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VELOCITY, DEFECT RATE AND PACING STRATEGY IN SIMULATED INSPECTION

by

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INTRODUCTION

Quality control is an inherent part of every industrial manufacturing process. While product quality is a function of many components in the production cycle (e.g., design, specification and purchasing), a critical step in quality assurance is product inspection. Inspection may be enacted during any period in the production cycle and involve partial or final products. The importance of inspection of any quality control effort is emphasized by Harris and Chaney (1969) who state :

> " While quality assurance has grown to incorporate a number of new disciplines, product inspection is still the most critical activity performed by this function . This inspection process is the basic source of information on workmanship and other types of error. As a result, the effectiveness of the total quality system is highly dependent on the accuracy of the basic quality data that are collected and reported by the inspector. " (P.9)

With this magnitude of importance assigned to inspection, any investigation of process to get a better understanding of it will be useful.

Many industries work on a production line system. In these systems, the raw materials and component parts enter the production facility at the beginning and at various other point in the production process. The actions of men and/or machines transform these input materials step by step into a finished product. After many of these operations and after completion, the product may be inspected. Conveyors are often used to transport the product from one operation to the next. So the inspection task is not only dependent upon visual acuity but often involves dynamic visual acuity.

During his task an inspector can make two types of errors : (1) he/she may classify a good item as bad, a " type I error " or a " false alarm " , (2) he/she may classify a bad item as good, a " type II error " or a " miss ". A probability matrix can be contructed for the inspection process as illustrated in Table1 , where

Q_o = a priori probability of a good product in an inspection lot,

P_o = a priori probability of a bad product in an inspection lot

= $(1 - Q_o)$,

P_1 = probability of a type I error; calling a good product defective (" false alarm "),

P_2 = probability of a type II error; calling a defective product good(" miss "),

$1 - P_1$ = probability of a correct acceptance decision for a good product,

$1 - P_2$ = probability of a correct reject decision for a bad product (" hit ", " defects detected "),

Good product = product that meets or exceeds the requirements of drawing and specification,

Bad product = product that does not meet the requirements of drawing and specification.

The products in each cell of the matrix are the joint probability elements of the conditional probability statements associated with each stimulus-response combination of the matrix. These statements are of the form

$$P(X] Y) = \frac{P(X] Y)}{P(Y)} ,$$

where

X = decisions (accept or reject) ,

Y = true condition (good unit or bad unit)

The following conditional probability statements can be written for the

TABLE 1

Definitions of Probability Statements

	Decision Based on Inspection		
	Accept	Reject	Total
Good product	$(1-P_1)\ Q_o$	$Q_o(P_1)$	Q_o
Bad product	$P_2(P_o)$	$(1-P_2)\ P_o$	P_o
Total	$(1-P_1)Q_o+P_2P_o$	$Q_oP_1+P_o(1-P_2)$	1

probability matrix for inspector decisions : Table 2 and Table 3

$$P\ (\text{ accept good product }) = \frac{(1 - P_1)\ Q_o}{Q_o} = 1 - P_1$$

$$P\ (\text{ reject bad product }) = \frac{(1 - P_2)\ P_o}{P_o} = 1 - P_2$$

$$P\ (\text{ reject good product }) = \frac{Q_o\ P_1}{Q_o} = P_1$$

$$P\ (\text{ accept bad product }) = \frac{P_o\ P_2}{P_o} = P_2$$

Any industrial inspection situation is composed of a multitude of factors that can influence its output. These can be listed as : the individual abilities of the inspector, the physical composition of the task in its environment, and the nature of the inspection task. So the design variables of the paced inspection include :

(1) Individual abilities

(2) Physical environment

  (a) Noise and temperature

  (b) Illuminance level, glare and contrast

(3) Inspection task

  (a) Time to view

  (b) Conveyor belt velocity (angular velocity)

  (c) Percentage of lot defectives

  (d) Type of pacing

TABLE 2

Definitions of Joint Probability Statements

	Decision Based on Inspection	
	Accept	Reject
Good product	$1-P_1$	P_1
Bad product	P_2	$1-P_2$

TABLE 3

Name for each decision

	Inspector's Decision		
	Accept	Reject	Total
Good product	Correct acceptance	False alarm	Total good
Bad product	Miss	Hit	Total bad
Total	Total acceptances	Rejection rate	Total

The discussion of each variable includes reference works related to its effects on paced inspection tasks.

Individual Abilities

Individual factors can be conceived of as being in one of two categories : inter-operator differences and intra-operator differences. Intra-operator differences --- such as illness, drug effects and fatigue --- are not readily subject to industrial control. Inter-operator differences, on the other hand, can be more practically regulated or selected for in the industrial situation. Past research has been concerned with differences such as abilities and aptitudes. The selection of personnel for scanning inspection tasks is emphasized by Harris and Chaney (1969) who state :

> " Many inspection jobs require a person simply to look at quality characteristics to determine whether or not they meet quality standards. Jobs of this general type are usually referred to as scanning inspection jobs. Although certain minimum levels of visual acuity and mental alertness are probably required for inspection jobs of this type, little success has resulted from attempting to predict inspection performance from measures of visual acuity or mental alertness. There appears to be a relatively specialized aptitude or combination of aptitude required for scanning inspection work. " (P. 171)

Physical Environment

Noise and temperature. The environmental variables of noise and temperature above certain levels have been shown to affect performance. The NIOSH (National Institute for Occupational Safety and Health) Criteria Document for Occupational Exposure to Hot Environments (1972) presents data indicating that the environmental temperature should not exceed 87°F on the WBGT scale (Wet-Bulb-Globe Temperature) for unimpaired mental performance for an exposure time of 240 minutes. This value may be viewed as an approximate guideline for the upper temperature limit in designing inspection tasks. It should also be noted that the NIOSH Criteria Document recommends a set of work practices to be followed when the environmental temperature exceeds 76°F for women and 79°F for men as measured on the WBGT scale.

Noise in industrial setting is common. Since it has been shown to induce long-duration and detrimental physiological effects at high levels of exposure, noise is considered to be an environmental stressor. Noise may be continuous or intermittent. Continuous noise sources have been previously investigated (Fox and Haselgrave, 1969). A series of studies by Warner (1969) and Warner and Heimstra (1971,1973) have investigated the effects of various intermittent noise parameters on visual target detection performance. Results indicated that no differences in detection times were found below 90 dB (decibel) intensity for any level of task difficulty. The OSHA(Occupational Safety and Healthy Administration) also has set of 90 dB unless personal hearing protection is provided.

Illuminance level, glare and contrast. Illuminance level as a variable affecting visual acuity has been studied by a number of investigators, including McCormick and Niven (1952), Tinker (1949), Shlaer (1937), Westheimer (1965) , and Faulkner and Murphy (1973). Most of the studies cited support the point of view that above a given point increase in illumination level neither task performance nor visual acuity increases appricially. Therefore, the illuminance of the workspace is emphasized by

Harris and Chaney (1969) who state :

" In general , the level of illumination desired for an inspection task is that which will provide the greatest inspection accuracy. The precise determination of illumination level in terms of performance measures is difficult to do, however, short of conducting an extensive experimental study for each task. As a consequence attempts have been made to study a range of different types of visual tasks to establish a set of bench marks. This approach provides a means for roughly establishing the illumination level for tasks in terms of certain specified task characteristics. A crude set of bench marks for visual inspection tasks was developed from a review of specified illumination requirements designed for a variety of categories. These recommended illumination levels are provided in Table 7 . " (P. 95,96)shown here as Table 4.

Glare is usually defined as any brightness within the field of vision which causes discomfort or interference with vision. There are two types of glare to be recognized. Direct glare refers to the effect of a light source within the visual field; reflected glare refers to the effect of surfaces which reflect light coming from outside the visual field. Research has indicated that direct glare may be reduced by (a) avoiding bringing light sources within 60 degrees of the center of the visual field, (b) using shields, hoods, and visors to keep direct light out of the viewer's eyes, (c) using indirect lighting, and (d) using several low-intensity lights instead of one high intensity light. Reflected glare may be reduced by (a) using working surfaces and tools

TABLE 4

Recommended Illumination Level for Inspection Tasks
(cited from Harris and Chaney 1969)

Type of Work	Foot-Candles
Unmagnified visual, functional, and dimensional product inspection.	100
Large area magnification for inspection of small details frequently requiring low power manification.	200
Microscopic examination of materials, surfaces, and finishes usually requiring spot illumination.	500
Highly magnified examination of materials and small details always requiring high intensity special lighting.	1000

that diffuse reflected light, (b) using a diffused light source, and (c) positioning light sources and work so that light is not reflected toward the eye.

Contrast is defined as the relative brightness difference between the object in the target and the target background and is expressed as a percentage. Blackwell (1959) shows curves for a given detection accuracy for particular values of target size, background luminance, and target contrast. He found that contrast had to be high to maintain performance for low illuminance levels could be low for high illuminance levels. Therefore, if the illuminance level, the glare, and the target contrast are satisfactory, this can be eliminated as a potential problem area.

The summary of the physical environment as shown in Table 5.

Inspection Task

Time to view. The time to view may effect inspection efficiency. Grahan and Cook (1937) and Niven and Brown (1949) found time to view in the range of 0.1 to 0.2 second in static visual acuity tests had an effect on performance, but not for longer times. Cochran, Purswell and Hoag (1973) found that inspection performance was significantly affected for a viewing time of 0.25 second, but not at level of 0.50 second. Thus, the time to view may possibly be reduced to less than 0.5 second without affecting performance, but levels of 0.25 second or less are likely to affect inspector performance significantly.

Conveyer belt velocity(angular velocity). The angular velocity of a target or an object as it passes before the obsever has been shown to have a definite effect on the observer's ability to perform accurately.

TABLE 5

Summary of Physical Environmental Variables

Temperature	NIOSH (1972), the environmental temperature should not exceed 87°F on WBGT scale	
Continuous noise	Fox and Haselgrave (1969)	No difference in detection times were found below 90 db intensity for any level of task difficulty. And should not exceed the OSHA standard of 90 db unless personal hearing protection is provided
Intermittent noise	Warner (1969) Warner and Heimstra (1971,1973)	
Illuminance	Harris and Chaney (1969)	in Table 4
Glare	Harris and Chaney (1969)	Direct glare may be reduced by (a) avoiding light sources within 60 degrees of the line-of-sight. (b) using shields, hoods, (c) using indirect lighting (d) using several low-intensity lights. Reflected glare may be reduced by (a) using working surfaces and tools that diffuse reflected light (b) using a diffused light source (c) positioning light sources
Contrast	Blackwell (1959)	Contrast should high for low illumination levels and low for high illumination levels

Westheimer (1954,1965) found that angular velocity had an important effect on dynamic visual acuity when the angular velocity was high, but not when it was low. He found that the eye can move smoothly up to about 40 degrees per second. Ludvigh and Miller (1949,1958) have authored numerous articles on dynamic visual acuity. In their studies, angular velocity was varied from 10 degrees per second to 170 degrees per second. They found that the visual acuity of moving targets decreased rapidly as the angular velocity increased. Studies of Burg and Hulbert (1959,1961) also support the findings of Ludvigh and Miller. Westheimer seems to be in disagreement with Ludvigh and Miller and with Burg and Hulbert about the effects of angular velocity on dynamic visual acuity when the angular velocity has a level of less than 40 degrees per second. Westheimer found that eye movement can only occur smoothly up to 40 degrees per second, and he therefore concluded that visual acuity should not suffer up to that point. Ludvigh and Miller and Burg and Hulbert based their ideas on actual data which shows that visual acuity suffers at values of 10 degrees per second of angular velocity and above. Their findings make it obvious that no study of dynamic visual acuity or dynamic inspection should ignore angular velocity as a factor.

The summary of angular velocity is shown in Table 6.

Percentage of lot defectives . Inspection errors may be assumed to occur according to some random process, and models of inspection result in a probability distribution of some sort. In general the models have been developed not on the basis of existing error data but rather on the basis of assumptions regarding inspector behavior. Over the past several years, there

Table 6

Summary of Angular Velocity

Westheimer (1954)	The eye can more smoothly up to about 40 degrees per second
Ludvigh and Miller (1949,1958)	Angular velocity was varied from 10°/sec - 170°/sec found that visual acuity of moving targets decreased rapidly as the angular velocity increased
Burg and Hulbert (1959,1961)	Showed that visual acuity suffers at values of 10 °/sec and above

has been an increasing interest in this problem.

Currently the study of the industrial inspection efficiency on the probability of a defect occurring under different angular velocities is one of the most active areas of quality control research. Harris(1968) studied four different defect rates: 0.25 percent,1 percent,4 percent, and 16 percent. Inspection was measured in terms of defects detected (hits) and false reports made. For each inspection condition the number of defects detected was divided by the number of defects present to give the percentage of defects detected. The percentage of false reports was computed by dividing the number of defects reported which were not actually defects by the total number of defects reports. Defects detected, or hits, decreased with reductions in defect rate. As shown in Figure 1, the percentage of defects detected decreased slightly between defect rates of 16 percent and 1 percent, but dropped sharply between 1 percent and 0.25 percent. False reports, the second indicator of inspection accuracy, became more frequent with reductions in defect rate. The percentage of false reports increased at an accelerated rate as the defect rate approached zero. The difference among the four defect rates for the percentages of defects detected and for the percentages of false reports was found to be statistically significant beyond the 0.05 level for both cases.

Studies performed in an industrial setting by Fox and Haselgrave (1969) should varying influences of defect rate on inspection efficency. The principal measure of the inspector's performance was hits. A second measure was the number of false alarms made, i.e. good items thrown out as defective(in terms of the ratio of false detection to the number of good items in the batch). Subjects showed no performance differences in terms of percent of

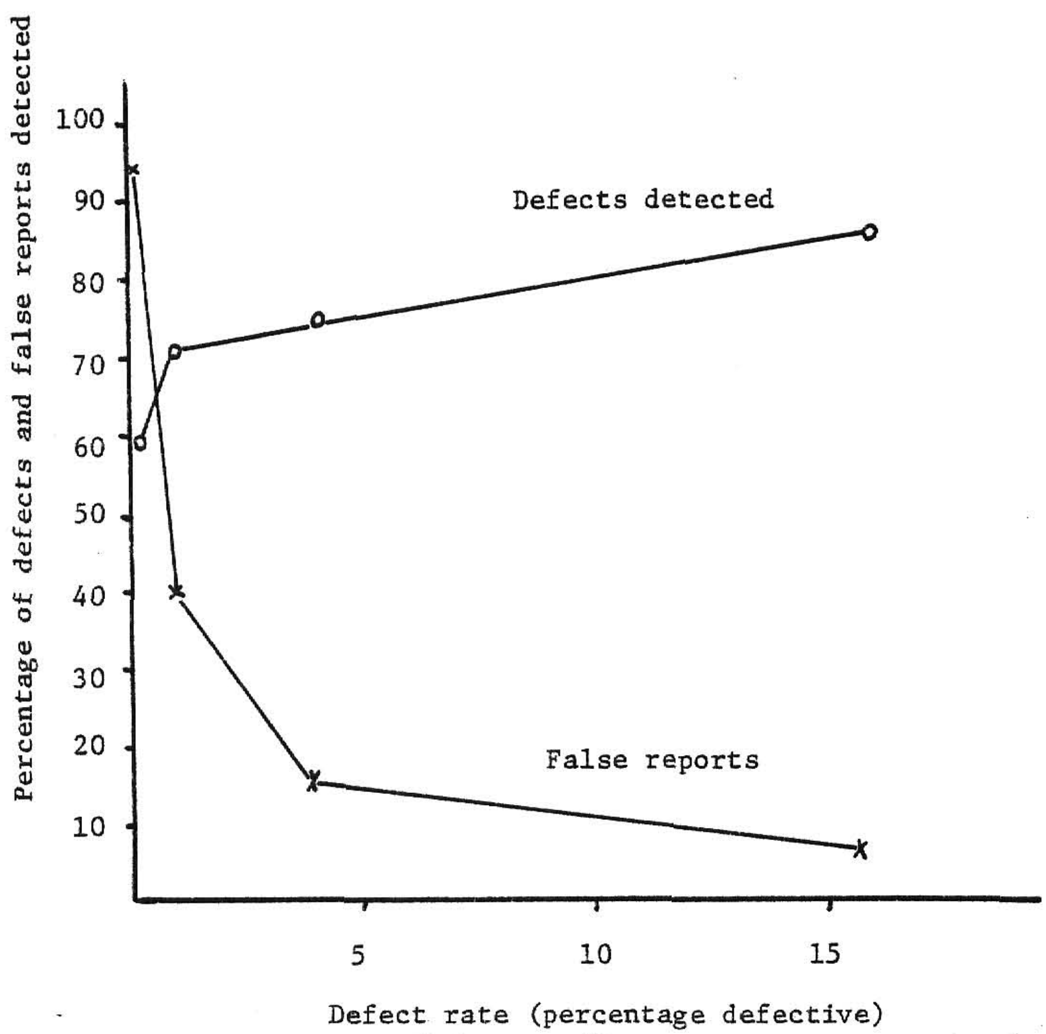


Figure 1. The relationship between defect rate and the percentage of defect detected and false reports (cited from Harris 1968).

defects detected at three defect rates (0.005,0.01 and 0.025) while inspecting products on a moving conveyor belt (the paced condition). On the other hand, inspectors working in unpaced situations at 0.01,0.02and 0.05 defect rates, there was improvement of defects detected as defect rate increased as shown Figure 2, but the number of false alarms varied widely for each subject, as shown in Figure 3.

Dorris,Hoag and Kasiviswanathan (1977), randomly assigned each subject to one of three percentages of defective items: 8%, 20%, 32%. The subject was seated inside of a circular conveyor and observed the targets as they passed within his field of view which was restricted to 14 inches. Each experimental run consisted of 25 items which were taken to be one lot.After inspecting a lot, the subject rested for 2 or 3 minutes while the targets were set up for the next lot. The number of defective items in a lot was a binomially distributed random variable. Thus, for example,for a subject in the 8% defective group, 8% of the total of 2500 items were defective with the distribution of the 200 defectives among the lots following the binomial distribution. Within a lot,the order of items was randomly determined. The number of items rejected by the inspector will be $P_o(1-P_2) + Q_oP_1$, defined in terms of defects detected times probability of defective items in a lot and false alarms times probability of good items in a lot . The results indicated that the overall probability of rejecting an item increased with increasing fraction defective but the replications(days) were not significantly influenced by the percentage of defectives, as shown in Figure 4.

The unpaced inspection, studies of Fox and Haslegrave (1969) also supported the findings of Harris (1968) , which concerned defects detected

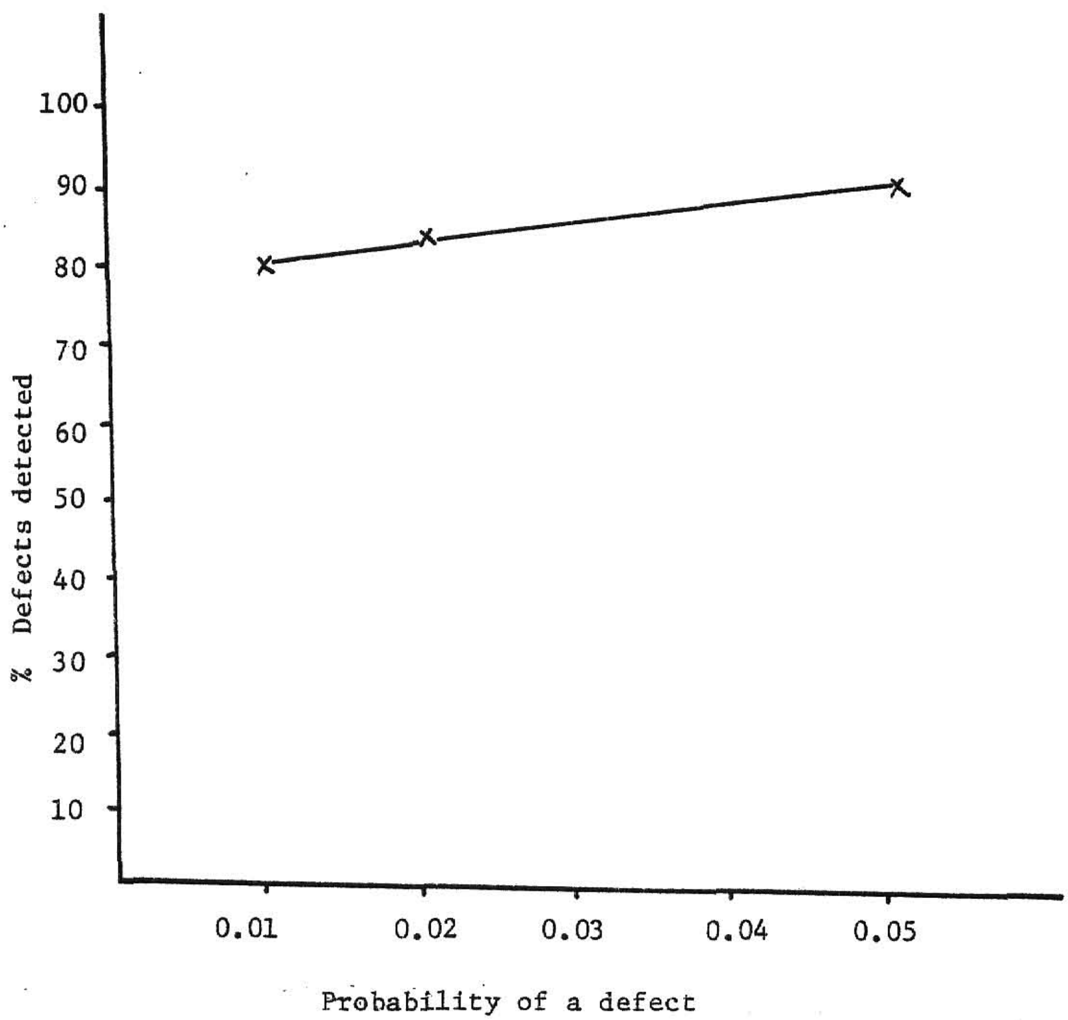


Figure 2. Variation of detection efficiency with probability of a defect in unpaced visual inspection (cited from Fox 1969).

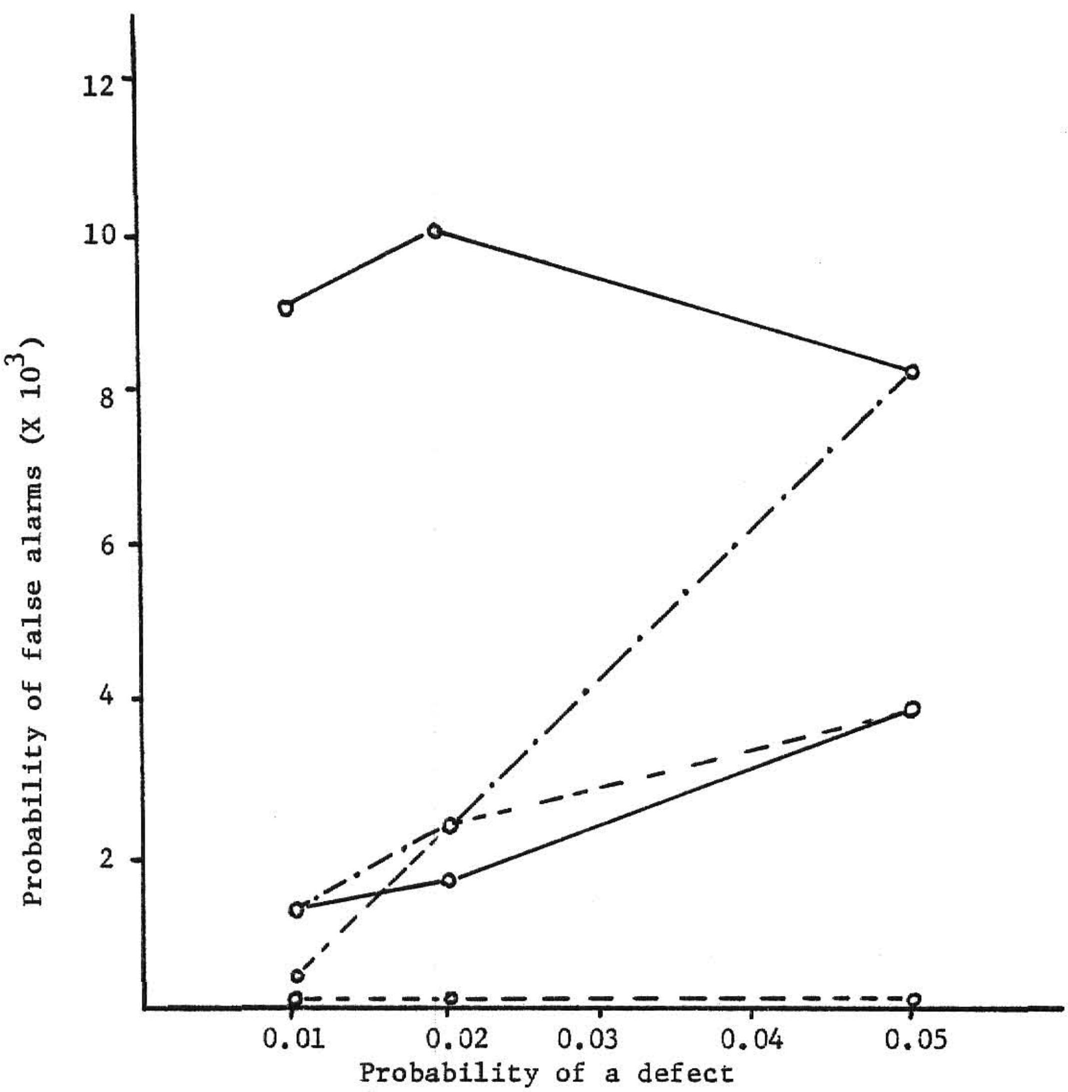


Figure 3. Variation in number of false detected with varying probability of defects for individual inspectors (5 subjects) in unpaced condition (cited from Fox 1969).

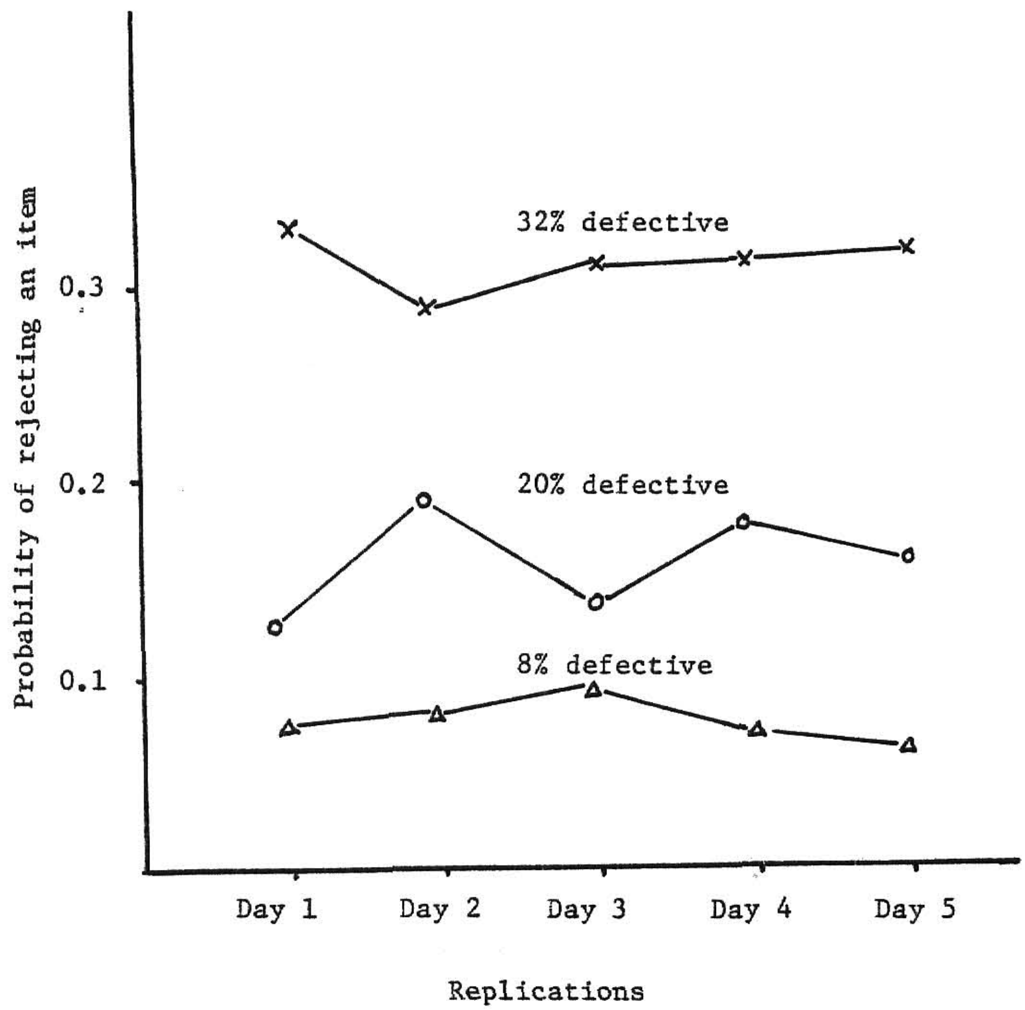


Figure 4. Effect of defect rate and replications on the probability of rejecting an item (cited from Dorris et al 1977).

(hits), but in false alarm studied were inconclusive. In the paced condition, studies of Dorris, Hoag and Kasiviswanathan (1977) were in disagreement with Fox and Haslegrave. The former found the overall probability of rejecting an item increased with the increase in percentage of defectives, the latter showed no performance differences in terms of percent of defects detected a different defect rates. Comparison of paced condition with the unpaced condition showed inconsistent results. Consequently, there has been an increasing interest in this problem.

Currently the study of the effects of inspection errors on machine paced versus self paced situation is one of the most active areas of quality control research.

The summary of percentage of lot defectives is shown in Table 7.

Type of pacing. Whether self-paced or machine-paced, speed of inspection will influence accuracy of fault detection. Given an infinite time to inspect the items, one might hope for near perfect fault detection. On the other hand, with a series of rapid, and hence necessarily cursory, scans of the items, one might expect a very low level of fault ditection.The unpaced task condition allows the inspector to determine how much time will be spent inspecting each item.This condition was studied by Harris(1964,1966, 1968). The machine-paced condition was studied in investigations by Purswell *et al* (1972), and Drury (1973).

A review of the effects of machine pacing versus self pacing (or unpaced) on inspection performance gives the following results. Williges and Streeter (1971) utilized an inspection task consisting of detecting pinhole defects in small plastic disks. Each groups of discs was displayed in two ways -

TABLE 7

Summary of Percentage of Lot Defectives.

Author	Percentage of lot defective	Measures: Defects detected (hit)	Measures: False alarm
Harris (1968)	unpaced 0.25%,1% 4%,16%	Defects detected decreased with reductions in defect rate; decreased slightly between defect rate of 16% and 1%, but dropped sharply between 1% and 0.25%	False reports* become more frequent with reduction in defect rate. The percentage of false reports increased at an accelerated rate as the defect rate approached zero
Fox and Haslegrave (1969)	unpaced; 1%,2%,5%	Defects detected decreased with reductions defect rate.	Varied widely among subjects
	paced: 0.5%,1%, 2.5%	Defects detected were not effected by defect rate	Varied widely among subjects
Dorris, Hoag, Kasiviswanathan (1977)	paced; 8%,20%, 32%	The probability of rejecting an item decreased with decreased in defect rate	

* Computed by dividing the number of defects reported which were not actually defects by the total number of defects reported.

a static (inspector paced) display with inspection discs mounted on a flat 6 x 40 inch light table, and a dynamic display with inspection discs mounted on a moving translucent belt on a drug capsule sorting machine. The belt moved at constant speed displaying approximately 100 discs at a time and persented the entire group of 600 discs in 20 second. Subject were given two 20 second trials in each condition. Analysis reveal signigicant differences in performance between the machine paced and self-paced situations. For all subjects, performance was better in the self-paced condition, in terms of hits. However, the subjects in this condition did not complete the inspection of all 600 items within the alloted 20 seconds per trial. Although the information derived from this investigation is of some value, several question occur. Since the differences in pacing were not of primary concern to the investigators, the self-paced condition was unstructured, allowing the subjects to perform only partial inspections. The duration of the task (20 seconds per trial) also extremely brief.

McFarling and Heimstra (1975), studied an inspection task consisting of 225 slide representations of printed circuits. In the machine paced condition the subject was automatically presented a circuit for inspection every 14 seconds. Each circuit was displayed for 8 seconds, during which the subject visually inspected the circuit and determined whether it was acceptable or defective. In the self-paced condition, circuit presentation rate was inspector-controlled. The results indicated, for all levels of circuit complexity, that self-paced inspection took longer but resulted in a higher level of defect detection. Correct acceptance of good circuits was maintained at a high level for both pacing conditions at all levels of circuit complexity, as shown in Table 8.

Questions concerning potential performance difference arising from comparisons between self-paced and machine-paced situations suggest another area of research, i.e., the self-adjusting speed of the inspector himself. The objective was to determine which of the machine-inspection (fixed) situations resulted in maximum detection of defectives, and then compare this with the self-selection results.

The summary of this type of pacing is shown in Table 9.

TABLE 8

Inspection Performance Comparing Machine and Self-paced Condition (cited from McFarling *et al* 1975)

	Circuit Complexity Level		
	one	two	three
Mean decision time			
Machine-paced	4.61 sec	4.99 sec	5.36 sec
Self-paced	6.22 sec	6.75 sec	7.78 sec
Defects detected			
Machine-paced	95.3 %	89.3 %	82.0 %
Self-paced	99.2 %	93.8 %	89.6 %
Correct accepted			
Machine-paced	98.0 %	99.0 %	98.8 %
Self-paced	99.7 %	99.3 %	99.3 %

TABLE 9

Summary of Type of Pacing

Type	Athor	Description
Unpaced	Harris(1966,1968)	Defects detected decreased with reduction in defect rate
	Fox and Haslegrave(1969)	Defects detected decreased with reductions in defect rate
Paced	Fox and Haslegrave(1969)	Defects detected not affected by defect rate
	Dorris, Hoag and Kasiviswanathan (1977)	The probability of rejecting an item decreased with decreased percentage of defectives
	Purswell et al (1972)	The total error (false alarm and misses) decreased with increased time to view. That means, the more viewing time, the more correct acceptances and hits
	Drury(1973)	As more time is allowed to inspect each item, the probability of defects detected increases while the probability of correct acceptances decreased.
Paced vs Self-paced	Williges and Streeter(1971)	The static display of items may provide superior inspection performance when compared to a dynamic display.In the self-paced case there were more defects detected and fewer false alarm errors
	McFarling and Heimstra(1975)	Self-paced inspection took longer but resulted in a higher level of defect detection. Correct acceptance of nondefective circuits was maintained at a high level for both pacing conditions at all levels of circuit complexity.

PROBLEM

The impact of the probablity of a defect occuring under different angular velocities on performance is one of the most active areas of inspection research. It is also important to determine whether machine-pacing or self-pacing results in higher detection of defectives.

The first hypothesis in this research was: the greater the percentage of defectives, the better the performance. This means that the inspector will detect more defects and have more correct acceptances. This is based on prior research finding.

The second hypothesis regards velocity: the angular velocity is interactive with the percentage of defectives. Specifically, at low speeds, for a low percentage of defectives, there will be disproportionately better performance. It previously suggested that one could expect better fault detection if given a greater inspection time.

The third hypothesis was that the self-paced inspection situation is similar to the optimum paced velocities. This means that the self-paced performance should correspond to the best performance in the range of machine paced velocities, if these include an optimum.

METHOD

The experimental method of this study is broken down into the following sections:

(1) Task and design

(2) Apparatus

(3) Subjects

The section on the task and design discusses target design,experimental procedures and dependent variables. The section on the apparatus shows the equipment and subject position. The section on the subjects indicates who they were, how many and how they were recruited.

Task and Design

A wide variety of targets have been used in the study of inspection. Past researchs have used numerous types of targets. Harris (1968) used geometric targets which contained 80 items, 20 each of the four types. Fox and Haslegrave (1969) used actual screws. Purswell, Greenhaw and Oacts (1972) used black and white photographs, 4 X 5 inches, of 5 X 5 and 7 X 7 grids, containing geometric figures of different sizes (3/8 inch and 1/4 inch). Badalamente and Ayoub (1969) and McFarling and Heimstra (1975) used slide representations of printed circuits. Nelson and Barany (1969) used a grid in which four or five of the 100 squares were white while the rest were black. The objective was to identify which targets had fewer than five white squares. Smith and Barany (1970) used small discs which contained four 1/16 inch holes equally spaced around the center of the disk at a radius of 1/4 inch. The discs had either three or four white dots on them. The objective was to determine which discs had three dots and which had four. Dorris,Hoag and Kasiviswanathan (1977) used rectangular glass plates (3.8 cm. X 3.2 cm.)

which had been painted an opaque gray color. A small piece of black wire, 0.32 cm. long and 0.02 cm. in diameter, was attached to the surface of some of the plates.

Based on review of previous studies, targets for inspection can be divided into major classes: missing item targets and defective item targets.When using the missing item type of target the subject must detect a missing component or symbol within the target. This was the type used by Nelson and Barany (1969) and Smith and Barany (1970) . When using the defective item target the subject is required to detect an item in the target previously defined as defective. Many industrial inspection tasks have as their purpose the detection of defective parts. This was the typed used by Harris (1968), Purswell (1972) and Dorris _et al_ (1977). The target chosen for this study was one in which the subject inspected for defective items. The summary of previous studies is shown in Table 10.

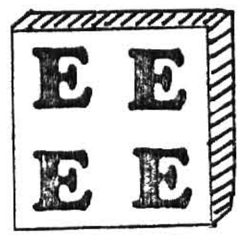
The targets used in this experiment consisted " E's " of size 0.3 X 0.3 inch which were printed on a white sheet of paper. Photo copies were made. The sheet was cut into a number of small pieces each measuring 1 X 1 inch containing four E's. These pieces were posted on a hard cardboard 1 X 1 X 1/8 inch. The defective targets had randomly broken or missing parts as shown in Figure 5. This broken part was 1/16 inch by 1/8 inch and missing part was 1/16 inch by 1/4 inch.

Each experimental task consisted of a two minutes practice period followed by a 10-minute performance period. Each subject was given the written instructions upon arriving for the experiment. For machine paced tasks the instructions are given in Figure 6 and for the self-paced task the instructions

TABLE 10

The Summary of Target of size and Material

Type	Author	Material	Size
Unpaced	Harris(1966,1968)	geometric form	
	Fox and Hasligrave(1969)	screws	industrial task
Paced	Fox and Haslegrave91969)	screws	industrial task
	Dorris et al (1977)	rectangular glass plates(3.8cm X 3.2 cm)	a small piece of black wire, 0.32cm long and 0.02cm in diameter
	Purswell et al (1972)	geometric form	3/8in. and 1/4 in.
	Drury(1973)	coins,glass bottle , bakery products.	
	Smith and Barany(1970)	round disk	one inch in diameter, contained four 1/6 inch holes
Paced v.s. unpaced	Williges and Streeter(1971)	plastic discs	detecting pin-hole defects in 1/4 inch diameter discs
	MacFarling and Heimstra(1975)	225 slide representations of printed circuits	117 X 104 mm.



Complete (accept)

Defective (reject)

Figure 5. Target used in inspection task.

INFORMED CONSENT AND INSTRUCTIONS FOR SUBJECTS

The purpose of this experiment is to determine how correctly you can detect defects in moving targets. Your job will be to look at the matrix of E's on those target cards as they pass in front of you. If the " E's " are not complete,they are defects. When you detect on of the incomplete E symbols on a card passing in front of you, remove the card from the belt and place it in container. If the target is not defective, leave it on the belt.

Thank you very much for your co-operation. If you have any questions or comments please feel free to ask them.

There are no dangers or risks involved in this experiment. However, you are free to stop at any time. I will appreciate if you will complete the experiment. If you are ready for the experiment please sign the consent form attached.

Once again, I thank you for your co-operation.

Figure 6. <u>Instruction for subjects at machine paced.</u>

are given in Figure 7.

The product units were spaced 12 inches (center-to-center). A target viewing window width of 12 inch and a viewing distance of 12-15 inch corresponds about 45.8 degrees. The belt was shielded in such a manner (see Figure 8) that the inspector could see only one part at a time. During any one task, the inspector made 550 to 140 inspections depending on the conveyor speed because the task times were held constant.

Scoring of performance was based on correct acceptances (and false alarms), hits (and misses), rejection rates and Borg scale ratings. The measures of inspector performance were correct acceptances and defined as the percentage of good items present in a lot which were accepted, the percentage of false detections made, i.e, good items thrown out as defective (this was stated in terms of the ratio of false alarms to the number of good items in the lot.), the percentage of defects detected defined as the percentage of defective items present in a lot which were detected, the percentage of missed detections made, ie, bad items accepted as good (this was stated in terms of the ratio of miss detection to the number of bad items in the lot.)

In this study the probability of a correct acceptance is the probability of a false alarm subtracted from one and the probability of a defects detected is the probability of a miss subtracted from one. Therefore, in the analysis of the results, there are the same tables for correct acceptance and false alarms or defects detected and misses.

A fifth measure was the percentage rejection rate. This was stated in terms of defects deteted times the probability of defective items in a lot

INFORMED CONSENT AND INSTRUCTIONS FOR SUBJECTS

The purpose of this experiment is to determine how fast and how correctly you can detect defects in targets. This experiment requires you to select the speed of the targets, which you can change any time you want to change it. You will have a two minutes practice period followed by a 10-minutes performance period. The time spent inspecting each target is up to you, that means, the conveyor speed is selected by you. Your job will be to look at the matrix of E's on these target cards as they pass in front of you. If the " E's " are not complete, they are defects. When you detect an incomplete E on a card passing in front of you, remove the card from the belt and place it in container. If the target is not defective, leave it on the belt.

Thank you very much for your co-operation. If you have any question or comments please feel free to ask them.

There are no dangers or risks involved in this experiment. However, you are free to stop at any time. I will appreciate if you will complete the experiment. If you are ready for experiment please sign the consent form attached.

Once again, I thank you for your co-operation.

Figure 7. Instruction for subject at self-paced.

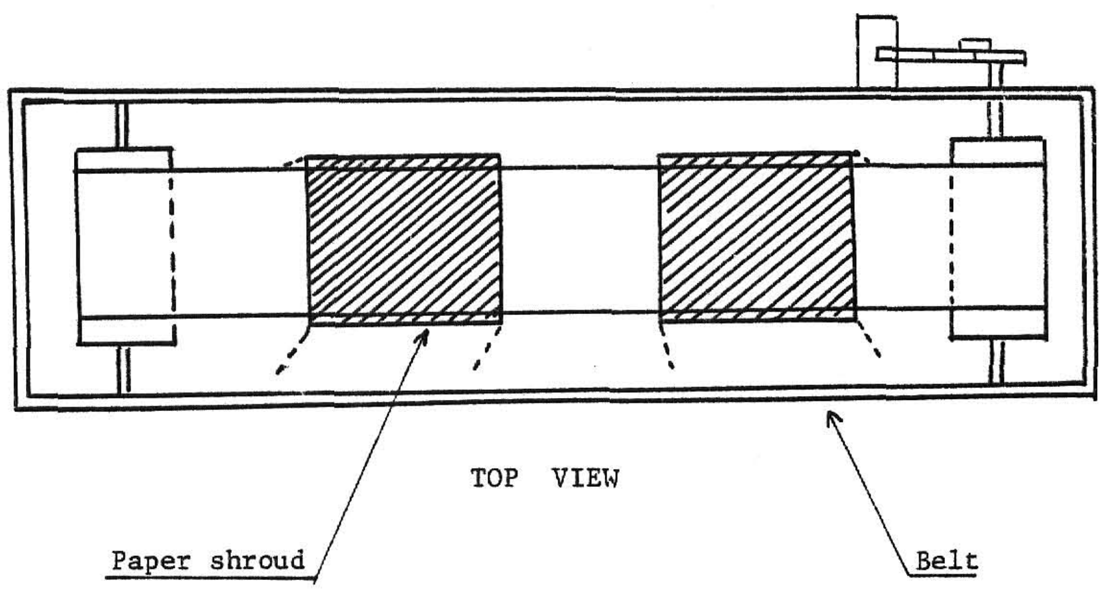


Figure 8. Straight conveyor.

and false alarms times the probability of good items in a lot. A sixth measure was the Borg scale rating of perceived exertion. In the case of physical work, the values are close to one tenth of the person's heart rate.

The experimental variables and their respective level are shown in Table 11.

Apparatus

A straight, belt conveyor with a variable speed drive where the belt moves smoothly over a supporting platform, was used. The conveyor belt was a textured gray. The belt was shrouded (see Figure 8) by yellow paper to allow the inspector to see only part at a time. This covering ensured that the subject view each product unit for the same angular degree (45.8^{o}),and also hid the experimenter as he placed targets on the conveyor at one end.

The straight line conveyor was 11.25 inches wide and 10 feet 3 inches long as shown in Figure 8. The conveyor was located in a laboratory with ambient illuminance of 110 footcandles in the inspection area where the conveyor was located. The noise level varied from 70 to 82 decibels when the conveyor was operating. The temperature was $75^{o}F$.

The experimental task required that the subject sit on a stool in front of a conveyor belt which moved the product unit. The viewing distance was 12-15 inches, since the distance varied slightly as each subject positioned himself to have adequate reach for removing targets with errors. It can be argued that the requirement of having subjects manually remove targets with errors results in a practical restriction upon visual inspection performance , However, this procedure was adopted to simulate an actual industrial task. Figure 9 depicts the arrangement of the task situation.

TABLE 11

Experimental Variable and Level

angular velocity	10 °/sec	20 °/sec	30°/sec	40 °/sec	self-paced
percentage of lot defective	1% 10% 20%	1% 10% 20%	1% 10% 20%	1% 10% 20%	1% 10% 20%
Inspect time for each condition	10 min.	10 min.	10 min.	10 min.	10 min.
Spacing of target angular unit	12 inch 45.8°	12 inch 45.8°	12 inch 45.8°	12 inch 45.8°	12 inch 45.8°
Number of targets to inspect	138	275	412	550	
Number of subject	8	8	8	8	8

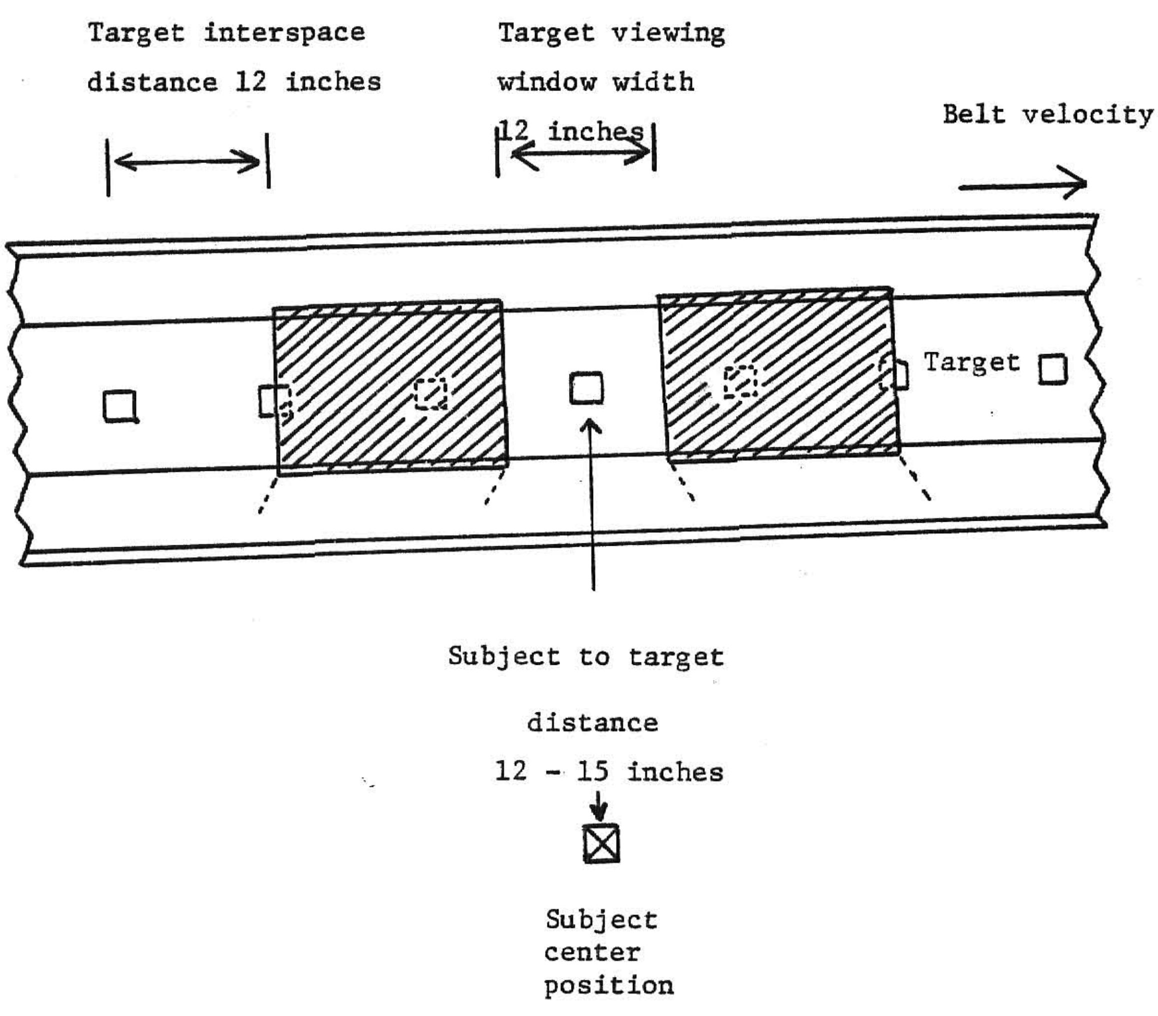


Figure 9. Diagram of experimental situation at paced inspection.

Subjects

The selection of subjects is always a difficult practical problem. Ideally, they should be drawn at random from the total population of industrial inspector in order to facilitate making inferences about industrial inspectors. This was not possible. There were however, some valid criteria which subjects for any experiment in inspection or visual acuity of any kind should meet. They should be between the ages of 18 and 70 years and have at least 20/20 corrected vision. In addition, subjects had to have a willingness to cooperate and make a sincere effort to do each trial as best they could.

Due to availability, university students and local people between the ages of 18 and 40 years were recuited. Both male and female subjects were used. Forty subjects were recruited for the experiment. There were six females and thirty-four males.

RESULTS

There were three lots of defective items with varying percentage of defectives presented with the same angular velocity or self-paced for each subject. The measures of inspector performance were correct acceptances and defined as the percentage of good items present in a lot which were accepted, the percentage of false detections made, i.e., good items thrown out as defective (this was stated in terms of the ratio of false alarms to the number of good items in the lot.), the percentage of defects detected defined as the percentage of defective items present in a lot which were detected, the percentage of missed detections made, i.e., bad items accepted as good (this was stated in terms of the ratio of miss detections to the number of bad items in the lot.). A fifth measure was the percentage rejection rate. This was stated in terms of defects detected times the probability of defective item in a lot and false alarms times the probability of good items in a lot. A sixth measure was the Borg scale rating of perceived exertion. Thus, the data are correct acceptances (and false alarms), hits (and misses), rejection rates and Borg scale ratings. Tables 12,13,14,15, 16,17 and 18 give the data and mean values for machine paced and self-paced.

In this research the mean correct acceptances for 10 ^{o}/sec, 20 ^{o}/sec, 30 ^{o}/sec, 40 ^{o}/sec and self-paced were 0.998,1.0,0.999,1.0 and 1.0, respectively. The mean hits for 10 ^{o}/sec, 20 ^{o}/sec, 30 ^{o}/sec, 40 ^{o}/sec and self-paced were 0.997,0.977,0.937,0.905 and 0.916, respectively. The mean rejection rates for 10 ^{o}/sec, 20 ^{o}/sec, 30 ^{o}/sec, 40 ^{o}/sec and self-paced were 10.47,10.21, 9.96, 9.54 and 9.73, respectively. The Brog scale rating

TABLE 12

Data for Machine Paced - 10 ^{o}/sec

% of lot defective / subject number	1%			10%			20%			Borg scale rating
	correct* acceptance	hits**	rejection rate	correct acceptance	hits	rejection rate	correct acceptance	hits	rejection rate	
1	1.0***	1.0***	1.0%	1.0	0.93	9.3%	1.0	1.0	20.0%	9
2	1.0	1.0	1.0%	1.0	1.0	10.0%	1.0	1.0	20.0%	7
3	1.0	1.0	1.0%	1.0	1.0	10.0%	1.0	1.0	20.0%	9
4	0.96	1.0	4.96%	1.0	1.0	10.0%	1.0	1.0	20.0%	9
5	1.0	1.0	1.0%	1.0	1.0	10.0%	1.0	1.0	20.0%	6
6	1.0	1.0	1.0%	1.0	1.0	10.0%	1.0	1.0	20.0%	9
7	1.0	1.0	1.0%	1.0	1.0	10.0%	1.0	1.0	20.0%	9
8	1.0	1.0	1.0%	1.0	1.0	10.0%	1.0	1.0	20.0%	6
Means	0.995	1.0	1.495%	1.0	0.991	9.912%	1.0	1.0	20.0%	8

* False alarms = 1- correct acceptances

** Misses = 1 - hits

*** Value is probability of each decision

TABLE 13

Data for Machine Paced - 20 ^{o}/sec

% of lot defective / subject number	1%			10%			20%			Borg scale rating
	correct* acceptances	hits**	rejection rate	correct acceptances	hits	rejection rate	correct acceptances	hits	rejection rate	
1	1.0***	1.0***	1.0%	1.0	1.0	10.0%	1.0	1.0	20.0%	9
2	1.0	1.0	1.0%	1.0	1.0	10.0%	1.0	0.98	19.6%	9
3	1.0	0.67	0.67%	1.0	0.96	9.6%	1.0	1.0	20.0%	11
4	1.0	1.0	1.0%	1.0	1.0	10.0%	1.0	0.98	19.6%	11
5	1.0	1.0	1.0%	1.0	1.0	10.0%	1.0	1.0	20.0%	11
6	1.0	1.0	1.0%	1.0	0.93	9.3%	1.0	1.0	20.0%	9
7	1.0	1.0	1.0%	1.0	0.96	9.3%	1.0	1.0	20.0%	7
8	1.0	1.0	1.0%	1.0	0.96	9.6%	1.0	1.0	20.0%	11
Means	1.0	0.959	0.959%	1.0	0.976	9.76%	1.0	0.995	19.9%	9.75

* False alarms = 1 - correct acceptances

** Misses = 1 - hits

*** Value is probability of each decision

TABLE 14

Data for Machine Paced - 30 °/sec

% of lot defective / subject number	1%			10%			20%			Borg scale rating
	correct acceptances*	hits**	rejection rate	correct acceptances	hits	rejection rate	correct acceptances	hits	rejection rate	
1	1.0***	1.0***	1.0%	1.0	0.97	9.7%	1.0	0.96	19.2%	10
2	1.0	1.0	1.0%	1.0	1.0	10.0%	1.0	1.0	20.0%	9
3	1.0	0.75	0.75%	1.0	0.97	9.7%	1.0	0.99	19.8%	9
4	1.0	1.0	1.0%	1.0	0.93	9.3%	1.0	0.94	18.8%	11
5	0.99	1.0	1.99%	0.99	0.97	10.6%	0.99	0.96	20.0%	13
6	1.0	0.75	0.75%	1.0	0.9	9.0%	1.0	0.94	18.8%	11
7	1.0	0.75	0.75	1.0	0.9	9.0%	1.0	0.91	18.2%	12
8	1.0	1.0	1.0%	1.0	0.95	9.5%	1.0	0.96	19.2%	11
Means	0.999	0.906	1.03%	0.999	0.948	9.6%	0.999	0.957	19.25	10.75

* False alarms = 1 - correct acceptances

** Misses = 1 - hits

*** Value is probability of each decision

TABLE 15

Data for Machine Paced - 40 ^{o}/sec

% of lot defective / subject number	1%			10%			20%			Borg scale rating
	correct acceptances *	hits **	rejection rate	correct acceptances	hits	rejection rate	correct acceptances	hits	rejection rate	
1	1.0 ***	1.0	1.0%	1.0	0.96	9.6%	1.0	0.98	19.6%	13
2	1.0	0.83	0.83%	1.0	0.94	9.4%	1.0	0.99	19.8%	11
3	1.0	0.83	0.83%	1.0	1.0	10.0%	1.0	0.96	19.2%	12
4	1.0	1.0	1.0%	1.0	0.85	8.5%	1.0	0.76	15.2%	10
5	1.0	0.83	0.83%	1.0	0.89	8.9%	1.0	0.98	19.6%	12
6	1.0	0.83	0.83%	1.0	0.82	8.2%	1.0	0.90	18.0%	15
7	1.0	0.83	0.83%	1.0	0.94	9.4%	1.0	0.95	19.0%	19
8	1.0	0.83	0.83%	1.0	0.78	8.7%	1.0	0.95	19.0%	12
Means	1.0	0.872	0.872%	1.0	0.909	9.09%	1.0	0.933	18.67%	13

* False alarm = 1 - correct acceptances

** Misses = 1 - hits

*** Value is probability of each decision

TABLE 16

Mean Values for Machine Paced*

Angular velocity	Subject	Correct acceptances**	Hits***	Rejection rate	Borg scale rating
10 °/sec	1	1.0****	0.977****	10.10%	9.0
	2	1.0	1.0	10.33%	7.0
	3	1.0	1.0	10.33%	9.0
	4	0.987	1.0	11.65%	9.0
	5	1.0	1.0	10.33%	6.0
	6	1.0	1.0	10.33%	9.0
	7	1.0	1.0	10.33%	9.0
	8	1.0	1.0	10.33%	6.0
20°/sec	1	1.0	1.0	10.33%	9.0
	2	1.0	0.993	10.20%	9.0
	3	1.0	0.877	10.09%	11.0
	4	1.0	0.993	10.20%	11.0
	5	1.0	1.0	10.33%	11.0
	6	1.0	0.977	10.10%	9.0
	7	1.0	0.987	10.20%	7.0
	8	1.0	0.987	10.20%	11.0
30 °/sec	1	1.0	0.977	9.967%	10.0
	2	1.0	1.0	10.333%	9.0
	3	1.0	0.903	10.083%	9.0
	4	1.0	0.957	9.700%	11.0
	5	0.99	0.977	10.863%	13.0
	6	1.0	0.863	9.517%	11.0
	7	1.0	0.853	9.317%	12.0
	8	1.0	0.970	9.900%	11.0
40 °/sec	1	1.0	0.980	10.067%	13.0
	2	1.0	0.920	10.010%	11.0
	3	1.0	0.930	10.010%	12.0
	4	1.0	0.870	8.233%	10.0
	5	1.0	0.900	9.776%	12.0
	6	1.0	0.850	9.010%	15.0
	7	1.0	0.907	9.743%	19.0
	8	1.0	0.883	9.510%	12.0

* Average over percent lot defective

** False alarms = 1 - correct acceptances

*** Misses = 1 - hits

**** Value is probability of each decision

TABLE 17

Data for Self-Paced

Subject number	% of lot defective / angular velocity	1%			10%			20%			Borg scale rating
		correct* acceptances	hits**	rejection rate	correct acceptances	hits	rejection rate	correct acceptances	hits	rejection rate	
1	19.0	1.0***	1.0***	1.0%	1.0	1.0	10.0%	1.0	1.0	20.0%	11
2	23.0	1.0	0.75	0.75%	1.0	0.80	8.0%	1.0	0.91	18.2%	12
3	29.0	1.0	0.75	0.75%	1.0	0.77	7.7%	1.0	0.92	18.4%	11
4	21.0	1.0	1.0	1.0%	1.0	1.0	10.0%	1.0	0.94	18.8%	9
5	20.0	1.0	1.0	1.0%	1.0	0.94	9.4%	1.0	1.0	20.0%	6
6	20.5	1.0	1.0	1.0%	1.0	1.0	10.0%	1.0	1.0	20.0%	11
7	20.5	1.0	0.75	0.75%	1.0	0.89	8.9%	1.0	0.93	18.6%	11
8	26.5	1.0	0.75	0.75%	1.0	0.92	9.2%	1.0	0.97	19.4%	10
Means	23.0	1.0	0.875	0.875%	1.0	0.915	9.15%	1.0	0.959	19.2%	10.12

* False alarms = 1 - correct acceptances

** Misses = 1 - hits

*** Value is probability of each decision

TABLE 18

Mean Values for Self-Paced*

Subject	Angular velocity	Correct acceptances**	Hits***	Rejection rate	Borg scale rating
1	19.0	1.0***	1.000***	10.33%	11.0
2	23.0	1.0	0.820	8.98%	12.0
3	29.0	1.0	0.813	8.95%	11.0
4	21.0	1.0	0.980	9.93%	9.0
5	20.0	1.0	0.980	10.13%	6.0
6	20.0	1.0	1.000	10.33%	11.0
7	25.0	1.0	0.857	9.42%	11.0
8	26.5	1.0	0.880	9.78%	10.0
Means	23.0	1.0	0.916	9.73%	10.125

*Averaged over percent lot defective

** False alarms = 1 - correct acceptance

*** Misses = 1 - hits

**** Value is probability of each decision for 10 ^{o}/sec, 20 ^{o}/sec, 30 ^{o}/sec, 40 ^{o}/sec and self-paced were 8.0, 9.75, 10.75,13.0 and 10.12, respectively.

The first hypothesis in this research was that the greater the percenttage of defectives, the better the performance. To evaluate this an analysis of variance with percentage of defectives as a variate was performed for each of the dependent variables. The second hypothesis was that at lower speeds there would be relatively better performance for the low percentage of defectives. To evaluate this an analysis of variance with interaction between angular velocity and percentage of lot defectives as a variate was performed for each of the dependent variables.(the same table as first hypothesis). The third hypothesis was the self-paced inspection situation is similar to the optimum paced velocity. To evaluate this an analysis of variance with machine-pacing versus self-pacing as a treatment was performed for each of the dependent variables.

Machine Paced

The analysis of variance model was $X_{ijk} = U + V_i + P_j + V_iP_j + S_k(V_i) + E_{ijk}$ where X is the observation, U is the overall mean, V is the effect of the angular velocity, P is the effect of percentage of lot defective, S(V) is the effect of subject within the angular velocity, VP is the effect of interaction between angular velocity and percentage of lot defectives, E is the error term. Angular velocity and percentage of lot defectives are fixed variables.

Correct acceptances (and false alarms). The analysis of variance (Table 19) shows that there are no significant differences in correct acceptances (and false alarms) among angular velocities and percentages of lot defectives.

TABLE 19

Analysis of Variance for Correct Acceptnaces or False Alarms

Source of Variation	DF	Mean square	F value	Alpha hat
Velocity	3	0.0000177	1.06	0.3732
Defect rate	2	0.0000166	1.00	0.3744
Velocity X Defect rate	6	0.0000167	1.00	0.4346
Subject (Velocity)	28	0.0000260	1.56	0.0778
Error	56	0.0000167		
Total	95			

The overall mean correct acceptances at 10 ^{o}/sec, 20 ^{o}/sec,30 ^{o}/sec and 40 ^{o}/sec were o.998, 1.0, 0.999 and 1.0, respectively. The overall mean correct acceptances at different percentage of lot defectives 1%, 10%, 20% were o.998, 0.999 and 0.999, respectively.

Hits (and misses). The analysis of variance (Table 20) shows that there are significant differences in hits (and misses) due to angular velocity and percentage of lot defective.

Hits (and misses) for angular velocities (see Figure 10) were significantly different. Hits (and misses) for percentage of lot defectives (see Figure 11) were also significantly different. Individual comparisons at different angular velocities (see Tables 21,22,23 and 24) show that there are no significant differences among hits (and misses) for particular speeds.

Comparisons at different angular velocities (see Figure 12,13,14 and 15) show that hits decreased (and misses increased) slightly between a defect rate of 20% and 1%, except that 10 degrees per second shows no difference. It is seen that there is a higher percentage of hits (or lower percentage of misses) when the percentage of lot defectives is higher.

Rejection rates. The analysis of variance (Table 25) shows that there are significant differences in rejection rates among angular velocities and percentages of lot defective. Rejection rates for angular velocities(see Figure 16) were different. Rejection rates for percentage of lot defectives (see Figure 17) were also different. Individual comparisons at different angular velocities (see Table 26,27,28 and 29) were also significant. For these data the lower the angular velocity, the higher the rejection rates. They also show that the greater the percentage of lot defectives,

TABLE 20

Analysis of Variance for Hits (and Misses)

Source of variation	DF	Mean square	F value	Alpha hat
Velocity	3	0.040345	10.77**	0.0001
Defect rate	2	0.011178	2.98*	0.0587
Velocity X Defect rate	6	0.001752	0.47	0.8293
Subject (Velocity)	28	0.004896	1.33	0.1947
Error	56	0.003745		
Total	95			

* significant at 10% level

** significant at 5% level

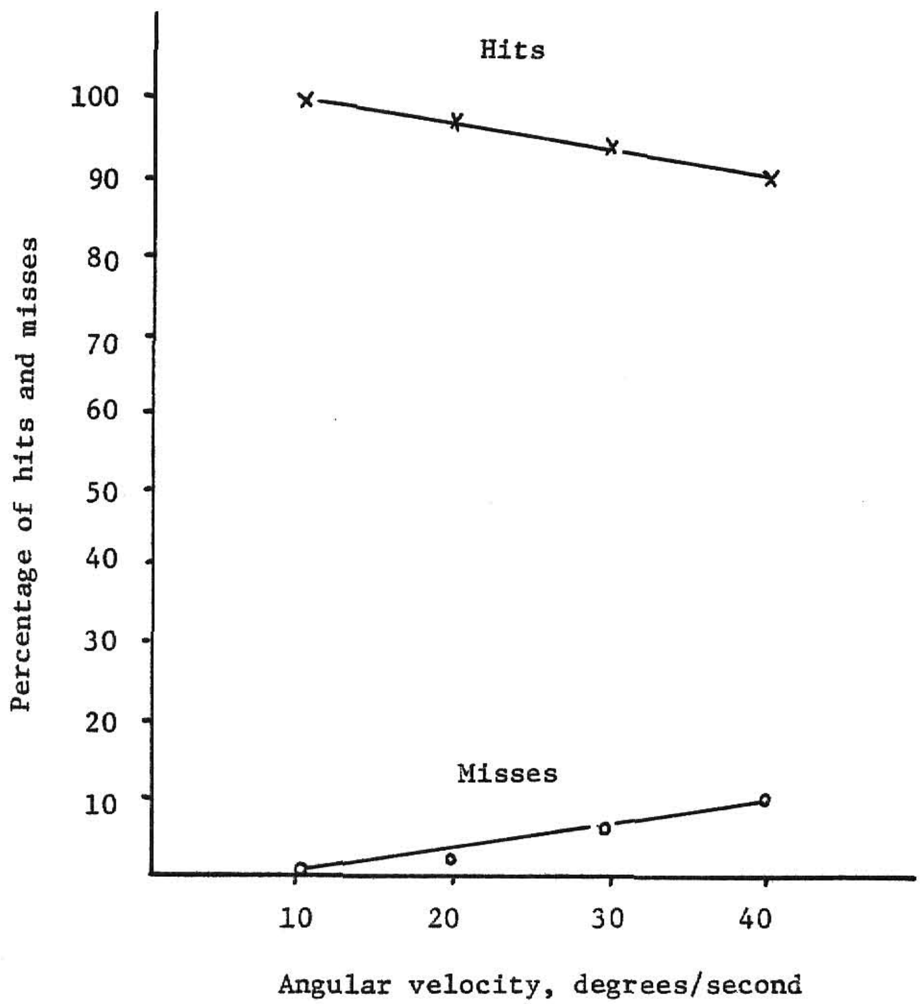


Figure 10. <u>Mean value for hits (and misses) across angular velocity level.</u>

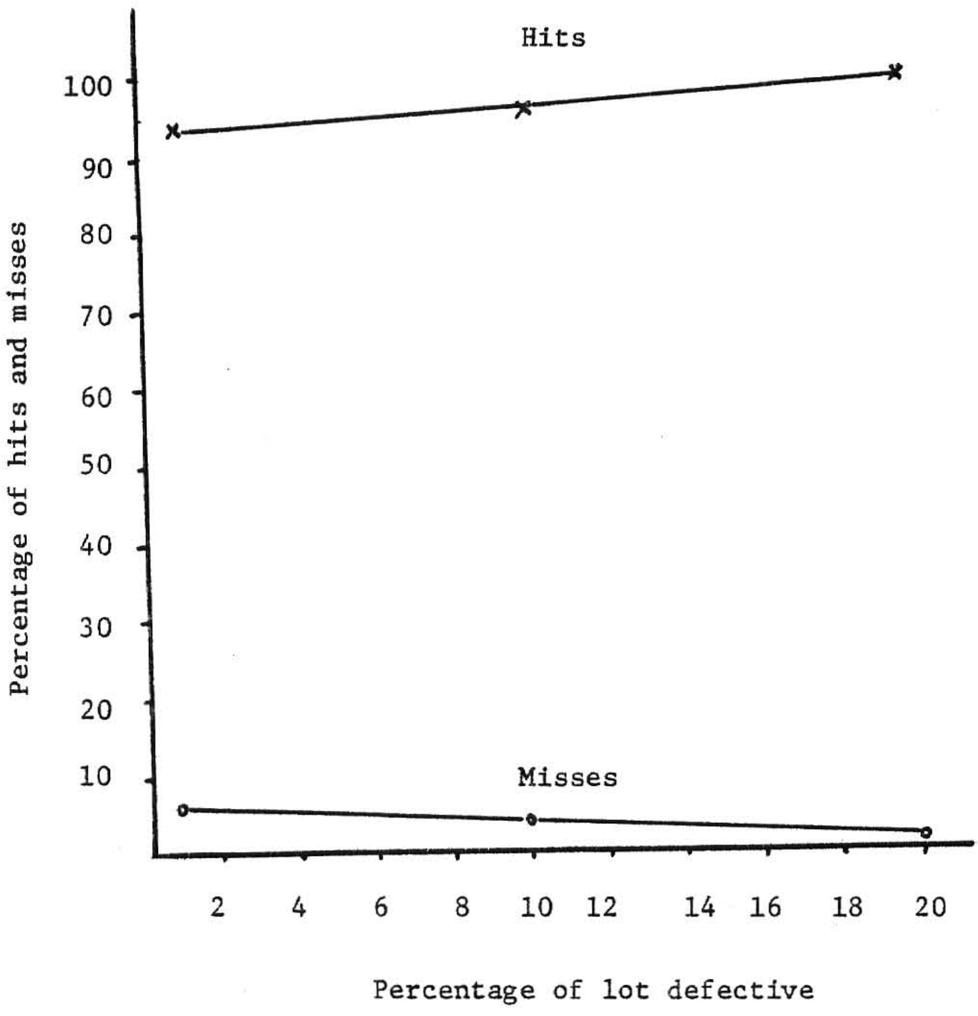


Figure 11. Mean value for hits (and misses) across percentage of lot defective.

TABLE 21

Analysis of Variance for Hits (and misses) at Angular Velocity -10°/sec

Source of variation	DF	Mean square	F value	Alpha hat
Defect rate	2	0.0002041	1.0	0.3847
Error	21	0.0002041		
Total	23			

TABLE 22

Analysis of Variance for Hits (and Misses) at Angular Velocity-20 °/sec

Source of variation	DF	Mean square	F value	Alpha hat
Defect rate	2	0.002629	0.55	0.5871
Error	21	0.004813		
Total	23			

TABLE 23

Analysis of Variance for Hits (and Misses) at Angular Velocity- 30 °/sec

Source of variation	DF	Mean square	F value	Alpha hat
Defect rate	2	0.006012	0.96	0.4004
Error	21	0.006287		
Total	23			

TABLE 24

Analysis of Variance for Hits (and Misses) at Angular Velocity- 40 ^{o}/sec

Source of variation	DF	Mean square	F value	Alpha hat
Defect rate	2	0.007587	1.46	0.2557
Error	21	0.005210		
Total	23			

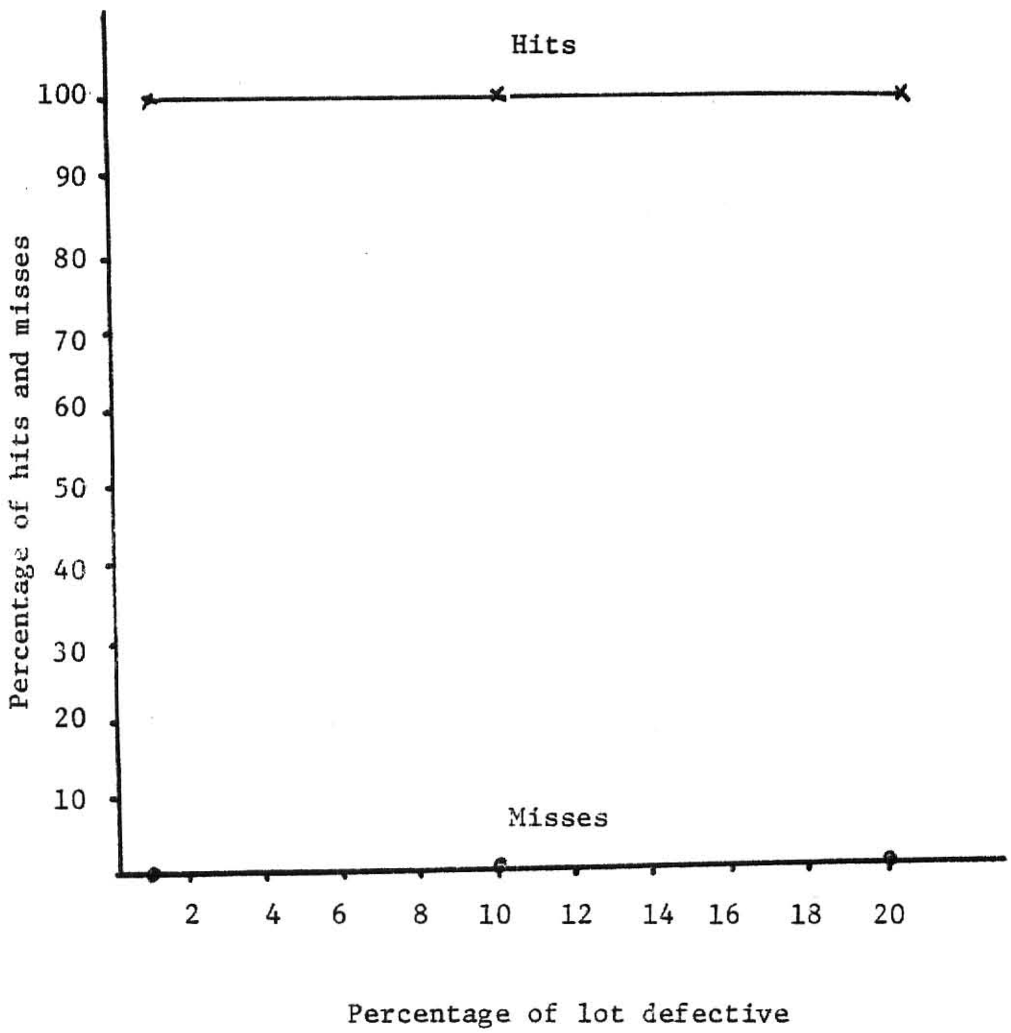


Figure 12. <u>Mean value for hits (and misses) at angular velocity- 10 °/sec.</u>

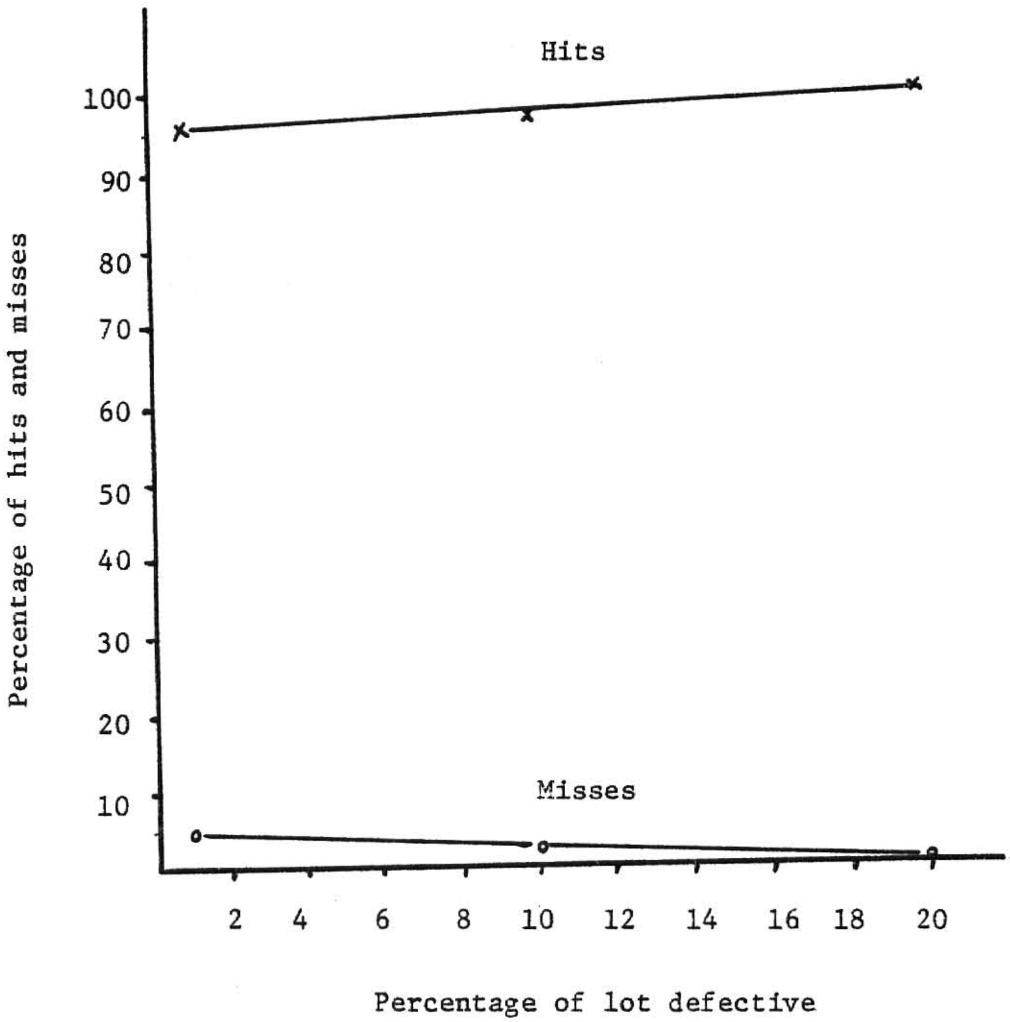


Figure 13. Mean value for hits (and misses) at angular velocity- 20 °/sec.

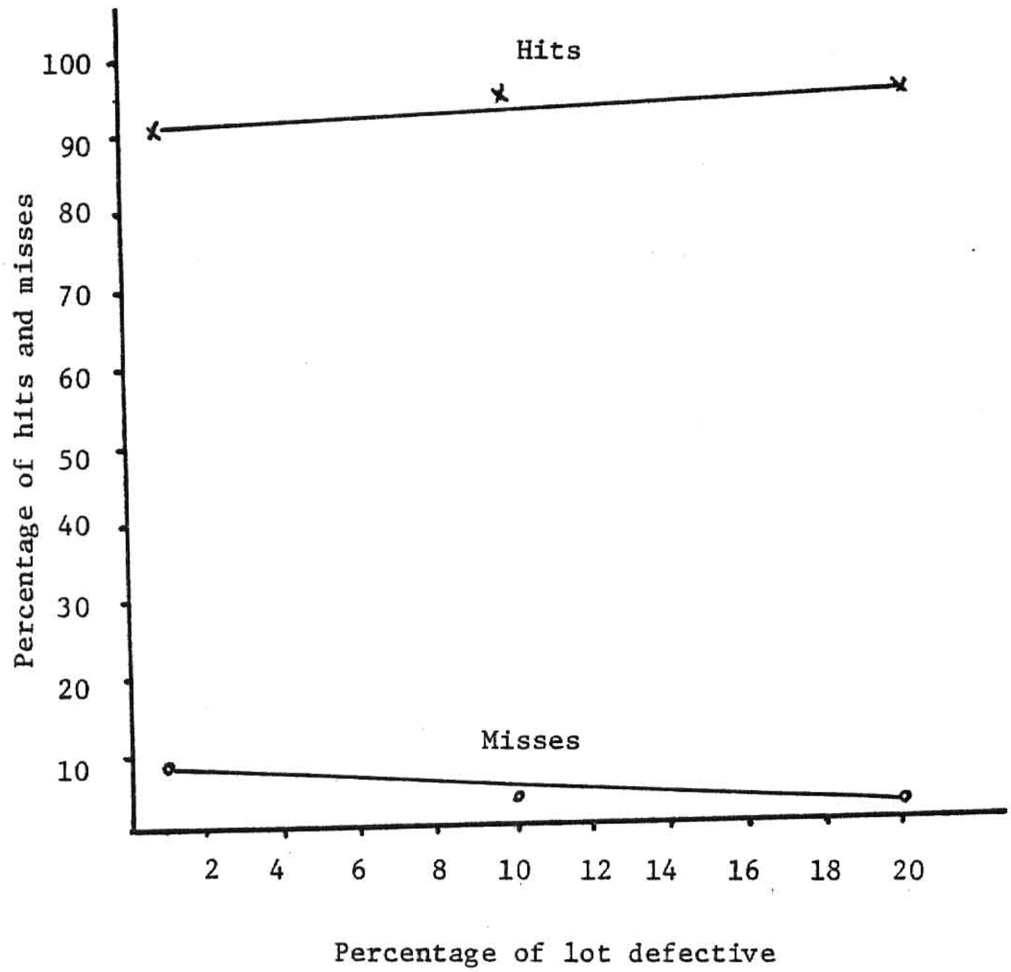


Figure 14. Mean value for hits (and misses) at angular velocity- 30 °/sec.

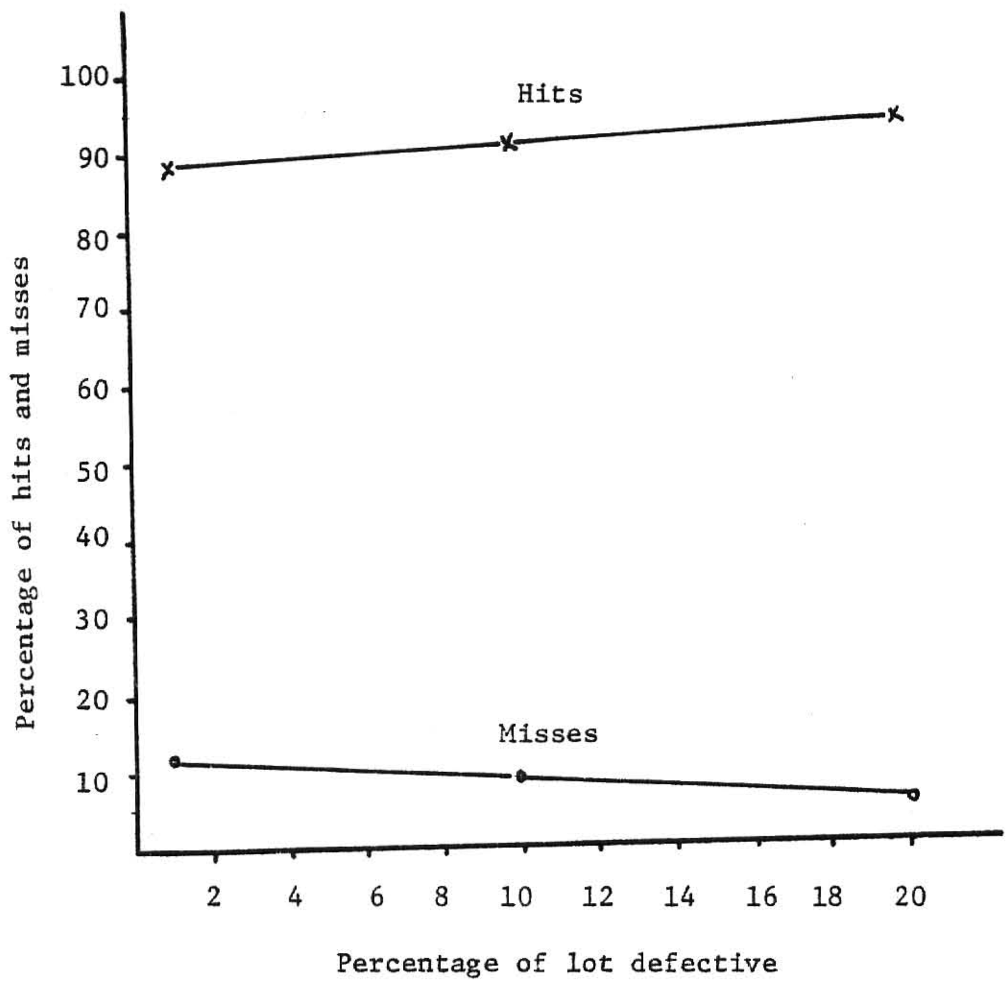


Figure 15. Mean value for hits (and misses) at angular velocity- 40 ^{o}/sec.

TABLE 25

Analysis of Variance for Rejection Rate

Source of variation	DF	Mean square	F value	Alpha hat
Velocity	3	3.7073	9.77***	0.0001
Defect rate	2	2703.7903	7122.31***	0.0001
Velocity X Defect rate	6	0.4983	1.31	0.2667
Subject (Velocity)	28	0.6604	1.74**	0.0392
Error	56	0.3796		
Total	95			

** significant at 5% level

*** significant at 0.1% level

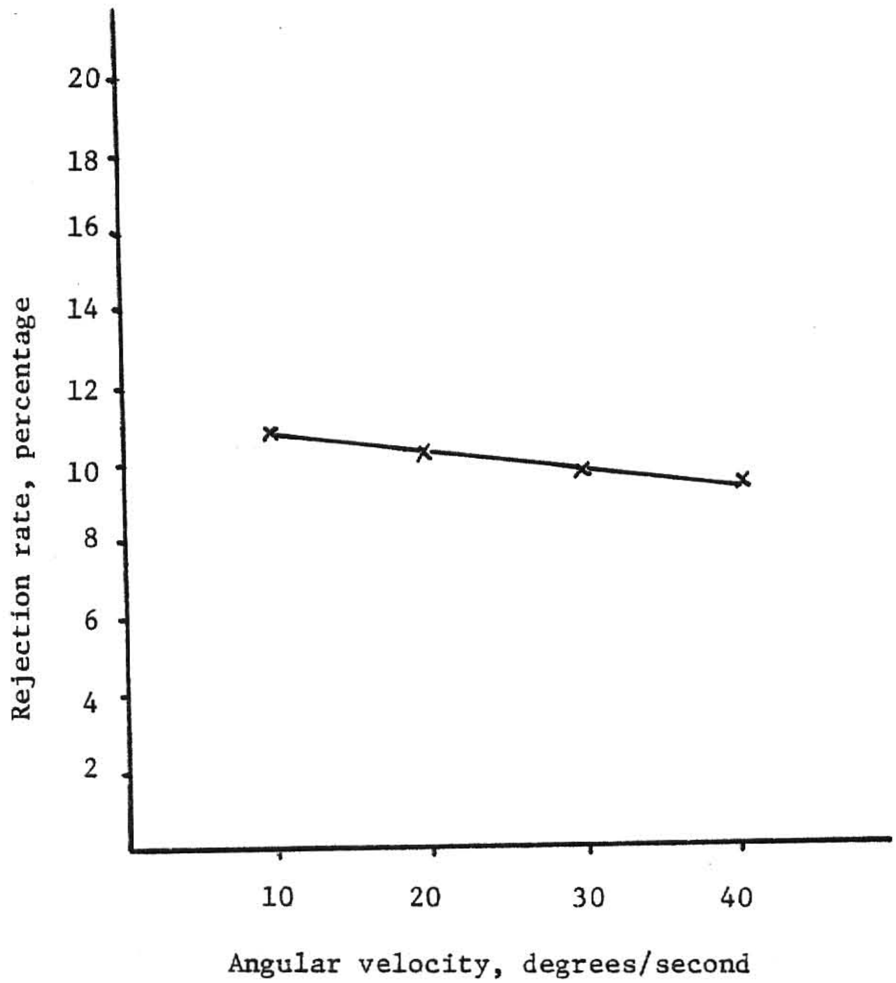


Figure 16. Mean value for rejection rate across angular velocity.

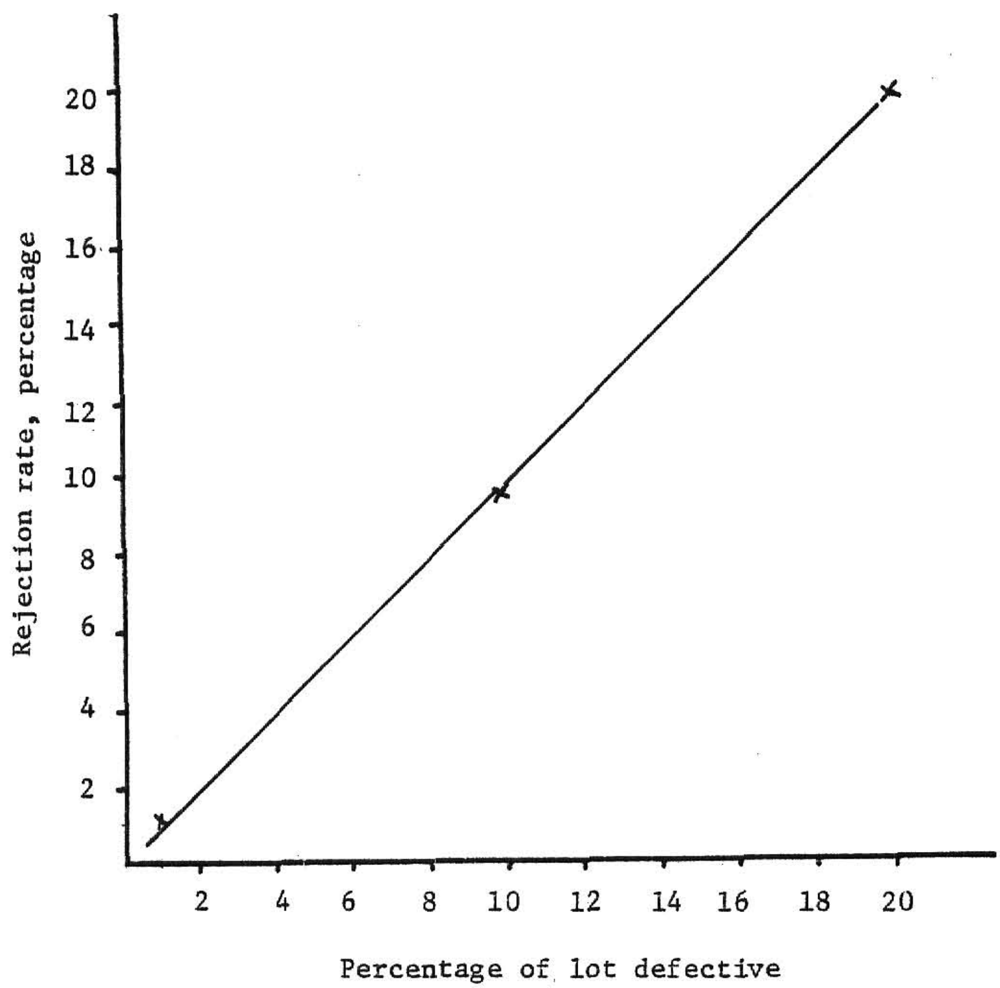


Figure 17. Mean value for rejection rate across percentage of lot defective.

TABLE 26

Analysis of Variance for Rejection Rate at Angular Velocity- 10 °/sec

Source of variation	DF	Mean square	F value	Alpha hat
Defect rate	2	686.7293	1019.16***	0.0001
Error	21	0.6738		
Total	23			

*** significant at 0.1% level

TABLE 27

Analysis of Variance for Rejection Rate at Angular Velocity- 20 ^{o}/sec

Source of variation	DF	Mean square	F value	Alpha hat
Defect rate	2	718.7278	17673.0***	0.0001
Error	21	0.0407		
Total	23			

*** significant at 0.1% level

TABLE 28

Analysis of Variance for Rejection Rate at Angular Velocity - 30° /sec

Source of variation	DF	Mean square	F value	Alpha hat
Defect rate	2	664.7144	2288.0***	0.0001
Error	21	0.2905		
Total	23			

*** significant at 0.1 % level

TABLE 29

Analysis of Variance for Rejection Rate at Angular Velocity- 40 ^{o}/sec

Source of variation	DF	Mean square	F value	Alpha hat
Defect rate	2	635.1138	715.25***	0.0001
Error	21	0.8879		
Total	23			

***significant at 0.1% level

the greater the rejection rate.

Borg scale ratings. The analysis of Borg scale ratings shows that the difference in angular velocity is statistically significant as shown in Table 30. The Borg scale ratings for angular velocities (see Figure 18) indicated significant differences. These results indicate that the lower the angular velocity, the easier the subject rated the task, the higher the angular velocity, the harder the task, according to the subject.

In summary for the machine paced situation, there are no significant differences in correct acceptances (and false alarms) over angular velocity and percentage of lot defective. But there are significant differences in hits (and misses) and rejection rates among angular velocity and percentage of lot defectives. There are also significant differences in Borg scale ratings for angular velocity. The tests show no significant interaction effects between angular velocity and percentage of lot defective.

Self-Paced

The analysis of variance model for the self-paced condition was $X_{ijk} = U + V_i + P_j + E_{ijk}$ where X is the observation, U is the overall mean, V is the effect of the angular velocity, P is the effect of the percentage of lot defective, E is the error term. The angular velocity is a random variable and the defect rate is fixed. Therefore this is a mixed model.

Eight subjects in the self-paced situation operated at intervals between 19 ^{o}/sec and 29 ^{o}/sec.

Correct acceptances (and false alarms). The correct acceptances (and flase alarms) are the same for all eight subjects, so there are no significant differce. The responses are hundred percent correct for all subjects.

TABLE 30

Analysis of Variance for Borg Scale Rating Tests of Hypothesis Using the Mean Square for Subject (Velocity) as an Error Term

Source of variation	DF	Mean square	F value	Alpha hat
Velocity	3	104.50	9.85***	0.0001
Subject (Velocity)	28	10.61		

***significant at 0.1% level

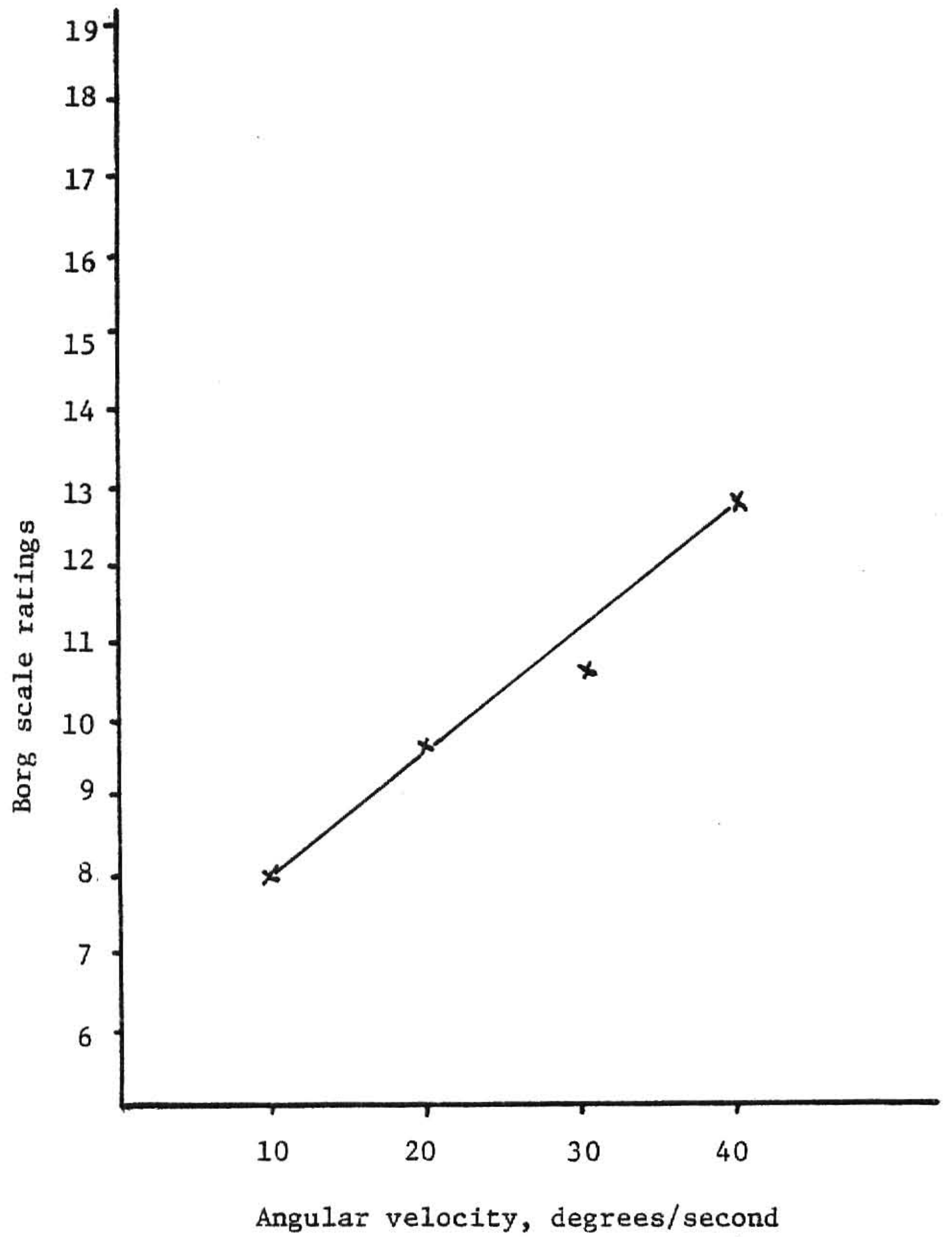


Figure 18. Mean value for Borg scale rating across angular velocity.

Hits (and misses). The analysis of variance (Table 31) shows that there is a significant difference in hits (and misses) among subjects and percentages of lot defective. The overall mean hits (and misses) at each percentage of lot defective level (see Figure 19) indicated that hits (and misses) were a linear function of the percentage of lot defective over the range studied.

Rejection rates. The analysis of variance (Table 32) shows that there is a significant difference in rejection rates for difference in angular velocity and percentage of lot defective. The overall mean rejection rates at each percentage of lot defective level (see Figure 20) indicated that rejection rate was a linear function of percentage of lot defective over the range studied.

Machine Paced Versus Self Paced

The analysis of variance model for comparing machine paced versus self paced was $X_{ijk} = U + T_i + P_j + T_iP_j + S_k(T_i) + E_{ijk}$ where X is the observations, U is the overall mean, T is the effect of the treatment (type of pacing), P is the effect of percentage of lot defective, TP is the effect of interaction between treatment and percentage of lot defectives. E is the error term. Treatment and percentage of lot defective are fixed variables.

Correct acceptances (and false alarms). The analysis of variance shows that there are no significant differences in correct acceptances (and false alarms) among treatment and percentage of lot defectives as shown in Table 33.

Hits (and misses). The analysis of variance shows that there are significant differences in hits (and misses) responses among treatment and percentage of lot defective as shown in Table 34. In Duncan's multiple

TABLE 31

Analysis of Variance of Hits (and Misses) at Self-Paced

Source of variation	DF	Mean square	F value	Alpha hat
Velocity	7	0.0201	5.42**	0.0036
Defect rate	2	0.0140	3.78**	0.0484
Error	14	0.0370		
Total	23			

** significant at 5% level

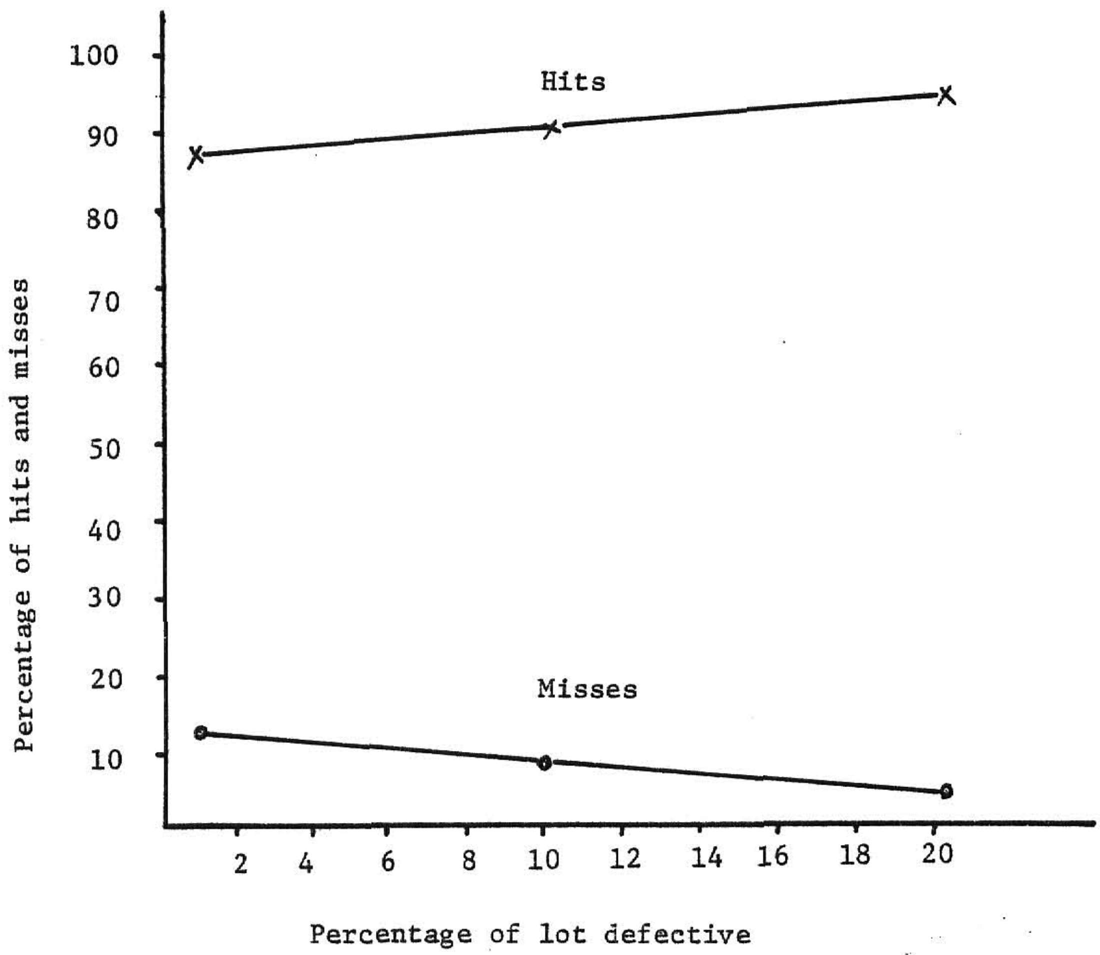


Figure 19. Mean value for hits (and misses) in self-paced.

TABLE 32

Analysis of Variance for Rejection Rate at Self-Paced

Source of variation	DF	Mean square	F value	Alpha hat
Velocity	7	0.9424	3.92**	0.0142
Defect rate	2	671.8216	2796.48***	0.0001
Error	14	0.2402		
Total	23			

** significant at 5% level

***significant at 0.1% level

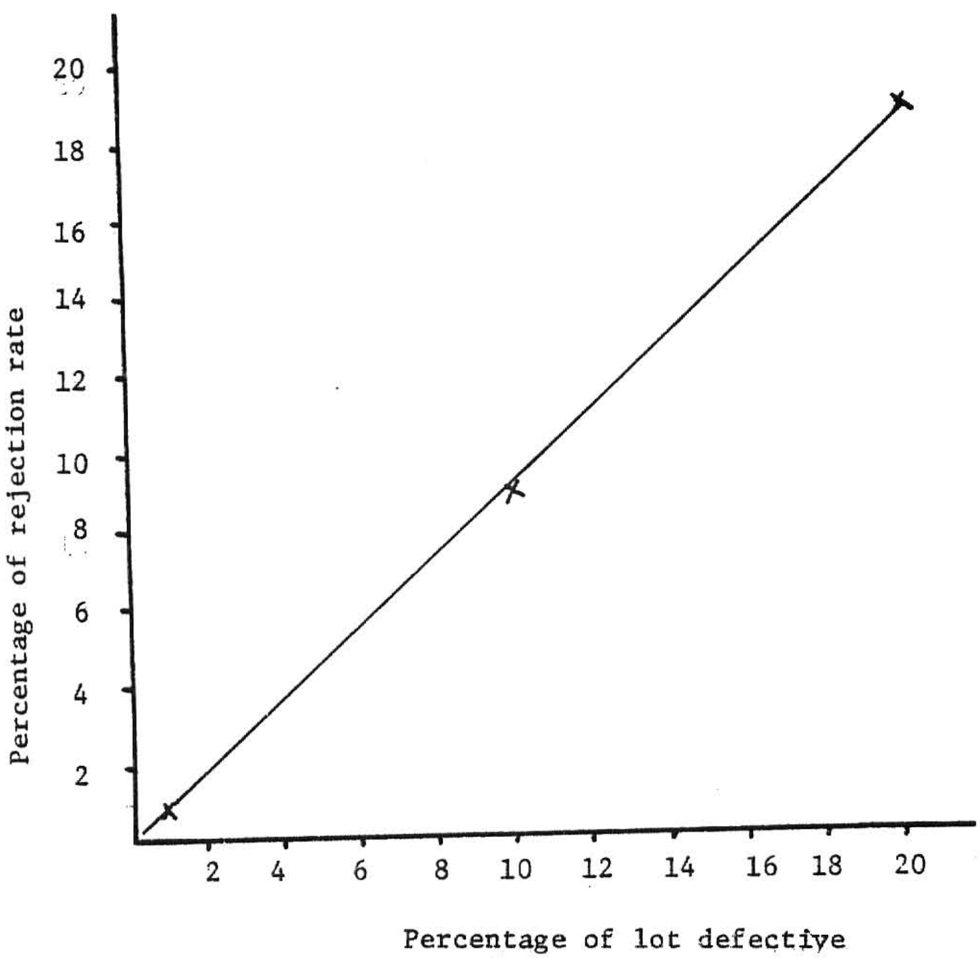


Figure 20. Mean value for rejection rate in self-paced.

TABLE 33

Analysis of Variance for Correct Acceptance (and False Alarm) at Machine Paced Versus Self-Paced

Source of variation	DF	Mean square	F value	Alpha hat
Treatment	4	0.0000158	1.19	0.3239
Defect rate	2	0.0000133	1.00	0.3731
Treatment X Defect rate	8	0.0000133	1.00	0.4440
Subject (Treatment)	35	0.0000208	1.56	0.0568
Error	70	0.0000133		
Total	119			

TABLE 34

Analysis of Variance for Hits (and Misses) at Machine Paced Versus Self-Paced

Source of variation	DF	Mean square	F value	Alpha hat
Treatment	4	0.03712	9.93***	0.0001
Defect rate	2	0.02169	5.80**	0.0047
Treatment X Defect rate	8	0.00219	0.59	0.7850
Subject (Treatment)	35	0.00793	2.12**	0.0038
Error	70	0.00374		
Total	119			

** significant at 5% level

*** significant at 0.1% level

range test there are three groups as shown in Table 35.

Rejection rates. The analysis of variance shows that there is a significant difference in rejection rates response among treatment and percentage of lot defective as shown in Table 36. In Duncan's multiple range test there are three groups and some of them overlap as shown in Table 37.

Borg scale ratings. The range of speed (from 19 degrees per second to 29 degrees per second) was selected by subjects in a self-paced situation. The subjects rated the task between very very easy (7) and fairly easy (11). The Duncan's multipler range test shows that there are three groups and just one overlap as shown in Table 38.

TABLE 35

Duncan's Multipler Range Test for Hits

Grouping*	Mean	Treatment
A	0.99708	10 °/sec
A B	0.97667	20 °/sec
B C	0.93750	30 °/sec
C	0.91625	self-paced
C	0.90500	40 °/sec

* Means with the same letter are not significantly different

TABLE 36

Analysis of Variance for Rejection Rate at Machine Paced Versus Self-Paced

Source of variation	DF	Mean square	F value	Alpha hat
Treatment	4	3.2476	9.23***	0.0001
Defect rate	2	3375.5253	9596.49***	0.0001
Treatment X Defect rate	8	0.3954	1.12	0.3581
Subject (Treatment)	35	0.7168	2.04	0.0058
Total	119			

*** significant at 0.1% level

TABLE 37

Duncan's Multipler Range Test for Rejection Rates

Grouping*			Mean	Treatment
A			10.4691	10 °/sec
A	B		10.2070	20 °/sec
A	B	C	9.9600	30 °/sec
	B	C	9.7333	self-paced
		C	9.5450	40 °/sec

* Means with the same letter are not significant different

TABLE 38

Duncan's Multipler Range Test for Borg Scale Ratings

Grouping*		Mean	Treatment
A		13.00	40 °/sec
B		10.75	30 °/sec
B		10.12	self-paced
B	C	9.75	20 °/sec
	C	8.00	10 °/sec

* Means with the same letter are not significantly different

DISCUSSION

It was hypothesized that an inspector will have more correct acceptances, more defects detected and higher rejection rates when there is a higher percentage of lot defectives. The second hypothesis regarding velocity was that there would be an interaction between angular velocity and percentage of lot defectives. Specifically, it was expected that at a low speed, the low percentage of lot defectives will yield disproportionately better performance than at high speed. The third hypothesis was that the self-paced performance would correspond to the performance in the same range of machine paced velocities.

Effect of Percentage of Lot Defective on Performance

Correct acceptances (and false alarms). No significant differences in the mean correct acceptances (and false alarms) for the percentage of lot defective were observed. This study also found that all subjects performed perfectly on correct acceptances and did not err on false alarms. This study is inconsistent with Fox *et al* findings on both paced (35 degrees per second) and unpaced situations. Fox found that the results of false alarms varied widely for each subject. The reason that this was not observed in this study could be due to the fact that the task was rather simple. It was easy to distinguish the defective targets. Further research should be carried out with more complex task or industrial tasks.

Hits (and misses). The defects detected (hits) decreased slightly between a defect rate of 20% and 1% in this experiment (from 40 ^{o}/sec down to 20 ^{o}/sec). At 10 degrees per second ,there was no difference. This agrees with the second hypothesis that at low speed, the low percentage of defectives there will be disproportionately better performance. This also agrees with the first hypothesis that an inspector will have higher defects detected in a higher percentage of lot defectives.

Research (Harris, 1968; Fox et al, 1969) have found that hits decreased with reduced defect rate in the unpaced case. Fox found that hits were not affected by defect rate in the paced case. In Fox's experiment, the screws could not be fed on the belt at a constant rate since the quantity leaving the hopper depended on the weight in it. However, further research is required before conclusions can be made on the effect of percentage of lot defective in the paced case. Further research in also needed on a more complex task at a lower speed situation.

Rejection rates. Significant differences in the mean rejection rate for the percentage of lot defectives were observed. However, individual comparisons also found a significant difference at a different defect rate for machine paced and self-paced. This agrees with the first hypothesis that an inspector has a greater rejection rate with a greater percentage of lot defectives.

Research (Harris,1968; Fox et al,1969) have found that rejection rates increasing defect rates in an unpaced case. Dorris et al (1977) also found that the rejection rates increased with increased defect rates in a paced case(25 degrees per second).

Figures 17 and 18 show that rejection rate was a linear function of percentage of lot defective. In this study the rejection rate is mostly derived from defects detected (hits) term and little from false alarms term.

Borg scale ratings. In this study each subject inspected under a constant angular velocity although the velocity rates varied from each of five groups of eight subjects. (10 °/sec, 20 °/sec, 30 °/sec, 40 °/sec and self-paced). However, although the angular velocity remained unchanged for a given subject the defect rates varied (1%, 10%, 20%). Therefore, the Borg scale ratings do not consider the changes in defect rate only the differences in velocity. It would be of interest to do further research on how the Borg scale ratings are affected by defect rates higher than 50% or less than 1%.

Effect of Angular Velocity on Performance

Correct acceptances (and false alarms). No significant differences in the mean correct acceptance and false alarms for the machine paced situation were observed. Purswell et al (1972) found false alarms decreased with decreased angular velocity (from 32 °/sec down to 20 °/sec). The reason that this was not observed in this study could be due to the fact that the task was rather simple. It was easy to distinguish the defective targets. Further research should be carried out with more complex tasks and greater angular velocities.

Hits (and misses). Significant differences in the mean hits (and misses) for the machine paced were observed. The result of defects detected indicated that the rate of decrease in performance increased as the angular velocity increased. The result in hits is in agreement with Drury (1973) that when more time (lower angular velocity) is allowed to inspect each item, the probability of defects detected increased. He also found that to achieve the same performances for higher angular velocity (10 °/sec to

30 ^{o}/sec),more search time is needed.

This is in accordance with Purswell et al (1972) and Drury (1973) who found that the misses decreased with decreased angular velocity.

It also supports Ludvigh and Miller's findings. In their numerous studies they found that dynamic visual acuity was affected by angular velocities from 10 to 170 degrees per second. The differences they found for the range of values used in this experiment (10 to 40 degrees per second) were, however very small, except that at 40 degrees per second performance decreased. This indicated that the rate of decrease in performance increased as the angular velocity increased. Therefore, at lower speed there might have been very little change in performance. This agrees with the second hypothesis that at low speed, the low percentage of lot defectives will result in disproportionately better performance.

Rejection rates. Significant differences in the mean rejection rates for the machine paced situation were observed. The rejection rate decreased slightly as the angular velocity increased over the range studied. It is reasonable to expect the probability of hits to increase with low angular velocity.

Further research is required with more complex tasks and a wider range of angular velocities.

Borg scale ratings. For Borg scal ratings,subjects within angular velocities showed no significant differences, but the group's mean at different angular velocities indicated significant difference. This means that the subjects in lowest or highest angular velocity evaluated the task as very very easy or very hard.

Machine Paced Versus Self Paced

The hypothesis was that the self-paced inspection situation is similar to the optimum paced velocities. This means that the self-paced performance should correspond to the performance in the same range of machine paced velocities.

Correct acceptances (and false alarms). No significant differences in the mean correct acceptances (and false alarms) for machine paced and self-paced situations were observed. The result in correct acceptances is in agreement with McFarling and Heimstra (1975) that correct acceptances were maintained at a high rate for machine paced and self-paced. In their studies of machine paced condition, the subject was automatically presented a printed circuit for inspection every 14 seconds. In the self-paced condition, circuit presentation rate was inspector controlled.

This study is inconsistent with the findings of Williges et al (1971) in false alarms. They found that there were fewer false alarms in the self-paced case. In their studies of the machine paced condition, the subject was presented 600 pin-hole discs in 20 seconds. In the self-paced condition, pin-hole discs presentation rate was inspector controlled. The results of this study are inconsistent with the findings of Williges. This could be due to many reasons. The subjects in Williges' study did not complete the inspection of all 600 items within the alloted 20 seconds per trial with self pacing. The other possibility is that this task was rather simple and it was easy to distinguish the defective targets. Further research should be carried out with more complex tasks or industrial tasks.

Hits (and misses). Significant differences in the mean hits (and misses) for machine pacing and self pacing were observed. Duncan's multiple range test shows no significant difference in performance for 20 ^{o}/sec and 30 ^{o}/sec or 30 ^{o}/sec, self-paced and 40 ^{o}/sec. The self-paced performance does not correspond to the performance in the same range of machine paced velocities (from 20 ^{o}/sec to 30 ^{o}/sec).

All subjects indicated a slightly different selection (range from 19 ^{o}/sec to 30 ^{o}/sec) in the self-paced situation. Subjects 1, 3 and 8 selected speeds from slow to high to slow. Subjects 2, 4, 5, 6 and 7 selected speeds from slow with slight increases. It seens that most of the subjects preferred slow speed with slight increases.

Williges et al (1971) found that there were more defect detected (hits) with self pacing. McFarling et al (1975) also found that a self-paced inspection took more time than machine paced, but resulted in a higher level of hits.

The results are inconsistent with previous studies and hypothesis. This could be due to many reasons. The subjects many not have concentrated on the inspection, because they were concentrating on adjusting speed. The other possibility is that task time may have been too short. Since these two factors are present in this experiment it may be reasonable to expect that the self paced situation shows different results than the optimum paced velocity situation. Further research should be carried out with more task time and greater angular velocities. More detailed observation the behavior of the inspection during self paced situations should be made.

Borg scale ratings. Duncan's multiple range test shows no significant difference in performance for 20 °/sec, self-paced, 30 °/sec or 10 °/sec and 20 °/sec. This agrees with the hypothesis that the self-paced performance should correspond to the performance in the same range of machine-paced velocities (from 20 °/sec to 30 °/sec).

<u>Summary of Results</u>

It was observed in general that the rejection rate was a linear function of percentage of lot defective.

The defects detected decreased slightly between defect rate of 20% and 1% in machine-paced and self-paced.

The rate of decrease in performance increased as angular velocity increased. At lower speeds (less than 20 degrees per second) there have very little change in performance.

The number of correct acceptances was not significantly different and was maintained at a high result for both machine-paced and self-paced situations.

The Borg scale ratings indicate the lower the angular velocity, the easier the subject rated the task.

<u>Future Research</u>

Researchs interested in the relationship between percentage of lot defectives and number of false alarm or correct acceptance should pursue futher study in both machine-paced and self-paced situations.

Further research is needed to confirm the findings of this study about the effect of percentage of lot defective on defects detected in machine paced situations.There is also a need to confirm the findings of this study that rejection rate was a linear function of percentage of lot defective.

The factors of complex tasks and task time could be considered. Further research in these area will help develop more detailed information.

The most important factor is angular velocity between 20 °/sec and 30 °/sec. Further research in this range will help determine how to control angular velocity and thus find optimum values.

It is of interest to find the differences existing between machine paced and operator paced task situations. It is also of interest to find the different behavior of inspectors during the self-paced situation.

It is of intest to find the Borg scale ratings for higher or lower defect rates.

Practical Implications

An important finding of this study is that rejection rate was a linear function of defect rate. It was also found that hits increased with increasing defect rate. Those findings have implications for management of inspection operations. For example, as hits increase, supervisors should be prepared to counteract the effect by checking each process.

Another finding of this study is that the self-paced inspection situation is similar to the optimum paced velocities.

The implication of this study is that to improve visual inspection quality control, engineers need to consider both the engineering design of the display of items as well as the inspector's capabilities in order to produce the best quality assurance.

CONCLUSIONS

(1) Defects detected decreased with reduction in defect rate as in previous research.

(2) Rejection rate was a linear function of percentage of lot defective as in previous research.

(3) There is no interaction between the percentage of lot defective and angular velocity over the range studied.

(4) The correct acceptances were maintained at a high rate for both the machine-paced and the self-paced situations.

(5) The Borg scale ratings indicate that the lower the angular velocity, the easier the subject found the task.

(6) It was suggested that the factors like task complexity, task time, the type of pacing and greater angular velocities should be studied.

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VELOCITY, DEFECT RATE AND PACING STRATEGY IN SIMULATED INSPECTION

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ABSTRACT

This study investigated the effects of velocity, percentage of lot defective and pacing in an inspection task. Two types of pacing were used. They were : machine paced - 10 ^{o}/sec, 20 ^{o}/sec, 30 ^{o}/sec, 40 ^{o}/sec, and self-paced. Forty subjects were tested and eight subjects were randomly assigned only one condition of paced. The search parameters recorded were, correct acceptances (and false alarms), hits (and misses), rejection rate and Borg scale ratings. The rejection rate was a linear function of percentage of lot defective. There was no interaction between the percentage of lot defective and angular velocity over the range studied. The correct acceptances were maintained at a high rate for both the machine paced and the self-paced situations. The Borg scale rating indicate that the lower the angular velocity, the easier the subject found the task. It was also observed the subjects under the self-paced condition selected a low speed with slight increases. Implications for tasks involving inspection are discussed.