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ANALYSIS OF THE EFFECT OF DISTANCE AND WEIGHT AS A DETERMINANT OF POSTURAL CONFIGURATIONS OF A SEATED WORKER

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by

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B. S. Kansas State University, 1963

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1965

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INTRODUCTION

The analysis of the effect of distance and weight is a seldom expressed combination when referred to the subject of postural configurations. Such men as Morgan (12), Maynard (10), Caldwell (2) have written books and articles on lifting forces and/or controlling muscle action when moving objects while in a standing position. Hunsicker (8) and Caldwell (2) have contributed much to seating characteristics when the strength of arm extension is involved. The subject of postural configuration implies the disposition of relative parts of the human body. To determine the optimum location of over the counter shelf installation, the relationship of weight and distance must be explored. This may be achieved by measuring the body distortion from a natural seated position while using two handed operations. This would involve different degrees of weight and various shelf heights.

The point of issue in this investigation is to evaluate a prototype mock-up model of a corridor designed kitchen and its relation with over the counter shelf heights and objects of different weights. This will involve the human factors and body mechanics principles that apply to the limitation of manual activity of female workers at a seated work station.

Much of the past research is oriented around the experimental situation of finding an average work height to do some particular household function. Roberts, Wilson and Thayer (13) were authors of a bulletin, in 1937, being one of the first groups to conduct studies concerned with work surface heights satisfactory for women in the home. This involved studying kitchen work, ironing, sewing and storage units such as closets and drawers. In 1959, McCracken and Richardson (11) conducted studies to locate the best heights for storage of household goods and compared the energy costs of different designs of storage. These studies included standing and sitting postures, one and two handed operations, and shelves of various heights and depths.

Anatomical studies on the range of joints by use of living subjects were made by Brown and Slater-Hammel (1), Hugh Jones (7), Dempster (3), Gaughan and Dempster (5) and Whitney (17). These studies are unsatisfactory in their relation to industry and commercial outlets because the data are not readily applicable. Dempster, Gabel, and Felts (4) was one of the first groups to attempt an approach to dynamic anthropometry. Their method of data collection was by use of planimeter measurements of areas obtained by the use of light tracings on photographic negatives. The light tracings represented a series of motions. A light was placed on the subject's hand and motions of the shoulder, elbow and wrist combinations would generate a light tracing. This technique defined some limits for a work space.

The extent of this thesis will encompass the measurement of the seated subject's body configurations while lifting objects to shelves. These sequences involving weight and shelf height, were filmed and then the deviations from the normal seated position were measured by use of a Veeco mechanical arm and a mirror device. A statistical analysis of the data was made to determine weight when related to the experimental corridor kitchen model.

DEVELOPMENT OF EXPERIMENTAL METHOD

During the review of literature which has been published concerning women performing tasks found in the home, it was noted that many of the studies were based on the use of respiratory measuring devices. Some studies involved the use of work simplification and methods improvement principles and were based on comparisons of old and new methods. The technique used in this thesis was similar to that studied by Dempster, Gabel, and Felts (4) which involved dynamic anthropometry.

The term dynamic anthropometry refers to the measurement of the individual body members working together to perform a task. As the body members perform together, a work area is created relative to the body. This work area has its outer limits determined by the anotomical structure of the individual and may be referred to as a space envelope.

There are three major planes of the body denoted X, Y, and Z, each of which is perpendicular to the remaining two planes. The planes of the body are defined as:

1. Sagittal plane - a vertical plane from front to back, dividing the body in half.
2. Frontal plane - a vertical plane from side to side, dividing the body in half.
3. Horizontal plane - a horizontal plane dividing the body into upper and lower halves.

The sagittal, frontal, and horizontal planes each bisect the body, therefore, having a common intersection which may be defined as the center of gravity of that body. The axes of the body are defined as:

1. Vertical axis - that axis which is perpendicular to the ground.

2. Frontal axis - that axis running horizontally from side to side.

3. Sagittal axis - that axis running horizontally from front to back.

The variety of ways in which a body may move seems to be countless, but careful consideration of these movements reveal that there are two major classifications of movement. A body may turn about a center of motion or it can move in its entirety from one position to another. The first classification is called angular motion and may be illustrated in terms of levers and wheels. "Angular motion is characterized by movements about an axis with all parts of the object moving in an arc..." (15).

The second classification is translatory because an object is moved as a whole unit from one position to another. Translatory movement is defined in terms of rectilinear and curvilinear motion. "Rectilinear motion, ..., is defined as the linear progression of an object as a whole, with all its parts moving the same, in the same direction, and at a uniform rate of speed." (15) Curvilinear is all translatory movement that is not classified as rectilinear motion.

Two examples of motion that may be calssified as angular and translatory are walking and riding a cycle. Most of the body joints display axial motion, therefore the related body segments display angular motion. As a result of the angular motion of the forearm and upper arm, the hand is able to have linear motion and when moving an object displays translatory motion.

The space envelope of interest in this study was the range of motion generated by the hands while the subject was in a seated position with the buttocks remaining semi-motionless on the seating surface of an experimental chair. The envelope is an invisible surface representing the maximum range of motion of the hand while being moved in different directions. This space envelope may be placed on an X, Y, and Z coordinate system having a size and shape relating to the chair seat and the subject's anatomical structure. The hip mark of the subject was selected as a reference point "O" which is the zero point of the coordinate system. With the hand or wrist mark being referenced directly to the point "O", the movements of the elbow, shoulder and trunk allow a broad range of translational movement. The space envelope generated by these movements is the combination of the range and freedom of the joints involved. The relative dimensions of limb segments in different people have a relationship, but this effect is small considering that they will create a space envelope of a distinctive shape and common to the average person when orientated to the same reference point (4).

Marking the Subject

The reference points which were measured by anthropometry, the science of measuring the human body and its parts, allowed the postural configurations of the subject to be measured from the filmed records through the use of a drafting machine. The subjects wore short shorts and a halter which allowed the markings to be placed directly on the body thus omitting some variation due to fit of clothing.

The age and weight of each subject were recorded because it was desired that each subject comply with an age and weight range so that a homogeneous population might be obtained. Along with the age and weight, various dimensions of body length and width were recorded for each subject involved in the sample population. The landmarks or points of interest were placed on the component parts of the body which generated the space envelope. Most of these landmarks were black adhesive tape but a grease pencil was used to mark the lines where the tape might cause skin irritation. The purpose of each landmark is to be able to measure the amount of movement of a particular portion of the body while the subject performs a task. The landmarks were connected by a straight line which acted as a visual aid in determining the point at which a subject had completed the act of placing an object on a shelf. These lines were between adjacent landmarks and were of the same material, black adhesive tape or grease pencil, as the landmark in that region. Although, some of the landmarks are not utilized in the collection of data for this experiment; the method of measurement of each is included for possible future reference and/or for continued studies of the film.

The line on the subject which best relates the distortion of the body from the normal seated position is that which connects the shoulder landmark to that of the hip.

Method of Measurement

Each subject was measured and marked by the same person using the procedure set forth below. To facilitate measurement, the following instruments were used; anthropometer - this instrument has a horizontal bar which moves vertically along a fixed calibrated scale; calipers - a scaled bar with one fixed and one sliding jaw; and a steel tape measure. See Plate I.

I. Stature - standing

   A. Instrument - anthropometer

   B. Procedure - the crossbar was lowered until it rested on the vertex of the subject's head.

II. Shoulder height - standing

   A. Instrument - anthropometer

   B. Procedure - the crossbar was lowered until it rested on the acromion.

III. Elbow - standing

A. Instrument - anthropometer

B. Procedure - the subject bent her arm so that a right angle was formed by the outside of the arm (upper arm hanging straight). The crossbar was moved to elbow level.

IV. Waist - standing

A. Instrument - anthropometer

B. Procedure - the waist level used lies at the lower edge of the lowest rib and was found by palpating the sides of the body at the midaxillary line. The crossbar was lowered until it rested on this landmark.

V. Hip - standing

A. Instrument - anthropometer

B. Procedure - the measurer's hand palpated the region of the trochanter. A rounded region was thus located, the mid-point of which marked the hip level. The crossbar was lowered to rest on this landmark.

VI. Knee height (tibiale) - standing

A. Instrument - anthropometer

B. Procedure - the tibiale was taken as the highest point on the margin of the glenoid of the tibia when the subject stood erect. The crossbar was brought to rest on this landmark.

VII. Finger tip height - standing

A. Instrument - anthropometer

B. Procedure - the subject was asked to hold the fingers straight but not rigid. The crossbar was lowered until it was at the level of the middle finger tip.

EXPLANATION OF PLATE I

Figure 1. Shows the subject being measured for the shoulder-elbow dimension by the use of the calipers.

Figure 2. Shows the subjects shoulder-elbow line being marked with black adhesive tape.

PLATE I

FIGURE 1

FIGURE 2

VIII. Vertex of heat[d] - sitting*

A. Instrument - anthropometer

B. Procedure - the crossbar was lowered to rest on the vertex of the subject's head.

IX. Shoulder - sitting

A. Instrument - anthropometer

B. Procedure - the crossbar was lowered to rest on the acromion process of the scapula.

X. Elbow - sitting

A. Instrument - anthropometer

B. Procedure - the subject bent her arm so that a right angle was formed by the outside of the arm (upper arm hanging straight). The crossbar was moved to the elbow level.

XI. Waist - sitting

A. Instrument - anthropometer

B. Procedure - the crossbar was lowered until it rested on the waist landmark (same as used in standing).

XII. Hip - sitting

A. Instrument - anthropometer

B. Procedure - the crossbar was lowered until it rested on the hip landmark.

XIII. Top of thigh - sitting

A. Instrument - anthropometer

B. Procedure - the crossbar was lowered to the thigh, subject moved forward until the greatest thickness of thigh was found.

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*The subject sat erect while sitting measurements were taken.

XIV. Height of top of knee - sitting

A. Instrument - anthropometer

B. Procedure - the crossbar was lowered to top of knee, just where the knee bends.

XV. Widest extension of hips or sitting width

A. Instrument - sliding caliper

B. Procedure - the measurer held the shaft parallel to the floor and placed the fixed bar at the furthest extension of the right hip. The movable bar was moved up to the left hip at the furthest extension.

XVI. Sitting length

A. Instrument - sliding caliper

B. Procedure - the measurer held the shaft of the caliper parallel to the floor and placed the fixed bar at the front of the knee. The movable bar was moved up against the buttocks.

XVII. Maximum span at working level - sitting

A. Instrument - steel tape

B. Procedure - subject leaned forward and reached as far along the counter top as possible. The distance measured was between the subject's middle fingertips.

XVIII. Normal span at working level - sitting

A. Instrument - steel tape

B. Procedure - subject placed hands along counter top without straining. The distance measured was between the subject's middle fingertips.

XIX. Sitting height above seat

Seat height of 36 inches was subtracted from vertex of head measurement.

XX. Sitting eye-level above seat

A. Instrument - anthropometer

B. Procedure - the crossbar was lowered to a position so that the subject could see half under the crossbar.

XXI. Elbow height above seat

Seat height of 36 inches was subtracted from elbow height measurement.

XXII. Shoulder to elbow

A. Instrument - sliding caliper

B. Procedure - the subject stood with normal, erect posture bending her right arm and placing a clenched fist on her hip with the back-side of the hand to the front. The fixed bar of the caliper was placed on the acromion process of the scapula and and the shaft was parallel with the outside of the upper arm. The movable bar was moved up against the elbow.

XXIII. Elbow to palm

A. Instrument - sliding caliper

B. Procedure - with the right arm bent at a right angle, the outside of the upper arm was placed against the fixed bar and the subject's forearm rested on the shaft of the caliper, The subject grasped the movable bar as it was moved up against the knuckle of the little finger and palm landmark.

Experimental Task

The primary object was to study postural configurations generated by the translational movements. This type of movement may be up and down, forward and backward, and right and left. This study was restricted to the first two of these, thus involving only movements in a vertical plane.

The primary records taken were micro-motion film showing the subject performing a series of specified tasks. A task consisted of lifting with both hands a covered baking pan (no pan, 0, 5 and 10 pounds) from the counter top and placing it on a designated shelf directly in front of the subject. The pan was placed to the rear of the nine inch deep shelf, released momentarily, regrasped, and returned to its original position on the counter in front of the subject.

The subject was asked to sit in a normal erect position, to start and finish each task with her hands resting on the counter edge and if possible to keep her feet within the rectangle marked on the foot rest. A series of sixteen tasks were composed by placing at random one of the four pan weights or the imaginary pan on one of the four shelves spaced ten inches apart. The subject was told that she could complete each task at her own pace.

An individual task began by having a helper set the desired pan in front of the subject. Directions were then read as to what shelf the pan was to be placed upon. The subject would then grasp the pan and complete the task. See Plate II. As soon as a task was completed, the helper would replace this pan with the next pan in the sequence indicated by a random numbers table. Directions concerning this new pan would then be read aloud to the subject. This procedure continued until the subject completed the series assigned to her by use of random numbers. In order that the subject would understand the directions as they were read, a preliminary series of tasks were given each subject after which they were given a rest period before testing.

Twenty-three female college students, with an age range of 18 to 21, formed the sample population. Their build was medium with reference to stature and wegith; rotund and thin types were excluded. The subjects selected were between 62 and 65 inches in height and were in the proper weight range as specified by Wessel (15). The most significant mean dimensions are shown below in Table 1.

TABLE 1

MOST SIGNIFICANT MEAN DIMENSIONS

Measurement	Length (Inches)	Sample Std. Deviation(Inches)	Range (Inches)
Stature standing	63.223	0.637	62.25 - 64.19
Shoulder sitting	47.073	2.479	42.25 - 55.19
Shoulder - elbow	12.665	0.345	12.13 - 13.31
Elbow - palm	12.565	0.420	11.94 - 13.50

EXPLANATION OF PLATE II

An overall view of the experimental set-up which includes subject, helper, person reading the directions, pan, and the subject's code number (A 8). The experimental set-up has four shelves with the counter top being number one, a shelf at ten inches designated number two, a shelf at twenty inches designated number three, and a shelf at thirty inches designated number four.

PLATE II

Apparatus

This experiment was performed in a full-scale mock-up model of an experimental kitchen. This kitchen is of the corridor design and has a chair mounted on a specially designed track which will allow it to move from one end of the counter to the other. For this experiment, the chair was not mobile but remained in one position at the counter. The chair and its relation to the counter and shelves is shown in Plate II.

The seat of this experimental chair was of a solid material, had a slope of approximately three degrees from front to back, and could revolve 360 degrees. The seat was equipped with a Michrohite seat height adjustment mechanism for adjustment of the seat from zero to twelve inches above its minimum height. This adjustment could not be made with the subject in the chair. The seat was positioned vertically so that the front edge of it was twelve inches below the counter top and it remained in this position throughout the experiment.

For the back of this chair, a large contour metal back rest was used which adjusted four ways - up and down, forward and backward. The back rest was adjusted to fit each subject in the small of the back.

A footrest which could be adjusted was mounted on the base portion of the chair. A rectangle, large enough to encircle both feet, was marked in the center of the footrest so that there would be a continuity in support by the legs from subject to subject.

A 16mm Paillard-Bolex, H 16 Reflex movie camera with a variable shutter was mounted on an adjustable tripod and positioned in such a manner that the camera lens was twenty feet from the subject's right shoulder. The camera was manually operated for each task of the series to allow the subject to work at her own pace. Eastman Tri-X, Type 7278, reversal safety film was used to record the data on 100 foot rolls. The camera position and model kitchen relationship is shown in Plate III.

The film was reviewed and data taken from it by the use of a 16mm Bell & Howell time and motion study projector and a mirror device whose relationship is shown in Plate III. A Veeco mechanical drawing arm was employed to determine the angular movement involved.

The experiment was conducted in the Housing - Equipment Research Laboratory of the Department of Family Economics in Justin Hall, the Home Economics Building.

Experimental Design

In preparing the series of tasks to be randomly assigned to each subject, a random number table was used. Numbers one through sixteen were coded to designate a pan and a shelf, by using two numbers (n and n + 16 as n goes from 1 to 16) to designate the same task the process was shortened. These random numbers then designated the order of a series of tasks and were recorded on a chart such as Form A in the Appendix.

The experiment was analyzed according to a factorial classification for a randomized complete block design, fixed effects model similar to the example discussed in Snedecor (14) pages 338 to 343. This design has shelves and pan as factors, with three and four levels respectively. The subjects were blocks in the design and through the use of several subjects the fluctuations could be averaged out. An analysis of variance was computed with the following sources of variation pooled into error: shelves by individuals; pans by individuals; and shelves by pans by individuals. The model for this design therefore becomes,

$$Y_{ijk} = \mu + I_i + S_j + P_k + SP_{jk} + \varepsilon_{ijk}$$

EXPLANATION OF PLATE III

Figure 1. A top view of the experimental set-up showing the relationship of the movie camera and the seated subject. A task involved moving Pan A to position Pan A' and then back to its original position.

Figure 2. A side view of the apparatus used to obtain the data from the film. A mechanical arm (not shown) was used to measure the angle of movement as it was viewed on the object surface.

PLATE III

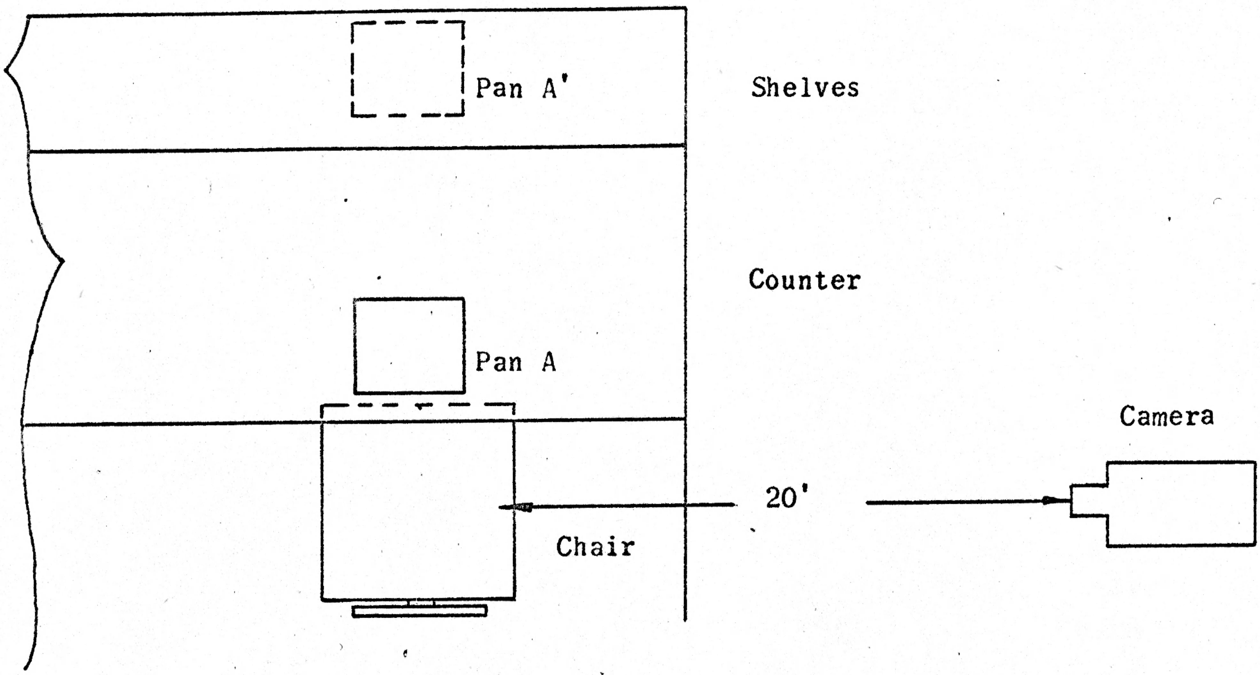

FIGURE 1

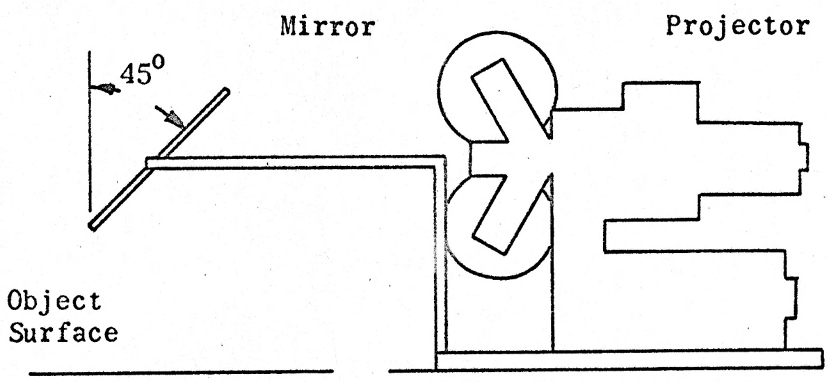

FIGURE 2

where μ = common or average effect, I_j = effect of the i^{th} individual, S_j = effect of the j^{th} shelf, P_k = effect of the k^{th} pan, SP_{jk} = additive effect of the k^{th} pan on the j^{th} shelf, and where ε_{ijk} is assumed to be a random variable drawn from a normal population with a mean of zero and a variance of σ^2. In this model Y_{ijk}, measured in degrees, is an trunk movement observation from the vertical plane made of the i^{th} individual placing the k^{th} pan on the j^{th} shelf. This model assumes each observation to be a linear function of the factorial effect and the experimental error.

Using this design, it was possible to test several hypotheses related to the different pans and shelves utilized in the series of tasks. The first hypothesis to be tested was to evaluate any differences between the pan weights used. The effects of shelf heights used were tested by a second hypothesis. Interaction effects between shelves and pans were also tested. Each hypothesis was checked for significance by the use of an F-test. The hypotheses were as follows:

1. There is no difference in response due to different pan weights:

   H_{01} : $P_k = 0$ for $k = 1, 2, 3, 4$

   H_{A1} : $P_k \neq 0$ for some k

   $F_1 = \frac{\text{M.S. pans}}{\text{M.S. error}}$ reject if $F_1 \geq F$ α, k, error degrees of freedom

2. There is no difference in response due to different shelf heights:

   H_{02} : $S_j = 0$ for $j = 1, 2, 3, 4$

   H_{A2} : $S_j \neq 0$ for some j

   $F_2 = \frac{\text{M.S. shelves}}{\text{M.S. error}}$ reject if $F_2 \geq F$ α, j, error degrees of freedom

3. The effects of shelves is constant for all pans:

   H_{03} : $SP_{jk} = 0$ for all j and $k = 1, 2, 3, 4$

H_{A3} : $SP_{jk} \neq 0$ for some j and k

$F_3 = \frac{\text{M.S. pxs}}{\text{M.S. error}}$ reject if $F_3 \geq F\ \alpha$, (j-1) (k-1), error degrees of freedom

RESULTS AND DISCUSSION

The object of this experiment was to evaluate a prototype model of a corridor designed kitchen and its relation with over the counter shelf heights using objects of different weights which may be used from a seated position.

The subjects were assigned a series of tasks in random sequence which had been composed by using a random number table. Through the use of 16 mm film, each subject was studied as she performed her particular series of tasks. By a mechanical method the degrees of rotation of the subject's trunk, angle created by the line joining the hip and shoulder landmark moving from the normal seated position, were recorded for each task. This data was subject to two criteria before being recorded; these norms were:

1. The subject was not allowed to arise from the chair as an aid in placing a pan on any particular shelf.
2. The subject had to maintain some sort of a grip on the pan as it was being positioned.

The possibility of a test concerning shelf number four has been omitted from this experiment because all but one subject failed to comply with the norms above. The use of the experimental design allowed the following information to be compiled:

1. Determine whether or not the response of subjects was different due to different pan weights. This response was measured in degrees as the subject performed the task with relation to pan weights.
2. Determine whether or not the response of subjects was different due to different shelf heights. The effect was tested as the shelf moved from counter top level to thirty inches at ten inch intervals.

3. A test as to whether or not there was interaction between the pans and shelves. This means a check to see if a subject had a shelf preference with a particular pan weight.

4. Test the variability between individuals to see if a difference in responce due to individuals was present.

The data was prepared in such a manner that it could be used in an IBM 1620 computer program which was applicable to the design of this experiment. The program and the output which contains the data and the complete analysis of variance are found in Form B of the Appendix.

The analysis of variance fitting this experimental design is shown in Table 2. Five degrees of freedom were lost due to the fact that there were five missing data which had to be estimated. Means were used for these estimations.

TABLE 2

ANALYSIS OF VARIANCE

Source	Degrees Freedom	Sum of Squares	Mean Squares	F
Individuals	17	1860.1	109.417	13.908*
Pans	3	139.7	46.567	5.919*
Shelves	2	901.5	450.750	57.296*
Pans X Shelves	6	99.7	16.617	2.112
Error	182	1431.7	7.867	
Total	210	4432.7		

*Significant at .05 level.

The null hypothesis, H_{01}, which was tested by the F_1-test was that there was no difference in response or angle of movement between pans (no pan, 0, 5, and 10 pounds) due to the weights of each pan. The alternate hypothesis, H_{A1}, was that there was a difference in response due to pan weight. The $F_1 = 5.919$ is greater than $F(.05, 3, 182) = 2.66$ and indicates a significant difference at the .05 level in the means due to pan weight.

The null hypothesis, H_{02}, which was tested by the F_2-test was that there were no differences in response between shelves (counter top, ten inches, and twenty inches) due to the height of each shelf. The alternate hypothesis, H_{A2}, was that there was some effects due to shelf heights. The $F_2 = 57.296$ is greater than $F(.05, 2, 182) = 3.05$ indicates a significant difference at the .05 level in the means due to shelf height.

The null hypothesis, H_{03}, which was tested by the F_3-test was that there was no interaction between pans and shelves, i.e., the effects of shelves is constant for all pans. The alternate hypothesis, H_{A3}, was that there was interaction between pans and shelves. The $F_3 = 2.112$ which is less than $F(.05, 6, 182) = 2.15$ indicates no significant interaction at the .05 level. It was noted however that without a pan as a guide, the subject tended to reach further into shelf one than the remaining shelves even though this effect did not lead to the rejection of H_{03}.

TABLE 3

PANS X SHELVES SUMMARY TABLE OF MEANS

	P_1	P_2	P_3	P_4	Shelf Mean
S_1	21.9674	19.4442	20.3377	21.3886	20.7843
S_2	14.6566	14.8007	16.9348	17.4213	15.9533
S_3	16.0205	17.1756	17.8330	18.5152	17.3861
Pan Mean	17.5481	17.1402	18.3685	19.1083	
Grand Mean					18.0412

Table 3 gives the mean for each pan-shelf combination used in this experiment. The means for pans averaged over shelves and shelves averaged over pans are also found in this table.

The relation of pan weight and response may be shown by plotting a response curve for each shelf as shown in Figure 1. The response curves are nearly parallel when comparing the individual shelves over pan weights, 0, 5, and 10 pounds. The "no pan" response is plotted and connected to the rest by a dotted line since it does not assume a specific weight and is used only as a visual aid. A study of the "no pan" relationship between shelves indicates that the subjects reach further into the lower shelf, this being number one or the counter top, than shelves number two and three. It would also indicate that there is a relationship between shelves in that the depth of reach is proportional to the height of the shelf.

The fact that shelf number two gave the smallest angle or response over each pan weight tested as seen in Figure 1 is better summarized in Figure 2. The relationship of the shelves shown in Figure 2 was found by plotting the means of the shelves averaged over the pans.

Since the shelf heights and pan weights were evenly spaced, a more detailed analysis was conducted to partition the pans, shelves, and pans by shelves interaction sums of squares into orthogonal comparisons. The linear and quadratic components for pans, shelves, and the interactions of the components for pans and shelves are given in Table 4. The coefficients are also given along with the sum of squares for each component. Pan 1 is compared to pans 2, 3, and 4 in line 1 of the table and the linear and quadratic comparisons of pan 1 are found in lines 10 and 11. Pan 1 was compared to the remaining pans and analyzed separately with respect to linear and quadratic

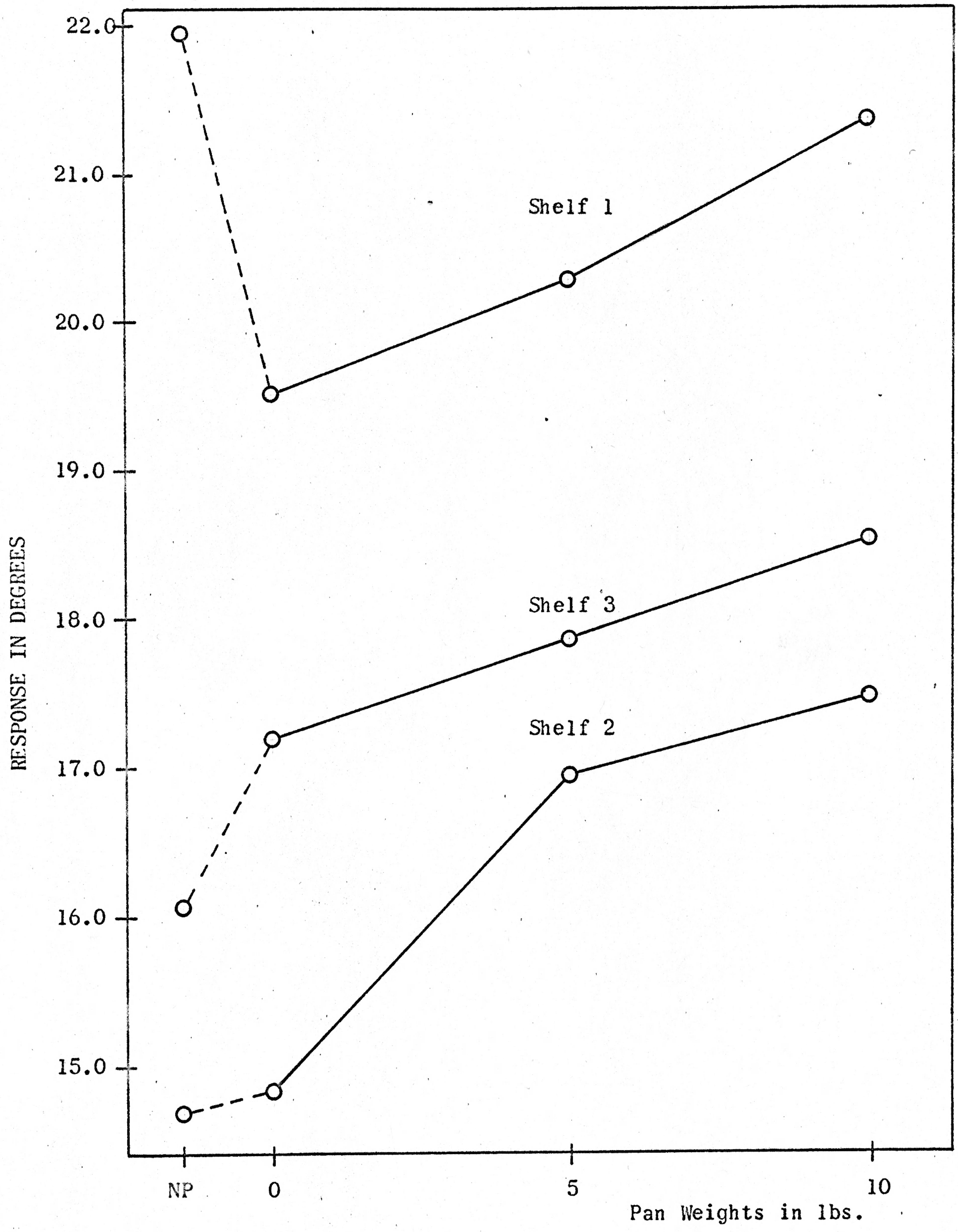

FIGURE 1

This is a graph of response vs. pan weights.

components for shelf height because its weight could not be given as a numerical measurement on the scale of pan weights. Each component may be tested for significance by computing $F = ((\Sigma\, c_i\bar{x}_i)^2 n/\Sigma c_i^2)/\text{M.S. error}$ with 1 and error degrees of freedom. The orthogonal comparisons that are significant have been starred in the table.

In order that the results found in this experiment may be illustrated better, a response surface has been determined as shown in Figure 3. The equation for the response surface can be computed from the treatments, lines 2 through 9 in Table 4, but due to the fact that only the comparisons 2, 4, and 5 were significant, they were the only terms used in this equation. These three comparisons were responsible for 97.15 percent of the variability of the means over the nine experimental treatments. The equation for the response surface is,

$$Y = 16.386 + .984z - 1.274x + 2.730x^2$$

where $z = (\text{pan weight} - 5)/5$ and $x = (\text{shelf height} - 10)/10$. The method of orthogonal polynomials presented in Kendall and Stuart (9) on page 356 was used for the determination of the equation. Assuming that the response surface presented in Figure 3 approximates the true relationship between the response and treatments, it may be used to determine an optimum set of experimental conditions.

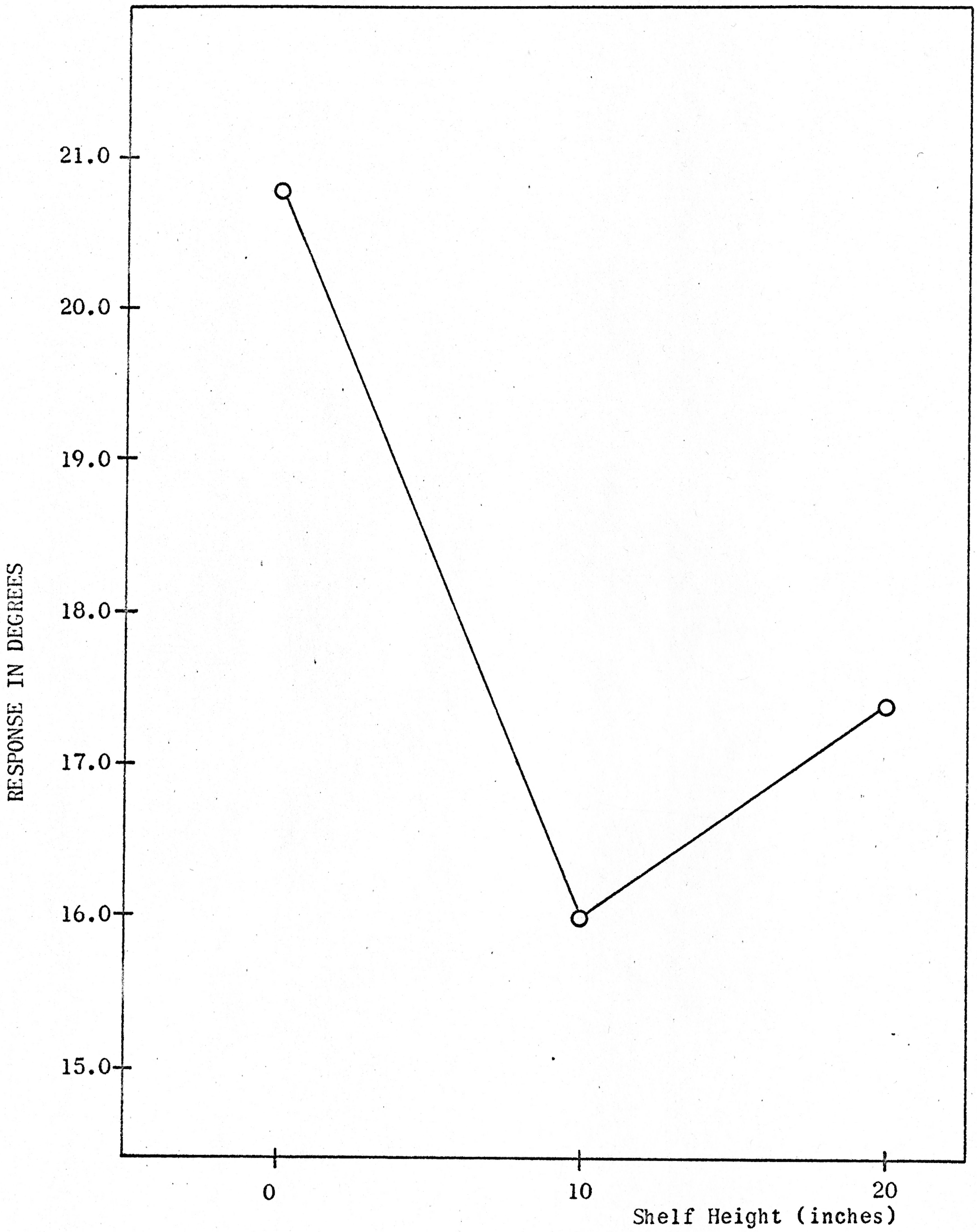

FIGURE 2

This is a graph of response vs. shelf means.

TABLE 4

ORTHOGONAL COMPARISONS

Line	Comparisons	P_1S_1	P_1S_2	P_1S_3	P_2S_1	P_2S_1	P_2S_3	P_3S_1	P_3S_2	P_3S_3	P_4S_1	P_4S_2	P_4S_3	$\sum c_i^2$	$\sum c_i\bar{X}_i$	$\frac{(\sum c_i\bar{X}_i)^2 n}{\sum c_i^2}$	F
1	P_1 to (P_2, P_3, P_4)	-3	-3	-3	1	1	1	1	1	1	1	1	1	36	5.9176	17.5089	
2	Linear Pans	0	0	0	-1	-1	-1	0	0	0	1	1	1	6	5.9049	104.6034	*
3	Quadratic Pans	0	0	0	1	1	1	-2	-2	-2	1	1	1	18	-1.4654	2.1474	
4	Linear Shelves	0	0	0	-1	0	1	-1	0	1	-1	0	1	6	-7.6467	175.4160	*
5	Quadratic Shelves	0	0	0	1	-2	1	1	-2	1	1	-2	1	18	16.3807	268.3273	*
6	Lin. Pans X Lin. Shelves	0	0	0	1	0	-1	0	0	0	-1	0	1	4	-.6048	1,6461	
7	Lin. Pans X Quad. Shelves	0	0	0	-1	2	-1	0	0	0	1	-2	1	12	-1.9472	5.7459	
8	Quad. Pans X Lin. Shelves	0	0	0	-1	0	1	2	0	-2	-1	0	1	12	-.1326	.0264	
9	Quad. Pans X Quad. Shelves	0	0	0	1	-2	1	-2	4	-2	1	-2	1	36	3.4774	6.0461	
10	Lin. for Pan 1	-1	0	1	0	0	0	0	0	0	0	0	0	2	-5.9469	318.2904	
11	Quad. for Pan 1	1	-2	1	0	0	0	0	0	0	0	0	0	6	8.6741	225.7200	
	Total															1125.4779	

*Significance at the .05 level.

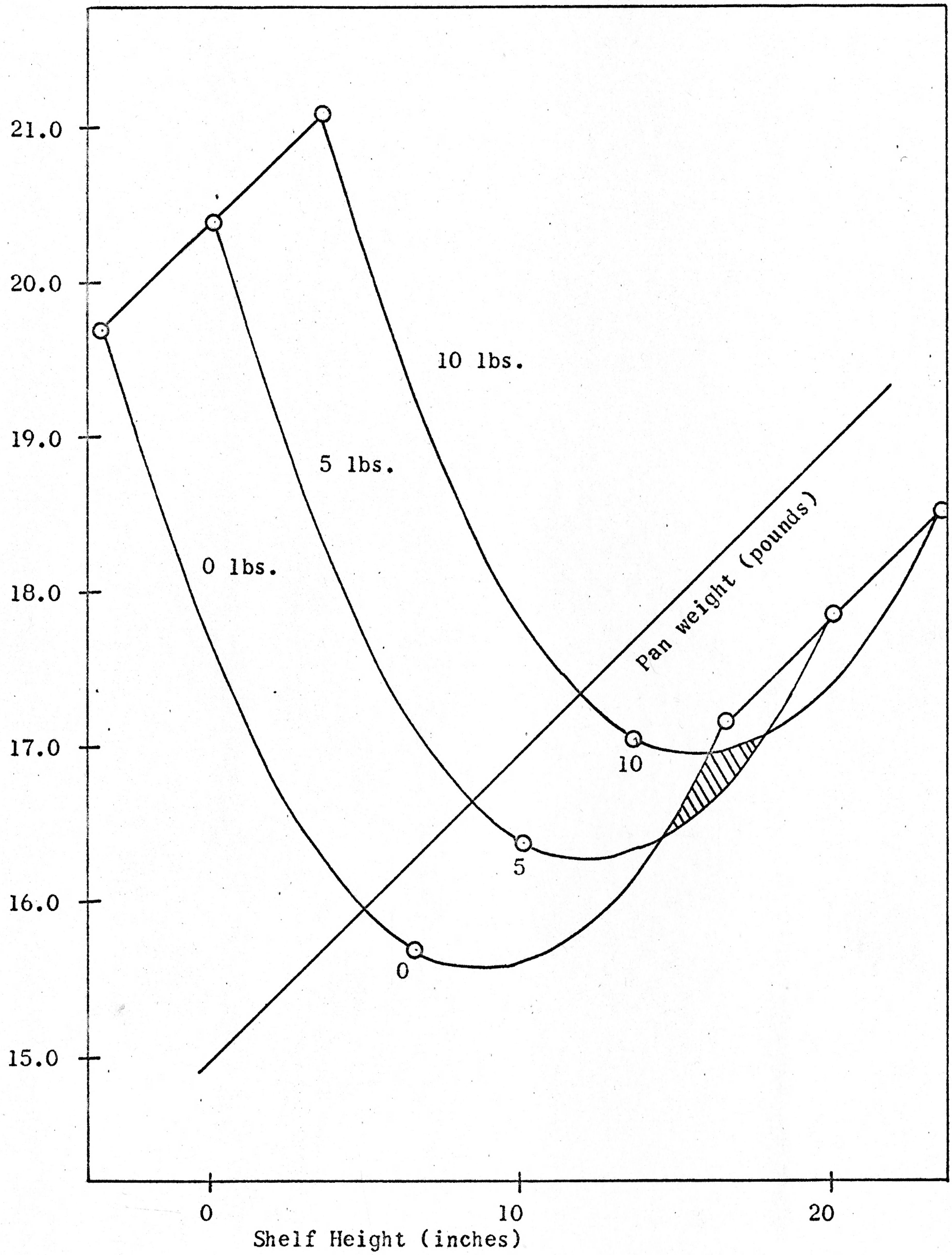

FIGURE 3

This is a graph of the response curve with the shelf heights shown related to a pan weight of 5 lbs.

CONCLUSIONS

This experiment was conducted to evaluate a prototype model of a corridor designed kitchen and its relation with the over the counter shelf heights and objects of different weights. The data collected from the filmed sequences of designated tasks allowed several conclusions to be drawn from the experimental model through the use of a analysis of variance and an orthogonal polynomial.

The analysis of variance allowed the following conclusions to be drawn:

1. There was a significant difference in the angle of response due to the difference in object weight.
2. There was a significant difference in the angle of response due to the difference in shelf heights.
3. There was no significant interaction between pans and shelves.
4. There was a significant difference in response due to variability of individuals.

The above conclusions were based on F-tests at the .05 level.

The relationship of the shelves, found by plotting the means of the shelves averaged over the pans, implies that shelf number two (10 inches above the counter top) is the shelf height which requires the least body movement. Therefore, shelf number two was the optimum shelf height tested while doing seated tasks. Using the mean of all pans tested, shelf number two required 30.3 percent less trunk movement than shelf number one and 8.9 percent less trunk movement than shelf number three. The approximate response to a particular object weight and shelf height may be determined by using the response surface, Figure 3, or its equation. Taking the first derivative of the response surface equation with respect to X, setting it equal to zero and solving for X, the optimum shelf height for the experimental kitchen being tested was found to be 12.33 inches above the counter top when doing seated tasks.

The relationship of the "no pan" and shelf height indicated that the depth of reach is proportional to the height of the shelf with the subject reaching further into the shelf as the shelf height approached the counter top.

Shelf number four was deleted from the experiment after it was found to be outside of the space envelope for the subjects when test procedures were followed.

The results of this experiment allows the positioning of utensils on different shelf heights according to object weight when considering minimum trunk movement which may be considered to be the least demanding in terms of effort. These results pertain only to two-handed, seated operations being performed by females with an age range of 18 to 21 and a specified height and weight range.

ACKNOWLEDGMENTS

The writer gratefully acknowledges the assistance rendered by faculty and staff members in the Department of Industrial Engineering. In particular, I would like to thank my major professor, Dr. George F. Schrader, Head of the Department of Industrial Engineering. The writer also wishes to thank Dr. L. Marcus for aid on the statistical problems and Professor T. Agan and staff for helping collect the data.

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APPENDIX

FORM A

Name ______________________________ Code ______________

The following sequences was used by this subject:

Take pan __________ Place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Take pan __________ place on shelf __________

Date ______________ time ____________________

FORM B

IBM program print-out

ESSAGE

```
                FORTRAN LISTING                 1410-FO-970
C       3-WAY ANALYSIS OF VARIANCE,UP TO TEN LEVELS OF EACH FACTOR
C       COMPUTES ORTHOGONAL POLYNOMIALS OF FIRST THREE DEGREE FOR TWO FACT
C       OMIT POLYNOMIALS BY READING BLANK CARDS
C       SEE FORMAT FOR DATA AND COEFFICIENT PUNCH INSTRUCTIONS
C       NN IS NO OF OBS PER CELL, DATA IS IN XIJH NOTATION AND
C       MUST BE ENTERED THAT WAY I=1 TO M,LEVELS OF S,J=1TOL,LEVELSOF R
C       AND H=1 TO N LEVELS OF T PACK DATA IN I,J,K ORDER, WITH THE
C       NN CELL OBS PUNCHED ON A SINGLE CANDL MAX OF SEVEN)
C       PROGRAM USES ONE CONTROL CARD
C       PACK, CONTROL CARD,DATA, POLYNOMIAL MULTIPLIER(OR6BLANK),REPEAT
C       FOR SEVERAL PROBLEM, LAST CARD IS A BLANK TO STOP ROUTINE
        DIMENSIONX(3),CT(42,4,4),TR(42,4),TRBAR(42,4),TT(42,4),TTBAR(42,4),TS(4,4),TSBAR(4,4),RT(4),RTBAR(4),TE(4
       ),TBAR(4),TI(42),TIBAR(42)
        DIMENSIONTLA(1,1),RLA(1,1)
C       DIMENSION TLA(10,10),RLA(10,10)
00001 FORMAT(F10.5)
00002 FORMAT(5I5)
00199 FORMAT(26H1  ANALYSIS OF VARIANCE,ID=,I7)
00200 FORMAT(18H   R MEANS BELOW,K=,I7)
00201 FORMAT(18H   S MEANS BELOW,K=,I7)
00202 FORMAT(18H   T MEANS BELOW,K=,I7)
00203 FORMAT(19H   RT MEANS BELOW,K=,I7)
00204 FORMAT(19H   ST MEANS BELOW,K=,I7)
00205 FORMAT(19H   RS MEANS BELOW,K=,I7)
00206 FORMAT(42H     SOURCE        DF              SS               MS)
00207 FORMAT(45H    FIXED, MIXED, OR RANDOM   , NO F TESTS DONE)
00208 FORMAT(6X,4HS    , F7.0,5X,E14.8,5X,E14.8)
00209 FORMAT(6X,4HT    , F7.0,5X,E14.8,5X,E14.8)
00210 FORMAT(6X,4HR    , F7.0,5X,E14.8,5X,E14.8)
00211 FORMAT(6X,4HTS   , F7.0,5X,E14.8,5X,E14.8)
00212 FORMAT(6X,4HTR   , F7.0,5X,E14.8,5X,E14.8)
00213 FORMAT(6X,4HRS   , F7.0,5X,E14.8,5X,E14.8)
00214 FORMAT(6X,4HTRS  , F7.0,5X,E14.8,5X,E14.8)
00215 FORMAT(6X,4HERR  , F7.0,5X,E14.8,5X,E14.8)
00216 FORMAT(6X,4HTOTL, F7.0,5X,E14.8)
00831 FORMAT(20H   RST MEANS BELOW,K=,I4)
00870 FORMAT(F20.10)
04000 FORMAT(17X,9HCOMPONENT,I7,6HSS=---,E14.8)
09000 FORMAT(15F4.0)
07001 FORMAT(F20.10)
00003 FORMAT(F10.5)
00004 FORMAT(1X,F1.0)
00005 FORMAT(2X,F1.0)
00006 FORMAT(3X,F1.0)
00007 FORMAT(4X,F1.0)
00008 FORMAT(5X,F1.0)
00009 FORMAT(6X,F1.0)
00010 FORMAT(7X,F1.0)
00011 FORMAT(8X,F1.0)
      IFOR=0
01000 READ(1,2)ID,L,M,N,NN
      IFOR=IFOR+1
      IF(L.EQ.0)STOP
      CTSQ=0.0
      WRITE(3,199)ID
      ANN=NN
      AL=L
      AN=N
      AM=M
      TOTN=L*N*M*NN
      TOT=0.0
      TOTSQ=0.0
      WRITE(3,831)NN
      DO50I=1,M
      DO50J=1,L
      DO50K=1,N
      CT(I,J,K)=0.0
      GOTO(800,801,802,803,804,805,806,807,808),IFOR
00800 DO502II=1,NN
00502 READ(1,3)X(II)
      GOTO12
00801 DO503II=1,NN
00503 READ(1,4)X(II)
      GOTO12
00802 DO504II=1,NN
```

```
00504 READ(1,5)X(II)
      GOTO12
00803 DO505II=1,NN
00505 READ(1,6)X(II)
      GOTO12
00804 DO506II=1,NN
00506 READ(1,7)X(II)
      GOTO12
00805 DO507II=1,NN
00507 READ(1,8)X(II)
      GOTO12
00806 DO508II=1,NN
00508 READ(1,9)X(II)
      GOTO12
00807 DO509II=1,NN
00509 READ(1,10)X(II)
      GOTO12
00808 DO510II=1,NN
00510 READ(1,11)X(II)
00012 DO56II=1,NN
      CT(I,J,K)=CT(I,J,K)+X(II)
      TOT=TOT+X(II)
00056 TOTSQ=TOTSQ+X(II)*X(II)
      CTSQ=CTSQ+CT(I,J,K)*CT(I,J,K)/ANN
      CTBAR=CT(I,J,K)/ANN
00050 WRITE(3,7001)CTBAR
C     CT  ARE CELL  TOTALS, HAVE SUM AND SUM OF SQUARES COMPUTED
C       BRANCH AROUND MODIFICATION
      GOTO6005
020
      DO851I=1,1
00851 READ(1,9000)(TLA(I,K),K=1,1)
      DO852I=1,1
00852 READ(1,9000)(RLA(I,J),J=1,1)
06005 DO47I=1,M
      DO47J=1,L
00047 TR(I,J)=0.0
      TRSQ=0.0
      DO51I=1,M
      DO51J=1,L
      DO53K=1,N
00053 TR(I,J)=TR(I,J)+CT(I,J,K)
      TRSQ=TRSQ+TR(I,J)*TR(I,J)/(AN*ANN)
00051 TRBAR(I,J)=TR(I,J)/(AN*ANN)
      DO59I=1,M
      DO59K=1,N
00059 TT(I,K)=0.0
      TTSQ=0.0
      DO60I=1,M
      DO60K=1,N
      DO63J=1,L
00063 TT(I,K)=TT(I,K)+CT(I,J,K)
      TTSQ=TTSQ+TT(I,K)*TT(I,K)/(AL*ANN)
00060 TTBAR(I,K)=TT(I,K)/(AL*ANN)
      DO79J=1,L
      DO79K=1,N
00079 TS(J,K)=0.0
      TSSQ=0.0
      DO70J=1,L
      DO70K=1,N
      DO71I=1,M
00071 TS(J,K)=TS(J,K)+CT(I,J,K)
      TSSQ=TSSQ+TS(J,K)*TS(J,K)/(AM*ANN)
00070 TSBAR(J,K)=TS(J,K)/(AM*ANN)
      CFAC=TOT*TOT/TOTN
      CTOTSQ=TOTSQ-CFAC
      DO83J=1,L
00083 RT(J)=0.0
      RTSQ=0.0
      DO81J=1,L
      DO80K=1,N
00080 RT(J)=RT(J)+TS(J,K)
      RTBAR(J)=RT(J)/(AM*AN*ANN)
00081 RTSQ=RTSQ+RT(J)*RT(J)/(AM*AN*ANN)
      DO94K=1,N
00094 TE(K)=0.0
```

```
      TESQ=0.0
      DO91K=1,N
      DO90J=1,L
00090 TE(K)=TE(K)+TS(J,K)
      TBAR(K)=TE(K)/(AL*AM*ANN)
00091 TESQ=TESQ+TE(K)*TE(K)/(AM*AL*ANN)
      DO100I=1,M
00100 TI(I)=0.0
      TISQ=0.0
      DO105I=1,M
      DO106K=1,N
00106 TI(I)=TI(I)+TT(I,K)
      TIBAR(I)=TI(I)/(AN*AL*ANN)
00105 TISQ=TISQ+TI(I)*TI(I)/(AN*AL*ANN)
      DFR=AL-1.0
      DFS=AM-1.0
      DFT=AN-1.0
      DFRS=DFR*DFS
      DFRT=DFR*DFT
      DFST=DFS*DFT
      DFSRT=DFST*DFR
      DFE=TOTN-1.0-DFR-DFS-DFT-DFRS-DFRT-DFST-DFSRT
      CRSS=RTSQ-CFAC
      CSSS=TISQ-CFAC
      CTSS=TESQ-CFAC
      CRSSS=TRSQ-CRSS-CSSS-CFAC
      CTSSS=TTSQ-CTSS-CSSS-CFAC
      CRTSS=TSSQ-CTSS-CRSS-CFAC
      CRSTSS=CTSQ-CFAC-CRSS-CSSS-CTSS-CRSSS-CTSSS-CRTSS
      ESS=CTOTSQ-CTSQ+CFAC
      RMS=CRSS/DFR
      SMS=CSSS/DFS
      TMS=CTSS/DFT
      RSMS=CRSSS/DFRS
      TSMS=CTSSS/DFST
      RTMS=CRTSS/DFRT
      RSTMS=CRSTSS/DFSRT
      EMS=ESS/DFE
      WRITE(3,205)N
      WRITE(3,870)((TRBAR(I,J),J=1,L),I=1,M)      — 18×4
      WRITE(3,204)L
      WRITE(3,870)((TTBAR(I,K),K=1,N),I=1,M)      — 3×4
      WRITE(3,203)M
      WRITE(3,870)((TSBAR(J,K),K=1,N),J=1,L)      — 3×18
      LM=L*M
      WRITE(3,202)LM
      WRITE(3,870)(TBAR(K),K=1,N)
      LN=L*N
      WRITE(3,201)LN
      WRITE(3,870)(TIBAR(I),I=1,M)
      MN=M*N
      WRITE(3,200)MN
      WRITE(3,870)(RTBAR(J),J=1,L)
      WRITE(3,206)
      WRITE(3,208)DFS,CSSS,SMS
      WRITE(3,209)DFT,CTSS,TMS
C       BRANCH AROUND MODIFICATION
      GOTO6001
020
      DO3001I=1,3
      TSUL=0.0
      TLAM=0.0
      DO3000K=1,N
      IF(TLA(1,1).EQ.0.0)GOTO6001
      TLAM=TLAM+TLA(I,K)*TLA(I,K)
03000 TSUL=TSUL+TLA(I,K)*TE(K)
      TCUSQ=TSUL*TSUL/(TLAM*AL*AM*ANN)
03001 WRITE(3,4000)I,TCUSQ
06001 WRITE(3,210)DFR,CRSS,RMS
C       BRANCH AROUND MODIFICATION
      GOTO6000
020
      DO2001I=1,3
      RSUL=0.0
      RLAM=0.0
      DO2000J=1,L
```

```
      IF(RLA(I,1).EQ.0.0)GOTO6000
      RLAM=RLAM+RLA(I,J)*RLA(I,J)
02000 RSUL=RSUL+RLA(I,J)*RT(J)
      RSUSQ=RSUL*RSUL/(RLAM*AM*AN*ANN)
02001 WRITE(3,4000)I,RSUSQ
06000 WRITE(3,211)DFST,CTSSS,TSMS
      WRITE(3,212)DFRT,CRTSS,RTMS
      WRITE(3,213)DFRS,CRSSS,RSMS
      WRITE(3,214)DFSRT,CRSTSS,RSTMS
      WRITE(3,215)DFE,ESS,EMS
      DFTO=TOTN-1.0
      WRITE(3,216)DFTO,CTOTSQ
      WRITE(3,207)
      GOTO1000
      END
```

FORTRAN NAME		LOCATION	FORTRAN NAME		LOCATION	FORTRAN NAME		LOCATION	FORTRAN NAME		LOCATION
0000+		00775	0000A		00780	0000C		00785	00000+9R		00793
10000+0A		00801	IFOR		00806	ID		00811	L		00816
M		00821	N		00826	NN		00831	I		00836
J		00841	K		00846	II		00851	LM		00856
LN		00861	MN		00866	X		00901	CT		06277
TR		07621	TRBAR		08965	TT		10309	TTBAR		11653
TS		11781	TSBAR		11909	RT		11941	RTBAR		11973
TE		12005	TBAR		12037	TI		12373	TIBAR		12709
TLA		12717	RLA		12725	CTSQ		12733	ANN		12741
AL		12749	AN		12757	AM		12765	TOTN		12773
TOT		12781	TOTSQ		12789	CTBAR		12797	TRSQ		12805
TTSQ		12813	TSSQ		12821	CFAC		12829	CTOTSQ		12837
RTSQ		12845	TESQ		12853	TISQ		12861	DFR		12869
DFS		12877	DFT		12885	DFRS		12893	DFRT		12901
DFST		12909	DFSRT		12917	DFE		12925	CRSS		12933
CSSS		12941	CTSS		12949	CRSSS		12957	CTSSS		12965
CRTSS		12973	CRSTSS		12981	ESS		12989	RMS		12997
SMS		13005	TMS		13013	RSMS		13021	TSMS		13029
RTMS		13037	RSTMS		13045	EMS		13053	TSUL		13061
TLAM		13069	TCUSQ		13077	RSUL		13085	RLAM		13093
RSUSQ		13101	DFTO		13109						
01000		13139	00800	FOR.	13799	00801	FOR.	13806	00802	FOR.	13813
00803	FOR.	13820	00804	FOR.	13827	00805	FOR.	13834	00806	FOR.	13841
00807	FOR.	13848	00808	FOR.	13855	13799	DEF.	13862	00502		13874
00012	FOR.	13975	13806	DEF.	13982	00503		13994	13813	DEF.	14102
00504		14114	13820	DEF.	14222	00505		14234	13827	DEF.	14342
00506		14354	13834	DEF.	14462	00507		14474	13841	DEF.	14582
00508		14594	13848	DEF.	14702	00509		14714	13855	DEF.	14822
00510		14834	13975	DEF.	14935	00056		15070	00050		15197
06005	FOR.	15343	00851		15362	00852		15533	15343	DEF.	15692
00047		15716	00053		15903	00051		16128	00059		16266
00063		16453	00060		16678	00079		16816	00071		17003
00070		17228	00083		17410	00080		17539	00081		17723
00094		17848	00090		17977	00091		18161	00100		18286
00106		18415	00105		18599	06001	FOR.	20741	03000		20954
03001		21136	20741	DEF.	21215	06000	FOR.	21263	02000		21476
02001		21658	21263	DEF.	21737						

PROGRAM SIZE IS 22104 PROGRAM ENTRY IS 13115

FORM B

Data and AOV print-out

```
ANALYSIS OF VARIANCE,ID=          1
RST MEANS BELOW,K=    1
       24.5000000000
       22.1666000000
       19.8333000000
       23.4166000000
       18.1666000000
       18.5833000000
       25.2500000000
       19.2500000000
       19.0833000000
       26.4166000000
       17.3333000000
       19.9166000000
       15.6666000000
        7.1666000000
       15.4166000000
       20.0000000000
       21.0833000000
       27.2500000000
       20.2500000000
       21.0000000000
       27.2500000000
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       18.1666000000
       26.9166000000
       23.1666000000
       13.0000000000
       18.0000000000
       18.2500000000
       11.5000000000
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       16.7500000000
       21.0000000000
       16.0000000000
       21.1666000000
       21.5000000000
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       13.2500000000
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       17.7500000000
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       16.7500000000
       16.9166000000
       14.0833000000
       15.8333000000
       18.9166000000
       16.7500000000
       16.7500000000
       20.0000000000
       15.5833000000
       16.1666000000
       24.0000000000
       15.5833000000
```

17.6666000000
13.8333000000
11.2500000000
12.6666000000
18.7500000000
14.9166000000
18.5833000000
19.5000000000
14.5000000000
20.7500000000
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19.4166000000
24.2500000000
17.0000000000
18.7500000000
23.5000000000
17.6666000000
21.4166000000
24.5000000000
18.5000000000
19.6666000000
22.1666000000
12.6666000000
14.0833000000
20.5833000000
14.0833000000
16.9166000000
19.2500000000
17.4166000000
14.5000000000
18.3333000000
17.0833000000
15.9166000000
24.7500000000
20.2500000000
17.4166000000
22.2500000000
12.5000000000
18.1666000000
21.9166000000
15.4166000000
17.4166000000
20.9166000000
16.9166000000
17.6666000000
19.0833000000
11.2500000000
11.1666000000
12.4166000000
9.7500000000
14.5833000000
18.5000000000
8.5000000000
11.7500000000
18.8333000000
14.2500000000
11.3333000000
20.0000000000
10.8333000000
17.2500000000
19.6666000000
17.3333000000
18.8333000000
17.6666000000
15.6666000000
19.1666000000
20.0000000000
15.2500000000
17.2500000000
22.1666000000
16.3333000000
16.5000000000
19.5000000000
15.7500000000
19.0833000000

```
17.8333000000
17.6666000000
21.3333000000
21.1666000000
14.5000000000
19.2500000000
31.0000000000
14.6566000000
16.0208000000
21.8333000000
20.0833000000
17.4166000000
22.6666000000
20.0833000000
16.3333000000
24.0833000000
21.1666000000
18.5156000000
11.0000000000
10.1666000000
11.3333000000
17.2500000000
11.5833000000
13.4166000000
18.5833000000
15.0833000000
17.1666000000
22.3333000000
16.9166000000
14.8333000000
24.0833000000
18.8333000000
11.6666000000
19.0000000000
15.5000000000
14.8333000000
18.7500000000
15.6666000000
17.6666000000
17.2500000000
17.3333000000
18.4166000000
12.2500000000
10.0000000000
16.0000000000
18.2500000000
15.0000000000
 9.5000000000
19.6666000000
15.0000000000
11.3333000000
17.3333000000
15.5833000000
14.5000000000
22.7500000000
11.7500000000
16.0208000000
13.5000000000
 2.0833000000
14.5000000000
16.7500000000
10.2500000000
11.5000000000
15.5833000000
17.4215000000
18.5156000000
RS MEANS BELOW,K=           3
22.1666000000
20.0555000000
21.1944000000
21.2221000000
12.7499000000
22.7777000000
22.8333000000
22.8888000000
18.0555000000
```

```
      15.9722000000
      17.9166000000
      20.9722000000
      16.8888000000
      15.5833000000
      19.4166000000
      19.3333000000
      22.2777000000
      27.5555000000
      26.6944000000
      26.9999000000
      17.5833000000
      15.6110000000
      17.4722000000
      17.2499000000
      19.0833000000
      12.5833000000
      17.4166000000
      18.2500000000
      22.5833000000
      20.0000000000
      20.8610000000
      20.8888000000
      16.3055000000
      17.1944000000
      17.0555000000
      17.1110000000
      20.8055000000
      17.6388000000
      18.2499000000
      18.4999000000
      13.8333000000
      12.2499000000
      12.9166000000
      14.8055000000
      16.0277000000
      18.6110000000
      17.4999000000
      17.5000000000
      18.3333000000
      18.1111000000
      18.9444000000
      18.3055000000
      20.5591000000
      19.7777000000
      19.6944000000
      21.2551000000
      10.8333000000
      14.0833000000
      16.9444000000
      18.0277000000
      18.1944000000
      16.4444000000
      17.3610000000
      17.6666000000
      12.7500000000
      14.2500000000
      15.3333000000
      15.8055000000
      16.8402000000
      10.0277000000
      12.8333000000
      17.1734000000
ST MEANS BELOW,K=         4
      24.8958000000
      19.2291000000
      19.3541000000
      19.8749000000
      16.8541000000
      24.2083000000
      19.8333000000
      16.7500000000
      18.1041000000
      21.0624000000
      16.2499000000
      16.1041000000
```

```
        29.9997000000
        23.3333000000
        24.3124000000
        19.2708000000
        15.2916000000
        16.3749000000
        19.0208000000
        14.0624000000
        17.4166000000
        24.9375000000
        18.4999000000
        19.8124000000
        20.0833000000
        15.3124000000
        15.3541000000
        22.4583000000
        16.2708000000
        17.6666000000
        17.2083000000
        10.9375000000
        12.2083000000
        19.3333000000
        14.7708000000
        18.1249000000
        20.1666000000
        16.0624000000
        19.0416000000
        24.8958000000
        18.9974000000
        17.0715000000
        17.2916000000
        13.4374000000
        14.1874000000
        19.7708000000
        16.8333000000
        15.6457000000
        16.8749000000
        13.8958000000
        12.8333000000
        17.1458000000
        10.3762000000
        15.1341000000
RT MEANS BELOW,K=        18
        21.9674000000
        14.6566000000
        16.0205000000
        19.4442000000
        14.8007000000
        17.1756000000
        20.3377000000
        16.9348000000
        17.8330000000
        21.3886000000
        17.4213000000
        18.5152000000
T MEANS BELOW,K=        72
        20.7843000000
        15.9533000000
        17.3861000000
S MEANS BELOW,K=        12
        21.1595000000
        20.3124000000
        18.2290000000
        17.8054000000
        25.8817000000
        16.9790000000
        16.8332000000
        21.0831000000
        16.9165000000
        18.7985000000
        13.4513000000
        17.4095000000
        18.4235000000
        20.3215000000
        14.9720000000
        17.4165000000
```

```
      14.5346000000
      14.2186000000
 R MEANS BELOW,K=        54
      17.5481000000
      17.1402000000
      18.3685000000
      19.1083000000
   SOURCE       DF          SS                  MS
      S         17.     .18601000E 04      .10941700E 03
      T          2.     .90150000E 03      .45075000E 03
      R          3.     .13970000E 03      .46566600E 02
      TS        34.     .30230000E 03      .88911700E 01
      TR         6.     .99700000E 02      .16616600E 02
      RS        51.     .57850000E 03      .11343100E 02
      TRS      102.     .55090000E 03      .54009800E 01
      ERR         .     .00000000E-99      .00000000E-99
      TOTL     215.     .44327000E 04
  FIXED, MIXED, OR RANDOM  , NO F TESTS DONE
```

FORM C

ANTHROPOMETRIC MEASUREMENTS

Name
Address

Age
Weight
Body Build Index $\frac{wt}{ht}$ =

Standing

Stature

Shoulder

Elbow

Waist

Hip

Knee

Fingertip

Sitting

Vertex of head

Shoulder

Elbow

Waist

Hip

Height top of thigh

Height top of knee

Standing

Greatest width at shoulders

Greatest width at arms bent

Greatest width below 36"

Height of stage 10½"

Depth

Bust

Abdominal

Bust

Hip

Widest extension of hips

Sitting length

Maximum span at working level

Normal span at working level

Sitting eye level above seat

Elbow height above seat

Seat length

Seat width

Seat height back / front

Arm Length

Shoulder to elbow

Elbow to palm

Classification of Stature — Short 1 Medium 2 Tall 3

Classification of Weight — Underweight 1 Medium 2 Overweight 3

ANALYSIS OF THE EFFECT OF DISTANCE AND WEIGHT AS A DETERMINANT OF POSTURAL CONFIGURATIONS OF A SEATED WORKER

by

JERRY W. WHITT

B. S., Kansas State University, 1963

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1965

The prime purpose of this experiment was to evaluate a prototype mock-up model of a corridor designed kitchen and its relation with over the counter shelf heights using objects of different weights which may be used from a seated position.

A literature review revealed that many books and articles had been written on lifting forces and/or controlling muscle action when moving objects while in a standing position. It was also noted that contributions have been made to seating characteristics when the strength of arm extension is involved. Adequate information concerning seated tasks which involved both object weight and shelf height was not available. In order to evaluate this model kitchen in terms of the optimum location of over the counter shelf installations, the relationship of weight and distance was explored. This was achieved by measuring the body distortion from a normal seated position while using two-handed operations. A task consisting of lifting an object (no pan, 0, 5, and 10 pounds) from the counter top and placing it on a designated shelf directly in front of the subject was tested. Each sequence, composed of a series of tasks, was filmed and then the deviations from the normal seated position were measured by the use of a mechanical drawing arm and a mirror device.

Twenty-three female college students, with an age range of 18 to 21, formed the sample population. Their build was medium with reference to stature and weight. The subjects selected were between 62 and 65 inches in height and were within a specified weight range according to age and height.

The effect of object weight, of shelf height, and the interaction between the objects were analyzed statistically using an analysis of variance.

The results of the analysis show that both object weight and shelf height are significant; therefore, there is a difference in response due to these two sources of variation. It was also noted that there was a significant variability from individual to individual although they were similar in stature and weight. A study of the graphical results indicates that shelf number 2 (10 inches above the counter top) required the minimal response on the part of the subject using anyone of the object weights tested; therefore, it may be assumed to be the optimal shelf height tested.