AN ANALYSIS FOR IMPROVING
TACTILE INSPECTION PERFORMANCE

by

SIDDHARTH BALVANTRAI DESAI

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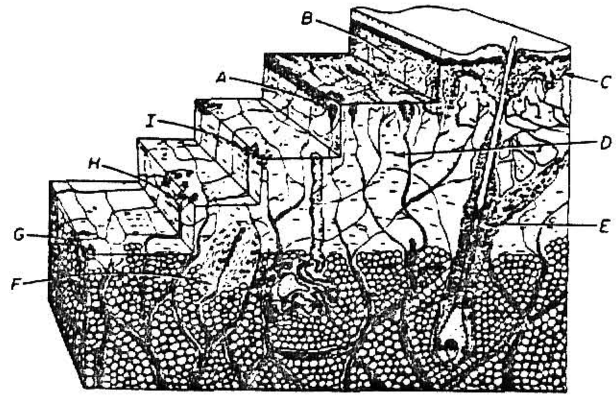
INTRODUCTION

LITERATURE REVIEW

The world we live in is primarily a visual one. From vision we can determine the shape, size, and orientation of an object. This information is obtained very rapidly and accurately. Studies abound showing the dominance of vision, and vision is more accurate than touch for spatial discrimination (Bryant and Raz 1975, Cashdan 1968, Milner and Bryant 1970). But these studies tend to overlook the perceptual activities for which the tactual system is better designed, including texture perception. According to Lederman (1978), texture perception is an interesting area of research in its own right.

Perceiving the texture of a surface by touch is a multimodal task in which information is available from several different sensory sources. In addition to cutaneous and thermal input, kinesthetic, auditory, and visual cues may be used when texture is perceived by touching a surface. Texture perception by touch, therefore, offers an excellent opportunity to study both the integrated and independent actions of sensory systems. In Niesser's (1976) terms, texture perception is "ecologically valid".

At this stage it may be interesting to find how the glaborous skin of human hand perceives an object. Figure 1 shows the skin structure. The outer layer is called the epidermis, the inner layer is called the dermis, a vascular material containing nerve endings and living cell. The entire tactile sense system is an interlace of complex receptor networks.



A - groups of Meissner's corpuscles subserving the sensation of touch

B - beaded nerve nets subserving pain (probably fast pain)

C - Merkel's discs subserving touch

D - beaded nerve fibers derived from nerve nets subserving pain and associated with blood vessels (probably slow pain)

E - nerve terminals around the sheath of a hair subserving touch

F - a pacinian corpuscle subserving pressure

G - a group of Ruffini endings subserving warmth

H,I - groups of Krause's end-bulb subserving cold (these lie at somewhat variable depths beneath the skin surface).

Figure 1. Weddell's conception of cutaneous innervation, based on the studies described in his article in British Medical Bulletin, vol. 3 (1945), 167.

Peripheral Mechanisms

Knibestol and Valbo (1970) first demonstrated that there are four different types of low-threshhold, mechanoreceptive units in the glaborous skin of human hand. See Table 1 for the skin structure. How the nerve endings are associated with mechanoreceptive units is not well-known. Valbo and Johansson (1978) define tactile sensory mechanisms as those which provide information on the pressure and characterics of mechanical events at the body surface. Mechanoreceptive units are divided into two parts. They are slowly adapting (SA) of two types (SA1 and SA2) and rapidly adapting (RA and PC).

Valbo and Johansson state that RA and SA1 units are responsible for spatial discriminative capacity of this skin area. Particularly striking is the high density of these two unit types at the fingertips indicating that this is a skin area with an outstanding peripheral mechanism for tactile spatial analysis. Early research by Weber (1875) indicated that there were four important aspects of touch:

1) the force with which objects resist the pressure of our organs (pushing a car).
2) the object shape and the shape of the space between two objects.
3) the force with which objects press our organs and especially their weight (lifting a weight).
4) the object temperature, whether hot or cold.

Weber gave localization an important status in touch. He invented a compass test to determine the least discriminable distance. Thus he invented the concept of "two point limen", Von Frey introduced the idea of pain, pressure, warmth, and cold as sense modalities and described

Table 1. Four types of tactile sensory units in the glaborous skin of the human hand. (From Valbo A.B. and Johansson (18) in Active Touch, 1978)

Adaption	Receptive Field Characteristics Distinct borders small size several sensitivity maximum	 Indistinct borders large size a single sensitivity maximum
Rapid- No static response	RA (Rapidly Adapting)	PC (Pacinian Corpuscles)
Slow- static response	SA I (Slowly Adapting)	SA II (Slowly Adapting)

the functions of elements as shown in Figure 1. Basically, three theories of somesthesis have come into prominence (Head, 1978).

1) Classical Theory: Application and modification of Von Frey's concept.

2) Head's Theory Of Dual Sensibilities: Head (1920) stated that 'Following the peripheral section of cutaneous nerves, the recovery of sensitivity comes in two phases. First, a primitive sensitivity that enables appreciation of heavy pressures, extremes of temperature and pain, but not permitted discrimination of light touch, pressure and moderate temperature. Later on, in the second phase, discrimination improved and sensation of light touch, pressure, and moderate temperature returned'.

3) Nafe's Pattern Theory Of Feeling: Nafe introduced the idea that specialized receptors have 'no tactual basis at all'; feelings such as wet, cold etc. depend on their similarities and differences upon the 'pattern' or 'arrangement' of neutral discharges.

Research On Touch

Despite some inadequacies of the classical theory, that theory has turned out to be of significant interest in the two aspects of adaption and active touch. By adaption, it is meant that people adapt to a tactile stimuli. Active touch (haptic) is characterised by free palpation of objects. As mentioned earlier and also stated by Griffing (1895), 'the great majority of so called tactile sensations are in reality the results of complex kinesthetic and haptic sensory elements', As Gibson (1962) put it, sensory physiologists and psychologists viewed the skin as a passive 'mosaic receptor', not an exploratory organ.

But the skin exhibits far greater acuities when used with active exploration than when used with passive touch.

Katz (1925) was one of the early researchers in the field of active touch. Katz was very interested in surface texture, or 'modification' of the surface. He argued strongly for the necessity of vibration. He offered the results of several demonstrations in support of vibration for texture perception. Katz emphaised motion. His studies also included the examination of the effects of handspeed and force on the perception of surface texture. He found that perceived roughness increases with increasing force when surfaces are moved. Among the present day researchers, Lederman and her associates (1975) have studied the same concept with a series of studies. Her sensory model of tactual perception depends strongly on the width of the groove cuts, increasing with spacing. In addition, Lederman and her associates have considered the effects of hand speed and force.

Taylor and Lederman proposed a sensory model for perceived roughness involving the effects of an applied force, the groove width, and coefficient of friction. See Figure 2 for their experiment. The final model given by Taylor and Lederman (1975) is

$$Kfg = \frac{2\,G^2\,(x - \sin x)}{G^2 + LG - (1/2)\,L^2 m \sin x} \qquad (1)$$

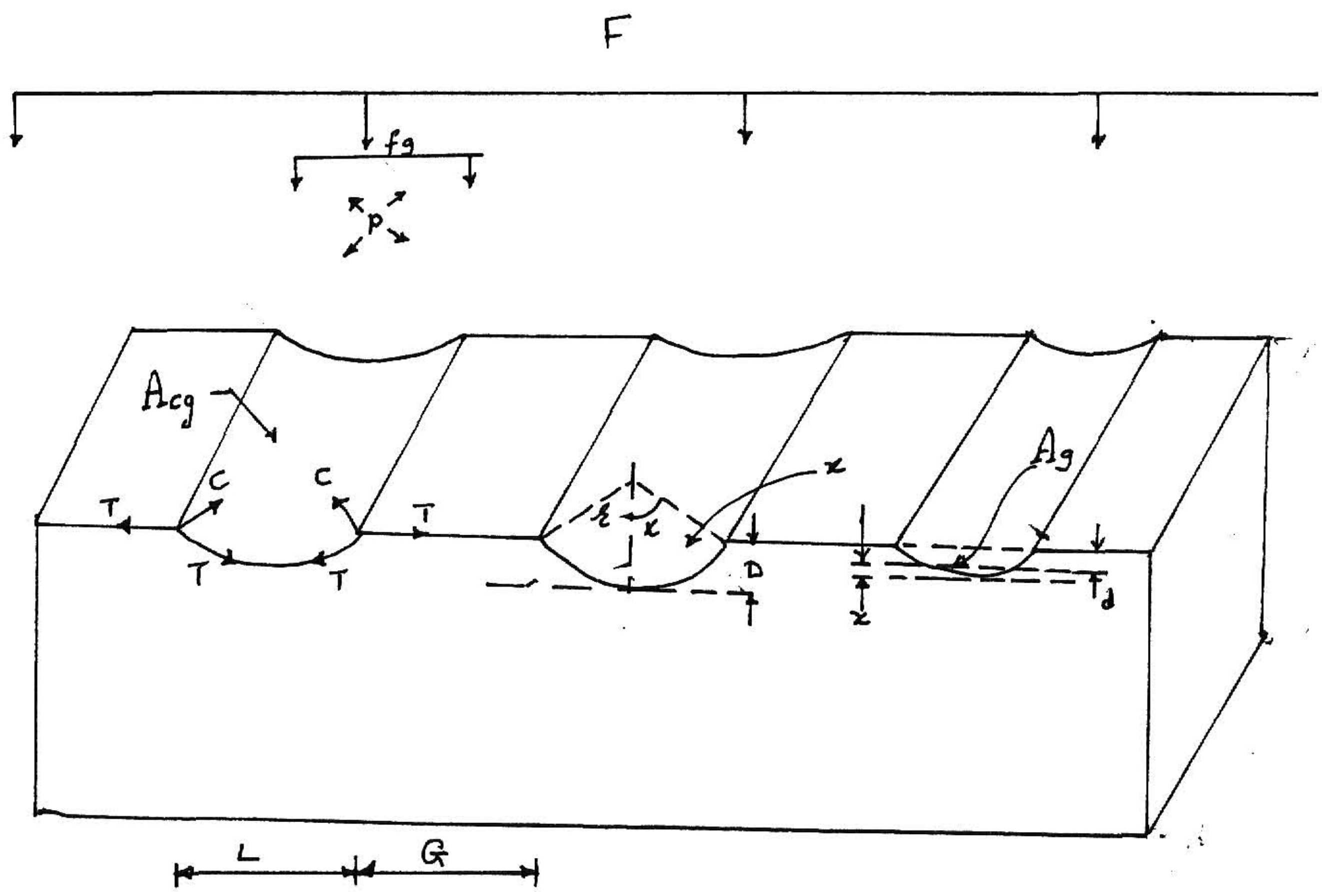
where :

Kfg - Force applied by hand (kilograms)

m - Coefficient of friction between hand and the object

G - Groove width (centimeters)

L - Distance between two grooves (centimeters)



T- Maximum skin tension

C- Maximum force at any point

P- Pressure on skin

F- Total finger force

D- Maximum depth difference between points

G- Groove width

L- Distance between two grooves

x- Maximum flexion of the skin at any point

Figure 2. The geometry of the idealised finger pressed onto a series of grooves. Different parameters are shown. The finger assumes the form of a circular arc within the groove.

x - Groove angle (degrees)

Acg - Cross sectional area of groove (cm^2)

Ag - Cross sectional area of the amount by which the skin is depressed below its mean (cm^2)

More recently, Lederman (1978) described a heightening roughness phenomenon that demands modification of her current model as described in the above equation. The modification includes the effects of skin shear as a result of relative motion between the skin and the surface. This work was derived from a simple but an intriguing result reported by Gordon and Cooper (1975). ' When a thin intermediate paper is used between the fingers and surface, and if you move the fingers along the surface with the intermediate paper, you will notice that the surface feels rougher'. Gordon and Cooper (1975) proved this for surface undulations, whereas Lederman (1978) proved the same phenomenon for surface roughness (in thousandths of an inch). To explain this, consider the different forces acting on the hand during the motion. Earlier experimental work pointed to the importance of vertical forces in the perception of roughness. The effect of shear was not evaluated. From the 'reduced shear interpretation', Lederman says that shear forces

were masked by the paper and thus perceived roughness was felt higher. So she says that the perceived roghness increased as the shearing force was reduced.

There are at least two other explanations of the above phenomenon.

One is that the paper serves as an amplifier, thereby producing travelling waves. Alternatively, the paper might serve as a filter.But these alternatives have not been studied and hence will not be discussed further.

La Motte (1977) performed a simple experiment on the apparent roughness of various fabric surfaces. He asked the subjects to rank several fabrics numerically according to the magnitude of the perceived roughness. He found that the perceived roughness decreased with an increase in weave density. His results also correspond to those of Lederman (1975).

The above discussion has been related to tactile impression and heightening of the tactile impression. Bradley (1969a,1969b) studied tactile impression and the effectiveness of an intermediate cloth with a surface. He studied the effect of gloves on control operation time and found that the effect of gloves depends on the types of gloves, the physical characteristics of the control, and the type of control operation required. Compared to the time taken for a barehanded switch operation, wearing gloves reduced the time taken for the same operation.

P R O B L E M

Parker-Hannifin Corporation, at its Manhattan facility, manufactures rubber hoses. Parker makes two kinds of hoses:

a) rubber cover hoses,

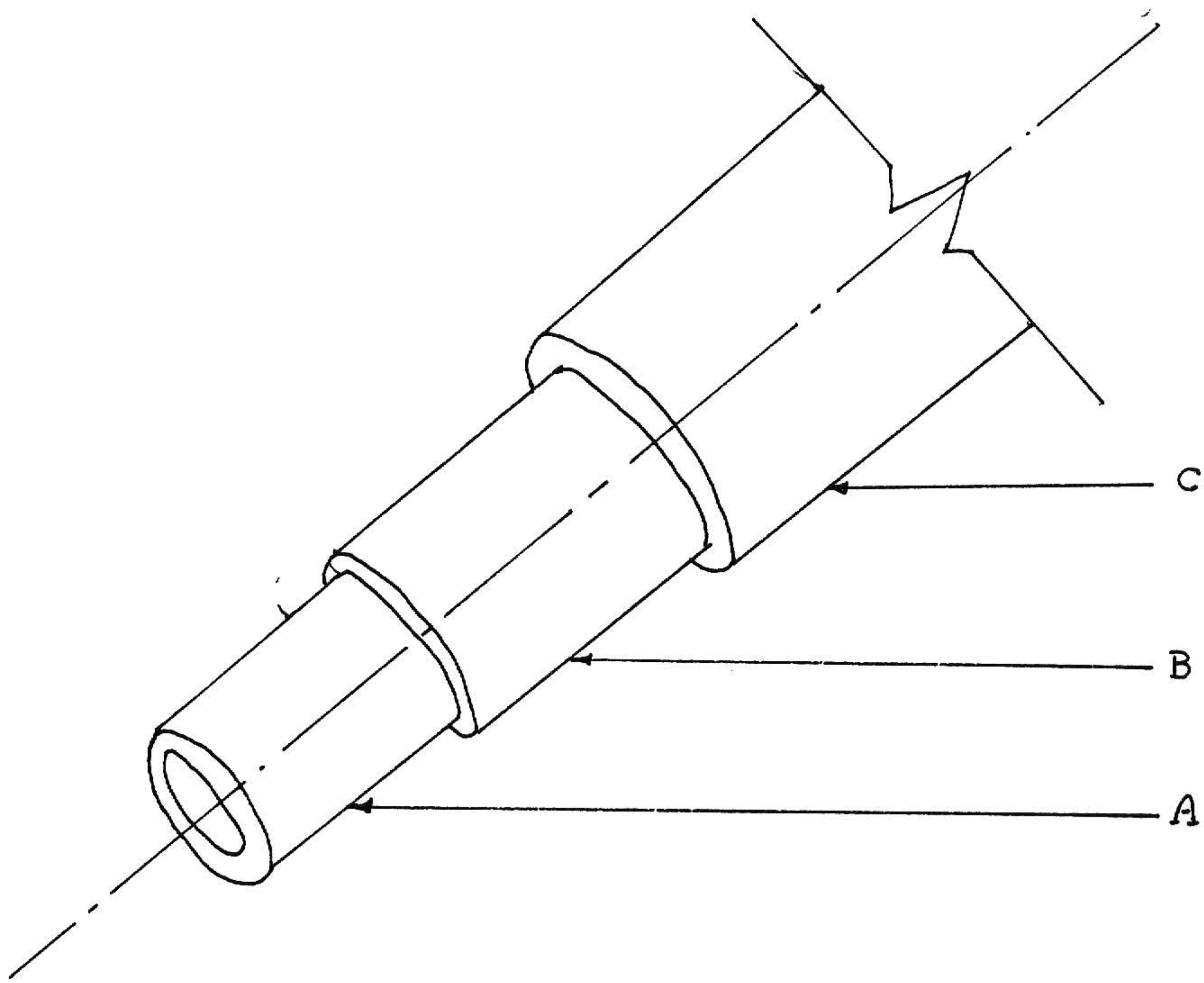
b) yarn cover hoses.

Figure 3 shows the basic construction. These hoses have to be of an acceptable quality and meet SAE or Parker specifications.

These hoses are manufactured by a stagewise manufacturing process. During these operations, the hoses are susceptible to different defects. Major stages of the manufacturing process are:

1) Extrusion A - putting the core tube on the mandrel,
2) Braid Cover - braids are put on the core tube,
3) Top Cover, extrusion B - top cover is put on the already braided material,
4) Vulcanising - the material is cured for strength,
5) Testing - at this stage, hydraulic pressure is applied to test the hoses for strength.

Although periodic inspection is done on the hoses at each station, it is still necessary to find the defects before final shipping. During the inspection at each stage, many defects can be missed because of a lack of time available by the operator at different stations. So a final inspection station was established before the pressure testing phase. At this phase, the responsibility of an inspector is to find defects in virtually completed hoses. This stage was established to safeguard



A - Core tube

B - Braid

C - Cover (Rubber or Yarn)

Figure 3. A typical hose.

against the shipment of defective hoses.

Figure 4 shows the various types of defects:

1) braid defects,

2) cover defects,

3) high outer diameter (O.D.) defects,

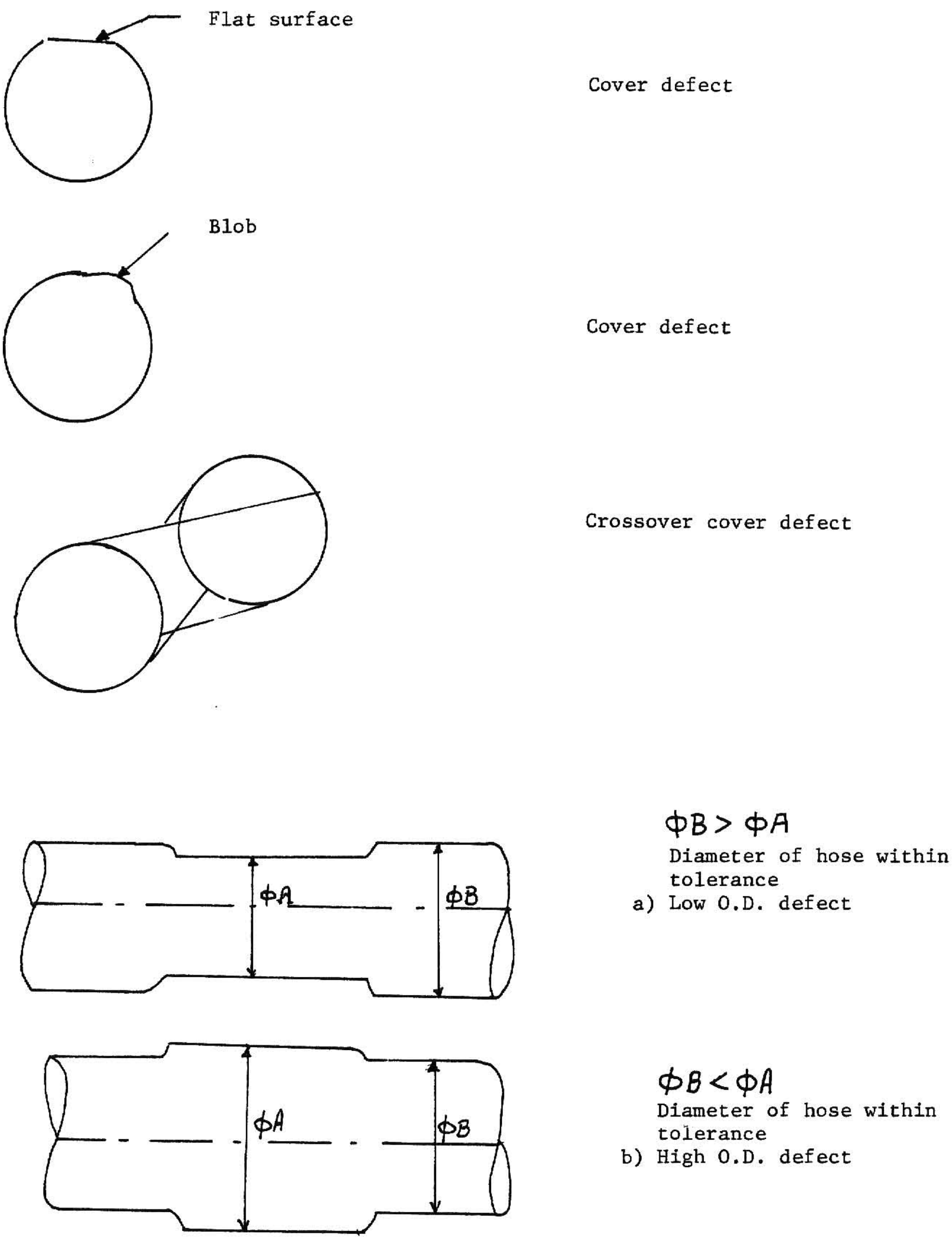
4) low outer diameter (O.D.) defects,

5) print defects.

Among these defects, the first four are determined by hand contact.

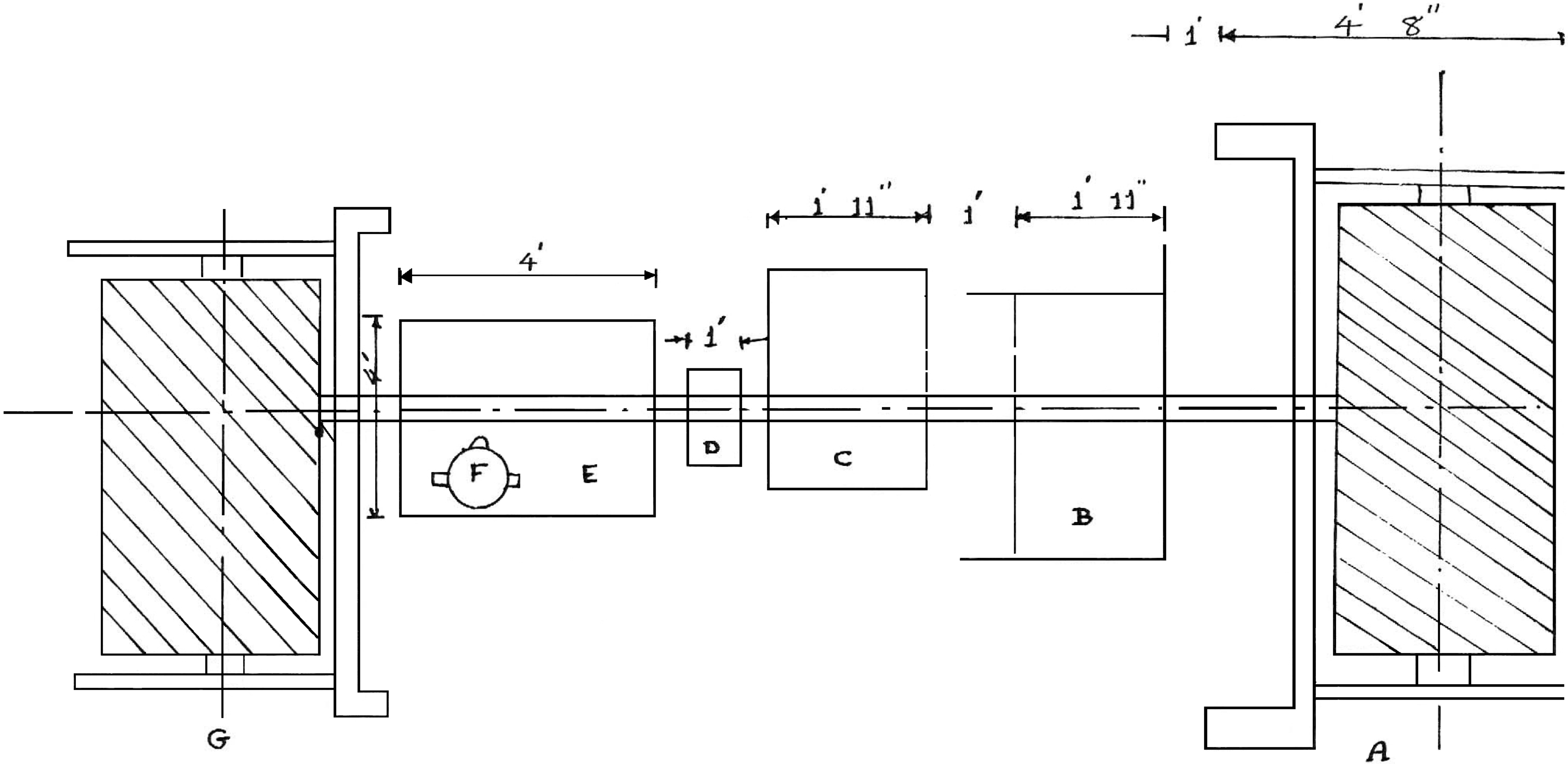
At present, there are two inspectors working on the inspection station. Figure 5 illustrates the way in which the inspection station is arranged. After vulcanizing and cable unwrap (yarn hoses), hoses come to this station. These hoses are on circular reels. At 'A', the reel is made ready for inspection in the queue. From 'A', the hose passes through 'B' and 'C', B and C are printing stations. Yarn hoses are printed here and also inspected. At 'D', a mirror is provided to aid the inspector to see the backside of the hoses being inspected. This mirror aids the inspector to see any prominent defect and print defects, which otherwise would be difficult to notice. 'F' is the inspector. She stands at station 'E' where her instruments lie. The reel on which the hose is wound on the other side is at station 'G'. The fixture here has a motor which drives the wheel (reel).

As mentioned previously, there are five different kinds of defects. Among these, the first four are detected by a continuous hand contact. The inspector holds her hand in continuous contact with the moving hose



Typical tolerance values: 100 R1 : O.D. $1.125''^{+0.031}_{-0.015}$

Figure 4. Different forms of defects



A - Unwinding wheel
B - Auxilliary device for printing
C - Printing device
D - Mirror
E - Workstation
F - Operator
G - Winding reel

Not to scale.

Figure 5. Inspector Work Station (Schematic arrangement)

as described above. This is necessary since these defects are the deformations on the outer periphery of the hoses. As described in the literature, the important idea for the inspectors is the tactile exploration of the surface. Also, this leads to the tactile discriminability of the inspectors between a good hose and a bad hose. All the hoses will have defects in terms of surface roughness and surface undulations. When a defect is identified by the inspector, she stops the motor on winding wheel 'G'. Then she puts an identification tape of an appropriate color on the hose. This identification tape helps the coilers to remove that defective segment of hose and ship the remaining good hose lengths.

At this stage of manufacturing at Parker, it seems that the present method of inspection may persist for some time. But the exact efficiency of the inspectors is not known. Also, the use of bare hands on the inspection task is felt to be quite primitive, although effective. This method of inspection leads to sore hands of the inspectors. As mentioned earlier, Gordon and Cooper (1975) described an interesting phenomenon. The orientation of gentle undulations on the surface of an object could be found more easily and accurately when a person moved fingers over an intermediate paper over the surface than when the surface is explored with bare fingers alone. Lederman (1978) also found the application of the same phenomenon on surface roughness.

Some craftsmen have been using this phenomenon in the inspection of surfaces.Gordon and Cooper (1978) learned, for example, that the inspection of Asto Martin sports cars is done by rubbing over the surface with a cotton glove in the hand.

Bradley (1969) suggested that the effect of woolen gloves was better for controlling operation time of knobs than that of a barehanded performance. But the effective thickness of an intermediate paper to help find the undulations is not described by other authors as yet. My study will be to find the effect of gloves on inspection performance and explore the avenues to improve inspection performance.

O B J E C T I V E

According to Mr. Ray Magill, Quality Engineer at Parker, there may be a few braid defects which are not detected by the inspectors. The objective of the study is to define "the effect of gloves and tactile impression heightening on rubber hose inspection". In the present task, visual inspection plays a minor role.

Another objective is to explore the avenues to improve the efficiency of the inspection process by some appropriate means.

METHOD

Task

The task required the inspection of hose samples and identifying whether there was a defect in the inspected hose sample. There were four conditions:

1) bare hand,
2) surgeon's gloves,
3) playtex gloves, and
4) vinyl-impregnated gloves.

These gloves were chosen in consultation with Mr. Magill and an Inco Safety Products Company paper (1981). Presently, vinyl-impregnated gloves are being used at Parker. Table 2 shows the different glove characteristics.

The hose samples for inspection were obtained from Parker-Hannifin. Hoses were a mixture of good and bad pieces. Since the bad pieces obtained had defect identification tape on them, the same kind of tape also was used on the good pieces. Table 3 shows the hose types used for inspection.

Three kinds of hoses were used to take into account the volume of production and the size variabilty of Parker output. Different hose sizes were necessary to insure the applicability of the findings of this study on the population of hoses being manufactured at Parker. The defects were braid, cover, high and low O.D. However, the subjects did not physically measure the O.D. of these hoses. They reported defects

Table 2. Glove characteristics

Glove type	Thickness , Thou. of an inch	Characteristics
Surgeon's Gloves	09	1. Superior dexterity 2. Sensitive 3. Strong 4. Lightweight, thin 5. Excellent grip
Playtex Gloves	15	1. Liquidproof 2. Superior tensile strength 3. Easy to put on and remove 4. Thin 5. Quite flexible
Vinyl impregnated Gloves	17	1. Substitutes for cotton, canvas or leather gloves 2. Non-slip grip 3. Flexible 4. Suitable for dexterous work 5. Quite good strength

Table 3. Hose sample dimensional characteristics.

Hose type SAE	Parker name	Number used	% Defective Diameter defects	% Defective Surface defects	Final product I.D., Inches Min/Max	Final Product O.D., Inches Min/Max
100 R1	421-6	25	28	60	0.367/0.398	0.656/0.719
100 R2	301-8	25	12	68	0.485/0.531	0.844/0.906
100 R2	301-12	25	24	72	0.735/0.781	1.125/1.188

if they found O.D. changes by means of which the inspection process is presently being carried out. The sample lengths varied in length from one foot to three feet. An orientation statement was read to the subjects before the starting of the experiment. See Appendix A. The orientation statement enabled the subjects to be familiar with the hose inspection and to discriminate between a good and a bad sample. A special fixture, as shown in Figure 6, permitted varying lengths of hoses.

Subjects were blindfolded during the experiment. This was necessary as the inspectors often checked hoses at a speed too fast for visual inspection. These speeds are sometimes as high as 200 ft/minute. The inspection process is basically a touch inspection process for common defects.

Subjects sensed the defects existing in the hose samples. If they found the defect, they told the experimenter that there was a defect. That way, it was possible to tell whether the subjects could really discriminate among different kinds of hoses.

Subjects

All the eight subjects were females (three Parker inspectors: five K.S.U. students). K.S.U. students were paid $14.00 each for the experiment lasting about 4 hours. Parker subjects were not paid. They volunteered.

Procedure and Experimental Design;

The objective of the study was to determine the percent of defects

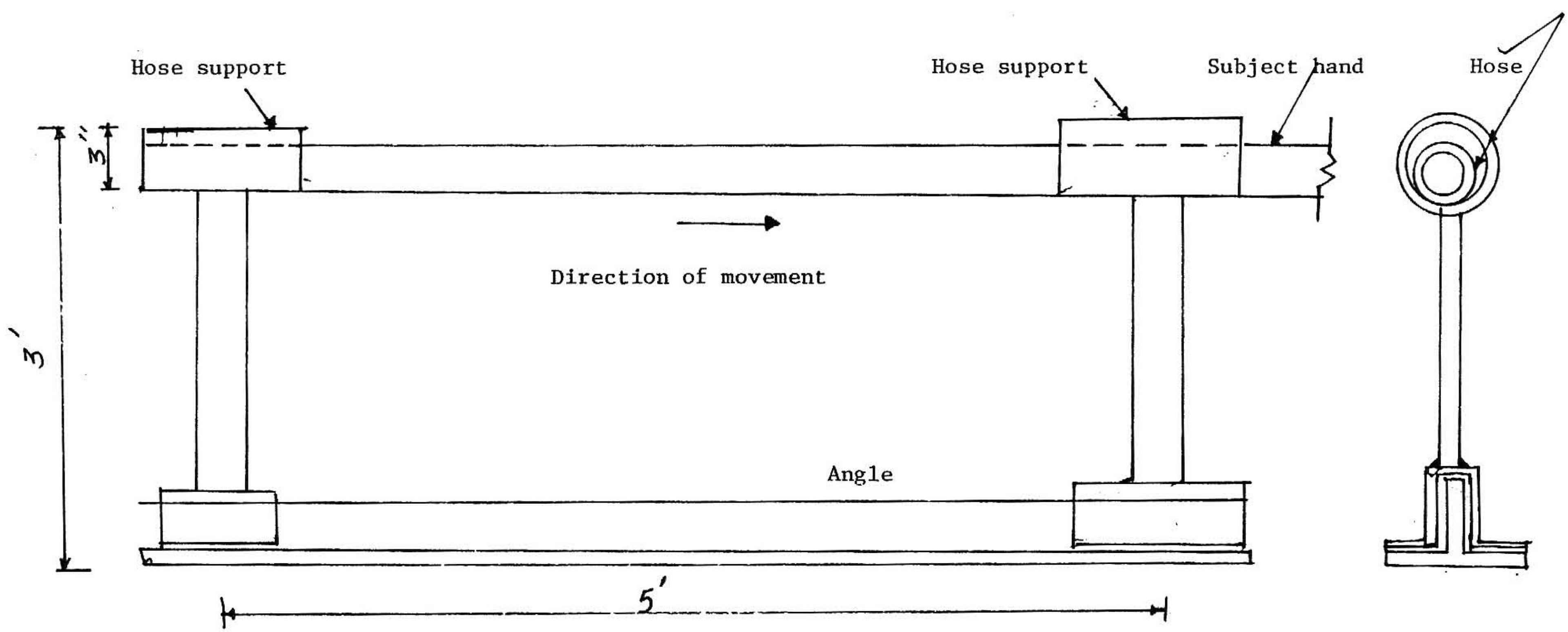


Figure 6. Fixture for inspection of hoses.

found versus the hose type and glove types. In the experiment, the independent variables were glove types (thicknesses) and hose diameters. After reading the instructions and orientation (Appendix A), subjects examined the hoses which passed through their hand. Subjects underwent four treatments (1-bare hand, 2-surgeon's gloves, 3-playtex gloves, 4-vinyl impregnated gloves). Subjects examined 25 hoses of each of three diameter varities. For each treatment, there were two replications. Each subject examined 25x2x3x4 = 600 hoses in all. Each observation took about 20 seconds.

Measurement and Insrumentation:

Figure 6 shows the experimental arrangement. Data collected were in the form as shown in Table 4.

Table 4. Observation table

Subject no.-

Hose diameter -

Glove condition -

Sr no.	Sample no.	Defects found		Actual condition	
		Dia.	Surface	Dia.	Surface

R E S U L T S

Type I and type II errors are important in inspection. Table 5 shows, for an inspection task, the relation between the two kinds of errors.

Good Samples

For good samples, the criteria chosen for analysis were 1) percent correct decisions and 2) percent incorrect rejections. Since there were no defects in the good hose samples, 'percent correct decisions' means the percent of decisions when the good sample was said to be good. However, since the incorrect rejections and the percent correct decisions are complementary, only the percent correct decisions are reported. Table 6 shows the four way analysis of variance for 1) replications, 2) subjects, 3) hose diameters, and 4) glove conditions on the percent correct decisions for diameter and surface defects. Glove conditions were not significant.

For diameter defects, replications were significant. Replication 2 had 100 % correct decisions; replication 1 had 99.8 % correct decisions. Though there is a statistical difference between the replications, this difference can be neglected for practical purposes.

Subjects and hose diameter were significant with surface defects but not with diameter defects. Subject differences were not significant because virtually every subject had 100 % correct decisions. Table 7 shows the subject means. Three Parker inspectors volunteered as subjects. All three inspectors had sufficient experience with the inspection

Table 5. Type I and type II errors

	Accept	Reject
Good product	Correct	Type I error
Bad product	Type II error	Correct

Table 6. Analysis of variance for good samples.

		Surface defects		Diameter defects	
		% Correct decisions		% Correct decisions	
Source	df	M.S.	F	M.S.	F
Replication	1	08.8	0.06	2.5	4.35**
Subject	7	2302.1	15.67**	0.68	1.21
Gloves	3	23.9	0.16	0.43	0.77
Diameter	2	3452.7	23.50**	1.14	2.04
Dia*Rep	2	115.5	0.79	1.14	2.04
Cond*Dia	6	136.6	0.93	0.86	1.54
Cond*Rep	3	37.7	0.26	0.43	0.77
Cond*Rep*Dia	6	100.3	0.68	0.86	1.54
Error	161	146.9		0.56	
Total	191				

* * alpha < 0.05

process. Although their tasks at Parker are different, the tasks are related to the hose inspection process. They are:

1) inspector 1- coiling,

2) inspector 2 - quality control,

3) inspector 3 - defect identification and actual inspection.

Inspector 1 achieved the highest percent correct decisions of 96 %. The other two Parker personnel found 91 % and 86 %, which was not much better than the average non-inspector mean of 85 %. There was no significant difference between Parker employees and the other subjects. Table 7 shows that three inexperienced subjects (number 3,6, and 7) also had a relatively good performance.

Table 8 and Figure 7 show the hose diameter differences. Errors were the least on the 0.84" hose with 95 % correct decisions. At 0.66" O.D., 86 % were correct and at 1.125" O.D., 81 % were correct.

Bad Samples:

The two dependent variables were 1) percent defects found and 2) percent defects missed. Since the two dependent variables are complementary, only the percent defects found is considered.

Table 9 shows the analysis of variance on 'percent defects found' for diameter and the surface defects. Subjects and hose diameters were significant. Table 10 shows the subject means. For surface defects, inspector 3 had the best performance with 74 % of the defects found. Inspector 2 found 67 % defects. The lowest performance of all the subjects

Table 7. DUNCAN's test on subject differences for good samples, surface defects

Subject	Mean % correct decisions	Grouping **
8 (Parker Inspector 1)	95.8	A
7	94.6	A
6	92.0	A B
3	90.6	A B
4 (Parker Inspector 2)	91.1	A B
5 (Parker Inspector 3)	86.3	C B
2	80.3	C
1	66.1	D
Overall	87.0	

** Means with the same letter are not significantly different.

Alpha = 0.05

Table 8. DUNCAN's test on hose diameter for good samples, surface defects.

Parker hose number	Diameter inches (Max.)	% Correct decision Mean	Grouping **
301-8	0.84	95.0	A
421-6	0.66	85.7	B
301-12	1.125	80.5	C

** Means with the same letter are not significantly different.

Alpha = 0.05

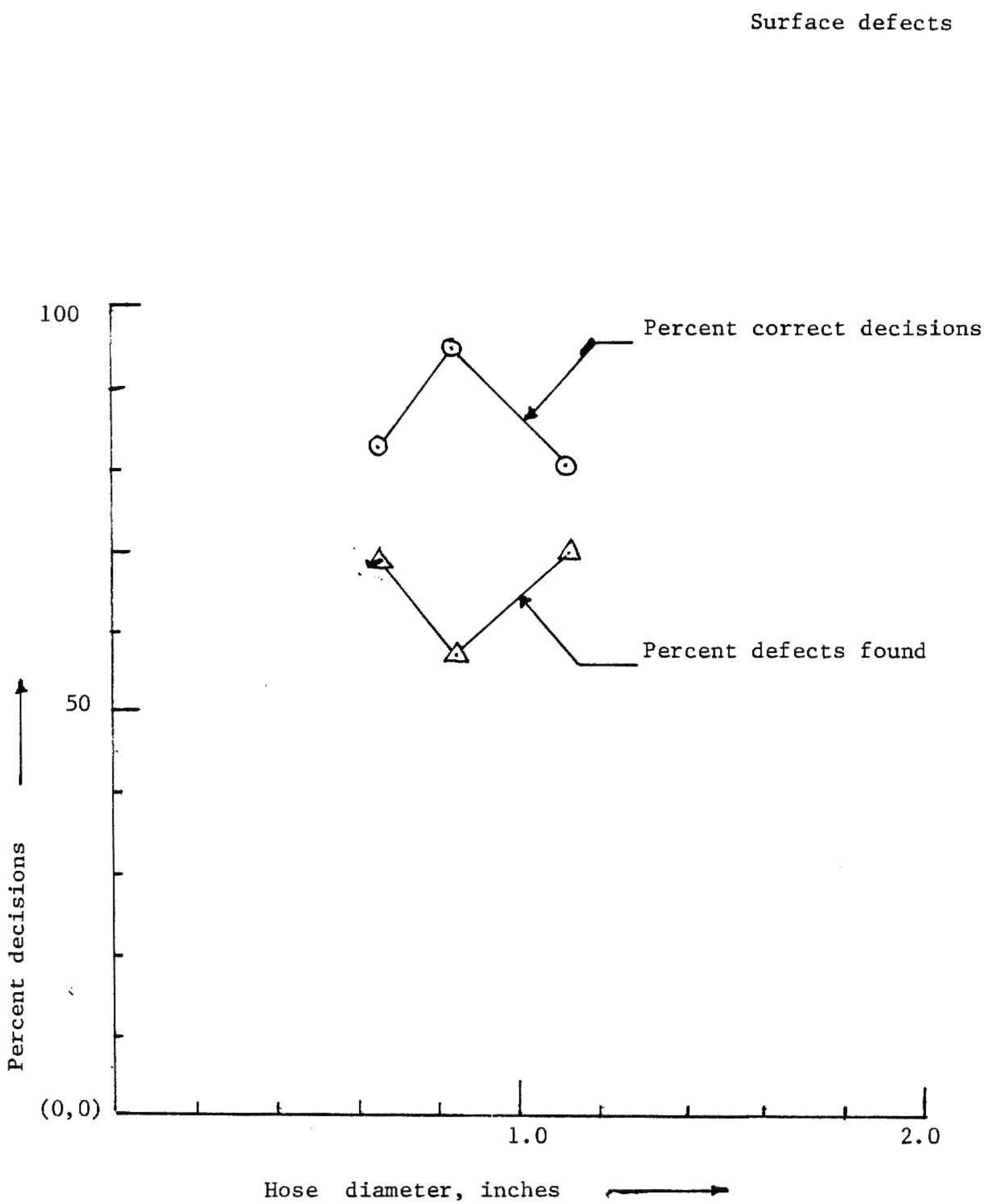


Figure 7. Performance with different diameters.

Table 9. Analysis of variance for bad samples.

		Surface defects		Diameter defects	
		% Defects found		% Defects found	
Source	df	M.S.	F	M.S.	F
Replication	1	12.9	0.11	686.7	1.30
Subject	7	985.8	8.37**	4046.1	7.68**
Gloves	3	145.7	1.24	812.3	1.54
Diameter	2	3083.7	26.18**	3780.9	7.17**
Dia*Rep	2	29.9	0.25	248.2	0.47
Cond*Rep	3	34.7	0.29	89.9	0.17
Cond*Dia	6	146.7	1.25	763.4	1.45
Rep*Cond*Dia	6	120.2	1.02	117.4	0.22
Error	161	117.8	527.00		
Total	191				

** Alpha $<$ 0.05

Table 10. DUNCAN's test on subject differences for bad samples, surface defects and diameter defects.

	Surface defects		Diameter defects	
Subject	% Defects found	Grouping **	% Defects found	Grouping **
5 (Parker Inspector3)	74.1	A	42.7	A
6	71.5	A B	31.9	A B
4 (Parker Inspector2)	67.0	B	29.4	C B
3	64.8	C B	21.3	C D
2	63.5	C	28.5	C B
1	60.5	C D	9.8	D
7	60.2	C D	43.9	A
8 (Parker Inspector1)	54.3	D	10.1	D
Overall	64.5		27.2	

** Means with the same letter are not significantly different.

Alpha = 0.05.

was of Parker inspector 1 with only 54 % of the defects found. These defects in the experimental hoses are important because they represent the majority of defects found in the hoses in the company. For diameter defects, the highest percent of defects found was 44 % by a non-Parker subject. The lowest percent of defects was 10 %, also by a non-Parker subject. Inspector 3 found 43 % of the diameter defects. She works on the inspection task. The very low percent of diameter defects found is alarming. The other two inspectors had 29 % and 10 % correct decisions. The Parker inspector mean was 65 % for the surface defects and 27 % for the diameter defects. (Non-Parker subjects found 64 % surface defects and 27 % diameter defects.). There was no significant difference between the performance of the Parker and non-Parker subjects.

Table 11 shows the DUNCAN's test on diameter means. Figure 7 shows the DUNCAN's test values plotted on the graph for surface defects. A diameter of 1.125" had the best performance. The least defects were found on 0.84". Figure 8 shows the plot of hose diameter means for diameter defects. The most defects (36 %) were found with 0.66" O.D. There was no significant difference between the 0.84" and 1.125" diameter hoses.

Overall the mean surface defects found were 64 % and the diameter defects only 27 %. Hence the type II errors were 36 % for the surface defects and 73 % for the diameter defects. The reduction of the diameter defects should be a key consideration. Table 12 shows the overall picture of inspection performance for both the types of defects.

Table 11. DUNCAN's test for hose diameter differences for bad samples.

		Surface defects		Diameter defects	
Parker hose number	Diameter inches, max.	% Defects found	Grouping **	% Defects found	Grouping **
301-12	1.125	68.6	A	36.0	A
421-6	0.66	68.4	A	23.2	B
301-8	0.84	56.5	B	22.4	B

** Means with the same letter are not significantly different.

Alpha = 0.05

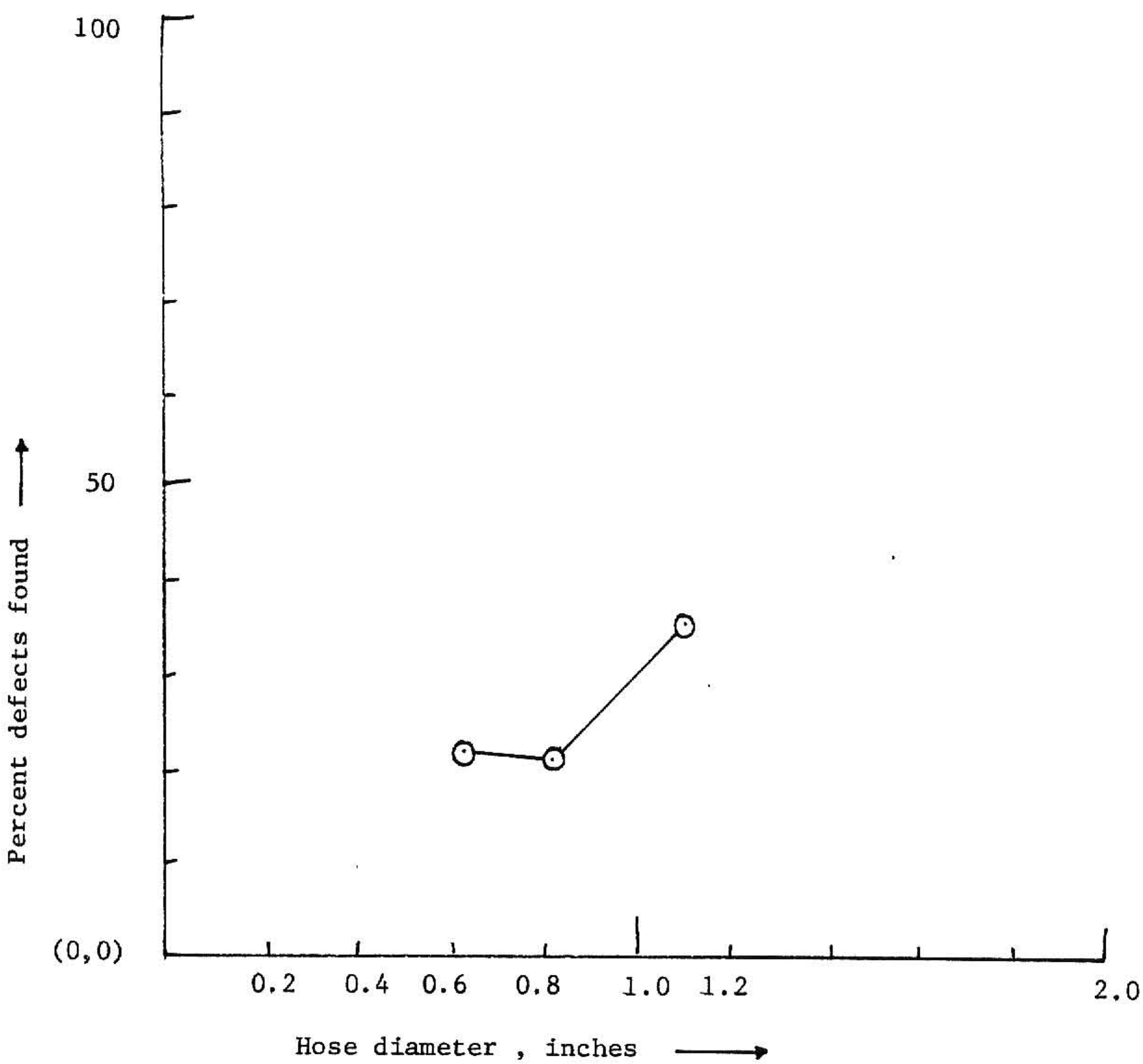


Figure 8. Performance with diameter defects.

Table 12. Type I and type II errors for both the defects.

a) Surface defects:

	Accept	Reject
Good product	87.1%	12.9 % (Type I)
Bad product	35.5 % (Type II)	64.5%

b) Diameter defects;

	Accept	Reject
Good product	99.9%	0.1% (Type I)
Bad product	72.6% (Type II)	27.4%

Signal Detection Theory Analysis:

An alternate method to look at the type I and type II errors is the theory of 'signal detection'. The two errors are referred to as false alarm rate (FAR) and miss rate (1-correct detection rate (CDR)), where,

$$FAR = \frac{\text{Frequency of false alarms}}{\text{Frequency of good items}} \qquad (2)$$

$$CDR = \frac{\text{Frequency of hits}}{\text{Frequency of bad items}} \qquad (3)$$

There are two important parameters defined in signal detection theory. Figure 9 shows the 'detectability' and the 'criterion' on the separation of 'noise' and 'signal+noise' distribution. Detectability is discussed first.

The separation of both the distributions depends on the strength of the signal. The detectability of the signal is the ratio of this separation to the standard deviation of the distributions. Detectability is usually symbolized as d^1.

$$d^1 = \frac{\mu_{p(defective)} - \mu_{p(good\ item)}}{\sigma_{p\ (good\ item)}} \qquad (4)$$

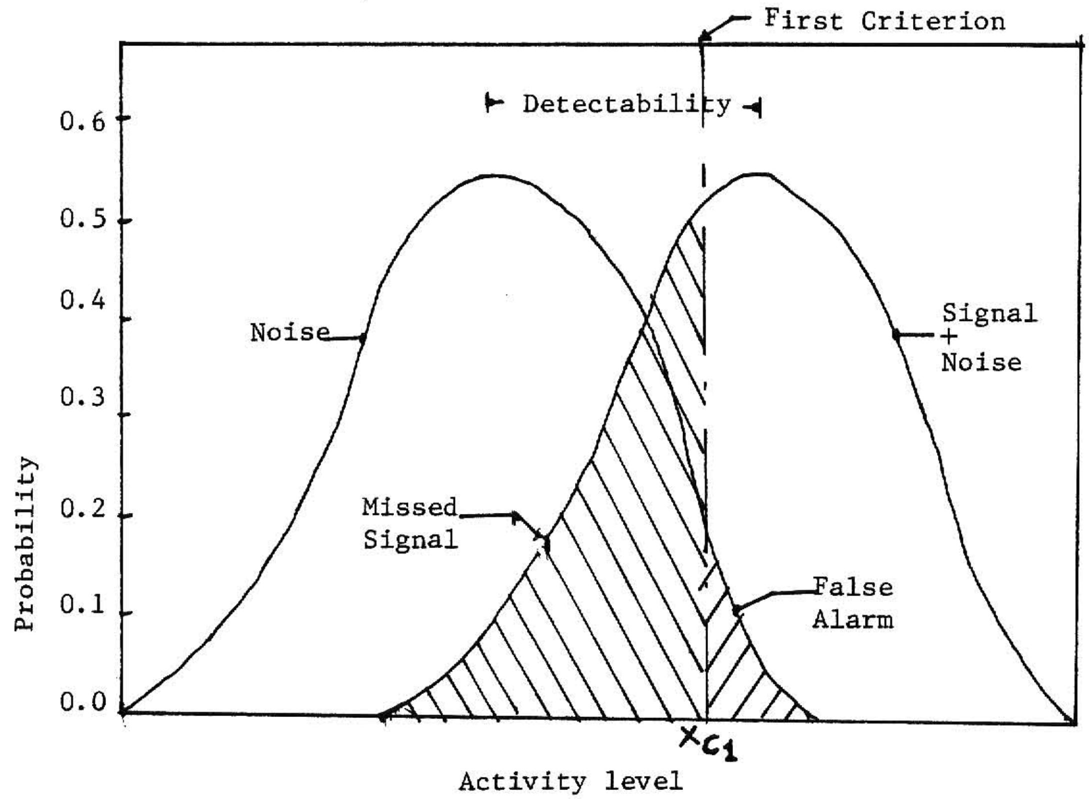
$$= z_{FAR} - z_{CDR} \qquad (5)$$

where,

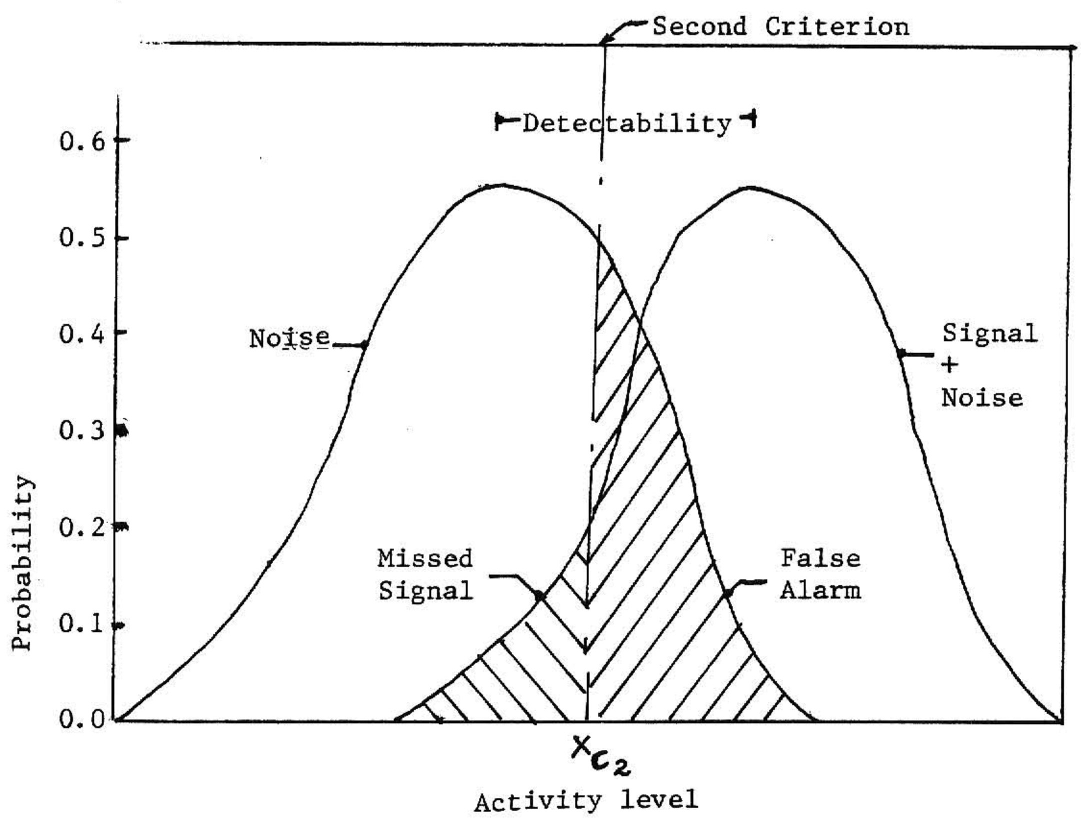
$p_{(defective)}$ = mean activity for distribution for signal and noise

$p_{(good\ item)}$ = mean activity for distribution for noise

$$z_{FAR} = \frac{\mu_{p(defective)} - x_c}{\sigma_{p(defective)}}$$



a) Decision situation, first criterion



b) Decision situation, second criterion

Figure 9. Two decision situations for inspection. Figure 9a shows a value for the criterion that gives more missed signals and less false alarms than Figure 9b.

$$z_{CDR} = \frac{x_c - \mu_{p(\text{good item})}}{p(\text{good item})}$$

x_c = criterion activity level

The only way to improve the detection rate and decrease the false alarm rate is to increase d^1 as indicated in equation 5.

Table 13 shows in three columns the average values of probability of correct detection (= 1 - p(type II)), the probability of false alarm (= p(type I)), and the corresponding values of detectability for the inspectors for the surface defects and the diameter defects. From the probability values for each inspector, d^1 can be calculated based on the equation 5. A readily available Table 1 from Appendix 1, of J.A. Swets book Signal Detection and Recognition by Human Observers, Contemporary Readings (Swets 1954) was used to find the detectabilities. For surface defects, the values of probability of correct detection are obtained by subtracting from one the mean value of defects missed for the actual defects as shown on Table 13. For example, for subject 1 and surface defects, p(correct detction) = 1-0.395 = 0.605. The probability of false alarm is equivalent to the probability of type I errors. For diameter defects, most of the probabilities for false alarm were zero. This will give a detectability of infinity - - - which is meaningless. Other workers in the field have circumvented the difficulty by calling a frequency of zero of a particular error as 'less than 1/2 an error'. For example, of 59 good samples, subject 1 said all the samples were good. For our purpose : $p(\text{false alarm}) = 1 - \frac{58.5}{59.0} = 0.008$.

The other parameter, criterion, defines accept and reject regions. Figure 9(a) shows x_{c1} as criterion 1 and Figure 9(b) shows x_{c2} as

Table 13. Values of probabilities and detectabilities.

a) Surface defects:

Subject	p(Correct detection) = 1-p(Type II)	p(False alarm) = p(type I)	Detectability (d^1)
1	0.605	0.339	0.7
2	0.635	0.197	1.2
3	0.648	0.094	1.7
6	0.715	0.080	2.0
7	0.602	0.054	1.9
Inspector1	0.543	0.042	1.8
Inspector2	0.670	0.089	1.8
Inspector3	0.740	0.137	1.7

b) Diameter defects:

Subject	p(Correct detection)	p(False alarm)	Detectability
1	0.098	0.008	1.0
2	0.285	0.004	2.1
3	0.213	0.008	1.6
6	0.319	0.008	1.9
7	0.439	0.008	2.2
Inspector1	0.101	0.008	1.0
Inspector2	0.294	0.008	1.9
Inspector3	0.427	0.008	2.2

criterion 2; x_{c1} shows higher missed signals and less false alarms for the first condition than with the criterion level x_{c2}. As shown in Figure 9, criterion is the activity level for the inspector.

Figure 10 presents a 'receiver operating curve' (ROC) for surface defects. Figure 11 presents a receiver operating curve for diameter defects. The values of p(correct detection) and p(false alarm) are plotted against each other. The curves are joined for those inspectors whose detectabilities were approximately the same. Increased probability of false alarms results in an increased probability of correct detection. Thus the curves should be expected to rise from (0,0) to reach (1,1).The dotted circle on the same detectablity curve in Figure 10 and 11 indicate a new criterion for the same inspector with higher detection and more false alarms. On which side of the curve to move can be achieved by a clear definition of acceptable and non acceptable items.

Increased d^1 results in an improved performance. For surface defects, inspector 1,2,and 3 had d^1 values of 1.84, 1.74 and 1.72. Inspector 3 could improve her performance by increasing d^1 to that of inspector 1 and moving in the direction of p(correct detection). d^1 is a true measure of difficulty of the task and outside the control of the inspector.Improvement can be sought by improving the task conditions. Inspector 3 had the highest d^1 value of 2.22 for diameter defects. Inspector 1 and 2 had 1.04 and 1.86. However p(correct detection) is very low for all the inspectors.

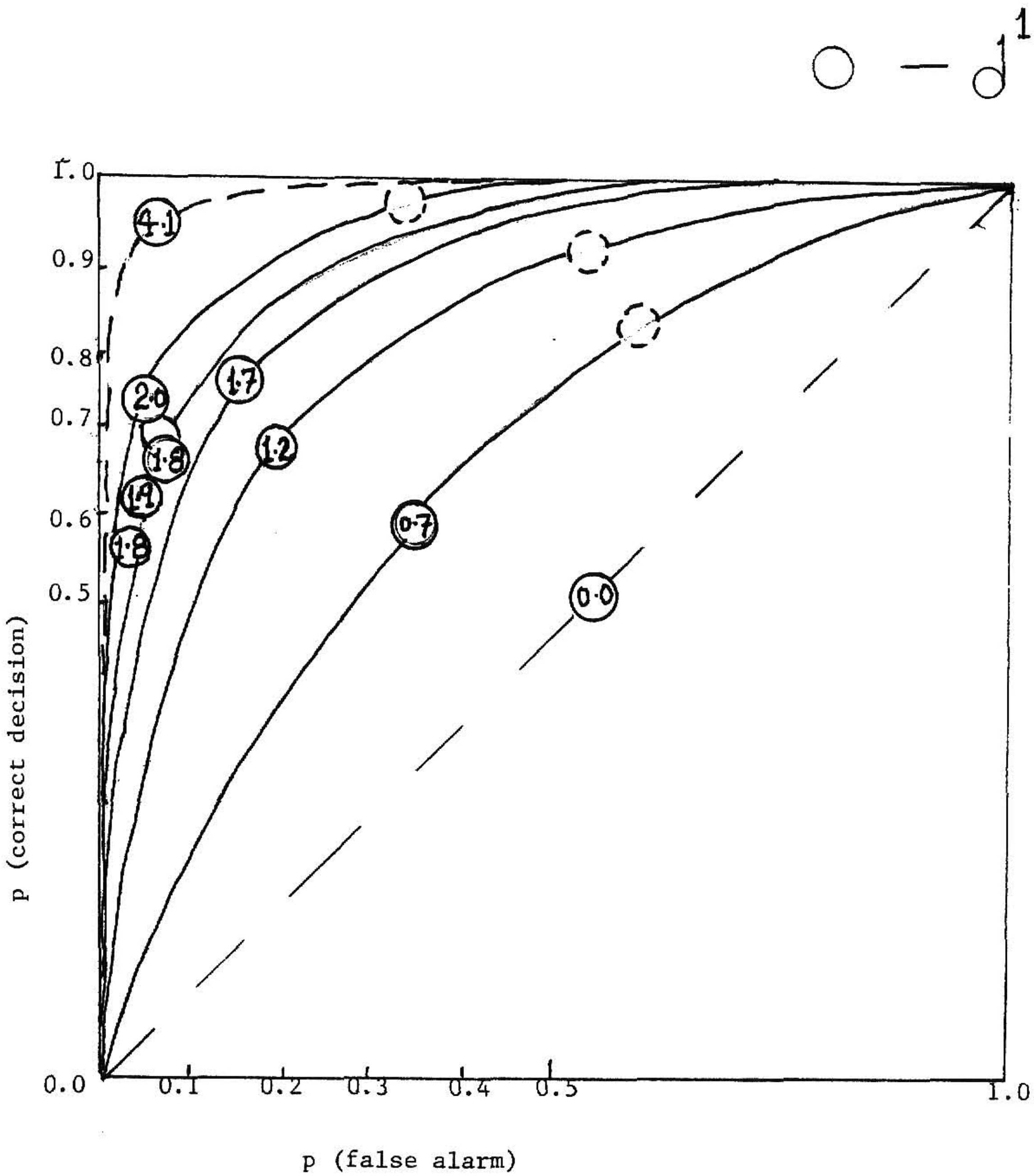


Figure 10. Inspector's mean performances, surface defects

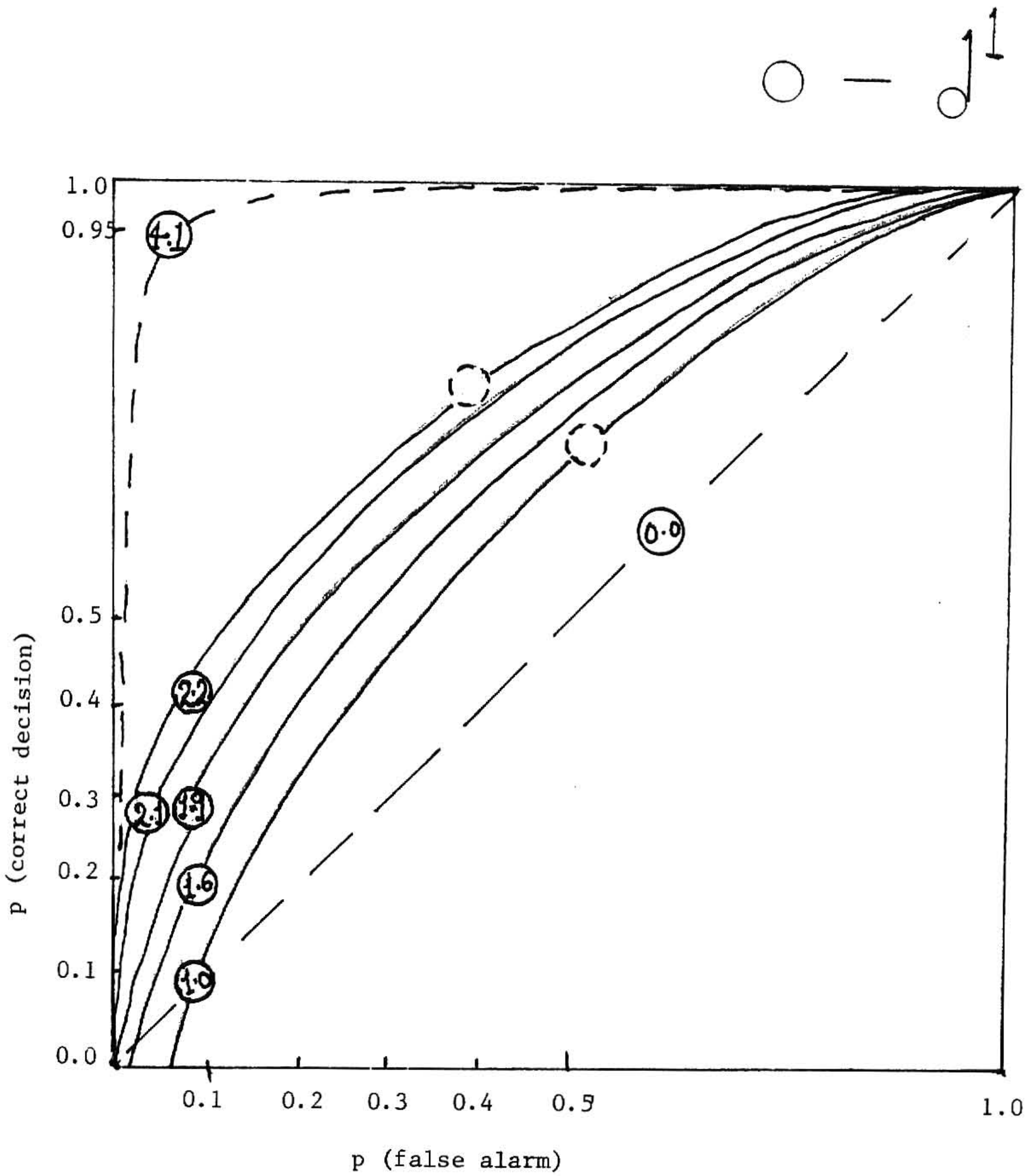


Figure 11. Inspector's mean performances, diameter defects

DISCUSSION

Subject differences were significant for the good and bad samples of surface defects, and the bad samples of diameter defects. Type I and type II errors can be opposing in nature. Fewer type I errors may be due to two reasons 1) the inspector may be very accurate in detecting the presence of a good hose sample or,

2) she may not be able to detect defects.

This second case should indicate higher type II errors. For surface defects, inspector 3 (who works on the inspection task at Parker) had the highest type I errors, but the lowest type II errors among the Parker inspectors. This result indicates that the inspector is very cautious. On the other hand, Parker inspector 1 had the lowest type I errors and the highest type II errors. She does not appear to be an accurate inspector. These results can be seen from signal detection theory view point.Inspector 1 had higher d^1 than that of inspector 3. Signal detection theory proposes that the higher is the d^1 the better is the performance. For inspector 3, to find a balance between the false alarms and the correct detections, she must reduce false alarms.

These results raise an issue for Parker management to decide the relative importance of the two types of errors. Though inspector 3 rejected more than other inspectors in the experiment, she would either stop the machine to verify the presence of a defect or she would reject a good hose sample due to a wrong signal. However, she would be stopping the running hose unnecessarily. Since there have not been problems about hoses returned from the customers at Parker, it seems reasonable to concentrate more on type I errors. Present type II error rate can be elevated a little more to increase the productivity of hose inspection process and reduce scrap, simultaneously increasing the d^1.

For diameter defects, inspector 3 had the best d^1 value of 2.22. But the correct detections are very low. This result raises a question of improving the correct detections or the type II errors. Practically, there were no incorrect rejections for diameter defects. But overall type II errors were very high. However, it must be emphasised that in the actual industrial task the inspectors are not blindfolded and so can check their tactile inspection with visual inspection.

Note that non-Parker (inexperienced) subjects can learn this process quickly. Their results generally were not significantly different from those of Parker personnel.

Glove effect including the barehanded condition was not found significant. Gordon and Cooper (1975) and Lederman (1978) concept of tactile impression heightening with an intermediate surface is not found useful in the inspection task.

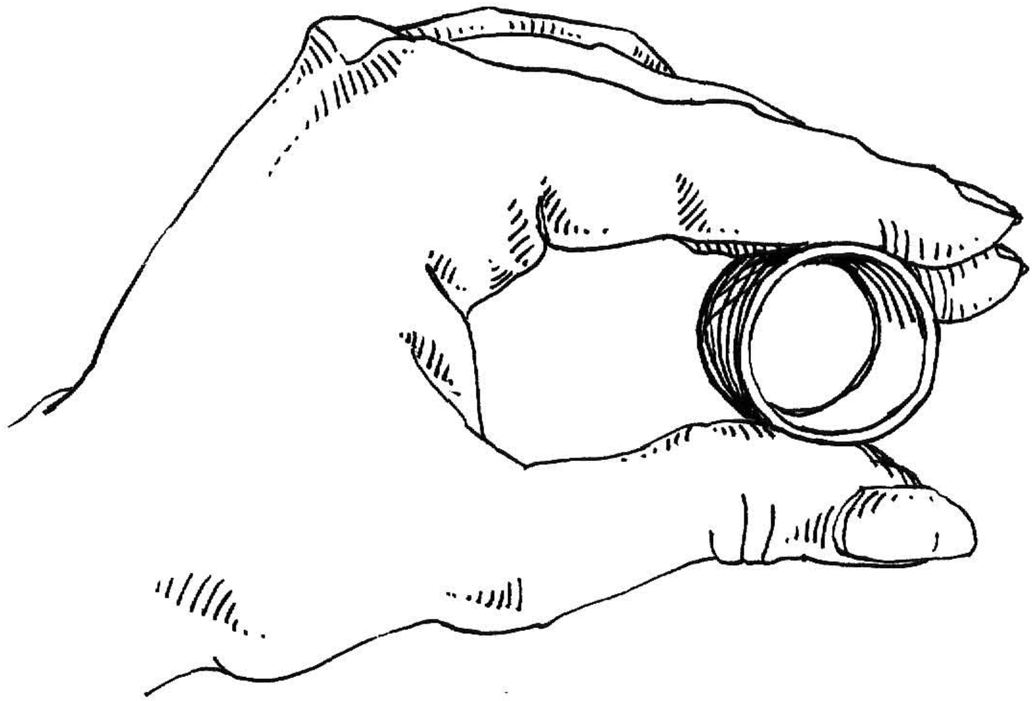
Signal Detection Theory Analysis

The major advantages of analysis by 'theory of signal detection' is that it gives two measures, the detectability and the criterion, which are more useful than either of the probabilities from which they are calculated. As discussed earlier in this section, detectability d^1 is an unbiased measure of the difficulty of the task. If inspectors know from the process cards about the quality of that batch of hoses to be inspected, they will perform better, due to vigilance.

Diameter of Hoses

Diameter of hoses significantly affected the error rate. The least (0.66") diameter hose and the largest (1.125") diameter hoses were easier to inspect. The 0.84" diameter was toughest to inspect. The 0.66" diameter hose can be inspected by fingertips alone. Fingertips are the most sensitive parts of the hand. The largest hose can be almost perfectly circularly explored with the palm. Figure 12 and Figure 13 illustrate the proposed improved methods for holding the hoses. The concept is to hold the hands opposing each other to give full and wider surface exploration.

a) Inefficient holding method- Point contact



b) Efficient holding method- Area contact

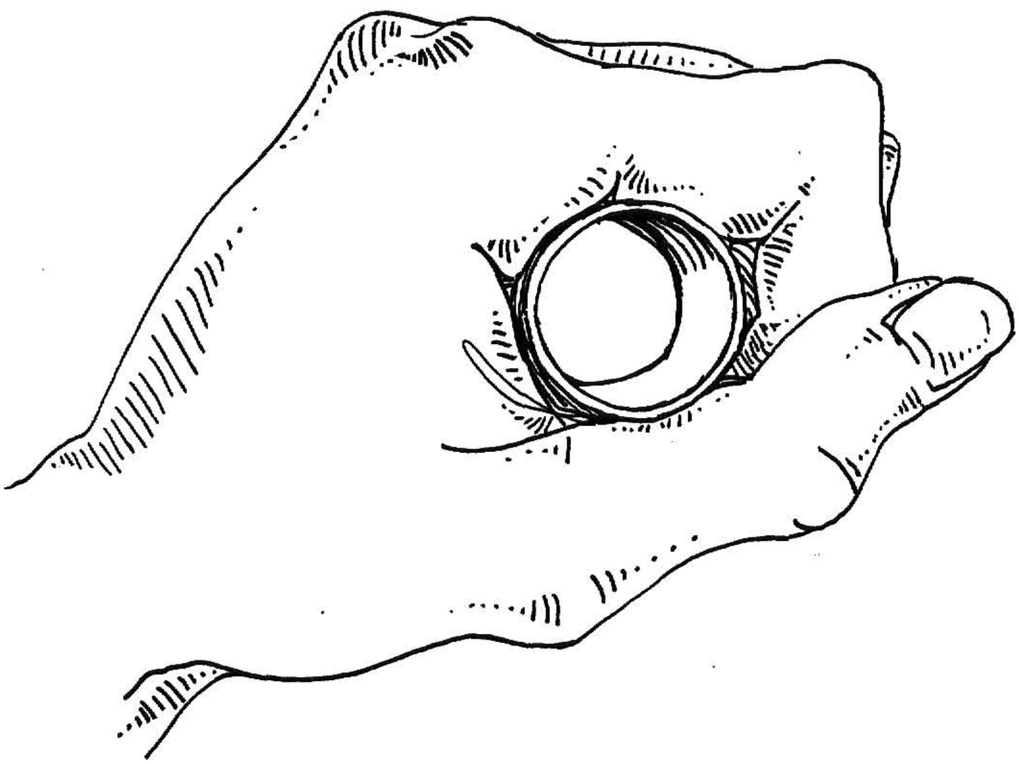
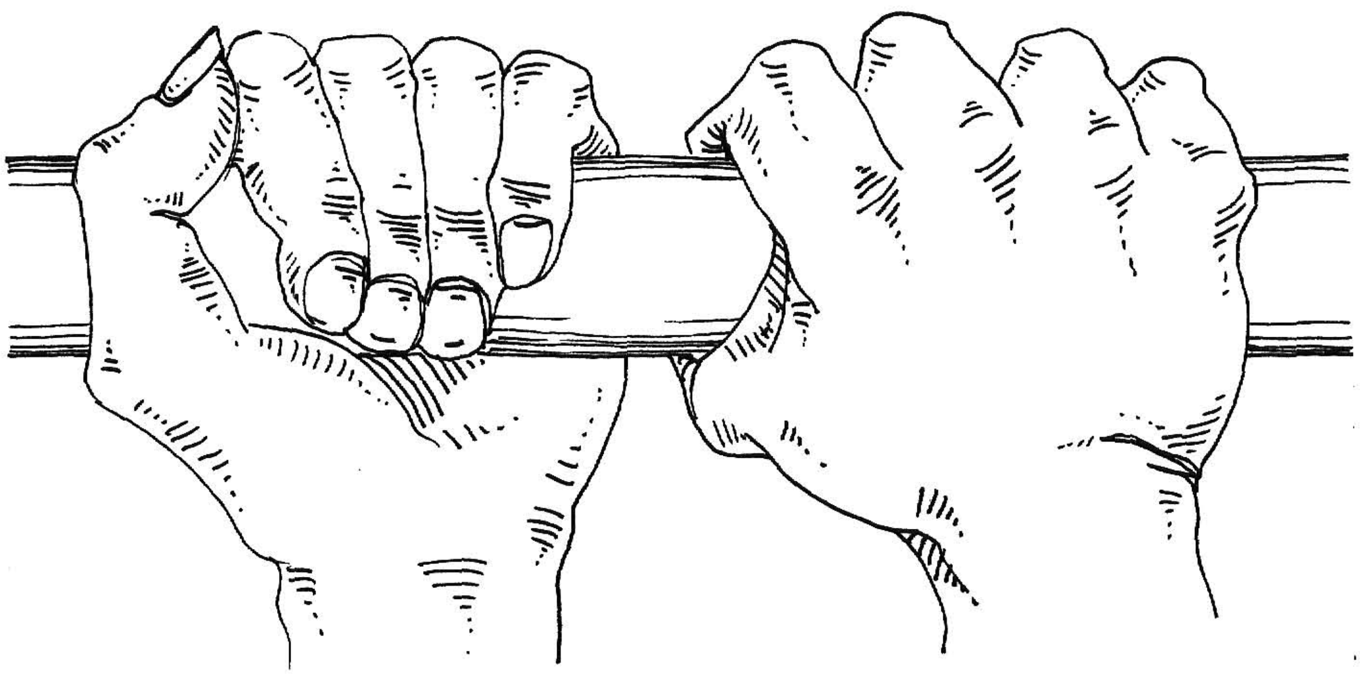


Figure 12. Holding method for each hand.



Opposing palms.

Figure 13. Suggested improved holding.

RECOMMENDATIONS

1) Glove type : Gloves did not make a significant difference versus the bare handed condition. Glove should be made compulsory for the inspectors from a health and comfort point of view. Playtex gloves should be tried. They are cheap and durable. The opinion of the subjects was to try Playtex gloves.

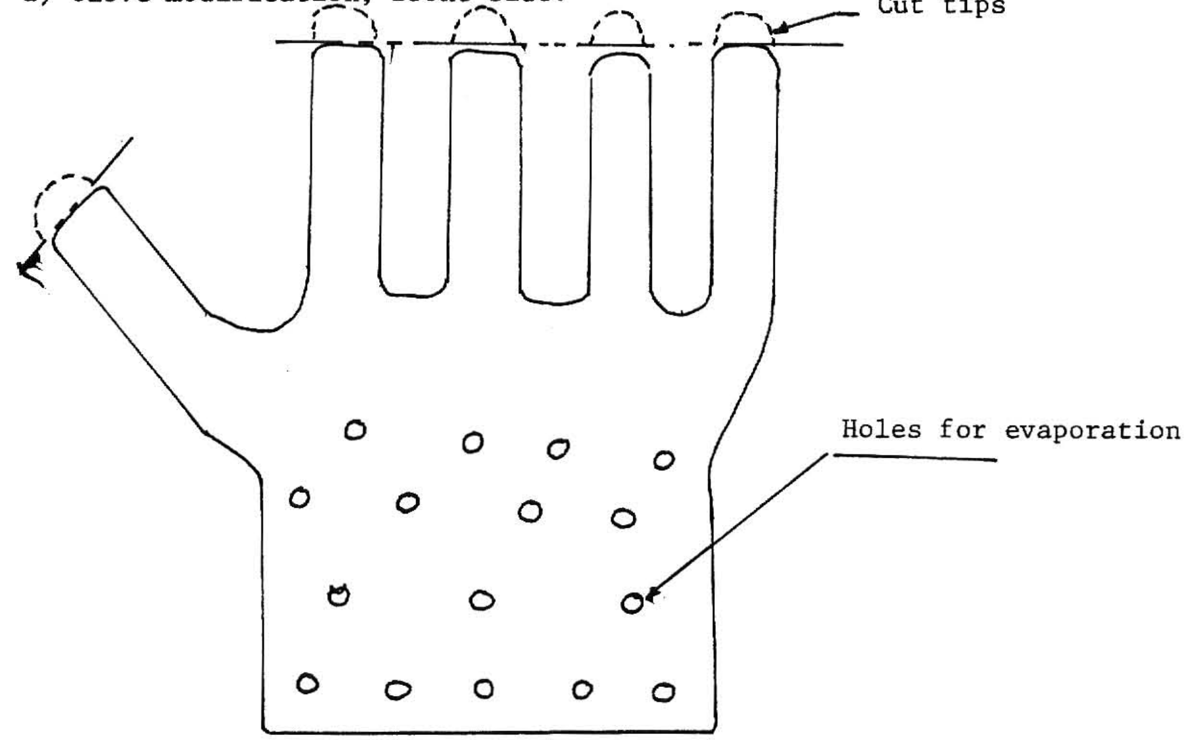
Modifications for comfort reasons are suggested on any type of gloves to be used. On the palm side, several small holes should be made. On the back side a large hole can be made. These holes will help evaporation. See Figure 14.

2) From fatigue considerations, the inspector should be allowed to sit down while inspecting. While talking to the subjects, it was felt very strongly that the inspection task would be more efficient if done while sitting. The opinion of the subject was unanimous that the task would be much more strenuous if performed while standing. There is no technical reason to require standing as they now do. An adjustable chair should be provided.

3) Arm supports should be provided when the inspection process is going on. The arm rest will ease the fatigue load on the hands and improve hand steadiness. See Figure 15 for a schematic arrangement.

4) A decision structure table is recommended for the inspectors. Since type I errors are to be reduced, a compromising situation is required with type II errors. See Table 14. To use the table, a redefinition of acceptable and nonacceptable defects is felt necessary. More borderline

a) Glove modification, front side.



b) Glove modification, back side,

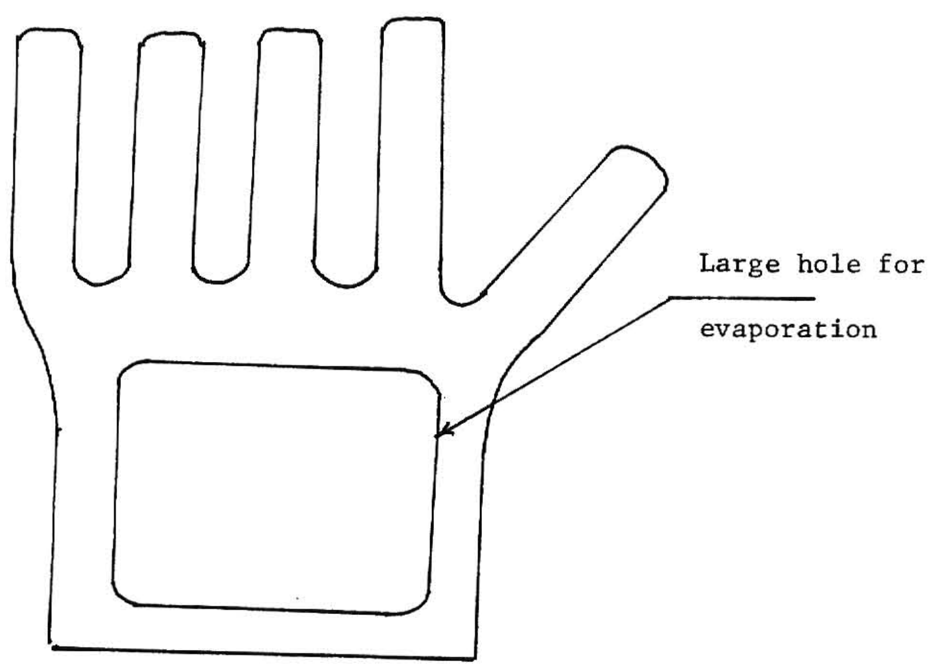


Figure 14. Glove modifications,

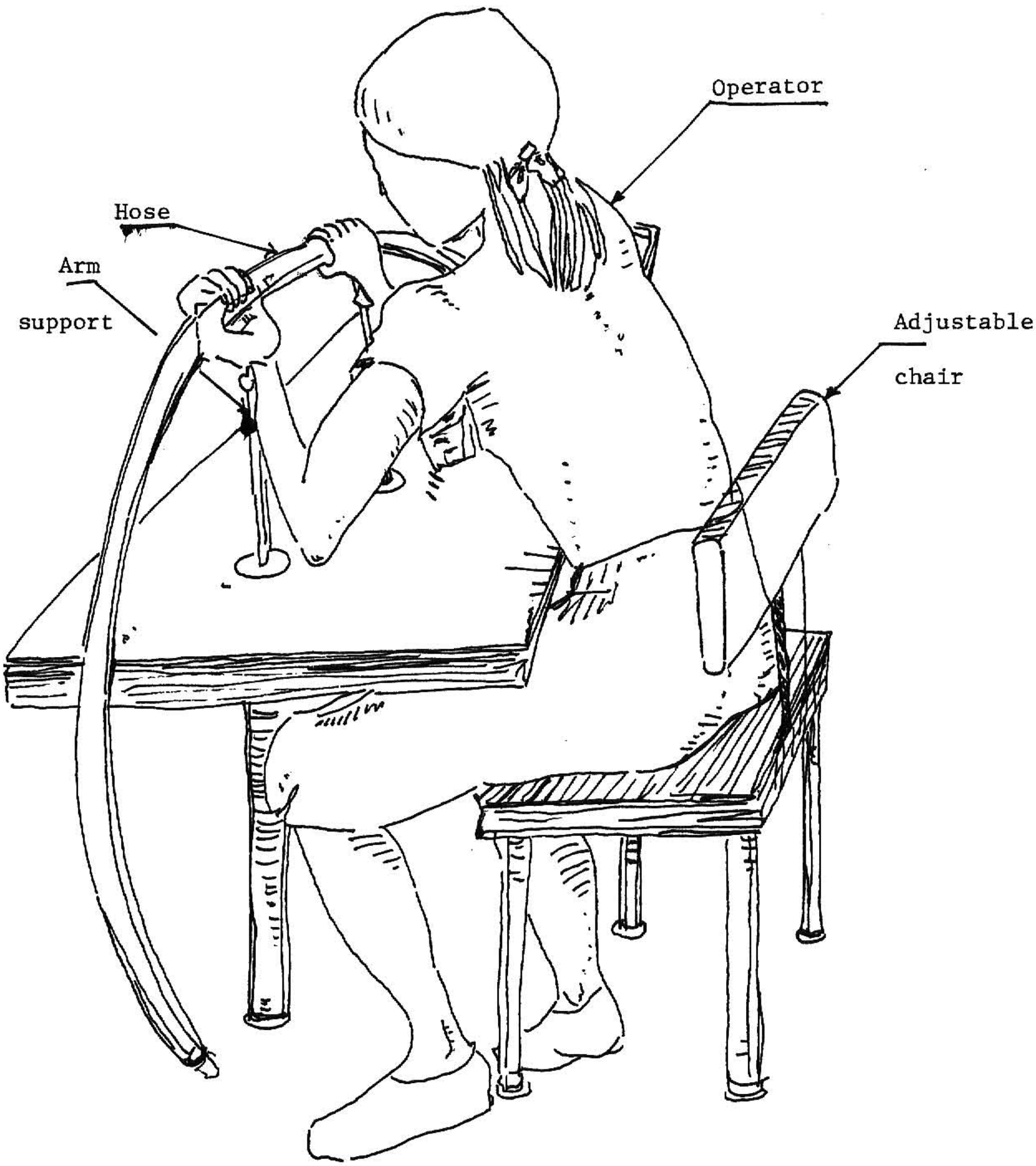


Figure 15. Chair and hand support arrangement.

Table 14. An example of possible decision structure table

If DEFECT is	and DEFECT TYPE is	and DEFECTIVE LENGTH OF hose is	and DEFECT feels	then DECISION is
Surface	Braid	Less than 2 feet	Acceptable	Accept
			Borderline case	Accept
			Not acceptable	Reject
		More than 2 feet	Acceptable	Accept
			Borderline case	Consult
			Not acceptable	Reject
Diameter	Diameter	Less than 2 feet	Out by 0.002"	Accept
			Out more than 0.002" and less than 0.005"	Accept
			Out more than 0.005"	Reject
		More than 2 feet	Out by 0.002"	Accept
			Out more than 0.005" and less than	Consult
			Out more than 0.005"	Reject

cases will have to be accepted. The tolerances will have to be defined for small hose lengths. Parker management will have to continuously monitor the output of the inspection stage. They can set and change the requirement of an acceptable or a defective hose length to find the balance between the type I and type II errors.

5) When the defects are identified, presently the inspector stops the machine and marks the defect with a tape. However, marking can be done without stopping the running hose. A dry spray paint should be used. The gun can be foot operated. As soon as a defect is noticed, the inspector can mark the defect with the spray gun without stopping the moving hose. The gun will be a step towards automation.

6) The diameter defects are not easy to find by the sense of touch. It is easy to check the diameter defects without stopping the running hose. A spring loaded outside vernier calipers can be used by setting the diameter on either the nominal O.D. or the maximum O.D. Calipers are used on steel rotating shafts for diameter checks. The tolerances on the hoses are large enough to permit the use of calipers. Besides, the calipers are cheap and can measure a wide range of diameters.

7) The holding method should be defined. As described in the discussion section, to get the full coverage of the surface by the fingers, both the palms should be opposing each other.

9) The signal detection theory analysis suggests that a new look should be taken at the criterion chosen by the inspectors. The economic

consideration of the two types of errors should be assessed and used to calculate an optimum criterion to minimise the total cost. This criterion could be taught to the inspectors by training sessions with them and providing them with feedback knowledge of their current performance in relation to the desired standard.

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A P P E N D I X : A

INSTRUCTIONS TO THE SUBJECTS

INSTRUCTIONS TO THE SUBJECTS:

This research is designed to study the effectiveness of the hand touch on an inspection task of hoses.

For orientation purposes, you will be shown some hose samples. These hose samples are some typical samples having defects in them. Feel these hoses. You will be told about the defects in that you will encounter while feeling the samples. The typical defects may be one of the folloing, 1) high O.D.,2)low O.D., 3) lumps, and 4) surface roughness. You will also be given good samples for detecting the difference between a good and a bad sample. When you are ready to find the defects in the hose samples, tell the experimenter.

You are now ready to begin the experiment. You will be inspecting the hoses under following conditions, 1) bare hand, 2) glove A, 3) glove B, and 4) glove C. The experiment will be carried out blindfolded. Between the inspection of two samples, you can remove the blindfold. In a single sample, there may be more than one defect. As soon as you detect any defect, tell the experimenter orally the type and the number of the defects.

There are no hazards or risks involved in the experiment. I hope you will complete the experiment. However you may feel free to leave the experiment at any time you wish. Your completing the experiment will be appreciated. Now, please sign the informed consent blank below.

If you are ready for the experiment, a cotton strap will be given for the blindfold. The time for the experiment will be about 4 hours.

You will examine the hoses passing through your hand and tell the experimenter, whether you find any defect in the hose sample.

If you have fully understood the instructions, let us start the experiment orientation procedure. Then you will commence the real experiment.

You will be paid $14.00 for participating in the experiment. (Only non Parker subjects).

__________________________ __________________

NAME DATE

AN ANALYSIS FOR IMPROVING TACTILE INSPECTION PERFORMANCE

by

SIDDHARTH BALVANTRAI DESAI

B.E.,Gujarat University, 1977

Ahmedabad, India

AN ABSTRACT OF A MASTER'S THESIS

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Kansas State University

Manhattan, Kansas

1983

A B S T R A C T

The objective of the study was to improve the tactile inspection process of hydraulic hoses.

Three Parker inspectors and five inexperienced subjects participated in an experiment to find the efficiency of gloves. For surface defects, type I errors were 12.9 % and type II errors were 35.5 %. For diameter defects, type I and type II errors were 0.1 % and 72.6 %. There was no significant difference with different gloves. Hose diameters were significant. Signal detection theory was applied to analyse the inspection process. Problem areas were identified in the inspection process. Improved methods were suggested for holding the hoses. Other related recommendations were suggested and found useful by the Parker management.