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DEFECT SIZE, ANGULAR VELOCITY, STATIC AND DYNAMIC DISPLAY AND INSPECTION PERFORMANCE

by

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INTRODUCTION

Inspection is necessary for maintaining of quality production in many manufacturing situations. The most common type of inspection task is that of visual scanning to detect items that do not meet a specified standard (Williges and Streeter, 1972). Often these inspection tasks require the human operator to scan a large number of items at a very rapid rate, for example, inspection for fruit or vegetable blemishes on a moving conveyor belt. Therefore, speed and accuracy become very important factors for determining the inspection performance.

During any task, an inspector can make two types of errors:

1) type I error (false alarm) - he/she may classify a good item as bad.

2) type II error (miss) - he/she may classify a bad item as good.

A probability matrix can be constructed for the inspection process as illustrated in Table 1, where

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

P_o = 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 rejection for a bad product ("hit", "defects detected").

In this research, the percentage of type I errors was defined as the number of type I errors divided by the number of good product units inspected. The percentage of type II errors was defined as the number of

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

TABLE 1

Definition of probability statements

	Inspector's Decision		
	Accept	Reject	Total
Good Product	$(1-P_1)\ Q_0$ Correct Acceptance	$Q_0(P_1)$ False Alarm	Q_0 Total Good
Bad Product	$P_2(P_0)$ Miss	$(1-P_2)\ P_0$ Hit	P_0 Total Bad
Total	$(1-P_1)Q_0+P_2P_0$ Total Acceptances	$Q_0P_1+P_0(1-P_2)$ Rejection Rate	1 Total

type II errors divided by the number of defective units inspected.

A variety of factors can influence inspection performance. These include:

1) Individual abilities: visual ability, sex, age, experience.
2) Physical environment: noise, temperature, illuminance level, glare and contrast.
3) The inspection task: static or dynamic display, conveyor belt velocity (angular velocity), defect size (visual angle), time to view, percent defect rate, etc.

This review discusses only briefly the individual abilities and physical environment and concentrates more extensively on the inspection task.

Individual Abilities

Visual ability. Inspectors for conveyor-paced inspection tasks are sometimes selected as the result of their performance on static visual acuity tests. However, Ludvigh and Miller (1958) showed that static visual acuity was a poor predictor of dynamic visual acuity. Nelson and Barany (1969), proposed a dynamic visual recognition test for paced inspection tasks. They were able to set up a test procedure which significantly increased the accuracy of predicting good inspectors over that attained by a static visual acuity test. These tests are adequate for predicting which people might make the best inspectors, but they are unsuitable for predicting inspector performance, given a specific task and work environment.

Sex. Waog (1973) and several other studies found that there were no significant differences at all between males and females on inspection tasks. McCann (1969), however found men superior to females.

Age. For high speed inspection, defect detection rate declined with increasing age. (Sheehan and Drury, 1969).

Experience. Harris (1964) concluded that the amount of relevant inspection experience was not positively related to inspection effectiveness.

Physical Environment

Temperature. The National Institute for Occupational Safety and Health (NIOSH), Criteria Document for Occupational Exposure to Hot Environment (1972) indicated the environmental temperature should not exceed 87° F on the Wet-Bulb-Globe Temperature Scale for unimpaired mental performance for 240 minutes exposure. This value could be the upper temperature limit in designing inspection tasks.

Noise. Occupational Safety and Health Administration (OSHA) has set a limit of 90 dBA for eight hours exposure, unless personal hearing protection is provided. A series of studies by Warner (1969) and Warner and Heimstra (1971, 1973) investigated the effects of various intermittent noise parameters on visual target detection performance. Results indicated that for any level of task difficulty, no differences in detection times were found below 90 dBA.

Illuminance. Harris and Chaney (1969) cited the recommended illumination level for different inspection tasks. (See Table 2). Faulkner and Murphy (1971) asserted that above a given point increases in illumination level do not increase either task performance or visual acuity.

Glare. Glare is defined as any brightness within the field of vision which causes discomfort or interference with vision disability. Direct glare refers to the effect of a light source within the visual field; reflected glare refers to the effect of surfaces which reflect lights coming from outside the visual field. Research has indicated that direct glare may be reduced by

a) avoiding bringing light sources to within 60 degrees of the center of the visual field,

TABLE 2

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

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

b) using shields, hoods, and visors to keep direct lights out of the viewer's eyes,

c) providing 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 that diffuse reflected lights,

b) using a diffused light source, and

c) positioning light sources and work so that light is not reflected toward the eye.

Contrast. 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) showed 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 luminance levels.

Inspection task

Static versus dynamic display. Burg (1966) found high intercorrelations between static and dynamic tests. These correlations decrease with increasing speed of target movement. Harris and Chaney (1969) concluded that in a scanning type inspection task, inspection accuracy is likely to be greater if the product is scanned while it is stationary rather than while it is moving. If it is necessary to conduct a scanning type inspection, the best method is to have the products move laterally past the inspector rather than toward him.

Rizzi, Buck and Anderson (1979) indicated that for dynamic visual inspection task, the inspector must:

1) identify the presence of an on-coming item,
2) gain visual acquisition of the item and commence visual tracking,
3) visually search the item during tracking,
4) compare the observed item attributes with specifications,
5) decide if the item adequately conforms to the specifications or not,
6) mentally act on that decision, and
7) physically act.

These elements are strictly sequential.

In order to decide whether to use static or dynamic display in a given industrial situation, several factors could be involved. Specially, the decision makers would have to consider the nature of the product and the degree of acceptable compromise between speed and accuracy of inspection.

Williges and Streeter (1972) found that inspectors developed a rapid scanning strategy when given only a brief orientation on dynamic displays, and this strategy transfered to static inspector-paced displays. Inspectors given orientation on static displays, however, did not seem to develop this strategy because they are never forced to scan rapidly. Therefore, dynamic display might be used as an inspector training aid to develop efficient, rapid scanning strategies. They also found that the static displays did result in fewer false alarm errors, but there were no differences overall between display modes in terms of defect detections.

<u>Conveyor belt speed (angular velocity)</u>. The proper working rate for an inspector is an important consideration for designing an industrial inspection system (Drury, 1973). The highest working speed, as often applied in industry, is not economical and has the risk of workers' overstrain

when this speed is maintained for a long time. On the other hand, too slow speeds also may have detrimental effects in the repetitive and monotonous nature of the work.

Research on visual tracking by Crawford (1960) and others showed that the eyes can move quickly to moving objects in a single saccade when the angular velocity is about 25 degrees per second to 30 degrees per second or less. 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 up to about 40 degrees per second.

Williams and Borow (1963) found that the rate of movement was unimportant provided that the angular velocity was less than about eight degrees per second at the eye. See Figure 1. They found that the performance began to fall off between eight and sixteen degrees per second angular velocity. Ludvigh and Miller (1958) studied the angular velocity from ten degrees per second to 170 degrees per second. They found that at 30 degrees per second there is little deterioration in the ability to detect small details. Their findings make it obvious that no study of dynamic visual acuity or dynamic inspections should ignore angular velocity as a factor.

Defect size (visual angle). Konz (1978) stated that visual acuity is affected by a number of factors of which contrast between the object and the background is the most important. Fortuin (1970) in Figure 2 plotted the threshold line of size versus contrast for luminance of 10 cd/m^2. Above the line an object is visible, but below the line it is invisible. The threshold

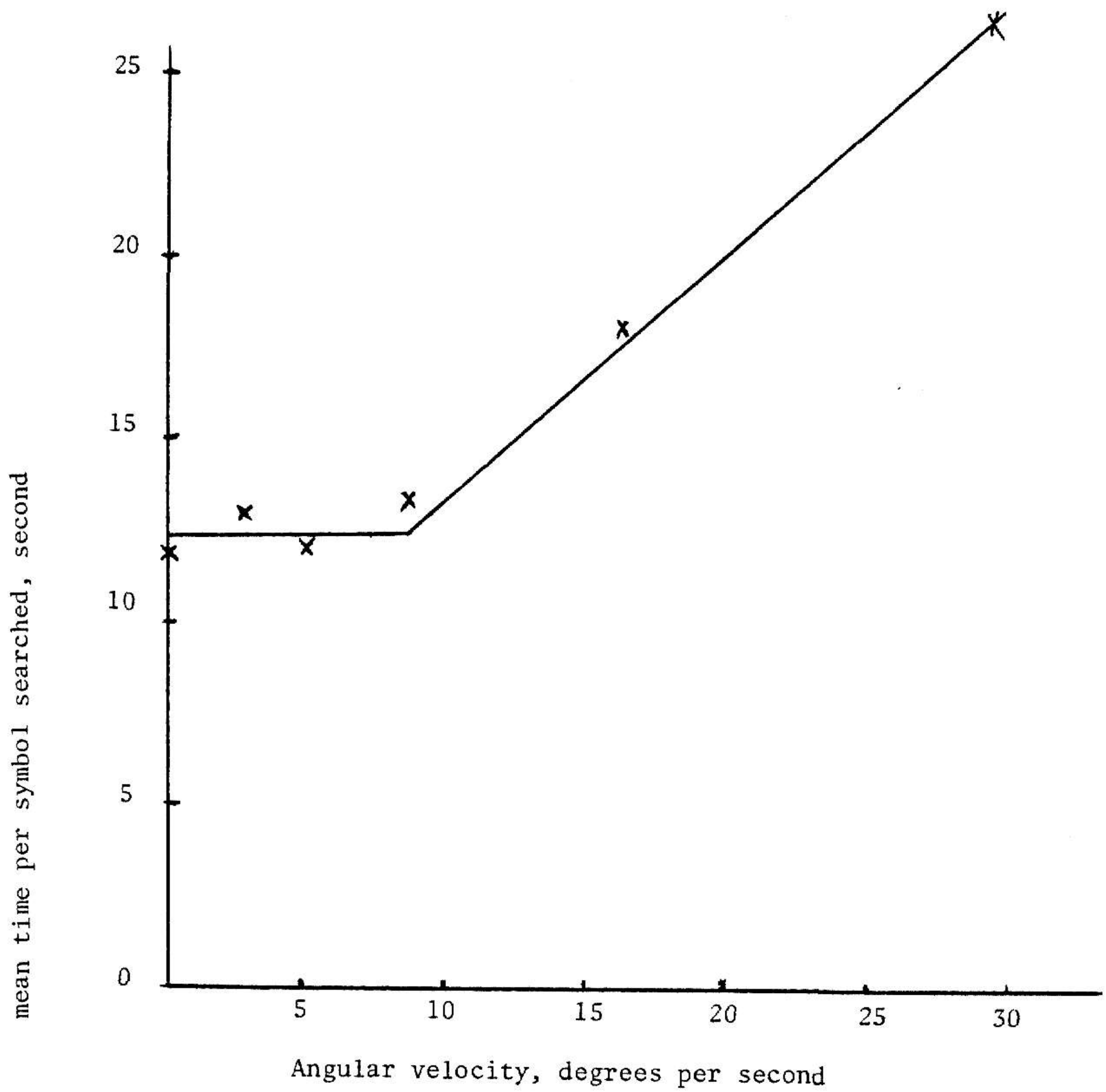

Figure 1 Effect of rate of movement (based on Williams and Borow (1963).

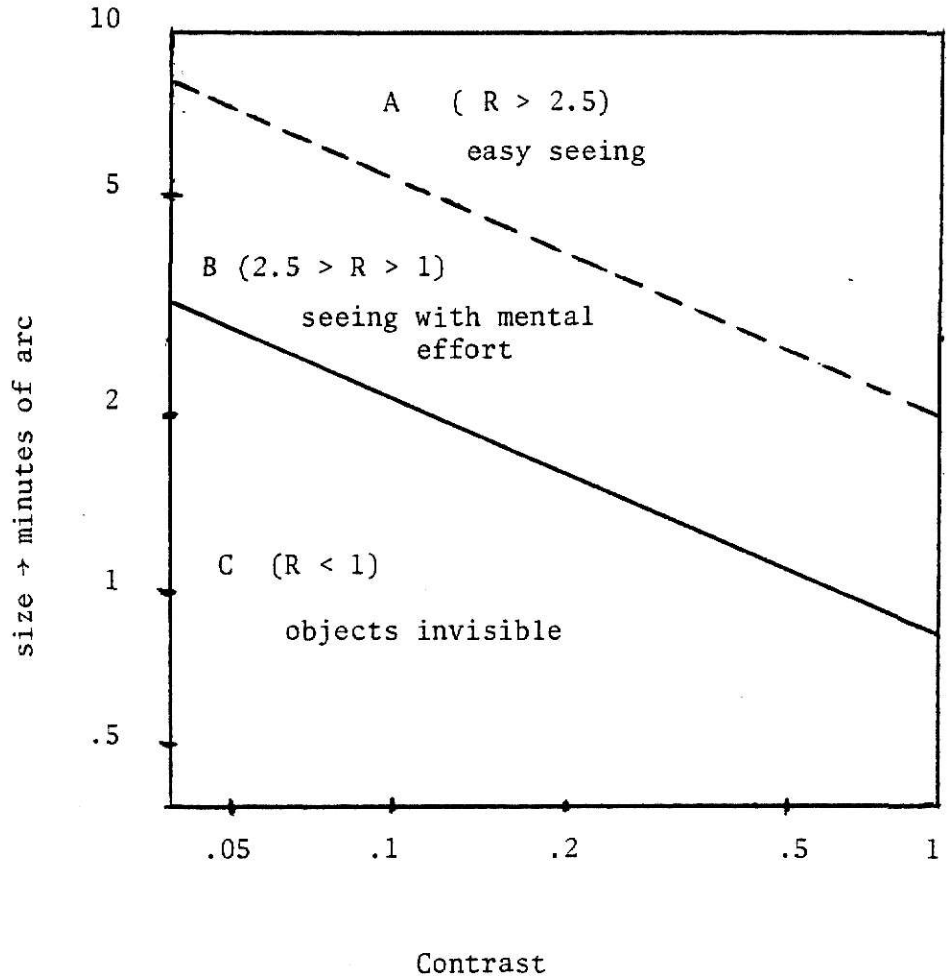

Figure 2. Threshold line vs size versus contrast for luminance of 10 cd/m^2.

line represents the line of maximum mental effort. Fortuin recommends a size at least 2.5 times threshold for easy seeing. Duncan and Konz (1976), using light-emitting-diodes and liquid crystal displays, confirmed that people do not like to use maximum mental effort. Subjects could read the displays with no errors at four to six minutes of arc but preferred 20 to 30 minutes of arc. Wei and Konz (1978) showed that inspection errors increased when the defect size became smaller. Smith and Adams (1971), using microscopes to study arrays of targets, reported time per correct inspection was minimal when the magnified image was eight to twelve minutes of arc. Steedman and Baker (1960) showed that changing the target size over a range from 12 to 100 minutes of arc produced little change in search behavior. However, when the maximum dimension of a target was less than 12 minutes of visual angle, errors and search times rose dramatically. They suggested that a minimum of 12 minutes of arc is required for target detection under ideal conditions and recommend that this value should be raised to 20 minutes of arc under operational conditions.

Time to view. Conrad (1955) indicated that the critical determinant of overall productivity was the time that the part was available to the inspectors. In general, inspection time is governed by the production cycle time so that the inspection time can only be varied by altering the number of inspectors. Blackwell (1952) found that there was a linear relationship between subject accuracy in a visual task and the logarithm of the time to view. Niven and Brown (1944) concluded that in the static case, time to view of less than 0.2 second caused a reduction in visual acuity.

A coin defects study by Fox (1964), a glass bottle inspection under different lighting conditions by Perry (1968), and an inspection of trays of bakery products by Sinclair (1971) all concluded that as more time is allowed to inspect each item, the probability of rejecting a faulty item increased while the probability of accepting a good item decreased. Figure 3 illustrates how the time available per item viewed affects fault detection (Sinclair, 1978).

Previous studies have indicated that visual acuity diminished with increasing angular velocity of the target and/or reduction in viewing time (Westheimer, 1954; Ludvigh and Miller, 1958; Burg, 1961 and Elkin, 1962).

Percent defect rate. Harris (1968) studied four different defect rates: .25%, 1%, 4% and 16%. Inspection was measured in terms of defect detections (hits) and false reports made. The percentage of defects detected decreased slightly between defect rates of 16% and one percent, but dropped sharply between one percent and .25%. False reports, the second indicator of inspection accuracy, increased at an accelerated rate as the defect rate approached zero. Figure 4 shows that the inspection accuracy decreased with reductions in defect rate. Smith and Barany (1969) predicted that both types of inspector error would increase as pace increased, that type I error would increase and type II error decrease as the percentage defective increased, and that each type of error would increase (decrease) as the cost associated with committing the type of error decreased (increased).

Fox and Haselgrave (1969) concluded that subjects showed no performance differences in terms of percent of defects detected at three

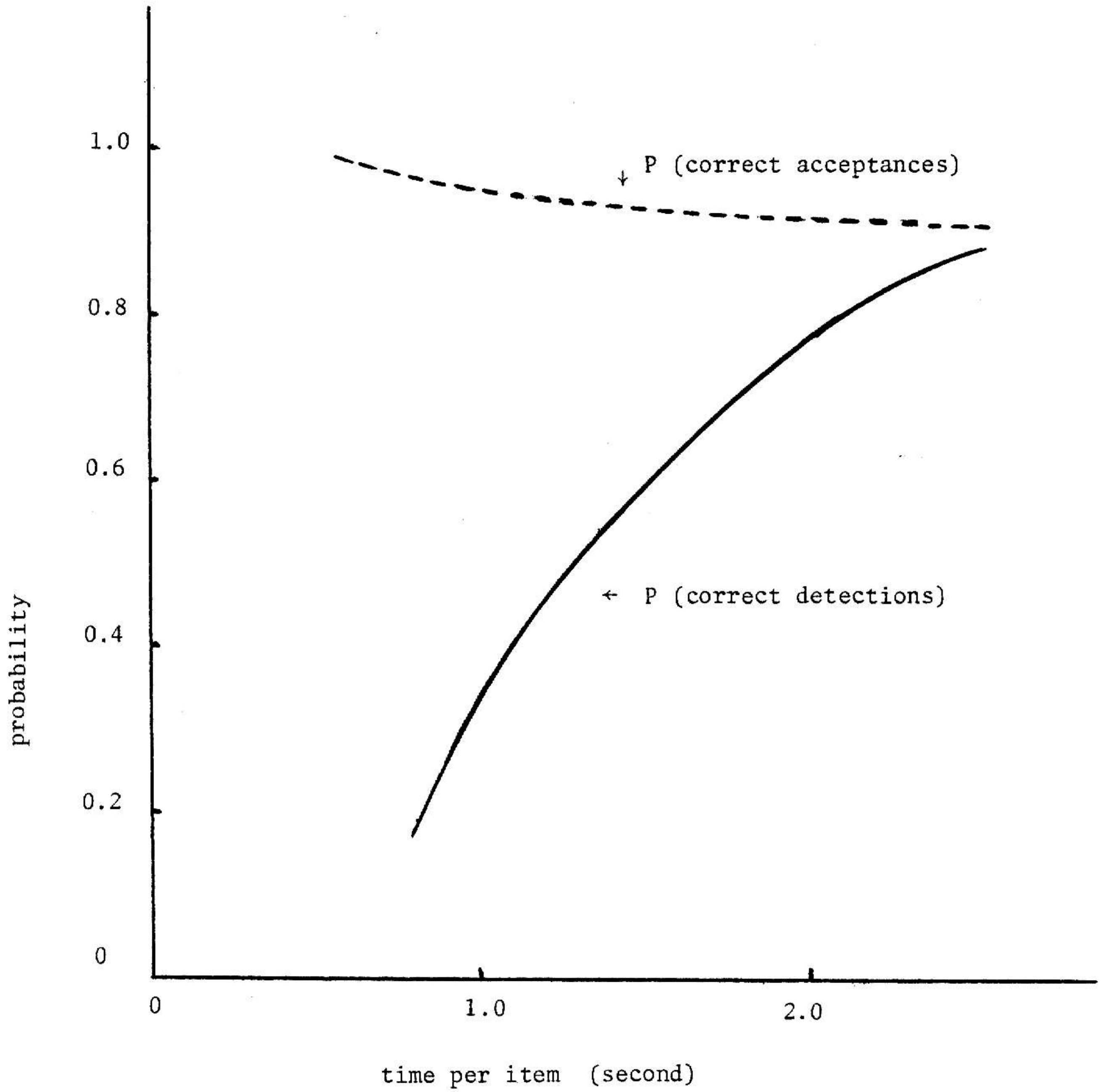

Figure 3. Effect of speed of working on detection performance (based on Drury, 1973).

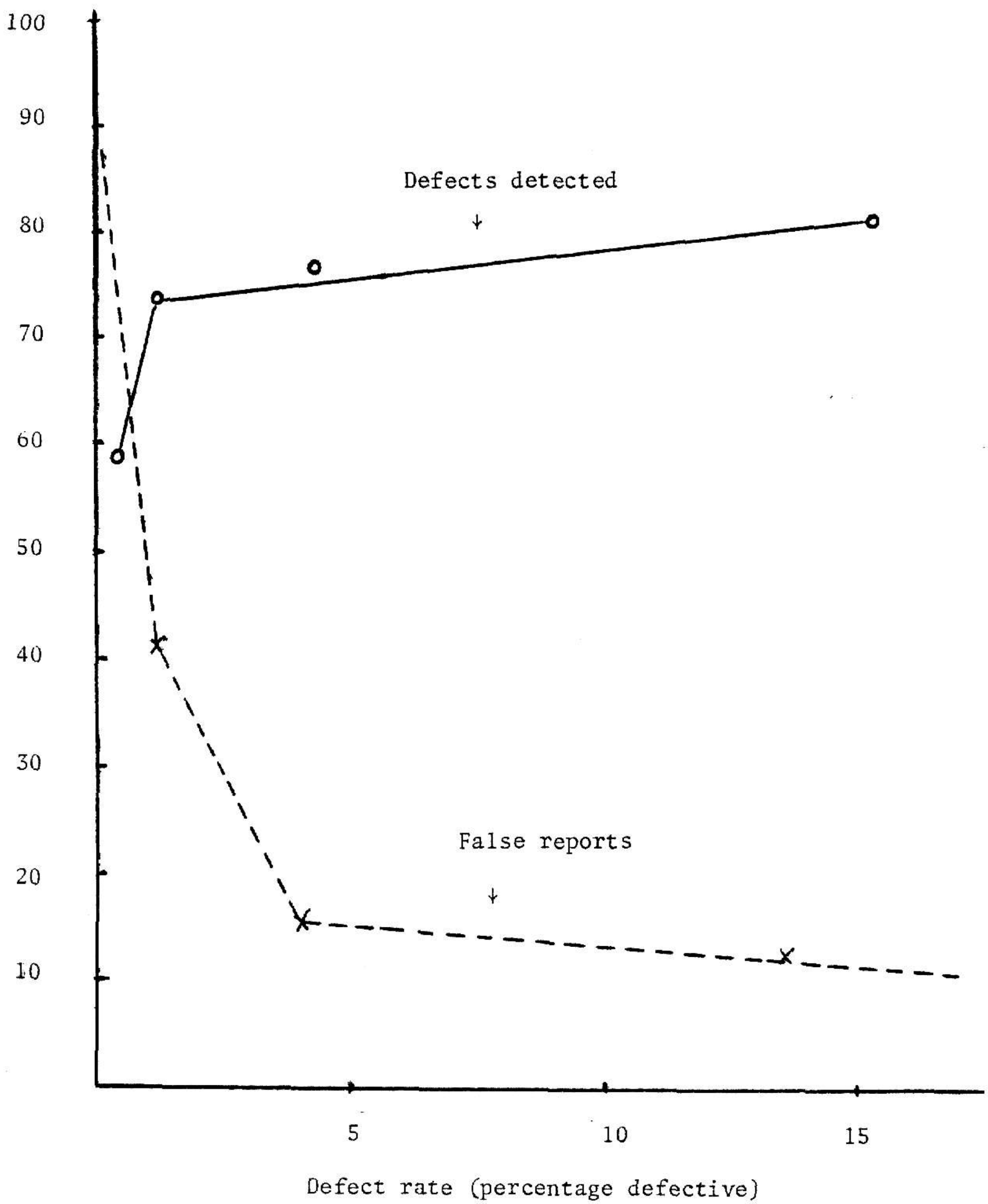

Figure 4. Relationship between defect rate and inspection accuracy. (Harris, 1968)

defect rates (0.005, 0.01 and 0.025) while inspecting products on a moving conveyor belt (the paced condition). The studies of Dorris, Hoag and Kasiviswanathan (1977) at three defect rates (.08, .20 and .32) found the overall probability of rejecting an item increased with the increase in percentage of defectives.

Two studies done by Lin (1979) and Ou (1978) have been used as the basis of the present research. The purpose of this research is to compare static and dynamic displays under various conditions.

Lin (1979) investigated the effect of velocity, percentage of lot defective and pacing in an inspection task with dynamic display. Two types of pacing were used. They were: machine paced at 10 degrees per second, 20 degrees per second, 30 degrees per second, 40 degrees per second velocities and self paced with the defect size about 14 minutes of arc (1/16 inch). Three defect rates were involved: one percent, 10 percent and 20 percent. Eight subjects were randomly assigned to each condition. Their job was to detect the incorrect "E's" as the letters passed in front of inspectors. The research parameters recorded were, correct acceptances (and false alarms), hits (and misses), rejection rates 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 indicated that the lower the angular velocity, the easier the subject found the task.

Ou (1979) studied the effect of speed of working versus inspection accuracy with a static display. The task was to detect incomplete "0's" with a gap of 14 minutes of arc (1/16 inch) distributed randomly with five percent chance of occurrence on the test patterns. Ten subjects were tested under five different speeds (4, 8, 12, 16 and 20 seconds per unit). The subject was located on the end of the conveyor. He inspected the pattern which dropped on his working table until the next one came. The subject was forced to keep up with the delivery rate by the conveyor. For P (correct accept), the analysis showed that inspection time was not significant. But for Q (correct rejections), the four second inspection time allowed was significantly poorer. The 12-second inspection time had the highest total percentage of correct decision (P + Q). Also the cost for type II errors was found to be the dominant factor for calculating the total cost, under certain assumptions about costs. The speed with 20-second inspection time had the smallest amount of total cost ($96.96 per 1000 units) with 99.83% correct decisions. It was the optimal speed in this experiment.

Rizzi, Buck and Anderson (1979) studied three speeds (100, 116 and 133 ft/min), four exposure times (.05, .10, .15, .20 seconds), three viewing positions (left, right, center) with 40% defectives. The targets consisted of 1.5 x 2 inch width-to-lenth grey-black rectangles with 3/16 inch circular white dots positioned within a central 1 1/8 x 1 5/8 inch rectangle. Defective targets had four dots. Subjects' heads were at a 12 inch viewing distance from the target center, the visual angle of the target dots approximately 54 minutes of arc.

They found that 1) the exposure time affects performance in addition to the effects of conveyor belt velocities, 2) central positions appeared to be the best while the leftward position worst, 3) the error-type criterion appeared to be unstable under changes in the task conditions in this study.

A function of total cost was derived by Drury (1973)

$$C_T = N \cdot P_g \cdot P_1 \cdot C_1 + N \cdot (1 - P_g) \cdot P_2 \cdot C_2 + C_3$$

where C_T = total cost per hour

N = number of items inspected per hour

P_g = probability of acceptable items

P_1 = probability of false alarms (type I errors)

P_2 = probability of misses (type II errors)

C_1 = cost of rejection of good items (production cost-scrap value)

C_2 = cost of accepting faulty items (replacement costs)

C_3 = labor cost per hour

The cost of making a type I error (false alarm) could be measured as the value of the item at that point in the process, less its scrap value. The cost of making a type II error (miss) could be measured simply (for other than final inspection) as the mean value added to that item by subsequent processing before its fault is finally detected. For final inspection, the full cost to the company in terms of replacement of faulty items can often be the only estimate of type II cost available.

Since the cost for making a type I or type II error varies for different kinds of products, the engineer could substitute the different type I and type II cost and the defect rate for the particular product into the economic model. Then in comparing the total costs, the optimal speed could be determined.

PROBLEM

The objective of this research was to compare the performance of static and dynamic displays in terms of percentage of correct decisions. Also to obtain a predictive model for inspection performance as a function of angular velocity and defect visual angle was desired.

The first hypothesis in this research was: static display will yield better performance than dynamic display in conveyor-pacing inspections. This means for the same viewing time, inspectors will have more correct decisions with static display.

The second hypothesis was: that small angular velocities with large visual angles will have better inspection performance. This means that the inspector will detect more defects and have more correct acceptances with the longer viewing times and larger defect sizes.

A final purpose was to perform an economic analysis in order to determine the optimal speed.

METHODS

The methods of this study will be discussed under the following headings: task and design, subjects, procedure and apparatus.

Task and Design

The task chosen was the detection of white circle dots (defects) inside of black circles with static and dynamic displays. The static mode used a conveyor to deliver the pattern at a fixed rate with inspection on a stationary 29 inch x 19 inch table, whereas the dynamic mode presented the inspection patterns on a continuously moving belt.

The test pattern was a 10 x 10 square matrix of .9 centimenter diameter black circles with the total dimension of 11 cm x 11 cm. The reflectance for black circles was 37.6%, for the background was 76.5%, the contrast was 51% (See Figure 5). Three sizes of defects with visual angles 1) 2.2 minutes of arc (.25mm), 2) 5.4 minutes of arc (.6 mm), 3) 8.5 minutes of arc (.95 mm) diameters were involved. These circles were randomly distributed throughout the patterns at a one percent occurrence rate. Ten patterns were made for each defect size. White circles could be anywhere inside of the black circles. During inspection, the experimentor fed thirty cards randomly to the conveyor, then fed the other thirty patterns 180 degree around in order to alter the patterns. Three speeds (10 degrees per second, 15 degrees per second, 20 degrees per second) were used.

For the static display, patterns were spaced 14 inches (center-to-center). The subject was located on the end of the conveyor. (See Figure 6). He was instructed to remove the pattern which slipped from the left onto his working table to the specified 14 inch wide inspection zone.

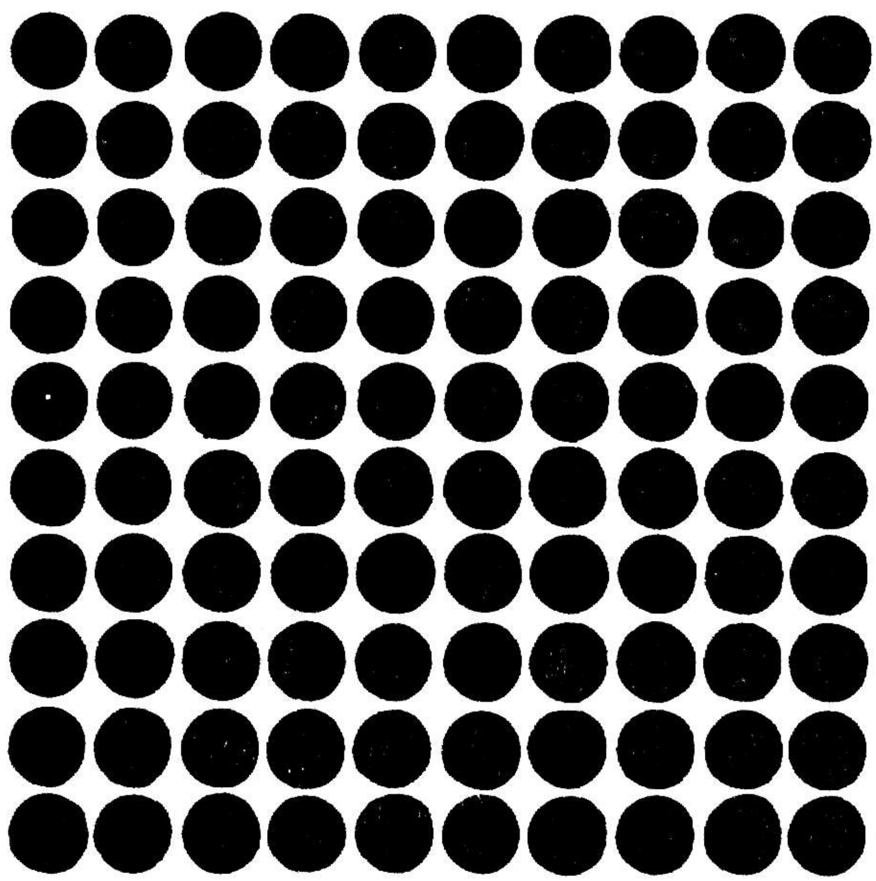

Figure 5. Example pattern

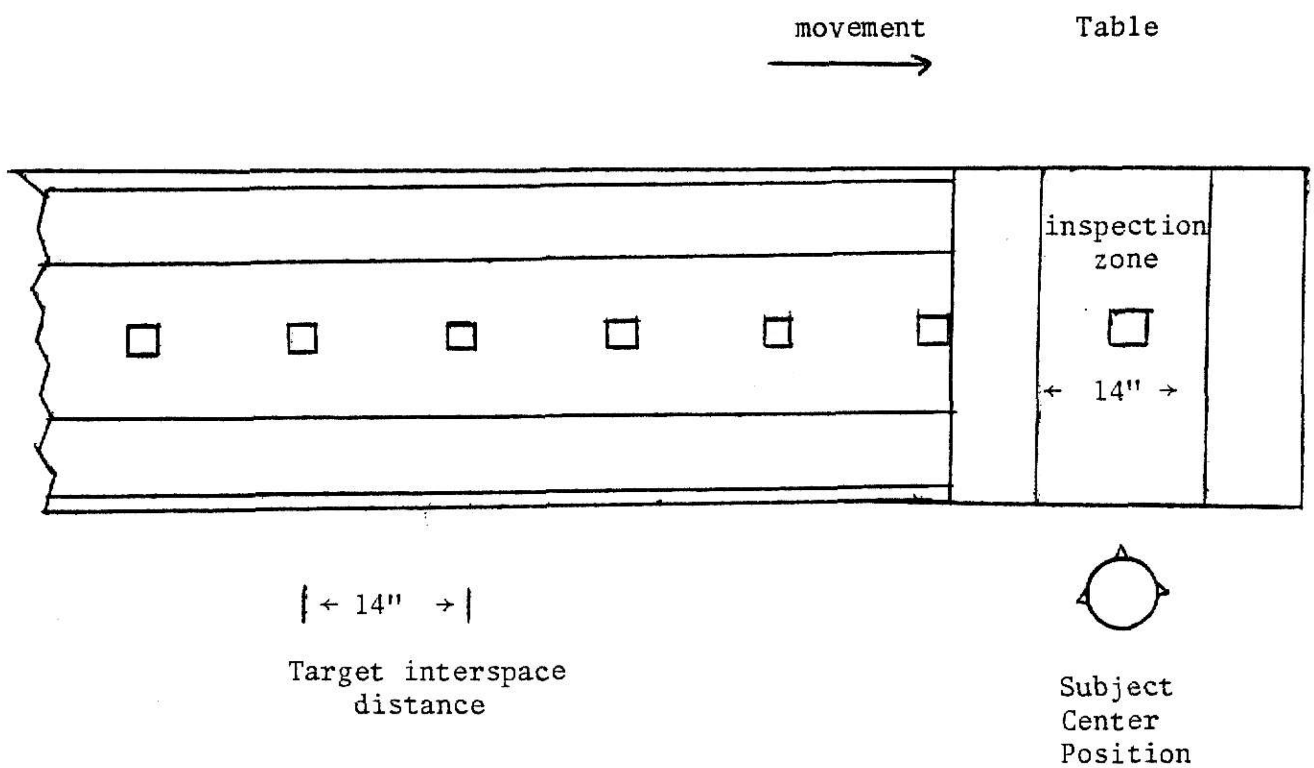

Figure 6. Diagram of static display.

The subject inspected the pattern until the next one came, then he had to take the new one immediately to the fixed area and start inspecting.

For the dynamic display, the patterns were also spaced 14 inches (center-to-center). A target viewing window with a width of 14 inch and a viewing distance of 12 to 15 inch corresponds to 53.5°. The belt was shielded by two wooden boards which served as armrests such that the inspector could see only one pattern at a time and he would not have to rest his arms on the board interrupting the belt speed. (See Figure 7). The conveyor was adjusted to 26 inches high, so the subject could sit comfortably. An adjustable chair was provided.

Table 3 classifies the six conditions involved in this experiment. The first 15 subjects were assigned to perform three conditions under the static display in a random fashion. The following 15 subjects performed the three conditions under dynamic display in a random order. Table 4 shows the sequence of performing.

Each subject was given ten patterns to practice with an angular velocity of 23 degrees per second with either the static or dynamic display depending on his assigned conditions. The reason for using 23 degrees per second, which is faster than the actual speeds, was to help the subjects to adjust to the actual task.

A Borg Relative Perceived Exertion Scale was used. (See Figure 8). In the case of physical work, the Borg values are close to one tenth of the person's heart rate produced by the task.

Scoring of performance was based on correct acceptances, false alarms (type I errors), misses (type II errors), hits and Borg scale ratings. In this experiment, the percentage of correct decisions was

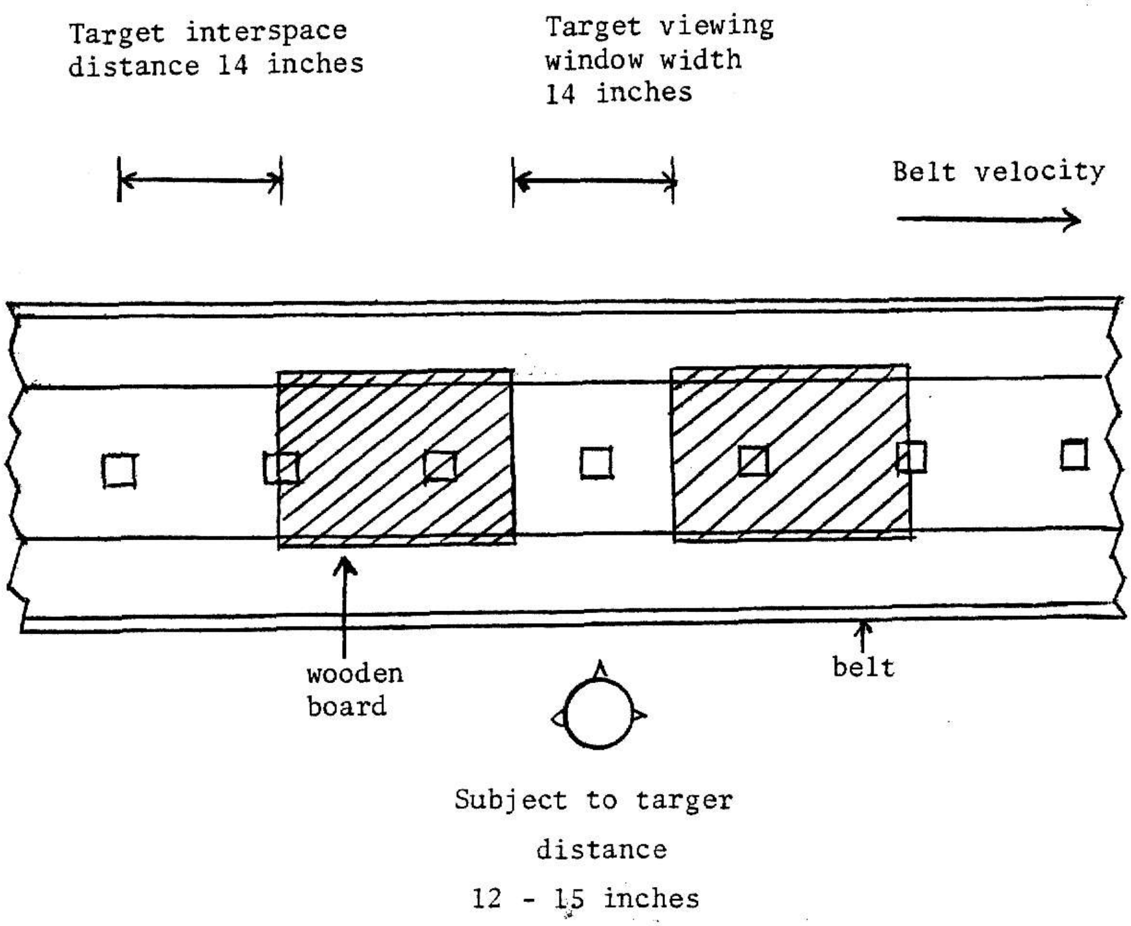

Figure 7. Diagram of dynamic display.

TABLE 3

Conditions classification

Display	Speed	Size	Condition
	(degrees per second)	(minutes of arc)	
Static	10	2.2 5.4 8.5	1
	15	2.2 5.4 8.5	2
	20	2.2 5.4 8.5	3
Dynamic	10	2.2 5.4 8.5	4
	15	2.2 5.4 8.5	5
	20	2.2 5.4 8.5	6

TABLE 4

From a random number table, each subject did the experiment according to the following sequence.

Subject No.	Conditions	Subject No.	Conditions
1	2 1 3	16	5 4 6
2	3 2 1	17	4 5 6
3	3 2 1	18	4 5 6
4	3 2 1	19	4 5 6
5	1 3 2	20	5 4 6
6	3 2 1	21	6 5 4
7	1 2 3	22	6 4 5
8	2 1 3	23	5 6 4
9	1 2 3	24	5 4 6
10	1 2 3	25	6 5 4
11	1 2 3	26	5 4 6
12	2 1 3	27	5 4 6
13	2 1 3	28	6 4 5
14	3 2 1	29	5 4 6
15	1 2 3	30	4 6 5

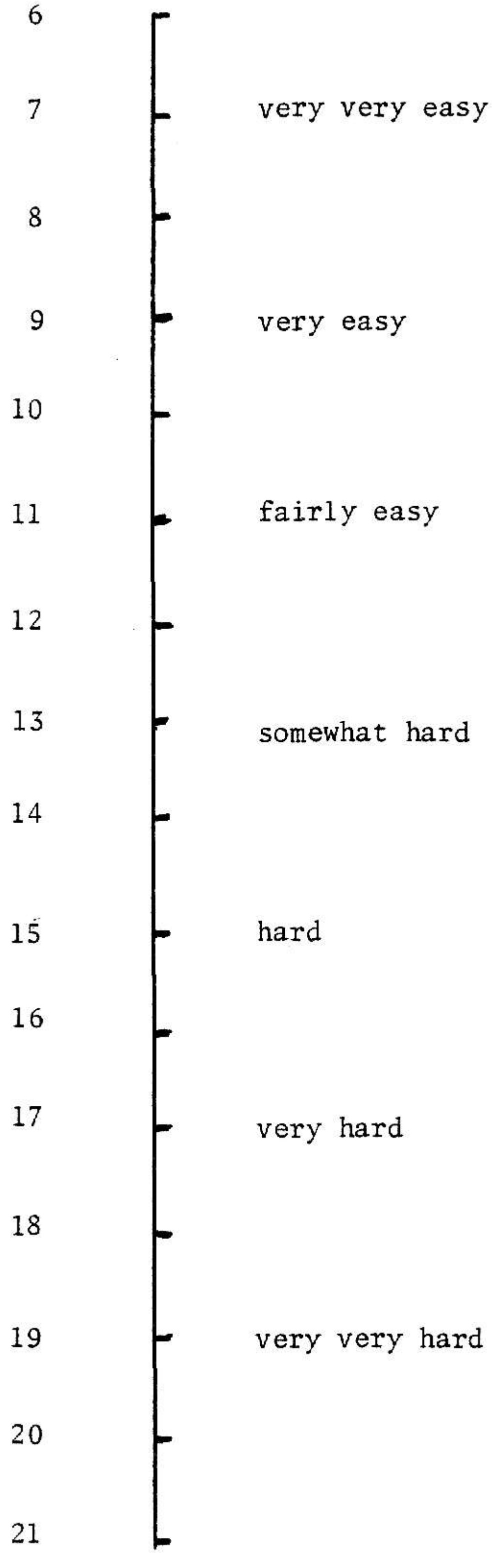

Figure 8. Borg perceived exertion scale

defined to be the sum of the percentage of correct acceptances and of hits. The experimental variables are shown in Table 5.

Subjects

Thirty Manhattan residents (students, friends, relatives), 22 males and 8 females with ages ranging from 13 to 43 were involved in this experiment. The mean age was 25. 20/20 corrected vision, the only requirement for participation, was tested with a Titmus Vision Tester. All subjects were paid for their performance. There were no personal risks involved in this experiment. To insure the subject's privacy, only the assigned subject number was written on the data sheet. The subjects were asked to operate on the basis that speed and accuracy were equally important.

Procedure

The procedure was as follows:

1) Each subject read the Written Instructions and signed the Subject Consent Form. (See Figure 9).
2) Each subject had ten patterns under 23 degrees per second for practice.
3) Subjects marked the defects on the patterns with a red pen.
4) a. Static: When the pattern came, the subject took the pattern into the 14 inch inspection zone immediately, and started to inspect.

   b. Dynamic: Subjects inspected the pattern within the 14 inch window size.
5) The subject completed the sixty patterns for the first condition.
6) The subject rated on the Borg Relative Perceived Exertion Scale for the condition.
7) The subject completed the other two conditions and made ratings.

TABLE 5

Experimental Variable and Level

Angular velocity (degrees per second)	10		15		20	
test situation	Static	Dynamic	Static	Dynamic	Static	Dynamic
defect sizes (minutes of arc)	2.2, 5.4, 8.5		2.2, 5.4, 8.5		2.2, 5.4, 8.5	
pattern inspected for each size	20		20		20	
spacing of target (inch) angular degree (degree)	14 53.5		14 53.5		14 53.5	
no. of subjects	10		10		10	

INFORMED CONSENT AND INSTRUCTION FOR SUBJECTS

The purpose of this experiment is to study various inspection conditions.

You will inspect 180 cards. There are black circles which may have small white circles within them. A black circle with a white circle is defined as a defect. There is never more than one defect size on each pattern. Your job is to identify the defects and mark them with this red pen. (Try not to mark right through the white dots.) You won't be able to change the mark once you have marked it. On the static display, when the new pattern comes, you'll have to bring the patterns into the 14 inch wide inspection zone and do the inspection there without delaying. Since inspection performance includes both speed and accuracy, please operate on the basis that speed and accuracy are equally important.

There will be no risk involved in this experiment. However, you are free to stop at anytime. I will appreciate if you will complete the experiment. Your name will be kept confidential, only the assigned number will be written on the report.

Please sign, if you agree to participate in this project. Thank you for your cooperation.

(Signature)

(Date)

Figure 9. Instruction for subjects.

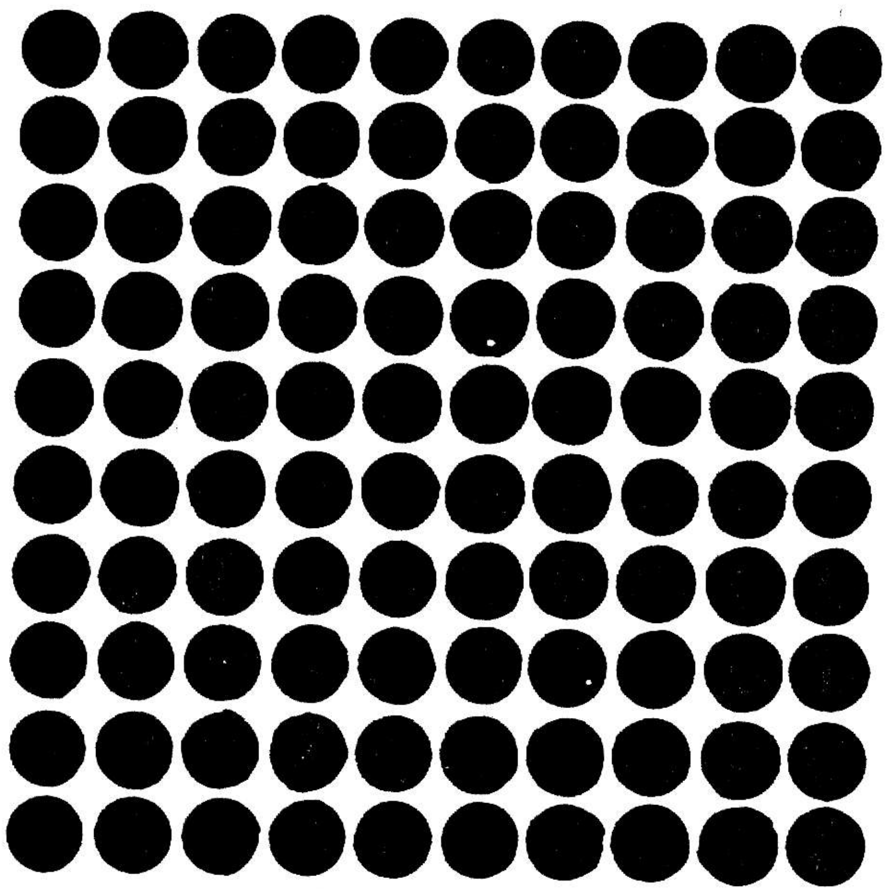

Figure 9. (cont). Example of defect sizes.

Apparatus

1) The Doll straight belt conveyor was used with a variable speed drive, where the belt moved smoothly over a supporting platform. The conveyor belt was light green in color, with a textured non-glare surface.

2) Two wooden boards were used to make the 14-inch-wide window.

3) A table (29 inch x 19 inch) was arranged to be the working station for static display.

4) The Titmus Vision Tester was used to test the subjects' vision ability.

5) Five thousand four hundred patterns with thirty different orientations were made for the experiment.

6) The straight line conveyor was 11.25 inches wide, 123 inches long and 26 inches high. It was located in a laboratory with ambient illumination of 170 footcandles on the viewing area. Room temperature was maintained at 75 degrees Farenheit, and the noise level varied from 70 to 82 dB when the conveyor was operating. Under above conditions, instead of changing the position of the subject, dynamic display was done by moving the conveyor about five feet to the right of the subject, so that he was in the middle of the conveyor.

RESULTS

There were two thousand black circles with one percent defectives under nine different size and speed combinations for each subject.

The data collected were number of type I errors (false alarms), number of type II errors (misses) and Borg scale ratings. Tables 6 and 7 describe the subjects. Tables 8 through 13 give the data. Tables 14 through 16 show the mean type I and type II errors for all the situations, for speed effects only and for size effects only. Tables 17 through 19 show the mean values for the various interactions.

The measures of inspection performance were 1) percentage of false detections made (type I errors), which is the ratio of false alarms to good items in the lot, 2) percentage of correct acceptances, which is the percentage of accepted good items. (1-percentage of type I errors), 3) percentage of missed detections made (type II errors), which is the ratio of miss detections to the number of bad items in a lot, 4) percentage of defects detected (hits) which is the percentage of detected defectives. (1-percentage of type II errors), 5) percentage of correct decisions, which is the sum of the percentage of correct acceptances times the probability of good items in a lot and hits times the defect rate, 6) Borg scale rating of perceived exertion.

The model used in the analysis of variance is given by:

$$\text{PERFORMANCE} = D(I) + V(J) + S(K) + DV(IJ) + VS(JK) + DS(IK) + DVS(IJK) + E(IJKN)$$

where D = display I = 2

V = velocity J = 3

S = size K = 3

N = 30

TABLE 6

Information about Subjects with the Static Display

Subj. no.	Age	Sex	Occupation
1	26	F	student
2	26	M	student
3	23	M	student
4	31	M	student
5	21	M	student
6	25	F	student
7	31	M	student
8	28	F	student
9	30	M	student
10	21	M	student
11	20	F	clerk III
12	28	M	student
13	15	M	student
14	21	M	student
15	17	F	student

median = 25

TABLE 7

Information about Subjects with the Dynamic Display

Subj. no.	Age	Sex	Occupation
16	13	F	student
17	43	F	homemaker
18	29	M	student
19	24	M	student
20	30	M	student
21	26	M	student
22	23	M	student
23	26	M	student
24	30	M	student
25	32	M	student
26	30	M	student
27	26	M	student
28	21	F	student
29	25	M	student
30	22	M	student

median = 26

TABLE 8

Percent errors and Borg Ratings for Static Display - 10°/sec

defect size / subj. number	2.2 minutes of arc		5.4 minutes of arc		8.5 minutes of arc		Borg Rating
	% Type I	% Type II	% Type I	% Type II	% Type I	% Type II	
1	.05	10	.25	0	.25	0	9
2	.66	10	.51	0	.46	0	9
3	.15	25	.05	0	0	0	9
4	0	5	.10	0	.05	0	7
5	.10	10	.05	0	.10	0	9
6	.30	25	.66	0	.51	0	11
7	0	20	0	0	.05	0	11
8	0	20	0	0	0	0	11
9	.15	0	.05	0	0	0	11
10	.05	10	.46	0	.20	0	10
11	.10	10	.20	0	.46	0	11
12	0	15	0	0	0	0	11
13	0	35	0	0	0	0	9
14	0	80	0	0	0	0	9
15	0	25	.10	0	.05	0	9
MEANS	.11	20	.16	0	.14	0	9.7

TABLE 9

Percent errors and Borg Ratings for Static Display - 15°/sec

defect size / subj. number	2.2 minutes of arc		5.4 minutes of arc		8.5 minutes of arc		Borg
	% Type I	% Type II	% Type I	% Type II	% Type I	%Type II	Rating
1	.20	20	.20	0	.40	0	11
2	.15	15	.40	0	.46	0	12
3	.05	15	.05	0	.10	0	11
4	0	20	.05	0	.05	0	9
5	.10	0	0	0	0	0	13
6	.20	5	.15	0	.40	0	9
7	.05	35	.15	0	.05	0	11
8	0	30	0	5	.05	0	13
9	.05	20	.05	0	0	0	13
10	.25	10	.20	0	.10	0	13
11	.05	5	.35	0	.25	0	14
12	.05	25	0	0	0	0	13
13	0	30	.05	0	0	0	13
14	0	100	0	0	0	0	13
15	.05	10	.35	0	.15	0	11
Means	.08	22.67	.14	.33	.14	0	12

TABLE 10

Percent Errors and Borg Ratings for Static Display - 20°/sec

defect size / subj. number	2.2 minutes of arc % Type I	% Type II	5.4 minutes of arc % Type I	% Type II	8.5 minutes of arc % Type I	%Type II	Borg Rating
1	.15	60	.05	0	0	0	13
2	.05	10	.46	0	.10	0	14
3	0	45	0	0	.05	0	11
4	0	35	.05	0	.10	0	13
5	.46	0	0	0	.05	0	13
6	.15	50	.05	0	.05	0	17
7	0	25	.10	0	.10	0	11
8	.05	15	0	0	0	0	13
9	.20	5	0	0	0	0	18
10	.05	30	.20	0	.05	0	15
11	.10	50	.30	5	.20	0	15
12	0	40	0	0	.05	0	17
13	0	30	.05	0	0	0	7
14	0	70	0	0	0	0	17
15	.05	50	.10	0	0	0	13
Means	.08	34.3	.09	33	.05	0	13.8

TABLE 11

Percent Errors and Borg Ratings for Dynamic Display - 10°/sec

defect size	2.2 minutes of arc		5.4 minutes of arc		8.5 minutes of arc		Borg
subj. number	% Type I	% Type II	% Type I	% Type II	% Type I	% Type II	Rating
16	0	20	0	10	0	0	7
17	.10	10	.05	0	.40	0	13
18	.10	25	.20	0	.05	0	11
19	.20	25	0	0	.05	0	11
20	0	20	0	0	0	0	9
21	0	50	0	0	0	0	11
22	0	100	0	0	0	0	11
23	.05	0	.05	0	0	0	11
24	0	0	.05	0	.10	5	9
25	0	40	.10	0	.20	0	12
26	0	100	0	0	0	0	9
27	.20	0	.51	0	.81	0	7
28	0	5	0	5	.05	0	10
29	0	35	0	0	0	0	9
30	.05	45	0	0	.05	0	11
Means	.05	31.67	.06	1.67	.12	.33	10.1

TABLE 12

Percent errors and Borg Ratings for Dynamic Display - 15°/sec

defect size / subj. number	2.2 minutes of arc		5.4 minutes of arc		8.5 minutes of arc		Borg
	% Type I	% Type II	% Type I	% Type II	% Type I	% Type II	Rating
16	.05	20	0	0	0	0	13
17	.15	25	.15	0	0	0	11
18	0	80	0	0	0	0	9
19	.20	10	.05	0	0	0	14
20	0	20	0	0	0	0	13
21	.51	0	.05	5	.05	0	11
22	0	100	0	0	0	0	11
23	0	15	0	0	.05	0	13
24	0	15	0	0	.10	5	11
25	0	30	.05	5	.10	0	13
26	0	55	0	0	0	0	7
27	.05	10	.81	10	.56	0	11
28	0	5	0	0	.05	0	11
29	0	80	0	5	0	0	12
30	0	45	.05	5	0	0	13
Means	.06	34	.08	2	.06	.33	11.5

TABLE 13

Percent errors and Borg Ratings for Dynamic Display - 20°/sec

defect size	2.2 minutes of arc		5.4 minutes of arc		8.5 minutes of arc		Borg
subj. number	% Type I	% Type II	% Type I	% Type II	% Type I	% Type II	Rating
16	0	50	0	0	0	0	17
17	.15	15	.15	0	.05	0	13
18	0	75	0	0	0	0	9
19	.10	30	0	0	0	0	15
20	0	30	0	0	0	0	15
21	0	50	0	0	0	0	13
22	0	100	0	10	0	0	11
23	0	15	0	0	0	0	12
24	0	35	0	5	0	0	13
25	0	55	0	0	0	0	15
26	0	100	0	5	0	0	11
27	0	30	0	0	0	0	14
28	0	15	0	0	.05	0	13
29	0	60	0	0	0	0	15
30	0	70	0	5	0	0	13
Mean	.02	48.67	.01	1.67	.01	0	13.3

TABLE 14

Mean Values for all Experimental Conditions

Display	Speed	Size	No. of subjects	% Type I	% Type II	Borg
		2.2	15	.105	20.	
	10	5.4	15	.162	0	9.7
		8.5	15	.142	0	
		2.2	15	.081	22.67	
Static	15	5.4	15	.135	.33	12
		8.5	15	.135	0	
		2.2	15	.084	34.33	
	20	5.4	15	.091	.33	13.8
		8.5	15	.051	0	
		2.2	15	.047	31.67	
	10	5.4	15	.064	1.67	10.1
		8.5	15	.115	.33	
		2.2	15	.064	34	
Dynamic	15	5.4	15	.078	2	11.5
		8.5	15	.061	.33	
		2.2	15	.017	48.67	
	20	5.4	15	.010	1.67	13.1
		8.5	15	.007	0	

TABLE 15

Mean Values for Speeds--10°/sec, 15°/sec, 20°/sec

Angular velocity	No. of subject	% type I (False alarm)	% type II (Miss)	Borg
10°/sec	30	.106	8.95	9.9
15°/sec	30	.092	9.89	11.7
20°/sec	30	.043	14.17	13.5

TABLE 16

Mean Values for each Visual Angle -- 2.2, 5.4, 8.5 (minutes of arc)

Visual Angle	No. of Subject	% Type I	% Type II
(minutes of arc)			
2.2	30	.066	31.89
5.4	30	.090	1.00
8.5	30	.085	.11

TABLE 17

Mean Values for Display vs. Angular Velocity

Display	Angular velocity	No. of subject	Correct acceptances	Hits	Borg
	10	45	99.864	93.33	9.7
Static	15	45	99.883	92.33	12.0
	20	45	99.925	88.44	13.8
	10	45	99.925	88.78	10.1
Dynamic	15	45	99.933	87.89	11.5
	20	45	99.989	83.22	13.3

TABLE 18

Mean Values for Display vs. Size

Display	Size	No. of Subjects	Correct Acceptances	Hits
	2.2	45	99.91	74.33
Static	5.4	45	99.87	99.78
	8.5	45	99.89	100.00
	2.2	45	99.96	61.89
Dynamic	5.4	45	99.95	98.22
	8.5	45	99.94	99.78

TABLE 19

Mean Values for Angular Velocity vs. Visual Angle

Angular velocity	No. of subject	Visual angle	Correct acceptances	Hits
10	30	2.2	99.924	74.17
		5.4	99.897	99.17
		8.5	99.872	99.83
15	30	2.2	99.929	71.67
		5.4	99.894	98.83
		8.5	99.902	99.83
20	30	2.2	99.949	58.5
		5.4	99.949	99.0
		8.5	99.971	100.00

TABLE 20

Analysis of Variance for False Alarms (and Correct Acceptance)

Mean % False Alarm = .0804

Standard Deviation = .1081

Source of Variance	DF	Mean Squares	F value	Alpha hat	
Display	1	.2278	2.67	.1136	
Subj. (Display)	28	.0854	7.39	.0001	*
Speed	2	.0968	8.38	.0003	*
Display * Speed	2	.0013	.11	.8925	
Error	236	.0117			
Total	269				

TABLE 21

Duncan's Multiple Range Test for False Alarms

Alpha level = .05 DF = 224 MS = .0117

Angular Velocity	Mean	N	Grouping *	
10	.1056	90	A	
15	.0922	90	A	
20	.0433	90		B

*Means with the same letter are not significantly different.

TABLE 22

Analysis of Variance for Misses (and hits)

Mean % misses = 11.0

Standard Deviation = 13.8571

Source of Variance	DF	Mean Squares	F Value	Alpha hat	
Display	1	1517.04	2.72	.1100	
Subj. (Display)	28	556:81	2.90	.0001	*
Speed	2	696.95	3.63	.0281	*
Size	2	29471.11	153.48	.0001	*
Display * Speed	2	3.98	.02	.9795	
Display * Size	2	1011.48	5.27	.0058	*
Speed * Size	4	714.72	3.72	.0059	*
Display * Speed * Size	4	8.43	.04	.9963	
Error	224	192.02			
Total	269				

TABLE 23

Duncan's Multiple Range Test for Misses--Angular Velocity

Alpha level = .05 DF = 24 MS = 192.021

Angular Velocity	Mean	Grouping*
10	8.944	A
15	9.889	A
20	14.167	B

*Means with the same letter are not significantly different.

TABLE 24

Duncan's Multiple Rangle Test for Misses-Visual Angle

Alpha level = .05 DF = 224 MS = 192.021

Visual Angle	Mean	Grouping*
2.2	31.89	A
5.4	1.00	B
8.5	.11	B

*Mean with the same letter are not significant different.

TABLE 25

Duncan's Multiple Range Test for Misses--Angular Velocity by Visual Angle

Angular velocity	Visual angle	Mean	Grouping *		
20	8.5	0.0000	A		
15	8.5	.1667	A		
10	8.5	.1667	A		
10	5.4	.1129	A		
20	5.4	1.0000	A		
15	5.4	1.2069	A		
15	2.2	25.3333		B	
10	2.2	25.8333		B	
20	2.2	41.5000			C

*Means with the same letter are not significant different.

$$LSD = t\ (20,\ .05)\sqrt{2(182.02)/30} = 7.0$$

The first hypothesis in this research was that the static display will yield better performance than the dynamic display in a conveyor-pacing inspection. To evaluate this, an analysis of variance was performed. The second hypothesis was that small angular velocities with large visual angles will yield better inspection performance. To evaluate this, an analysis of variance with an interaction between speed and size as an variate was performed for each of the dependent variables.

False alarms (and correct acceptances)

The analysis of variance (Table 20) shows that speed and subjects within display was significant ($\alpha < .05$). Table 21 uses Duncan's Multiple Range Test to separate the means.

Misses (and hits)

Table 22 shows that there were significant differences in misses (and hits) due to speed, defect size, subjects within display, interaction between display and size, and interaction between speed and size. The type of display was not significant. However, the mean percentage of hits for the static display was 91.4 and 86.6 for the dynamic display, therefore a one tailed t-test was performed. The t-value for hits was 1.65 (> 1.313). This indicated that the type of display is significant with static better than dynamic display. Tables 23, 24 and 25 show the groupings by Duncan's Multiple Range Test for angular velocity, visual angle, and relationship between angular velocity and visual angle.

Borg scale ratings

In this experiment, each subject inspected under three speeds (10, 15 and 20 degrees per second). For each speed, three defect sizes (2.2, 5.4 and 8.5 minutes of arc) were mixed randomly. However, subjects rated only at the end of each speed, so the ratings consider the speed effect and not the changes in defect size. Table 26 shows that the angular velocity and subject within display were statistically significant. Duncan's Test results are shown in Table 27.

TABLE 26

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

Source of variation	DF	Mean squares	F value	Alpha hat	
Display	1	.90	.29	.6766	
Subj. (Display)	28	5.07	1.65	.0559	
Speed	2	99.01	32.23	.0001	*
Display * Speed	2	1.63	.53	.5906	
Error	56	3.07			
Total	89				

TABLE 27

Duncan's Multiple Range Test for Borg Ratings

Angular Velocity	Mean	Grouping*
10	9.90	A
15	11.73	B
20	13.53	C

*Means with the same letter are not significally different.

DISCUSSION

For correct acceptances, subjects within display and speed were significant.

For hits, subjects within display, speed, size, display by size and speed by size were all significant at the five percent significant level.

For Borg scale ratings, subjects within display and speed were significant.

Figure 10 shows the speed effect for the correct acceptance. For hits, Figures 11 through 16 show the speed effect, display by speed, defect size effect, speed by size and display by size relationship. The speed effect for Borg scale rating is shown in Figure 17.

Display (static and dynamic)

Harris and Chaney (1969) concluded that stationary inspection is better for a scanning type of inspection task if searching activity is required. While in this study, the display type was not found to be a significant factor for either false alarms (and correct acceptances), misses (and hits), nor Borg ratings by using the mean square for subjects within display as an error terms at five percent significant level. The reason for failing to agree with the finding could be the fact that the individuals were different. However, the one tail t-test at 10 percent significant level showed that static did perform better.

Figure 12 shows that static display has more hits. In relation to speed, hit rates drop slightly for both displays after 15 degrees per second. Stationary inspection allows the inspector to have smaller eye-movements than for a moving target, so inspectors have more time to look for the defects and make more false alarms.

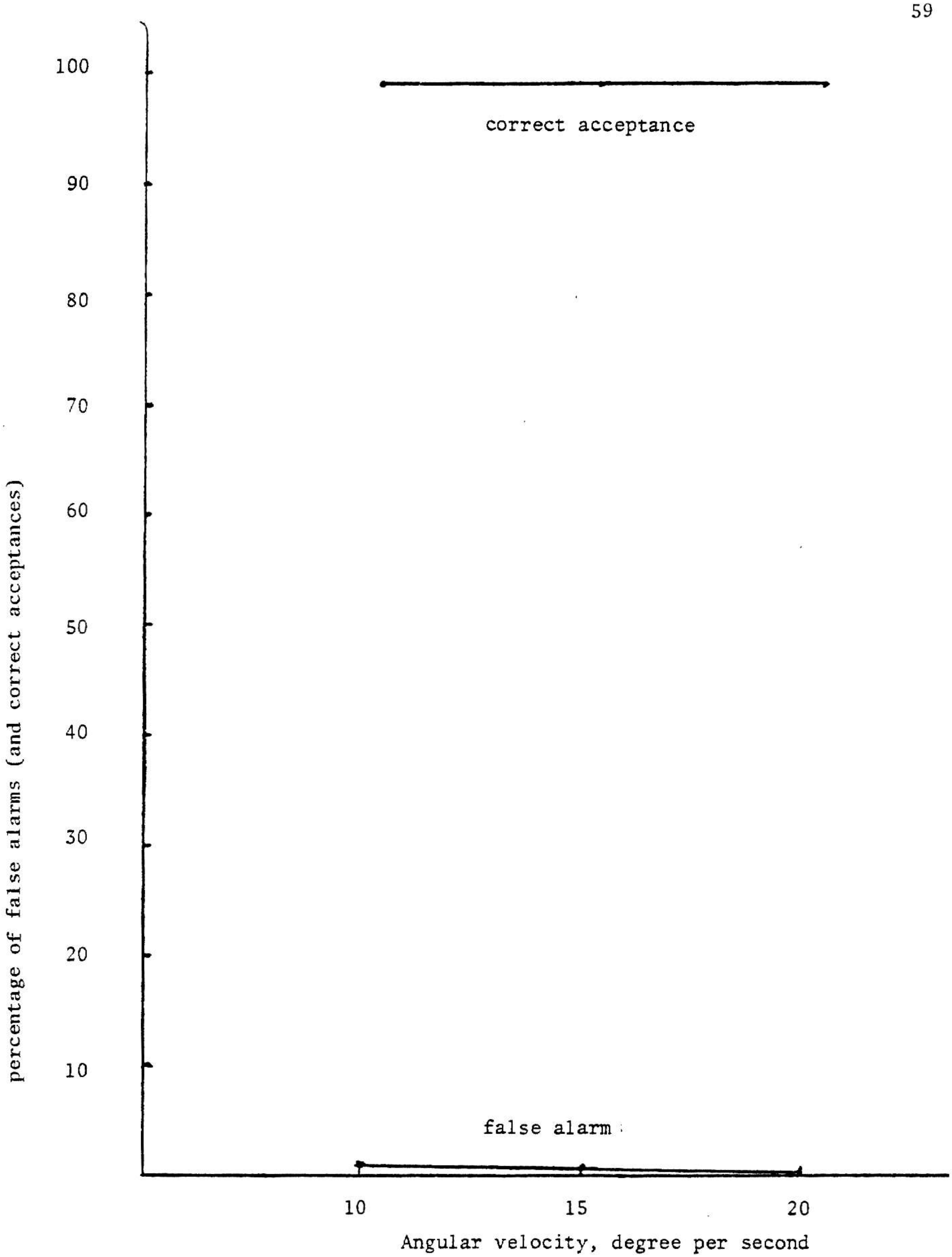

Figure 10. Angular velocity vs. mean value of false alarms (and correct acceptances).

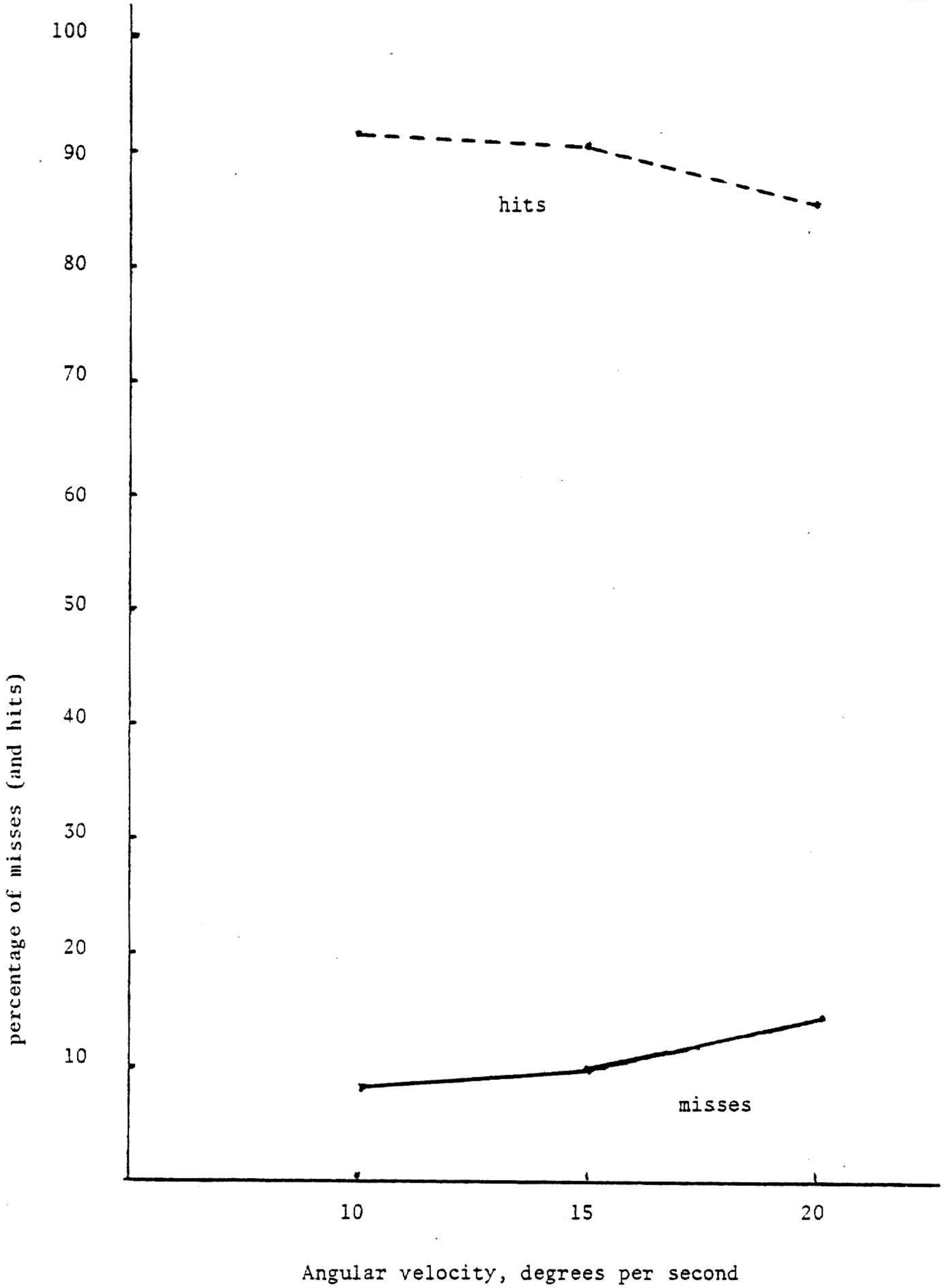

Figure 11. Angular velocity vs. mean value of misses (and hits).

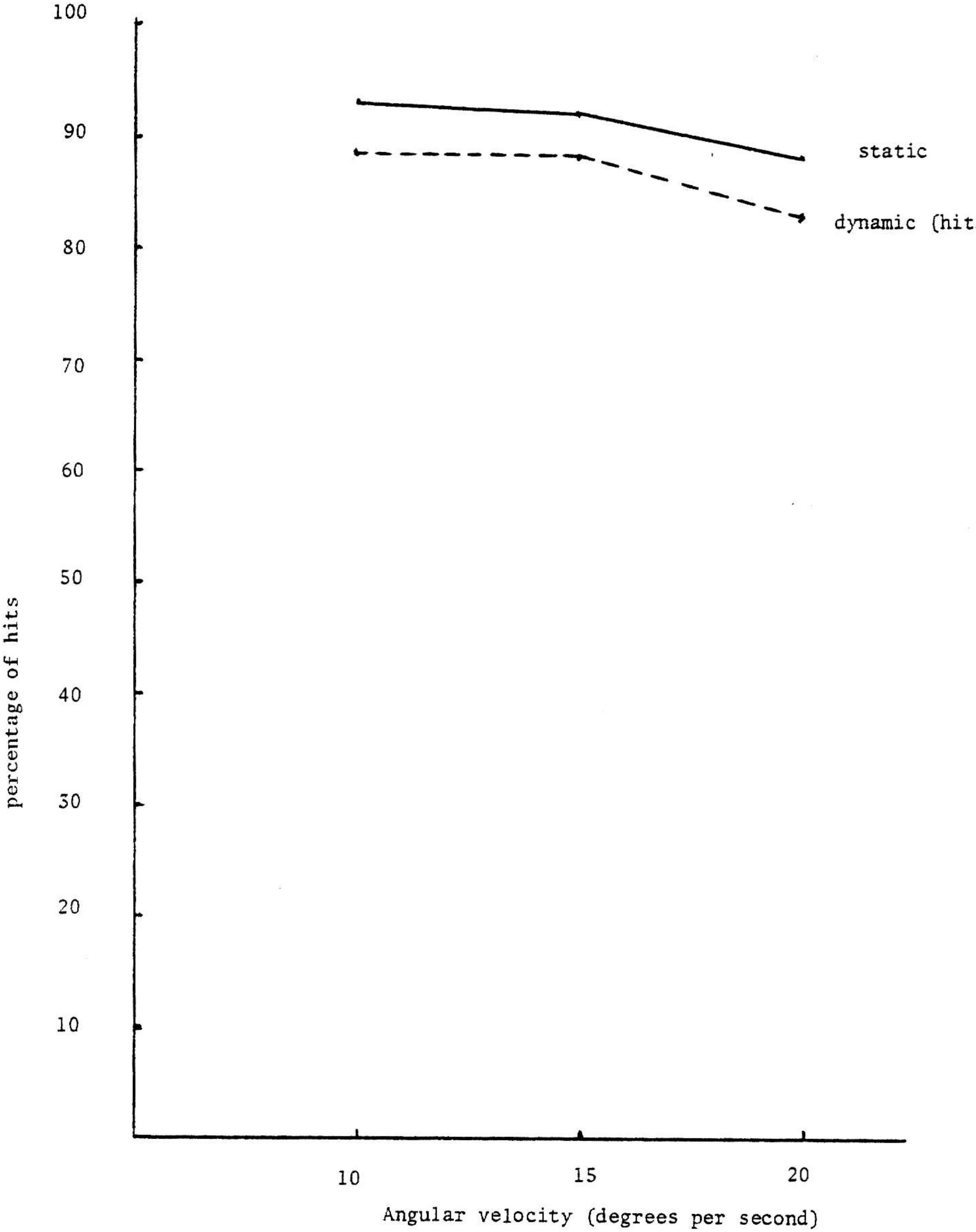

Figure 12. Angular velocity vs. hits at different display

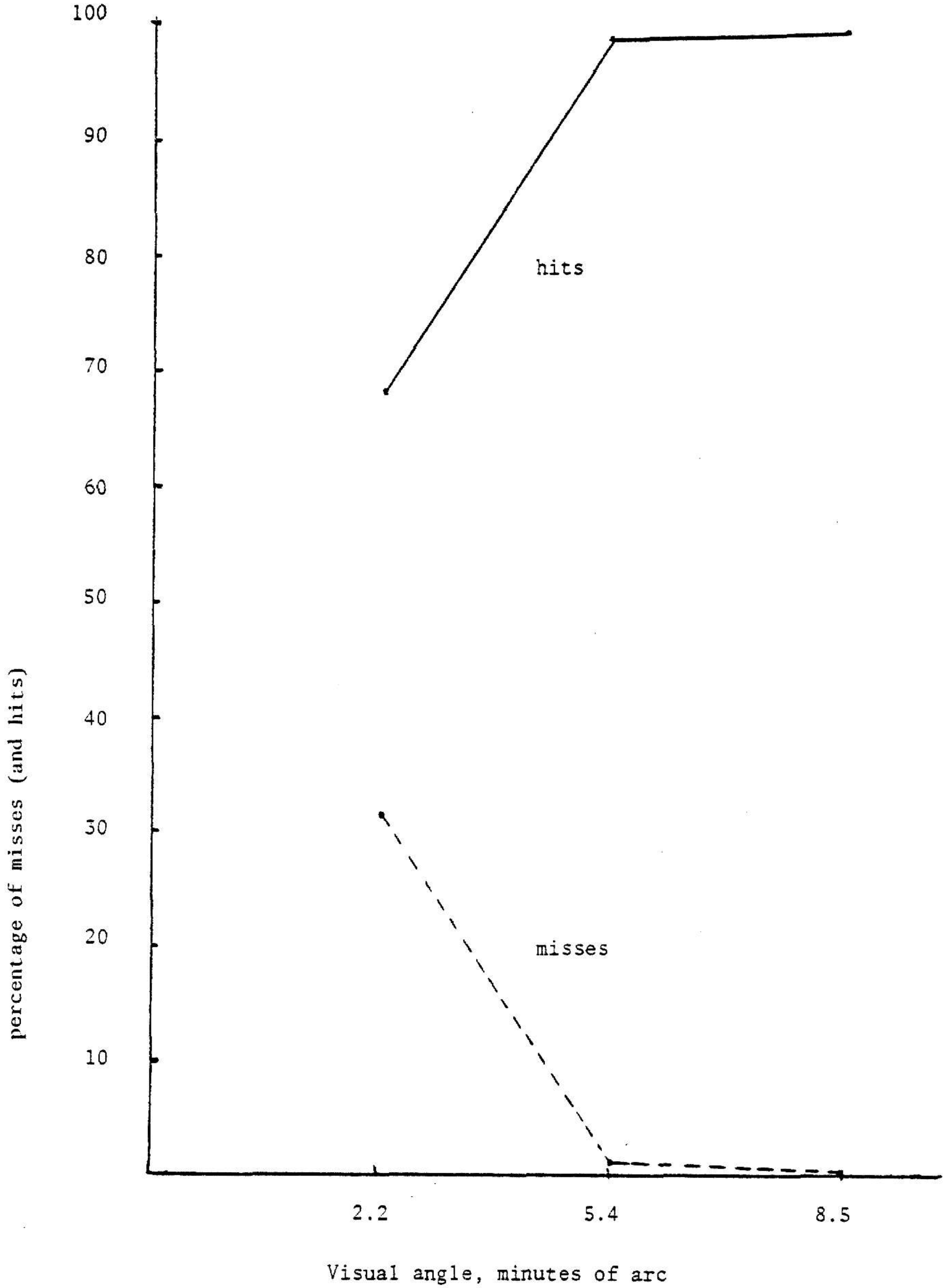

Figure 13. Mean value for misses (and hits) across the visual angle.

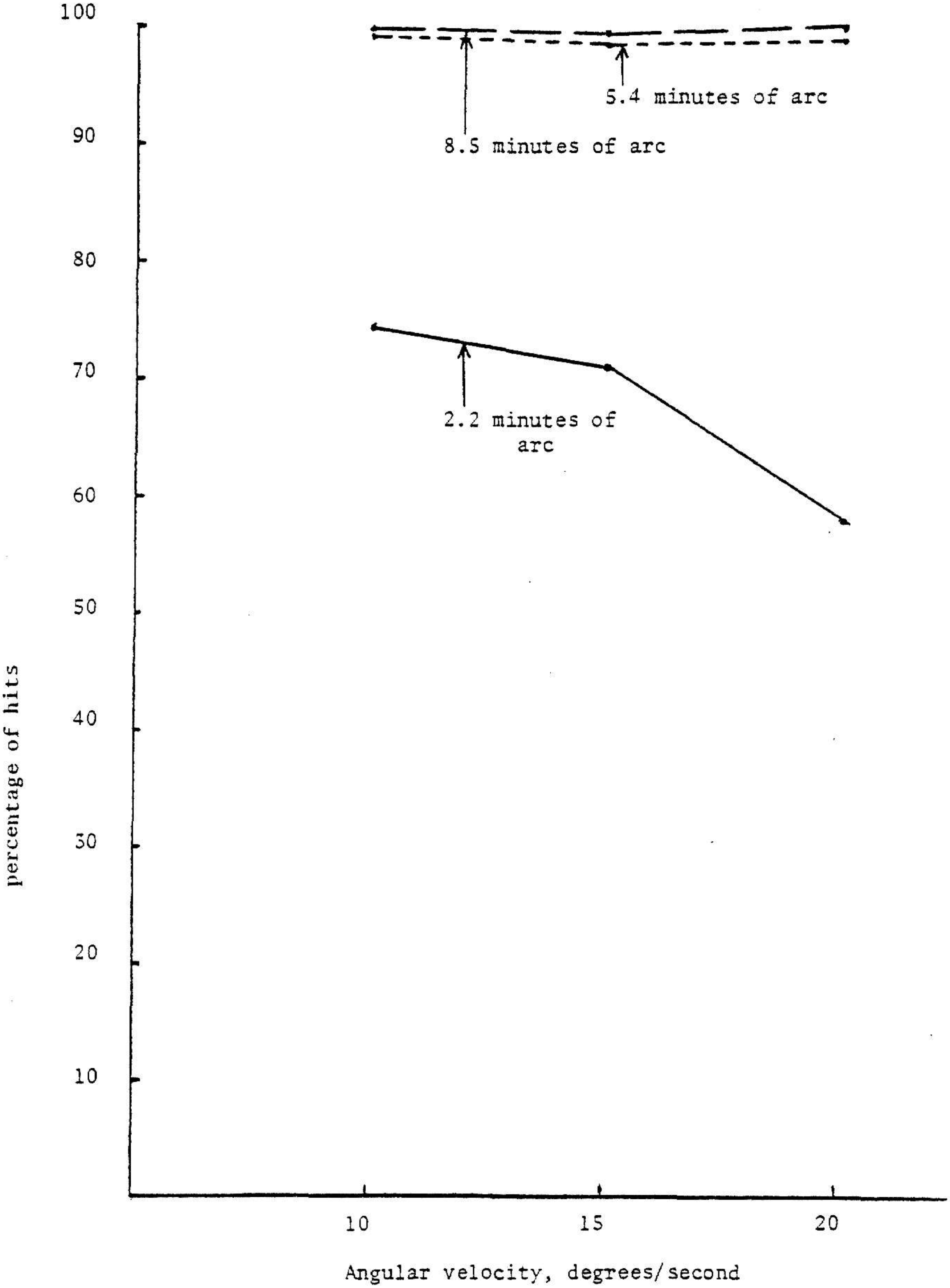

Figure 14. Angular velocity vs. hits at different visual angle.

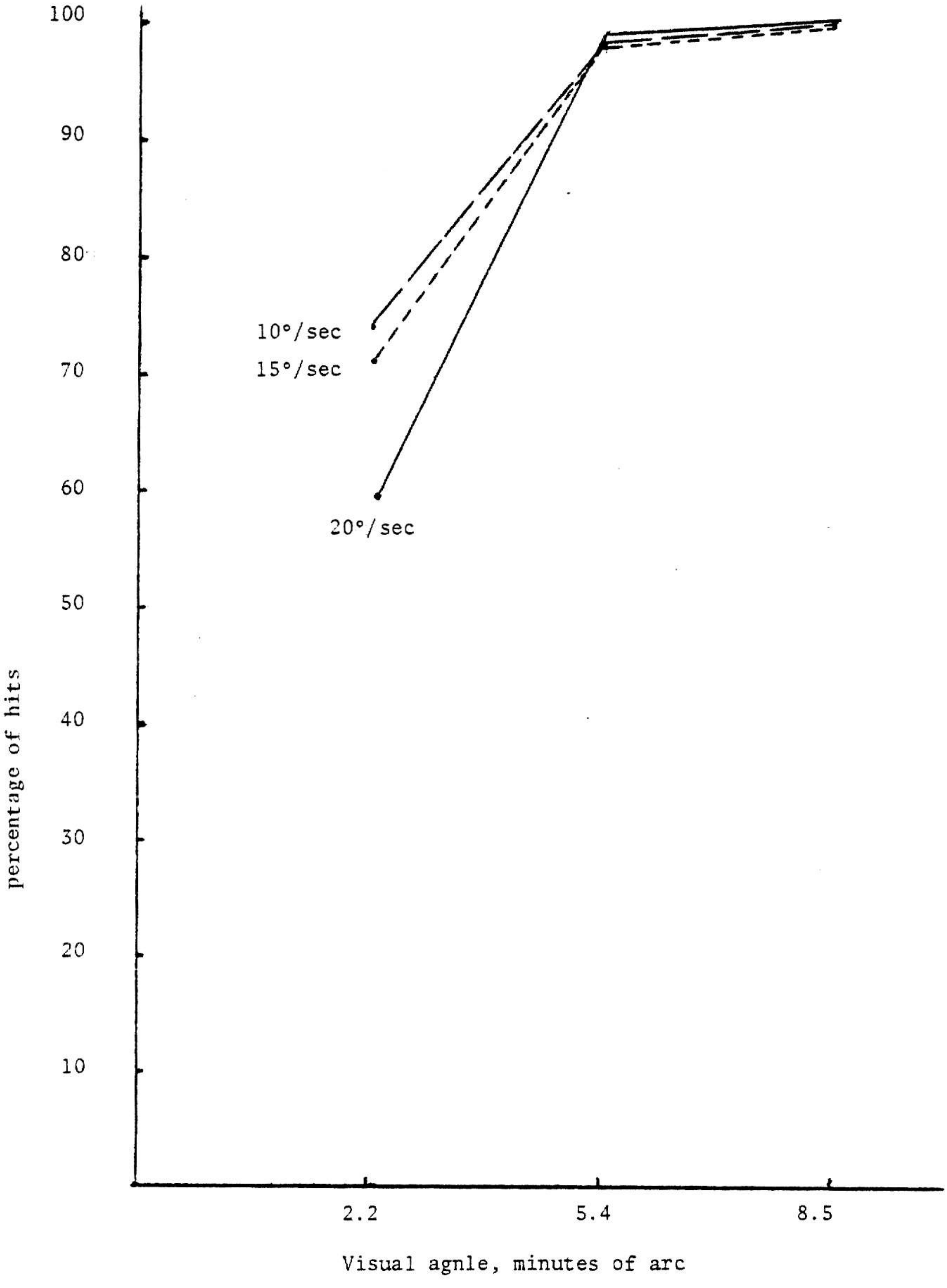

Figure 15. Visual angle vs. hits at different angular velocity.

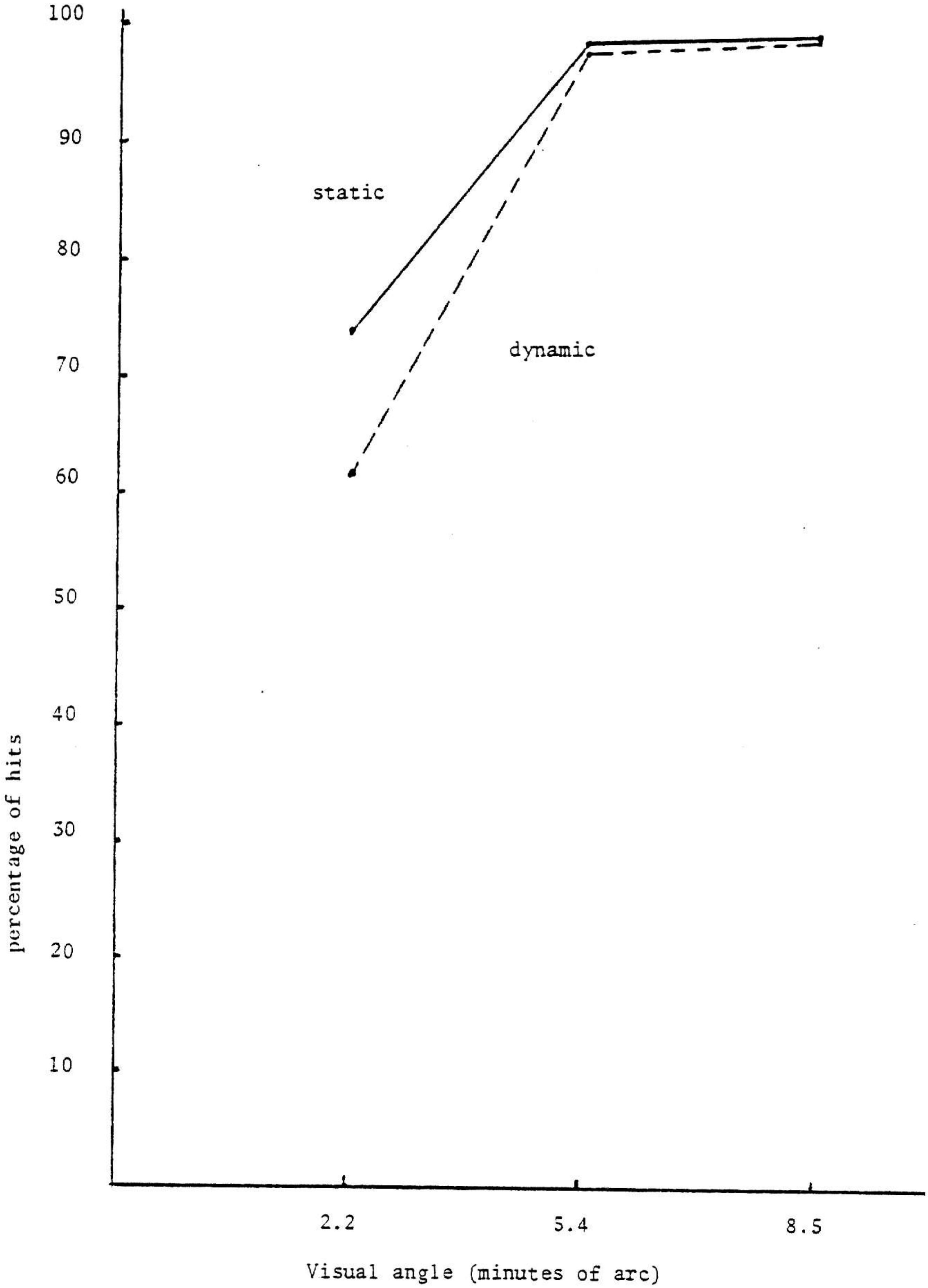

Figure 16. Visual angle vs. hits at different display.

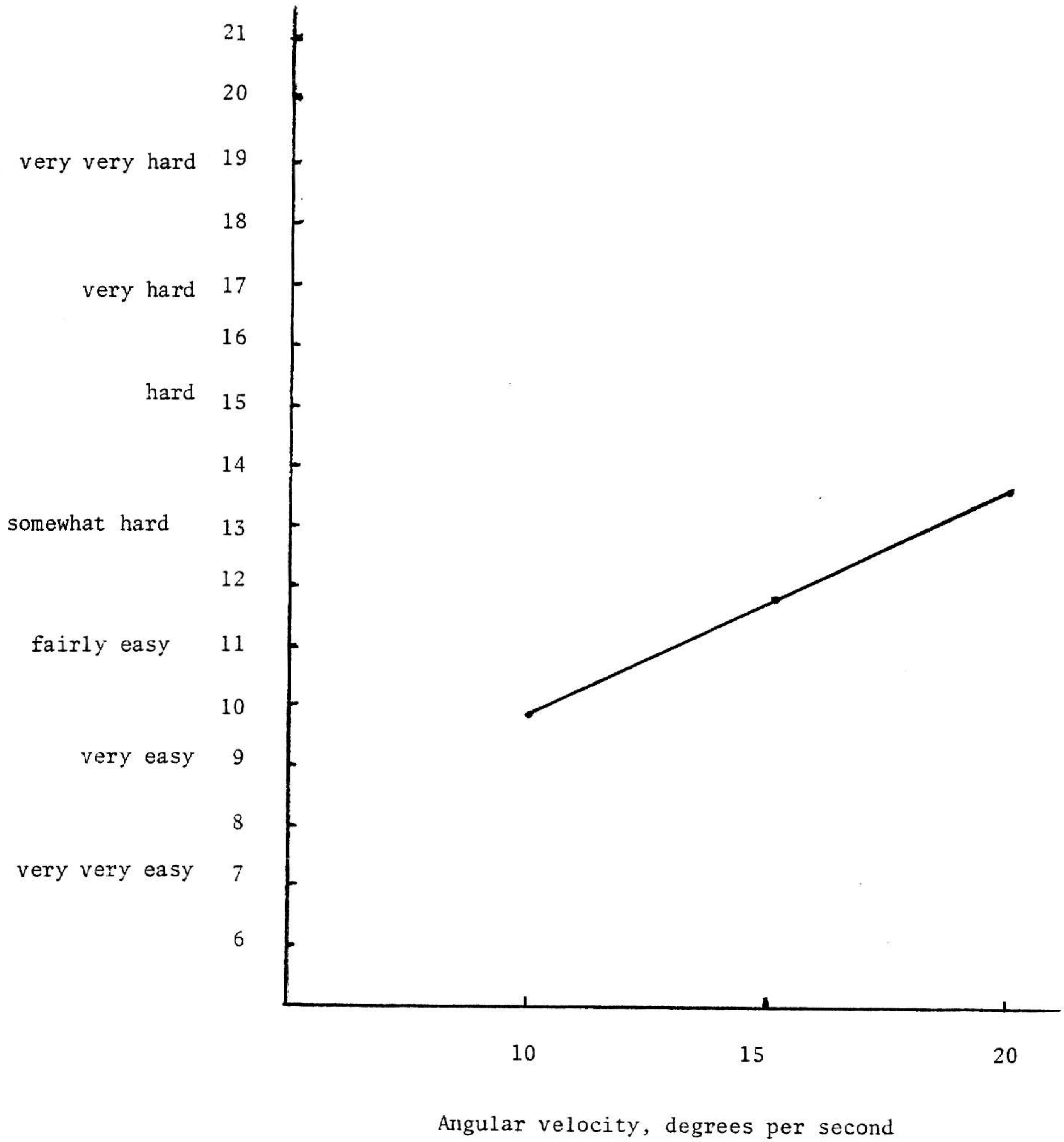

Figure 17. Mean value for Borg scale ratings across angular velocity.

Williges and Streeter (1972) found that static display resulted in fewer false alarm errors but found no differences overall between display modes in terms of defect detections. This is contrary to the results of the present research. However, Williges and Streeter defined a static situation as an inspector's paced task, which is different from the definition of the static display in this research, so the result is not comparable. The interaction between display and size in Figure 16 shows that both displays with the larger defect size yield good performance, while dynamic display with the small defect size is especially poor. The hits drop sharply when visual angle is smaller than 5.4 minutes of arc, so further study should be concentrated on the smaller defect sizes.

Conveyor belt speed (angular velocity)

Figures 10 and 11 show that acceptances at 10 and 15 degrees per second were different than at 20 degrees per second. It appears that the high angular velocity (20 degrees per second) yields slightly better correct acceptances but fewer hits than the others. With the fixed space between the targets, high angular velocity means short inspection time allowed (5.32 seconds per unit, 3.47 seconds per unit, 2.63 second per unit for 10 degrees per second, 15 degrees per second, 20 degrees per second). Studies done by Fox, Perry and Sinclair, reported that a shorter time to view yields high correct acceptances and lower rejection rate because there is little time to make false alarms.

Williams and Borow (1963) found that performance began to decline between eight and sixteen degrees per second, while this experiment found that at up to 15 degrees per second the results hardly changed. Further study could be made on higher angular velocity inspection tasks.

Defect size (visual angle)

Figure 13 indicates the size effect in relation to misses (and hits). It is obvious that the smaller the defect size, the lower the percentage of hits. When the size gets smaller, the defects become harder to distinguish, so the percentage of hits decreases. This supports Wei and Konz's (1978) finding that a small defect size produces more inspection errors. Smith and Adams (1971) found that time per correct inspection was minimal when the magnified image was 8 to 12 minutes of arc. In this experiment, the size of 8.5 minutes of arc had the highest percentage of hits at the fixed period of time.

Fortuin (1970) plotted the threshold line of size versus contrast for a luminance of 10 cd/m^2. He recommended a size at least 2.5 times threshold for easy seeing. The contrast for this experiment is 51%. According to Figure 2, the size of 2.2 minutes of arc is classified as "seeing with mental effort", while 5.4 and 8.5 minutes of arc are "easy seeing". Further study could concentrate on the sizes smaller or larger than the range studied.

The interaction between speed and size in Figure 15 shows that the large visual angle with any velocities had the highest hits. It supports in part the second hypothesis in which the inspector will detect more defects with the longer viewing time and larger defect size. However, the hypothesis for the higher correct acceptances at large size and slow speed was not supported by this research, due to the fact that when more time was allowed, more false alarms occurred. It would be of interest to do further study on a smaller visual angle and higher angular velocity situation.

Borg scale ratings

Figure 17 shows that the subjects in the lowest or highest angular velocities evaluated the task as very easy or somewhat hard. The ratings are a linear function of angular velocity. Subjects made higher ratings for higher velocity.

Percentage of correct decisions

Ou (1979) demonstrated the calculation of percentage of correct decisions.

Let x = probability of "good items" in the experiment

$1-x$ = probability of "bad items" in the experiment

P = probability of correct acceptances

q = probability of hits

Then A = total probability of correct decision

$= x(P) + (1-x)\,q$

In this experiment, x was fixed as 99 percent, therefore $A = .99\,P + .01\,q$. Table 28 shows the percentage of correct decisions in different situations. Since the defect rate was only one percent, the false alarms became a dominant factor for percentage of correct decisions. However, the percentage of correct decisions was above 99 percent for all the conditions; further study should be investigated on higher defect rates and a more complicated task.

Economic analysis

A cost analysis was carried out to demonstrate the optimal speed on an economic basis. This research studied two kinds of labor cost – 5 dollars per hour and 10 dollars per hour, with four costs of making type I and type II errors (.5, 1, 5, 10 dollars per error). There were a total of thirty-two cost combinations.

TABLE 28

Calculations for A (total probability of correct decision)

A = .99 (correct acceptances) + .01 (hits)

Display	Speed	Size	No. of subjects	A	
		2.2		99.6965	
	10	5.4	15	99.8399	
		8.5		99.8598	
		2.2		99.6930	
Static	15	5.4	15	99.8631	
		8.5		99.8664	
		2.2		99.5731	
	20	5.4	15	99.9065	
		8.5		99.9498	
		2.2		99.6366	
	10	5.4	15	99.9198	
		8.5		99.8832	
		2.2		99.5965	
Dynamic	15	5.4	15	99.9032	
		8.5		99.9366	
		2.2		99.4966	**
	20	5.4	15	99.9733	
		8.5		99.9933	*

The function of total cost was derived where

T = (inspection cost/unit) (no. of units)

+ (type I error cost/error) (no. of type I errors out of total no. of units)

+ (type II error cost/error) (no. of type II errors out of total no. of units)

Since display wasn't a significant factor, only speed and size were studied. The number of units for each combination = (20 units/person) (30 people) = 600 units. Table 29 shows the labor cost for inspection at five dollars per hour and 10 dollars per hour. Tables 30 through 32 show the total cost for different price combinations at 10 dollars per hour labor cost.

Labor cost. When labor cost is five dollars per hour, it cost only $4.44 for inspecting 2.2 minutes of arc, $2.89 for 5.4 minutes of arc and $2.19 for 8.5 minutes of arc in this experiment. The relationship is the same as 10 dollars per hour. Therefore, the labor cost is not a dominant factor for the total expenses. The idea to accelerate the conveyor and make people work harder and faster doesn't prove to be the right way to improve production.

Type I cost < Type II cost. When the cost of type I is cheaper than type II, (Table 30), the main factor affecting total cost is the number of type II errors. The cost at 20 degrees per second is greater than at 10 or 15 degrees per second. Figure 11 shows the relationship. In terms of size effect, it reduces as the size increases, so 8.5 minutes of arc has the lowest cost. (See Figure 13). In comparing the speed by size term, speed of 20 degrees per second and size of 2.2 minutes of arc was most expensive, while the same speed with size 8.5 minutes of arc was the cheapest mainly due to the extremely low misses and false alarms. (See Figure 14).

TABLE 29

Calculations for cost per unit (5 $/hr, 10 $/hr)

Speed	Time (sec/unt)	Unit/hr	Inspection cost/unit 5$/hr	10 $/hr	cost/600 unit 5 $/hr	10 $/hr
10	5.32	676	.0074	.0148	4.44	8.88
15	3.47	1037	.0048	.0096	2.89	5.76
20	2.63	1368	.0037	.0073	2.19	4.38

TABLE 30

Calculations of Total Cost (Type I < Type II)

Speed	Size	No. of type I	No. of type II	TC I=.5 II=1	TC I=.5 II=5	TC I=.5 II=10	TC I=1 II=5	TC I=1 II=10	TC I=5 II=10
	2.2	90	310	364	1604	3154	1649	3199	3559
10	5.4	134	10	83	123	173	190	240	776
	8.5	153	2	83	91	101	167	177	790
	2.2	87	340	392	1752	3452	1787	3496	3844
15	5.4	127	14	83	139	209	203	273	781
	8.5	117	2	65	73	83	131	141	609
	2.2	61	498	537	2529	5019	2560	5050	5294
20	5.4	61	12	48	96	156	127	368	431
	8.5	34	0	21	21	21	38	38	174

TABLE 31

Calculations of Total Cost (Type I = Type II)

Speed	Size	No. of Type I	No. of Type II	TC I=.5 II=.5	TC I=1 II=1	TC I=5 II=5	TC I=10 II=10
	2.5	90	310	204	409	2044	4089
10	5.4	134	10	75	150	749	1498
	8.5	153	2	80	159	797	1594
	2.5	87	340	218	436	2179	4359
15	5.4	127	14	73	147	734	1468
	8.5	117	2	62	123	617	1234
	2.2	61	498	284	568	2839	5679
20	5.4	61	12	39	79	394	788
	8.5	34	0	19	38	192	384

TABLE 32

Calculations of Total Cost (Type I > Type II)

Speed	Size	No. of Type I	No. of Type II	TC I=1 II=.5	TC I=5 II=.5	TC I=5 II=1	TC I=10 II=.5	TC I=10 II=1	TC I=10 II=5
	2.2	90	310	254	614	769	1064	1219	2259
10	5.4	134	10	145	681	686	1351	1356	1396
	8.5	153	2	158	770	771	1535	1536	1544
	2.2	87	340	266	614	784	1049	1219	2579
15	5.4	127	14	140	648	655	1283	1290	1346
	8.5	117	2	122	590	591	1175	1176	1184
	2.2	61	498	319	563	812	868	1117	3109
20	5.4	61	12	73	317	323	622	628	676
	8.5	34	0	38	174	174	344	344	344

Type I cost $\geq$ type II cost. When the cost of type I error is equal or more expensive than type II error, the main factor would be the number of type I errors. (See Tables 31, 32). Therefore the cost at 20 degrees per second is less expensive than at 10 or 15 degrees per second. (See Figure 10). In terms of visual angle, the cost is less expensive for bigger visual angle. For speed by size, the costs become irregular, depending on the number of type I and type II errors. (See Figure 15).

This analysis strengthened the statistical findings of the speed and size effect in this research. Since the cost of making type I and type II errors varies for different kinds of products, the total costs would depend heavily on the number of type I and type II errors. In other words, the higher the cost of type I errors, the greater the effort should be to eliminate them. A compnay should conduct an experiment based on their particular defect size, then determine the set speed for their particular system, through an economic analysis.

Future research

Research on the relationship between defect sizes and speeds could be pursued further in both dynamic and static display, since the results of this research does not quite agree with the previous findings.

Further research could be done by using higher defect rates, higher angular velocities (over 15 degrees per second) and smaller visual angles (beyond 5.4 minutes of arc).

Practical implications

This study showed inspection performance improved with increasing defect size. Also, hits increased with decreasing speed, but correct acceptances tended to decrease slightly with low speeds. Management should be aware of the relationship between speed and size for their particular products.

Another finding of this study is that the performance of static and dynamic display were quite similar to each other. As long as there is enough time allowed to perform the inspection, the type of display will not affect to results. Since the individuals were quite different, inspector selection is important.

The main factors for controlling the total cost were found to be the number of type I and type II errors. Labor cost is only a small portion of the total cost. Therefore, instead of increasing inspector speed, it would be more profitable to adjust the speed to the minimum errors.

CONCLUSIONS

1. The angular velocity and subject within display were significant for false alarms (and correct acceptances).
2. The angular velocity and visual angle had a significant influence on misses (and hits). In addition, the interaction between angular velocity and visual angle, display and size and subject within display were also significant.
3. There was no interaction between the display and angular velocity over the range studied.
4. The type of display was significant for hits at one tail t-test, ten percent significant level.
5. Defects detected (hits) decreased with reduction in defect size as in previous study.
6. Defects detected (hits) increased with the decreasing angular velocity.
7. The process of selecting good inspectors is important for good performance.
8. The angular velocity affects the number of type I and type II errors directly, therefore adjusting the speed to the minimum errors is more effective than making workers work fast.
9. The Borg scale ratings indicated that the lower the angular velocity, the easier the subject found the task.
10. It was suggested that the factors like task complexity, smaller visual angle, higher angular velocity and higher defect rate should be studied.

APPENDIX 1

The distributions of the defects.

Pattern No.	Row	Column	Pattern No.	Row	Column
1	9	7	16	0	0
2	3	9	17	7	4
				3	2
3	8	5	18	0	0
4	9	2	19	3	5
	2	2		6	1
5	0	0	20	1	5
6	4	9	21	8	8
7	0	0	22	9	6
8	6	8	23	9	3
9	1	5	24	4	4
	2	6		1	8
10	6	3	25	0	0
11	3	4	26	0	0
	6	6			
12	3	4	27	4	4
				8	9
13	8	6	28	0	0
	3	7			
14	2	8	29	2	4
15	0	0	30	2	6

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DEFECT SIZE, ANGULAR VELOCITY, STATIC AND DYNAMIC DISPLAY AND INSPECTION PERFORMANCE

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ABSTRACT

This study investigated the effects of velocity, defect size on static versus dynamic display in an inspection task. Three velocities were used. They were: 10 degrees of visual angle per second, 15 degrees per second and 20 degrees per second. One percent defects were randomly distributed with the defect size of 2.2 minutes of arc, 5.4 minutes of arc and 8.5 minutes of arc. The search parameters were correct acceptances (and false alarms,) hits (and misses), percentage of correct decisions and Borg scale ratings.

The static situation showed better hits than the dynamics display at one tail t-test, ten percent significant level. Hits decreased with reduction in defect size and increased with the decreasing angular velocity. The Borg scale rating indicated that the lower the angular velocity, the easier the subject found the task. It was observed that the process of selecting good inspectors is necessary for good performance. The angular velocity affected the number of type I and type II errors directly. Therefore, instead of trying to get people to work fast , it's more effective to adjust the speed to the minimum errors.