

**LIFTING FORCES, TORQUES AND INITIAL POSTURES-----
EXPERIMENTAL AND SIMULATION RESULTS**

by

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INTRODUCTION:

One of the most important problems of work physiology is to determine whether a man's work may be considered as normal or an overload. In manual material handling, man is limited by both his skeleto-muscular system and his cardio-respiratory system. Man's skeleto-muscular system limits the amount of weight that he can handle at infrequent intervals. Man's cardio-respiratory system, on the other hand, limits the amount of weight if the lifting is frequent. An important aspect of all weight lifting operations is the risk of structural injuries--in particular to the skeleto-muscular structure of the back. Much attention has been given to the problem of back injuries, and there are numerous publications available on the subject.

In the United States, the problem today is injuries to the skeleto-muscular system rather than overload of the cardio-vascular system. The percentage of industrial injuries due to lifting has remained constant for the last two to three decades. In order to analyze the effects of forces and torques on the spine when a lift is made and thereby to establish a safety standard for different percentiles of the population, it is essential to know how different variables in lifting are related to the various forces, torques and accelerations involved.

LITERATURE REVIEW:

There have been many studies done on lifting due to its importance in industry. A brief review of the related literature follows.

Back injuries:

Wayne (1954) and Ruseek (1955) made statistical inquiries and established the high number of back injuries in tasks involving weight lifting. According to Armstrong (1965), Morris, Lucas and Bresler (1961), and Nachemson (1962) injuries to the spine in lifting seem concentrated on the vertebral bodies, intervertebral discs and soft tissues--that is muscles and ligaments. Thus, from a safety viewpoint, stress is on the skeletal muscular system and not on the cardiovascular system.

Since the occurrence of injury to the lower back is so common, it has given rise to a specific recommended method of weight lifting (Ministry of Labor and National Service, 1944), Anderson (1951), Cyriax (1954) and Floyd and Silver (1955). Lifting by bending the trunk, with the knees kept straight, is more dangerous than the method of lifting which involves flexed knees and an upright trunk ("knee-action"). Floyd and Silver proved that the "knee-action" method minimizes strains to the posterior ligaments of the spine.

Thieme (1950) concluded that the low back lumbar region is the main area where spinal injuries occur. In fact, 89% were in the lowest two lumbar discs which are situated between L-4/L-5 and L-5/S-1 vertebral bodies. Perey (1957) established that the compressive strength of

vertebral discs ranges from about 83 to 126 kg/sq cm for the under 40 group and 30 to 49 kg/sq cm for the over 60 group.

Morris, et al (1961) demonstrated that when a subject is holding 90 kg with the trunk flexed 60 degrees from the normal standing position, and with the arms hanging straight down, the forces on L-5/S-1 disc are approximately 635 kg. Sonoda (1962) estimated that the fracture load, the load to fracture the spinal column, for women is 5/6 of that for men. He also found a difference in strength per unit area of the spinal column existed between men and women. This difference indicates the difference in the surface area of the vertebral bodies.

Davis (1963) studied some effects on lifting, pulling and pushing on the human trunk. The effects on intra-thoracic and intra-abdominal pressures, chest diameters and respiratory capacity when pushing, pulling and stooping to lift increasing series of weights were examined in 16 male and 15 female adults. For pushing and pulling, a transverse handle at a standard height was used; for lifting, a simple pallet with low handles was used. In this series, pressures within the trunk cavities were increased when lifting. Similar and sometimes greater pressure increases occurred when pushing but were less common and less intense when pulling.

Respiratory fluctuations of intra-abdominal pressure increased markedly, suggesting that increased pulmonary ventilation derived mainly from increased diaphragmatic excursion.

Troup (1965) studied back injuries in industry and back pains caused by lifting or twisting movements. He concluded: 1) Only small proportions of low back disorders can properly be attributed to accidents. 2) Heavy manual work is the major contributing factor. 3) In men engaged in heavy work, the prevalence of lumbar vertebral degeneration is higher, low back disability is more common and causes more incapacity than in those engaged in light work.

Nachemson (1965) demonstrated that, in upright unsupported sitting, the load on the disc is about three times the body weight above the level measured. In sitting with forward leaning, the load on the disc is calculated by the equation:

$$F_{\text{Disc}} \text{ (kg)} = 30 + 2.8 W + 3.6 W \sin A$$

where 30 stands for the "intrinsic" load, W in kilograms is the body weight above the level measured, and A is the angle of forward leaning. Similarly, in the standing position, the load can be calculated from:

$$F_{\text{Disc}} \text{ (kg)} = 15 + 2.1 W_a + 3.6 W_a \sin A$$

where the factor ' W_a ' includes not only the body weight but also added loads carried in the hands or on the shoulder. In all the body positions studied so far, mathematical expressions can be formulated by which it is possible to calculate the load on the lower lumbar discs with "reasonable accuracy".

Poulsen (1970) predicted the maximum loads in lifting from measurement of back muscle strength. The formula for prediction is:

$$\text{Maximum load} = L \text{ (kg)} = 1.4 F - 0.5 BW$$

where F is maximum pull that can be exerted on a dynamometer in an attempted extension of the back in the standing position and BW is

body weight in kilograms. The regression lines for maximum load and back muscle strength, and for maximum load and predicted maximum load were different for men and women; men were able to lift heavier burdens than women with the same measured back muscle strength.

Poulsen and Jorgensen (1971) studied the back muscle strength for lifting and stooped working postures. They predicted the formulae for maximum loads from tests with 50 male and female subjects. For men,

$$\text{Maximum load} = L \text{ (kg)} = 1.1 \text{ IW}$$

where IW is isometric back muscle strength, and for women,

$$\text{Maximum load} = L \text{ (kg)} = 0.95 \text{ IW} - 8.$$

From tests with 65 rehabilitates, it was found that the maximum isometric strength of the back muscles measured at shoulder height should exceed 2/3 of the body weight, if fatigue and/or pain in the back muscles is to be avoided during work in a standing position.

Snook and Ciriello (1972) did a literature survey on low back pain in industry. Davies (1972) considered different aspects of manual lifting. These included legal aspects, recommended loads, techniques of lifting and carrying, dress, pulling and pushing, and pace of work. A new film on lifting and handling was noted and a plea was made to industry to consider training one or two workers as instructors in good techniques of physical moving of loads.

Brown (1975) surveyed factors contributing to the development of low back pain in industrial workers. In this population, back injuries were more frequent among women, as were absences for other illness. Most employees sustaining back injury subsequently returned to their original jobs.

Kramos, et al (1975) took a new look at the old subject of back injuries. One of the conclusions was that traditional lifting standards covering how much a worker should lift just are not workable. They found that back injuries resulted from many factors. Work environment, physical condition, distance and configuration of object, frequency of the lift and even the time of day contributed to the problem.

Simulation Models:

Fine (1966) developed a model to predict the compressive force against the lumbrosacral disc, and the weight of the object lifted; all weights acted through their respective centers of gravity. The resisting internal forces were the intensity of intra-abdominal pressure times the effective abdominal cross-section, the tension in the deep muscles of the back, and the reactions on the lumbrosacral disc. For one specific person lifting a 40 kg weight, Fine calculated a compressive force of 454 kg on the disc. He also pointed out that a 9 kg part lifted 1 meter in front of the operator was equivalent to a 27 kg weight in the upright position (317 kg on the disc).

Chaffin (1967) and Chaffin and Baker (1970) developed a model of the human body. It assumed the skeletal muscular system to be analogous to a series of eight solid links representing the major body segments. The model was restricted to symmetric sagittal body-plane activities. This model could evaluate various static situations, such as when one is holding a weight or pushing or pulling. This type of a model represents a rational method for investigating many variables

that affect the physical strength capabilities of any individual required to perform material handling activities.

Chaffin and Martin (1972) made a biomechanical computerized simulation of human strength in sagittal plane activities. This model is a modification to an earlier biomechanical strength modeling procedure along with a series of strength prediction curves resulting from simulations typical of industrial material handling tasks. These families of curves predict human strength capabilities for performing general tasks (lifts, pushes and pulls) over a wide range of feasible body positions. Profile curves at the 50th and 95th percentile ranking for both male and female populations were presented.

Park (1973) further studied the biomechanical model and showed that people assume lifting postures which minimize the physical work done while reverting to an upright posture. His study also demonstrated that a rational computer model could be successfully applied in predicting the body postures during weight lifting.

Ayoub, McDaniel and Dryden (1973) studied modeling in lifting activities. They gave a formula each for men and women, predicting the maximum lifting weight. The error found was 6 to 8 percent. In conclusion, they wrote that predictive models for performance as well as biomechanical models are very useful in gaining an insight into factors and methods in lifting activities that relate to lifting capacity of men.

Drury and Pfeil (1975) studied the performance of a task based model of manual lifting. Their paper first demonstrated that the effect of one variable - age - is similar in a study of 45 subjects

using a non-compact object to that found in previous studies using compact objects. A model is proposed to predict lifting performance from a large number of task related variables.

Drury (1975) did a study on predictive models for setting safe limits in manual materials handling. He showed that duration of lifting at constant weight leads to the same results as the criterion of maximum weight lifted. Other findings are that the height of the object at both the beginning and at the end of the lift are required to specify performance, and that carrying performance can be treated as an extension of static lifting performance.

METHOD

The main objective of this study was to find the initial posture of a person as well as forces and torques on the body while lifting a weight in the symmetrical sagittal plane. In addition, a simulation with a computerized model was also tried for initial posture prediction.

Task

The subjects stood on a six axis force platform (Hearn and Konz, 1968) with their feet in a parallel position; see in Figure 1. They lifted loads of 5, 10 and 15 kg without jerking in the symmetrical sagittal plane. The loads were placed at four different initial positions of $(x=25, y=25)$, $(x=50, y=25)$, $(x=25, y=50)$ and $(x=50, y=50)$ cm. The distances were measured from the body center line, assuming it passes through the center of the force platform, and the center of gravity of the box. The vertical distance was measured from the top of the force platform to the center of gravity. The final phase of lifting was to hold the load in front of the body with arms "straight" down. The 12 conditions per subject are listed in Table 1. Toteboxes were weighted with sand and the accelerometer to 5, 10 and 15 kg. The size of the totebox was 43.2 x 34.3 x 12.7 cm.

Subjects

With a screening procedure as given in Appendix 1, six female subjects were chosen with the following criteria.

- a) body weight in the range 50-75 kg
- b) height in the range 160-180 cm
- c) age in the range 20-35 yr.

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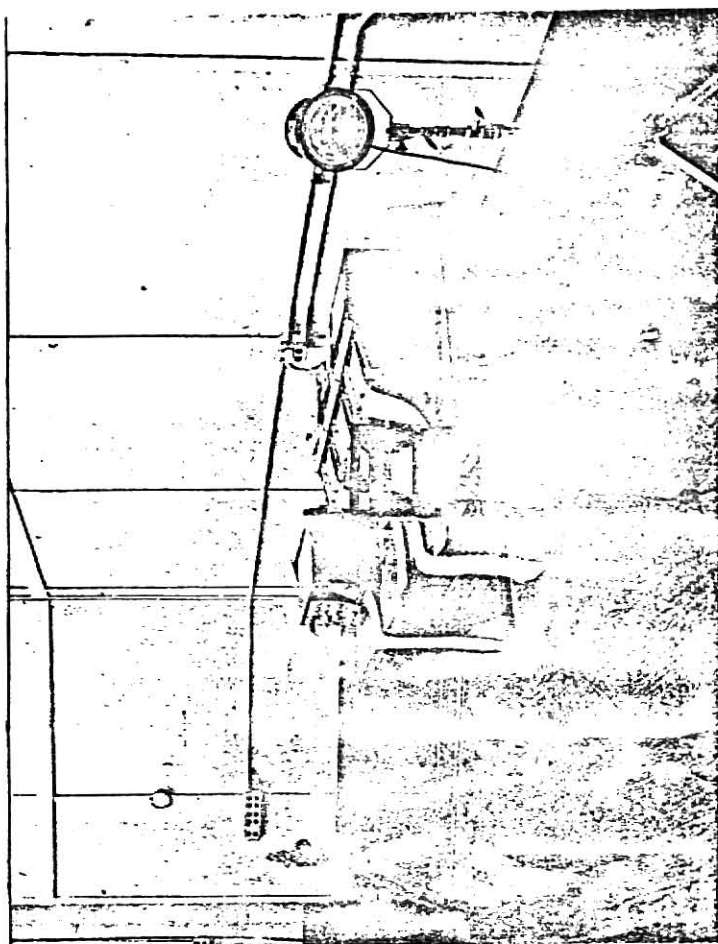
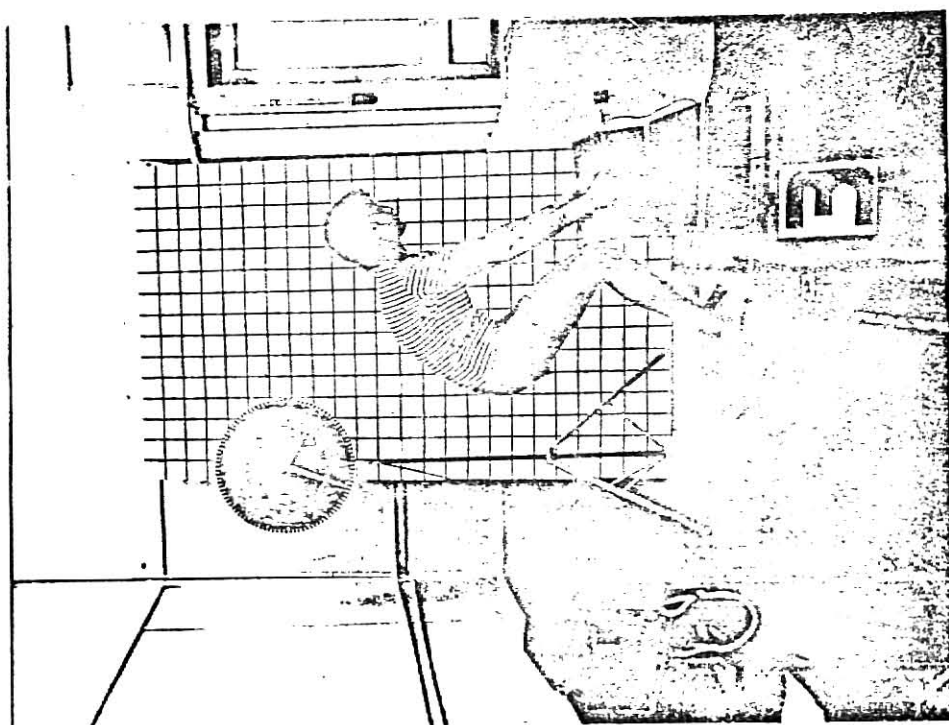


Figure 1. Photograph of experimental set-up.

Table 1. Load location and weights.

Weight W_L (kg)	Condition	Load location (cms.)	
		X	Y
5	1	25	25
	4	25	50
	7	50	25
	10	50	50
10	2	25	25
	5	25	50
	8	50	25
	11	50	50
15	3	25	25
	6	25	50
	9	50	25
	12	50	50

Then, two subjects were selected from them with similar characteristics as shown in Table 2. The subjects were paid \$25 for participation. Definitions of the various strengths measured are given in Appendix 3.

For the computerized model, subjects were asked to go through a series of different joint strengths. These strengths and the other data as body weight, body height, load weight and load location were the input data for the computerized model, which predicted the initial posture during lifting for each condition. The values of various strengths are given in Table 2. Figure 2 shows the strength measurement procedure.

Procedure

Using a random number table, two sequences were obtained for performing the 4 (initial positions) $\times$ 3 (weights) = 12 conditions. To counter balance any serial effect, the sequence was also performed in the reverse order. Table 3 shows the random sequences for each subject. At each trial, each subject made three lifts. Thus there were data for six lifts/subject at each condition.

Before each run, the center of gravity of the subject was aligned with that of platform's (cartwheel and somersault torques registered zero). The placement of subject's feet was marked with tape so that the position did not shift appreciably throughout the experiment. To assure smooth and steady lifts throughout the experiments, the subjects were given pretest training. The subjects practiced lifting in synchronization with a videotape of the task for ten lifts.

Table 2. Individual characteristics of subjects.

<u>Characteristics</u>	<u>Subject L</u>	<u>Subject C</u>
Age (yrs)	26	22
Weight (kgs)	65.5	61.5
Height (cms)	177	172
Max. O ₂ intake (ml/kg/min)	45.5	35.5
Back flexibility (degrees)	83	95
Trunk flexibility (no dimension)	0.667	0.763
Leg strength (kg)	49.9	49.6
Back strength (kg)	85	68
Grip strength (kg)	28	25
Average arm push (kg)	22	11.5
% body fat (%)	23	22
Radius length (cm)	25.4	25.4
Tibia length (cm)	42.5	39.4
Foot length (cm)	24.1	22.9
Standing elbow height (cm)	114.3	109.9
Length of wrist to hand's center of gravity (cm)	7.0	6.35
Knee extension @ 90 deg. (kg-cm)	893.54	1427.69
Back extension @ 90 deg. (kg-cm)	1440.18	3497.59
Shoulder flexion @ 30 deg. (kg-cm)	137.16	160.07
Elbow flexion @ 90 deg. (kg-cm)	203.2	203.2
Ankle extension @ 90 deg. (kg-cm)	675.64	914.40
Knee flexion @ 90 deg. (kg-cm)	935.99	708.67
Hip extension @ 90 deg. (kg-cm)	444.50	555.57

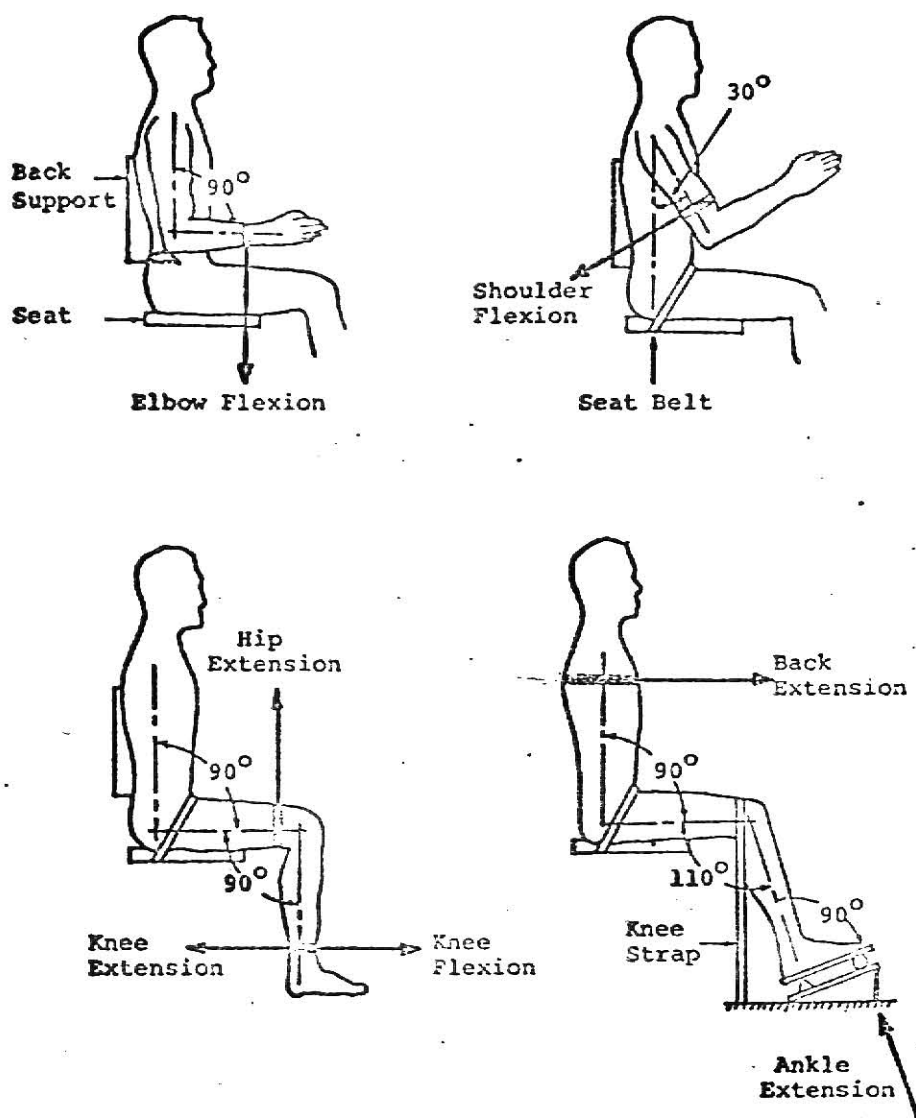


Figure 2. Strength measurement procedure.

Table 3. Random sequence of conditions for subjects.

Subject L		Subject C	
Sequence 1	Sequence 2	Sequence 1	Sequence 2
07	09	04	06
02	06	01	08
10	08	11	03
04	01	07	02
11	03	09	10
05	12	12	05
12	05	05	12
03	11	10	09
01	04	02	07
08	10	03	11
06	02	08	01
09	07	06	04

After the preparatory session, a lift occurred every 20 sec with a 60 sec interval between conditions. An assistant lowered the box to the initial position.

During the experiment, frontal, vertical and lateral forces and twist, cartwheel and somersault torques were recorded. An accelerometer measured the vertical acceleration of the totebox.

The subject's body was marked (with masking tape having a black dot on it) at eight different link joints (ear, shoulder, elbow, palm (wrist), thigh, knee, lower leg, and toe) to aid the analysis of position at different times; see Table 4. To record the various postures, a Bolex 16 mm movie camera was used to take a continuous picture of 64 frames per second, with a grid at the back of the subject to locate the position of different links with respect to time. Three lights were used to illuminate the working area for the pictures. Thus we have the position of each link at every time during lifting.

Table 4. Cinematographical record.

<u>Subject</u>	<u>Reel nos.</u>
L	1, 2, 3 and 4
C	5, 6, 7 and 8

Equipment placementCamera

distance from subject	510 cm.
lens height from floor	93 cm.
speed	64 fps

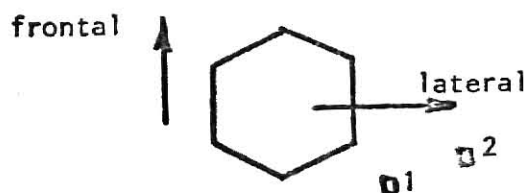
Time clock

distance from camera	585 cm.
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Lighting

distance 60, 75 and 255 cm.

□ 3

Joint markings

ear, shoulder, elbow, palm (wrist),

thigh, knee, lower leg and toe.

Anatomical measurements (cm)

	<u>Subject L</u>	<u>Subject C</u>
elbow to wrist	25	25
knee to ankle	41	39

RESULTS AND DISCUSSION

1. Analysis of Forces and Torques

Forces and torques were measured in three directions. They are vertical, frontal and lateral forces and twist, cartwheel and somersault torques as shown in Figure 3. Vertical acceleration of the box also was measured.

Peak values of each force and torque were recorded for each condition. Peak values of vertical force, lateral force and somersault torque were positive, and peak values of frontal force, cartwheel torque, twist torque and vertical acceleration were negative. The peaks occurred just after the subjects started lifting the box from the shelf. Values for vertical force are given in Table 5, for (vertical force)/(weight lifted) in Table 7, for frontal force in Table 9, for lateral force in Table 11, for cartwheel torque in Table 13, for somersault torque in Table 15, for twist torque in Table 17 and for vertical acceleration in Table 19. Since the task was mainly lifting in the symmetrical sagittal plane, the peak values of lateral force, cartwheel and twist torques were small. Even the vertical acceleration of the box was small.

A sign test was used to analyze the data because

- a) It is a distribution free (non-parametric) method,
- b) It is efficient for a paired-group method.

The results are summarized as follows. Analysis for vertical force is given in Table 6, for the (vertical force)/(weight lifted) in Table 8, for frontal force in Table 10, for lateral force in Table 12,

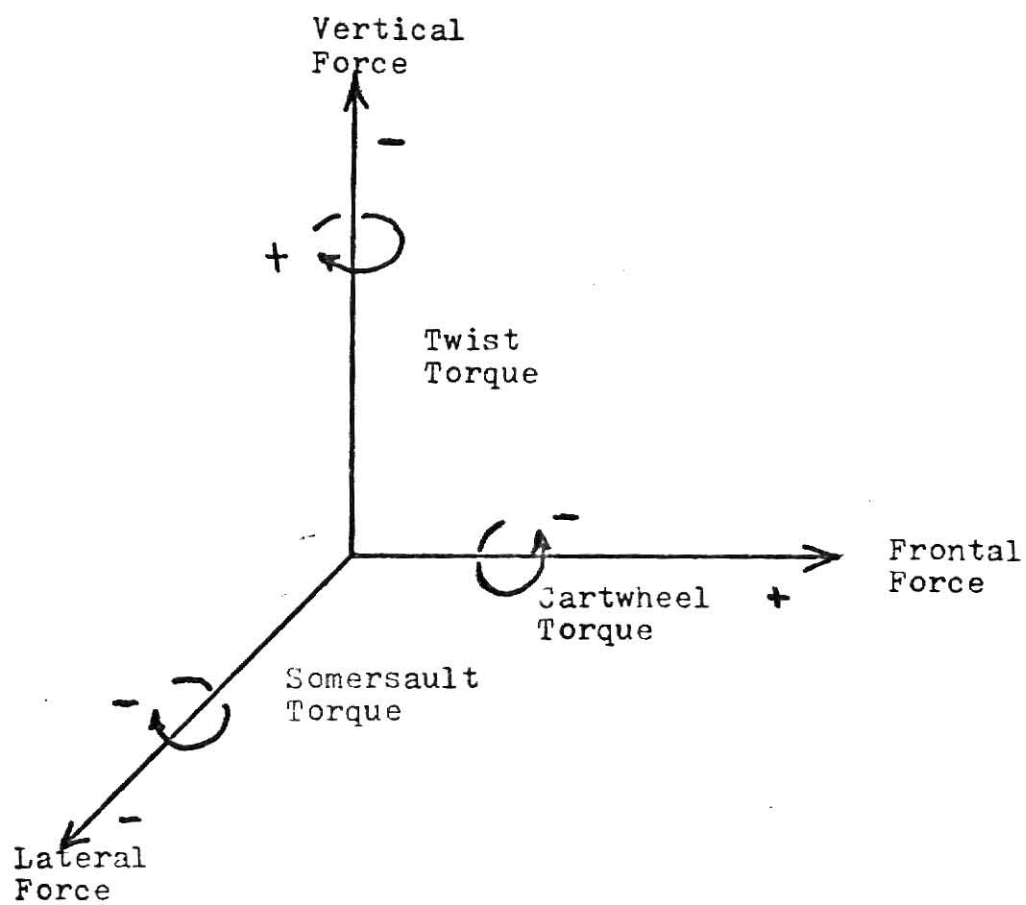


Figure 3. Forces and torques in three axes.

for cartwheel torque in Table 14, for somersault torque in Table 16, for twist torque in Table 18 and for vertical acceleration in Table 20.

The level of significance for the analysis is 0.05.

Vertical Force

Tables 5 and 6 show that the weights of 5, 10 and 15 kg are significantly different. The positions 1 vs 2, 2 vs 3, 2 vs 4 and 3 vs 4 were significantly different whereas position 1 vs 3 and 1 vs 4 were not significantly different.

(Vertical force)/(Weight lifted)

This is a transformed variable from the experimental values.

The weight lifted was calculated by

$$\text{Weight lifted} = (\text{body weight} - \text{weight of feet}) + \text{load weight}.$$

The weight of the feet = $0.02 (w) + 0.7$ where w is body weight in kg, see Damon et al. (1966). This ratio gives an interesting and informative result.

Tables 7 and 8 show that the comparisons between weights 5 vs 10, 5 vs 15 and 10 vs 15 are not significantly different. The ratio is independent of the load weights. The value of the ratio remains almost constant. The mean value is 0.60; that is, the value of the vertical force is about 60 % of the weight lifted.

Frontal Force

Tables 9 and 10 show that the weights 5 vs 10 and 5 vs 15 are significantly different, but positions 1 vs 2 and 3 vs 4 are not significantly different.

Table 6. Comparison between conditions for vertical force.

<u>Position</u>	<u>Mean value</u> (kg)
2	40.9
4	42.9 *
1	44.0 * *
3	45.2 *

<u>Weight</u>	<u>Mean value</u> (kg)
5	39.0
10	43.9
15	46.8

* non-significant groupings are connected by asterisks (significance level = 0.05).

Table 7. Ratio = Vertical force/Weight lifted = Transformed values.

WEIGHT OF LOAD (in kgs)	POSITION OF LOAD (in cms)							
	1		2		3		4	
	(x=25 y=25)		(x=25 y=50)		(x=50 y=25)		(x=50 y=50)	
	SUBJECTS							
	L	C	L	C	L	C	L	C
5	0.52	0.59	0.49	0.49	0.62	0.66	0.59	0.61
	0.52	0.52	0.51	0.52	0.64	0.62	0.57	0.54
	0.55	0.64	0.51	0.49	0.62	0.59	0.55	0.55
	0.65	0.61	0.52	0.52	0.59	0.64	0.54	0.54
	0.65	0.62	0.55	0.52	0.60	0.61	0.62	0.59
	0.62	0.68	0.54	0.52	0.59	0.64	0.54	0.59
SUM	3.51	3.66	3.12	3.06	3.66	3.76	3.41	3.42
MEAN	0.59	0.61	0.52	0.51	0.61	0.63	0.57	0.57
10	0.62	0.58	0.61	0.55	0.62	0.61	0.56	0.58
	0.62	0.58	0.62	0.54	0.61	0.61	0.56	0.58
	0.64	0.60	0.67	0.56	0.62	0.60	0.58	0.60
	0.59	0.64	0.62	0.53	0.70	0.63	0.56	0.61
	0.58	0.59	0.61	0.53	0.65	0.63	0.59	0.56
	0.59	0.64	0.64	0.58	0.70	0.61	0.58	0.60
SUM	3.64	3.63	3.77	3.29	3.90	3.69	3.43	3.53
MEAN	0.61	0.61	0.63	0.55	0.65	0.62	0.57	0.59
15	0.61	0.64	0.59	0.53	0.60	0.54	0.57	0.54
	0.64	0.54	0.60	0.57	0.61	0.57	0.61	0.56
	0.66	0.63	0.59	0.59	0.63	0.57	0.80	0.54
	0.61	0.55	0.63	0.54	0.66	0.66	0.66	0.57
	0.63	0.59	0.61	0.54	0.66	0.59	0.66	0.60
	0.60	0.55	0.61	0.54	0.60	0.62	0.63	0.63
SUM	3.75	3.50	3.63	3.31	3.76	3.55	3.93	3.44
MEAN	0.63	0.58	0.61	0.55	0.63	0.59	0.66	0.57
OVERALL MEAN	0.61	0.60	0.59	0.54	0.63	0.61	0.60	0.58
	0.605		0.565		0.62		0.59	

Table 8. Comparison between conditions for (vertical force)/
(weight lifted).

<u>Position</u>	<u>Mean value</u>
2	0.57
4	0.59
1	0.61 *
3	0.62 *

<u>Weights</u>	<u>Mean value</u>
5	0.58 *
15	0.60 *
10	0.61 *

* non-significant groupings are connected by the asterisks (significance level = 0.05).

Table 9. Frontal force (kgs) experimental values

$$1^{\text{mm}} = 2.269 \text{ kgs} \quad \text{SUB \#L}$$

SF:

$$1^{\text{mm}} = 0.818 \text{ kgs} \quad \text{SUB \#C}$$

WEIGHT OF LOAD (in kgs)	POSITION OF LOAD (in cms)								
	1		2		3		4		
	(x=25 y=25)		(x=25 y=50)		(x=50 y=25)		(x=50 y=50)		
	SUBJECTS								
	L	C	L	C	L	C	L	C	
5	9.08	5.32	10.21	4.50	11.35	9.82	7.94	16.77	
	10.21	4.50	5.67	3.44	7.94	18.81	11.35	15.13	
	10.21	9.90	11.35	7.36	12.48	13.09	6.81	9.00	
	15.88	14.72	15.88	5.73	17.02	15.54	18.15	16.36	
	13.61	18.00	15.88	10.80	9.08	16.61	13.16	13.09	
	22.69	18.81	12.48	12.27	11.35	15.71	18.15	13.09	
SUM	81.68	71.25	71.47	44.10	69.22	89.58	75.56	83.44	586.30
MEAN	13.61	11.88	11.91	7.35	11.54	14.93	12.59	13.91	12.21
10	7.94	10.63	14.75	18.41	19.29	21.68	12.48	22.09	
	9.08	12.27	14.75	16.11	19.29	26.18	14.75	17.18	
	9.08	15.54	20.42	18.00	21.56	21.68	15.88	23.48	
	19.29	13.91	9.08	13.09	15.88	26.59	17.02	15.62	
	13.61	17.18	13.61	12.68	24.96	17.18	18.15	16.52	
	15.88	20.45	18.15	7.44	24.96	16.77	22.69	15.62	
SUM	74.88	89.98	90.76	85.73	125.94	130.08	100.97	110.51	808.85
MEAN	12.48	15.00	15.13	14.29	21.00	21.68	16.83	18.42	16.85
15	14.75	18.00	10.21	9.82	18.15	22.09	20.42	24.54	
	15.88	12.43	9.08	13.50	23.83	22.25	20.42	24.05	
	15.88	24.13	17.02	10.23	27.23	21.27	24.96	26.59	
	13.61	15.62	9.08	9.82	20.42	22.09	27.23	21.27	
	19.29	17.18	7.94	9.82	30.63	20.45	20.42	20.45	
	12.48	13.91	9.53	9.41	15.88	17.18	19.29	19.63	
SUM	91.89	101.27	62.86	62.60	136.14	125.33	132.74	136.53	849.36
MEAN	15.32	16.88	10.48	10.43	22.69	20.89	22.12	22.76	17.70
SUB #1									SUB #2
1114.11	248.45	262.50	225.09	192.43	331.30	344.99	309.27	330.48	1130.40
15.47	13.80	14.58	12.51	10.69	18.41	19.17	17.18	18.36	15.70
	510.95		417.52		676.29		639.75		2244.51
	14.19		11.60		18.79		17.77		15.59

Table 10. Comparison between conditions for frontal force.

<u>Position</u>	<u>Mean value</u> (kg)
2	11.6 *
1	14.2 *
3	17.8 *
4	18.8 *

<u>Weight</u>	<u>Mean value</u> (kg)
5	12.2
10	16.9 *
15	17.7 *

* non-significant groupings are connected by asterisks (significance level = 0.05).

These comparisons show an interesting result. It indicates that frontal force is significantly different for the objects positioned at different distances from the body center line; that is, it is the 'x' distance which matters. But for a given 'x' distance the vertical height 'y' of the object does not matter for these experimental conditions. That is, for a given horizontal distance, frontal force doesn't differ significantly for vertical heights.

Lateral Force

Tables 11 and 12 show that the weights 5, 10 and 15 are not significantly different, but positions 1 vs 4 and 3 vs 4 are significantly different.

Cartwheel Torque

Tables 13 and 14 show that the weights 5, 10 and 15 are not significantly different as well as positions 1, 2, 3 and 4 are not significantly different.

Somersault Torque

Tables 15 and 16 show that the weight comparisons 5 vs 10, 5 vs 15 and 10 vs 15 are significantly different. That is, all the weights are significantly different for somersault torque values. Positions 1 vs 2 and 3 vs 4 are not significantly different.

These findings seem to confirm the results of the frontal force. The values of the somersault torque are significantly different for the objects which are at different 'x' distances. But, for a given 'x' distance, the vertical height 'y' of the box didn't matter for these experimental conditions.

Twist Torque

Tables 17 and 18 show that the weight comparison 10 vs 15 is significantly different as well as the position comparison 2 vs 3 is significantly different.

Vertical Acceleration

Tables 19 and 20 show that the weight comparisons 5 vs 10 and 5 vs 15 are significantly different. None of the position comparisons are significantly different.

Thus, most of the comparisons between weights and between positions (29 out of 36 comparisons) for lateral force, cartwheel torque, twist torque and vertical acceleration of the box are not significantly different. This was as expected because of symmetrical sagittal plane lifting.

Table 11. Lateral force (kgs) experimental values.

SF: 1^{mm} = 2.215 kg SUB #L
SUB #C

WEIGHT OF LOAD (In kgs)	POSITION OF LOAD (in cms)								
	1		2		3		4		
	(x=25 y=25)		(x=25 y=50)		(x=50 y=25)		(x=50 y=50)		
	SUBJECTS								
	L	C	L	C	L	C	L	C	
5	9.97	6.65	2.22	3.32	6.65	8.86	4.43	5.54	
	4.43	4.43	6.65	2.24	4.43	7.75	6.65	5.54	
	6.65	8.86	5.54	6.65	4.43	6.65	5.54	8.86	
	11.08	8.86	11.08	6.65	11.08	9.97	6.65	4.43	
	11.08	8.86	9.97	7.75	11.08	9.97	7.75	4.43	
	11.08	6.65	7.75	8.86	9.97	11.08	9.97	5.54	
SUM	54.29	44.31	43.21	35.45	47.64	54.28	40.99	34.34	354.51
MEAN	9.05	7.39	7.20	5.91	7.94	9.05	6.83	5.72	7.39
10	6.65	5.54	8.86	4.43	4.43	6.65	5.54	5.54	
	4.43	8.86	7.75	7.75	6.65	4.43	6.65	5.54	
	3.32	6.65	6.65	8.42	7.75	8.86	6.65	4.43	
	9.97	6.65	11.08	6.65	8.86	7.53	8.86	6.65	
	9.97	8.86	9.97	7.75	8.86	3.99	8.86	6.65	
	9.97	7.97	9.97	6.65	11.08	6.42	8.86	5.54	
SUM	44.31	44.53	54.28	41.65	47.63	37.88	45.42	34.35	350.05
MEAN	7.39	7.42	9.05	6.94	7.94	6.31	7.57	5.73	7.29
15	9.97	5.76	6.65	5.98	7.75	11.08	7.75	9.97	
	9.97	6.65	6.65	6.42	8.86	8.86	6.20	6.65	
	13.29	7.53	8.86	5.54	7.75	8.86	6.65	4.43	
	7.75	8.86	8.86	7.31	6.65	13.29	12.18	5.54	
	9.97	6.65	11.08	5.54	7.75	9.97	11.08	6.65	
	8.86	8.86	11.08	6.42	9.97	7.75	9.97	6.65	
SUM	49.81	44.31	53.18	37.21	48.73	59.81	53.83	39.89	386.77
MEAN	8.30	7.39	8.86	6.20	8.12	9.97	8.97	6.65	8.06
SUB #1									
583.32	148.41	133.15	150.67	114.31	144.00	151.97	140.24	108.58	SUB #2 508.01
8.10	8.25	7.40	8.37	6.35	8.00	8.44	7.79	6.03	7.06
	281.56		264.98		295.97		248.82		1091.33
	7.82		7.36		8.22		6.91		7.58

Table 12. Comparison between conditions for lateral force.

<u>Position</u>	<u>Mean value</u> (kg)
4	6.9 *
2	7.4 * *
1	7.8 *
3	8.2 *

<u>Weight</u>	<u>Mean value</u> (kg)
10	7.3 *
5	7.4 *
15	8.1 *

* non-significant groupings are connected by asterisks (significance level = 0.05).

Table 14. Comparison between conditions for cartwheel torque.

<u>Position</u>	<u>Mean value</u> (kg-m)
2	0.86 *
3	0.97 *
1	1.01 *
4	1.03 *

<u>Weight</u>	<u>Mean value</u> (kg-m)
5	0.92 *
10	0.95 *
15	1.03 *

* non-significant groupings are connected by asterisks (significance level = 0.05).

Table 15. Somersault torque (kg-m) experimental values.

SF: $1^{\text{mm}} = 0.976 \text{ kg-m}$

WEIGHT OF LOAD (in kgs)	POSITION OF LOAD (in cms)								
	1		2		3		4		
	(x=25 y=25)		(x=25 y=50)		(x=50 y=25)		(x=50 y=50)		
	SUBJECTS								
	L	C	L	C	L	C	L	C	
5	3.42	3.90	1.95	1.95	4.39	0.98	4.88	7.03	
	0.98	2.93	2.44	2.73	5.86	5.17	5.86	5.95	
	1.95	3.03	3.42	2.93	5.37	5.86	4.88	5.86	
	3.90	2.93	2.93	3.90	6.83	7.81	6.34	6.83	
	4.39	2.73	2.44	2.54	5.86	6.64	5.86	8.10	
	1.95	5.08	1.46	3.71	6.83	7.22	5.86	7.03	
SUM	16.59	20.60	14.64	17.76	35.14	33.68	33.68	40.80	212.89
MEAN	2.77	3.43	2.44	2.96	5.86	5.61	5.61	6.80	4.44
10	4.39	1.46	6.34	1.95	6.34	7.42	6.34	6.34	
	5.37	3.42	6.83	2.93	5.86	6.93	5.86	7.03	
	5.86	1.76	6.83	2.15	6.34	7.22	6.83	7.22	
	3.63	4.88	0.0	4.98	7.81	7.81	7.37	7.81	
	4.88	5.95	3.90	4.20	7.81	6.83	6.83	6.64	
	4.39	5.76	6.34	2.44	6.83	7.81	6.83	7.22	
SUM	27.92	23.23	30.24	18.65	40.99	44.02	40.06	42.26	267.37
MEAN	4.65	3.87	5.04	3.11	6.83	7.34	6.68	7.04	5.57
15	1.95	2.73	1.95	6.83	7.81	7.32	7.81	7.81	
	4.88	3.90	3.90	5.86	5.37	7.81	7.81	8.78	
	3.90	6.73	4.39	6.83	7.81	7.81	7.37	7.91	
	2.93	5.86	3.42	6.34	7.37	7.22	6.83	8.00	
	4.88	7.22	4.39	6.25	8.30	8.00	7.81	7.81	
	4.39	7.02	3.90	5.95	7.37	7.03	5.86	8.78	
SUM	22.93	33.46	21.95	38.06	44.03	45.19	43.49	49.09	298.20
MEAN	3.82	5.58	3.66	6.34	7.34	7.53	7.24	8.18	6.21
SUB #1									SUB #2
371.66	67.44	77.29	66.83	74.47	120.16	122.89	117.23	132.15	406.80
5.16	3.75	4.29	3.71	4.14	6.63	6.83	6.51	7.34	5.65
	144.73		141.30		243.05		249.38		778.46
	4.02		3.93		6.75		6.93		5.41

Table 16. Comparison between conditions for somersault torque.

<u>Position</u>	<u>Mean value</u> (kg-m)
2	3.9 *
1	4.0 *
3	6.8 *
4	7.0 *

<u>Weight</u>	<u>Mean value</u> (kg-m)
5	4.4
10	5.6
15	6.2

* non-significant groupings are connected by asterisks (significance level = 0.05).

Table 18. Comparison between conditions for twist torque.

<u>Position</u>	<u>Mean value</u> (kg-m)
2	0.21 *
1	0.23 * *
4	0.26 * *
3	0.27 *

<u>Weight</u>	<u>Mean value</u> (kg-m)
5	0.20
10	0.26 *
15	0.28 *

* non-significant groupings are connected by asterisks (significance level = 0.05).

Table 20. Comparison between conditions for vertical acceleration of box.

<u>Position</u>	<u>Mean value</u> (m/sec ²)
2	4.4 *
4	4.6 *
3	5.1 *
1	5.2 *

<u>Weight</u>	<u>Mean value</u> (m/sec ²)
15	4.1 *
10	4.4 *
5	5.9

* non-significant groupings are connected by asterisks (significance level = 0.05).

2. Analysis of Initial Posture and Predicted Posture.

In this study, the human body was divided into seven links as shown in Figure 4. The pictures give the initial posture taken by the subjects during lifting. The initial posture was defined as the posture taken by the subjects just before lifting the totebox from shelf. The film was analyzed on an analyzer. As shown in Table 4, different joints of the body were marked with masking tape. These markings were used to determine the actual angles of the different links. As shown in Figure 4, five angles were measured to describe the initial posture. The values for angle a_1 (ankle) are given in Table 21, for angle a_2 (knee) in Table 23, for angle a_3 (hip) in Table 25, for angle a_4 (shoulder) in Table 27 and for angle a_5 (elbow) in Table 29. Figures 5 through 12 show the actual initial posture for different positions. Since the subjects were asked to do a squat lift, their initial posture showed that the back was at an angle of 45-50 degrees to the horizontal.

To predict the initial posture, the computerized mathematical model developed at the University of Michigan (Park, 1973) was used with slight modifications at KSU. It gives initial posture angles for a given data of various strengths of subjects, weight of the load, and the location of the load.

This program, for the conditions of the experiment, tends to give a bend lift with the ankle angle (angle a_1) of 85-90 degrees. In the experiment, subjects were asked to do a squat lift so the ankle angle had a range of 50 to 80 degrees. This condition was modified in the computer program. The data input was the actual value of ankle

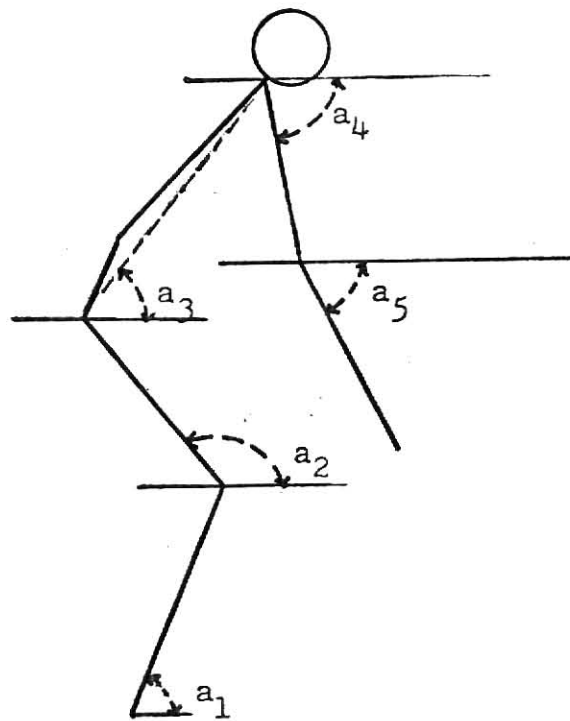


Figure 4. Human body divided into seven links. a_1 , a_2 , a_3 , a_4 and a_5 are the angles measured and predicted.

angle for each condition as an "optimum angle". Based on that angle, the other angles were calculated by minimizing a constraint--in this case, minimizing the low back compression. The predicted values of different angles are given in Table 31. These angles are also plotted for each condition as shown in Figures 5 through 12.

A sign test was used to analyze the conditions for the actual values of angles. See Table 22, Table 24, Table 26, Table 28 and Table 30. None of the comparison for the weights 5, 10 and 15 are significantly different. For ankle, knee and hip angles all comparisons for positions are significantly different. But for shoulder and elbow angles the positions 1 and 2 were not significantly different. This indicates that when the object was closer to the subjects, the shoulder and elbow angles didn't change significantly.

Comparing the actual angles and the angles predicted from the model, there is a large difference in the hip angle. This is mainly because the model predicts a bend lift by minimizing the back compression. Again, due to bent back, the shoulder and elbow angles differ from the actual angles. The model seems to give a good prediction of angles for position 2 ($x=25$, $y=25$ cm).

Due to unidentified reasons, the model does not give any output for subject L for 5 out of the 12 conditions. The program worked very well for all the conditions for subject C.

One of the main factors involved in calculating the low back compression is the distance of the weight from the body center of gravity. This distance has a smaller value for a bend lift compared

Table 21. Values of actual angle a_1 (ankle) (degrees).

Weights (kg)		5		10		15		Mean
Subjects		L	C	L	C	L	C	
Position (cms)								
1.	(25, 25)	69.1	71.1	67.6	69.6	66.9	69.4	69.0
2.	(25, 50)	79.8	80.5	64.5	79.8	80.5	78.0	78.5
3.	(50, 25)	53.7	52.9	54.8	55.8	51.8	59.6	54.8
4.	(50, 50)	57.9	56.8	58.7	58.4	59.8	58.5	58.4
Mean		65.1	65.3	61.4	65.9	64.8	66.4	
		65.2		63.7		65.6		

Table 22. Comparison between conditions for angle a_1 (ankle).

<u>Position</u>	<u>Mean value (degrees)</u>
3	54.8
4	58.3
1	69.0
2	77.2

<u>Weight</u>	<u>Mean value (degrees)</u>
10	63.7 *
5	65.2 *
15	65.6 *

* non-significant groupings are connected by asterisks
(significance level = 0.05)

Table 23. Values of actual angle a_2 (knee) (degrees).

Weights (kg)		5		10		15		Mean
Subjects		L	C	L	C	L	C	
Position (cms)								
1.	(25, 25)	139.4	147.3	139.5	146.3	143.3	147.5	143.9
2.	(25, 50)	121.1	124.9	135.9	127.4	121.6	124.0	125.8
3.	(50, 25)	148.1	159.3	150.2	153.7	149.7	155.3	152.7
4.	(50, 50)	131.9	141.3	133.8	139.6	139.0	142.3	138.0
		135.12	143.20	139.9	141.8	138.4	142.3	
Mean		139.2		140.8		140.4		

Table 24. Comparison between conditions for angle a_2 (knee).

<u>Position</u>	<u>Mean value (degrees)</u>
2	125.8
4	138.0
1	143.9
3	152.7

<u>Weight</u>	<u>Mean value (degrees)</u>
5	139.2 *
15	140.4 *
10	140.8 *

* non-significant groupings are connected by asterisks
(significance level = 0.05)

Table 25. Values of actual angle a_3 (hip) (degrees).

Position (cms)	Weights (kg)		5		10		15		Mean
	Subjects		L	C	L	C	L	C	
1. (25, 25)			28.9	39.3	30.1	36.9	32.4	36.9	34.1
2. (25, 50)			44.3	48.4	39.4	48.3	46.7	50.8	46.4
3. (50, 25)			38.7	50.3	36.0	45.5	40.1	40.6	41.9
4. (50, 50)			55.3	56.0	51.2	58.0	46.8	57.2	54.1
			41.8	48.5	39.2	47.2	41.5	46.4	
	Mean		45.2		43.2		44.0		

Table 26. Comparison between conditions for angle a_3 (hip).

<u>Position</u>	<u>Mean value (degrees)</u>
1	34.1
3	41.9
2	46.4
4	54.1

<u>Weight</u>	<u>Mean value (degrees)</u>
10	43.2 *
15	44.0 *
5	45.2 *

* non-significant groupings are connected by asterisks
(significance level = 0.05)

Table 27. Values of actual angle a_4 (shoulder) (degrees).

Weights (kg)		5		10		15		Mean
Subjects		L	C	L	C	L	C	
Position (cms)								
1.	(25, 25)	-84.8	-68.5	-85.0	-71.7	-81.6	-69.3	-76.8
2.	(25, 50)	-82.8	-70.7	-77.8	-66.1	-80.3	-65.3	-73.8
3.	(50, 25)	-77.6	-49.2	-71.8	-57.0	-71.1	-53.2	-63.3
4.	(50, 50)	-64.4	-45.5	-63.7	-46.3	-68.0	-44.0	-55.3
		-77.4	-58.5	-74.6	-60.3	-75.3	-58.0	
	Mean	-68.0		-67.4		-66.6		

Table 28. Comparison between conditions for angle a_4 (shoulder).

<u>Position</u>	<u>Mean value (degrees)</u>
4	-55.3
3	-63.3
2	-73.8 *
1	-76.8 *

<u>Weight</u>	<u>Mean value (degrees)</u>
15	-66.6 *
10	-67.4 *
5	-68.0 *

*non-significant groupings are connected by asterisks
(significance level = 0.05)

Table 29. Values of actual angle a_5 (elbow) (degrees).

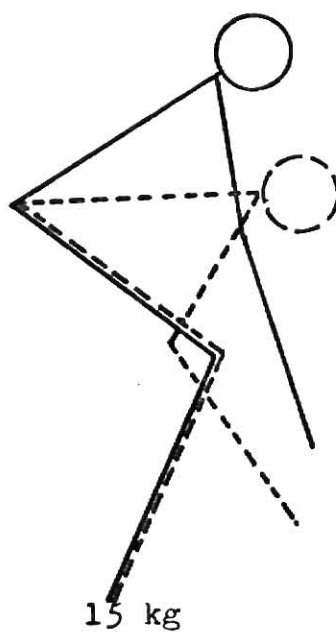
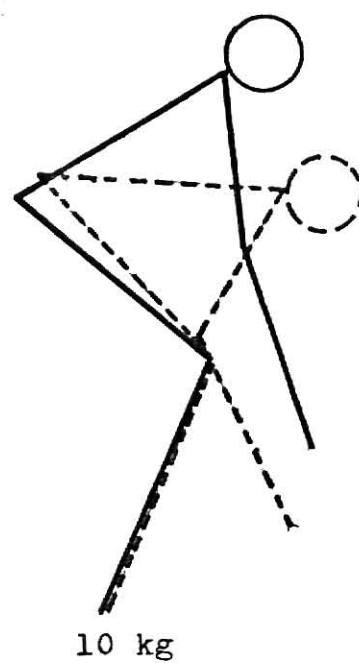
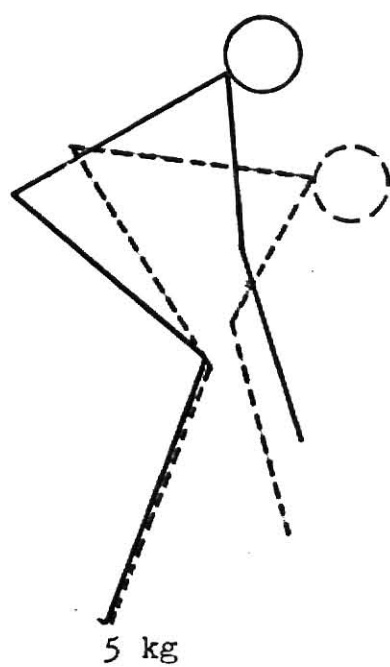
Weights (kg)		5		10		15		Mean
Subjects		L	C	L	C	L	C	
Position (cms)								
1.	(25, 25)	-72.3	-69.8	-71.6	-71.3	-70.3	-70.9	-71.1
2.	(25, 50)	-70.4	-72.4	-59.6	-71.1	-69.6	-70.2	-69.2
3.	(50, 25)	-56.6	-56.6	-56.6	-58.4	-59.0	-55.6	-57.1
4.	(50, 50)	-53.2	-49.2	-52.2	-52.8	-43.3	-48.2	-49.8
		-63.1	-62.0	-60.0	-63.4	-60.6	-61.2	
Mean		-62.6		-61.7		-60.9		

Table 30. Comparison between conditions for angle a_5 (elbow).

<u>Position</u>	<u>Mean value (degrees)</u>
4	-49.8
3	-57.1
2	-69.2 *
1	-71.1 *

<u>Weight</u>	<u>Mean value (degrees)</u>
15	-60.9 *
10	-61.7 *
5	-62.6 *

* non-significant groupings are connected by asterisks
(significance level = 0.05)



— Actual posture
- - - Predicted posture

Figure 5. Initial postures of subject L for position 1:(25,25) cm.

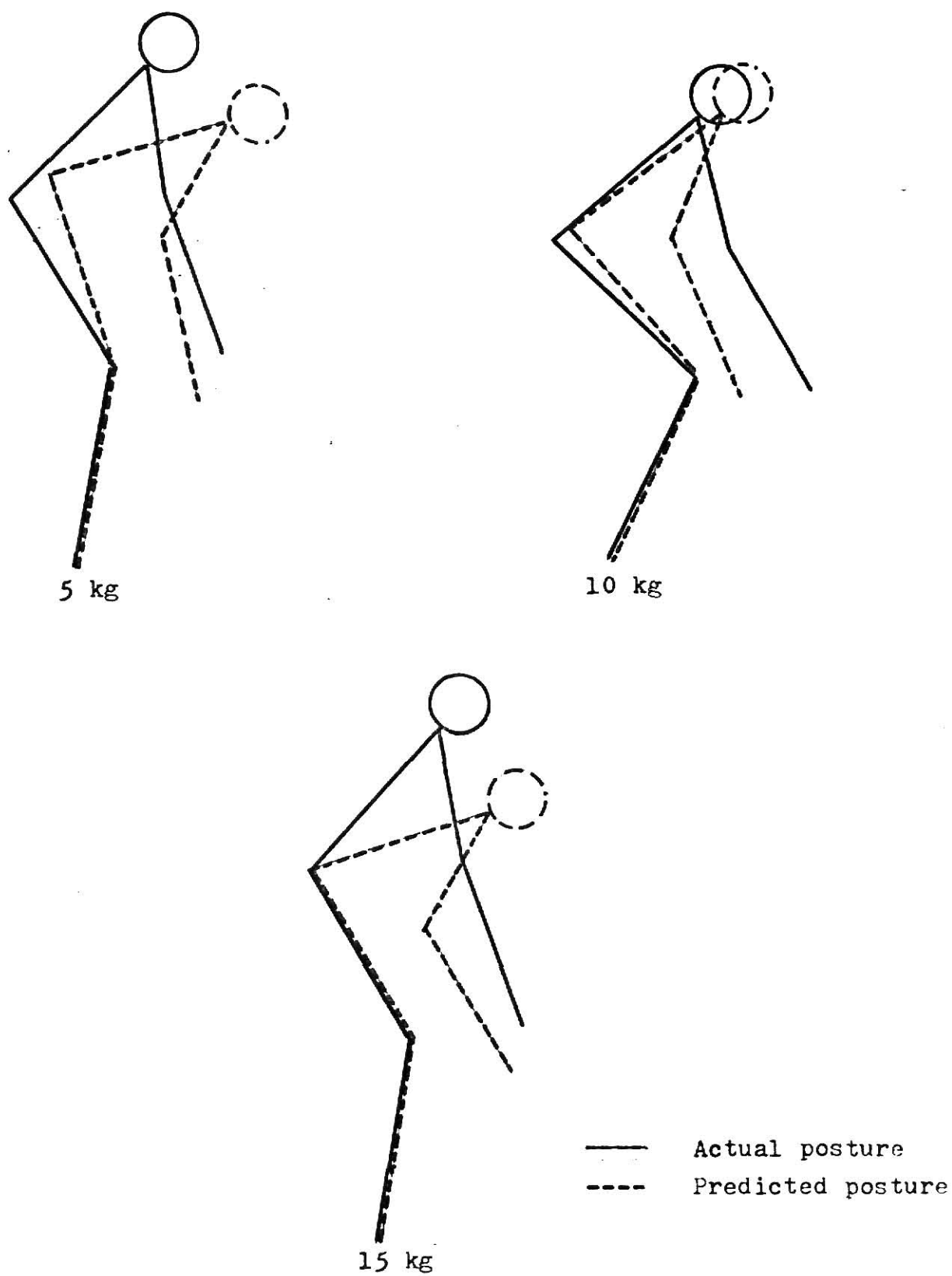


Figure 6. Initial postures of subject L for position 2:(25,50) cm.

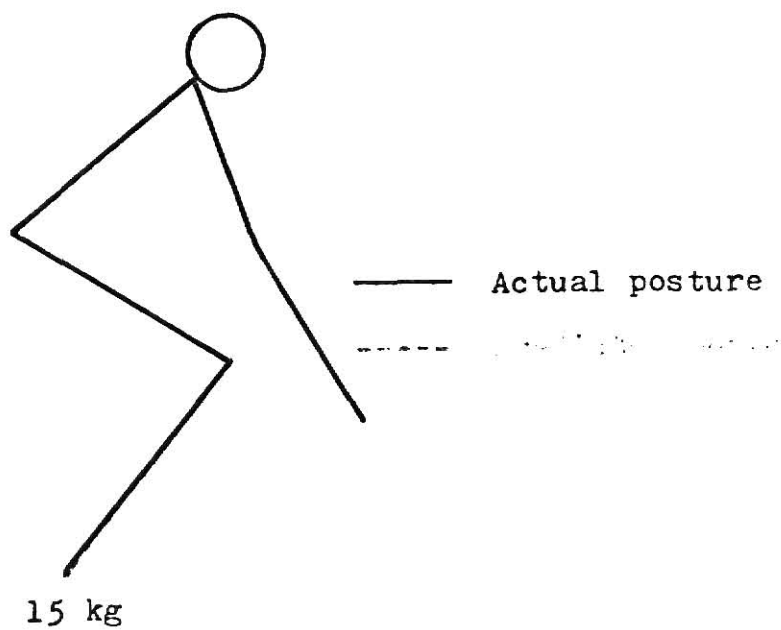
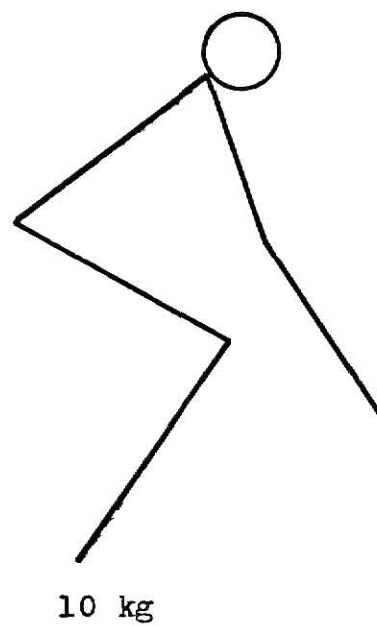
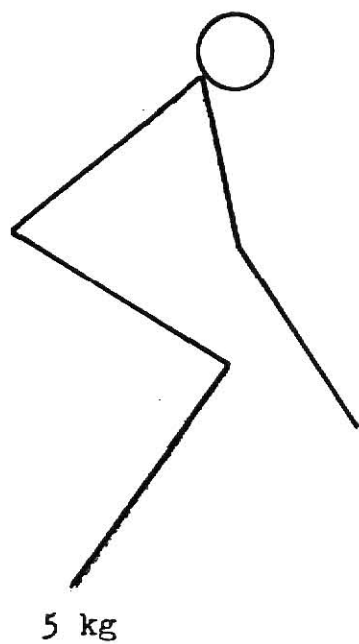


Figure 7. Initial posture of subject L for position 3:(50,25) cm.

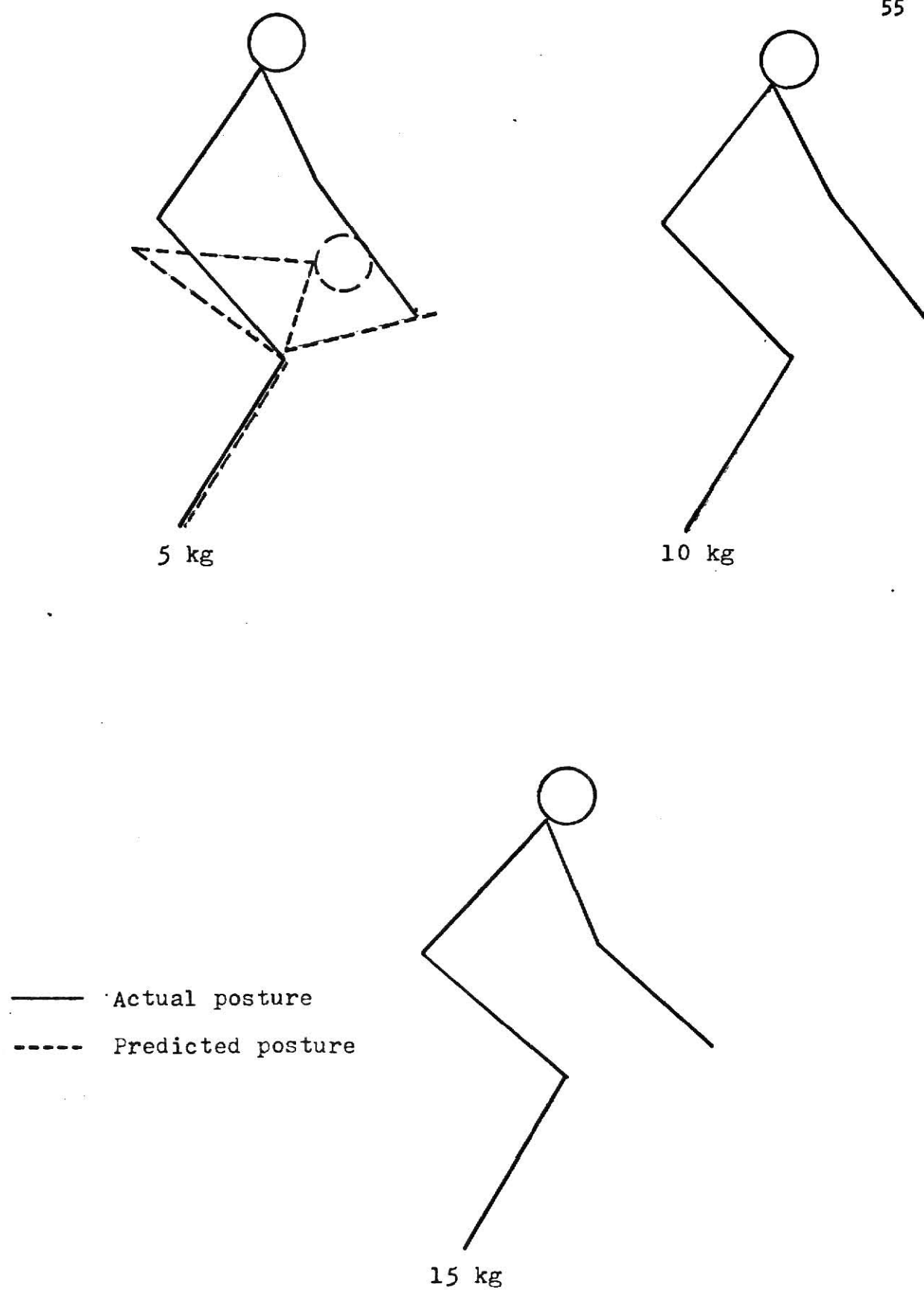


Figure 8. Initial posture of subject L for position 4: (50,50) cm.

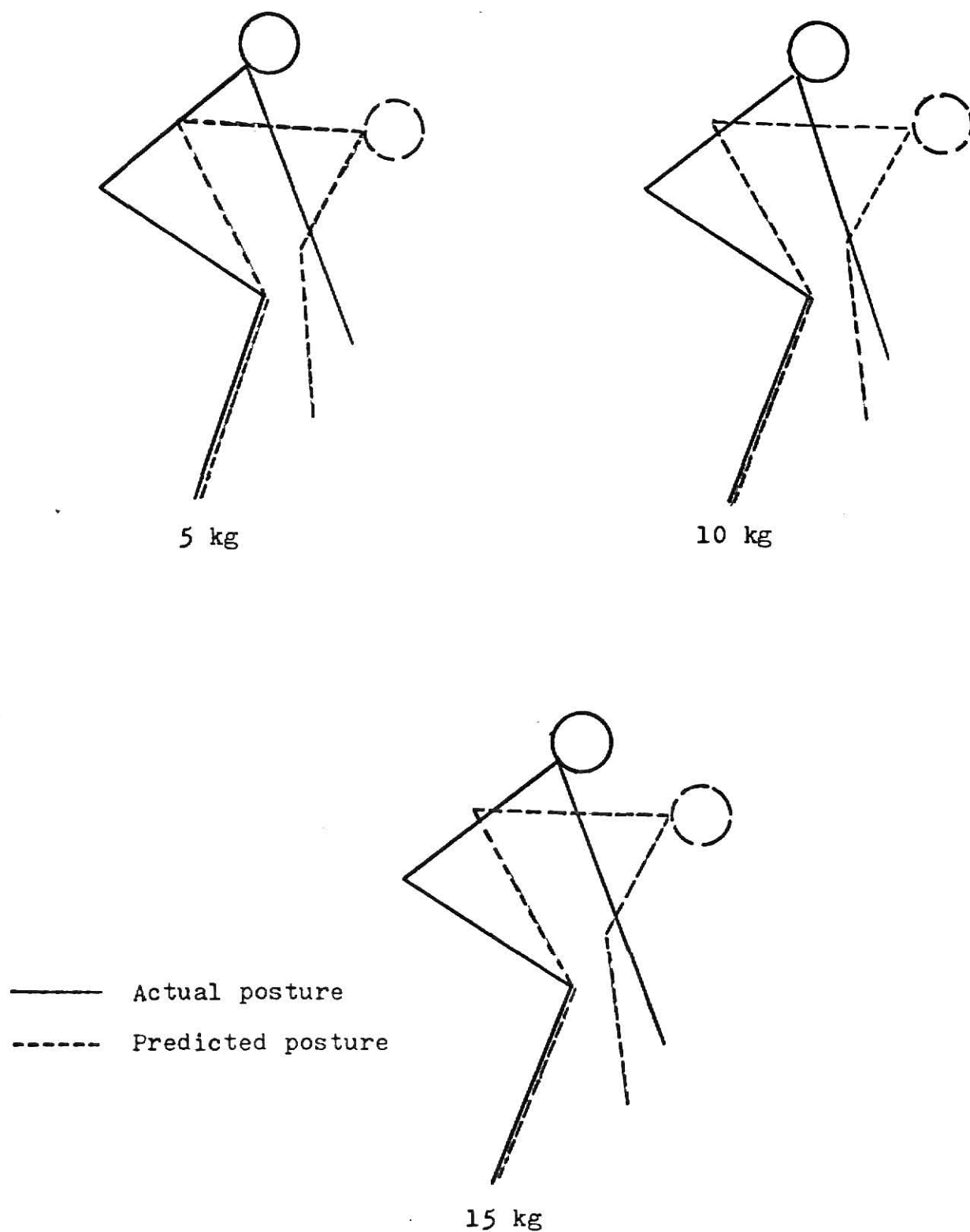


Figure 9. Initial postures of subject C for position 1:(25,25) cm.

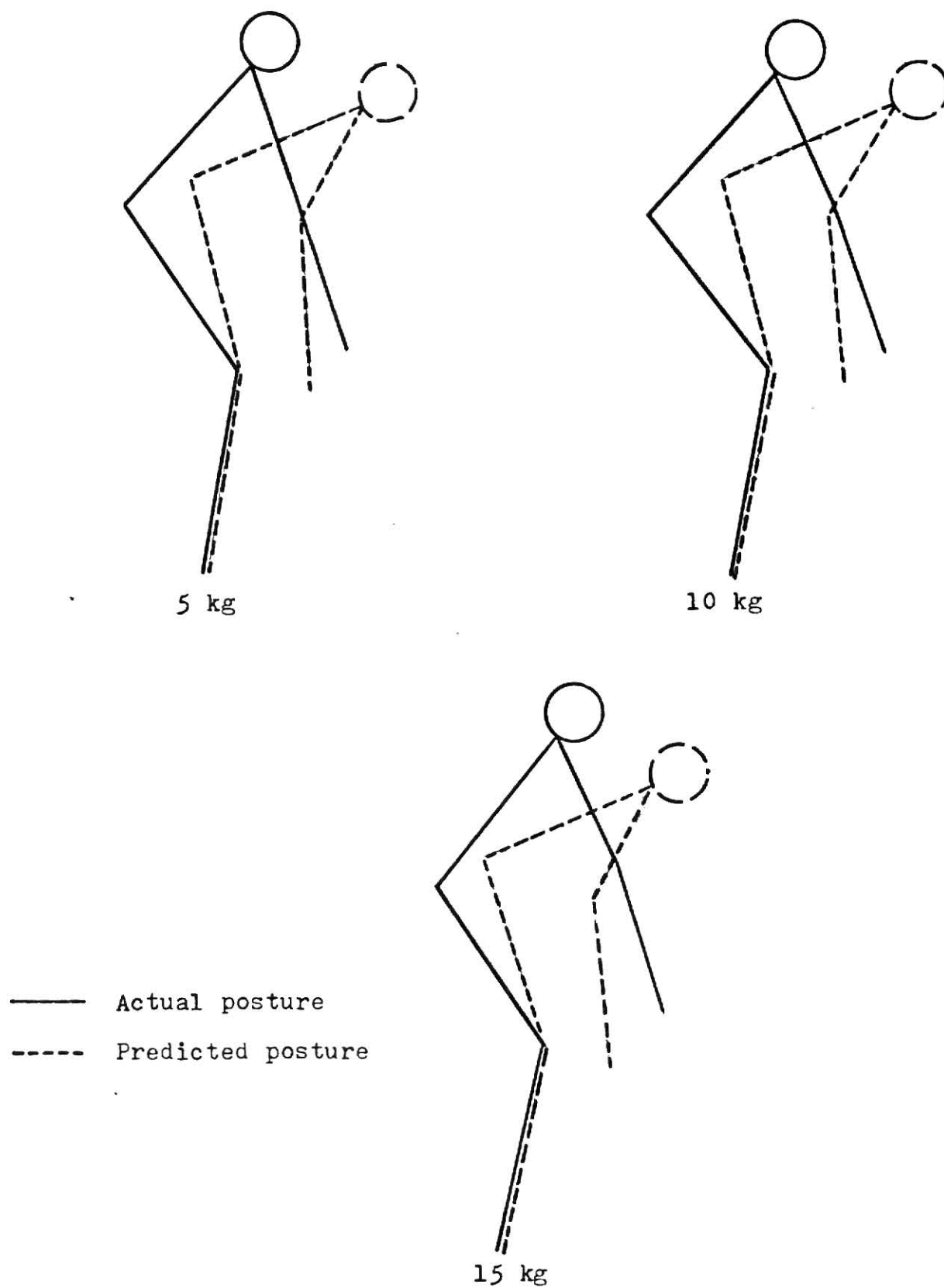


Figure 10. Initial postures of subject C for position 2:(25,50) cm.

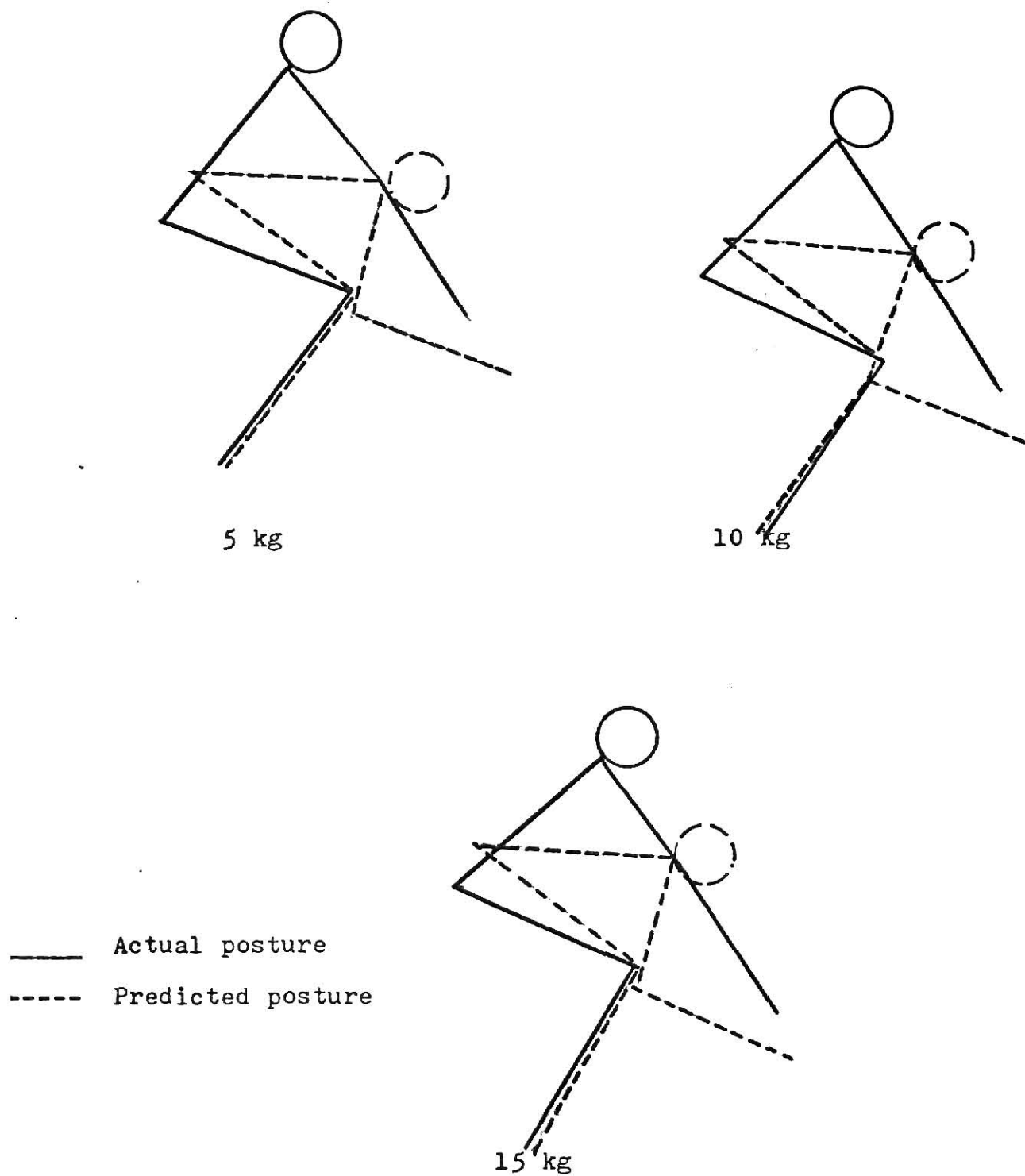


Figure 11. Initial postures of subject C for position 3:(50,25) cm.

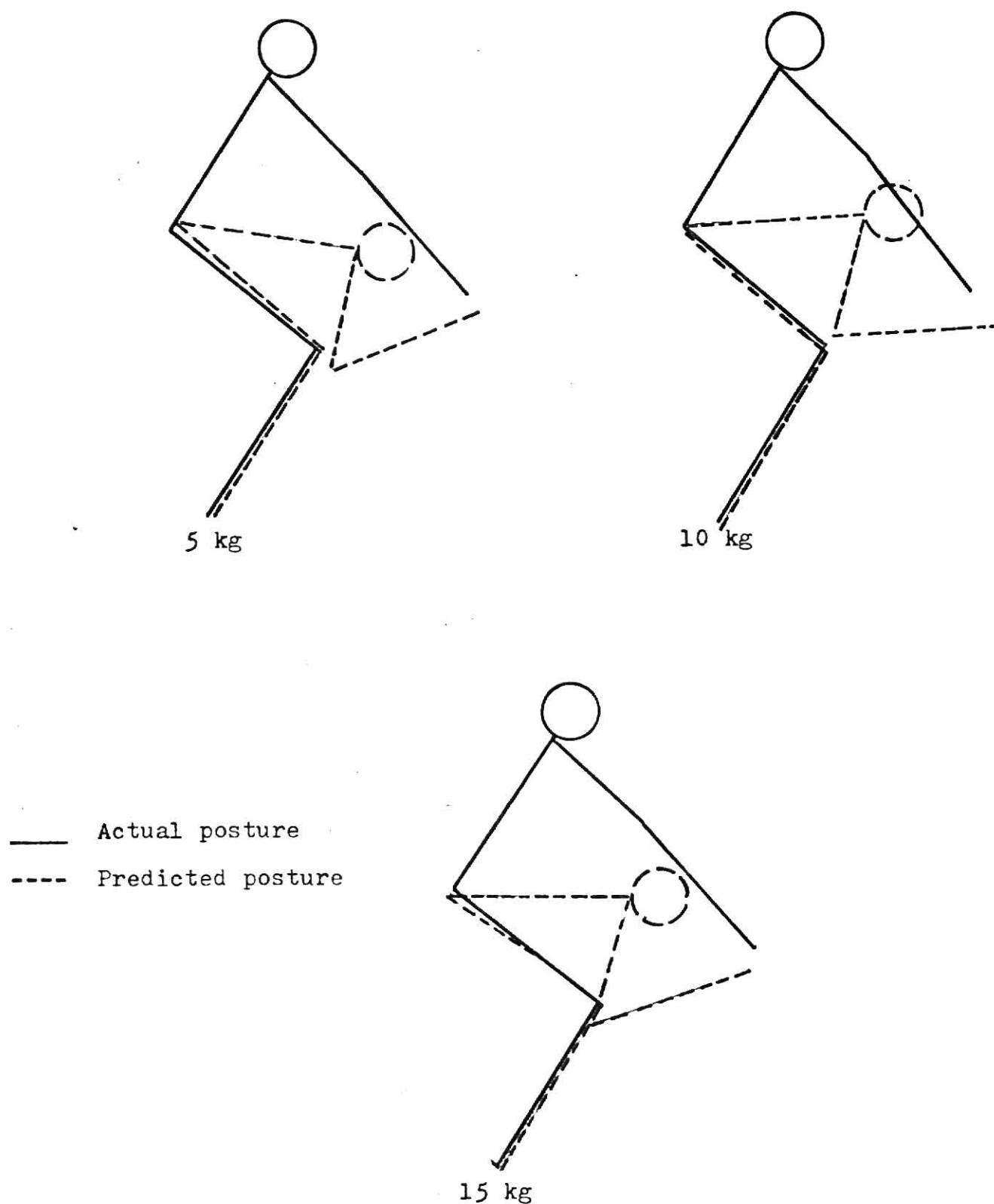


Figure 12. Initial postures of Subject C for position 4:(50,50) cm.

Table 31. "Optimum" value of angles given by model for all conditions.

Condition	a_1		a_2		a_3		a_4		a_5	
	L	C	L	C	L	C	L	C	L	C
1	69.1	71.1	122.5	116.3	-8.8	-3.8	-119.8	-119.3	-74.6	-84.7
2	67.7	69.6	132.5	118.8	-3.8	-1.9	-119.7	-118.6	-65.1	-84.1
3	66.9	69.4	143.1	119.4	+1.9	-1.9	-119.0	-119.5	-55.1	-82.9
4	79.8	80.5	108.8	103.1	16.9	23.1	-119.8	-118.9	-77.8	-86.0
5	64.5	79.8	130.0	104.6	35.6	23.5	-111.7	-120.3	-67.1	-84.3
6	80.5	78.0	121.3	106.9	17.5	24.4	-119.5	-119.2	-59.2	-83.2
7		52.9		143.1		-4.4		-113.9		-20.9
8		55.8		143.1		-4.4		-110.0		-21.7
9		59.6		141.3		-4.4		-105.5		-25.4
10	57.9	56.8	143.8	138.1	-4.4	-9.4	-106.6	-112.7	13.7	22.2
11		58.4		140.0		4.4		-115.5		4.0
12		58.5		145.0		0.0		-106.8		18.0

to a squat lift. Thus, for a low back compression, the distance between the load and the body center of gravity should be reduced.

Table 32 shows the comparison of different angles between Park (1973) and the present study. Park (1973) had similar initial position of loads. The values of angles a_1 (ankle), a_2 (knee) and a_5 (elbow) changed 10, -8 and -5 degrees, while angles a_3 (hip) and a_4 (shoulder) changed about -25 degrees. One of the main reasons is due to the difference in instructions. In this study, subjects were asked to do a squat lift, whereas Park did not specify the method of lifting; his subjects then lifted with a bend posture.

There are two fixed points in all conditions. They are the position of the load and the feet. As the angles a_1 , a_2 and a_5 do not differ much from Park's, the position of hip as well as elbow is the same for both cases. It is only the other angles a_3 and a_4 that adjust themselves so that the position of hip and elbow remains almost the same in both a bend and a squat lift.

Table 32. Comparison of initial posture angles between Park (1973) and present study.

Positions (cms)	a_1 (degrees)			a_2 (degrees)			a_3 (degrees)			a_4 (degrees)			a_5 (degrees)		
	P	D	d	P	D	d	P	D	d	P	D	d	P	D	d
¹ (25, 25)	75	69	6	124	111	13	4	34	-30	-106	-77	-29	-80	-71	-9
² (25, 50)	78	77	1	116	126	-10	38	46	-8	-102	-74	-28	-74	-69	-5
³ (50, 25)	69	55	14	132	153	-21	6	42	-36	-82	-63	-19	-61	-57	-4
⁴ (50, 50)	77	58	19	122	138	-16	23	54	-31	-79	-55	-24	-50	-50	0
Mean		10			-8			-26			-25			-5	

CONCLUSIONS

The study measured different forces, torques, angles and accelerations involved in lifting. It also includes some facts about the initial posture taken during lifting.

For the vertical forces, the weights are significantly different and the vertical force remains constant with respect to the weight lifted. The value of this ratio was 0.60 i.e. 60 % of the weight lifted contributes to the vertical force.

For the frontal force and the somersault torque, only the 'x' distance of the load affects the force or torque. For a given 'x' distance, the vertical height 'y' does not affect force or torque.

As the lifting was in the symmetrical sagittal plane the values of lateral force, cartwheel, and twist torques were small. The vertical accelerations of the box also were small.

Regarding the initial posture prediction, the simulation model predicts a bend lift instead of a squat lift. One of the main factors which play the important role is the distance between center of gravity of the box and the center of gravity of the body. In predicting the posture, this distance plays a major role. For a low back compression, this distance should be minimized.

The initial posture angles did not differ significantly for all weights of 5, 10 and 15 kg. For shoulder and elbow angles positions 1 and 2 were not significantly different. For ankle, knee and hip angles, all comparisons were significantly different. The above results show

that when the object was closer to the subjects, the shoulder and elbow angles did not change significantly.

Another interesting result was also found. It is only the hip and shoulder angles that adjust themselves so that the position of hip and elbow remains almost the same in both a bend and a squat lift.

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APPENDIX 1

Application for approval submitted to the committee on research
involving human subjects.

Objective: The main objective of this study is to find the posture of a person as well as forces and torques on the body while lifting a weight in a symmetrical sagittal plane. In addition to this experiment, a simulation with computerized model will also be tried for posture prediction.

Task: The subjects will be standing on a six-axis force platform (Hearn & Konz, 1968) and they will be asked to lift loads of 5, 10 and 15 kgs., without jerking and standing upright in the symmetrical sagittal plane. The loads will be placed at four different initial positions of $(x=25, y=25)$, $(x=25, y=50)$, $(x=50, y=25)$ and $(x=50, y=50)$ from the subject. The final phase of lifting will be the hands holding the load in front of the body and arms "straight" down.

Subjects: For this experiment, two subjects will be used. Subjects will be selected so that their individual characteristics comply with the following selection criterion, and also the subjects have quite similar characteristics.

- (a) Subjects will be females
- (b) The body weight should be between 50-75 kgs
- (c) The body height should be between 160-180 cms
- (d) The age range should be 18 to 26 years
- (e) They will have to go through a screening procedure as shown in the Appendix.

The subjects will be paid (\$25) for their participation. However, to assure smooth and steady lifts throughout the experiments, the subjects will be given a pretest training.

Procedure: Using a random number table, two sequences will be obtained for performing 4 (initial positions) $\times 3$ (weights) = 12 conditions. To counter balance any serial effects, the sequence will also be performed in reverse order. At each condition, each subject will make three lifts. Thus there will be data for six lifts/subject at each condition.

Before each run, the center of gravity of the subject will be aligned with the platform's. (Cartwheel and somersault torques registered zero). The placement of subject's feet will be marked with tape so the position will not shift appreciably throughout the experiment. The subjects will be asked to practice lifting in synchronization with a videotape of the task for 10 minutes. After the preparatory session, three lifts will be made for each condition, one every 20 seconds with a one-minute interval between conditions. An assistant will lower the box to the initial positions.

During the experiment, with the help of the force-platform, frontal, vertical and lateral forces as well as twist, cartwheel and somersault torques will be recorded.

For the posture of the subjects, a Bolex 16 mm movie camera will take continuous pictures at 64 frames per second (fps), with a grid at the back of the subject. Four lights will be used to brighten the working area for the pictures. The subject's body will be marked at 8 different link joints to aid the analysis of position at different times. Thus we will have the position of each link at every time during lifting.

For the computerized model, subjects will be asked to go through a series of different joint strengths. These strengths and other data as body weight, body height, load weight, load location will be the input data for the computerized model, which will predict the postures during lifting.

APPLICATION FOR APPROVAL TO USE HUMAN SUBJECTS

1. PROJECT TITLE: - Forces and torques on different parts of body as well as posture prediction while lifting ... simulation and experimental values.
2. PROPOSED SPONSOR: - Dept. of Industrial Engineering
3. PERSONNEL INVOLVED: -

<u>Name</u>	<u>Dept.</u>	<u>Phone</u>
Dr. Stephan A. Konz	Industrial Engineering	532-5606
Girish D. Desai	Industrial Engineering	532-5606

4. ATTACHED IS A COPY OF THE PROJECT PROPOSAL

A. RISK:

The subject participating in the experiment are exposed to the possibility of physical risk. This includes the possibility of strain to both the cardio-vascular and skeleto-muscular system. To minimize the risk associated in participating in the experiment a four stage subject screening procedure has been introduced. (As I am going to use the same subjects as Mr. Coetzee, I will have same screening procedure, which is as follows). Each stage will consist of the following:

Stage 1. Subject will be given a questionnaire (see attachment 1) to be completed by themselves in which background information is sought regarding ailments that could be aggravated by their participation in the lifting experiment. Any subject answering in the affirmative to any of the questions will be automatically rejected from further consideration.

Stage 2. Subjects will be given a physical fitness test in which emphasis will be placed on their cardiovascular muscular strength, and muscle flexibility profile. Attachment gives a description of the test procedure. The fitness test will be conducted in conjunction with the Department of Health, Physical Education and Recreation at KSU under supervision of Dr. William B. Zuti. Subjects with a performance rating below the minimum specified (see attachments 2 and 3) will be screened out.

Stage 3. During this stage the subjects will be given a routine roentgenogram and the reporting radiologist will be asked to complete the questionnaire shown in the attachment 4. Any subject with more than two abnormalities of minor importances or worse (class B or C abnormalities) will be screened out.

Stage 4. Subjects will be given a physical examination by a local physician. The physician will have all prior information (questionnaire, physical fitness profile and x-ray report) available for final clearance of the subjects.

It is believed that while there is always risk associated in any experiment involving human subjects the above screening procedure is a sufficient attempt to minimize the possibility of such an occurrence.

While there is no immediate personal benefit to the participating subjects, there is a significant contributonal potential in the study itself which could lighten the discomforts man is suffering from back pain.

B. INFORMED CONSENT:

The procedure for securing informed consent is outlined in the attachment 5.

C. EMERGENCIES:

The procedure for emergencies is not outlined in the proposal.

The possible emergencies that may arise are:

1. Cardiovascular strain
2. Skeleto-muscular strain
3. Injury due to dropping the object that is being lifted.

The preventive procedure was partly outlined in A above under RISK.

In addition to this the possibility of cardiovascular strain will be minimized by the fatigue recovery time of at least 300 seconds between consecutive tasks. To prevent skeleto-muscular strain the weight of the object will not be more than 15 kg. which is well within current International Labor Office (ILO) limits. (ILO gives 55 kg. as their recommended limit). Injury due to dropping the object will be reduced by having wooden tote-boxes and sand as their contents.

In the unlikely event of an emergency the following facilities can be used depending on the severity of the emergency.

1. Student Health Service (100 meters from the Human Factors Laboratory)
2. Ambulance from the Memorial Hospital (3 min.)
3. A passenger vehicle for transportation to the hospital
4. First aid kit in the laboratory itself
5. A telephone about 3 meters from the experiment site.

D. PRIVACY

The procedure for keeping research private is not addressed specifically in the proposal. However all questionnaires and other test reports will be either destroyed or returned to the subjects that are screened out. The remaining subjects will be allocated a number on a random basis and thereafter identified only by it. On completion of the research the documents containing private information will be destroyed. The pertinent data will, however, remain in possession of the Department of Industrial Engineering in a coded form.

E. STATEMENT OF AGREEMENT

The below named individual certifies that he has read and is willing to conduct the activities in accordance with the Handbook for Research, Development, Demonstration, or other Activities Involving Human Subjects. Further, the below named individual certifies that any changes in the procedures from those outlined above or in the attached proposal will be cleared through committee 8290, The Committee on Research Involving Human Subjects.

Signed _____
The Responsible Individual

Date: _____

ATTACHMENT - 1

STAGE 1. SUBJECT SCREENING QUESTIONNAIRE

Name _____ Age _____ Date _____

Address _____ Occupation _____

_____ Body weight _____ (lb)

_____ Phone _____ Height _____ (in.)

(Please check correct answers. If any of the answers is 'yes',
please explain on the back page).

	YES	NO
1. Have you ever had weight lifting training?	_____	_____
2. Have you ever formally instructed a safe weight lifting method?	_____	_____
3. Have you ever had severe pains in the chest?	_____	_____
4. Has a doctor ever said your blood pressure was too high or too low?	_____	_____
5. Are you often conscious of heavy beating of your heart?	_____	_____
6. Does your heart often beat very rapidly?	_____	_____
7. Do you get out of breath with an ordinary amount of exercise?	_____	_____
8. Do your hands and feet feel cold even in hot weather?	_____	_____
9. Has a doctor ever said you had heart trouble?	_____	_____
10. Do you suffer from frequent painful cramps in your legs?	_____	_____
11. Have your joints ever been painfully swollen?	_____	_____
12. Do your muscles and joints always feel stiff?	_____	_____

	YES	NO
13. Do you usually have severe pains in the arms or legs?	_____	_____
14. Are you crippled with severe rheumatism (arthritis)?	_____	_____
15. Do you suffer from weak or painful feet?	_____	_____
16. Do you have pains in the back that make it hard for you to keep up with your daily activities?	_____	_____
17. Are you troubled by a serious bodily disability or deformity?	_____	_____
18. Have you ever had a medical problem associated with weight lifting?	_____	_____
19. Is your skin usually sensitive or tender?	_____	_____
20. Do you have frequent severe headaches?	_____	_____
21. Do you frequently feel faint?	_____	_____
22. Have you fainted more than twice in your life?	_____	_____
23. Was any part of your body ever paralyzed?	_____	_____
24. Have you ever noticed a twitching of any part of your body?	_____	_____
25. Did you ever have a convulsion (epilepsy)?	_____	_____
26. Were you ever treated by a doctor for anemia (thin blood)?	_____	_____
27. Have you ever had a serious operation?	_____	_____
28. Have you ever had a serious injury?	_____	_____
29. Has a doctor ever said you had a hernia (rupture)?	_____	_____
30. Do you sweat or tremble a lot during examinations or questioning?	_____	_____

	YES	NO
31. Do you get nervous and shaky if anyone is watching you?	_____	_____
32. Does every little effort wear you out?	_____	_____
33. Do you suffer from severe nervous exhaustion?	_____	_____
34. Are you considered a sickly person?	_____	_____

As indicated by my signature below and being of sound mind, I agree that the above questionnaire has been correctly and truthfully completed to the best of my knowledge. I also further understand that all the data contained therein is confidential and I agree to allow publication of any or all of the data in a coded form.

_____ Signature of Subject	_____ Date
-------------------------------	---------------

_____ Signature of witness	_____ Date
-------------------------------	---------------

ATTACHMENT - 2

PHYSICAL FITNESS PROFILE

The physical fitness profile will be obtained with the help of the Department of Health, Physical Education and Recreation at the Kansas State University. Information in the profile will be used in two ways. The first will be as a means of screening potential subjects and the second as inputs to the regression model. For screening purposes the subject's fitness performance will have to meet certain minimum requirements in each of the fitness categories. Table 1 shows these requirements. The minimum requirements are set for both male and female subjects and are determined from the least acceptable levels for the oldest subject group.

The physical fitness profile will be made up of three kinds of tests, namely, a test of the cardiovascular and respiratory fitness condition, the body's flexibility and its strength. Cardiovascular fitness is an indication of the amount of oxygen the body can deliver to the working muscles. A simple explanation as to the reason that cardiovascular fitness is a measurement of the fitness performance is that: 1) in order for a large amount of oxygen to be delivered, one must have "good" hemoglobin to carry the oxygen, 2) a good pumping system is required to transport the blood through the arteries, veins and capillaries, and 3) a good pump (the heart) is needed to move the blood; therefore the individual that can deliver more oxygen has a better

cardiovascular and respiratory system. A test of the cardiovascular and respiratory system also gives an indication of the "overall" physical condition of the body because cardiovascular fitness is influenced simultaneously by the condition of all working muscles. Body flexibility is the range of motions available in a joint. Adequate flexibility can contribute to increased work performance, increased resistance to muscle injury and soreness, and a general state of good health. Body strength is the amount of external force that a muscle or group of muscles can exert.

For the cardiovascular fitness the "bike-test" (bicycle ergometer) will be used. Body flexibility will be subdivided into shoulder, trunk, and back flexibility. Body strength will be measured in terms of left and right grip strength, leg, back and arm push strength. The procedure for testing the flexibility and isometric strengths are described in Zuti (1975) and also by Asmussen (1959) and Poulsen (1970).

Figure 6.1 shows the fitness sheet to be completed for each potential subject. The arthropometric data obtained in the fitness profile will also be used directly as inputs to the mathematical model formulation.

The fitness test will be conducted in a one hour session in which the flexibility and strength test will be done first. In each of the test measures the subject will be asked to perform the test three times. The best performance out of this will then be taken as the measured

flexibility or strength. After the completion of these tests, the subject will be given sufficient time (15 minutes) to rest before the bicycle test is started. This is done to avoid fatigue prior to the start of this test. Specific care will also be given to the accuracy of observing the different fitness measures.

Table 1. Minimum Fitness Requirements.

Sex	Male	Female
Fitness test		
Cardiovascular	34 ml/kg/min.	29 ml/kg/min.
Back flexibility	Relative rating 7	Relative rating 9
Trunk flexibility	Relative rating 4	Relative rating 6
Shoulder flexibility	Relative rating 10	Relative rating 10
Average grip strength	50 kg	30 kg
Isometric back muscle strength	Greater than 67% of body weight	Greater than 67% of body weight
Isometric leg muscle strength	140 kg	80 kg
Average arm push strength	Greater than 50% of body weight	Greater than 50% of body weight

BACK X-RAY REPORT

Location _____ Date _____

Age _____ Sex _____

Height _____ Weight _____

Previous History _____

ABNORMALITIES OF MINOR IMPORTANCE
(Combination of several may be important)

- ☐ Mild tropism lumbar joints
- ☐ Minor spina bifida occulta (X-Ray findings only)
- ☐ Schmorl's nodes L1-2-3
- ☐ Minor cong. defects - no symptoms
- ☐ Minor lordosis
- ☐ Osteoarthritis - X-Ray only
- ☐ Minimal Scoliosis
- ☐ 6 Lumbar Vertebrae

B. ABNORMALITIES OF INCREASED IMPORTANCEQuestionable Acceptance for Sustained Heavy Work
(Combination of several is significant)

- 1. ☐ Marked tropism lumbar joints or facets
- 2. ☐ Extensive spina bifida occulta
- 3. ☐ Schmorl's nodes L3-4-5 - & loss lumbar curve
- 4. ☐ Moderate degenerative changes upper lumbar or lesser in lumbar spine
- 5. ☐ Mild to moderate scoliosis
- 6. ☐ Decrease in lumbar segments (5 to 4)
- 7. ☐ Transitional lumbosacral vertebra & no pseudoarthrosis
- 8. ☐ Minimal Narrowing L-5, S-1 interspace

ABNORMALITIES INDICATING SUBSTANDARD RISK FOR SUSTAINED HEAVY WORK

- ☐ Spondylolysis or spondylolisthesis
- ☐ Transitional lumbosacral vertebra with pseudoarthrosis
- ☐ Narrowing intervertebral space L3-4-5, especially associated with marginal spurring, sclerosis, etc. Upper lumbar narrowing possibly less significant
- ☐ Marked hypertrophic degeneration - upper lumbar, Moderate " " L4-5 and Milder " " if under 30 years
- ☐ Collapsed or wedged vertebra; evidence old fractures of vertebral body or neural arch, or multiple defect spines or transverse process
- ☐ Neoplasm or destruction of bone
- ☐ Extensive spina bifida of 2 or more vertebrae
- ☐ Prior back surgery; radio-opaque materials evidence previous infections; Marie-Strumpell spondylitis; major congenital anomaly, disease of lumbosacral or sacroiliac joints

- 9. ☐ Active osteomyelitis or substantiated history of osteomyelitis, or reactive change at sacroiliac in younger persons
- 10. ☐ Symptomatic osteoarthritis or rheumatoid
- 11. ☐ Herniated nucleus pulposus, or history of surgery re.
- 12. ☐ Disease of sacroiliac or lumbosacral joints, chronic with radiated pain; postural deformities and/or limitation of motion, lumbar
- 13. ☐ Rotary scoliosis
- 14. ☐ Degenerative diseases (i.e. osteoporosis)
- 15. ☐ Definite epiphysitis deformity
- 16. ☐ Multiple Schmorl's nodes

DESCRIPTION AND DIAGNOSIS

Signed _____ M.D.

ATTACHMENT -4

FITNESS SHEET

Name _____ Age _____ (years) Height _____ (cm)

Address _____ Sex _____ Weight _____ (kg)

_____ Phone _____

Date _____ Resting heart rate _____ (B/M)

Resting blood pressure _____ (B/M)

1. Bike test: KPM _____ HR _____
averageEst. O_2 _____ l. Est. O_2 _____
ml/kg/min2. Flexibility: Back _____, trunk _____,3. Strength: Left grip _____, right grip _____ (kg), leg _____ (kg),
back muscle _____ (kg), left arm push _____ (kg),
right arm push _____ (kg).

Average grip strength _____ (kg)

Average arm push strength _____ (kg).

4. Skinfold: Chest _____, Iliac _____, Tricep _____,

Waist girth _____ (cm), % body fat _____, Ideal weight _____.

PERSONAL HISTORY

What is your past history of exercise?

Recent regular exercise - type _____

Recent occasional exercise - type _____

Current formal exercise _____

Former athlete - sport _____

Fitness testing summary.

ATTACHMENT - 5

INFORMED SUBJECT CONSENT

Name _____

Address _____

Personnel: Stephan A. Konz Professor, Dept. of Industrial
 Engineering

 Girish D. Desai Graduate Student, Dept. of
 Industrial Engineering

1. I, _____, being of sound mind and _____
 (name of subject)
years of age, do hereby consent to, authorize and request each of the
persons named above (and the agents, employees and fellow employees of
each of them) to undertake and perform on me the proposed procedure,
treatment, research or investigation (herein called 'Procedure') iden-
tified and explained in the document entitled:
'Forces & Torques on body as well as posture prediction while lifting'
simulation and experimental values which document dated _____ is
attached to and is hereby made part of this consent.

2. I have read the attached document, referred to ~~the~~ above, and I
have been fully advised of the Procedure and the possible risks (cardio-
vascular and skeleto-muscular strain or damage) and complications
Involved in it, all of which risks and complications I hereby assume
voluntarily.

Signed at _____ this day of _____, 1975, in
the presence of the witnesses whose signatures are below, opposite
my signature.

Witnessed by:

Subject's signature

First witness signature

Second witness signature

APPENDIX 2

Simulation Model - Computer Program

Table . List of input data and format

(All input data is in inch-pound system.)

Card No.	Usage	Start Column	Format	Description
0	Control	1	I1	Biomechanical stress factor specification (2=low back compression)
		2	I1	Posture plot request (0=no)
1	Anthropometry	1	A2	Subject number or name
		10	F10.2	Subject weight
		20	"	Subject height
		30	"	Radius length
		40	"	Length from wrist to hand-center of gravity
		50	"	Tibia length
		60	"	Foot length
		70	"	Standing elbow height
2	Strength	10	F10.2	Knee extension @ 90 deg.
		20	"	Back extension @ 90 deg.
		30	"	Shoulder flexion @ 30 deg.
		40	"	Elbow flexion @ 90 deg.
		50	"	Ankle extension @ 90 deg.
		60	"	Knee flexion @ 90 deg.
		70	"	Hip extension @ 90 deg.
3	Task	1	F5.2	Weight of the load
		6	"	Horizontal distance from ankle to the hand with load
		11	"	Vertical distance from floor to the hand with load

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C PSEUDODYNAMIC BIOMECHANICAL SIMULATION MODEL
 C OF POSTURES DURING SYMMETRIC SAGITTAL PLANE LIFTING
 C

```

0001      DIMENSION ANG(5),OPT(5)
0002      CALL TABLE
0003      10 CALL SUBJ
0004      20 CALL TASK(ENDS,ANG(1))
0005      IF(ENDS.EQ.0.) GO TO 10
0006      CSFV=9999999999999999.
0007      DO 51 IK=90,145,5
0008      ANG(2)=IK
0009      DO 50 IH100=100,185,5
0010      ANG(3)=IH100-100.
0011      JFANGE=0
0012      CALL SF(JRANGE,ANG,SFV)
0013      GO TO (52,51,50),JRANGE
0014      IF(SFV.GT.CSFV) GO TO 50
0015      DO 30 J=1,5
0016      30 OPT(J)=ANG(J)
0017      CSFV=SFV
0019      50 CONTINUE
0019      51 CONTINUE
0020      52 CONTINUE
0021      IF(0SFV.EQ.9999999999999999.) GO TO 20
0022      70 DO 90 IN=1,4
0023      IGRID=500./(2.**((N-1)))
0024      IAF=CPT(1)*100-IGRID
0025      IAT=OPT(1)*100+IGRID
0026      IKF=CPT(2)*100-IGRID
0027      IKT=CPT(2)*100+IGRID
0028      IHF100=OPT(3)*100-IGRID+10000
0029      IHT100=OPT(3)*100+IGRID+10000
0030      DO 80 IK=IKF,IKT,IGRID
0031      ANG(2)=IK/100.
0032      DO 80 IH100=IHF100,IHT100,IGRID
0033      ANG(3)=(IH100-10000)/100.
0034      JRANGE=0
0035      CALL SF(JRANGE,ANG,SFV)
0036      IF(JRANGE.NE.0) GO TO 80
0037      IF(SFV.GT.CSFV) GO TO 80
0038      DO 75 J=1,5
0039      75 OPT(J)=ANG(J)
0040      CSFV=SFV
0041      80 CONTINUE
0042      90 CONTINUE
0043      CALL PLT(CPT)
0044      M=0
0045      N=0
0046      99 GO TO 20
0047      END

```

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0001      SUBROUTINE TABLE
0002      C DATA INITIALIZATION SECTION
0003      IMPLICIT REAL(K,L)
0004      DIMENSION ANGLE(1000),STACK(1000),STPRESS(2500)
0005      DIMENSION STORF(45),KTORF(27),ANG(5),RL(5),SINF(5),
0006      HTORF(30),STORF(45),KTORF(27),ETORF(20),ANGLE(5),COSINE(5),
0007      2F16(800),LIAK(5,2),OSDIA(6,2),BOX(40,2),FACE(16,2)
0008      C AVERAGE TORQUE CAPABILITY CURVES (SHIFTED ACCORDING TO TEST STRENGTH VALUES)
0009      DATA KTORF /-1410.,-1450.,-1485.,-1530.,-1568.,-1619.,-1650.,
0010      1-1692.,-1737.,-1780.,-1821.,-1866.,-1905.,-1938.,-1946.,-1941.,
0011      2-1928.,-1957.,-1941.,-1758.,-1641.,-1534.,-1438.,-1342.,-1262.,
0012      3-1185.,-1103./ ,KTORF /195.,225.,255.,285.,315.,350.,375.,415.,
0013      4450.,490.,520.,560.,600.,650.,695.,750.,800.,850.,895.,925.,
0014      5945.,960.,965.,960.,940.,915.,890./
0015      DATA HTORF /2400.,2595.,2570.,2545.,2510.,2465.,2420.,2370.,2320.,
0016      12260.,2200.,2150.,2115.,2070.,2075.,2070.,2065.,2060.,2055.,
0017      22050.,2045.,2040.,2035.,2030.,2025.,2020.,2015.,
0018      32010.,2005.,2000./
0019      ETORF(X)=3365.123-23.947*X
0020      DATA STORF /895.,910.,940.,965.,983.,1009.,1027.,1044.,1058.,1071.,
0021      11082.,1089.,1092.,1086.,1076.,1059.,1025.,973.,932.,900.,873.,
0022      2848.,825.,807.,783.,775.,762.,745.,727.,714.,695.,672.,656.,634.,
0023      3610.,585.,555.,527.,494.,460.,422.,378.,333.,280.,210./,
0024      4STORF /-540.,-620.,-670.,-725.,-764.,-800.,-832.,-860.,
0025      5-883.,-900.,-927.,-932.,-943.,-952.,-960.,-964.,-967.,-969.,
0026      6-967.,-964.,-961.,-958.,-950.,-943.,-933.,-921.,-909.,-894.,
0027      7-879.,-863.,-847.,-830.,-809.,-787.,-765.,-740.,-713.,-696.,
0028      8-659.,-632.,-603.,-574.,-543.,-510./
0029      DATA ETORF /400.,485.,545.,594.,632.,664.,693.,717.,736.,752.,
0030      1769.,775.,779.,777.,771.,759.,747.,733.,721.,705.,689.,672.,654.,
0031      2639.,621.,602.,583.,565.,547./, PI/3.14159265/
0032      READ(5,11) IWSF,IPLT
0033      11 FORMAT(211)
0034      DO 550 I=1,1000
0035      ANGLE(I)=0.
0036      STACK(I)=0.
0037      550 CONTINUE
0038      DO 555 I=1,2500
0039      STPRESS(I)=0.
0040      555 CONTINUE
0041      M=0
0042      N=0
0043      RETURN
0044      ENTRY SUBJ
0045      C SUBJECT DATA SECTION
0046      N=N+1
0047      110 READ(5,111,FMT=2001) NAME,WEIGHT,HEIGHT,LLA,HAND,LLL,FOOT,HTE,
0048      ITTORKE,ITTORBE,ITTORSE,ITTORFE,ITTORAE,ITTORKE,ITTORFE
0049      111 FORMAT(A2,T1),7F10.2/T10,7F10.2)
0050      SJDV=((ITTORKE-1440.9)/419.+(ITTORBE-1209.893)/305.+
0051      1(ITTORSE-743.7)/159.+(ITTORFE-616.)/126.7)/4.
0052      IF(ITTORAE.GT.0.) GO TO 140
0053      ITTORAE=1969.3+600.*(ITTORKE-1440.9)/419.
0054      ITTORKE=455.7+71.*(ITTORKE-1440.9)/419.
0055      ITTORBE=2588.7+941.*(ITTORBE-1209.893)/305.
0056      140 ITTORSE=733.2+153.*(ITTORSE-743.7)/159.
0057      HIGH=2.54*HEIGHT
0058      LLA=2.54*LLA

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**CARD 1
**CARD 2

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0034      WCGH=2.54*HAND
0035      LLL=2.54*LLL
0036      FOOT=2.54*FOOT
0037      HTE=2.54*HTE

C LENGTHS FROM JOINTS TO CENTERS OF GRAVITY (DEMPSTER, ET AL, 1955, 1964)
0038      FW=1.0709*LLA
0039      SE=5.80752+(1.5646*LLA)
0040      FORARM=FW+WCGH
0041      ARM=SE+FORARM
0042      AK=1.0770*LLL
0043      KH=13.28253+(1.9172*LLL)
0044      FA=FOOT*(8.2/26.1)
0045      HTS=HTE+SE
0046      HSS=HTS-(FA+AK+KH)
0047      HEAD=HIGH-HTS
0048      ECGLA=0.430*EW
0049      SCGUA=0.47*(SE
0050      ACGLL=0.567*AK
0051      KCGUL=0.567*KH
0052      HCGTS=(HSS+HEAD)*.356
0053      HLSS1=.195*HSS
0054      LSS1S=.805*HSS

C STANDARD LINK LOCATION-----
0055      SYK=FA+AK
0056      SYH=SYK+KH
0057      SYE=HTS-SE
0058      SYLOAD=HTS-ARM
0059      SYCLL=FA+ACGLL
0060      SYCUL=SYK+KCGUL
0061      SYCT=SYH+HCGTS
0062      SYCUA=HTS-SCGUA
0063      SYCLA=SYE-ECGLA
0064      STACK(10*N-8)=SYCLA
0065      STACK(10*N-7)=SYCLL
0066      STACK(10*N-6)=SYCT
0067      STACK(10*N-5)=SYCUA
0068      STACK(10*N-4)=SYCUL
0069      STACK(10*N-3)=SYE
0070      STACK(10*N-2)=SYH
0071      STACK(10*N-1)=SYK
0072      STACK(10*N)=SYLOAD

C MASS OF BODY SEGMENTS (DRILLIS AND CONTINI, 1966)-----
0073      W=WEIGHT*(-0.45359)
0074      WH=.015*W
0075      WLA=.036*W
0076      WUA=.062*W
0077      WT=.554*W
0078      WUL=.209*W
0079      WLL=.092*W

C RESULTANT FORCES (DIRECTION: +DOWN)
0080      RW=-WH
0081      RF=-(WLA-RW)
0082      RS=-(WUA-RF)

C (% OF TRUNK WEIGHT ABOVE L5/S1 DISC=0.635)
0083      RLSS1=RS-0.655*WT
0084      RH=-(WT-RS)
0085      RK=-(WUL-RH)
0086      RA=-(WLL-RK)

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0087      RETURN
0088      ENTRY TASK(ENDS,ANG1)
C TASK DATA SECTION*****
0089      300 READ(5,301,FND=2001) LPS,HOR,VER
0090      301 FORMAT(3F5.2)
0091      ENDS=LBS+HOR+VER
0092      IF(ENDS.EQ.0.) RETURN
0093      LOAD= LBS*.45359
0094      ACCLX=-.0935+.0106085*HOR
0095      ACCLY=.5144?+.00281465*HOR-.123405*STDV**2
0096      1=.0000584*WEIGHT*HEIGHT+.000050555*WEIGHT*HEIGHT*STDV
0097      WLOAD=LOAD*SQR((1.+ACCLY)**2+ACCLX**2)
0098      ALFA=-ATAN(ACCLX/(1.+ACCLY))
0099      HORZ=2.54*HOR
0100      VERT=2.54*VER
0101      IF(HOR.GE.15.) ANG1=75.8
0102      IF(HOR.LT.15.) ANG1=75.8
0103      RETURN
0104      ENTRY SF(JRANGE,ANG,SFV)
0105      M=M+1
C FEASIBILITY CHECK AND COMPUTATION SECTION*****
0106      93 ZET2=180.0+ANG(1)-ANG(2)
0107      ANKLE(4*M-3)=ZET2
0108      STRESS(14*M-13)=ZET2
0109      STRESS(14*M-5)=ANG(1)
0110      STRESS(14*M-9)=ANG(2)
0111      STRESS(14*M-7)=ANG(3)
0112      IF(ZET2.LE.50..OR.ZET2.GE.180.) GO TO 1002
0113      ZET3=180.0+ANG(3)-ANG(2)
0114      STRESS(14*M-12)=ZET3
0115      IF(ZET3.LE.30..OR.ZET3.GE.180.) GO TO 1003
0116      DO 580 J=1,3
0117      ANGLE(J)=ANG(J)*0.017453
0118      SINE(J)=SIN(ANGLE(J))
0119      COSINE(J)=COS(ANGLE(J))
C SHORTENING IN "FS" LINK DUE TO 2-LINK STRUCTURE OF BACK-----
0120      600 HIPCHG=ANG(2)-ANG(3)
0121      PANG=AMAX1(0.,.33*(HIPCHG-27.))*0.017453
0122      IF (ABS(HIPCHG).GE. 5.0) GO TO 685
0123      HS=HSS
0124      GO TO 700
0125      685 HLXX=HL5S1*COS(PANG)
0126      HLYY=HL5S1*SIN(PANG)
0127      LSXX=SQR(L5S1S**2-HLYY**2)
0128      HS=LSXX+HLXX
C REACHABILITY CHECK SECTION-----
0129      700 XK=AK*COSINE(1)
0130      IF(XK.GE.HCR7) GO TO 1001
0131      YK=FA+AK*SINE(1)
0132      XH=XK+KH*CCSINE(2)
0133      YH=YK+KH*SINE(2)
0134      X4=HS*CCSINE(3)
0135      Y4=HS*SINE(3)
0136      X56=HORZ-X4
0137      Y56=VERT-Y4
0138      X56A=((X56**2)+(Y56**2))
0139      F2=SQR(X56A)

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0140      IF(F2 .GT. ARM) GO TO 1002
      C ARM ANGLES COMPUTATION-----
0141      SM2=.5*(ARM+F2)
0142      R2=SQRT(ABS((SM2-SE)*(SM2-FCR/ARM)*(SM2-F2)/SM2))
0143      BETA2=2*ATAN(R2/(SM2-FCR/ARM))
0144      IF((SM2-F2) .LE. .0001) ZET5R=P1
0145      IF((SM2-F2) .GT. .0001) ZET5R=2*ATAN(R2/(SM2-F2))
0146      ANGLE(4)=ARCSIN(Y56/F2)-BETA2
0147      IF(X56.LT.0..AND.Y56.LT.0.) ANGLE(4)=-ARCSIN(Y56/F2)-BETA2-P1
0148      IF(X56.LT.0..AND.Y56.GE.0.) ANGLE(4)=-ARCSIN(Y56/F2)-BETA2+P1
0149      ANGLE(5)=P1+ANGLE(4)-ZET5R
0150      ANG(4)=ANGLE(4)*57.2967
0151      STRESS(14*M-6)=ANG(4)
0152      IF(ANG(4) .LE. -120.) GO TO 1003
0153      ANG(5)=ANGLE(5)*57.2967
0154      STRESS(14*M-5)=ANG(5)
0155      ZET4=180.+ANG(4)-ANG(3)
0156      STRESS(14*M-11)=ZET4
0157      IF(ZET4 .LE. -40..OR. ZET4.GE.130.) GO TO 1003
0158      ZET5=ZET5R*57.2967
0159      STRESS(14*M-10)=ZET5
0160      IF(ZET5 .LE. 40..OR. ZET5.GE.130.) GO TO 1003
      C LIFTING LINK CENTER LOCATION-----
0161      DC 730 J=4,5
0162      SINE(J)=SIN(ANGLE(J))
0163      730 COSINE(J)=COS(ANGLE(J))
0164      XE=XS+SE*COSINE(4)
0165      YE=YS+SE*SINE(4)
0166      750 HCGT=(HS+HEAD)*.396
0167      YCUL=FA+ACGLL*SINE(1)
0168      YCUL=YK+KCGUL*SINE(2)
0169      YCT=YH+HCGT*SINE(3)
0170      YCUA=YS+SCGUA*SINE(4)
0171      YCLA=YE+ECGLA*SINE(5)
0172      XCUL=ACGLL*COSINE(1)
0173      XCUL=XK+KCGUL*COSINE(2)
0174      XCT=XH+HCGT*COSINE(3)
0175      XCUA=XS+SCGLA*COSINE(4)
0176      XCLA=XE+ECGLA*COSINE(5)
      C TORQUE COMPUTATION SECTION-----
      C (DIRECTION: RESULTANT=+CW; REACTIVE=+CCW)
      C RESULTANT TORQUES DUE TO BODY WEIGHT AND LOAD ACCELERATION
0177      LDMW=WCGH*COS(ANGLE(5)+ALFA)
0178      LDMAE=LDMW+EW*COS(ANGLE(5)+ALFA)
0179      LDMAS=LDMW+SE*COS(ANGLE(4)+ALFA)
0180      LDMAH=LDMAS+HS*COS(ANGLE(3)+ALFA)
0181      LDMAL=LDMAS+LSXX*COS(ANGLE(3)+ALFA)
0182      LDMAK=LDMH+KH*COS(ANGLE(2)+ALFA)
0183      LMAA=LMAK+AK*COS(ANGLE(1)+ALFA)
      C TOTAL RESULTANT TORQUE AT THE WRIST (WRIST ANGLE=ELRCW ANGLE)
0184      TWR=WCGH*COSINE(5)*RW
0185      TEW=LDMW*WLOAD
      C RESULTANT TORQUE AT ELBOW DUE TO WRIST RESULTANT FORCE
0186      TEW=EW*COSINE(5)*RW
      C TORQUE DUE TO THE MASS OF THE FOREARM
0187      TECG=-ECGLA*COSINE(5)*WIA
      C TOTAL RESULTANT TORQUE AT THE ELBOW
0188      TEP=TWR+TEW+TECG

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0189      TF=TSR+LDMAL*WLOAD
0190      TSE=SE*CLSINE(4)*RE
0191      TSCG=-SCGUA*CCSINE(4)*WUA
0192      TSR=TEB+TSE+TSCG
0193      TS=TSR+LDMAS*WLOAD
0194      THS=HS*CCSINE(3)*RS
0195      THCG=-TCGT*CCSINE(3)*WT
0196      THB=TSR+THS+THCG
0197      TH=THB+LDMAH*WLOAD
0198      HLSSIX=HLSSI*CCS(ANGLE(3)+PANG)
C (HIP TO CENTER OF GRAVITY OF TRUNK ABOVE L5/S1=0.5337HS)
0199      TLSSI=TSR+RS*(X4-HLSSIX)-C.655*WT*(X4*0.5237-HLSSIX)+LDMAL*WLOAD
0200      IF(TH.GT.0.) GO TO 780
0201      TABDOM=0.
0202      GO TO 785
0203      780      ABDIS=AMAX1(SIN(AMIN1(HIPCHG,90.)*.008727),0.)*0.47
0204      PABDOM=(.6516-.005447*AMIN1(HIPCHG,90.))*TH*.18*.0001
0205      TABDCM=AMIN1(PABDOM,150.)*.0136*ABDIS*465.*12.7*.1
0206      785      TLSSI=TLSSI-TABDCM
0207      TKF=KF*CCSINE(2)*RH
0208      TKCG=-KCGUL*CCSINE(2)*WUL
0209      TKB=THB+TKF+TKCG
0210      TK=TKB+LDMAX*WLOAD
0211      TAK=AK*CCSINE(1)*RK
0212      ANKLE(4*M-2)=TAK
0213      TACG=-ACGLL*CCSINE(1)*WLL
0214      ANKLE(4*M-1)=TACG
0215      TA=TKB+TAK+TACG+LDMAA*WLOAD
0216      ANKLE(4*M)=TA
C BODY BALANCE AND TORQUE CAPABILITY CHECK SECTION-----
0217      IF(FCOT*.9*(PA+LQAD*(1.+ACCLY)).LT.TA) GO TO 1003
0218      IF(2.5*(PA+LQAD*(1.+ACCLY)).LT.-TA) GO TO 1003
C MAXIMUM VOLUNTARY REACTIVE TORQUES (IF TE,TS,TK: >0=FLEXION; <0=EXTENSION)
C (ANGLE MAXIMUM REACTIVE TORQUE CAPABILITY IS ASSUMED CONSTANT AT ALL ANGLES)
C (KNEE      .0012241=(2.*1.15)/(KTOR @ 90)      .0051111=(2.*1.15)/(KTOR @ 90))
C (HIP       .0009914=(2.*1.15)/(HTOR @ 50))
C (SHOULDER .0021375=(2.*1.15)/(STOR @ 30)      .0023958=(2.*1.15)/(KTOR @ 30))
C (ELBOW     .0029909=(2.*1.15)/(ETOR @ 50))
C (BACK      .000995=1.15/(BTOR @ 50 ACCORDING TO SCHANNE, 1972))
0219      RL(1)=TA/(TTORAE*2.0*1.15)
0220      IF(TK.GT.0.) RL(2)=TK/(TTORKE*KTOR(IFIX(ZET2/5.-9.))*0.0051111)
0221      IF(TK.LE.0.) RL(2)=TK/(TTORKE*KTOR(IFIX(ZET2/5.-9.))*0.0012241)
0222      RL(3)=TH/(TTORPE*HTOR(MAX1(1.,ZET3/5.-9.))*0.0009914)
0223      IF(TS.GT.0.) RL(4)=TS/(TTORSE*STOR(IFIX(ZET4/5.+9.))*0.0021375)
0224      IF(TS.LE.0.) RL(4)=TS/(TTORSE*STOR(IFIX(ZET4/5.+9.))*0.0023958)
0225      RL(5)=TF/(TTORFF*ETOR(IFIX(ZET5/5.-7.))*0.0029909)
0226      RL(6)=TLSSI/(TTORBE*BTOR(ZET3)*.000995)
0227      DO 810 J=1,6
0228      IF(RL(J) .GT. 1.)
0229      810      CONTINUE
C STRESS FACTOR COMPUTATION -----
0230      900      SFR=(FCOT*.8*(WLI*XCLL+WUL*XCOL+WT*XCT+WUA*XCUA+WLA*XCLA
1+(WH-LOAD)*HGR)/((PA+LQAD))/10.
C RESULTANT NORMAL FORCE ON L5/S1 DISC (SACRUM ANGLE=.69812)
0231      RN=RLSSI*SIN(ANGLE(3)+PANG-.69812)
1+WLOAD*SIN(ANGLE(3)+PANG-.69812+ALFA)
0232      SFC=(RN+TLSSI/5.-TABDCM/(ABDIS*12.7))/1000.
0233      SFT=0.

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0234      DO 905 J=1,6
0235      905      SFT=SFT+PL(J)**2
0236      SFW=(-WLL*(SYCLL-YCLL)-WHL*(SYCUL-YCUL)-WT*(SYCT-YCT)
1-WUA*(SYCUA-YCLA)-WLA*(SYCLA-YCLA)-(WF-LCAD)*(SYLOAD-VERT))/10000.
0237      IF(IWSF.EQ.1) SFV=SF8
0238      IF(IWSF.EQ.2) SFV=SF9
0239      IF(IWSF.EQ.3) SFV=SFT
0240      IF(IWSF.EQ.4) SFV=SFW
0241      STRESS(14*M-4)=SF8
0242      STRESS(14*M-3)=SF9
0243      STRESS(14*M-2)=SFT
0244      STRESS(14*M-1)=SFV
0245      STRESS(14*M)=SFW
0246      RETURN
0247      1001 JRANGE=1
0248      RETURN
0249      1002 JRANGE=2
0250      RETURN
0251      1003 JRANGE=3
0252      RETURN
0253      ENTRY PLT(ANG)
0254      IF(IPLT.NE.1) GO TO 1900
0255      1900 WRITE(6,1901) (ANG)
0256      1901 FORMAT(T30,'BODY LINK ANGLES (DEGREES)'/T20,'LOWER LEG UPPER LEG'
1,' TRUNK UPPER ARM FCREARM'/T15,5X,5(F9.2,3X)/)
0257      RETURN
0258      2001 CONTINUE
0259      STOP

```

APPENDIX 3

Procedure to Measure Various Strengths

The testing procedure for various strengths and flexibilities are described in Zuti (1975).

Grip strength:

Grip strength is measured using a hand dynamometer. Both the right and left grip are measured and recorded in kg. The procedures for the grip strength include keeping the arm extended and away from the side of the body around the hip and leg area. The dynamometer records the highest tension that the individual produces; so a single maximal squeeze is the proper procedure.

Leg strength:

Leg strength is measured with the leg dynamometer. The individual is positioned on a platform with his back straight and his legs bent with the knees at an angle of approximately 120 degrees. It is absolutely imperative that they keep the back straight. With the position properly taken, the individual holds the bar with a "mixed grip". A "mixed grip" means that one hand is facing forward and the other hand is turned backwards. The individual then proceeds to do a single maximal lift with the leg; not with the back.

Back strength:

This is a measure of the strength of the upper back and shoulder girdle area. For this test, the legs and lower back remain straight, the bar is held in a reverse grip, and the shoulders are dropped forward. The individual then rolls his shoulders backwards in a manner in which he is attempting to throw out his chest. The individual should keep his weight evenly distributed and not lean backwards.

LIFTING FORCES, TORQUES AND INITIAL POSTURES----
EXPERIMENTAL AND SIMULATION RESULTS

by

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An analysis was performed for a symmetrical sagittal plane lifting task to gain an insight of the forces and torques as well as the initial posture of the body.

To test the above variables, a lifting experiment was performed and the resultant forces and torques were measured by a force platform. For initial posture, a movie was taken during the experiments.

The experimental results revealed that the vertical force increases significantly with increasing load, and its value is about 60 % of the total weight lifted. The frontal force and somersault torques differ significantly with respect to the 'x' distance of the load position. For a given 'x' distance, the vertical height 'y' did not change the values of the frontal force and somersault torque significantly.

Regarding initial postures, subjects were asked to do a squat lift, but the simulation model predicts a bend lift. The main program criterion seems to be the distance between the center of gravity of load and that of the body. The initial posture angles did not differ significantly for various weights. For shoulder and elbow angles positions 1 and 2 were not significantly different. For ankle, knee and hip angles, all comparisons were significantly different.

For a small amount of back compression, the distance between load and body should be minimized.