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ABSTRACT

The purpose of this research was to determine the relative roles of experience/learning and selected visual aptitude factors on the ability to detect and identify indications of defects in X-ray film of welds and other materials. Penetrameter Detection and Defect Identification Tests were developed to measure the ability of radiographic film inspectors to detect and identify weld defects. These tests and the Ortho-rater examination were given to Navy certified film inspectors. Test results and visual examination results were compared to determine the relationship between vision and film reading skills. Both film tests were readministered six months later to determine film inspector reliability. No significant relationship was found to exist between the selected visual aptitude factors and film reading ability. Low levels of inter- and intrasubject reliability were found to exist on both the detection and identification tests, and a significant intrasubject relationship was found between identification test reliability and experience. This suggests that learning plays an important role in the acquisition of film reading skills. Further research in new training methods is recommended based on the above findings. (Author/MW)

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RELATIVE ROLES OF EXPERIE… '/LEARNING AND VISUAL FACTORS ON RADIOGRAPHIC I… ECTOR PERFORMANCE

by

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June 1973

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SUMMARY AND CONCLUSIONS

Problem

The purpose of this research was to determine the relative roles of experience/learning and selected visual aptitude factors on the ability to detect and identify indications of defects in X-ray film of welds and other materials.

Background and Requirements

Today's Navy continues to adopt sophisticated systems whose components are fabricated from exotic materials, are subjected to greater stresses, and require extremely thorough radiographic testing (RT) to insure their safe and reliable operation. To meet this requirement, large numbers of film readers (RT inspectors) are needed. The current training program cannot accommodate this need because the RT training technology has not kept pace with the hardware technology.

Approach

Two tests were developed to measure the ability of film readers to detect and identify welding defects as shown on X-ray film. These tests and the Ortho-Rater examination were given to Navy certified film inspectors. Results of the film tests were compared to the visual examination results to determine the relationship between vision and film reading skills. Both film tests were readministered six months later to determine if experienced film readers were more reliable than less experienced film readers.

Findings, Conclusions, Recommendations

1. No significant relationship was found to exist between the selected visual aptitude factors measured and film reading ability. The problem of providing more RT inspectors cannot be solved by imposing more stringent visual selection factors on trainees. (Page 11)

2. Low levels of inter-rater agreement were found to exist on both the detection and identification tests; a significant intra-subject relationship was found between identification reliability and experience. This suggests that learning plays an important role in the development of film reading skills. (Pages 11 and 12)

3. Based on the above findings, it was recommended that research be conducted to determine optimum learning strategies in the dimensions underlying film reading skills and based on that research, a new RT inspector training program be developed to incorporate the findings of that research. Specific areas of study should include:

a. The perception of subtle changes in shades of gray in a darkened black/white environment.

b. The detection of shapes with poorly defined outlines caused by fuzziness of radiographic film.

c. The conversion of brightness and contrast on the radiographic film to material density.

d. The conversion of three dimensional effect of solid form on a flat projection. (Page 12)

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RELATIVE ROLES OF LEARNING AND VISUAL FACTORS ON RADIOGRAPHIC INSPECTOR PERFORMANCE

A. Introduction

This is the first research effort by the Naval Personnel and Training Research Laboratory (NPTRL) concerned with determining optimum learning strategies for reading X-ray film of welds and other materials.[1] Research into the basic dimensions underlying film reading skills and abilities is required because of a lack of applicable knowledge and a new requirement for large numbers of certified radiographic testing (RT) inspectors (film readers) to fill current fleet shortages. This requirement results from the Navy's increased adoption of sophisticated systems whose components are: (1) fabricated from exotic materials; (2) exposed to greater stresses; and (3) thus require extremely thorough testing to insure their safe and reliable operation. Currently, only RT inspection provides this level of assurance.

To determine whether welds are safe and reliable, radiographs are taken using both X- and gamma ray sources. Defects hidden within the interior of the welds appear on the exposed radiographic film as minute, subtle changes in shades of gray. The task of the RT inspector (film reader) is to first <u>detect</u> these minute, subtle changes of gray and then <u>identify</u> which of over 15 types of defects they may be. These defects may appear differently depending on the location in the weld and within the weld configuration itself (e.g., pipe, plate, casting).

To further compound the task, the RT inspector must be able to identify several types of film and processing artifacts that can appear as weld defects or mask indications of defects. Additionally, he must be able to overcome the confusing influences of fuzziness in shadow picturing of the X-ray process, the photographic representation of density in achromatic black and white, and the third-dimensional effects of solid form on a flat projection. It is generally conceded by those in the field that this task is most complex and that little inter-inspector agreement exists today.

In RT inspector training today, the student is given radiographs, containing examples of defects, to review. When and <u>if</u>, the level of the student's judgments of defects approximates that of his instructor, he is

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[1]Henceforth the term weld will be used to include other materials.

certified as an RT inspector; otherwise, and this is what usually happens, he fails. This system of training is similar to the system used to train apprentices in the medieval guilds. In that system, a student apprenticed himself to a master until he could successfully mimic the skills and judgments of the master. At that time, he was adjudged competent. Under such a system, the apprentice typically duplicated not only the master's skill, wisdom, and knowledge but, also, his master's biases, misconceptions, and foibles. Fundamental concepts of learning (e.g., feedback, reinforcement, structuring of material, provisions for individual differences) were not used in a systematic manner to maximize learning.

This system is used to train RT inspectors because radiographs are one of a kind--they represent pictures of actual ship repairs. No method is currently available to reproduce industrial X-rays with 100% fidelity; therefore, training programs vary everywhere depending on the radiographs available. The X-rays used for training also change frequently because radiographs damage so easily. For example, the slightest mark or scratch on them appears as a defect and then it is not possible to interpret the X-ray correctly.

The present research program was undertaken to provide insights into the dimensions underlying film reading skills and to point the way for development of RT inspector training. As a starting point, the specific purpose of this study was to determine the relative roles of experience/learning and selected visual aptitude factors on the ability to detect and identify indications of defects on X-ray film of welds and other materials.

B. Methodology

1. Design

A penetrameter detection test and a defect identification test were constructed to measure the ability of film readers to detect and identify defects. These tests, and the Ortho-Rater visual examination, were given to certified film inspectors. Results of the film tests were compared to the visual examination results to determine the relationship between vision and film reading skills. Approximately six months after their original administration, both film reading tests were readministered to determine if experienced film readers were more reliable than less experienced film readers.

a. Penetrameter Detection Test (Penny Test). The penny test was designed to measure the ability of film readers to detect minute, subtle changes of shades of gray on radiographic film.

A penetrameter (penny) is a device used by radiographers to demonstrate the quality of a radiograph. It is a small thin piece of metal with three holes of different size and is placed on the part to be RT inspected. The penetrating radiation passes through the three holes and makes small dark images on the film. The quality of the film is then determined by the detection of the penetrameter outline and the dark spots.

For the penny test, 100 radiographs of welds of varying thicknesses, materials, and RT processes were selected. The penny images from these radiographs were then cut out and mounted on cards for ease of administration, control, and to assure handling without damaging the film.

b. Defect Identification Test. The defect test measured the ability of film readers to identify indications of defects on X-ray film. For this test, 96 radiographs containing representative samples of the various defects in various configurations were selected. These radiographs were specifically selected to minimize the detection skills while focusing on the subject's identification skills. This was accomplished by selecting radiographs with essentially singular prominent defects. The defect areas of the radiographs were then cut out and mounted similar to penny test images. This procedure also reduced the area to be viewed to about 1/20 of an actual radiograph.

c. Ortho-Rater Test. To determine visual aptitude factors related to reading X-ray film, the following types of experts were consulted: radiologists, ophthalmologists, and human factors research personnel at the Naval Electronics Laboratory Center (NELC). Based on these discussions, the Bausch & Lomb Ortho-Rater was selected to measure the visual aptitudes. The Ortho-Rater measures near and far acuity, near and far phoria, depth perception, and color perception.

2. Subjects

The subjects were 12 certified film readers attached to the NDT School in February 1972. The NEC codes certifying the subjects as film readers are presented in Table 1. The mean years of film reading experience was four years and ranged from six months to ten years.

3. Apparatus

Standard X-ray film viewers in the Film Reading Room at the NDT School were used to illuminate the radiographs on both tests. The standard Ortho-Rater and accompanying software was used to administer the Ortho-Rater vision test.

4. Procedure

All subjects were given an eye examination, the penny test, and then the defect test.

TABLE 1

Summary of Subjects Film Reading Certifications

NEC CODE	TITLE	NUMBER
4935	Nuclear Inspector	9
4936	Nonnuclear Inspector	3
4938	Nuclear Examiner	5
4939	Nonnuclear Examiner	4

Note: Some subjects have multiple certifications.

In the penny test, the subjects were instructed to report when they saw the small dark image that corresponded to one of the three holes in the penny.

For the defect test, the subjects were instructed to identify all defects within each film chip that they would consider in the acceptance or rejection of a weld. They were asked to be as specific and as accurate as possible.

Test scoring was complicated because it was not possible to develop an absolute scoring key. The only way to validate whether a film reader correctly reads a film is to compare his analysis with the specimen itself. This means the actual specimen must be cross-sectioned, polished, and acid etched. For this study, over 1,000 radiographs of actual shipboard repairs were reviewed and, obviously, it is not feasible to rip apart actual shipboard repairs.

An alternate method of designing the test would have been to weld specific defects into specimens, radiograph them, and then cross-section them. This method was not used because it would have taken months and been extremely expensive. Thus, when viewing each chip in the tests, there was no way to make an absolute right-wrong determination of whether a dark image was present on a penny or if a shadow on a piece of X-ray film was, in fact, a specific defect. Review of statistical tests revealed little in the way of meaningful analysis for these types of data.

After much investigation, level of relative agreement was selected as the basic measure for both tests. This measure provided a method of analysis with sufficient power to answer the questions set forth in the problem statement.

a. Penny Test Scoring. The penny test was scored to determine interrater agreement and intrarater reliability. For the former, each item was individually analyzed as follows. If on a single item or film chip all subjects reported they saw (or did not see) the required dark image, the item received a score of "0". If all subjects but one reported seeing (or not seeing) the image, the item received a score of "1". The scoring progressed in this manner until a maximum score of "6" was reached, this score indicating that six subjects responded "yes" and six "no".

b. Defect Test Scoring. The defect test was scored for interrater identification agreement and intrarater reliability. For interrater agreement, both the number and kind of defects were tallied for each frame. Because this data was basically non-ipsitive in nature, it was necessary to consider both how much a subject agreed with himself and how much he disagreed with himself. Additionally, the measure had to allow for differences in the number of defects each subject saw per frame. An agreement/disagreement ratio (A/D) was derived from the data to meet these criteria.

Table 2 contains the scoring strategy for the A/D ratio. Each subject's responses on both administrations were compared in this manner. For example, Table 2 indicates that the subject saw only porosity both times he read Frame 1. Thus, he got an agreement score of "1" and a disagreement score of "0". In Frame 2, the subject saw IM both times for an agreement score of "1" but, because he also saw BT in August, he got a disagreement score of "1". In Frame 3, the identification of BT and RO on both tests yielded an agreement score of "2", and the single MT response counted to a "1" in the disagreement column. Finally, in Frame 4, the subject saw three different defects over both administrations for an agreement score of "0" and a disagreement score of "3".

Each reader's 96 responses were scored in this manner. First, the agreements and disagreements were scored for each subject. Then, the total agreements were divided by the total disagreements to obtain the A-D ratio for each subject. A/D ratios greater than 1.00 meant that a subject tended to agree with himself more than disagree.

TABLE 2

Example of Subject's Defect[1] Test Response
and Scoring for A/D Ratio

FRAME NO.	SUBJECT RESPONSE		SCORING	
	1st Admin. (Feb)	2nd Admin. (Aug)	Agree	Disagree
1	P	P	1	0
2	IM	IM-BT	1	1
3	MT-BT-RO	BT-RO	2	1
4	P	CP-MT	0	3

[1]Key to defect abbreviations for Table 2:

BT - Burn Through
CP - Crater Pit
ER - Excessive Reinforcement
FM - Foreign Material
IM - Incomplete Insert Melt
MT - Melt Through
P - Porosity
RO - Root Oxidation
T - Tungsten Inclusion

C. Results

1. Penny Test

Figure 1 and Table 3 list the results of the penny test.

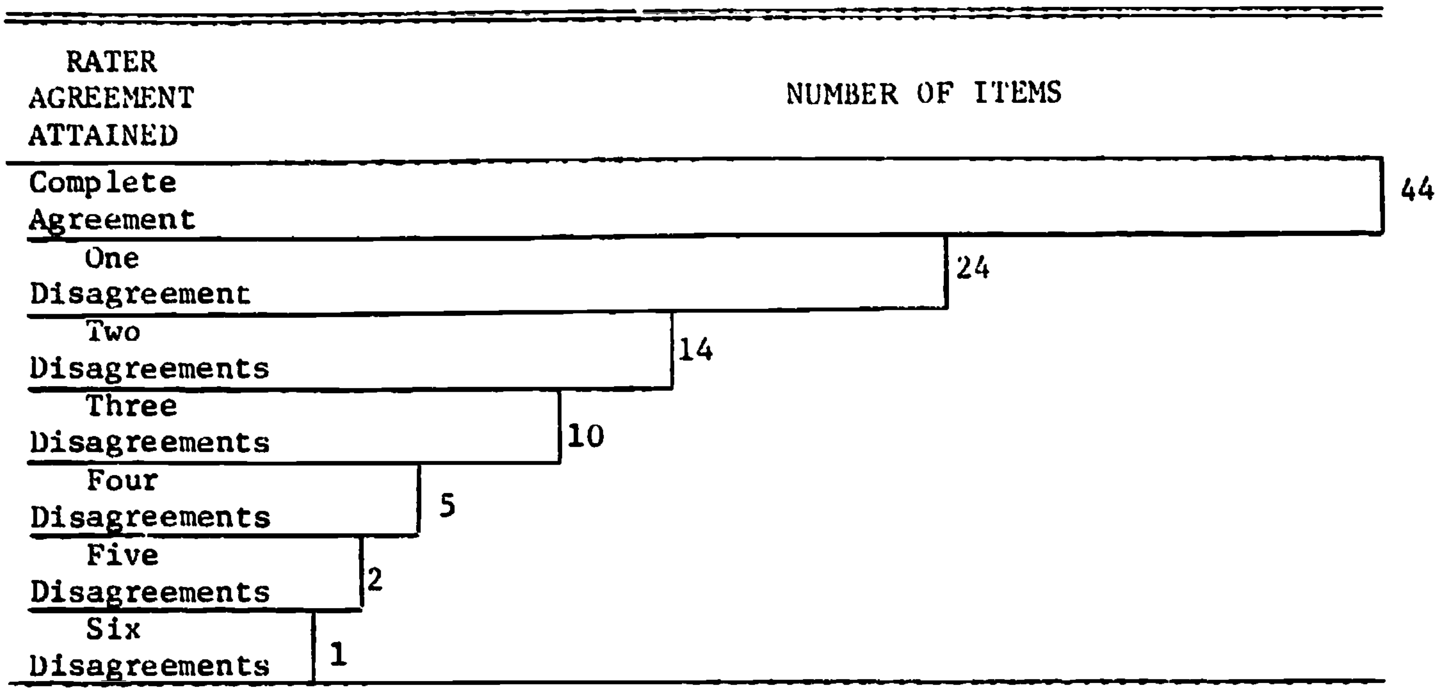

Figure 1. Interrater Agreement for Penny Test.

From Figure 1 it can be seen that interrater agreement was less than satisfactory. For example, it can be seen that total agreement was reached on just 44 items; or on 24 items, one rater's judgment differed from all the others.

TABLE 3

Penny Test Reliability Results

Variables	Penny Test r
Intrarater Reliability	.85*
Intrarater Reliability X Experience	.16
Intrarater Reliability X Vision	.13
Test Reliability (Split Half)	.94*

*Significant at the .01 level or less.

From Table 3, it can be seen that intrarater reliability was high ($r = .85$) but that penny detection performance was unrelated to both experience ($r = .16$) and vision ($r = .13$). Further analysis of intrarater reliability data revealed that the mean number of items on which a rater disagreed with himself was 15.8 with a range of 7 to 48 disagreements. It may be noted here that prior to the second administration of the penny test, the subjects estimated mean number of disagreements was 7.0. Total agreement across both administrations for all raters was reached on only 16 items over both administrations of the penny test.

2. Defect Test

Defect test interrater agreement also was less than satisfactory. Subjects detected a mean of 1.1 defects per frame but, across subjects, that one defect was identified as 5.1 different defects. The range of different names that the 1.1 defect per frame was called varied from 2 to 9 and there was not one frame that everyone agreed upon.

Table 4 presents two typical examples of responses to defect test film chips.

TABLE 4

Two Examples of Responses on Individual Frames of Defect Test

FRAME A		FRAME B	
Defect	f	Defect	f
No Defects	1	No Defects	4
RO	5	FM	1
MT	4	T	1
P	2	CP	1
BT	2	P	1
IM	1	BT	1
ER	1	RO	1
T	1	IM	1

Note: Raters may report more than one defect.

Key to defect abbreviations for Table 4:

BT - Burn Through
CP - Crater Pit
ER - Excessive Reinforcement
FM - Foreign Material
IM - Incomplete Insert Melt
MT - Melt Through
P - Porosity
RO - Root Oxidation
T - Tungsten Inclusion

The wide range of identified defects in the above table is especially evident in Frame B where four subjects saw no defects and the remaining seven each saw a different defect.

TABLE 5

Defect Test Reliability Results

Variable	Relationship
Intrarater Reliability	Mean AD Ratio = .93
Intrarater Reliability X Experience	r = .76*
Intrarater Reliability X Vision	r = .05
Test Reliability (Split Half)	r = .94*

*Significant at the .01 level or less.

Intrarater reliability again was based on each subject's A/D (agreement/disagreement) ratio. The mean A/D ratio was .93 with a range of .54 to 1.50. In addition, the mean number of items with complete agreement within raters was 36.6 with a range of 22 to 47.

From Table 5, it can also be seen that intrarater reliability was related to experience (r = .76) and unrelated to vision (r = .05). It should be noted that all subjects' vision was within the range required for tasks demanding high visual acuity as defined by Bausch & Lomb. Several subjects had near perfect scores on acuity tests for both near and far vision. All subjects scored well on the other visual aptitude factors tested.

D. Discussion and Conclusions

The low levels of interrater agreement on both the detection (penny) test and identification (defect) test substantiates what is generally conceded by field personnel, that is, that little interinspector agreement exists today.

The detection problem is even more confounding than the penny test results indicate. Detection generally requires that man first employ "search" strategies and often the configuration of the item searched for is unknown. To detect the penny holes on the X-ray film, the subjects knew the exact configuration of what they were trying to detect and precisely where to look. Yet, all subjects agreed on just 44% of the penny "holes" in a task requiring 100% agreement.

The identification problem is equally as serious as the detection problem. Not only was the interrater agreement low on the defect test, but the film inspectors did not even totally agree on one frame. In most cases, all subjects did see an indication of a defect on each film but substantially disagreed as to its identification. Here again, the testing problem was simplified by presenting the subject with a very small area to view, about 1/20th of the area of an average radiograph[2], and instructing him to report the defects he saw. Thus, he may have been influenced to identify a defect only because a set had been established for him to identify a defect. The exact determination of the type of defect is very important because certain defects are acceptable in certain situations and other defects are not.

Logically it appears that the film reading problem could be caused by deficient visual abilities, inefficient learning, requiring man to do an impossible task, or possibly some mix of the above. Concerning vision, the lack of a significant relationship between vision and film reading ability (detection and identification of indications of defects) suggests that the answer to the problem of providing the fleet with critically needed film inspectors cannot be solved by merely imposing more stringent visual selection factors on prospective film inspection trainees. The fact that all subjects scored so well on the visual tests indicates that the present visual selection procedure is more than adequate.

The significant positive relationship between intrarater reliability and experience ($r = .76$ $p < .01$) on the defect test indicates that within themselves the raters have learned to be more consistent, that is, that film reading is in the realm of man's capabilities. The film readers may not agree with others as to what a defect should be called, but from one

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[2] In a pilot study, the full radiograph was used with comparable results. Because reading entire radiographs was so time consuming, the small chip format was adopted.

time to the next, they are more likely to call a defect by the same name. The problem then may be reduced to providing the proper environment which allows both student and certified film inspector to become more consistent with experience but, most importantly, experience that will be based on learning experiences designed to maximize agreement on both detection and identification of defects.

E. Recommendations

Based on the results of this research, it is recommended that:

1. Research be conducted to determine optimum learning strategies in the dimensions underlying film reading skills. Specific areas of study should include:

   a. The perception of subtle changes in shades of gray in a darkened black/white environment.

   b. The detection of shapes with poorly defined outlines caused by the confusing influences of fuzziness of radiographic film.

   c. The conversion of brightness and contrast on the radiographic film to material density or thickness.

   d. The conversion of three dimensional effects of solid form on a flat projection.

2. Research be conducted to reproduce radiographs with 100% fidelity to be used for training purposes.

3. A new film reader training program be developed to incorporate the findings of the above research, that will maximize the learning of film reading skills.

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13. ABSTRACT

The purpose of this research was to determine the relative roles of experience/learning and selected visual aptitude factors on the ability to detect and identify indications of defects in X-ray film of welds and other materials.

Penetrameter Detection and Defect Identification Tests were developed to measure the ability of radiographic film inspectors to detect and identify weld defects. These tests and the Ortho-rater examination were given to Navy certified film inspectors. Test results and visual examination results were compared to determine the relationship between vision and film reading skills. Both film tests were readministered six months later to determine film inspector reliability.

No significant relationship was found to exist between the selected visual aptitude factors and film reading ability. Low levels of inter and intra-subject reliability were found to exist on both the detection and identification tests, and a significant intra-subject relationship was found between identification test reliability and experience. This suggests that learning plays an important role in the acquisition of film reading skills.

Based on the above findings it was recommended that research be conducted to determine optimum learning strategies in the dimensions underlying film reading skills and that the results from that research be used to develop a new radiographic inspector training program.

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