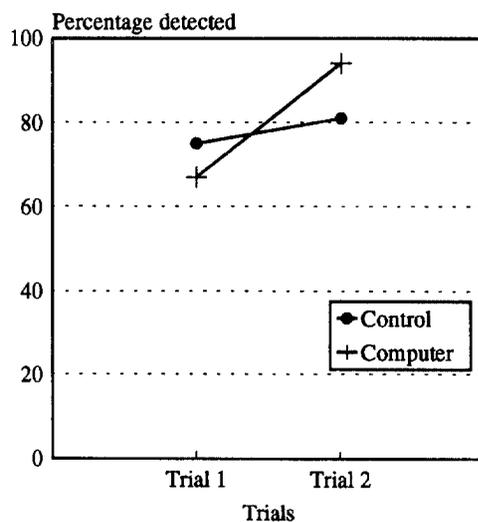


Figure 9.4 Search performance (percentage detected)

Figure 9(1)–9(4) Search performance

Table 5 Usability analysis

Issues Addressed	5 point rating scale		Mean (S.D.)	Wilcoxon test)
	1	5		
1. Ease of performing inspection	Very difficult	Very easy	3.90 (0.80)	4.29 ($p < 0.05$)
2. Quality of lens images	Very bad	Very good	4.44 (1.02)	4.89 ($p < 0.05$)
3. Readability of text on the screen	Very difficult	Very easy	4.14 (0.92)	4.58 ($p < 0.05$)
4. Helpfulness of the performance feedback	Not helpful	Very helpful	4.32 (0.84)	4.80 ($p < 0.05$)
5. Software overview	Did not explain	Expalined clearly	4.39 (0.82)	4.81 ($p < 0.05$)
6. Usefulness of performance feedback	Not useful	Very useful	3.95 (1.02)	4.15 ($p < 0.05$)
7. Ease of navigation	Very difficult	Very easy	3.86 (0.92)	4.31 ($p < 0.05$)
8. Defect descriptions	Did not explain	Expalined clearly	3.77 (1.2)	3.53 ($p < 0.05$)
9. Utility as a job aid	Not helpful	Very helpful	4.23 (0.85)	4.70 ($p < 0.05$)

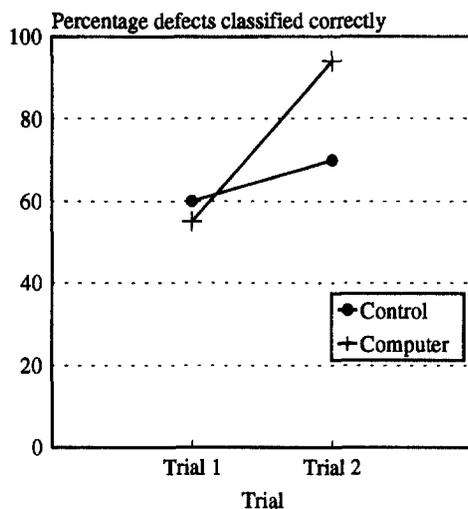


Figure 10.1 Decision making performance (defect classification)

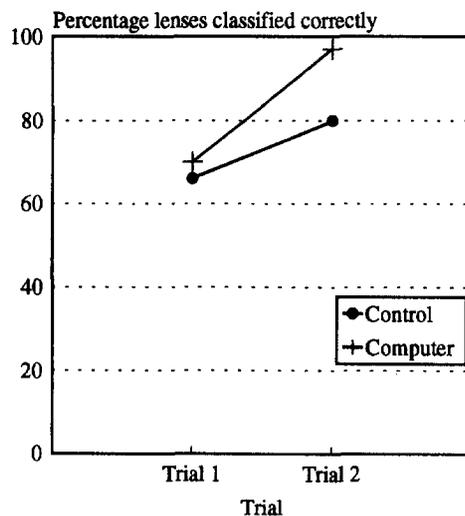


Figure 10.2 Decision making performance (lens classification)

Figure 10(1)–10(2) Decision making performance

using actual lenses and the non-standardization in training resulting from the use of different sets of defects by different instructors. All the trainees are trained on the same set of defects to the same set of standards, and the problem of collecting test samples periodically due to lens degradation is eliminated.

Adaptability: Batch files of lens images can be created to train inspectors on particular facets of the inspection task with which they have a problem. Thus, the program can be tailored to accommodate individual differences in inspection abilities. Furthermore, borderline defects which are difficult to capture and train for are now easily available.

Convenience: The trainees can work on the system whenever they have available time, and retraining can be accomplished more conveniently. Furthermore, trainees are not intimidated by the presence of an instructor.

Record keeping: The record keeping process is automated. Instructors can more easily monitor and track an individual's performance as the trainee uses the system, initially for training and later for retraining.

The company has formally implemented the training system for three different product lines at two different manufacturing sites. It should come as no surprise to ergonomists that the acceptance of the training program would not have been achieved without closely interacting with the management and all personnel, especially those who use the final system. The program was centered on human requirements and evolved through stages of specification, prototyping, development, evaluation and implementation.

The current study demonstrates how the pragmatic application of advanced technology, along with our basic knowledge in the application of training principles, can be used to design an efficient training program for several inspection tasks. It is important to realize that the development of the training program was driven by the requirements of the inspection environment rather than the availability of new technology. The results of this study indicate that advanced technology has much promise to be used as a very effective tool, but only if its potential is realized in a way which is consistent with our existing knowledge of the instructional design process and how people learn.

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