ASSEMBLY ON INCLINED WORK SURFACES

by

SARAN SHANKAR VERMA

B. Sc., B. E. (Elect.), Allahabad University,
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Approved by:

Dr. Stephen Konz

Major Professor

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INTRODUCTION

The Importance of the Design of Work Stations

The combination of man and machine influences the productivity in an industry. Farley (1955) emphasizes this idea when he stated: "In today's manufacturing plant the machine, the assembly operation, or the process all have been designed, obviously, for the best possible performance and efficiency. It is the man-machine combination which results in the product and the overall output is evaluated as man-machine performance." Work stations can be classified as machines. Murrell (1965) pointed out, "When a man is said to be functioning as part of a man-machine unit, the word 'machine' is used to imply any piece of equipment with which an individual accomplishes some purpose." McCormick (1957) emphasizes the man-machine relationship when he stated, "Where compatible man-machine relationships can be utilized, the probability of improved system performance usually is increased." He further emphasizes the arrangement of work space -- "In many human activities, the amount and arrangement of work space is a potentially important variable in performance and human comfort." Industrial designers are concerned with the problem of reduction of fatigue and physiological cost since they have a strong influence over both the quality and quantity of production.

Some studies have been conducted towards the design of work stations. The general conclusions from these investigations is that ideally the facilities should be adjusted so as to "fit" the user. Tichauer (1964) emphasizes this idea when he stated: "Even minor changes in the dimensions of the work place may cause considerable changes in posture and position of the limbs." He further emphasizes the optimum work place height -- "A small variation only from the optimum work place height may produce large variations in the arm angle and, hence, in the radius of gyration of a limb. Therefore, considerations of work-surface height should receive the most thorough attention in the design of materials-handling equipment such as is used on assembly lines."

Measurement of Physiological Cost:

Physiological cost refers to the cost to the individual to perform the work. Work energy requirements are measured by many different methods. It has been observed that measuring the work load with the oxygen consumption is reasonably accurate. However, the most serious problem with the oxygen consumption method is the intensive effort required before the difference between the basal and the working oxygen consumption can be distinguished.

The heart rate is a sensitive indicator of physiological cost. A practical aspect is that the measurement of heart rate is easier to obtain than that of oxygen consumption.

Purpose of the Investigation:

A series of experiments have been performed on work stations at Kansas State University. Research has been done towards determining work surface height, eye-hand coordination at different heights and directions of movements, the effect of angle and direction of movement, the normal work area on the horizontal plane, physiological costs of symmetrical and simultaneous motions, and the distance between shoulder and work table. A problem, which had not been examined, was whether a significantly better performance could be achieved on inclined work surfaces, and, if so, what should be the inclination and height of the work surface.

Specifically, the task was to assemble wooden washers on pegboards at five different inclined (0°, 5°, 10°, 15° and 20°) surfaces. The work surface was at two heights - one inch and two inches below the elbow of each subject. The number of pieces assembled, incremental heart beats during work, the standard deviation of the inter beat interval, errors, preferences and adjustment of the work surface by the subjects were the six criteria.

LITERATURE REVIEW

The literature review has been divided into three parts. The first part explores the importance of the design of work stations. The second part deals with effect of inclinations; and the third part with the height of work surfaces.

Design of Work Stations:

The scientific improvement of the design of work stations was started in 1911 by Gilbreth. He emphasized the design of work stations as he stated, "It is of great importance in obtaining the largest output that the work shall be so arranged and the workman so placed that he can do his work with the least possible amount of foot-pounds of work done per unit of output accomplished."

Dempster (1955) emphasized comfort, efficiency, convenience and safety in various phases of human life. He pointed out that the dynamic measurements of the body should contribute to the improved design of work equipment, vehicles, furniture, prosthetic devices and any other facilities and items of personal equipment.

Barany (1963) studied the nature of individual differences in bodily forces exerted during a motor task. He found that the anthropometric measurements of individuals do not affect the ability of individuals to perform specific motor tasks. The position of an operator in relation to his work was found to be an important factor. He emphasized that while there are accepted average values for placement of tools, knobs, handles, cranks, etc., there is also a great need for an analysis of the specific work place design for specific individuals.

Konz (1967) conducted studies on the design of work stations. He investigated the effect of work surface height on performance, eye-hand coordination and direction of movement, height and direction of movement, and the effect of angle and direction. He concluded that the optimum height is about one inch below the elbow. Further, he emphasized that the effect of angle at a height is important; the best moves for right-hand movement was found to be 45 degrees.

Sankaran (1969) cited Dunnington (1961) and Hudson (1962) who studied the effect of work place dimensions on the physiological cost as measured by the force platform. The simulated drilling task contained a variety of motions. They found that adjusting the work place to fit the subject's anthropometric measurements significantly reduced the effort (lb-sec of area) to perform the task.

Effect of Inclinations:

Yllo (1958) described the improvements in working conditions for six female key punch machine operators at the Volvo Skovde Work. During the investigation, it was discovered that the keyboard was too high in relationship to the working arm. The operator tried to compensate for this fault by lifting up the shoulder or by moving the elbow out in a lateral direction, so that the working fingers were placed improperly relative to the keyboard; this caused static muscle

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Figure 1. Card punching on standard IBM 0-24, conventional working position.

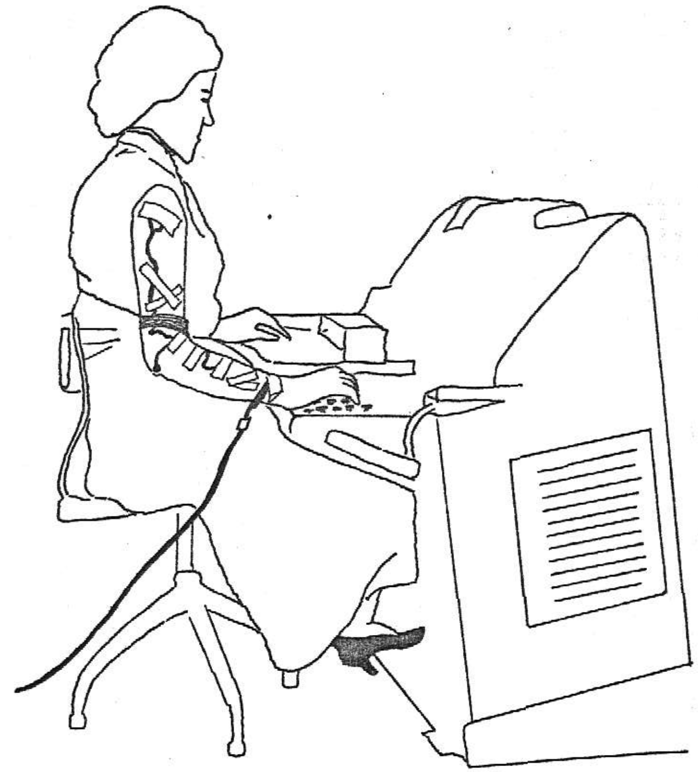

Figure 2. Card punching in modified position (electromyographic study situation).

activity in the neck, shoulder and arm. It was suggested that the keyboard be lowered; this made possible a wider elbow angle. Further the keyboard was made adjustable to suit individual's needs avoiding an unnatural wrist position. See Figures 1 and 2. There is no experimental detail mentioned in the paper.

Creamer and Trumbo (1960) conducted a study of the relationship between multiple finger tapping performance and the direction of tapping movements. The keyboard, consisting of the eight keys of the starting position of a typewriter, was hinged in the middle, so that the direction of tapping movements could be varied from the horizontal to the vertical. The task was to tap with a simple alteration of both fingers and hands. Five male nontypist subjects were given three minute trials at each of five keyboard positions 0°, 22°, 44°, 66° and 88° for 20 consecutive days. Data were analyzed for Blocks I and IV to indicate initial performance (for first 5 days) and performance after subjects appeared to be reaching an upper limit of both speed and accuracy (for last 5 days). Rate of tapping was found to be greatest at the positions intermediate between horizontal and vertical keyboards. The initial (Block I) mean taps per trial were 800, 825, 855, 865 and 840 at 0, 22, 44, 66 and 88° keyboard angle positions. The corresponding values after subjects appeared to be reaching an upper limit of both speed and accuracy (Block IV) were 1455, 1505, 1530, 1510 and 1470 respectively. The standard (horizontal keyboard) position yielded the poorest performance both in Block I and after 15 sessions of practice in Block IV. The optimal angle for Block I was 66°, but by Block IV trials the optimal angle had declined to 44°. The improvement at this position was found to be 5.2% as compared with the horizontal keyboard position.

The errors decreased monotonically from the horizontal to the vertical keyboard positions. Errors per trial at five keyboard positions were 40, 28, 27, 25 and 24 at 0°, 22°, 44°, 66° and 88° respectively. It was also observed that errors were highly infrequent at all positions after five days of practice. Results of the analysis of variance for Blocks I and IV indicated a significant ($p<0.01$) effect for keyboard angles. The highly significant F value for days reflected the large increase in rate of tapping, especially for Block I data, attributable to practice. Results of the analysis of variance for error scores indicated a significant difference among keyboard positions with p 0.01. The effect of practice in reducing the number of errors was indicated by the significant F for days. The tapping x day interaction and the errors x day interaction were both significant.

Wotzka, Grandjean, Burandt, Kretzschmar and Leonhard (1969) conducted a four-stage study of an auditorium seat. In this study they tested five types of chairs - HY200, HY210, HY211, Eames and Keegan as shown in Figure 3. The tests were made during regular lectures. Prior to every lecture, five students

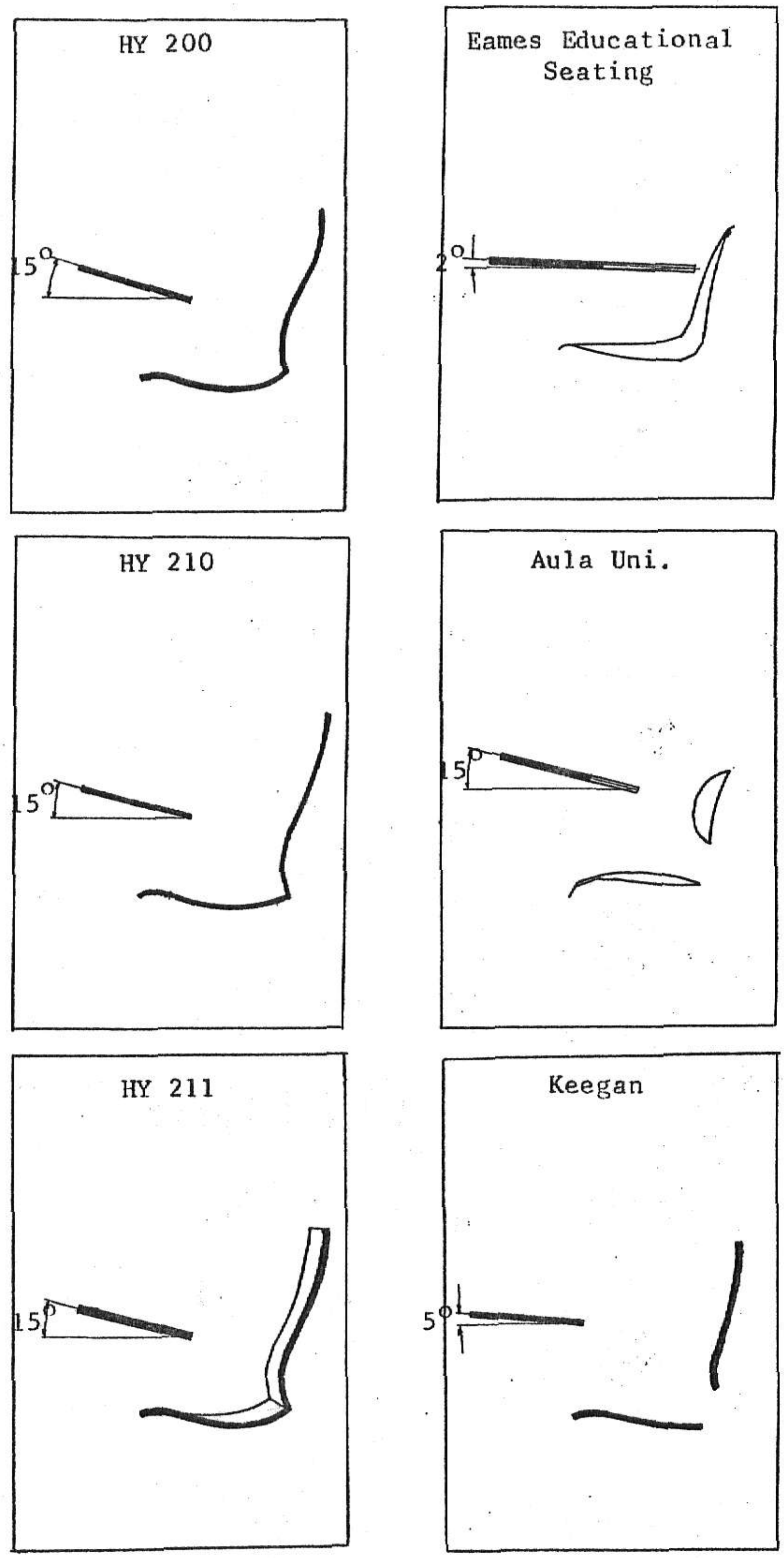

Figure 3. Types of seats which were tested by Grandjean et al.

(male or female) were requested to sit on the five experimental seats and to complete the questionnaire at the end of the lecture. Two hundred questionnaires were completed. As regards the writing surface, they concluded that the height (front edge to seat surface) of 28 cms. (11 inches) was assessed to be good by the majority; however "too low" was more frequently stated than "too high". The inclination of 15° ("HY211", "HY210" and "HY200") was largely described as good; "excessive" was more frequently scored than "insufficient". With "Keegan" the inclination of 5° was found to be insufficient. On the other hand, the majority found "Eames Educational Seating" good. It was found that the angle of the writing surface of "HY211" was somewhat excessive. So the "HY211" auditorium seat was modified by decreasing the inclination of the writing surface to 10° from 15°.

The slightly modified seat was designated as "HY212" and is shown in Figure 5.

The literature survey revealed that there is some effect of inclination on the productivity and performance. There is no published data of any experiment investigating the effect of inclination on assembly work.

Height of Work Surface - In Standing Position:

Ellis (1951) investigated the effect of work surface height on performance of a block turning task for 48 subjects in a

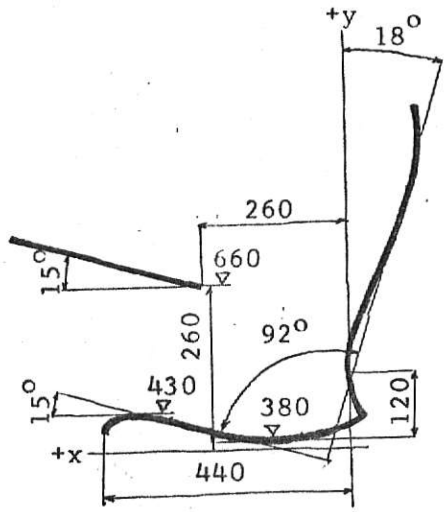

Figure 4. Profile and dimensions of the developed auditorium seat HY 211.

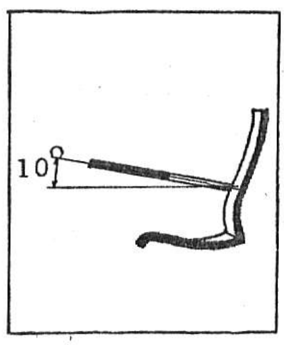

Figure 5. The recommended 'HY 212' auditorium seat.

standing position. Each subject worked for two - three minute periods at six heights: 19, 8, 4 and 3 inches below and 2 and 8 inches above the elbow height. The best performance was at three inches below (42 inches for Ellis' subjects). The feeling of strain, determined by the rating scale, was also minimum at this height. At 19, 8 and 4 inches below, and at 2 and 8 inches above the elbow the performance was 4.4, 0.7, 1.7, 4.4 and 6.4 percent less than the performance at 3 inches below the elbow height.

Frederick (1959) conducted a study of the energy consumption for men of "average height" while lifting weights of 20 to 65 pounds. Each lift of 20 inches vertical distance was made starting with the heights 0, 20, 40 and 60 inches. It was found that the least energy was required while lifting from 40 inches to 60 inches.

Konz and Day (1966) studied the height and handle orientation of a push-pull task performed on the force platform in the standing position. The ten subjects operated the push-pull device at each of the five handle heights - knee, hip, waist, chest and eye and the force was measured by the force platform. They concluded that the force exerted by the subject was minimum when the handle was at chest height.

Konz (1967) cited that Bratton (1959) measured oxygen consumption and calculated the calories required for doing light work while sitting and standing at a 36-inch high counter. She found that there was no significant difference between the energy costs in the sitting and standing conditions.

Konz (1967) studied the assembly task of eight wooden pieces with two 3/8 inch holes on a pegboard. Twenty-four standing subjects, having elbow heights ranging from 38 to 45 inches, performed the task at three heights: two and six inches below and two inches above the elbow. The average numbers assembled in 20 minutes in the low, high and middle conditions were 100.40, 103.21 and 103.34. High and middle were not significantly different from each other but both differed significantly from low. Subjects liked the middle height most and low height least.

In another study of eye-hand coordination and direction of movement, Konz also investigated the effect of height. The task was the assembly of sixteen washers on a pegboard (one on each peg). The pegboard was placed such that its front edge was at a 45-degree angle and parallel to the front at one inch and four inches below the elbow height. Sixteen male subjects performed the task. The total number of washers assembled at one inch below the elbow was 1.5 percent more than the 11,708 washers assembled at four inches below the elbow; the difference was statistically significant.

This part of the literature survey reveals that there is a difference in energy costs, under sitting and standing conditions for doing light work, at various work surface heights and at various levels of orientation of a push-pull device. The optimum height of the work surface for standing operation should be from one to two inches below the elbow.

Height of Work Surface - In Sitting Posture:

Burandt and Grandjean (1963) studied the most comfortable seat height for 68 adult subjects. The study was conducted on the basis of questionnaires completed by the subjects while sitting on a fixed chair and writing. The variation between the surface of the table and seat was done by varying the seat height (the chair was on an adjustable floor panel). It was concluded that the necessary space range between the seat and the top of the table should be between 10.6 to 11.8 inches. For key punching or typing, this distance should be less than 11 inches. It was recommended that the height of seats from the floor should be adjustable between 15.8 and 19.2 inches.

Langdon (1965) studied the measurements of 142 female key punch operators and the dimensions of the chairs and key punch machines. The subjects also completed a questionnaire. The measurements taken were the heights above the floor of the seat, keyboard, and, in some cases elbow, while the subject was actually depressing a key in the middle of the keyboard. The correlations between seat height and keyboard height and elbow height and keyboard were found to be 0.45 and 0.41 respectively. It was recommended that when the height of the middle rank key of the keyboard is 29 inches above the floor, the chair should be 18 inches above the floor.

Chatterjee and Daftuar (1966) confirmed Corbusier's concept of a relationship of 1:1.617 between the chair and table height for maximum efficiency of typing work. Fifteen professional typists were tested for two minutes with a typing test at eleven heights. The table was initially adjusted at 1.617 times the height of the seat. Five successive heights above and below the initial table height were evaluated by increasing or decreasing the height by one inch. The best height of the table and seat was found to be 24.7 and 15.1 inches above the floor. The table height was 1.18 inches below the elbow height.

Hastings (1966) conducted a study to determine the optimum height of the work station for an operator in sitting position. He studied the performances of a simulated assembly task done by the operator at six heights:- 4, 2 inches below, 0, 2, 4 and 6 inches above the elbow height. The criteria used were the average change in heart rate, pulmonary ventilation and alpha wave depression. He found, using heart rate as the criterion, that two inches above the elbow was the best height and four inches below the elbow height was the worst. There was no significant difference between two inches below elbow height and two inches above elbow height. Using pulmonary ventilation as the criterion, elbow level was found to be the best work surface height. There was no significant difference between the elbow level, 2 inches below and 2 inches above elbow height. He concluded that the elbow height is the best and 4 inches below the elbow level is the worst height. He further found a correlation between the length of the upper arm and the average increase in ventilation rate. He recommended that the optimum work station height in terms of physiological cost is best determined on an individual basis.

Sankaran (1969) determined the optimum height of a work table for a simple arm movement while sitting. The criterion used was the physiological cost as measured by the force platform. The task was to pick up, with the right hand, a 5/8 pound bolt from a bin starting from the inner bin and place it in the outer bin. The movement angle was 45 degrees in the horizontal plane. The distance between both the bins was 40 cms. The return motion was empty. The subjects were asked to transfer the bolts keeping pace with the metronome, set at 105 beats per minute, during one ten second trial. The same task was repeated for the inward motion. The ten female subjects performed at five heights (+3, 0, -3, -6, -9 cm) from the elbow. There was a significant difference between heights. On an average, a work table set at three cms. below the elbow (-1.15 inches) required the minimum physiological cost for a seated person.

The literature survey revealed that the height of the work surface affects the productivity, performance and physiological cost required for performing the task. It is concluded that the optimum height varies between one inch and two inches below the elbow.

METHOD

Task

See Plate I and II. Sixteen 3/8-inch thick, 7/8-inch diameter and 3/8-inch hole wooden washers painted red on one side and white on the other were assembled (one on each peg) with the red side up on a wooden pegboard. The pegboard was a rectangular 6.3 x 6.3 inch wooden block having sixteen pegs on 1-1/4 inch centers. The top of the peg was four inches above the table (one inch for the base and three for the peg). The subject picked up only one washer at a time with each hand. If the columns of pegs are mentally labeled one to four from left to right, the assembly of washers on the pegboard was started from column (2) followed by column (1) for the left hand and column (3) followed by column (4) for the right hand, always from top to bottom. When one pegboard was filled, it was placed on the left side on the table by the subject. Then it was removed by the experimenter, checked for errors, and the washers were placed back in the containers. In the meantime the subject assembled on one of the other pegboards, previously on the table on the right side of the subject.

The location of the pegboard was such that all rows of pegs were parallel to the front edge; the centers of the pegs of the middle row were eight inches from the front edge of the work surface. This design was based on the anthropometric studies of the shape of the normal work area by Konz and Goel (1969) on a horizontal plane and Aurora and Mehrotra (1969) on a plane inclined

Plate I

The layout while performing the task.

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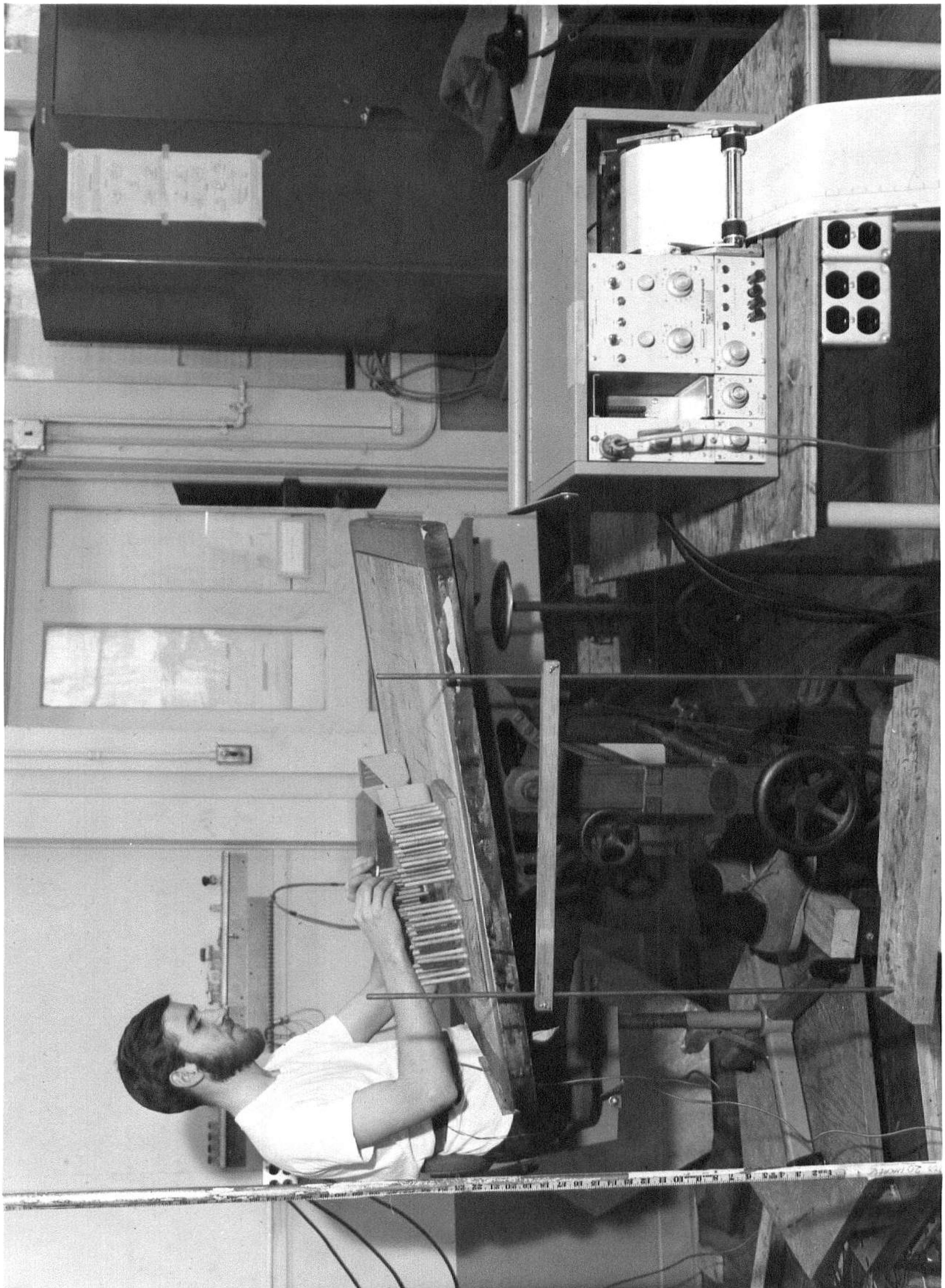
Plate II

A subject performing the task.



30°. Konz and Goel found that forearm length varies from 14.9 to 18.0 inches for males, and 14.0 to 16.3 inches for females. The containers were placed such that their front edges were at an angle of 45°. The centers of each container's front edge were three inches from the nearest corner of the pegboard. The placement of containers was based on the conclusion of the study by Konz (1967) - the best moves are at 45 degrees. Thirty-two washers were kept and maintained by visual inspection in each container. The task was within the normal reach of all subjects.

Each subject performed the assembly task, using symmetrical and simultaneous hand motions for five minutes at one particular height and inclination. In this way each subject performed the task for a total of fifty minutes. The total number of washers assembled within each five minute trial, the heart beats of each subject for the 30 seconds before the task and the last 30 seconds of the task, and the number of errors in each five minute trial was recorded. At the end of the experiment each subject indicated the work surface that he preferred "best", "least", "second best" and "second least"; these were scored as "+2", "-2", "+1" and "-1" respectively. Then each subject adjusted the inclination and height of the work surface according to his own choice. The choice of the height was restricted to either one inch or two inches below the elbow.

Subjects

The U. S. Public Health Service (Anon, 1965) reported that, for the age group 18-29 years, the 5th percentile men were 63.6 inches tall and the 95th percentile were 72.8 inches. The corresponding figures for women were 59.0 inches and 67.1 inches. These ranges were divided into four quartiles using Nelson's (1968) procedure:

Males: 63.6" to 66.2", 66.3" to 68.2", 68.3" to 70.2", 70.3" to 72.8".

Females: 59.0" to 61.2", 61.3" to 63.0", 63.1" to 64.7", 64.8" to 67.1".

Two U. S. students were selected to represent each quartile of the U. S. population. In this way the sixteen subjects represented the middle 90% of the U. S. population.

Sixteen students (8 male and 8 female) from Kansas State University were paid by the hour. See Table 1. Their ages varied from 18 to 27 for males and 18 to 22 for females with averages of 22.2 and 19.5 years respectively. Their heights varied from 65 to 72 inches for males and 61 to 66 inches for females with averages of 68.2 and 63.4 inches respectively.

Their elbow heights ranged from 26 to 29 inches for males and 23.2 to 28.5 inches for females with averages of 27.8 and 26.7 inches respectively.

It may be noted that industrial employees are a selected group and probably are slightly bigger and stronger than the population as a whole.

Table 1

Subject Characteristics

Subject	Sex	Age (Years)	Height (inches)	Elbow Height (inches)
1	M	22	65	27.5
2	M	27	66	28
3	M	24	67	28.5
4	M	18	67	27
5	M	23	69	28
6	M	20	69	26
7	M	23	70.5	29
8	M	21	72	28.5
Mean		22.2	68.2	27.8
9	F	20	61	26.5
10	F	19	61.5	27.5
11	F	18	63	28
12	F	18	63	24.5
13	F	21	64	23.2
14	F	20	64	27
15	F	22	65	28.5
16	F	18	66	28.5
Mean		19.5	63.4	26.7

Equipment (See Plate II)

(a) Adjustable table:

An adjustable table having a work surface of 47 x 35 inches was used. Its surface was adjustable in height between 38-1/2 and 44 3/4 inches above the floor and in inclination between -8° and 75° approximately, taking the horizontal surface as the reference axis.

(b) Biomechanics chair:

A biomechanics chair, whose seat and back rest could be adjusted to the desired positions, was placed on a 15.25 inches high platform so that the subject's elbow could be in the desired position.

(c) Stop watch:

A decimal-minute stop watch was used to record time.

(d) Measuring tape:

A steel tape with half inch increments was used to measure the elbow height of the seated subject.

(e) Heart rate recorder:

A Beckman Dynograph (Type RS) was used to record the heart beats of the subject. Three E and M Instrument Co. surface electrodes were pasted and taped to the left side of the chest, near the heart. The female subjects were provided a special jacket to reduce embarrassment. The leads of these electrodes were connected to a junction box, worn around the waist by a belt. Electrical impulses received by these electrodes were transmitted to a DC amplifier.

The output of heart beats was obtained as a series of peaks on a continuous roll of graduated paper, moving at a speed of 25 mm per sec. The distance between two consecutive beats was measured and noted for further analysis.

Experimental design and procedure:

The experiment was conducted in the Human Engineering Laboratory, Kansas State University, from January 23 to January 31, 1970.

Heights of the work surface:

The elbow height above the floor for each subject was measured while the subject was sitting comfortably on the chair such that his lower legs were perpendicular to the floor, his upper and lower legs were perpendicular to each other, and his right upper arm vertically downwards. The heights of the work surface was adjusted mechanically as well as adjusting the height of the platform to one or two inches below the elbow height for each subject.

Inclinations of the work surface:

The angle of inclination of the work surface, keeping the front edge fixed at one of the two heights, was adjusted mechanically at 0°, 5°, 10°, 15° or 20° with the horizontal.

Effect of learning:

The effect of learning by each subject was balanced by following the sequences of heights and inclinations as shown in

Table 2

Sequence of work surface followed by each subject

Quartile No.		I		II		III		IV	
Sex	Subject No.								
Male	No.	1	2	3	4	5	6	7	8
	Height range	63.6" to 66.2"		66.3" to 68.2"		68.3" to 70.2"		70.3" to 72.8"	
	Subject No.								
Female	No.	9	10	11	12	13	14	15	16
	Height range	59.0" to 61.2"		61.3" to 63.0"		63.1" to 64.7"		64.8" to 67.1"	
		BH_1	AH_2	DH_1	EH_2	BH_1	CH_2	AH_1	CH_2
		CH_2	EH_1	AH_2	DH_1	DH_2	BH_1	DH_2	EH_1
		EH_2	EH_1	BH_2	CH_1	CH_2	EH_1	BH_2	AH_1
		AH_1	BH_2	CH_1	AH_2	EH_1	AH_2	EH_1	DH_2
SEQUENCE OF		DH_1	CH_2	EH_1	BH_2	AH_1	DH_2	CH_1	BH_2
WORK SURFACES		DH_2	CH_1	EH_2	BH_1	AH_2	DH_1	CH_2	BH_1
		AH_2	BH_1	CH_2	AH_1	EH_2	AH_1	EH_2	DH_1
		EH_1	DH_2	BH_1	CH_2	CH_1	EH_2	BH_1	AH_2
		CH_1	EH_2	AH_1	DH_2	DH_1	BH_2	DH_1	EH_2
		BH_2	AH_1	DH_2	EH_1	BH_2	CH_1	AH_2	CH_1

Angles: A $=0^\circ$, $B=5^\circ$, $C=10^\circ$, $D=15^\circ$, $E=20^\circ$ Height: H_1=elbow-1", H_2=elbow-2"

Table 2.

Each subject was asked to sit comfortably on the biomechanics chair. Adjustments were made such that their lower legs were perpendicular to the floor and upper and lower legs were perpendicular to each other. See Plate II. A foot rest was provided wherever it was needed. Then the elbow height was measured.

The distance between the subject and work table was adjusted by the subject according to his comfort and reach. Five practice trials were given to make the final adjustments and to understand the task. After the final adjustments, subjects were not allowed to move forward or backward. This eliminated the effect of variability in the forearms and upper arms on the number of assemblies done. No specific rest period was provided between each set of assemblies. Each subject got some rest automatically during the adjustments in the height and inclination of the work surface.

The subjects were instructed verbally with the words "ready", "go" and "stop". At the instruction "ready" each subject put his forearms on the work table, then started the assembly task at the instruction "go". The end of the work cycle was instructed with the word "stop". If both the hands, with one washer in each, were half way or more than that at the instruction "stop", they were included in the number of assemblies in that trial.

RESULTS

A series of sign tests indicated no significant ($p < .05$) differences in performance between men and women so sex differences were ignored in the following analyses.

Assemblies:

The assembly of one washer on a peg was counted as an assembly. The number of assemblies produced and errors in each 5 minute trial by each subject are shown in Table 6 in the Appendix. The effect of learning and fatigue on the mean assemblies produced by the sixteen subjects in each trial was estimated with respect to the overall mean of 294.4. By subtracting 294.4 from the mean of each condition, these values were found to be -19.5, -11.0, -1.9, -1.8, -2.0, +2.0, +7.2, +10.1, +10.1 and +6.2 for the first to tenth trial respectively. By subtracting these values from the raw data for each subject the effect of each condition, disregarding learning and fatigue, was calculated. See Table 7 in the Appendix. For example, from Table 6, the assemblies produced by subject 1 with the work surface horizontal at one inch below the elbow height was 326. This was the fourth trial for the subject. The effect of learning and fatigue for this trial was found to be -1.8. The number of assemblies of 327.8 shown in Table 7 was found by computing (326 - (-1.8)).

Table 3 shows that there were 295.1 assemblies at the horizontal work surface. The mean assemblies produced in five minutes at 5° and 10° inclined work surfaces were 298.6 and 297.4

Table 3

Results

Criterion	Inclination					Height	
	0°	5°	10°	15°	20°	H_1	H_2
Assemblies/ period	295.1	298.6	297.4	292.6	288.5	294.6	294.2
Incremental heart beats/ minute	7.0	6.6	6.9	8.1	9.4	7.1	8.0
Decrease in st.dev.of inter beat interval, seconds	0.0115	0.0105	0.0105	0.0145	0.0160	0.0117	0.0115
Total errors/period	0.7	1.4	1.1	0.6	0.8	1.6	1.2
Total preference score	-4	+7	+16	+7	-26	+1	-1

Adjustment between	0° - 4°	5° - 9°	10° - 14°	15° - 20°	H_1	H_2
No. of subjects	4	8	3	1	10	6

respectively. These assemblies were 1.77% and 0.77% more than the 295.1. The mean assemblies at 15° and 20° inclinations were 292.6 and 288.5 which were 0.85% and 2.24% less than the 295.1. The assemblies produced by each subject in each condition are shown in Figure 6. The mean assemblies while the front edge was kept at one inch below the elbow of each subject was 294.6; at two inches below the elbow it was 294.2.

The data for assemblies was normalized by subtracting each subject's mean for all conditions from his estimated assemblies in each condition. The mean assemblies for ten conditions for subject 1 was shown in Table 7 as 345.8. This value was subtracted from the estimated value 327.8; the normalized value was -18.0.

A three-way analysis of variance was used to analyze the normalized data of the assemblies produced. See Table 4. The effect of inclination was found to be significant ($p<0.05$). The effect of height and the interactions were nonsignificant. The effect of inclination on assemblies produced was further analyzed by using the Wilcoxon Matched-Pairs Signed-Ranks test with $p<0.05$ on the thirty-two pairs of various inclinations. It was found that the 298.6 assemblies produced at the 5° inclination was significantly more than the 288.5 at the 20° inclination. There was no significant difference between the remaining angles.

Figure 6 shows that the maximum number of assemblies was produced at 5° inclination, while the second best was at 10°. Though there was no significant difference between 0° and 5°,

Table 4

Analysis of variance for assemblies and incremental heart beats (normalized)

Source of Variation	Assemblies (normalized)			Incremental heart beats (normalized)		
	D/F	Mean Square	F	D/F	Mean Square	F
Subjects (S)	15	0.01	-	14	0.13	-
Inclinations(I)	4	523.99	3.26*	4	43.21	3.53*
Height (H)	1	9.22	0.11	1	36.90	2.90
S x I	60	160.79	0.71	56	12.23	1.01
S x H	15	83.27	0.37	14	12.71	1.05
I x H	4	93.70	0.41	4	7.37	0.61
S x I x H	60	227.43		56	12.14	
Total	159			149		

$p^{*} < 0.05$

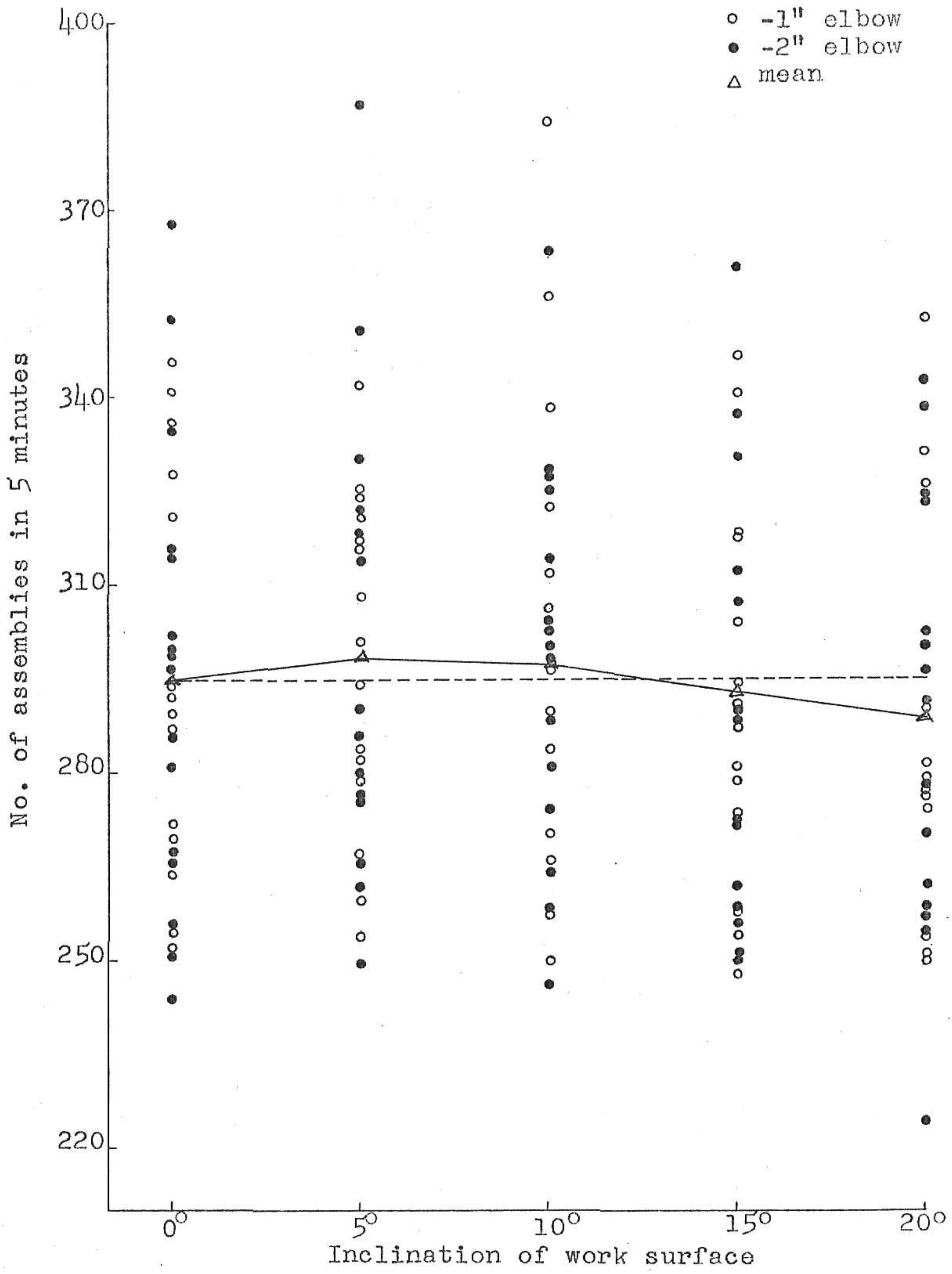


Figure 6. Inclination vs assemblies at one inch and two inches below the elbow.

0° and 10°, and 5° and 10° inclinations, a slight inclination of the work surface seems desirable. The trend of the curve indicated that the optimum inclination of the work surface should be between 5° and 10°.

Heart Rate:

The incremental heart beats per minute for each subject was found by computing the difference between heart rates in last 30 seconds during each trial (work period) and last 30 seconds before each trial (rest period). Each 30 seconds period was divided into two periods of 15 seconds each. The heart rates for work and rest periods were found by taking the mean of the corresponding values for the two 15-second periods. The heart rates during these four 15-second periods were computed by using the raw data of distances between consecutive beats. It was found that the basal and incremental heart rate of subject 14 were 125.6 and 18.3 beats per minute which proved to be an outlier, using the Dixon Test with $p < 0.05$. Excluding subject 14, the mean (for 15 subjects) for basal and incremental heart rates were 81.9 and 7.6 beats per minute. The effect of learning and fatigue on the mean (for 15 subjects) incremental heart beats was determined with respect to the overall average, 7.6 beats per minute. This effect was found to be -0.6, -0.9, -1.7, +0.4, +0.2, -1.9, +0.1, -0.2, +2.1 and +2.5 beats per minute for the first to tenth trial respectively. The raw data was adjusted as was done for assemblies. For example, the heart rates for subject 1, with the work surface horizontal at one inch below the elbow, was 83.1 and 83.3

beats per minute during rest and 87.3 and 92.2 beats per minute during work. The mean heart rates during rest and work periods were 83.2 and 89.8 beats per minute which gave an incremental heart rate of 6.6 beats per minute. This trial was the fourth in order of sequence; the effect of learning and fatigue was +0.4. Subtracting this effect from 6.6 gave 6.2 beats per minute as the estimated incremental heart rate. The incremental heart beats per minute at various work surfaces for each subject are shown in Table 8 in the Appendix. The value for subject 1 at 10° inclined work surface at one inch below the elbow was found to be an outlier, using the Dixon Test with $p<0.05$. Excluding this value for this condition for subject 1, the mean incremental heart beats per minute for the 15 subjects were 7.0, 6.6, 6.9, 8.1 and 9.4 at the horizontal, 5°, 10°, 15° and 20° inclined work surfaces respectively. See Table 3. The overall mean of basal and incremental heart rate were 81.9 and 7.5 beats per minute. The incremental heart rate of each subject in each condition is shown in Figure 7. The incremental value at one inch below the elbow was found to be 7.1 beats per minute, while at two inches below the elbow it was 8.0 beats per minute.

The data for incremental heart rate was normalized by subtracting each subject's mean for all conditions from the estimated values. The mean value for subject 1 in all conditions was found to be 6.2 beats per minute as shown in Table 8 in the Appendix. The normalized value of 0.0 at the horizontal work surface at one inch below the elbow was obtained by subtracting 6.2

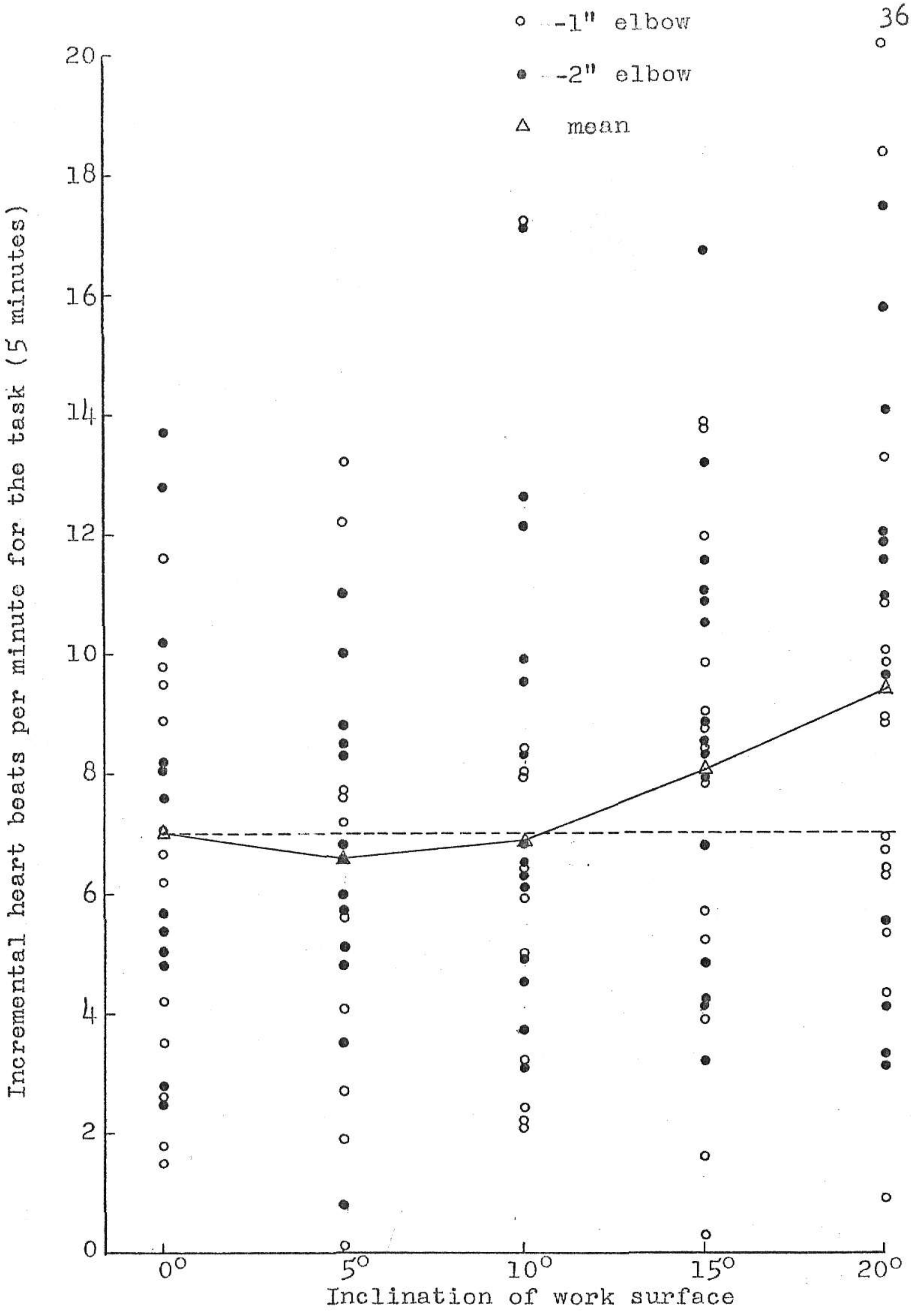


Figure 7. Inclination vs incremental heart beats at one inch and two inches below the elbow.

from the estimated value 6.2 beats per minute. Similarly other normalized values were found.

A three-way analysis of variance was used to analyze the normalized data. See Table 4. The missing value for 10° inclination at one inch below the elbow for subject 1 (eliminated as an outlier) was replaced by -2.6, the mean value (for 15 subjects) for the condition. An analysis of variance (Table 4) indicated that angle was the only significant variable. The Wilcoxon Matched-Pairs Signed-Ranks Test on thirty and twenty-nine pairs with $p < 0.05$ indicated that the 7.0, 6.6 and 6.9 beats per minute at 0°, 5° and 10° inclinations respectively were significantly lower than the 9.4 beats per minute at 20°. There was no significant difference between the remaining angles.

Heart Variability:

The data for the standard deviation for inter heart beat interval was computed by using the same original data of distances between consecutive beats in various conditions which was used to determine heart rates. The standard deviations for rest and work periods were found by taking the mean of the values for the two 15-second intervals for each condition for each subject. The decrease in standard deviation of the inter beat interval was determined by subtracting the mean value for the work period from the mean value for the rest period for each subject in each condition. Due to the higher basal and incremental heart rates, commented on previously, subject 14 was excluded from further analysis. The mean (for 15 subjects) effect of learning and fatigue for all the conditions was determined with respect tothe overall mean of 0.0126 seconds. These average effects were -0.004, -0.004, +0.003, -0.003, -0.001, -0.002, +0.005, -0.001, +0.005 and +0.002 for the first to tenth trial respectively. These effects were subtracted from the individual readings and estimated decrease in standard deviations for each subject at each work surface was tabulated in Table 9 in the Appendix.

As an example calculation, the four values of standard deviations with the work surface horizontal at one inch below the elbow for subject 1 were .031, .017, .025 and .013; the first two for the rest period and last two for the work period. The standard deviations for the rest and work periods, .024 and .021, were computed by taking the mean of the two corresponding values. The decrease in standard deviation was .003. This was the fourth trial, for which the effect of learning and fatigue was -0.003. The decrease in standard deviation for this condition, .006, as tabulated in Table 9, was found by subtracting -0.003 from 0.003. A larger number indicates a greater mental load.

The mean decreases in standard deviations for inter beat interval at horizontal, 5°, 10°, 15° and 20° were found to be 0.0115, 0.0105, 0.0105, 0.0145 and 0.0160 seconds respectively with an overall mean of 0.0126 seconds. The corresponding values for the two heights (one inch and two inches below the elbow) were 0.0117 and 0.0115 respectively. See Table 3. The decreases in standard deviations of inter beat intervals in various conditions for each subject are shown in Figure 8. The Wilcoxon

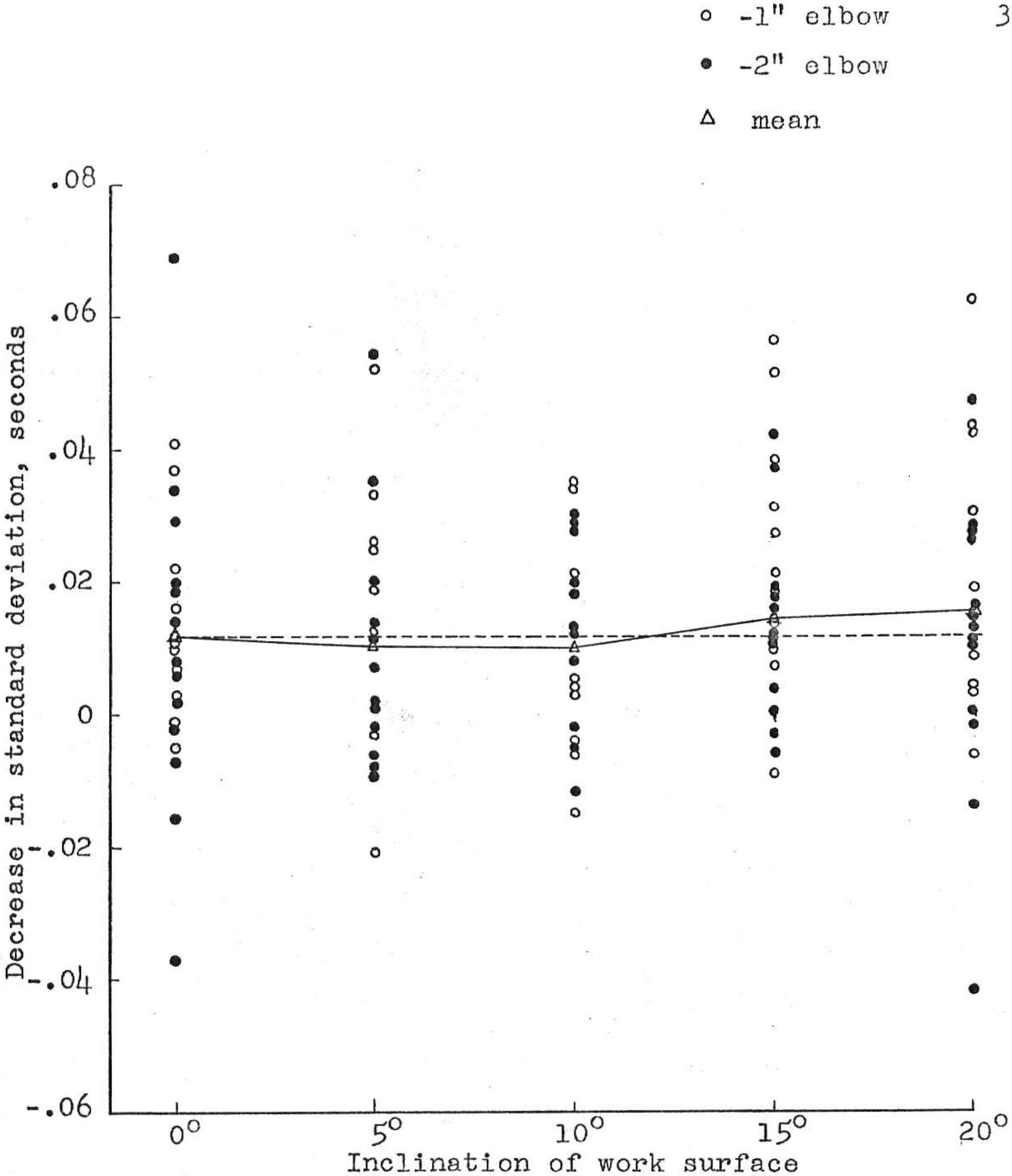


Figure 8. Inclination vs decrease in standard deviation of inter beat interval at one inch and two inches below the elbow.

Matched-Pairs Signed-Rank tests on 30 pairs with $p < 0.05$ indicated no significant difference among various inclinations as well as between the two heights.

Errors:

In the study of total number of errors made by each subject, it was found that subject 16 was an outlier using the Dixon Test with $p < 0.05$. Subject 16 was excluded from further analysis. The effect of learning and fatigue on mean errors for fifteen subjects was found with respect to the overall mean number of errors of 0.94 per trial. These values were found to be +0.4, +0.3, 0.0, 0.0, 0.0, -0.2, -0.5, +0.3, 0.0 and -0.3 for the first to the tenth trial respectively. The data was adjusted as in the previous three analyses. The mean errors for each subject for each trial at horizontal, 5°, 10°, 15° and 20° inclinations were found to be 0.7, 1.4, 1.1, 0.6 and 0.8 respectively. See Table 3 and Figure 9. The value at one inch below the elbow was 1.6 and at two inches below it was 1.2. The Wilcoxon Matched-Pairs Signed-Ranks test with $p < 0.05$ indicated no significant difference between errors at various inclinations and heights. The shape of the curve, however, was opposite the shape for the other criteria.

Preferences:

The scores for subject's preference show that subjects liked the 10° inclination most and the 20° inclination least. The scores at the horizontal, 5°, 10°, 15° and 20° inclinations were -4, +7, +16, +7 and -26 respectively. See Table 3. The

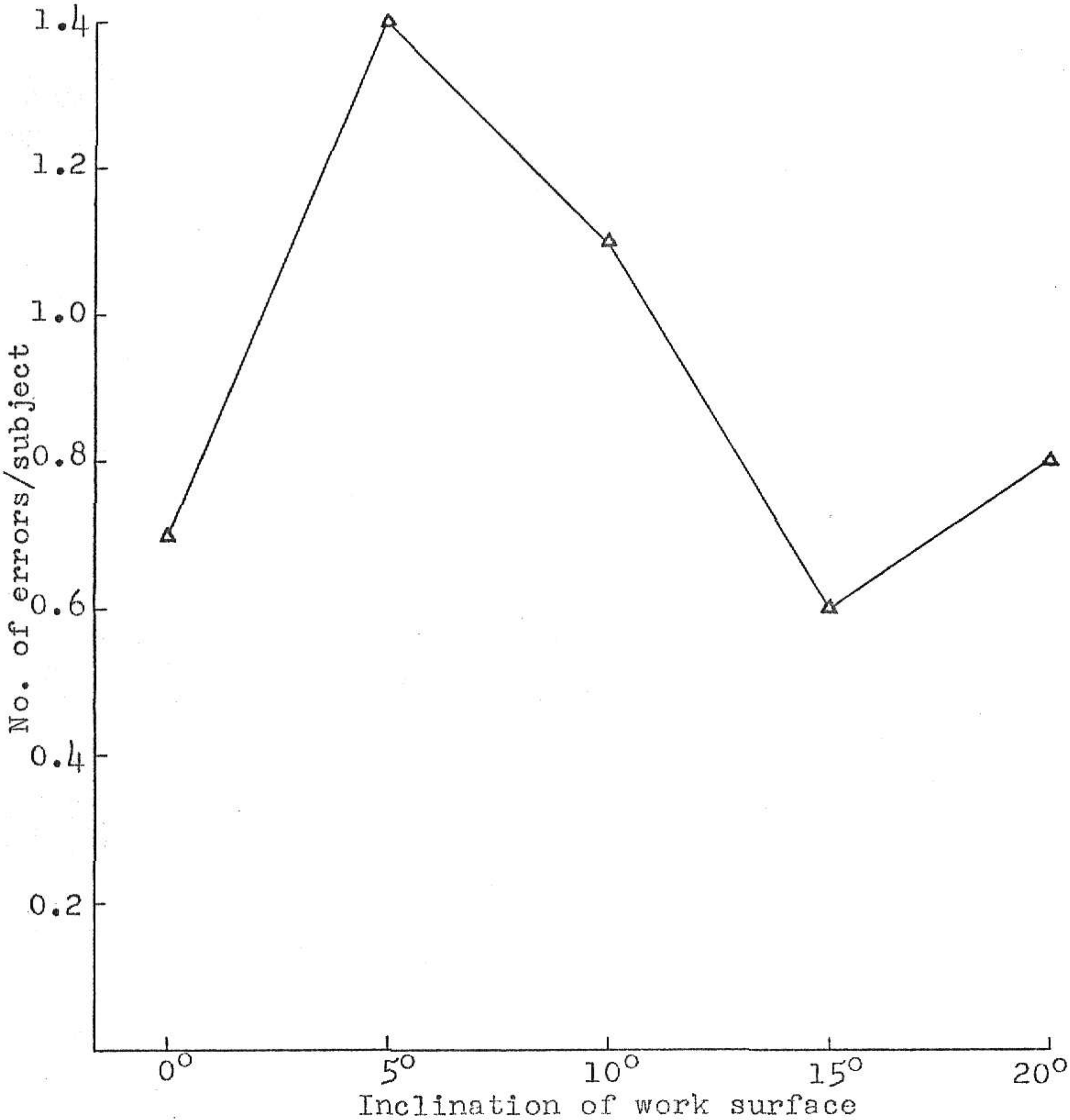


Figure 9. Inclination vs no. of errors.

height, at one inch below the elbow, was slightly preferred over two inches below elbow; the scores were +1 and -1 respectively. The preference scores are shown in detail in Table 5. A series of sign tests indicated that 5°, 10° and 15° inclinations were significantly ($p < 0.05$) preferred more than 20°. There was no significant difference between the remaining angles. The results on the basis of preference scores agree very nearly with the results obtained on the basis of the first two criteria.

The adjustment of work surface by each subject indicated that four subjects adjusted the inclination to between 0° and 4°, eight to between 5° and 9°, three to between 10° and 14° and one to between 15° and 20°. Ten subjects chose the work surface height at one inch below the elbow, while six chose two inches below the elbow. The maximum number of subjects adjusted the inclination to between 5° and 9°.

Combining all criteria, the 5° inclination at one inch below the elbow seems to be the best work surface for this assembly task. The 20° inclination was worst.

Table 5

Preference Score Data

	Angle and Height										
Subject	H_1 0°	H_2 0°	H_1 5°	H_2 5°	H_1 10°	H_2 10°	H_1 15°	H_2 15°	H_1 20°	H_2 20°	Adjusted Work Surface
1				-1	+2	+1				-2	H_1-8°
2		-2			+1	+2			-1		H_1-8°
3	-1	-2					+1	+2			H_1-15°
4			+1	+2		-2				-1	H_2-5°
5	-2	-1					+1	+2			H_2-14°
6		-2		+2	+1				-1		H_1-7°
7			+1	+2					-2	-1	H_2-4°
8					+1	+2			-2	-1	H_1-10°
9					+2	+1			-1	-2	H_1-7°
10	-1	-2			+2			+1			H_1-12°
11			-2	-1			+1	+2			H_2-18°
12	+2	+1							-2	-1	H_1-0°
13			+1	+2					-2	-1	H_2-6°
14	+2	+1							-1	-2	H_1-0°
15					+1	+2	-2	-1			H_2-10°
16	+2	+1							-1	-2	H_1-0°
Total	+2	-6	+1	+6	+10	+6	+1	+6	-13	-13	
Total	-4		+7		+16		+7		-26		

DISCUSSION

Considering all criteria, it was found that statistically there was no difference among 0°, 5°, 10° and 15° inclinations. The results based on data shown in Table 3 indicated that maximum number of assemblies were produced at minimum energy cost and minimum mental concentration at the 5° inclination. The minimum production at maximum energy cost and maximum concentration was at 20° inclination. From the curves of Figures 6, 7 and 8 it is interpreted that the optimum inclination will be between 5° and 10°. Though there was no significant effect of height, results shown in Table 3 indicate that work surface height at one inch below the elbow should be preferred over the other height. At this height the production was slightly more with lesser energy cost.

The results of this study that between 5° and 10° is the best inclination of the work surface agrees with the findings of Wotzka, Grandjean, Burandt, Kretzschmar and Leonhard (1969) who modified the inclination of the writing surface from 15° to 10°. Since no study directly related with this has been done yet, exact comparison of the results can not be made.

The result of this investigation that one inch below the elbow is best height agrees very nearly with the studies of Chatterjee and Daftuar (1966) and Sankaran (1969). Chatterjee and Daftuar found that best efficiency could be achieved when the height of the table was 1.18 inch below the elbow. Sankaran found a work table set at 1.15 inches below the elbow required the minimum physiological cost. Hasting (1966) determined the optimum height of the work station to be elbow level. Konz (1967) concluded that one inch below the elbow is the best height for a standing operator. From this investigation, it can be said that the same can be applied for a sitting operator also.

CONCLUSION

It is concluded that a slight inclination of work surface is desirable for this task. The results of this study indicate that the work surface should be inclined between 5° and 10° with the horizontal while the front edge is kept fixed at one inch below the elbow.

Since no study has been conducted for the evaluation of inclination between 5° and 10°, the actual behavior of work surface between these limits is unknown. Further studies should be conducted to determine the optimum inclination for other tasks.

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APPENDIX

THIS BOOK CONTAINS NUMEROUS PAGES THAT HAVE GLUE STAINS ON THE PAGES.

THESE ARE THE BEST IMAGES AVAILABLE.

Table 6

Assemblies/five minutes

Work Surface / Subject	AH_1 No. of Assembly	AH_1 Errors	AH_2 No. of Assembly	AH_2 Errors	BH_1 No. of Assembly	BH_1 Errors	BH_2 No. of Assembly	BH_2 Errors	CH_1 No. of Assembly	CH_1 Errors	CH_2 No. of Assembly	CH_2 Errors	DH_1 No. of Assembly	DH_1 Errors	DH_2 No. of Assembly	DH_2 Errors	EH_1 No. of Assembly	EH_1 Errors	EH_2 No. of Assembly	EH_2 Errors	Total No. of Assembly	Total Errors	Mean No. of Assembly	Mean Errors
1	326		360		301	1	393	2	394		314	1	326		332		372		340		3458	4	345.8	0.4
2	276		248	2	286		264		272	1	272	1	246	2	266	1	240		280		2650	7	265.0	0.7
3	304	1	270	2	326	1	278	1	282	2	310	2	254		294	1	272	2	304		2894	12	289.4	1.2
4	328	1	312	3	326		328		310	2	324		306	3	322	1	330	2	276	3	3162	15	316.2	1.5
5	250	1	246		240		282	2	260	2	256		268		240		248	2	232		2522	7	252.2	0.7
6	262		249		256	2	272	5	272		244		256	1	256		274		264		2605	8	260.5	0.8
7	258	3	262		264	1	248	2	256	2	248		272	1	260		272	1	264		2604	10	260.4	1.0
8	272		276	1	296		274	1	264	2	268		288		288		268		268		2762	4	276.2	0.4
9	334	1	342		322	2	336		366	1	352	7	344	1	362		336	2	336	8	3430	22	343.0	2.2
10	296		280		308	1	288		298		296		302	1	298		266		272		2904	2	290.4	0.2
11	288	2	288	1	294	8	316	3	288	4	288	2	259	3	256	1	288	6	256	5	2821	35	282.1	3.5
12	294		294	1	284		284	4	288	1	304	3	276		272	1	260		258		2814	10	281.4	1.0
13	290		304		288		320		316		288		304	2	296	1	272		298		2976	3	297.6	0.3
14	348		366		306	1	360		344		308		342		358		336		344		3412	1	341.2	0.1
15	326		322		332		320		320		329		320		326	1	329		320		3244	1	324.4	0.1
16	270	9	296	18	288	18	264	10	304	16	268	5	298	14	270	7	270	6	310	14	2838	117*	283.8	11.7*
Total	4722	9	4715	10	4717	17	4827	20	4834	17	4669	16	4661	14	4696	7	4633	15	4622	16	47,096	141*		
Mean	295.1		294.7		294.8		301.7		302.1		291.8		291.3		293.5		289.6		288.9		294.4		294.4	

A-0°, B-5°, C-10°, D-15°, E-20°.

H_1-one inch below the elbow height

H_2-two inches below the elbow height

* excluding subject 16

Table 7

Number of assemblies in 5 minutes and normalized data after adjusting for the effect of learning and fatigue

Work Surface / Subject	AH_1 No.of Assembly	AH_1 No.of Assembly -Mean	AH_2 No.of Assembly	AH_2 No.of Assembly -Mean	BH_1 No.of Assembly	BH_1 No.of Assembly -Mean	BH_2 No.of Assembly	BH_2 No.of Assembly -Mean	CH_1 No.of Assembly	CH_1 No.of Assembly -Mean	CH_2 No.of Assembly	CH_2 No.of Assembly -Mean	DH_1 No.of Assembly	DH_1 No.of Assembly -Mean	DH_2 No.of Assembly	DH_2 No.of Assembly -Mean	EH_1 No.of Assembly	EH_1 No.of Assembly -Mean	EH_2 No.of Assembly	EH_2 No.of Assembly -Mean	Total Assemblies	Mean
1	327.8	-18.0	352.8	7.0	320.5	-25.3	386.7	40.9	383.9	38.1	325.0	-20.8	328.0	-17.8	330.0	-15.8	361.9	16.1	341.9	-3.9	3458.5	345.8
2	269.7	4.7	267.5	2.5	278.8	13.8	265.8	0.8	270.0	5.0	274.0	9.0	247.9	-17.1	255.9	-9.1	251.0	-14.0	269.9	4.9	2650.5	265.0
3	293.9	4.5	281.0	-8.4	315.9	26.5	279.9	-9.5	283.8	-5.6	302.8	13.4	273.5	-15.9	287.7	-1.7	274.0	-15.4	302.0	12.6	2894.5	289.4
4	320.8	4.6	313.8	-2.4	324.0	7.8	330.0	13.8	311.9	-4.3	313.9	-2.3	317.0	0.8	311.9	-4.3	323.7	7.5	295.5	-20.7	3162.5	316.2
5	252.0	-0.2	244.0	-8.2	259.5	7.3	275.7	23.5	249.9	-2.3	257.9	5.7	257.9	5.7	251.0	-1.2	249.8	-2.4	224.2	-28.0	2522.5	252.2
6	254.8	-5.7	250.8	-9.7	267.0	6.5	261.9	1.4	265.7	5.2	263.5	3.0	254.0	-6.5	258.0	-2.5	275.9	15.4	253.9	-6.6	2605.5	260.5
7	277.5	17.1	255.9	-4.5	253.9	-6.5	249.9	-10.5	258.0	-2.4	246.0	-14.4	261.9	1.5	271.0	10.6	273.8	13.4	256.8	-3.6	2604.5	260.4
8	273.9	-2.3	265.9	-10.3	294.0	17.8	276.0	-0.2	257.7	-18.5	287.5	11.3	280.8	4.6	289.8	13.6	279.0	2.8	257.9	-18.3	2762.5	276.2
9	335.8	-7.2	334.8	-8.2	341.5	-1.5	329.7	-13.3	355.9	12.9	363.0	20.0	346.0	3.0	360.0	17.0	325.9	-17.1	337.9	-5.1	3430.5	343.0
10	289.7	-0.8	299.5	9.0	300.8	10.3	289.8	-0.7	296.0	5.5	298.0	7.5	303.9	13.4	287.9	-2.6	277.0	-13.5	261.9	-28.6	2904.5	290.5
11	277.9	-4.2	299.0	16.9	283.9	1.8	317.9	35.8	289.8	7.7	280.8	-1.3	278.5	-3.6	249.7	-32.4	290.0	7.9	254.0	-28.1	2821.5	282.1
12	286.8	5.4	295.8	14.4	282.0	0.6	286.0	4.6	289.9	8.5	293.9	12.1	287.0	5.2	261.9	-19.5	253.7	-27.7	277.5	-3.9	2814.5	281.4
13	292.0	-5.6	302.0	4.4	307.5	9.9	313.7	16.1	305.9	8.3	289.9	-7.7	293.9	-3.7	307.0	9.4	273.8	-23.8	290.8	-6.8	2976.5	297.6
14	340.8	-0.4	367.8	26.6	317.0	-24.2	349.9	8.7	337.7	-3.5	327.5	-13.7	340.0	-1.2	360.0	18.8	337.9	-3.3	333.9	-7.3	3412.5	341.2
15	345.5	21.1	315.7	-8.7	321.9	-2.5	321.9	-2.5	322.0	-2.4	327.0	2.6	309.9	-14.5	337.0	12.6	330.8	6.4	312.8	-11.6	3244.5	324.4
16	271.9	-11.9	285.9	2.1	286.0	2.2	266.0	-17.8	297.7	13.9	287.5	3.7	290.8	7.0	271.8	-12.0	281.0	-2.8	299.9	16.1	2838.5	283.8
Total	4710.8	1.1	4732.2	22.5	4754.2	44.5	4800.8	91.1	4775.8	66.1	4738.8	28.1	4671.0	-39.1	4690.6	-19.1	4658.2	-50.5	4570.8	-138.9	4709.6	294.4
Mean	294.4	.06875	295.8	1.4063	297.1	2.7813	300.1	5.6938	298.5	4.1313	296.2	1.7563	291.9	-2.4438	293.2	-1.1938	291.1	-3.1563	285.7	-8.6813	2944.0	294.4
Variation w.r.t. H_1 or H_2					+0.92%		+1.45%		+1.39%		+0.14%		-0.85%		-0.88%		-1.09%		-3.41%			

Table 8

Incremental heart beats per minute and normalized data after adjusting for the effect of learning and fatigue

Work Surface / Subject	AH_1	AH_1-Av.	AH_2	AH_2-Av.	BH_1	BH_1-Av.	BH_2	BH_2-Av.	CH_1	CH_1-Av.	CH_2	CH_2-Av.	DH_1	DH_1-Av.	DH_2	DH_2-Av.	EH_1	EH_1-Av.	EH_2	EH_2-Av.	Total	Mean (Av.)
1	6.2	0.0	5.7	-0.5	7.6	1.4	11.0	4.8	17.2		6.5	0.3	0.3	-6.5	8.5	2.3	6.7	0.5	3.1	-4.2	55.6*	6.2*
2	7.6	0.5	7.6	0.5	8.8	1.7	0.8	-6.3	3.2	-3.9	12.6	5.5	7.9	0.8	3.2	-3.9	1.9	-5.2	17.4	10.3	71.0	7.1
3	11.6	1.1	8.1	-2.4	7.2	-3.3	8.5	-2.0	2.1	-8.4	17.1	6.6	9.0	-1.5	16.7	6.2	8.9	-1.6	15.7	5.2	104.9	10.5
4	1.5	-4.7	4.8	-1.4	4.1	-2.1	4.8	-1.4	5.9	-0.3	6.3	0.1	5.2	-1.0	7.9	1.7	10.8	4.6	10.9	4.7	62.2	6.2
5	2.6	-4.1	7.6	0.9	3.5	-3.2	6.0	-0.7	2.4	-4.3	6.8	0.1	13.8	7.1	13.1	6.4	5.3	-1.4	5.5	-1.2	66.6	6.7
6	8.7	0.7	8.1	0.1	7.7	-0.3	8.8	0.8	7.9	-0.1	8.3	0.3	5.2	-2.8	11.0	3.0	9.8	1.8	4.1	-3.9	79.6	8.0
7	7.1	2.0	2.5	-2.6	5.6	0.5	4.8	-0.3	5.0	-0.1	6.1	1.0	1.6	-3.5	4.8	-0.3	10.0	4.9	3.3	-1.8	50.8	5.1
8	1.8	-3.5	8.2	2.9	0.1	-5.2	8.3	3.0	-0.5	-5.8	4.5	-0.8	8.7	3.4	4.1	-1.2	6.3	1.0	11.5	6.2	53.0	5.3
9	9.5	0.0	2.8	-6.7	12.2	2.7	10.0	0.5	11.5	2.0	4.9	-4.6	8.4	-1.1	10.5	1.0	13.2	3.7	12.0	2.5	95.0	9.5
10	8.2	2.1	5.0	-1.1	1.9	-4.2	6.8	0.7	6.3	0.2	9.9	3.8	5.7	-0.4	6.8	0.7	6.4	0.3	4.1	-2.0	61.1	6.1
11	9.7	0.9	5.4	-3.4	2.7	-6.1	5.7	-3.1	4.9	-3.9	3.7	-5.1	9.8	1.0	11.5	2.7	20.5	11.7	14.0	5.2	87.9	8.8
12	3.5	-1.6	10.2	5.1	6.0	0.9	3.5	-1.6	6.4	1.3	4.8	-0.3	3.9	-1.2	4.2	-0.9	4.3	-0.8	4.1	-1.0	50.9	5.1
13	4.2	-4.0	8.1	-0.1	8.8	0.6	5.1	-3.1	2.2	-6.0	12.1	3.9	11.9	3.7	10.8	2.6	6.9	-1.3	11.9	3.7	82.0	8.2
14					O		U		T		L		I		E		R					
15	8.9	-1.4	12.8	2.5	13.2	2.9	10.0	-0.3	8.0	-2.3	9.5	-0.8	13.7	3.4	8.3	-2.0	8.8	-1.5	9.6	-0.7	102.8	10.3
16	7.6	-2.2	13.7	3.9	8.8	-1.0	6.6	-3.2	8.4	-1.4	3.1	-6.7	7.8	-2.0	8.8	-1.0	18.3	8.5	15.2	5.4	98.3	9.8
Total	98.7	-14.2	110.6	-2.3	98.2	-14.7	100.7	-12.2	73.7*	-33.0*	116.2	3.3	112.9	-0.6	130.2	17.3	138.1	25.2	142.4	28.4	1121.7	112.8
Mean	6.6	-0.9	7.4	-0.2	6.5	-1.0	6.7	-0.8	5.3*	-2.4*	7.7	0.2	7.5	0.0	8.7	1.2	9.2	1.7	9.5	1.9	76.0	7.5
Variation w.r.t. H_1 or H_2					-0.1		-0.7		-1.3		+0.3		+0.9		+1.3		+2.6		+2.1			

*excluding subject 1 for CH_1

Table 9

Decrease in standard deviation of heart beat interval after adjusting for the effect of learning and fatigue

Work Surface / Subject	AH_1	AH_2	BH_1	BH_2	CH_1	CH_2	DH_1	DH_2	EH_1	EH_2	Total	Mean
1	.006	.002	.026	-.002	.030	.008	-.009	.012	.004	.010	.087	.0087
2	.016	.020	.007	-.009	.034	.018	.016	.004	-.006	.028	.128	.0128
3	.022	.006	.007	.035	.005	.027	.007	.010	.027	.016	.162	.0162
4	-.002	-.007	-.008	.001	-.012	-.005	.014	.010	.019	-.002	.008	.0008
5	-.007	-.037	.033	.054	-.015	.027	.009	.011	.042	.014	0.131	.0131
6	.007	.029	.011	.002	-.006	.012	.027	.016	.016	.027	.141	.0141
7	.012	-.016	-.021	-.006	-.004	.013	-.006	-.016	.004	.028	-.012	-.0012
8	.037	.014	.013	.035	-.005	-.002	.021	-.003	.030	-.042	.098	.0098
9	.011	.034	.019	.007	.012	0.012	.031	-.003	.043	.000	.142	.0142
10	.007	.008	-.008	.014	.004	.018	-.015	.019	.009	.013	.069	.0069
11	.003	-.002	-.003	-.008	.021	-.017	.038	.037	.010	.011	.090	.090
12	.010	.019	-.009	.000	.003	.029	.031	.000	.003	-.014	.072	.0072
13	.041	.019	.025	.020	.035	.030	.051	.042	.011	.027	.301	.0301
14				O	U	T	L	I	E	R		
15	.020	.007	.014	+.012	.009	.020	.036	.018	.013	.026	.175	.0175
16	-.005	.069	.052	.003	.029	.020	.018	.012	.062	.047	.307	.0307
Total	.178	.165	.158	.158	.140	.186	.269	.169	.287	.189	1.899	.1899
Mean	.012	.011	.0105	.0105	.009	.012	.018	.011	.019	.013	.130	.013

ASSEMBLY ON INCLINED WORK SURFACES

by

SARAN SHANKAR VERMA

B. Sc., B. E. (Elect.), Allahabad University,
India, 1967

AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

The effect of inclination and height of the work surface was determined for a simple assembly task while the subjects were sitting. The number of assemblies produced in five minutes, incremental heart rate, decrease in standard deviation of inter beat intervals, errors, preference and self-adjustment of the work surface by each subject were the six criteria. The task was to assemble 16 wooden washers (one on each peg) on a peg-board with sixteen 1/4-inch wooden pegs arranged into 4 x 4 matrix on 1-inch centers at five (horizontal, 5^o, 10^o, 15^o and 20^o inclined) work surfaces. Sixteen students (8 males and 8 females) performed the task at two heights, -1 and -2 inches from the elbow. The task was performed by using symmetrical and simultaneous hand motions.

There was a small but significant effect of inclination. On an average, a work surface between 5^o and 10^o inclination at one inch below the elbow required the minimum physiological cost and provided maximum production. The decrease in standard deviation of inter heart beat intervals at this work surface was also minimum. The subjects liked it most; and eight out of sixteen subjects adjusted the inclination to between 5^o and 9^o while ten subjects preferred the height at one inch below the elbow. The 20^o inclined work surface at two inches below the elbow was the worst.