AN ANALYSIS OF THE VISUAL DEMANDS ASSOCIATED WITH AVIATION MAINTENANCE INSPECTORS

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Background: Aircraft maintenance inspectors spend many hours searching for defects in aircraft. Vision guidelines exist for NDI/NDT personnel, but not for visual inspectors. A detailed task analysis is required before job-relevant vision guidelines can be developed. This study is a descriptive investigation of the visual tasks of aviation visual inspectors. **Methods:** Visual inspectors at aircraft maintenance facilities were observed performing inspections on commercial aircraft. Various measures of the visual tasks were recorded. **Results:** On over 900 fixations during inspection procedures, working distances of 50 cm or less were recorded 60.6% of the time. Intermediate distances (>50 cm to 1 m) comprised 27.7% of the working distances. The mean age of inspectors at these locations was 44.7 years. **Conclusions:** The primary duty of visual inspectors is the identification of defects in aircraft when viewed at near and intermediate distances. Data from this study support the need for nearpoint visual acuity requirements.

INTRODUCTION

Visual inspection is an important component of aircraft maintenance. The National Transportation Safety Board (NTSB) has cited the failure to identify visually detectable corrosion, cracks, or inclusions as the probable cause of several aviation accidents (1989, 1990, 1998). In addition, visual inspection is an important component of Non-Destructive Inspection (NDI) and Non-Destructive Testing (NDT) procedures. NDI/NDT personnel must use their vision, with or without various aids, to make gross judgments, as well as when inspecting aircraft using highly sophisticated imaging and scanning devices (e.g., borescopes, ultrasonic scans, eddy current imaging, X-ray). Inspectors within aircraft maintenance facilities can have primary responsibilities within visual inspection or within NDI/NDT areas. In a recent survey of maintenance facilities, 52% of inspectors were classified solely as visual inspectors, 36% were classified as visual and NDI/NDT inspectors, while only 12% were classified solely as NDI/NDT inspectors (Nakagawara et al., 2003).

While guidelines exist for vision standards for NDI/NDT personnel, no such guidelines exist for visual inspectors. Because of the intimacy between the two inspection classifications (i.e., visual vs. NDI/NDT), most facilities use similar testing requirements for the two types of inspectors. The two jobs are inherently different, however, in terms of the visual task and sophistication of testing equipment.

To the greatest extent possible, vision standards should ensure that workers have the necessary visual skills to perform job-relevant tasks in an efficient and safe manner. For NDI/NDT inspectors, vision skills should be adequate to identify areas of concern (i.e., detect) and to evaluate (i.e., decision) these areas as to whether further action is required (Drury, 2001). Although the NDI/NDT personnel have many tools to aid in the detection of defects (e.g., fluorescent penetrant and magnetic particle inspections, eddy current and ultrasonic devices, borescopes, magnification aids), simple visual inspection may account for up to 80% of all inspections (Goranson and Rogers, 1983).

As to what constitutes the minimum acceptable vision for an NDI/NDT inspector is difficult to determine. In terms of visual acuity, the standard should be based upon the angular size of the smallest detail for which detection is required.

Rummel (1998) generated probability of detection (POD) curves using NDT procedures to standardize testing by NASA for the space shuttle system. This led to the use of an anomaly size of 1.3 mm (0.05 inches) as the 90 / 95 level that operators performing special NDT procedures must detect 90% of the time with 95% confidence. In a POD study, Spencer and coworkers (1996) had inspectors visually identify cracks in an out-of-service Boeing-737. In this study, the 90% detection point was found for cracks around 0.3 inches. This value is much larger than the 90 / 95 value (i.e., 0.05 inches) for NDI/NDT specialty procedures. The authors also state that for the visual inspection, the length of the crack, crack width, contrast, and inspector accessibility all affected detection performance. These data suggest that calculation of a minimum acceptable visual acuity limit is difficult given the many variables involved. Defect length, width, and contrast, light level, as well as viewing distance are all factors contributing to the visual acuity demand of a given defect. In none of the studies mentioned, did the researchers attempt to manipulate, restrict, or document viewing distances. With a greater viewing distance, a defect of a given size subtends a smaller angle, and hence will have a greater visual acuity demand.

Drury (2001) analyzed the visual task for inspections in terms of identifying a signal from background noise. He concluded that the greater the strength of the signal (visibility of the crack), relative to the noise (background detail), the more likely it is that detection will occur (for an on-site inspection). Relative signal strength can be increased by decreasing the viewing distance (crack subtends larger angle to the observer), ensuring a focused retinal image (proper correcting lens for the specific working distance), or by improving the quality (eliminate glare) and quantity (increase illumination) of light on the search area. Additionally, just as performance is enhanced by increasing target size and contrast above threshold levels, requiring better vision than that predicted from a direct calculation of minimum target detail is advisable whenever possible. This is particularly important when considering the "sensitivity decrement" that is found with extended searching times especially when finding defects are relatively rare events, a phenomenon known as "vigilance decrement" (Mackworth, 1948).

Since 1988, the FAA has funded numerous human factors projects for Aviation Maintenance Technicians (AMTs) and Inspectors (Johnson and Watson, 1999). These projects were intended to increase the efficiency and accuracy of work performance. For NDI/NDT personnel, contributions were made in the development of "Good Practices" for several inspection procedures (Drury 1999, 2001, Drury and Watson, 2000). Additionally, several studies have documented the essential tasks of Aviation Maintenance Personnel (AMP) (Adams et al., 1999, Allan 1970). These studies provided beneficial data for job-related curriculum development at AMT schools and provided excellent human factors guidance to increase job accuracy and/or efficiency. The studies failed to document, however, measures of visual detail and working distances, which are required to develop job-relevant vision standards.

For an inspector over 50 years of age, the lack of accommodation can greatly affect nearpoint searching. Bifocal lenses can provide appropriate focus for a given working distance, for example at 16 inches with a +2.5 diopters (D) reading addition. For a normally-sighted inspector, with vision correctable to 20/20, these bifocal spectacles would allow for passage of the present Air Transport Association Specification 105 standard. Should such an inspector be restricted to a viewing distance of 32 inches, however, the search area would be 1.25 D out-of-focus in both the distance and near portions of his spectacles. He would now be inspecting the aircraft with reduced visual acuity, estimated to be 20/50 to 20/60. The FAA deals with this situation for pilots older than 50 years of age and over by requiring the ability to see 20/40 or better at both 16 and 32 inches (Nakagawara and Wood, 1998). This age-related requirement is based upon the need for pilots to see cockpit instruments at intermediate distances and the physiological finding that active focus ability deteriorates with age.

A detailed task analysis, with documentation of required working distances and visual detail dimensions, is not present in the aviation literature for NDI/NDT and visual inspectors. This type of vision-related task analysis is required for these inspectors before a job-relevant vision standard can be developed. This study is a descriptive investigation of the visual task performance of aviation visual inspectors.

METHODS

The research protocol was approved by the Institutional Review Board of the Ohio State University. Visual inspectors at two aircraft maintenance facilities were observed as they performed visual inspection duties on various types of commercial aircraft (B727, B737, B767, A320, DC8, DC9, MD80). Various measures of the visual tasks were recorded along with the specific auxiliary materials used (i.e., flashlight, magnifier, measuring rule) during inspection procedures. Visual inspection tasks were divided into two categories depending upon the main focus of the procedures. These categories were termed "buy back" and "primary" inspection tasks.

Buy Back Inspections. Inspections were termed "buy back" when inspectors checked jobs individually completed by AMTs. These tasks were very specific and generally involved repair or replacement of individual parts or aircraft components. Many involved the inspectors reviewing the AMT's job card for repair descriptions at an inspection station before traveling to the AMTs work bench or aircraft section. During the inspection, the observer would record the fixation distance, fixation direction, the illumination on the viewed component, specific auxiliary equipment used, and inspector body position (as described further below). A buy back inspection would typically last only 30 to 60 seconds but could last as long as a few minutes when a complicated visual inspection was necessary.

Primary Inspections. Primary inspections were those tasks where workers checked general areas during the initial phases of maintenance to identify specific types of defects identified on work cards. Overall these inspections could last between several minutes for small jobs to several hours for inspections of large areas. For these inspections, observers would record visual measures at specific time intervals. For example, in most locations, the researcher would record the specific fixation distance and direction every thirty seconds. This technique would generate 120 visual data points for every hour of inspection. When a defect would be found, a description of that specific defect would additionally be recorded. If the inspector was scanning an area at the specific moment when the observer recorded activity, several fixation directions and/or distances could be recorded under a single measure.

For both inspection types, observers indicated the primary viewing direction and fixation distance while observing inspectors performing inspections. Up was marked when the object of regard (OR) was above the level of the eyes, down was marked when the OR was between eye level and the waist, and full down was marked when the OR was below the inspector's waist. The distance measures were in centimeters and corresponded to 0.5 units of inverse meters (diopters). Body position was also indicated as follows: Bent Over, Kneeling, Sitting, and on "All Fours." Ambient light level was measured, and the use of a flashlight (FL), a mirror (Mir), or a magnifier (Mag) was also noted. Furthermore, the relative size of visual detail that the inspector was evaluated qualitatively using the following criteria: C = coarse, M = medium, and F = fine. The distributions of these measures (i.e., fixation distance and position) were compared between inspection types using chi square analysis.

Finally, a voluntary survey including demographic and refractive error correction information (e.g., glasses, contact lenses, refractive surgery) was distributed to NDI/NDT and visual inspectors at the various maintenance facilities.

RESULTS

Data included in these analyses were from 2 maintenance facilities. The mean age of inspectors responding to the survey administered at these facilities was 44.4 ± 7.8 years (n = 86). Approximately 30% of surveys were returned. Of those inspectors responding to the survey, 60.5% reported wearing spectacles, 7.0% reported wearing contact lenses, and only 3.5% reported having refractive surgery. Of the respondents, 40% reported never wearing refractive correction. Of those wearing spectacles, 57.7% reported wearing single vision lenses, 9.6% reported wearing traditional bifocals, 23.1% reported wearing progressive bifocals, 1.9% reported wearing trifocals, and 1.9% reported wearing double bifocals. Of those wearing contact lenses, 80% reported wearing soft lenses and none of these lenses were reported as being bifocal or monovision lenses.

The distribution of fixation distances and directions for buy back and primary inspections for over 900 recorded fixations are shown in Table 1. Also included in this table are the inspector reported fixation distances.

Fixation Distance	Buy Back Inspection (Percent)	Primary Inspection (Percent)	Overall Inspector Reported (Percent)
Near	80.2%	58.1%	76.3%
Inter.	8.3%	30.2%	17.8%
Far	11.5%	11.7%	5.7%
Fixation Position	**Buy Back Inspection (Percent)**	**Primary Inspection (Percent)**	
Up	21.5%	24.7%	
Down	62.0%	49.7%	
Full Down	16.5%	25.6%	

Table 1. Distribution of fixation distances and positions for buy back and primary inspections as measured by observers and reported by inspectors.

For both types of inspection, visual detail was often viewed at "normal" reading distances (less than 50 cm) and in a normal reading position (slightly below eye level). Chi square analysis showed that the buy back and primary fixation distance distributions were significantly different from one another (χ^2 = 27.3, $p < 0.001$). When these observational data are combined and compared to reported data from the survey (see Table 1), no difference across fixation distances was noted (χ^2 = 5.8, $p > 0.05$). This indicates that these personnel are generally aware of the working distances involved in their inspections, and supports the validity of our findings. Chi square analysis also showed that the distribution of fixation positions were different for buy back and primary inspections (χ^2 = 8.0, $p = 0.02$).

Table 2 lists fixation distances and positions for primary inspections for five different aircraft sections.

Fixation Dist.	External Fuselage	Wing	Engine	Special	Cargo Floor
Near	35.0%	79.3%	63.6%	85.6%	50.0%
Inter.	37.6%	17.0%	29.9%	12.4%	41.9%
Far	27.4%	3.7%	6.5%	2.1%	8.1%
TOTAL	263	188	184	97	198
Fixation Position	**External Fuselage**	**Wing**	**Engine**	**Special**	**Cargo Floor**
Up	23.4%	27.6%	37.7%	45.5%	1.6%
Down	41.1%	54.6%	56.3%	48.9%	47.1%
Full Down	35.5%	17.8%	6.0%	5.7%	51.3%
TOTAL	214	163	167	88	191

Table 2. Distribution (percentages) of job-specific fixation distances and positions for primary inspections.

Chi square analyses showed the inspections across these five sections to be different for both distance and position. External fuselage inspection appears to be the primary outlier, however, individual comparisons shown in Table 3 indicate that the fixation distance distributions are specific to the areas of the aircraft that are inspected. Shorter fixation distance (< 50 cm) is the most common for primary inspections within four sections of the aircraft at 67.2% (Table 2), but the three ranges of fixation distances are approximately equal at 35% to 37.6% to 27.4% (near, intermediate, far) for the external fuselage.

Job Location	Wing	Engine	Specialty	Cargo Floor
External Fuselage	< 0.001	<0.001	< 0.001	< 0.001
Wing	--	0.004	0.413	< 0.001
Engine	--	--	< 0.001	0.027
Specialty	--	--	--	< 0.001

Table 3. Chi-square analyses for job-specific fixation distance comparisons.

DISCUSSION

The setting of a vision standard shares many similarities with determining the cut score for any ability test. The essential job functions must be identified as well as the consequences of non-performance. While the frequency of task performance is an important element in setting a standard, task frequency cannot always be equated with task importance. It can certainly be argued that within aircraft maintenance, because the consequences of an error are so great, all essential tasks are equally important regardless of frequency of completion.

The majority of inspection work performed by these visual inspectors is done at viewing distances of less than 50 cm. Thus, the essence of this work is the identification of defects at near working distances. Coupled with the extreme potential consequences of missing a defect, the frequency data greatly supports the need for a nearpoint visual acuity standard for visual inspectors.

The argument supporting an intermediate visual acuity standard is also strong. The difference in distribution of working distances between buy back and primary inspections appears to be due to the greater control of the visual task inspectors have during buy back inspections. Inspectors can take more time to position themselves properly to see the point of regard clearly during these inspections. Often the inspection may be at an AMT's workstation away from the aircraft. As such, a very large percentage of viewing was done in a normal reading position of less than 50 cm (80.2%) and at just below eye level (62%).

During primary inspections, inspectors were required to scan large areas efficiently and effectively. Primary viewing direction and distance were more varied (only 58% were 50 cm or less and 49% were just below eye level) and depended upon the physical positioning of the inspector relative to the observed structures. While only 8.3% of visual work with buy back inspections was done at intermediate distances (>50 cm to 1 m), this value was over 30% of visual tasks for primary inspections. As defects are identified chiefly within the primary inspections, the need for an intermediate visual acuity standard should be based upon this figure. If the defect is not identified initially (i.e., during the primary inspection), a repair with the need for a buy back inspection will not be realized.

Because of our normal physiologic accommodative ability, if a worker under 40 years of age can pass a vision standard at a given distance using normal, single vision glasses, he/she should be able to pass the same standard at all working distances. For workers greater than 45 years, however, specially designed multifocal lenses may be required to allow sharp vision at intermediate and near working distances.

As the mean age of inspectors is about 45 years, a large proportion of inspectors have lost significant natural accommodative power. Eyewear must be designed with viewing distances and directions in mind. Although the majority of fixation directions for both type inspections corresponds to the normal bifocal position (slightly down), much primary inspection activity is directed upward (24.4%) and at intermediate to long viewing distances (42%). Inspectors should thoroughly discuss with their eye care practitioners the variations in object distance and direction required of their jobs. In order to ensure clear and comfortable vision at all working distances, special eyewear designs may be required. Inspectors older than 45 years may require trifocals or progressive addition bifocals (i.e., no-line) to allow clear vision at all required viewing distances.

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