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AN INVESTIGATION OF THE EFFECT ON WORK OF VARYING THE DISTANCE BETWEEN SHOULDER AND WORK-TABLE

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by

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INTRODUCTION

The effect on work performance of varying the distance between shoulder and work table was studied through the use of a force platform.

The primary objective of this investigation was to determine the existence of an optimum vertical distance between a work table and the shoulder of a seated worker. The measure of performance or criterion used to determine this optimum distance was the work expended by a given task of moving a two-pound weight through specific paths and trajectories.

The second objective was to compare the work expended at various angles and to find at which angles the least work will be produced. A third objective was to determine whether the work done by movement in an inward direction and an outward direction is the same or different.

In the present investigation, the vertical distance between a work table and the subject's shoulder was specified as a percentage of the length of the upper arm (L) of each subject. Thus, the distance between the shoulder and the work surface could be 1.1L for two subjects but the distance would be 16.5 inches for a subject with a 14 inch arm and 15.4 inches for a subject with a 14 inch arm. The experimental task was performed at five levels of shoulder to work table distance: 0.7L, 0.85L, 1L, 1.15L, and 1.3L.

The work expended by a given task of moving a two-pound weight through the specific paths must be constant, but the quantity of work was measured experimentally on the task work plus the work done by the subject in positioning himself for the task. Therefore the significant difference must be due to the work done by the subject in positioning himself.

To the best of this writer's knowledge, no previous work has been done on the primary and third objectives of this experiment. The following references were used to formulate the second objective. Schidtke and Steir (8) made an experimental evaluation of predetermined time systems. They found that the maximum time for reaching was at 145 degrees and the minimum time was 55 degrees with a time difference of 19%. McCormick (7) cited a study of continuous movements in different directions. The study showed the error index at different angles and indicated that errors were least at around 135 and 315 degrees. Maximum errors were at around 45 and 225 degrees. Therefore, continuous hand movements from lower left to upper right are more accurate than those from lower right to upper left. Briggs (3) states that in many industrial jobs in which parts are being assembled, the hand is required to move from the work at the assembly point to a bin or tool located at another point and then return. Holding the distance constant at 14", he found that the angle at which the maximum response was required was significantly farther to the right when the point was centrally fixed than when the point was at the periphery.

In the present experiment, the subject was required to use his right hand in moving a two-pound weight from the central point p to points at 0, 45, 90, 135 and 180 degrees, and then return the weight to point p (see Figs. 1 and 2).

The force platform, based on Barany's design (Fig. 3) with two two-channel Sanborn Recording Amplifiers (Fig. 4) was used. Barany's (1) platform was a mechanical device which permitted a Linear Variable Differential Transformer to simultaneously pick up forces transversely (X plane), frontally (Y plane) and vertically (Z plane). (See Fig. 5.) In this experiment, the traces for the forces were obtained on a heat sensitive paper with a resistance-type stylus. Analysis was made on the forces in the S, Y and Z planes and the total forces from all three planes. The force trace originates from an established zero mark and deviates either above or below the zero. Work is directly proportional to the work exerted in the specified plane. By calibration with known weights, it was found that one square inch of area on the output paper was equal to 400 work units (inch-pounds) in the X and Y planes, and 100 in the Z plane.

Several people have previously used a force platform. Jacobson (4) studied a dynamic evaluation of a three-dimensional beam spring scale. The scale had sufficient sensitivity to measure 1/2 pound force in the frontal (Y plane) axis and 1 pound force in the lateral (X plane) and vertical (Z plane) axes. The results proved that this minimum force sensing capability was unaffected by frequencies of force application from 50-200 cpm or by variation in subject weight from 100 to 200 pounds.

Barta (2) investigated the existence of a relationship between the external force exerted by a worker (measured by the force platform) and time as the criterion for work measurement. He found that the three components of external force, measured by the force platform, increased at a much greater rate than the increase in time for work measurement as the weight handled increased from 0.35 pounds to 12.92 pounds. Markstrom (6) determined whether the variation of lateral orientation (direction) or sector (location) of a move in three dimensional space caused variation either in the length of time required for the move or in external force. Lateral orientation produced no significant time or external force difference. The variable sector (location) caused significant external force differences but no time differences.

In this study, three hypotheses were made: Hypothesis I, work is the same for movement done in an inward and an outward direction; Hypothesis II, the work done in the X, Y and Z planes and their arithmetic total is independent of horizontal angle; Hypothesis III, there is an optimum distance between a work table and the shoulder which results in the least work in the X, Y and Z planes and their arithmetic total.

In order to prove or disprove these hypotheses, a series of experiments was conducted using inward and outward movement at various work levels and at various horizontal angles. Hypothesis I was tested according to a paired comparison t-test. The design to test Hypotheses II and III was split plot with work heights as whole plots and angles as split plots with duplicate observations.

The results indicated that an optimum vertical distance for least work was between 0.7L and 1L; that is, the average work was less than 6.00 inch-pounds for the inward direction and less than 4.80 inch-pounds for the outward direction. The angle for least work was zero degrees for the subjects for all levels of shoulder to work table distances investigated; that is, the average work was less than 3.99 inch-pounds for the inward direction and less than 4.26 inch-pounds for the outward direction. The work done in an inward direction (an average of 6.23 inch-pounds) was 1.2 times greater than that done in the outward direction (an average of 5.18 inch-pounds). In other words, it is easier to push than to pull.

PROBLEM

Hypothesis I. Work is the same for movement done in an inward and an outward direction.

Hypothesis II. The work done in the X, Y and Z planes and their arithmetic total is independent of horizontal angle.

Hypothesis III. There is an optimum distance between a work table and the shoulder which results in the least work in the X, Y and Z planes and their arithmetic total.

METHOD

Task

The experimental task was performed at five levels of shoulder to work table distance: 0.7L, 0.85L, 1L, 1.15L, and 1.3L. The subject was required to use his right hand to move a two-pound weight from the central point p to points at 0, 45, 90, 135 and 180 degrees, and then return the weight to point p. (See Figs. 1 and 2.)

In this manner, the subject continued to move the weight with his right hand from p to another position. Each step consisted of an outward movement of the weight and an inward movement to point p. Each work cycle consisted of five steps which were performed in a random order. For example, the first cycle could consist of movement from point p to 45 and return, from p to 90 and return, from p to 0 and return, from p to 180 and return, and from p to 135 and return. The second cycle could be that the subject repeated this first cycle with variation in the random order of points. For each working level, the subject performed two cycles of movements.

Subjects

Seven men and three women, all right-handed, were selected from the student body of Kansas State University. In order to get a wide variation, the student subjects were selected to include long-armed men and short-armed women. (See Table 1.) The length of the subjects' upper-arms were between 11.5 inches and 16.0 inches by which was the middle 95% of the male and female population indicated in Morgan, et. al. (6).

Materials and Apparatus

(a) Work table (See Figs. 1 and 6).

A drawing type table was used. The work area was the plane surface near the inner edge of the table. From the center of point p a semicircle of 15 inches radius was constructed. Five points, located at 0, 45, 90, 135 and 180 degrees with respect to the front edge of the table in a counter-clockwise direction, were drawn on this curve.

(b) Hydraulic lift (See Fig. 6).

A hydraulic lift was used as a base for the table so the table surface could be adjusted vertically. In this way the working level for a subject was controlled.

(c) Chair (See Fig. 3).

A drawing type work chair was used. The seat could be adjusted vertically to regulate the working height of a subject.

(d) Weight (See Fig. 1).

The subjects worked with a two-pound weight.

(e) Cards.

Fifty cards were used, five for each subject. On each card was three series of the five angles, each series arranged in random order. The first series was used for practice.

(f) Metronome.

A metronome was used to keep the time of the subjects' work motions constant.

(g) Wooden slat (See Fig. 7).

A wooden slat was used to keep the subject's arm parallel to the table for measurement of the distance between the shoulder and the table. A ruler was used to measure the distance between the shoulder and the work table.

(h) Force platform and Sanborn Record Amplifier (See Figs. 3 and 4).

The equipment consisted of a force platform based on Barany's design (Fig. 3), plus two two-channel Sanborn Record Amplifiers (Fig. 4). The basic vertical, lateral and frontal support elements of the platform used the principle of linearity of the cantilever beam. Complete independence of the three perpendicular axes was assured by the use of an equilateral triangular support of the vertical forces and by use of a single point transmittal for the lateral and frontal forces.

The recorders had a four-volt excitation and a frequency response of 2500 cps and were capable of measuring one micro-inch of core displacement of the Linear-Variable-Differential-Transformer.

In this experiment, the traces were obtained on a heat sensitive paper with a resistance type stylus. The force trace originates from an established zero mark and deviates either above or below it. The area above or below the zero mark is directly proportional to the work exerted in the specific plane.

(i) Planimeter

A planimeter was used to determine the area of work from record paper.

Experimental Design and Analysis

Hypothesis I was tested using a paired comparison t-test: (Snedecor (9)). The null hypothesis might be stated

$$H_o : \mu_d = 0$$

$$H_a : \mu_d \neq 0$$

$$t = \bar{d} \,/\, S_{\bar{d}}$$

$$d_{(i)} = Z_{(i)\text{inward}} - Z_{(i)\text{outward}}$$

$$S^2_{\bar{d}} = \frac{d^2_{(i)} - (\Sigma\, d_{(i)})^2}{n(n-1)}$$

$\bar{d}$ = the average of the $d_{(i)}$

$Z_{(i)\text{inward}}$ = the average work for each pair of readings for inward direction for the ith trial.

$Z_{(i)\text{outward}}$ = the average work for each pair of readings for outward direction for the ith trial.

n = the total number of observations.

Hypothesis I is rejected if $|t| \geqslant t_{n-1,0.05}$ where $t_{n-1,0.05}$ is the tabled student's t statistic with (n - 1) degree of freedom. Otherwise, accept Hypothesis I.

The experimental design for Hypotheses II and III was a split plot design with work levels as whole plots and angles as split plots with duplicate observations. A detailed description of the model follows and the analysis of variance with expected mean squares (adapted from Snedecor (9)), may be found on the next page. Duplicates were averaged for the analysis.

$$X_{ijk} = \mu + \rho_i + H_j + \gamma_{ij} + \alpha_k + \alpha H_{jk} + \epsilon_{ijk}$$

ρ_i = subject effect (a random factor)

H_j = distance between the shoulder and work table (a fixed factor)

γ_{ij} = error for distance

α_k = angle (fixed factor)

αH_{jk} = interaction of angle and distance

ϵ_{ijk} = error for angle and interaction

The assumptions were that the ϵ_{ijk} was NID$(0,\sigma^2)$, i.e. the errors were normally and independently distributed with homogenous variance over subjects and treatments (angles and distances). These assumptions seemed to be reasonable for this experiment, though a test for homogeneity of variance was not carried out.

Hypotheses II and III can be tested using the following statistical hypotheses for each plane and the total.

A. H_0 : $H_{jk} = 0$ for $j = 1, \ldots, 5$.

If A is accepted, we may test hypotheses B and C.

B. H_0 : $H_j = 0$, for $j = 1, \ldots, 5$.

C. H_0 : ${}_k = 0$, for $k = 1, \ldots, 5$.

H_0 is rejected in each case if F observed $\geq$ F, v1,v2 where α = P (Type I error), v_1, v_2 are numerator and denominator degrees of freedom, respectively.

ANALYSIS OF VARIANCE FOR SPLIT PLOTS DESIGN (SNEDECOR 9)

SOURCE	D.F.	S.S	MS=SS/d.f.
Subject (R)	9	$25\Sigma x^2_{..i.} - 250x^2_{...}$	
Distance (F)	4	$50\Sigma x_{.j..} - 250x^2_{...}$	
Error (a) for subject and distance	36	$5\ x^2_{.ji.} - 50\Sigma x^2_{.j..} - 25\Sigma x^2_{..i.} + 250x^2_{...}$	
Angle (F)	4	$50\Sigma x^2_{k...} - 250x^2_{...}$	
Interaction for angle and distance	16	$10\Sigma x^2_{kj..} - 50\Sigma x^2_{k...} - 50\Sigma x^2_{.j..} + 25x^2_{...}$	
Error (b) for angle and angle x distance	180	Subtraction	
TOTAL	249	$\Sigma\Sigma\Sigma_{ijk} x^2_{ijk.} - 250x^2_{...}$	

SOURCE	D.F.	E MS
Subject (R)	9	$\sigma_\epsilon^2+5\sigma_\delta^2+25\ ^2$
Distance (F)	4	$\sigma_\epsilon^2+5\sigma_\delta^2+(50/4)\Sigma H_j^2$
Error (a)	36	$\sigma_\epsilon^2+5\sigma_\delta^2$
Angle (F)	4	$\sigma_\epsilon^2+(50/4)\Sigma\alpha_i^2$
Distance x Angle	16	$\sigma_\epsilon^2+(10/16)\Sigma(\alpha H)^2_{ij}$
Error (b)	180	σ_ϵ^2

To compare (1) Two distances' means, (2) Two angles' means L.S.D. for (1) = $t\sqrt{(2E_a/50)}$, for (2) = $t\sqrt{(2E_b/50)}$.

No significant interaction was found in any of the analyses, so angle and shoulder to work table height were analyzed. If there had been significant interaction, then a least significant difference criterion would be applied directly to the means (Snedecor (9)) for angle and shoulder to table level combination.

If work did not vary significantly from position to position of the tool, then the null hypothesis was accepted. If the different angles did provide significant differences in the requisite forces, then the null hypothesis was rejected and the differences were examined using a least significant difference criterion, (see Snedecor (9)). These same steps were used in analyzing the variation in the shoulder to work table height.

Experimental Procedures

The work table was put on the hydraulic lift. The table could then be adjusted vertically to regulate the working height of the task. (See Fig. 3). This adjustment was made if the shoulder to work table distance was 0.7L, 0.85L or 1L.

The work chair was put on the force platform. Its seat also could be adjusted vertically to regulate the working height of the subject. This adjustment was used to make the distance between the shoulder and work table 1.15L and 1.3L.

This study was made in the machine shop of the Kansas State University Department of Industrial Engineering.

All subjects were tested individually. Upon entering the experimental station, each subject had a measurement taken of the length of his upper arm between shoulder bone and elbow with fore-arm at a 90 degree angle. Next, the subject was seated at the work chair and extended his arms from the shoulder parallel to the table. The experimenter laid the wooden slat along the arm and measured the distance to the work table. Then the experimenter adjusted the distance between the subject's shoulder and the work table. After starting the metronome, the recorder pen was adjusted to zero.

Each subject was given a 60 minute period for practicing at least 10 working cycles which was described in the task section, identical to the regular experimental task to see that he understood what to do.

When the subject began the experimental task, the experimenter assumed a position in front of the Sanborn Record Amplifier in order to push buttons provided on the recorder to mark the start and end of each movement while it recorded data on the X, Y and Z axes. By calibration with known weights, it was found that one square inch of area on the output paper was equal to 400 work units (inch-pounds) in the X and Y planes, and 100 in the Z plane.

The experimenter then recalculated the area tabulated on a form given in Fig. 9 in the terms of Fig. 8 by multiplying X and Y each by 400 and Z by 100 to be a work unit (inch-pound). All data for each of the three planes in each of two directions of movement (inward and outward) were tabulated on separate sheets according to shoulder to work table distance and tool position. Thus, there were six sheets. In addition, the arithmetic sum of data for the three planes was recorded on similar sheets for the inward and outward movements. This made a total of eight sheets used in the form shown by Fig. 9.

RESULTS AND DISCUSSION

To test the first hypothesis, that work is the same for movement done in an inward and an outward direction, a paired comparison t-test was applied to the work of subjects participating in the force platform experiment. (See Table 2.) Since the t-test value obtained was greater than the critical tabled value at the 0.01 level, this hypothesis was rejected. Work value was not the same for work done in inward and outward directions. Work done in an inward direction (average work 6.23 inch-pounds) is 1.2 times greater than work done in an outward direction (average work 5.18 inch-pounds).

To test the second hypothesis, that the work done in the X, Y and Z planes and their arithmetic total is independent of horizontal angle, an analysis of variance F-test for a split plot design was applied. The F value obtained was greater than the critical F value at the 0.01 significant level for all tests of the effect of angle (Tables 3 to 10). In other words, the work done by moving a two-pound weight in horizontal inward and outward directions in the vertical, lateral and frontal planes and the total work are dependent on horizontal angle.

Tables 11 - 18 show the means for each angle and least significant difference values. The least work angle for inward and outward movement are basically the same. The angle at which the minimum work is required was zero degrees, although for some planes 45 and 90 degrees did not require significantly more work. The most work was exerted at 135 degrees, although for some planes 90 and 180 degrees were not significantly different.

The hypothesis, that there is an optimum distance between a work table and the shoulder which results in the least work in the X, Y and Z planes and their arithmetic total, was tested with an analysis of variance F-test for a split plot design. The F value obtained was greater than the tabled value of F at the 0.05 level for all planes and directions except the X plane in both directions and the Y plane in outward direction (Tables 3-10). To find an optimum distance between a work table and the shoulder for work done in a horizontal inward direction which results in the least work in the Y and Z planes and the arithmetic total and outward direction which results in the least work in the Z plane and the arithmetic total, the procedure was the same as that used in finding the angle for the least work. It was found that the optimum distance between the shoulder and work table was between 0.7L and 1L. The most work was exerted between 1.15L and 1.3L. (Tables 11-18.)

Figures 10 through 14 show the distance in inches between shoulder and work table for all the different subjects for each angle. Fig. 10 shows that the optimum distance between the shoulder and the work table was between 11 inches and 13 inches, because the work required was slightly below the average mean values of 4.0 work units in an outward direction and 3.7 work units in an inward direction.

The other charts (Figs. 11-14) also indicate the same optimum distances. Note that work in an inward direction was less than work in an outward direction for zero degrees, but the work in an inward direction was greater than the work in an outward direction for the remaining angles.

Figure 15 shows that work in the inward direction increases rapidly as the angle changes from 0 degrees to 135 degrees for any specific work level but decreases for 180 degrees. Figure 16 shows that work in the outward direction changed only slightly with change in angles at various work levels.

Figure 17 indicates that the work changed significantly as the angle was changed. The average work for various work levels for a given angle increased as the angle increased. It was also observed that the optimum work level was about 0.85L. Figure 18 shows that the optimum work level was less than the length of upper arm since the work for levels of less than one L are lower than those of more than one L.

In this experiment, several factors were constant: (1) each subject was a right-handed student; (2) the weight of the object moved was always two pounds; (3) the work time was constant for each movement; and (4) the distance moved was fifteen inches. The only variable among the subjects was the length of the upper arm.

The tests show that the angle of movement and the table level do not interact. In other words, if the work situation is being considered, it is possible to find the optimum level of the work table independently of the optimum angle of movement and vice versa and it is not necessary to consider their interaction.

Since the experimental results described above indicate that outward movements need less work than the inward movements, not only table level and angle but also inward-outward direction should be considered.

The experimental results indicated that a measure of the distance between the shoulder and work table based on each individual's arm length is better than the fixed amount 12" determined from Figs. 10 to 14. For example, a person with an upper arm length of 14" has his optimum work level at less than 14 inches, while another person having an upper arm length of 11.5 inches has his optimum work level at less than 11.5 inches. Therefore, we cannot say that 12 inches is the optimal work level for both.

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REFERENCES

1. Barany, J. W., The nature of individual differences in bodily forces exerted during a motor task as measured by a force-platform. J. Ind. Engr., 1963, Vol. XIV, No. 6, 333-341.

2. Barta, T. A., An investigation of the variable weight as measured by two criteria, time and force-time. Master's Thesis, State Univ. of Iowa, 1962.

3. Briggs, S. J., A study in the design of work areas. Ph.D. Thesis, Purdue Univ., 1955.

4. Jacobson, I. L, A dynamic evaluation of a three-dimensional beam spring scale. Master's Thesis, State Univ. of Iowa, 1960.

5. Markstrom, P. A., An investigation of the directional and locational effects on an unconstrained movement as measured by two criteria, time and force time. Master's Thesis. State Univ. of Iowa, 1962.

6. McCormick, E. J., Human factor engineering. McGraw Hill, 1964.

7. Morgan, C. T., T. S. Cook, A. Chapnis, and M. W. Lund, Human engineering guide to equipment design. McGraw-Hill, 1963.

8. Schmitke, H., and F. Stier, An experimental evaluation of the validity of predetermined elemental time systems. J. Ind. Engr., May-June, 1961.

9. Snedecor, George W., Statistical methods. Ames: The Iowa State University Press, 1961.

APPENDIX A

Table 1. Subject data summary.

sub. no.	length of the upper arm (inch)	build	sex
1	14.5	medium	male
2	14.0	medium	male
3	14.0	medium	male
4	14.5	medium	male
5	13.5	medium	male
6	12.0	short	female
7	11.5	short	female
8	12.0	short	female
9	15.5	long	male
10	16.0	long	male

Table 2. The differences between inward work and outward work for the arithmetic total of forces from the three planes. ($d_i = Z_{i(in.)} - Z_{i(out.)}$).

subjects	distance \ angle	0	45	90	135	180
1		0.9	0.9	2.2	2.5	1.3
2		1.2	-0.5	1.2	2.7	1.3
3		-0.2	2.5	3.8	4.2	2.0
4		0.4	0.1	1.3	2.2	0.9
5	0.7L	0.0	1.0	1.0	1.1	0.2
6		0.3	1.9	1.6	3.7	1.6
7		-0.8	0.3	0.9	2.9	2.6
8		-0.4	0.2	1.5	2.4	1.1
9		0.0	0.5	1.0	0.6	0.0
10		0.5	0.0	2.0	1.8	0.5
1		-1.0	0.6	0.5	2.0	0.2
2		0.9	0.8	0.7	0.9	0.9
3		-0.4	1.5	0.6	0.7	1.4
4		1.0	0.0	1.3	0.5	-0.6
5	0.85L	0.0	0.2	0.5	0.9	0.8
6		-0.7	0.2	3.8	2.4	-0.9
7		-0.3	0.4	0.9	0.3	0.7
8		1.2	2.8	0.8	1.5	3.6
9		-0.6	0.1	1.6	1.0	0.5
10		-0.3	-0.1	0.3	0.7	-0.4
1		-1.3	0.4	2.0	2.2	1.4
2		0.4	0.2	1.6	2.5	2.0
3		-0.1	1.2	1.1	4.0	2.9
4		-0.4	-0.6	1.4	1.8	1.5
5	1L	0.3	0.4	0.6	1.2	0.6
6		-2.0	1.5	3.6	4.4	1.6
7		-1.0	1.7	1.9	1.9	-0.7
8		-0.7	0.6	1.8	3.6	0.8
9		0.0	1.7	1.7	0.5	0.5
10		-0.3	0.3	3.2	3.7	1.1
1		-0.2	-0.1	3.0	2.0	1.8
2		-0.3	1.0	2.1	2.3	3.6
3		-0.2	1.2	2.6	2.5	0.8
4		0.1	-0.3	1.8	1.5	1.1
5	1.15L	-0.8	0.4	1.5	0.8	-0.3
6		-0.5	1.0	4.1	3.9	1.6
7		-1.5	0.4	3.8	3.3	1.6
8		-0.7	-0.9	3.1	4.0	1.9
9		-0.8	0.5	1.3	2.2	0.7
10		0.2	-0.4	0.1	1.4	0.2

Table 2. (Continued).

angle / subjects	distance	0	45	90	135	180
1		-0.7	0.8	-0.6	0.1	1.5
2		0.1	1.4	2.6	0.2	1.7
3		-0.4	0.4	1.4	2.3	1.4
4		-2.2	0.3	1.5	2.2	1.1
5	1.3L	-1.2	-0.1	1.6	3.1	-0.3
6		0.9	1.2	3.5	5.7	1.0
7		-0.8	0.7	3.4	4.2	3.3
8		0.5	-3.0	0.1	-0.7	0.0
9		-0.8	1.1	0.4	1.9	0.7
10		-0.8	0.8	3.0	3.1	1.5

$\bar{d} = 1.05$ $S_{\bar{d}} = 0.085$ $t = 12.37^{**}$

$P < 0.05$ for 2 tail tests.

CI: $0.86 \leq \bar{d} \leq 1.24$

Table 3. Analysis of variance of inward work in the X plane.

Source	d.f.	M.S.	F
Subjects (R)	9	1.199	5.52
Distance (F)	4	0.398	1.84
Error (a) for subjects and distance	36	0.217	
Angle (F)	4	3.227	78.71**
Angle X Distance	16	0.034	0.83
Error (b) for angle and angle X distance	180	0.041	
Total	249		

** $P < 0.01$

Table 4. Analysis of variance of inward work in the Y plane.

Source	d.f.	M.S.	F
Subjects (R)	9	2.386	6.74
Distance (F)	4	1.236	3.49*
Error (a) for subjects and distance	36	0.354	
Angle (F)	4	16.283	129.53**
Angle X Distance	16	0.128	1.02
Error (b) for angle and angle X distance	180	0.126	
Total	249		

* $P < 0.05$

** $P < 0.01$

Table 5. Analysis of variance of inward work in the Z plane.

Source	d.f.	M.S.	F
Subjects (R)	9	50.418	29.97
Distance (F)	4	18.557	11.03**
Error (a) for subjects and distance	36	1.682	
Angle (F)	4	36.170	85.76**
Angle X Distance	16	0.644	1.14
Error (b) for angle and angle X distance	180	0.565	
Total	249		

** $P < 0.01$

Table 6. Analysis of variance of inward work in the arithmetic total.

Source	d.f.	M.S.	F
Subjects (R)	9	49.891	4.51
Distance (F)	4	34.965	3.19*
Error (a) for subjects and distance	36	11.052	
Angle (F)	4	122.228	567.18**
Angle X Distance	16	0.111	0.51
Error (b) for angle and angle X distance	180	0.218	
Total	249		

* $P < 0.05$

** $P < 0.01$

Table 7. Analysis of variance of outward work in the X plane.

Source	d.f.	M.S.	F
Subjects (R)	9	1.152	5.19
Distance (F)	4	0.353	1.59
Error (a) for subjects and distance	36	0.22	
Angle (F)	4	0.580	12.64**
Angle X Distance	16	0.003	0.06
Error (b) for angle and angle X distance	180	0.046	
Total	249		

** $P < 0.01$

Table 8. Analysis of variance of outward work in the Y plane.

Source	d.f.	M.S.	F
Subjects (R)	9	2.043	12.38
Distance (F)	4	0.313	1.89
Error (a) for subjects and distance	36	0.165	
Angle (F)	4	2.423	24.08**
Angle X Distance	16	0.037	0.37
Error (b) for angle and angle X distance	180	0.101	
Total	249		

** $P < 0.01$

Table 9. Analysis of variance of outward work in the Z plane.

Source	d.f.	M.S.	F
Subjects (R)	9	23.013	5.81
Distance (F)	4	22.126	5.59**
Error (a) for subjects and distance	36	3.956	
Angle (F)	4	4.611	4.84**
Angle X Distance	16	0.061	0.06
Error (b) for angle and angle X distance	180	0.952	
Total	249		

** $P < 0.01$

Table 10. Analysis of variance of outward work in the arithmetic total.

Source	d.f.	M.S.	F
Subjects (R)	9	32.064	7.24
Distance (F)	4	27.708	6.27**
Error (a) for subjects and distance	36	4.429	
Angle (F)	4	15.626	78.44**
Angle X Distance	16	0.029	0.14
Error (b) for angle and angle X distance	180	0.199	
Total	249		

** $P < 0.01$

Table 11. The means of inward work (inch-pound) in the X plane.

Angle / Distance	0	45	90	135	180	average
0.7L	0.50	0.53	0.83	1.02	0.91	0.79
0.85L	0.61	0.60	1.00	1.02	1.06	0.86
1L	0.52	0.47	0.88	1.27	1.12	0.85
1.15L	0.62	0.67	0.95	1.18	1.13	0.91
1.3L	0.61	0.51	0.80	1.06	0.90	0.78
average	0.57	0.56	0.89	1.11	1.02	0.83

Least significant different test

(1) to compare two distance means; L.S.D. = 0.19 ($t\ \alpha = 0.05, 36 = 2.032$)

conclusion:

work levels	0.7L	1.3L	1L	0.85L	1.15L
work units	0.76	0.78	0.85	0.86	0.91

(2) to compare two angles' means; L.S.D. = 0.08 ($t\ \alpha = 0.05, 180 = 1.98$)

conclusion:

angles	45	0	90	180	135
work units	0.56	0.57	0.89	1.02	1.11

Table 12. The means of inward work (inch-pound) in the Y plane.

Angle / Distance	0	45	90	135	180	average
0.7L	0.88	1.11	1.70	1.87	1.17	1.34
0.85L	1.03	1.12	1.57	1.70	1.04	1.29
1L	0.57	1.07	1.99	1.95	1.02	1.32
1.15L	0.78	1.21	2.33	2.33	1.25	1.58
1.3L	0.68	1.33	2.32	2.10	1.30	1.53
average	0.78	1.17	1.99	1.99	1.16	1.41

Least significant different test

(1) to compare two distances' means; L.S.D. = 0.25 ($t\ \alpha = 0.05,36 = 2.032$)

conclusion:

work levels	0.85L	1L	0.7L	1.3L	1.15L
work units	1.29	1.32	1.34	1.53	1.58

(2) to compare two angles' means; L.S.D. = 0.14 ($t\ \alpha = 0.5,180 = 1.98$)

conclusion:

angles	0	180	45	90	180
work units	0.78	1.16	1.17	1.99	1.99

Table 13. The means of inward work (inch-pound) in the Z plane.

Angle Distance	0	45	90	135	180	average
0.7L	2.49	3.23	3.88	4.70	4.12	3.68
0.85L	2.38	3.13	3.45	3.67	3.40	3.21
1L	2.19	3.76	4.13	4.88	4.02	3.79
1.15L	2.94	3.96	5.25	5.88	5.20	4.64
1.3L	3.37	4.35	5.00	5.53	4.87	4.62
average	2.67	3.67	4.35	4.93	4.33	3.99

Least significant different test

(1) to compare two distances' means; L.S.D. = 0.72 ($t_{\alpha} = 0.01,36 = 2.72$)

conclusion:

work levels	0.85L	0.7L	1L	1.3L	1.15L
work units	3.21	3.68	3.79	4.62	4.64

(2) to compare two angles' means; L.S.D. = 0.30 ($t_{\alpha} = 0.05,180 = 1.98$)

conclusion:

angles	0	45	180	90	135
work units	2.67	3.67	4.33	4.35	4.93

Table 14. The means of total inward work (inch-pound).

Angle / Distance	0	45	90	135	180	average
0.7L	3.87	4.77	6.39	7.58	6.20	5.76
0.85L	3.84	4.86	6.03	6.41	5.51	5.33
1L	3.28	5.33	7.01	8.13	6.23	6.00
1.15L	4.33	5.85	8.48	9.39	7.57	7.12
1.3L	4.61	6.27	8.13	8.55	7.11	6.97
average	3.99	5.41	7.21	8.01	6.52	6.23

Least significant different test

(1) to compare two distances' means; L.S.D. = 1.35 ($t_{\alpha} = 0.05,36 = 2.032$)

conclusion:

work levels	0.85L	0.7L	1L	1.3L	1.15L
work units	5.33	5.76	6.00	6.97	7.12

(2) to compare two angles' means; L.S.D. = 0.19 ($t_{\alpha} = 0.05,180 = 1.98$)

conclusion:

angles	0	45	180	90	135
work units	3.99	5.41	6.52	7.21	8.01

Table 15. The means of outward work (inch-pound) in the X plane.

Angle / Distance	0	45	90	135	180	average
0.7L	0.46	0.50	0.54	0.64	0.65	0.57
0.85L	0.58	0.65	0.82	0.83	0.85	0.75
1L	0.50	0.52	0.65	0.85	0.79	0.66
1.15L	0.71	0.69	0.65	0.89	0.91	0.76
1.3L	0.63	0.53	0.67	0.73	0.76	0.66
average	0.57	0.58	0.67	0.79	0.79	0.68

Least significant different test

(1) to compare two distances' means; L.S.D. = 0.19 (t_{α} = 0.05,36 = 2.032)

conclusion:

work levels	0.7L	1L	1.3L	0.85L	1.15L
work units	0.56	0.66	0.66	0.75	0.77

(2) to compare two angle tests; L.S.D. = 0.09 (t_{α} = 0.05,180 = 1.98)

conclusion:

angles	0	45	90	135	180
work units	0.57	0.58	0.67	0.79	0.79

Table 16. The means of outward work (inch-pound) in Y plane.

Angle / Distance	0	45	90	135	180	average
0.7L	0.79	0.87	1.23	1.24	0.89	1.00
0.85L	0.85	0.91	1.27	1.37	0.92	1.05
1L	0.65	0.70	1.13	1.12	0.73	0.89
1.15L	0.61	0.88	1.35	1.39	0.91	1.03
1.3L	0.72	0.95	1.41	1.20	0.91	1.03
average	0.73	0.88	1.28	1.27	0.88	1.00

Least significant different test

(1) to compare two distances' means; L.S.D. = 0.17 (t_{α} = 0.05,36 = 2.032).

conclusion:

work levels	1L	0.7L	1.15L	1.3L	0.85L
work units	0.89	1.00	1.03	1.03	1.05

(2) to compare two angles' means; L.S.D. = 0.13 (t_{α} = 0.05,180 = 1.98)

conclusion:

angles	0	45	180	135	90
work units	0.73	0.88	0.88	1.27	1.28

Table 17. The means of outward work (inch-pound) in the Z plane.

Angle / Distance	0	45	90	135	180	average
0.7L	2.89	2.71	3.00	3.27	3.50	3.07
0.85L	2.41	2.64	2.83	3.14	3.08	2.82
1L	2.56	3.36	3.28	3.48	3.55	3.25
1.15L	3.49	4.07	4.24	4.73	4.45	4.18
1.3L	3.79	4.44	4.40	4.66	4.25	4.32
average	3.02	3.43	3.56	3.87	3.76	3.53

Least significant different test

(1) to compare two distances' means; L.S.D. = 1.09 (t_α = 0.01,36 = 2.72)

conclusion:

work levels	0.85L	0.7L	1L	1.15L	1.3L
work units	2.82	3.07	3.25	4.18	4.32

(2) to compare two angles' means; L.S.D. = 0.39 (t_α = 0.05,180 = 1.98)

conclusion:

angles	0	45	90	180	135
work units	3.02	3.43	3.56	3.76	3.87

Table 18. The means of total outward work (inch-pound).

Angle / Distance	0	45	90	135	180	average
0.7L	3.78	4.08	4.73	5.18	5.05	4.57
0.85L	3.86	4.23	4.93	5.33	4.88	4.64
1L	3.71	4.59	5.12	5.56	5.06	4.80
1.15L	4.81	5.58	6.14	7.00	6.27	5.95
1.3L	5.15	5.91	6.45	6.35	5.92	5.96
average	4.26	4.86	5.46	5.87	5.42	5.18

Least significant difference test

(1) to compare two distances' means; L.S.D. = 1.14 (t_{α} = 0.01,36 = 2.72)

conclusion:

work levels	0.7L	0.85L	1L	1.15L	1.3L
work units	4.57	4.64	4.80	5.95	5.96

(2) to compare two angles' means; L.S.D. = 0.18 (t_{α} = 0.05,180 = 1.98)

conclusion:

angles	0	45	180	90	135
work units	4.26	4.86	5.42	5.46	5.87

APPENDIX B

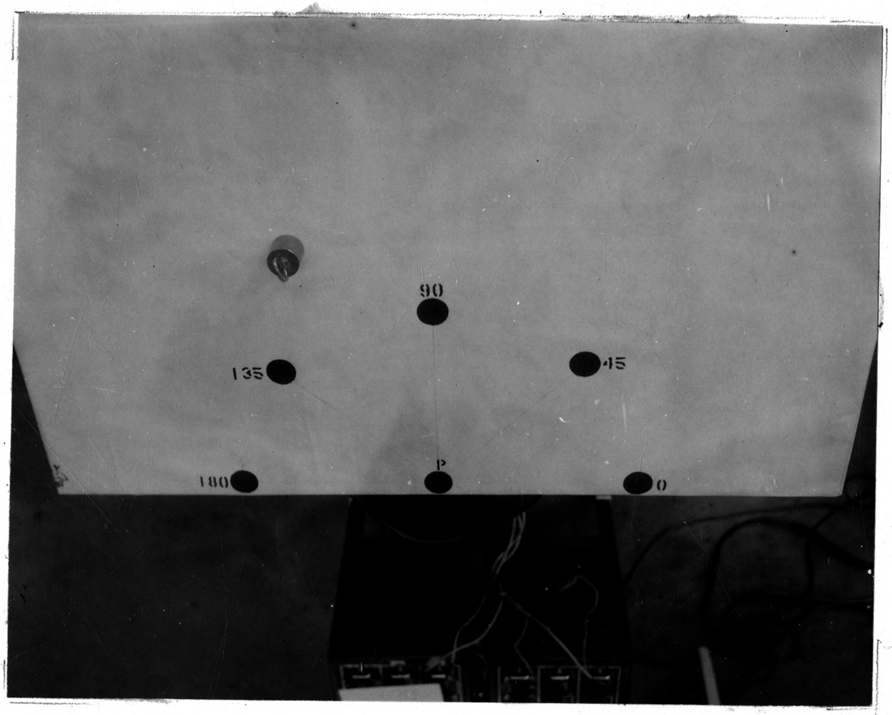


Fig. 1. Locations of points used on the work surface (taken from an angle of 45 degrees to the work surface toward the operator).

Fig. 2. Work place.

Fig. 3. Chair on the force platform.

Fig. 4. Sanborn Record-Amplifier.

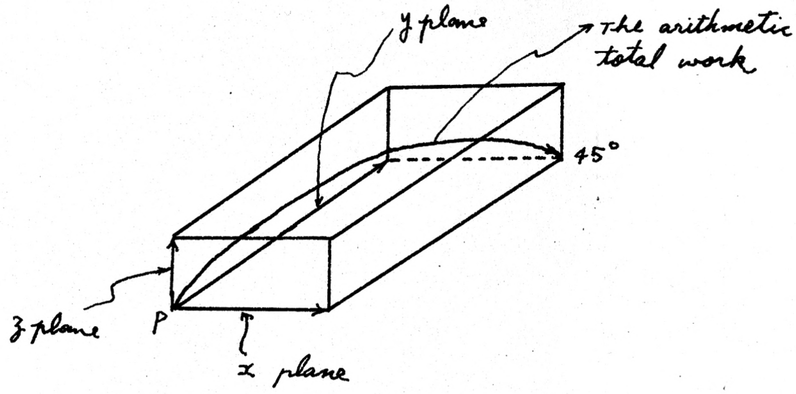


Fig. 5. The exponents' work indicated under assumed movement 45 degrees.

Fig. 6. Hydraulic lift base for the work table.

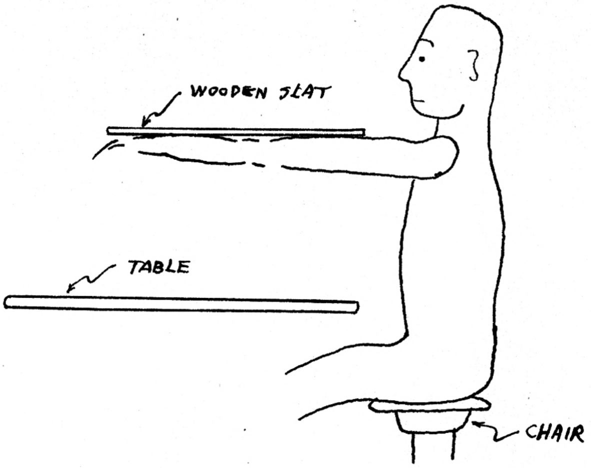


Fig. 7. Measurement of the distance between the shoulder and work table.

Fig. 8. Raw data summary form.

Subject ____________________ L = ____________________

Angle / Plane / Direction		0^o			45^o			90^o			135^o			180^o		
		x	y	z	x	y	z	x	y	z	x	y	z	x	y	z
1st Cycle	Inward															
	Outward															
2nd Cycle	Inward															
	Outward															
Average	Inward															
	Outward															

Fig. 9. Coding data sheet form.

Angle / Distance	0^o			45^o			90^o			135^o			180^o			Average
0.7L																
0.85L																
L																
1.15L																
1.3L																
Average																

Fig. 10. Comparison between work and work level for the 0 degrees angle.

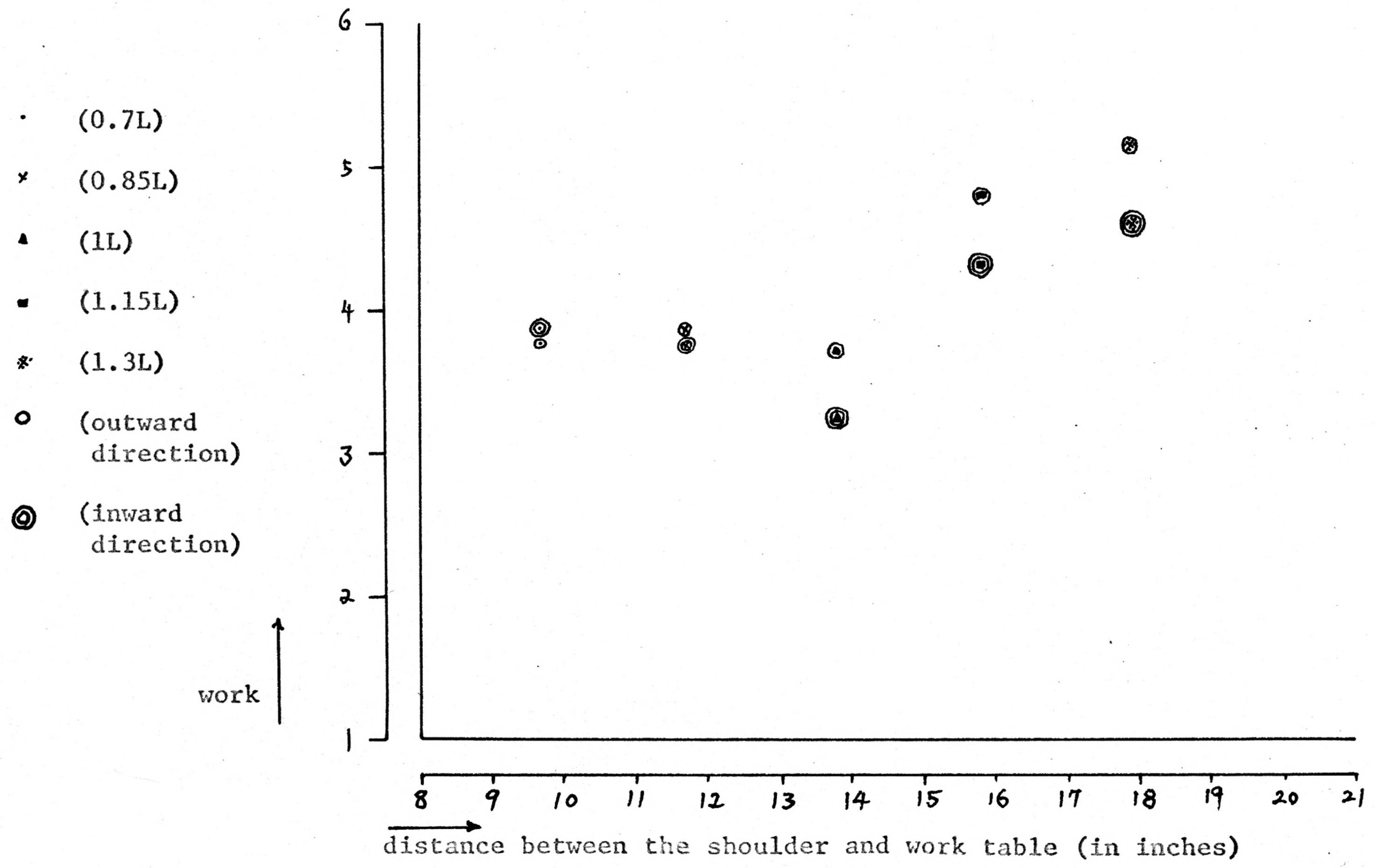


Fig. 11. Comparison between work and work level for the 45 degrees angle.

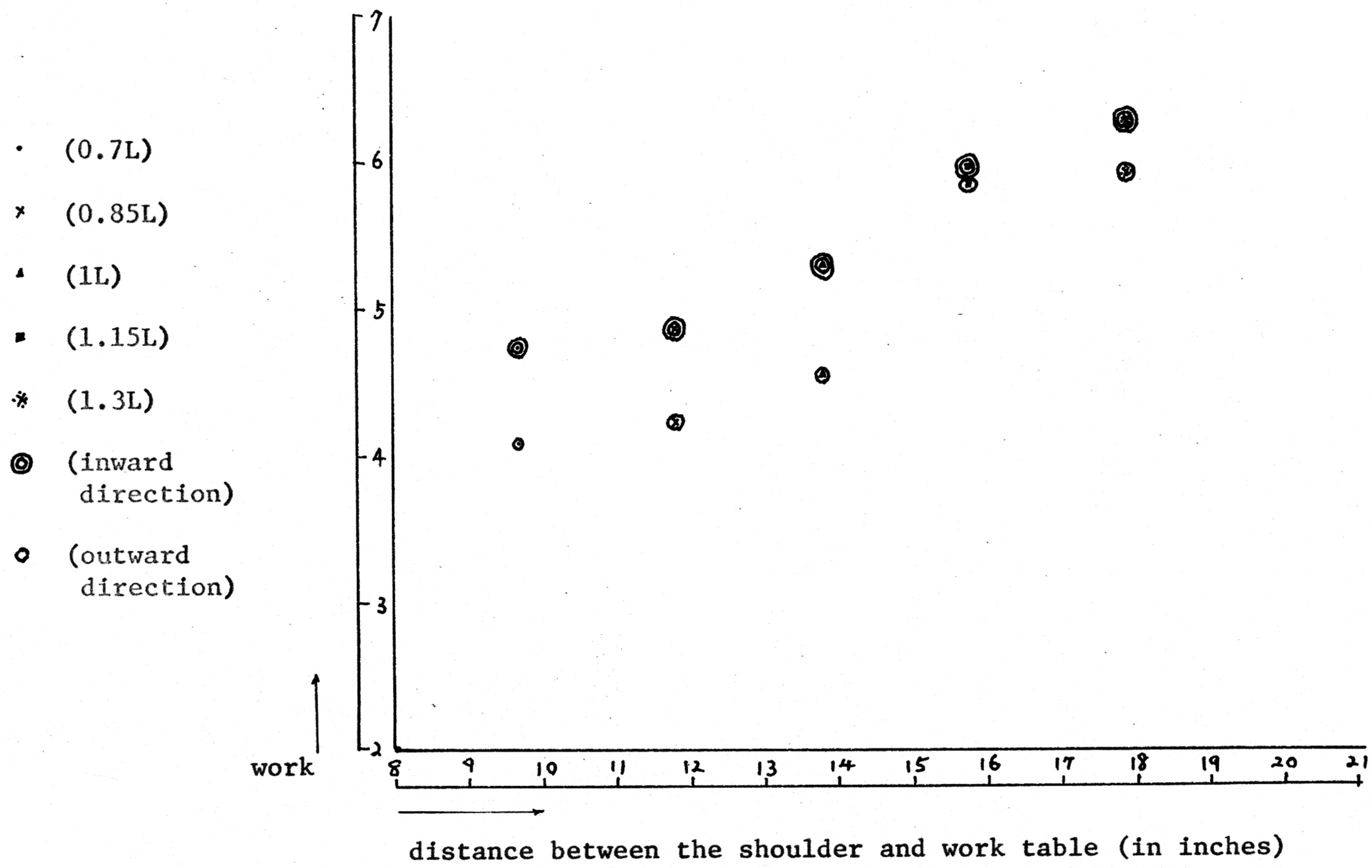


Fig. 12. Comparison between work and work level for the 90 degrees angle.

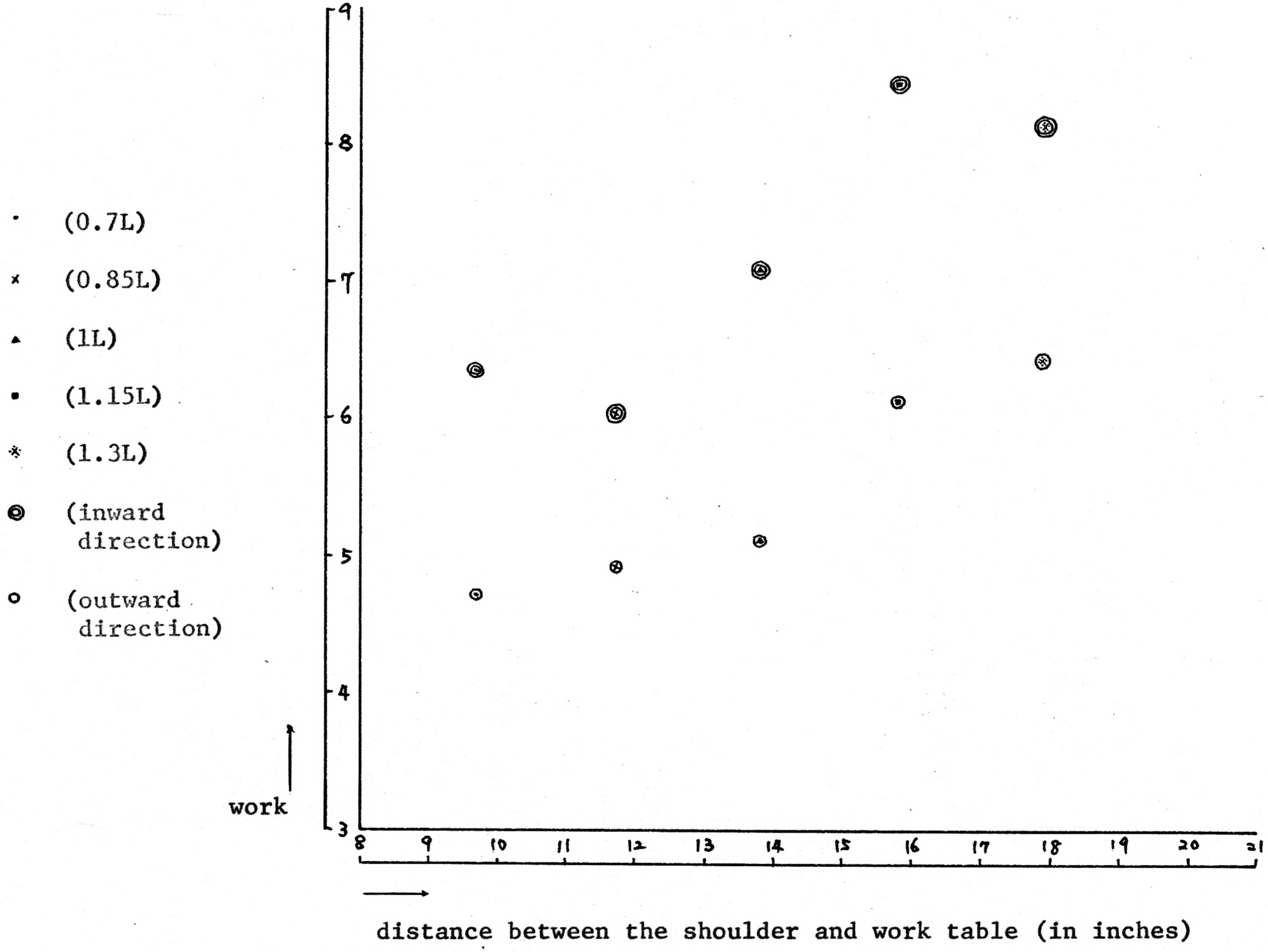


Fig. 13. Comparison between work and work level for the 135 degrees angle.

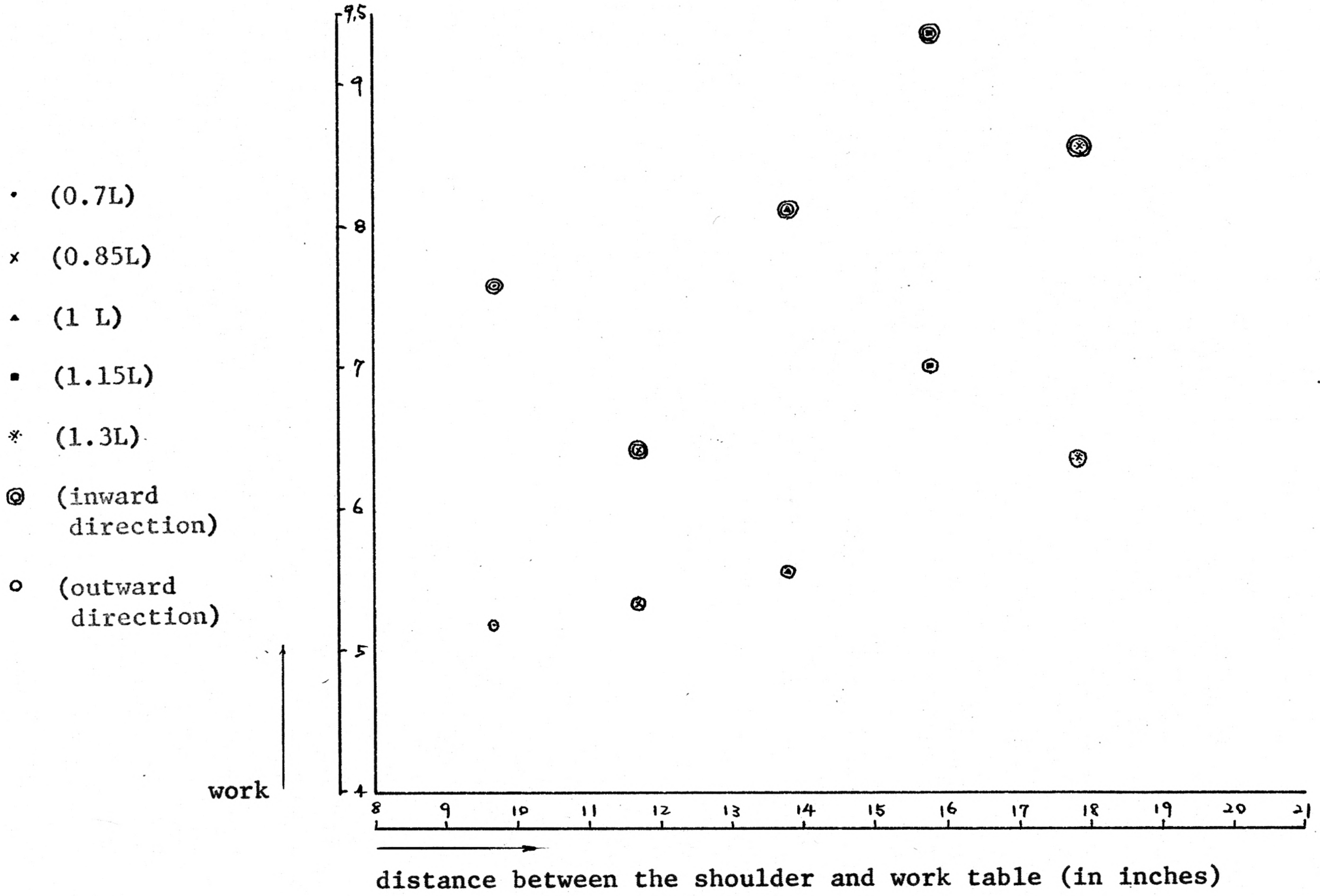


Fig. 14. Comparison between work and work level for the 180 degrees angle.

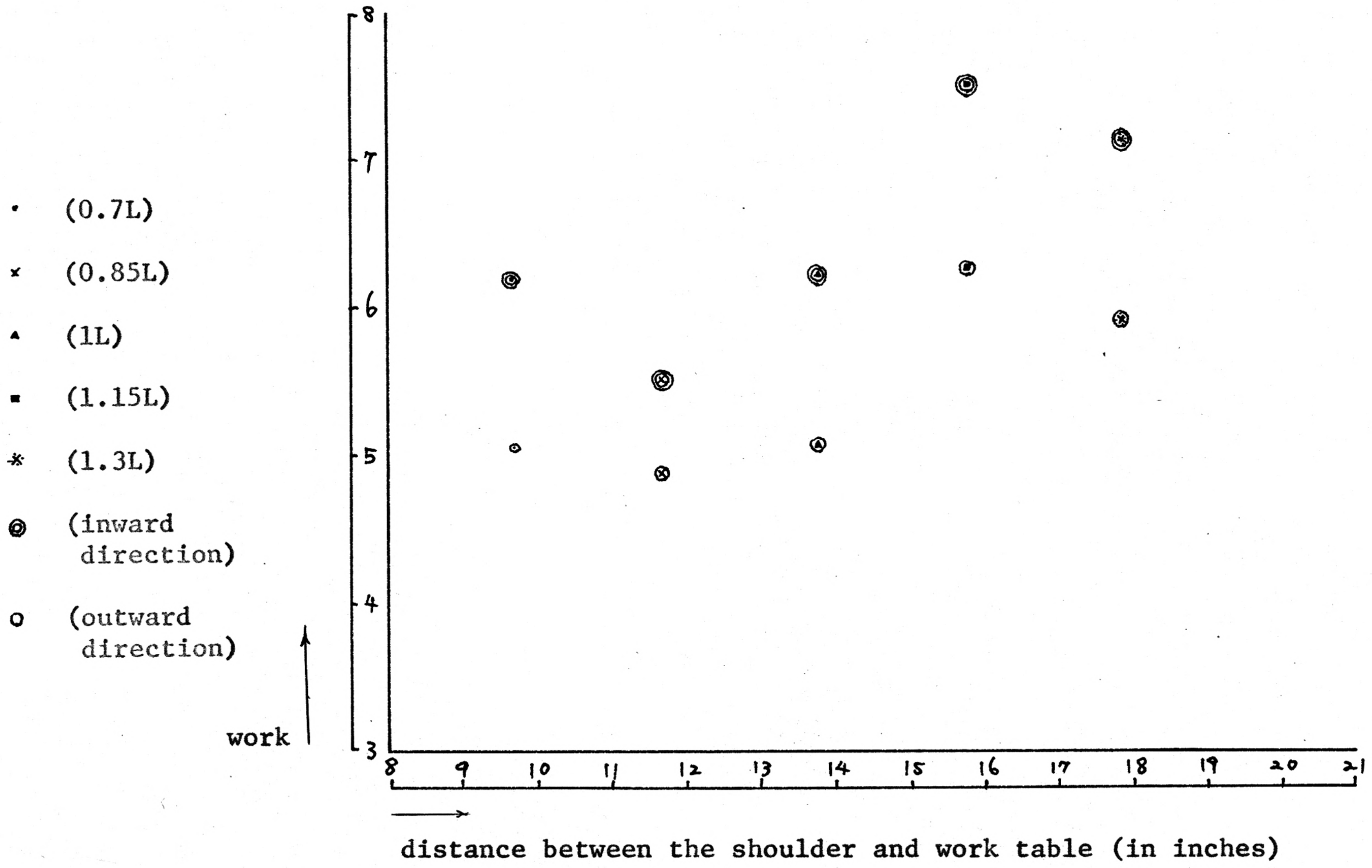


Fig. 15. Comparison between work in the inward direction and angle.

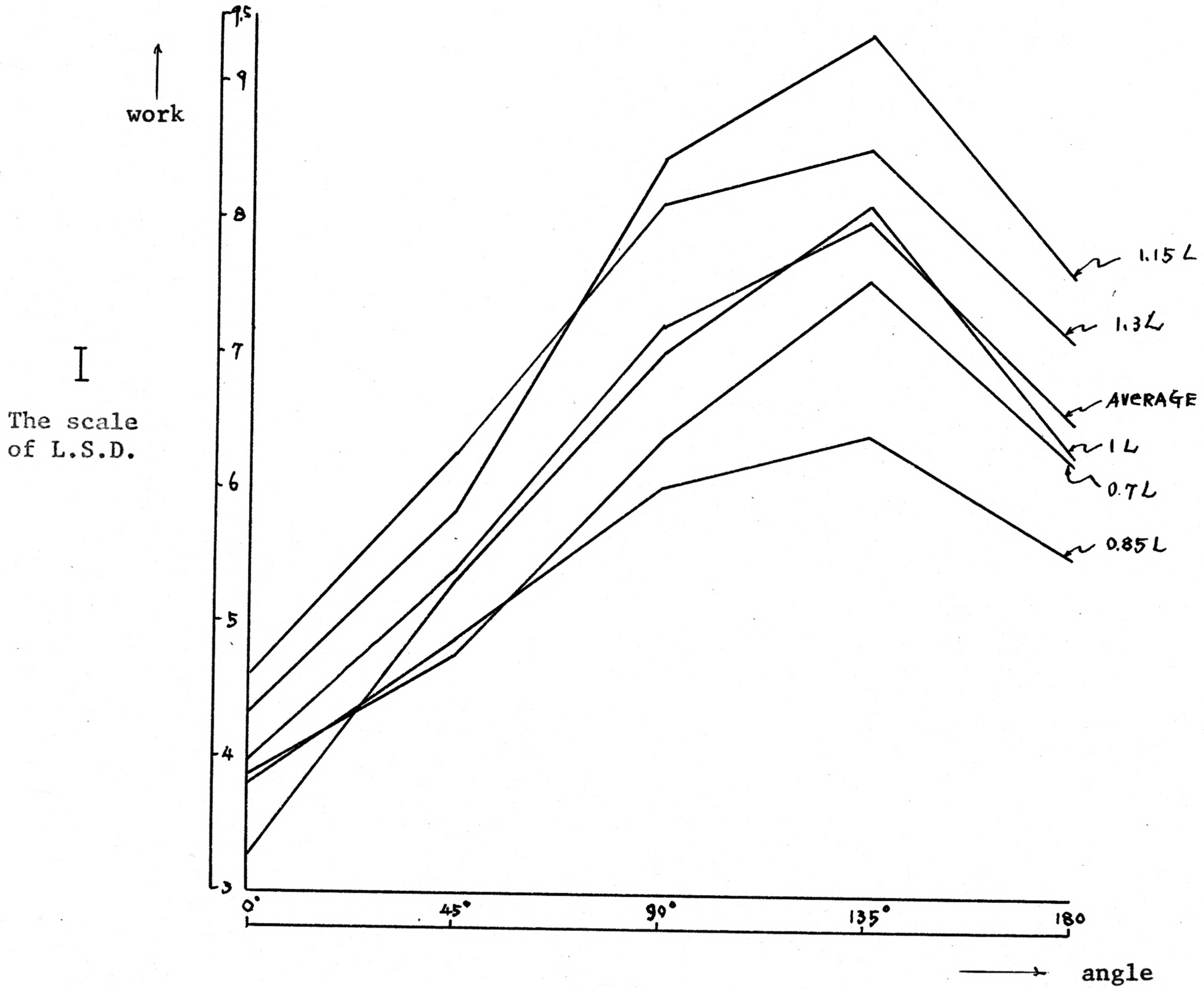


Fig. 16. Comparison between work in the outward direction and angle.

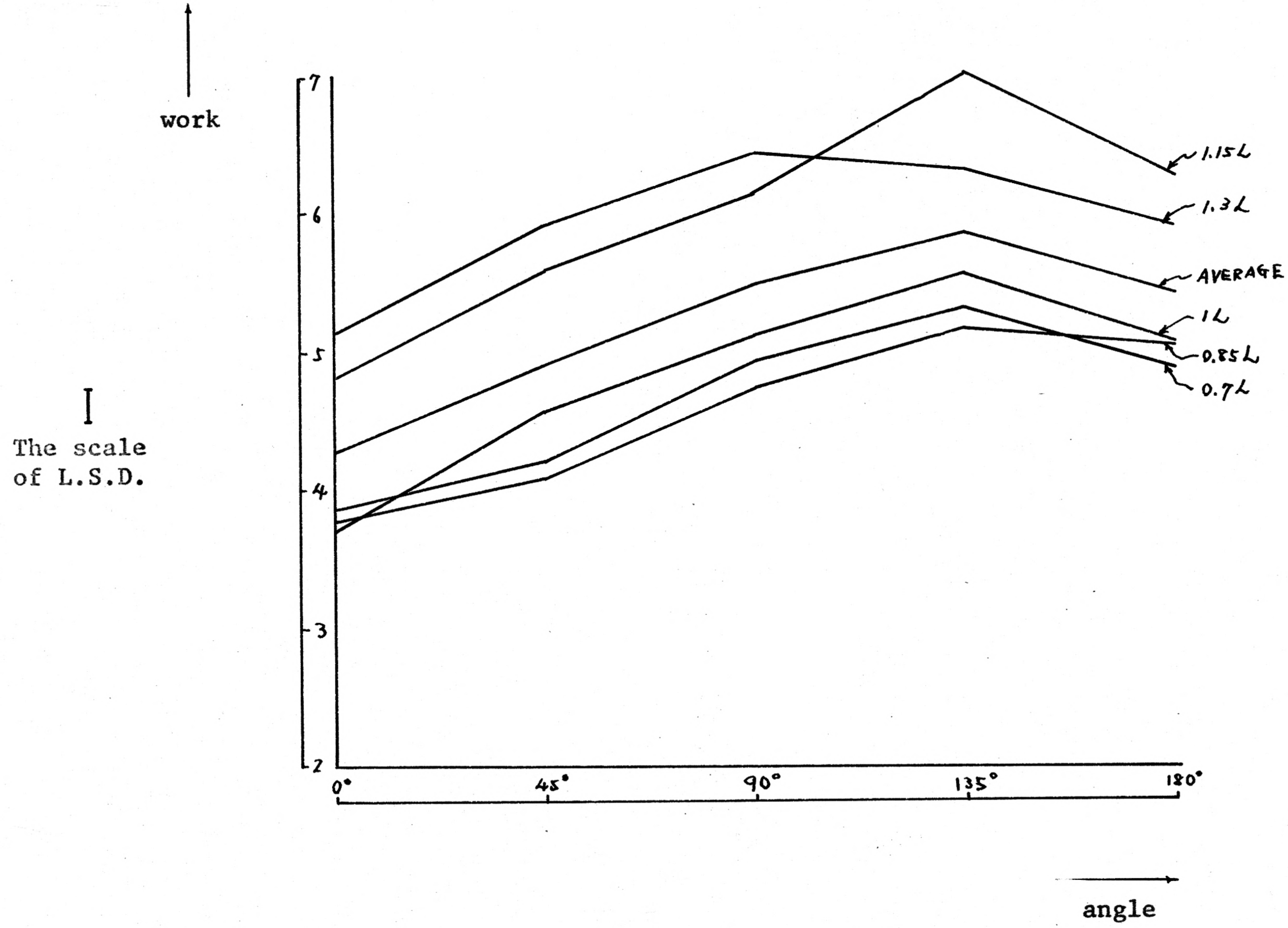


Fig. 17. Comparison between work in the inward direction and table height.

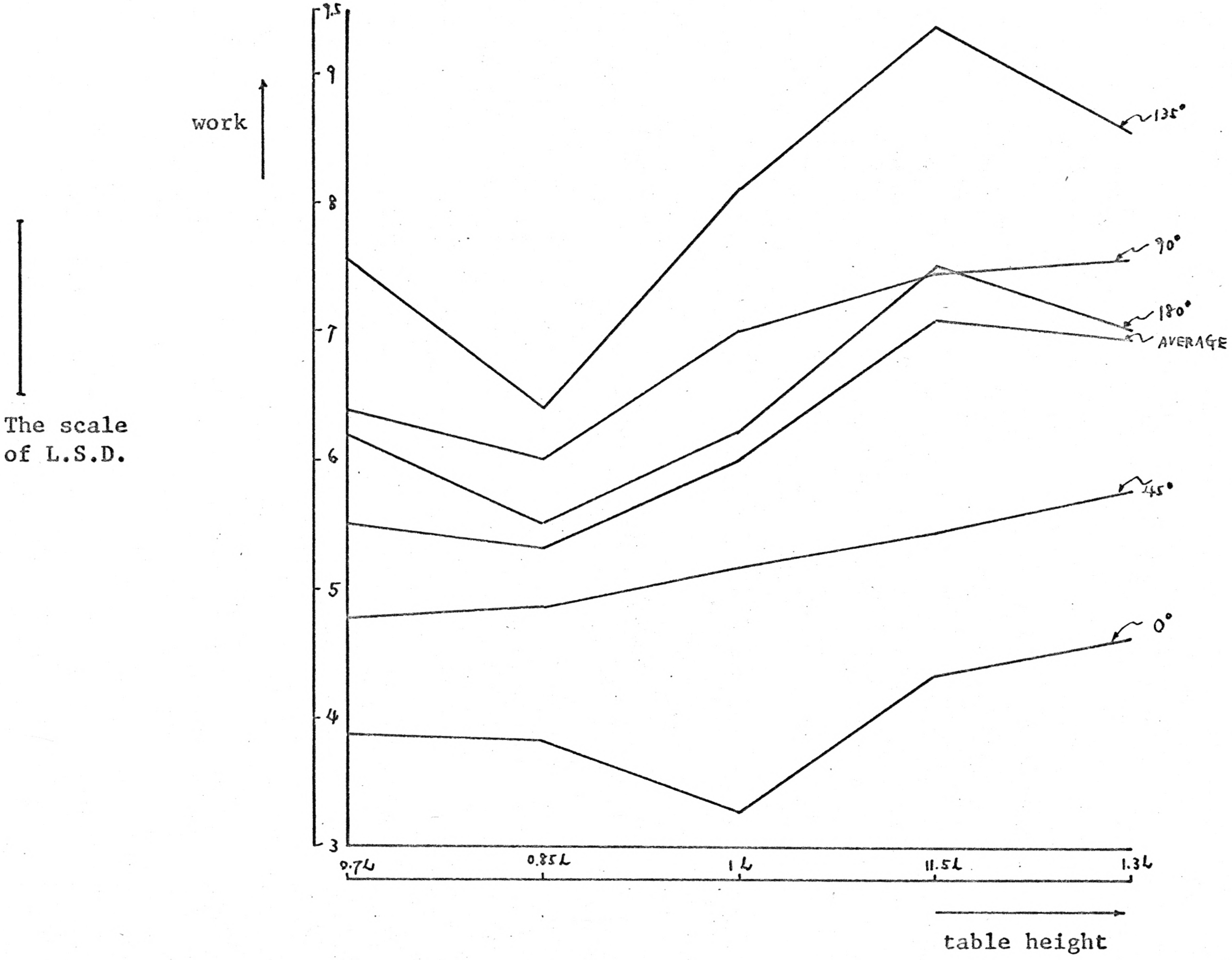
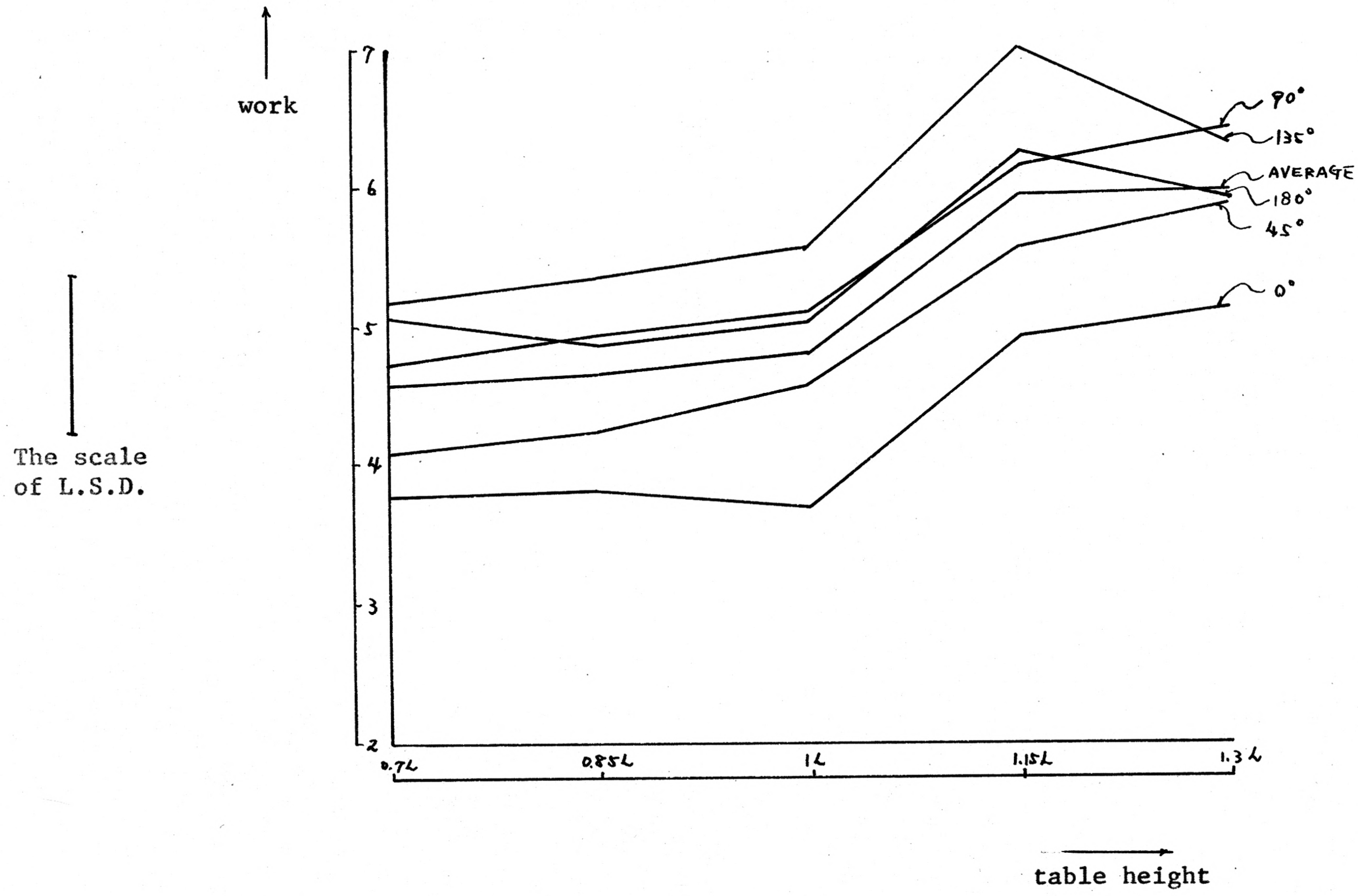


Fig. 18. Comparison between work in outward direction and table height.



AN INVESTIGATION OF THE EFFECT ON WORK OF VARYING THE DISTANCE BETWEEN SHOULDER AND WORK-TABLE

by

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B. S., Taiwan Provincial Cheng Kung University, 1962

AN ABSTRACT OF A MASTER'S THESIS

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1965

The effect on work performance of varying the distance between shoulder and work table was studied with the use of a force platform.

The primary objective of this investigation was to determine the existence of an optimum vertical distance between a work table and the shoulder of a seated worker. The measure of performance or criterion used to determine this optimum distance was the work expended by a given task of moving a two-pound weight through specific paths and trajectories.

The second objective was to compare the work expended at various angles and to find at which angles the least work will be produced. A third objective was to determine whether the work done by movement in an inward direction and in an outward direction is the same or different.

The experimental task was performed at five levels of shoulder to work table distance: 0.7L, 0.85L, 1L, 1.15L, and 1.3L, where L is length of worker's upper arm. Seven men and three women, all right-handed, were selected from the student body of Kansas State University. Each moved a two-pound weight with their right hand from a central point p to points 15 inches away at 0, 45, 90, 135 and 180 degrees of horizontal angle. A force platform based on Barany's design with two two-channel Sanborn Recording Amplifiers was used.

The results indicated that an optimum vertical distance for least work was between 0.7L and 1L; that is, the average work was less than 6.00 inch-pounds for the inward direction and less than 4.80 inch-pounds for the outward direction. The angle for least work was zero degrees for the subjects for all levels of shoulder to work table distances investigated; that is, the average work was less than 3.99 inch-pounds for the inward direction and less than 4.26 inch-pounds for the outward direction. The work done in an inward direction (an average of 6.23 inch-pounds) was 1.2 times greater than that done in the outward direction (an average of 5.18 inch-pounds). In other words, it is easier to push than to pull.