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REVIEW OF THE STRENGTH AND CAPACITY DATA FOR MANUAL MATERIAL HA--ETC(U)

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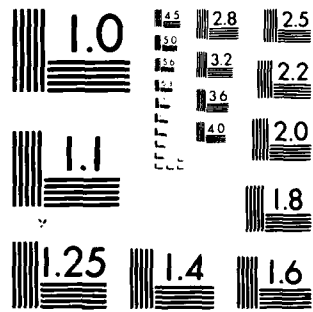
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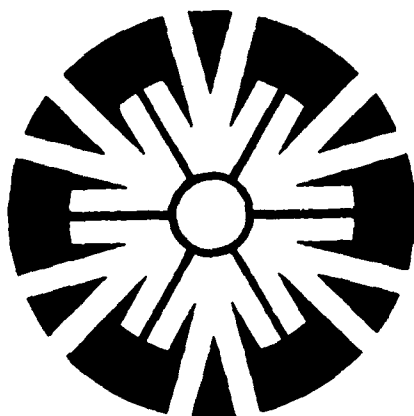
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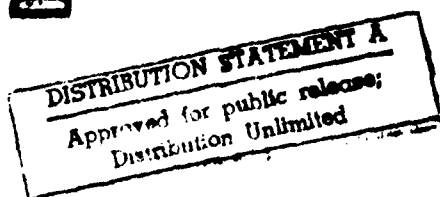


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the research efforts and the literature review were used to formulate recommendations for the revision of Military Standard 1472B for MMHA.

A brief summary of the results found for lift/lower, push/pull and carry activities is provided in the text.

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SUMMARY

This report describes the results of activities to review the strength and capacity data for Manual Material Handling Activities (MMHA). These efforts primarily involved a review of MMHA literature, preparation of an annotated bibliography and a summary of literature findings. To supplement these findings, experimental data were collected on the effect of the location of the center of gravity of the load and the effect of the presence or absence of couplings on the amount of weight lifted. The results from both of the research efforts and the literature review were used to formulate recommendations for the revision of Military Standard 1472B for MMHA.

A brief summary of the results found for lift/lower, push/pull, and carry activities is given below.

Lifting and Lowering

It has been generally found that the maximum acceptable weight of a load tends to decrease as the height of lift increases. The greatest maximum acceptable weight is usually found in the floor to knuckle height range with a consequent decrease in the acceptable weight as the height of lift ranges from knuckle to shoulder and from floor to shoulder heights. In addition, the amount of weight lifted is also a function of the rate of lift; as the frequency of lift (lifts/min) increases, the maximum acceptable weight decreases.

The dimensions of a load (i.e., length and width) have also been shown to affect lifting capacity. Generally, research has shown that as the object length (i.e., distance of the object's center of gravity [C.G.] from the carrier's body) is increased, while maintaining the load constant, the nature of the lifting task becomes more demanding. Data show that the ability to lift is reduced when the C.G. of the load is moved away from the carrier's spine in the sagittal plane. Object width (i.e., distance between hands) has also been shown to have little effect on the demands of the lifting task.

The presence or absence of handles on boxes has been

shown to have an additional effect on the amount of weight lifted; equipping boxes with handles usually allows for approximately 15% greater lifting capability.

When comparing the lifting capabilities of both male and female employees, it was found that females had a lifting capability of approximately 65 percent of the males lifting capability.

Pushing and Pulling

Research dealing with the effects of body posture on sustained pushing and pulling forces has shown that a change in body position, control placement, or body stabilization would reduce the required effort to maintain a given force under control. For example, a greater pulling force is usually generated from a sitting, rather than a standing position. Further, an increase in the knee and elbow angles gives similar results. The isometric pushing and pulling forces also vary as a function of the interaction between a subject's body weight, foot, and hand placements (foot placement is the distance of rear foot from vertical plane; hand placement is based on the height of the handle from the floor). For example, stronger pushing forces are usually found with higher hand placements and larger foot distances, while stronger pulling forces are generally generated by smaller foot distances and lower hand placements.

When examining the pushing and pulling capabilities for males and females, it is commonly found that the initial force (lbs) is greater than the sustained force. In addition, the generated initial force seems to depend on whether the rate of work is low, intermediate, or high; a higher initial force is found at low work rates than at intermediate or high work rates.

Carrying

The data generally reveal that an increase in carrying distance results in a decrease of the maximum acceptable weight when carrying a tote box at elbow height. When examining

the maximum work loads (ft.-lb./min.) acceptable to male and female workers while carrying a tote box at elbow height, an opposite trend was found; an increase in carrying distance results in an increase of acceptable work loads for the male and female workers.

A comparison of the maximum acceptable weights for males and females while carrying a 19 x 13.5 x 5.5 inch tote box at elbow height revealed that the acceptable weight for females was approximately 75 percent of the acceptable weight for males.

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INTRODUCTION

Poulson (1970) pointed out that the "rules for what workers handle manually vary widely from country to country, and the way in which these rules have been laid down very often depends on national laws and tradition."

It is now recognized that regulations for manual materials handling activities (MMHA) must be based on known human limits [Jones, 1971, 1972; Brown, 1971; Snook and Ciriello, 1972]. The selection of such limits is difficult, however, because of the variations in the operating conditions of the Man-Task-Environment System, namely, worker variables, task variables, and environmental variables.

OBJECTIVES

The objectives of this project were:

1. to review the current MMHA literature and prepare an annotated bibliography,
2. to conduct small experiments, to provide additionally needed data pertinent to MMHA, and
3. to provide data summaries to be used in updating standards to reflect the current state of the art in the manual material handling strengths and capacities.

To meet these objectives, the scientific literature was searched to determine the amount and quality of existing research on capacity and strength in MMHA. Relevant articles were abstracted. The information obtained from them was then classified into one of three categories depending upon the type of activity described in the article. These categories were:

1. lifting and lowering,
2. pushing and pulling, and
3. carrying.

These literature survey efforts identified MMHA that have not been adequately researched. Therefore, experimental data were collected on the effects of the presence of handles

and the location of the center of gravity on lifting activities.

Summaries of all available literature in each group were then prepared for use in updating MIL-STD-1472B.

METHODS

LITERATURE SEARCH

In the search for information on capacity and strength in manual materials handling activities (MMHA), the reviewers contacted as many sources as possible to make sure that reports of limited distribution, as well as reports in the published literature were included. The Texas Tech University library and the Texas Tech School of Medicine libraries were used for periodical holdings, cataloging systems, reference area containing abstract and bibliographic sources, and sources of referral to other libraries and institutions containing pertinent information through the interlibrary loan system. Computer data base facilities were assessed for their possible usefulness in the information search. To identify specific references of possible interest, four computer searches were actually used. They were:

1. American Psychological Association, Computer Search of Psychological Abstracts,
2. Medline, off-line Bibliographic Citation of the National Library of Medicine,
3. National Technical Information Service, U.S. Department of Commerce, and
4. Biosis, Computer Search of Biological Abstracts.

The Computer Search was supplemented by a manual search of abstract sources. Among those examined were:

1. Occupational Safety and Health Abstracts,
2. Dissertation Abstracts,
3. Engineering Abstracts, and
4. Index Medicus.

The various search procedures used to identify appropriate literature may generally be characterized as yielding three types of materials. These were:

1. titles, usually obtained from computer searches or referrals from other sources,

2. abstracts, (which of course included titles) usually resulting from the search of periodical abstract listings, and
3. documents, reprints of actual articles, books, reviews obtained by library search or by referral.

When only titles were obtained as from a computer search or referral from another source, the title generally indicated whether the reference was appropriate or not. If the title indicated that the article was inappropriate, it was eliminated from further consideration. When titles appeared promising, the document was obtained, reviewed, and relevant articles were abstracted. Frequently, references were mentioned in an article. If these were of importance to the objectives, they were obtained and abstracted (Appendix).

EXPERIMENTAL PROCEDURES

To achieve the second objective of this project, providing additionally needed data pertinent to MMHA, two laboratory experiments were conducted. Lifting capacity data were generated at Texas Tech University's Department of Industrial Engineering Laboratory. Conducting these two experiments helped in studying the effects of frequency of lift, height and range of lift, box size, location of the center of gravity (C.G.) of the load, and the effect of equipping the loads with handles on the lifting capacity of the individuals. In the two experiments a modified psychophysical technique was used.

Psychophysics is a very old branch of physiology that is concerned with the relationship between sensations and their physical stimuli; very rarely is this a one-to-one relationship. Stevens (1975) indicated that the strength of a sensation (S) is directly related to the intensity of

its physical stimulus (I) by means of a power function:

$$S = kI^n$$

where

S = strength of a sensation

I = intensity of physical stimulus

k = a constant which is a function of the particular units of measurement that are used

n = the slope of the line that represents the power function when plotting in log-log coordinates. It is equal to 3.5 for electric shock, and 1.6 for the perception of muscular effort and force.

The modified psychophysical technique used in these experiments allowed the subject to subjectively, (i.e., based upon his estimate of his working capacity, fatigue, and endurance) adjust the amount of weight he could lift repetitively for an 8 hour work day. The subject was instructed to adjust his work load to the maximum amount that he could perform, without strain or discomfort and without becoming tired, weakened, overheated, or out of breath.

Experiment (I): Unbalanced Load

Experimental Variables

There are three categories of variables that can influence the lifting capacity data values. These are: (1) worker variables, (2) task variables, and (3) environmental variables.

1. Worker Variables

The subjects participating in this project were four students with no experience in manual materials handling. All subjects were males. No attempt was made either to change or standardize each subject's method of lift; i.e., the subjects were allowed to use their "free style" lifting technique.

2. Task Variables

Frequency to Lift. The frequency of lift for

each task consisted of one of two levels utilized in the experiment. These were 2 and 6 lifts per minute. These frequencies were chosen to cover the range of frequencies encountered in industry. The subjects were paced in order to maintain the assigned lifting frequency for the duration of that particular lifting task combination.

Height and Vertical Range of Lift. The vertical range of lift consisted of three levels, each with a specific starting and terminating point. The combinations are given in Table 1.

Location of the Center of Gravity of Load Lifted. Two locations of the C.G. of load lifted were utilized:

- a. The C.G. of load lifted coincided with the geometrical C.G. of the box used, and
- b. the C.G. of the load shifted 4 in. in the direction of the non-preferred or weaker arm. The shift was in the frontal plane.

The box used had a size of 12 in. x 12 in. x 7 in. (width x length x depth).

3. Environmental Variables

Environmental Variables (e.g., humidity, temperature illumination) were not varied, but rather they were maintained within normal ranges throughout the experimental phase (72°F-74°F room temperature held constant).

The Task:

The lifting task required the use of a lifting apparatus, a container with handles, and lead weights. Each lifting task was comprised of one level of each of the task variables (frequency of lift, vertical range, and offset C.G.). There were 12 different possible combinations. The subject began each task without prior knowledge of the amount of weight in the container.

The subject lifted the box, using the handles mounted on the container. He lifted the box from one prescribed height level to another at a set frequency of lift for a

TABLE 1
Vertical Range of Lifts Used for Testing the Effects
of Location of C.G. on Lifting (Experiment I)

<u>Range</u>	<u>Starting Point</u>	<u>Ending Point</u>
Floor to knuckle	Floor level	Measured knuckle height (MKH)
Floor to shoulder	Floor level	MKH + 20"
Knuckle to shoulder	MKH	MKH + 20"

*Experiment was conducted at the Texas Tech Labs

specified offset of the C.G. of the load. After the lift was completed, the lifting apparatus lowered the container to the initial level and the subject lifted the box again at the onset of the signal. During the period between lifts, the subject was free to adjust the weight of the load. The container's weight at the end of the 20 minute period was considered the subject's maximum acceptable weight of lift for that particular task combination.

Experimental Design:

A randomized complete block design with factorial treatment combinations was utilized. Each subject was considered as a block. A random number table was used to determine the order in which the experiment was to be performed by a given subject. Each subject under this randomized design performed the 12 possible treatment combinations. The layout of the experiment is given in Table 2.

Experimental Procedure:

The experimental procedure, with respect to the lifting task, was selected to be a modified psychophysical technique.

The lifting procedure associated with this experiment allowed the individual to subjectively adjust, based upon the individual's estimate of his working capacity, fatigue, and endurance, the amount that he could perform without straining or discomfort and without becoming tired, weakened, overheated, or out of breath. Lead weights were placed in or taken out of the box by the subject until the maximum weight the subject could lift repetitively was determined. The subject lifted at a specified frequency controlled by the cadence of a light, and a buzzer signaled the start of each lift.

Each subject was required to read and listen to a recording of instructions explaining the experiment and the task that was expected of the subject.

TABLE 2
Experimental Layout Used for Testing the Effects of Location of C.G. on Lifting.
The Box Dimensions Were 12"x12"x7". (Experiment 1)*

		Height Level of Lift					
Subject	Frequency Lifts/min	Floor to Knuckle		Floor to Shoulder		Knuckle to Shoulder	
		0"	4"	0"	4"	0"	4"
Subject 1	2						
	6						
Subject 2	2						
	6						
Subject 3 . . .							

*Experiment was conducted at the Texas Tech Labs

Each subject was required to perform the 12 possible treatment combinations. Each treatment combination was performed for approximately 20 minutes. A brief rest period was provided between each 20 minute period while the equipment was being adjusted for the subsequent task combination.

The subject was not provided with any external motivational cues, i.e., [such as encouragement to lift more] reference made to the fact that the individual was performing better or worse than an arbitrary reference value.

Experiment (II): Effect of Couplings

Experimental Variables:

1. Worker Variables

The subjects participating in this project were four naive male students with no experience in manual materials handling. The subjects selected were a stratified sample. The basis of stratification was strength and endurance. The first subject had high strength and high endurance. The second had high strength and low endurance. The third had low strength and high endurance. The fourth had low strength and low endurance. The subjects were allowed to use their "free style" lifting technique.

2. Task Variables

Frequency of Lift. The frequency of lift for each task consisted of one of four levels utilized in the experiment. These were: 0.1, 0.2, 1 and 6 lifts per minute. The subjects were paced in order to maintain the assigned lifting frequency for the duration of that particular lifting task combination.

Height and Vertical Range of Lift. The vertical range of lift consisted of three levels, each with a specific starting and terminating point. The combinations are given in Table 3.

Handles. The effect of having boxes with handles and without handles was studied.

TABLE 3
Vertical Range of Lifts Used for Testing the
Effects of Handles on Lifting (Experiment II)

<u>Range</u>	<u>Starting Point</u>	<u>Ending Point</u>
Floor to knuckle	Floor level	Measured knuckle height (MKH)
Floor to shoulder	Floor level	MKH + 20"
Knuckle to shoulder	MKH	MKH + 20"

Bakken (1979)

3. Environmental Variables

Once again, the environmental variables were not varied, but rather they were controlled and maintained constant throughout the experimental phase as in Experiment I.

The Task:

The subjects were required to perform lifting tasks. Each task was comprised of one level of each of the task variables (frequency of lift, vertical range, box size, and handles). There were 48 different possible combinations.

The lifting task required the use of a lifting apparatus, a container with or without handles, and lead weights. The subject lifted the container with both hands, in the sagittal plane, using a free style lifting technique. After the lift was completed, the lifting apparatus lowered the container to the initial level at the onset of the signal. The subject began the task without prior knowledge of the amount of weight in the container. The subject was free to adjust the weight of the container at any time during the task period (20 min.) until the maximum load the subject could lift repeatedly for a long period of time (a work shift) was reached. The subject was to continue repetition of the task until the 20 minutes were over, even if they arrived at their maximum weight before then. The container's weight at the end of the 20 minute period was considered the individual's maximum acceptable weight of lift for that particular task combination.

Experimental Design:

A randomized complete block design with factorial treatment combinations was utilized. Each subject was considered as a block. Each subject replicated the whole experiment three times. A random number table was used to determine the order in which the experiment was to be performed by a given subject. The layout of the experiment is given in Table 4.

TABLE 4
Experimental Layout Used for Testing the Effects of Handles
On Lifting (Experiment II)

		Height of Lift					
		Floor to Knuckle		Floor to Shoulder		Knuckle to Shoulder	
		Handles		Handles		Handles	
		W'	W'O	W'	W'O	W'	W'O
Subject 1	Repl. 1	Box		14"	Frequency Lifts/min	0.1 0.2 1 6	
		Size		20	Frequency Lifts/min	0.1 0.2 1 6	
		Box		14"	Frequency Lifts/min	0.1 0.2 1 6	
		Size		20	Frequency Lifts/min	0.1 0.2 1 6	
	Repl. 3			etc.			
	Repl. 2	Box		14"	Frequency Lifts/min	0.1 0.2 1 6	
		Size		20	Frequency Lifts/min	0.1 0.2 1 6	
	Repl. 1	Box		14"	Frequency Lifts/min	0.1 0.2 1 6	
		Size		20	Frequency Lifts/min	0.1 0.2 1 6	
	Repl. 3			etc.			

Bakken (1979)

Experimental Procedure:

The experimental procedure, with respect to the lifting task, was selected to be a modified psychophysical technique.

The lifting procedure associated with this experiment allowed the individual to subjectively adjust, based upon the individual's estimate of his working capacity, fatigue, and endurance, the amount that he could perform without straining or discomfort and without becoming tired, weakened, overheated, or out of breath. Lead weights were placed in or taken out of the box by the subject until the maximum weight the subject could lift repetitively was determined. The subject lifted at a specified frequency controlled by the cadence of a light and buzzer signaling the start of each lift. Each subject was required to read and listen to a recording of instructions explaining the experiment and the task and what was expected of each subject.

RESULTS AND DISCUSSION

The data from the literature review were evaluated and organized into three categories: (1) lifting/lowering; (2) pushing/pulling; and (3) carrying. Pertinent results are given below. Sufficient data were found for additional subdivisions to be made in the lifting/lowering and pushing/pulling categories. For each of these subdivisions and for the undivided category of carrying, a summary was prepared of the best values presently available for use in preparing and/or revising standards on MMHA.

LIFTING AND LOWERING

Considerable research has been conducted on various aspects of lifting. Therefore the material in this category has been divided into five areas: Strength norms, capacity norms, physiological models, effects of frequency of lift on the amount of weight lifted, and effects of box size on the amount of weight lifted.

Strength Norms: Literature Review

Emanuel, et al. (1956) instructed 19 young students (17 to 28 years old) to lift "the greatest weight possible without a feeling of possible injury" using the psycho-physical approach. The subjects then varied the weight of the object lifted by adding or subtracting 10 lb. bags of lead shots. They were required to lift with a straight, though not necessarily vertical, back. The subjects were classified as untrained in lifting and lifted an F-86H ammunition case 10-3/4 in. high, 25-1/2 in. wide, and 6-3/4 in. deep. The case had two handles at the top. Maximum acceptable weight for a single lift is given in Figure I.

The study discussed above gives estimates of the load magnitudes that a person can lift for different heights of lift. Two additional studies were concerned with muscular strength as related to lifting. Whitney (1958) studied the position of the foot and its effect on lifting force using

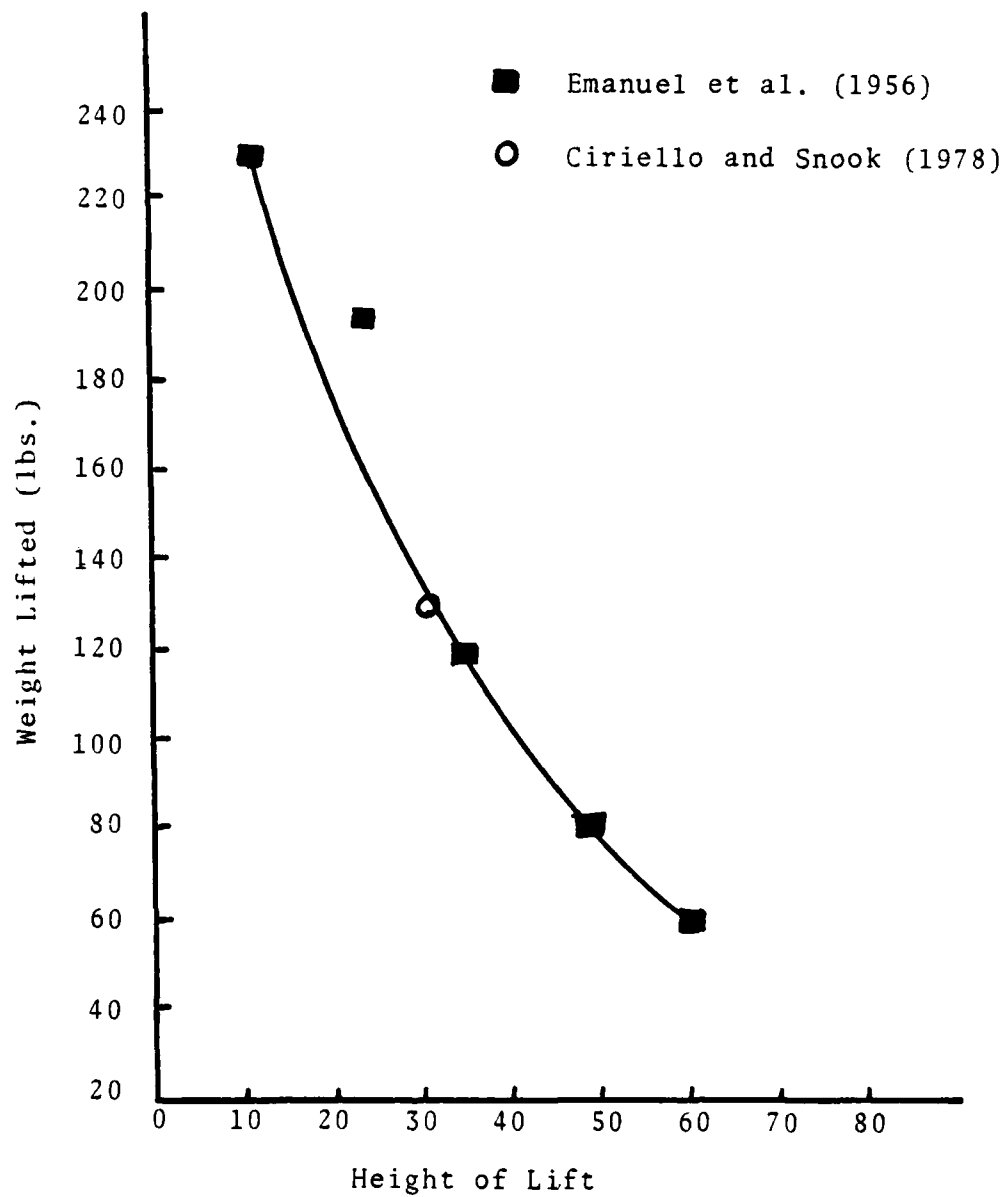


Figure 1: Maximum Acceptable Weight for Males and Different Heights (the lifting capacity of women is 6.5% of each plotted value)

eight male subjects. They were instructed to exert a steady maximum lifting force on a horizontal bar (1.3 inches dia.) placed in a frontal plane for a period of 3 sec. The distance between the hands was maintained at 15.7 inches. Three levels of grasp height were investigated: 4.9, 9.8, and 19.7 inches above ground level. Three distances of foot placement were considered: 11.8, 15.7 and 19.7 inches. The subjects adopted one of two types of lifting action, either a derrick action or knee action. The results indicated that the lifting force decreased as the distance between the feet or of the feet from the bar increased. This decrease, due to foot placement, was more significant as compared to the decrease in the lifting force due to the increase in grasp height. The maximum isometric force exorable on a horizontal bar varied from 33 to 264 lbs. for the different lifting conditions.

Chaffin, (1974) studied the lifting strength as demonstrated by employees in a standard position strength testing. A total of 103 jobs held by 411 men and women were evaluated for physical stress. The modal value for females (26 lbs.) was 65 percent of the modal value for men (40 lbs.). Women had a lifting strength mean of 30 lbs. with a standard deviation of 16 lbs, while the mean for men was 52 lbs. with a standard deviation of 23 lbs. Snook and Ciriello (1974) have also indicated that the weights and work loads acceptable to female workers were significantly different from those acceptable to male workers.

Strength Norms: Summary

The data in Figure 1 from Emanuel, et al. (1956) can be used as a summary for the strength norms for men. The data points are connected with a line to facilitate using the graph in predicting the weight lifted for other heights. It is worth mentioning that when the data of Ciriello and Snook (1978) for subjects performing one lift every 8 hours was plotted on the same graph (Figure 1), it was very close to

the line connecting Emanuel's data points. This in itself adds to the reliability of Emanuel's data.

As Chaffin (1974) reported, women had a lifting strength of about 65 percent of men. The graph in Figure I can be used for estimating the weight lifted by a female to a certain height by multiplying the value obtained from the graph by 0.65.

No data are available at the present for lowering strength norms.

Capacity Norms: Literature Review

Snook and Irvine (1967) used a subjective criterion to determine the maximum acceptable weight the male industrial population could lift. Nine male subjects, between 25 and 37 years of age (average age 30.1 years) were used. They were instructed to adjust the weight of a box until they felt that it was the maximum amount that could be lifted comfortably once every 15 minutes. Subjects were industrial workers in good health. They performed a daily schedule of push-ups, and pull-ups, and deep knee bend exercises in their homes during the week prior to their scheduled participation in the experiment.

During the first 4 days of the experiment, subjects were instructed in the correct lifting procedures and given 18 practice trials at adjusting the weight of the lifted object by lifting for varying periods of time. Subsequently, eighteen 5-minute sessions and three 30-minute sessions of repeated lifting were performed by each subject. The object lifted was similar to an industrial tote box, 13-1/2 in. x 19 in. x 15 1/2 in. with two 7 in. x 1-5/8 in. handles. The box weighed 10 lbs. and had a false bottom which could hold a maximum of 40 lbs. of lead shot. Subjects made only one judgement per lifting height in a single day. Each subject made a total of 18 judgements: six for the floor to knuckle height lift, six for the knuckle to shoulder height lift, and six for the shoulder to reach height lift. For one

half of the judgements, the initial weight of the box was 30 lbs.; for the other half, 100 lbs. was the initial weight. The results of this study are shown in Table 5.

In a second study, Snook and Irvine (1968) used a psychophysical approach to determine the maximum acceptable frequency of lift for different combinations of height of lift and box weight. Three heights of lift were used: floor level to knuckle height, knuckle to shoulder height, and shoulder to reach height. Two weights were used, 35 and 50 lbs. Eight male workers from local industry performed as subjects. Their age ranged from 26 years to 37 years (average 31 years). They were trained in the same way as the subjects in the previous study (Snook and Irvine, 1967) were trained.

The subjects were asked to adjust the frequency of lift according to their sensations or feelings of fatigue. They were specifically instructed to imagine that they were on piece work, getting paid for the number of lifts each could make, but working a normal 8-hour shift that allowed each subject to go home without feeling fatigued. In other words, the subject should work as hard as he can without becoming tired, weakened, overheated, or out of breath. The experiment was replicated three times for each subject. The heart rate of the subjects was monitored and recorded.

The results indicated that there were no significant heart rate differences between the two loads, 35 lbs. and 50 lbs., while there were significant heart rate differences among the three heights of lift. Subjects maintained a mean heart rate of 112 beats per minute for floor to knuckle lift, while they maintained a mean heart rate of 99 beats per minute for the other two heights of lift. The final frequencies of lift selected by each worker were converted into ft-lbs/min. to provide a comparison between 35 lb. and 50 lb. weights of lift. A significant difference was found for these work loads among the three heights and two weights. The maximum

TABLE 5
Maximum Acceptable Weight (lbs.) of Lift for Males for
Three Different Heights of Lift*

Height of Lift	Mean	Std. Devia.	Percent of Population										
			95	85	75	65	55	50	45	35	25	15	5
Floor to Knuckle	66	11	48	51	59	62	65	66	67	70	73	81	84
Knuckle to Shoulder	62	9	48	50	56	59	61	62	63	65	68	74	76
Shoulder to Reach	60	10	44	47	53	56	59	60	61	64	67	73	76

Snook and Irvine (1967)

*Assuming a normal distribution. The box dimensions were 13.5"L x 19"W x 5.5"H.
Frequency of lift was 1 lift every 15 minutes.

work loads acceptable to the industrial male workers are summarized in Table 6.

Snook, et al. (1970) conducted another study to determine the maximum weights and work loads acceptable to male industrial workers. The manual materials handling tasks involved lifting, lowering, pushing, pulling, and carrying tasks. Twenty-eight male subjects from the local industry participated in the experiment. They were all in good health. Three height ranges were used for lifting and lowering tasks: Floor level to knuckle height; knuckle height to shoulder height; and shoulder height to arm reach height. Force was the dependent variable for all tasks, except for paced carrying, where it was adjusted by varying the weight of the object being handled (tote box: 13-1/2 in. x 19 in. x 15-1/2 in. with two 7 in. x 1-5/8 in. handles). All tasks except carrying were performed at high, medium, and low rates of work. Subjects were instructed to adjust their work load to the maximum amount that they could perform without strain, discomfort, weakness or getting tired. Three subjects performed simultaneously. Each task took about 40 min. The results of the study for lifting and lowering are given in Tables 7 and 8. Results for the other tasks are presented in the subsequent categories of pushing/pulling and carrying.

Snook and Ciriello(1974) performed a similar study on female workers to find out the maximum weights and work loads acceptable to them. Thirty-one women served as subjects. Sixteen of these were housewives with a mean age of 35.6 years while the remaining 15 were workers from local industry with a mean age of 38.5 years. The experimental setup was identical to the one described in the previous study (Snook, et al., 1970). The results of this study are summarized in Tables 9 and 10.

Ciriello and Snook, (1978) investigated the effect of additional variables: object length (distance between the hands); object width (distance away from the body);

TABLE 6
Distribution of Maximum Workloads (ft.-lb./min.) Acceptable to Male
Industrial Workers for Three Different Heights
and Two Different Weights*

Height of Lift	Wt. of Object (lbs.)	Mean Work Load	Std. Devia.	Percent of Population										
				95	85	75	65	55	50	45	35	25	15	5
Shoulder to Reach	50	374	71	257	277	326	347	365	374	383	401	422	471	491
	35	342	71	225	245	284	315	333	342	351	369	390	439	459
Knuckle to Shoulder	50	454	102	286	314	385	414	441	454	467	494	523	584	622
	35	413	95	256	283	349	376	401	413	425	450	477	543	570
Floor to Knuckle	50	317	89	171	186	257	283	306	317	328	351	377	438	463
	35	244	49	164	178	211	225	238	244	250	263	277	310	324

Snook and Irvine (1968)

*Assuming a normal distribution. The box dimensions were 19"L x 13.5"W x 5.5"H.
Frequency of lift was selected by subject (Psychophysical method).

TABLE 7
Distribution of Maximum Weights (lbs.) of Lift and Lower
Acceptable to Male Industrial Workers*

Height Levels	Activity	Mean	Std. Devia.	Percent of Population										
				95	85	75	65	55	50	45	35	25	15	5
Floor to Knuckle	Lift	54	13	33	40	45	49	52	54	55	59	62	67	75
	Lower	62	20	29	41	48	54	59	62	64	70	75	83	95
Knuckle to Shoulder	Lift	63	14	29	38	43	47	51	53	54	58	63	68	76
	Lower	55	12	34	42	46	50	53	55	56	59	63	67	75
Shoulder to Reach	Lift	49	15	24	33	39	43	47	49	51	55	59	64	74
	Lower	44	12	24	32	36	40	43	44	46	49	52	57	64

Snook, et al. (1970)

*Assuming a normal distribution. A tote box measuring 13.5"L x 19"W x 5.5"H was used. The frequency of lift was randomly varied.

TABLE 8
Distribution of Maximum Workloads (ft.-lb./min.) for Lifting and
Lowering Tasks Acceptable to Male Industrial Workers for
Three Different Height Ranges*

Height Levels	Activity	Mean	Std. Devia.	Percent of Population										
				95	85	75	65	55	50	45	35	25	15	5
Floor to Knuckle	Lift	322	88	177	230	262	288	311	322	333	356	382	414	467
	Lower	539	178	246	354	419	470	517	539	561	608	659	724	832
Knuckle to Shoulder	Lift	468	105	294	359	397	427	455	468	481	509	539	577	642
	Lower	667	184	364	476	543	596	644	677	690	738	792	858	970
Shoulder to Reach	Lift	370	140	157	236	282	320	354	379	386	420	458	505	583
	Lower	471	169	193	296	357	406	450	471	492	536	585	646	749

Snook, et al. (1970)

*Assuming a normal distribution. The box dimensions were 13.5"L. x 19"W x 5.5"H.
The frequency of lift was randomly varied.

TABLE 9
Distribution of Maximum Weights (lbs.) Acceptable to Both Industrial
Women and Housewives during Lifting and Lowering
for Three Different Heights*

Height of Lift	Activity	Mean	Std. Devia.	Percent of Population											
				97	85	75	65	55	50	45	35	25	15	5	
Shoulder to Reach	Lift	29	4	23	25	36	27	29	29	29	3	32	34	35	
	Housewives	18	4	12	14	15	16	18	18	18	20	21	22	24	
	Lower	30	5	22	25	27	28	29	30	31	32	33	35	38	
	Housewives	19	5	10	13	16	17	18	19	20	21	22	25	28	
Knuckle to Shoulder	Lift	34	7	22	27	29	31	33	34	35	37	38	41	46	
	Housewives	21	4	15	17	18	19	21	21	21	23	23	25	27	
	Lower	35	7	23	28	31	32	34	35	36	38	39	42	46	
	Housewives	22	7	10	15	18	19	21	22	23	25	26	29	34	
Floor to Knuckle	Lift	37	7	25	30	33	34	36	37	38	40	42	44	48	
	Housewives	21	5	12	15	17	19	20	21	23	23	24	27	30	
	Lower	38	6	28	32	34	36	37	38	39	40	43	44	48	
	Housewives	22	7	10	15	18	19	21	22	23	25	27	29	34	

Snook and Ciriello (1974)

*Assuming a normal distribution. The box dimensions were 13.5"L x 19"W x 5.5"H.
Frequency of lift was selected by subject (psychophysical method).

TABLE 10
Distribution of Maximum Workloads (ft.-lb./min.) Acceptable to Both Industrial Women
and Housewives While Lifting and Lowering for Three Different Heights*

Height of Lift	Activity	Mean	Std. Devia.	Percent of Population										
				97	85	75	65	55	50	45	35	25	15	5
Shoulder to Reach	Lift	252	34	197	217	230	239	248	252	256	265	274	287	307
	Housewives	145	33	91	111	124	132	141	145	149	158	166	179	199
	Lower	411	80	280	328	358	380	401	411	421	442	464	494	543
	Housewives	236	52	151	183	202	216	229	236	242	256	271	289	321
Knuckle to Shoulder	Lift	335	48	255	285	303	316	329	355	341	354	367	385	415
	Housewives	203	41	135	160	176	187	198	203	208	219	230	246	271
	Lower	561	111	379	446	488	518	547	561	575	604	635	676	745
	Housewives	303	55	213	246	267	282	296	303	310	324	339	359	393
Floor to Knuckle	Lift	241	52	156	188	207	221	234	241	247	261	276	294	326
	Housewives	121	31	70	89	101	109	117	121	125	133	142	153	172
	Lower	398	74	276	321	349	369	389	398	407	426	446	475	520
	Housewives	216	55	126	159	180	195	209	216	223	237	251	273	306

Snook and Ciriello (1974)

*Assuming a normal distribution

lifting distance; and pushing and pulling height. Fifteen male industrial subjects were used. Sixty one different lifting, lowering, pushing, and carrying tasks were performed in a moderate environment of 21.5°C dry bulb and 45 percent relative humidity. There were no significant weight differences in object length. There were no significant weight differences ($p < 0.01$) among three object widths (14.2, 19.3 and 29.5 in.), but only for those lifts between floor level and knuckle height. Significant weight differences ($p < 0.01$) also occurred among three lifting distances (9.8, 20.0, and 29.9 in).

Snook (1978) attempted to integrate the results of all the studies that he had conducted over a period of 10 years into a format that considered all of the significant variables. Tables 11 and 12 summarized that attempt. However, it is important to note that not all of the values in these tables were based upon the experimental data; assumptions had to be made to fill in the gaps that have not yet been studied. For example, lifting data for the 19.3 inch and 29.5 inch object widths had not been collected at the time of preparing the table. Therefore, the values in Table 12 for 19.3 and 29.5 inches represent adjustments of the 14.0 inch female data based upon the proportional differences observed in male workers. Similar adjustments were also made for the other frequencies and distances that had not yet been studied.

Ayoub, et al. (1978) conducted a study to determine and model the lifting capacity of 73 male and female industrial workers. Six different height levels and four frequencies were employed. The height levels were: (1) floor to knuckle; (2) floor to shoulder; (3) floor to reach; (4) knuckle to shoulder; (5) knuckle to reach; and (6) shoulder to reach. The frequencies studied were 2, 4, 6, and 8 lifts/min. The experimental procedure was similar to the one described in the study by Snook, et al. (1970). Subjects were asked to

TABLE II
Maximum Acceptable Weight (lbs.) of Load for Males and Females for Different
Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift	MALES					FEMALES				
			One Lift Every					1 min.				
			9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.
Floor to Knuckle	29.5"	x	40	57	77	90	26	33	44	53		
		30"	0	14	21	26	5	5	7	9		
		x	40	59	79	95	29	33	46	55		
		20"	0	15	22	26	5	7	7	9		
		x	46	66	90	106	33	37	53	62		
		10"	0	19	24	29	5	7	9	10		
	19.3"	x	46	66	90	66	31	37	53	62		
		30"	0	19	26	31	5	7	7	10		
		x	46	68	92	110	31	40	53	64		
		20"	0	21	28	33	7	7	10	10		
		x	55	77	106	123	37	44	62	73		
		10"	0	22	31	38	7	9	9	12		
	14.2"	x	50	73	99	117	35	42	57	68		
		30"	0	21	29	34	7	7	9	10		
		x	53	75	103	121	35	44	59	70		
		20"	0	22	29	36	7	7	10	12		
		x	62	86	117	136	42	48	66	79		
		10"	0	24	34	41	9	9	12	14		

Snook (1978)

TABLE 11 (continued)
Maximum Acceptable Weight (lbs.) of Lower for Males and Females for Different
Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift	MALES					FEMALES					
			One Lift Every										
			9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.
Knuckle to Shoulder	29.5"	x	40	48	55	66	29	31	37	42			
		30"	0	12	15	21	5	5	7	9			
		x	42	53	64	75	31	33	40	46			
		20"	0	14	17	22	7	5	9	9			
		x	51	64	75	88	37	37	48	55			
		10"	0	15	19	28	9	9	9	10			
	19.5"	x	40	48	59	66	29	31	37	42			
		30"	0	12	17	21	5	5	7	9			
		x	42	53	66	75	31	33	40	46			
		20"	0	14	21	22	7	5	9	9			
		x	51	64	79	88	37	37	48	53			
		10"	0	15	19	28	9	9	9	10			
14.2"	x	44	51	64	73	29	33	40	46				
	30"	0	12	19	21	7	7	9	9				
	x	46	57	72	81	33	35	44	48				
	20"	0	14	21	24	7	7	9	10				
	x	55	68	86	97	40	42	51	57				
	10"	0	15	24	28	19	7	10	12				

Snook (1978)

TABLE 11 (continued)
Maximum Acceptable Weight (lbs.) of Lower for Males and Females for Different
Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift	MALES					FEMALES				
			One Lift Every									
			9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.		
Shoulder to Reach	29.5"	x	31	40	48	55	24	26	33	37		
		30"	0	10	14	15	5	3	5	5		
		x	33	44	55	62	26	29	35	40		
		20"	0	12	15	17	5	3	5	7		
		x	40	51	64	73	33	33	40	46		
		10"	0	15	19	21	5	5	7	7		
	19.5"	x	31	40	48	55	24	26	33	37		
		30"	0	10	14	15	5	3	5	5		
		x	37	44	55	62	26	29	35	40		
		20"	0	12	15	17	5	3	5	7		
		x	40	51	64	73	33	33	40	46		
		10"	0	15	19	21	5	5	7	7		
14.2"	x	33	42	53	59	26	29	35	40			
	30"	0	12	15	17	3	5	5	7			
	x	35	46	69	66	29	31	37	42			
	20"	0	12	14	19	5	5	7	7			
	x	42	55	68	77	33	35	44	62			
	10"	0	14	21	24	7	7	7	9			

Snook (1978)

TABLE 12
Maximum Acceptable Weight (lbs.) of Lift for Males and Females for Different
Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift	MALES				FEMALES			
			One Lift Every				One Lift Every			
			9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.
Floor to Knee	29.5"	x	37	48	66	79	26	31	44	51
		30"	12	14	15	21	5	7	9	10
		x	40	51	68	82	26	33	44	53
		20"	10	14	19	22	5	7	9	10
	19.3"	x	46	57	77	93	31	37	51	59
		10"	14	15	22	26	7	7	10	12
		x	42	57	77	93	29	37	51	59
		30"	12	17	24	28	7	7	10	12
	14.2"	x	44	60	82	95	29	37	53	62
		20"	12	17	24	29	7	9	10	12
		x	51	66	90	108	35	44	59	70
		10"	15	21	28	31	7	9	12	14
	14.2"	x	48	64	86	101	33	42	55	66
		30"	15	19	26	31	7	7	12	12
		x	51	66	88	106	35	42	57	68
		20"	15	19	23	31	7	9	12	14
	10"	x	60	75	101	119	40	48	66	77
		10"	17	21	29	36	9	9	12	15

Snook (1978)

TABLE 12 (continued)
Maximum Acceptable Weight (lbs.) of Lift for Males and Females for Different
Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift	MALES					FEMALES					
			One Lift Every					One Lift Every					
			9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.
Shoulder to Reach	29.5"	30"	33	44	55	62	20	24	29	33			
		0	10	12	15	17	3	3	5	5			
		20"	37	48	62	68	24	26	33	37			
		0	10	15	17	21	2	5	5	5			
		10"	44	57	73	82	29	31	40	44			
		0	12	17	21	22	3	5	5	7			
	19.5"	30"	33	44	55	62	20	24	29	33			
		0	10	12	15	17	3	3	5	5			
		20"	37	48	62	68	24	26	33	37			
		0	10	15	17	21	2	5	5	5			
		10"	44	57	73	82	29	31	40	44			
		0	12	17	21	22	3	5	5	7			
14.2"	30"	35	46	60	66	22	26	33	35				
	0	10	15	17	19	3	3	3	5				
	20"	40	53	66	75	24	29	35	40				
	0	12	15	19	22	3	5	5	7				
	10"	48	62	77	88	31	35	42	48				
	0	14	19	24	26	3	3	7	7				

Shook (1978)

TABLE 12 (continued)
Maximum Acceptable Weight (lbs.) of Lift for Males and Females for Different
Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift	MALES				FEMALES			
			One Lift Every				One Lift Every			
			9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.
Knuckle to Shoulder	29.5"	x	42	46	60	66	26	29	35	40
		30"	10	14	15	19	3	5	7	7
		x	44	53	66	75	29	31	40	44
		20"	12	15	19	21	3	7	7	9
	19.3"	x	53	62	77	88	33	37	46	51
		10"	14	19	22	24	5	7	9	10
		x	42	46	60	66	26	29	35	40
		30"	10	14	15	19	3	5	7	7
	14.2"	x	44	53	66	75	29	31	40	44
		20"	12	15	19	21	3	7	7	9
		x	53	62	77	88	33	37	46	51
		10"	14	19	22	24	5	7	9	10
	29.5"	x	44	51	64	71	29	31	37	41
		30"	10	15	19	22	3	5	7	9
		x	46	57	71	79	31	33	42	46
		20"	12	17	21	24	3	7	9	10
	19.3"	x	55	68	84	95	35	40	48	55
		10"	14	19	24	28	5	9	10	12
	14.2"	x	46	57	71	79	31	33	42	46
		20"	12	17	21	24	3	7	9	10
		x	55	68	84	95	35	40	48	55
		10"	14	19	24	28	5	9	10	12

Snook (1978)

lift a tote box, which had a dimension in the sagittal plane of 12 in., 18 in., or 24 in. Strength and anthropometric measurements were recorded for each subject and were used to develop lifting capacity prediction models. Lifting capacity values for the various height levels are summarized in Table 13.

Capacity Norms: Experimental Findings

Experiment (I): Unbalanced Loads

The maximum acceptable weights for experiment (I) are listed in Table 14 for different frequencies of lift, different height levels and different locations of center of gravity of the load lifted.

An analysis of variance of the data showed that the frequency of lift had a significant effect on the amount of weight lifted ($p < 0.01$). Subjects lifted less weight for the frequency of 6 lifts/min.

The three height levels had a significant main effect on the maximum acceptable weights ($p < 0.01$). However, only the floor to knuckle height was significantly different from the other levels. Subjects lifted more weight from floor to knuckle height.

The location of the center of gravity (C.G.) of the load lifted had a significant effect on the amount of weight lifted ($p < 0.01$). Subjects lifted less weight when the C.G. of the load lifted was shifted a distance of 4 in. in the frontal plane from the center of gravity of the box used.

Experiment (II): Effect of Couplings

The effects of handles on the maximum acceptable weight of lift are presented in Figure 2.

An analysis of variance of the data showed that the frequency of lift had a significant effect on the amount of weight lifted ($p < 0.01$). Subjects lifted less weight for the frequency of 6 lifts/min.

TABLE 13
Distribution of Maximum Weights (lbs.) of Lift Acceptable to
Male and Female Industrial Workers (Corrected for one lift/
min.) for Various Height Levels

Height of Lift	Sex	Mean	Std. Devia.	Percent of Population											
				95	85	75	65	55	50	45	35	25	15	5	
Floor to Knuckle	Male	61	17	33	44	50	55	59	61	63	68	73	79	89	
	Female	37	7	26	30	33	35	36	37	38	40	42	44	48	
Floor to Shoulder	Male	51	12	31	39	43	47	50	51	53	56	60	64	71	
	Female	31	7	20	24	27	29	30	31	32	34	36	38	42	
Floor to Reach	Male	49	11	31	38	41	45	48	49	51	53	57	61	68	
	Female	28	5	19	22	24	26	27	28	29	30	32	34	37	
Knuckle to Shoulder	Male	57	15	33	42	47	52	56	57	59	63	68	73	82	
	Female	32	7	21	35	27	29	31	32	33	35	36	39	43	
Knuckle to Reach	Male	54	11	36	42	46	49	52	54	55	58	61	65	71	
	Female	26	5	18	21	23	24	26	26	27	28	30	31	34	
Shoulder to Reach	Male	44	10	26	33	36	40	42	44	45	48	51	54	61	
	Female	26	4	19	21	23	24	25	26	26	27	29	30	33	

Ayoub, et al. (1978)

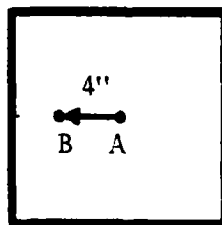
*Assuming a normal distribution. The box dimensions were (width x height x length): 12"x7"x12", 12"x7"x18", and 12"x7"x24".

TABLE 14
Maximum Acceptable Weights for Males Performing Lifting
Tasks at Different Frequencies of Lift, Different
Height Levels, and Different Locations of
C.G. of Load Lifted (Experiment I)*

Frequency of Lift (lifts/min.)	Height Level	Location of C.G. of Load Lifted	Ave. Weight Lifted (lbs.)
2	F ¹ - K ²	0" ⁴	63
2	F - S ³	0"	58
2	K - S	0"	56
2	F - K	4" ⁵	63
2	F - S	4"	54
2	K - S	4"	50
6	F - K	0" ⁴	59
6	F - S	0"	43
6	K - S	0"	45
6	F - K	4"	60
6	F - S	4"	38
6	K - S	4"	42

1. F = Floor height
2. K = Knuckle height
3. S = Shoulder height
4. 0" = C.G. of load lifted is at the exact same point as the C.G. of the box used
5. 4" = C.G. of load lifted is shifted 4" in the frontal plane from the C.G. of box used. A drawing which illustrates a shifted load from the center of gravity is presented for the reader.

Plan View of
Box
(12"LX12"WX7"H)



A - Center of Gravity
B - Shifted Load

*Data generated at Texas Tech Labs.

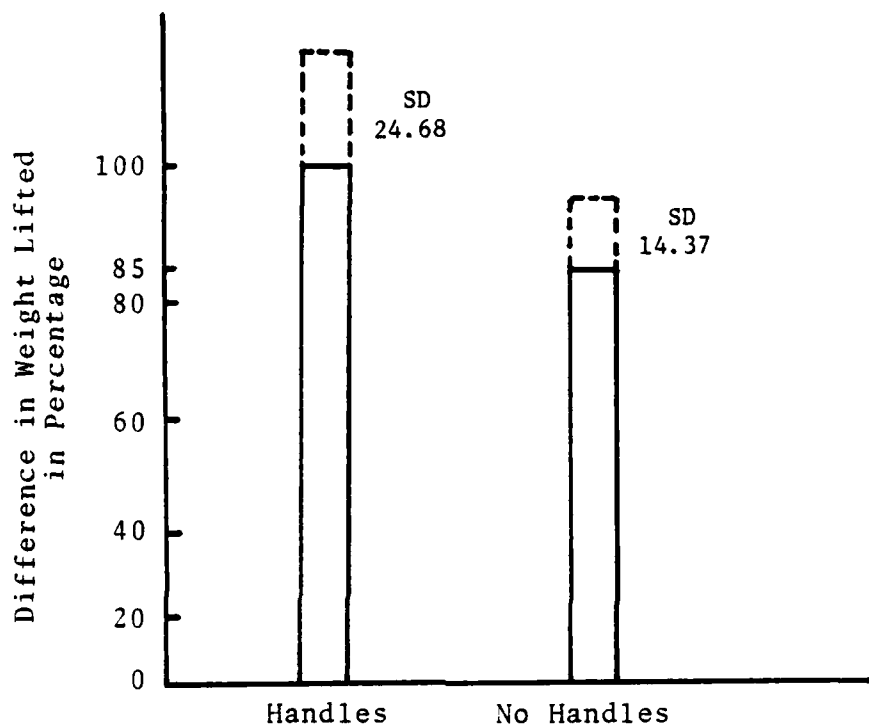


Figure 2: Effects of the Presence of Handles on Lifting Capacity (Bakken, 1979).

Significant weight differences ($p < 0.01$) were found among the three height levels. Subjects lifted more weight from floor to knuckle height.

The two lengths of the box studied (14 in. and 20 in.) did not have any significant effect on the amount of weight lifted.

Equipping boxes with handles had a pronounced effect on the amount of load lifted by the students ($p < 0.01$). Subjects were able to lift 16 percent more weight when boxes were equipped with handles, as shown in Figure 2.

Capacity Norms: Summary

At the present time there is no general agreement regarding the capacity limits for lifting and lowering tasks for male and female workers. Table 15 gives a summary of the lifting capacity of male and female workers; the values of this table were formulated by adjusting the lifting capacity values for the box size and frequency effects generated by Ayoub, et al. (1978) and Snook (1978). A linear box size and frequency of lift effect were assumed for this purpose. The box size used here was the box dimension in the sagittal plane. According to Snook (1978), the lifting capacity is not affected by the box dimension in the frontal plane as it has been shown to affect capacity in the sagittal plane. The standard deviation value given in table 15 is the larger of the values generated by Ayoub, et al. (1978) and Snook (1978).

For the floor to shoulder height, floor to reach height, and knuckle to reach height levels, the lifting capacity values recommended by Ayoub, et al. (1978) have been used, as there were no other lifting capacity data available in the literature for these height levels. For the same reason, Snook's (1978) data for the frequencies of 1 and 12 lifts/min. were used, while for the frequencies of 2 and 8 lifts/min., Ayoub, et al. (1978) data were used. For the frequency

TABLE 15
Mean and Standard Deviation of the Maximum Recommended Weight of Lift
(lbs.) for Male and Female Workers

Height of Lift	Box Dimension in the Sagittal Plane	MALE WORKERS					FEMALE WORKERS						
		Frequency of Lift/min											
		1	2	4	6	8	12	1	2	4	6	8	12
Floor to Knuckle	12	67	61	53	49	46	39	44	41	35	31	29	25
	18	19	21	15	18	17	12	7	3	7	8	7	7
	24	59	57	52	48	43	34	39	30	28	27	26	23
Floor to Shoulder	12	17	19	21	13	14	9	7	7	11	7	5	5
	18	53	51	47	53	39	31	34	28	27	27	25	21
	24	17	15	17	11	18	9	7	5	6	5	6	5
Floor to Reach	12	52*	51	48	45	42	36*	29*	29	29	28	28	27*
	18	13	14	12	13	14	14	7	7	3	8	4	2
	24	54*	53	51	49	47	43*	32	32	30	28	26	22*
Floor to Reach	12	7	7	13	11	15	10	6	6	7	10	5	4
	18	51*	51	59	47	45	41*	30	29	28	26	25	22*
	24	11	11	10	8	14	12	6	6	4	5	8	7
Floor to Reach	12	48*	47	45	42	40	35*	28*	27	26	25	24	21*
	18	11	11	13	7	8	6	5	5	6	6	4	6
	24	57*	54	47	40	33	19*	29	28	27	25	24	22*
Floor to Reach	12	14	14	13	9	8	4	5	5	5	4	4	1
	18	41*	41	39	38	37	34*	27	26	25	24	23	20*
	24	12	12	3	9	10	8	6	6	7	5	4	5

TABLE 15 (continued)
Mean and Standard Deviation of the Maximum Recommended Weight of Lift
(lbs.) for Male and Female Workers

Height of Lift	Box Dimension in the Sagittal Plane	MALE WORKERS						FEMALE WORKERS					
		Frequency of Lift/min											
		1	2	4	6	8	12	1	2	4	6	8	12
Knuckle to Shoulder	12	5.5	5.1	4.8	4.4	4.1	3.4	5.2	3.1	3.0	2.8	2.6	2.3
	18	6	15	12	10	14	9	5	8	5	5	8	3
	24	5.9	5.7	5.3	4.9	4.4	3.1	2.9	2.9	2.9	2.8	2.5	2.0
	12	6	14	16	19	14	12	9	5	5	5	7	3
	18	4.6	4.5	4.2	3.9	3.6	3.1	2.9	2.8	2.6	2.5	2.3	1.9
	24	6	14	16	15	19	16	9	5	6	7	6	4
Knuckle to Reach	12	4.9*	4.7	4.3	4.0	3.6	2.9*	2.8*	2.8	2.7	2.5	2.4	2.2*
	18	6	15	15	9	11	8	3	8	6	5	7	6
	24	5.5*	5.3	4.8	4.4	4.0	3.1*	2.6	2.6	2.5	2.5	2.4	2.3*
	12	6	9	9	8	7	11	10	4	3	4	4	4
	18	5.4*	5.2	4.8	4.4	4.0	3.2*	3.2	3.1	2.9	2.6	2.4	1.9*
	24	6	13	13	7	5	7	4	5	6	2	5	5
Shoulder to Reach	12	5.0	4.9	4.6	4.0	3.5	2.4	2.7	2.6	2.4	2.1	1.9	1.4
	18	6	15	5	14	12	9	9	3	5	4	5	2
	24	4.5	4.1	4.0	3.8	3.3	2.4	2.5	2.4	2.2	2.0	1.7	1.3
	12	6	12	10	12	17	9	5	3	4	3	4	3
	18	4.4	4.0	3.9	3.8	3.4	2.4	2.6	2.5	2.3	2.2	2.0	1.3
	24	6	12	11	11	11	9	5	3	5	4	3	2

Ayoub, et al. (1978), Snook (1978)

*Data extrapolated from data generated for the other lifting frequencies

of 4 and 6 lifts/min., Snook's (1978) data were adjusted for box size and frequency. Then the average of these two values (Snook, 1978; Ayoub, et al. 1978) was computed. Larger standard deviation values were used for this purpose. These values were then adjusted to show a linear frequency effect.

Physiological Models: Literature Review

After a thorough review of the literature, it was found that very few researchers have attempted to develop prediction models for the energy cost of lifting or lowering tasks. These efforts were mainly made by Chaffin (1967), Åberg, et al. (1968), Garg, (1976) and Frederik (1959). Some researchers have used the oxygen uptake of a subject while performing a lifting task as a measure of the load by dividing the O_2 uptake for the task by the subject's maximum O_2 uptake to determine the maximum load that can be lifted (Åberg, 1961); to determine the maximum frequency of lifting (Jorgensen, et al., 1974); and to assess the physical load on a subject while performing a moderate or strenuous task using time standards set by traditional industrial engineering methods. A few other researchers (Datta, et al., 1973; Goldman, et al., 1962) have developed prediction models for energy cost, but these were for tasks other than lifting or lowering.

Frederik's Model

In his study, Frederik (1959) conducted tests to determine the energy cost for lifting various weights in four different height ranges. Each lift was performed over a 20 in. vertical distance, in a range of 0 to 20, 20 to 40, 40 to 60, and 60 to 80 in. The weights lifted ranged from 20 to 65 pounds. A graph was plotted from the experimental results with an ordinate of the energy consumption in gram-calories per foot-pound and an abscissa of the weight lifted in pounds. It should be noted that the energy consumed was

determined for lifting in a single performance. The following relationship was suggested to give the rate of energy expended for manual lifting:

$$E = (f * a * w * c) / 1000$$

where:

E = total energy expenditure/hour in kilocalories
(no more than 200 Kcal/hr for an average man),
f = number of lifts/hour,
a = lifting height in feet,
w = weight of the load in pounds, and
c = consumption of energy in gram-calories per foot-pound taken from the graph at a certain lifting range.

The limitations of this model are that:

1. the consumption of energy in gram-calories per foot-pounds was based on a single performance of lifting.
2. the effect of the posture during lifting is not taken into account,
3. the effect of body weight is not taken into consideration,
4. it is valid only for lifting in the sagittal plane,
5. the effect of box size is not accounted for in this model, and
6. it is valid for lifting but not for lowering tasks.

Chaffin's Model

Chaffin (1967) developed a model for the prediction of metabolic energy expenditure during arm activities. Chaffin's model is as follows:

$$E_{ijk} = f(s_{ik} * a_{ij} * T_i^{bi})$$

where:

E_{ijk} = predicted metabolic rate (Kcal/min) for ith muscle action, jth articulation angle and kth subject,

- s_{ik} = individual difference parameter for i th muscle action and k th subject,
 a_{ij} = muscle group efficiency coefficient for i th muscle action and j th articulation angle,
 T_i = resultant torque at articulation spanned by muscles that produce the i th muscle action (kg=to-cm). and
 b_i = a parameter, which transforms the rate of increase in torque of i th muscle action to the increase in energy expenditure rate.

The limitations of this model are that:

1. The model is primarily limited to static weight holding arm activities in the sagittal plane,
2. the precise knowledge of body position (arm angles), resultant torques, and individual size differences is required,
3. the computations are laborious and time consuming,
4. it cannot be applied with reliable accuracy in the case of dynamic lifting or lowering, and
5. it does not take into account the effects of posture and box size.

Åberg's Model

Åberg, et al. (1968) developed a model based on the principle that mechanical work is related to a change of the positional energy of a mass, a change of the velocity of a mass, and frictional losses. The resulting model was:

V_{O_2} = oxygen consumption rate due to (Basal metabolism + posture + body motion + motion of tool and work piece),

$$\begin{aligned}
 V_{O_{2comp}} &= \underset{\substack{\text{basal} \\ \text{metab.}}}{BW_n * k_1} + \underset{\substack{\text{posture}}}{BW_{cl} * k_2} + \overset{\text{or}}{BW_{cl} (GCB_h * k_3 + GCB_v * k_7)} \\
 &\quad + (WWP + WT) (\underset{\substack{\text{motion of tool and work piece}}}{L_{ha} * k_5} + u * L_{hc} * k_6 + L_{vu} * k_7 + L_{vd} * k_8)
 \end{aligned}$$

where:

$V_{O_{2comp}}$ = computed oxygen uptake
 BW_n = body weight, naked
 BW_{cl} = body weight, with clothing
 GCB_h = horizontal displacement per time unit of the
body's center of gravity
 GCB_v = vertical displacement per time unit of the
body's center of gravity, up plus down
WWP = weight of work piece
WT = weight of tool
 L_{ha} = horizontal displacement per time unit of tool
and work piece, arm work
 L_{hc} = horizontal displacement per time unit of tool
and work piece, carrying or dragging
 L_{vu} = upward vertical displacement per time unit of
tool and work piece, lifting
 L_{vd} = downward vertical displacement per time unit
of tool and work piece, lifting
 u = coefficient of friction in horizontal movement
 k_1-k_8 = constants.

Limitations of the model are that:

1. Although the model is simple, it is difficult to determine the body's center of gravity,
2. it does not take into account the effect of posture on the energy expenditure while lifting,
3. the effect of sex is neglected,
4. it is valid only for lifting in the sagittal plane,
5. the effect of box size is not accounted for in this model.

Garg's Model

Garg (1976) developed regression equations to estimate metabolic energy expenditure rate for MMHA with reasonable

accuracy (coefficient of variation - 10%).

$$\Delta E = 10^{-2}f[0.13BW + 0.40L + 0.51 \times 10^{-4}L^3 + 0.77 SXL \\ - 0.31 \times 10^{-2}SxBWxL + T_{SQ}(0.067BW + 0.26L) + T_{ONE} \\ (0.56L) + T_{ARM} (-0.10BW + 0.49L - 0.26 \times 10^{-2}S*BW*L)].$$

where:

ΔE = net metabolic rate of lifting (Kcal/min.),
 f = frequency of lifting (lifts/min.),
 BW = body weight (lbs.),
 L = load (lbs.),
 S = sex (male-1, female-0),
 T_{SQ} = squat lift (1 for squat lift, otherwise 0),
 T_{ARM} = arm lift (1 for arm lift, otherwise 0), and
 T_{ONE} = one hand lift (1 for one hand lift, otherwise 0).

The resulting regression equation for lowering was:

$$\Delta E = 10^{-2}f[0.10BW + 0.74L + 0.26S*BW - 0.30 \times 10^{-2}BW*L \\ + T_{SQ} (0.09BW - 0.016S*BW) + T_{ARM} (-0.07BW - 0.4L \\ - 0.02S*BW - 0.29 \times 10^{-2}BW*L + 0.5 \times 10^{-4}S*L^3)].$$

The notations are the same as those for lifting. The limitations of these models are that:

1. they are only valid for lifting and lowering in the sagittal plane,
2. only two height ranges (0-32in. and 32-60 in.) were studied (It was suggested by the author that in order to determine the energy expenditure for a height range that falls between the two ranges, the job can be divided into two tasks. The first task would be within the first height range and the second task would be within the second height range. The total metabolic rate for the two tasks could then be calculated using the model. This assumption of additivity needs to be verified.).
3. they do not take into account the effect of box size,

for the model was developed using only one box size, and

4. some operator-related variables were not taken into account, such as surface area of the body and lean body mass (free body weight).

Physiological Models: Summary

From the above literature review, it can be seen that very few prediction models have been developed to predict the energy cost of lifting and lowering tasks, and that all of these models have their limitations. Therefore, there is a need for developing a more complex prediction model which takes into account the effect of additional task-related variables such as the body's angle of twist and box size. The need for studying the effect of the body's angle was pointed out by Herrin, et al. (1974) when they recommended that research should strive to provide information about postures other than the sagittal plane. Troup (1965) also emphasized this point when he reported that in 100 cases of back pain in industry, 39 were caused by lifting and 33 by a twisting movement of the spine, 25 of which occurred when lifting.

There is also a need for the inclusion of some extra operator-related variables in order to account for the variability between individuals. Lean body mass and surface area of the body are two examples of these variables.

For a single lifting performance in the sagittal plane, Frederik's model (1959) is the only available model that gives the rate of energy expenditure in gram-calories per foot pound. The limitations of this model are that it does not take into account the effects of posture during lifting, the body weight of the subject, or the box size.

The most comprehensive models available at present for estimating the metabolic energy expenditure for lifting and lowering tasks are Garg's (1976) models as given in this section. In table 16, Garg (1976) gives the weight lifted in

TABLE 16
Weight Lifted (lbs.) by a 169 lb. Male at
Different Frequencies Resulting in an
Energy Consumption of 5 Kcal/min.*

<u>Lifting Technique</u>	<u>Frequency of Lift (lifts/min.)</u>	<u>Wt. Lifted (lbs.)</u>
Squat lifting (floor - 31.49")	4	48
	6	18
	8	7
Stoop lifting (floor - 31.49")	4	73
	6	35
	8	24
Arm lift (31.49" - 59")	4	114
	6	79
	8	59

Garg (1976)

*Box Dimensions were 12"W, 7"H, 6.5"D

kilograms by a 169 lb. male at a certain frequency that will tax him at 5 Kcal/min. for a certain lifting technique.

Effect of Frequency: Literature Review

It is obvious that the frequency of lift plays a very important role in determining the amount of weight that can be lifted by an individual. The higher the frequency of lift, the more energy he will expend and the sooner he will be fatigued.

Van Wely (1961) suggested that physiological efficiency depends not only on the weight lifted but also on the number of lifts per unit time.

Aberg (1961) investigated baling operations in a pulp factory. The experiment revealed a marked dependence on the relationship between the momentary work load and the distribution of pauses.

Bastina, et al. (1961) examined 146 women workers at two brick works. These women were permanently engaged in transporting small loads during the entire work day. It was found that these women suffered from reproduction disturbances, physiological time shifts and occupational diseases of the skeletal and motor systems. The authors provided no standards for the total weight shifted per day by women. However, they did recommend a load of 44 lbs. as the maximum weight for a single lift.

Noro (1967) emphasized that in trying to fix the maximum permissible weight to be carried by one worker, many factors must be taken into consideration, such as duration of carrying, technique, work breaks, etc.

Jorgensen, et al. (1974) conducted an experiment on repetitive lifting of loads from floor to table. Four males and four females participated in the experiment as subjects. For each subject, they determined both the maximum load which could be lifted from floor to table height and the maximum oxygen uptake. From the maximum load, they calculated the relative load of 10, 25, 50, and

75 percent. Lifting with at least three different frequencies was performed with each relative load. The maximum lifting frequency which did not demand more than 50 percent of the subject's $\dot{V}O_2$ max was then determined for each relative load for each of the subjects. Their results showed that the maximum lifting frequency of females was about 70% of that for the males at the same relative burden.

Aquilano (1968) studied the effect of pace on energy expenditure and showed that increasing the pace of handling cartons was accompanied by an increase in the energy expenditure.

Hamilton and Chase (1969), in an experiment to determine the main differences in the effects of variations of load weight and work pace on carton handling tasks, found that pace and weight had no significant effects on energy expenditure and heart rates. They also found from the trend analysis of work pace on the energy expenditure rate that the relationship between work pace and energy expenditure was linear. In their conclusions, they recommended moving heavier weights at a slower pace and lighter weights at a faster pace.

Ronnholm et al. (1962), in a study of one handed lifting (lifting a weight of 11 lbs. from a height of 24.8 in. to a height of 29.5 in. and then lowering it) varied the rate of lift from 10 to 40 lifts/min. They found that the optimum efficiency in terms of energy expended was reached at approximately 30 lifts/min. Aghzadeh (1974) fitted a least square regression line to the data for the floor to knuckle height lift obtained by Snook (1971) using three different frequencies (1, 3.75, and 4.29 lifts/min.). The line had a negative slope, i.e., the load lifted decreased with the increase in the frequency.

Snook and Irvine, (1968) utilized a psychophysical approach to determine the maximum frequencies of lift acceptable to male industrial workers. The subjects were asked to perform a repetitive lifting task using 35 lb. and

50 lb. weights. They were instructed to adjust the frequency of lift until they reached the maximum that they could maintain without excessive fatigue. Three height levels were used: floor to knuckle, knuckle to shoulder, and shoulder to reach. Negative correlations were found between selected frequency of lift and subject's height and weight. The maximum frequency and workloads selected by male workers are shown in Table 17.

Ayoub, et al. (1978) studied the effect of frequency on the weight lifted at different height levels using a psychophysical approach. Table 18 gives the means of maximum weights acceptable to male and female industrial workers. For males, there was a continuous decrement in the maximum acceptable weight of lift for all six height levels as the frequency increased. However, between intermediate levels of frequency, the slope was not very steep. For females, this trend was evident only for the floor to shoulder and floor to reach heights. The decrement was continuous for all other heights on a large sample size of industrial workers (146 males and females).

Effect of Frequency: Summary

Table 19 gives a comprehensive summary of the effects of frequency effect on amount of weight lifted in the form of regression equations (Ayoub, et al., 1978). In order to obtain the maximum acceptable weight of lift for a given frequency, (ranging from 2 to 8 lifts/min.) at a given height level, interpolate any frequency factor into any of the given equations.

Effect of Box Size: Literature Review

So far, research efforts have primarily concentrated on the safety of the load with very little importance associated with protecting the worker against injuries. According to Herrin, et al. (1974), the need for research in the load dimension area is substantiated in the technical literature, with the research criteria based on

TABLE 17
Maximum Frequency and Workloads
Selected by Male Industrial
Workers While Lifting
Continuously*

<u>Lift Range</u>	<u>Weight of object (pounds)</u>	<u>Frequency (lifts/min)</u>	<u>Mean Workload (ft.-lb./min.)</u>
Shoulder to arm reach	50	4.4	374
	35	5.9	342
Knuckle to shoulder	50	5.3	454
	35	7.1	413
Floor to knuckle	50	3.8	317
	35	4.2	244

Snook and Irvine, 1968

*The Box dimensions were 19"L x 13.5"W x 5.5"H
Frequency of lift was selected by subject (Psychophysical
method).

TABLE 18
Mean and Standard Deviation of the Maximum Weights (lbs.)
Acceptable to Male and Female Industrial Workers for
Different Frequencies (lifts/min.), Using Three Box
Sizes in the Sagittal Plane - 12 in., 18 in., and
24 in., With Handles*

Height of Lift	Sex	Frequency=2			Frequency=4			Frequency=6			Frequency=8		
		Mean	Std. Devia.		Mean	Std. Devia.		Mean	Std. Devia.		Mean	Std. Devia.	
Floor to Knuckle	Male	60	18		57	17		55	16		52	17	
	Female	30	6		32	8		29	7		30	6	
Floor to Shoulder	Male	50	10		48	11		47	12		44	14	
	Female	30	7		27	6		26	8		26	6	
Floor to Reach	Male	48	13		44	12		43	8		36	9	
	Female	27	5		25	6		24	5		24	4	
Knuckle to Shoulder	Male	56	14		52	15		52	15		48	14	
	Female	30	7		27	5		30	5		25	7	
Knuckle to Reach	Male	50	12		44	9		42	8		38	9	
	Female	26	6		26	5		26	4		24	5	
Shoulder to Reach	Male	43	10		42	11		39	11		36	9	
	Female	25	5		23	4		23	3		24	5	

Ayoub, et al. (1978)

*Box dimensions were (width x height x Length): 12"x7"x12",
12"x7"x18", and 12"x7"x24".

TABLE 19
Regression Equations of Frequency (lift/min)
Effect on Weight (lbs.) Lifted*

Sex	Height Level	Regression Equation
Male	Floor to knuckle	Weight lifted = 61.96 - 1.19 (frequency)
Female	Floor to knuckle	Weight lifted = 30.81 - 0.09 (frequency)
Male	Floor to shoulder	Weight lifted = 51.79 - 0.91 (frequency)
Female	Floor to shoulder	Weight lifted = 30.11 - 0.57 (frequency)
Male	Floor to reach	Weight lifted = 51.64 - 1.79 (frequency)
Female	Floor to reach	Weight lifted = 28.13 - 0.63 (frequency)
Male	Knuckle to shoulder	Weight lifted = 57.49 - 1.14 (frequency)
Female	Knuckle to shoulder	Weight lifted = 31.21 - 0.68 (frequency)
Male	Knuckle to reach	Weight lifted = 52.91 - 1.85 (frequency)
Female	Knuckle to reach	Weight lifted = 26.72 - 0.26 (frequency)
Male	Shoulder to reach	Weight lifted = 46.45 - 1.28 (frequency)
Female	Shoulder to reach	Weight lifted = 24.26 - 0.15 (frequency)

*Ayoub, et al. (1978)

accepted and well developed methods.

Unlike the load characteristics, the dimensions of the load have received very little attention. Since there are so many shapes possible, it is difficult to account for all of them. For this reason they have not been considered as variables by most researchers. Garg (1976) has assumed that the dimensions of the load are not major variables affecting the metabolic cost of lifting, although he does concede that there will be some effect.

Badger, et al. (1972), in a report on the prevention of low back pain in the industrial work force, have recommended that further research be carried out using this task characteristic. The Ergonomics Guide to Manual Lifting (1970) has considered the size of the load as one of the task variables and recommended, without substantiation, that it be taken as a significant hazard factor in evaluating work situations concerning manual materials handling.

Drury and Pfeil (1973) have indirectly presented the effects of load dimensions on lifting capacity. In their experiment, they used a 20 in. cube as the lifting object, as this was very difficult to lift using any kind of lifting technique. It appeared that the non-compact objects used in the experiment allowed about 60 percent of the lifting capacity of that of compact objects (8.5 in. x 19 in. x 19 in.). The lifting capacity used was the one quoted by ILO (1964) and Davies (1972) for the compact objects. These observations were further confirmed by using the equal-moment formula developed by Tichauer (1971).

McConville and Hertzberg (1968) examined the interaction of two variables (weight and width) of one handed, symmetrical boxes. The maximum weight of the box that subjects were able to lift varied linearly with the width of the box. They found that the maximum weight that 95 percent of the population would be able to lift, but not

necessarily carry, could be expressed by a linear equation:

$$Y = 60 - X$$

where Y is the weight (in lbs.) of the package to be lifted and X is the width (in inches). According to the authors, the numerical value of the above expression provides a recommended upper limit on the design of industrial or military equipment.

As is evident from above, if the container or package width is increased without changing the load of the object, the nature of the task may change from light to medium to heavy, and consequently may increase the hazard risk.

Woodson and Conover (1964) have suggested maximum weights for different size containers to be lifted to specific heights. They, however, have provided no justification or basis for recommending a particular size box for a given weight of the object.

Tichauer (1971) presented the concept of weight/bulk ratio and attempted to quantify the physical stress to which anatomical structures are subjected. According to him, lifting stress should not solely depend on the weight of the object, but rather on the moment exerted on the vertebral column. The moment concept implies that a bulky object must be "physiologically heavier" than a compact object of the same weight. He has demonstrated that the muscle stress produced as a result of lifting an object is proportional to the moment exerted on the lumbar spine rather than to the weight of the object being held. He also established that the weight/bulk ratio of the object handled is a major determinant of the severity of a lifting task. He recommends that 'quantitative relationships' between weight/bulk ratios and physiological work stress, as well as critical weight/bulk ratios affecting tolerance be established at higher levels of confidence through further experimentation. In his opinion, "weight limitations on lifting legislated or recommended by governmental,

intergovernmental, and private bodies are often irrelevant and valueless because they do not consider weight/bulk ratio of the object handles...". The moment concept is expressed in the following equation developed by Tichauer:

$$(8 + 0.5L) (W) = ME$$

where:

W = the weight of the load,

L = the length in inches of one side of a cube of uniform density, and

ME = the moment exerted on the vertebral column.

According to McFarland (1969), bulky objects (i.e., 30 in. on a side) should not exceed 20 lbs., with the center of gravity not more than 20 in. away from the carrier's body. This is more a statement than experimental verification, although according to Tichauer, (1971), this constitutes 'heavy' work.

Aghazadeh (1974) attempted to verify the moment relationship developed by Tichauer (1971). He concluded that the acceptable weight of lift is linearly related to the box size (where the box size is the box dimension perpendicular to the frontal plane of the body). This conclusion is identical to the one made by Tichauer (1971). Aghazadeh (1974) recommended that "the effects of height, width, and handle of container in relation to the amount of weight should be analyzed and studied."

Kellerman and Van Wely (1961) have attempted to determine the optimum shape and size of a container for use by the flower bulb industry. In their study, they first determined the optimal weight and then the optimal size. They considered the same weight with different size containers. In short, the weight/bulk ratio was not considered. It was found that for the optimal size determined by them, the optimal weight was 38.5 lbs.

Ayoub (1976) considered a different approach and attempted to show that the design of containers is a problem

of mechanics. He maintains that the use of optimization techniques for the design has a lot more potential. He also believes that the application of the probabilistic approach is possible.

Martin and Chaffin (1972) showed that the lifting force decreased linearly with an increase in length (length in the sagittal plane).

Tichauer, et al. (1973) demonstrated experimentally that it is not easy to hold large boxes weighing 10 and 15 lbs.-weights which are not considered severe by current lifting standards. The response to physical work stress is met by a change in the posture. He concluded that lifting when performed by tall, thin women may lead to lower back trauma because of their limitations for postural adjustments.

Tichauer, et al. (1973) stressed the need for further research to provide adequate hard data and to establish criteria for package and container design. Furthermore, they suggested that these efforts should be broadened and deepened in order to quickly produce reliable data related to biomechanical parameters of package design. Regarding the general criteria for the design of packages and containers, they recommend compliance with two different sets of specifications; namely, technical specifications and ergonomics specifications. Technical specifications refer to conforming to the dimensional standards, while the ergonomics specifications refer to making the container handling less stressful and safe.

It can be safely deduced from the foregoing research that bulky and light loads are less safe to handle than compact and heavy loads. Furthermore, Tichauer, et al. (1972) suggested that any lifting task imposing a sagittal bending moment upon the lumbar spine exceeding substantially 250 lb.-in. constitutes heavy work; and that such a task must be carefully designed in order to avoid injury. But presently, no reliable information about the optimality of shape or container configuration is available.

Most of the research results reported in this country are concerned with lifting and not with container and package dimensions which are very much a part of maintaining occupational safety and health.

Ayoub, et al. (1978) studied the effect of box size on the lifting ability of male and female industrial workers using a psychophysical approach. The box size in this study was defined as the distance of the box's center of gravity from the spine of the subject in the sagittal plane. Three box sizes were used: 12 in., 18 in., and 24 in. Six lifting height levels were used:

1. floor to knuckle height,
2. floor to shoulder height,
3. floor to reach height,
4. knuckle to shoulder height,
5. knuckle to reach height, and
6. shoulder to reach height.

Figures 3 through 8 show the effects of box size for the six height levels for males and females. For the sequences floor to knuckle height, floor to reach height, and knuckle to shoulder height, the maximum acceptable weight of lift for the male subjects decreased. This decrement was most significant for the floor to knuckle height (about 10 lbs.). For the female subjects, a similar effect was observed for all height levels except for the knuckle to reach height, in which case the maximum acceptable weight first decreased and then increased slightly.

In the floor to shoulder height and knuckle to reach height for males, the maximum acceptable weight of lift first increased and then decreased. For the shoulder to reach height, it decreased very slightly and then increased.

The maximum decrement due to change in the box size for female subjects was about 4 lbs. for the floor to knuckle height. For males, the maximum decrement was also observed at this height level. Table 20 gives regression equations

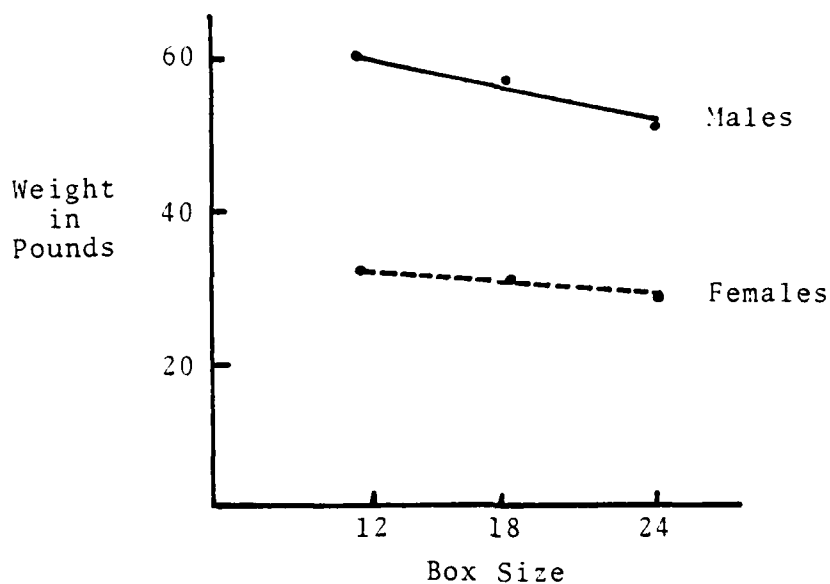


Figure 3: The Effects of Box Size for Males and Females for Height Level 1 (floor to knuckle).

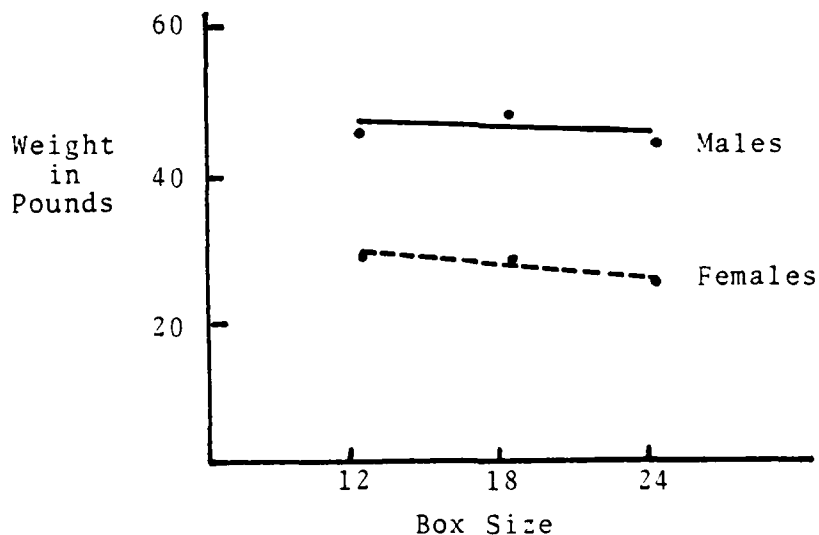


Figure 4: The Effects of Box Size for Males and Females for Height Level 2 (floor to shoulder).

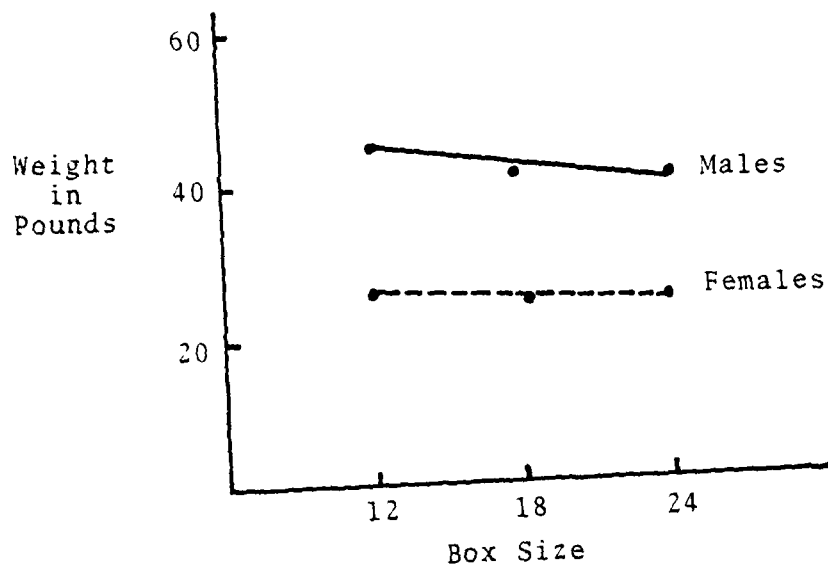


Figure 5: The Effects of Box Size for Males and Females for Height Level 3 (floor to reach).

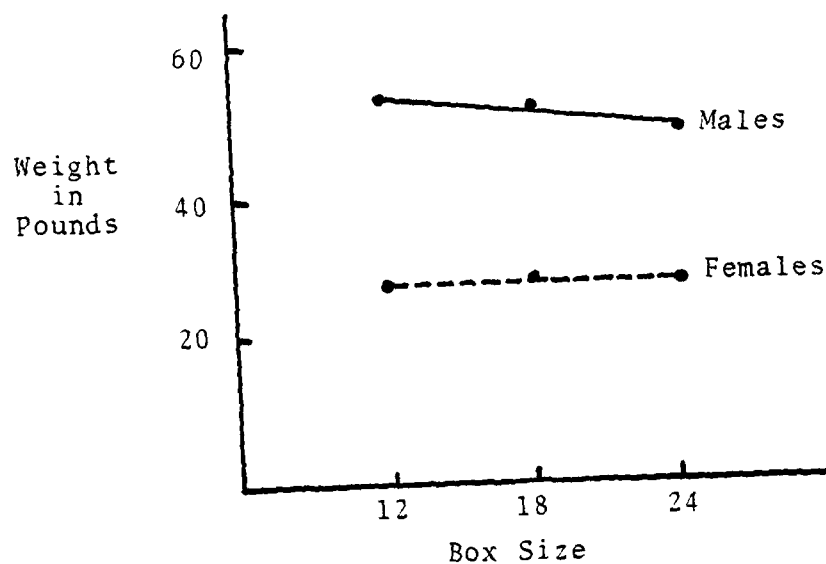


Figure 6: The Effects of Box Size for Males and Females for Height Level 4 (knuckle to shoulder).

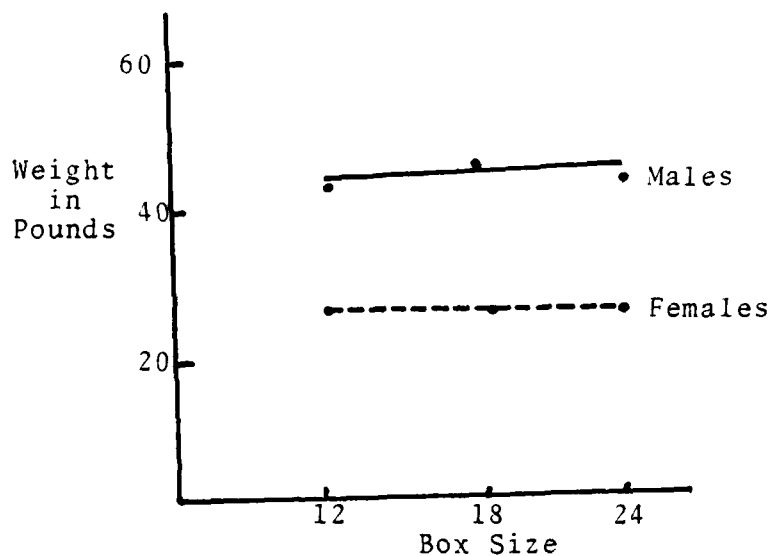


Figure 7: The Effects of Box Size for Males and Females for Height Level 5 (knuckle to reach).

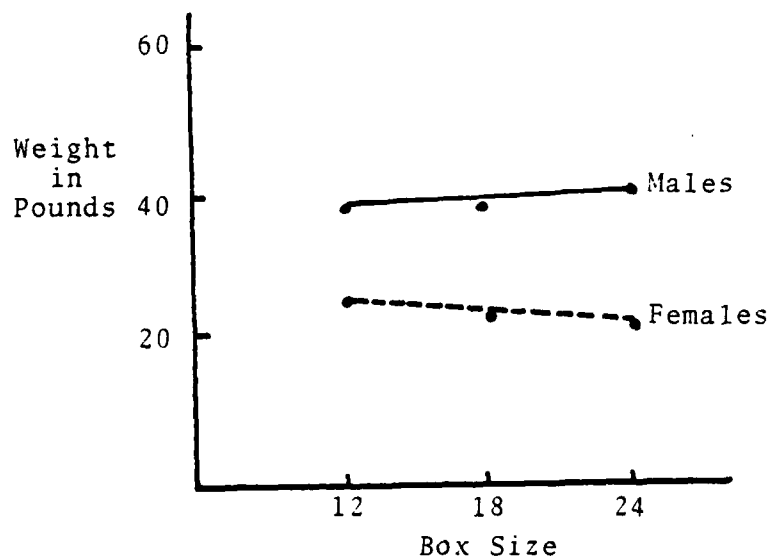


Figure 8: The Effects of Box Size for Males and Females for Height Level 6 (shoulder to reach).

TABLE 20
Regression Equations for Box Size* (in.) Effects
on Amount of Weight (lbs.) Lifted

Sex	Height Level	Regression Equation
Male	Floor to knuckle	Weight lifted = $70.57 - 0.808$ (box size)
Female	Floor to knuckle	Weight lifted = $36.09 - 0.323$ (box size)
Male	Floor to shoulder	Weight lifted = $48.48 - 0.093$ (box size)
Female	Floor to shoulder	Weight lifted = $33.03 - 0.303$ (box size)
Male	Floor to reach	Weight lifted = $49.36 - 0.386$ (box size)
Female	Floor to reach	Weight lifted = $27.80 - 0.148$ (box size)
Male	Knuckle to shoulder	Weight lifted = $56.83 - 0.285$ (box size)
Female	Knuckle to shoulder	Weight lifted = $29.98 - 0.121$ (box size)
Male	Knuckle to reach	Weight lifted = $43.24 + 0.0442$ (box size)
Female	Knuckle to reach	Weight lifted = $25.59 - 0.004$ (box size)
Male	Shoulder to reach	Weight lifted = $37.62 + 0.124$ (box size)
Female	Shoulder to reach	Weight lifted = $27.18 - 0.206$ (box size)

Ayoub, et al. (1978)

*Box dimensions were (width x height x length): 12"x7"x12", 12"x7"x18", and 12"x7"x24"

for predicting the weight lifted for a specified box size based on the data of Ayoub, et al. (1978).

Effect of Box Size: Summary

Most researchers agree on the fact that increasing the size of the box in the sagittal plane is associated with a linear decrease in the amount of weight lifted by a subject.

The data of Ayoub, et al. (1978) in Figures 3 through 8 were utilized for summarizing the effect of box size on the amount of the weight lifted, as it was the most complete data set available at present, covering a wide range of lifting heights. It was also based on a large sample size of industrial workers (146 male and female).

PUSHING AND PULLING

Considerably less data were found for pushing and pulling than for lifting. Thus this category is only divided into the data for strength norms and capacity norms.

Strength Norms: Literature Review

Troup and Chapman (1969) observed the maximum steady pulling force (for 1 sec.) exerted by 132 male and 98 female subjects. The forces were measured in sitting and standing positions using a strain-gauge dynamometer. It was found that forces were greater in the sitting position than in the standing position. However, the forces transmitted by the erector spinae were of similar magnitude for sitting and standing. When standing the lumbar spine is extended and the erector spine shortened; this provides a relatively greater mechanical advantage than a sitting posture. In the sitting position, the smaller mechanical advantage is compensated by a shorter distance between the pelvis and the upper limbs resulting in a turning movement similar to when standing.

Ayoub and McDaniel (1974) studied the maximum isometric pushing and pulling forces exerted by 35 males and 11 females as a function of foot and hand placement. Foot placement was defined as the distance of the rear foot away from the vertical plane of the handle, and the hand placement was predicated upon the height of the handle above the floor.

The effects of bar height and foot position on the horizontal pushing and pulling forces are summarized in Tables 21 and 22 (the values presented in these tables were obtained by interpolating from the graphs given by Ayoub and McDaniel, 1974). It was found that optimal pushing forces were generated when the hands were placed at 50 percent of the subject's reach height on the object to be pushed, and, the feet were placed at 70 percent of the worker's reach height from the vertical plane. For pulling forces, it was found that optimal forces were generated when the bar height (i.e., the gripping surface) was at 70 percent of the worker's shoulder height, and the foot distance 10 percent of the worker's height.

Subject body weight also had a significant effect on pushing and pulling forces. Its interaction with both foot distance and bar height resulted in considerably higher pushing forces at high bar height and larger foot distance, and higher pulling forces at the shortest foot distance and lowest bar height. The ratio between the horizontal and resultant pushing forces, for both males and females, was greatest at bar heights of about 70 and 80 percent of the shoulder height (or 50 percent reach height). The ratio was lowest for a foot distance of 80 percent of the reach height.

Kroemer (1974) measured the maximal isometric (static) horizontal push forces which could be exerted in many common working conditions. Seventy-three male subjects were used. Of these, 45 participated in the experiments with wall or footrest, 28 took part in the experiment with slippery floors. The experiment simulated all kinds of body supports and body postures which might occur in daily life when one has to exert

TABLE 21
Effect of Bar Height and Foot Position On
Horizontal Pushing Force (lbs.)
For Males and Females

MALES

Bar Height* (% Reach Height)	Foot Distance* (% Reach Height)				
	<u>30</u>	<u>40</u>	<u>50</u>	<u>60</u>	<u>70</u>
30	50	55	75	94	110
40	48	64	83	99	130
50	45	67	90	103	132
60	40	61	84	122	150
70	37	67	95	127	137
80	52	86	123	100	---

FEMALES

Bar Height* (% Shoulder Height)	Foot Distance* (% Reach Height)				
	<u>50</u>	<u>60</u>	<u>70</u>	<u>80</u>	<u>90</u>
60	40	44	50	56	59
70	40	50	51	59	61
80	38	42	54	59	70
90	38	46	50	61	78
100	40	43	56	60	78

Ayoub and McDaniel (1974)

*Bar height is height of the handle above the floor. Foot distance is the distance of the rear foot away from the vertical plane of the handle. Both of these parameters are reported in percent of the subject's shoulder height or reach height.

TABLE 22
Effect of Bar Height and Foot Position On
Horizontal Pulling Force (lbs.)
For Males and Females

MALES

Bar Height* (% Reach Height)	Foot Distance*(% Reach Height)				
	<u>30</u>	<u>20</u>	<u>10</u>	<u>0</u>	<u>-10</u>
30	57	82	106	135	154
40	63	77	90	105	116
50	52	65	78	85	95
60	49	60	65	70	75
70	45	48	52	55	58
80	35	40	59	46	45

FEMALES

Bar Height* (% Shoulder Height)	Foot Distance*(% Reach Height)				
	<u>30</u>	<u>20</u>	<u>10</u>	<u>0</u>	<u>-10</u>
60	51	63	70	81	89
70	50	66	71	80	85
80	42	56	63	70	75
90	40	53	56	63	65
100	41	45	50	52	55

Ayoub and McDaniel (1974)

*Bar height is the height of the handle above the floor. Foot distance is the distance of the rear foot away from the vertical plane of the handle. A negative value of the foot distance means the feet are on the other side of the handle. Both of these parameters are reported in percent of the subject's shoulder height or reach height.

a maximal horizontal push force. Subjects were instructed to maintain a maximal horizontal push force steadily over the 5 second period. The force exerted increased during the first second, then stayed constant, and then dropped during the last second. The mean force applied during the third second was used.

Table 23 shows the lowest horizontal static forces that healthy male adults, under common working conditions, should be able to exert intermittently and for short periods of time. It was concluded from Kroemer's study (1974) that body posture, body support, and the chain of body members through which the force was transmitted had significant effects on the amount of force exerted. Body weight, alone or in combination with the body size, was not very useful in predicting force output. A physically strong subject may be able to exert only weak push or pull forces due to lack of body support.

The force (for each operator) given in Table 23 can be added to obtain the combined push capacity of up to three people. Beyond this, the force added does not increase proportionately and consequently cannot be directly added. In conjunction with the study by Snook, et al. (1970), it can be concluded from Kroemer's (1974) study that 90 percent of the male workers should be able to exert an initial two-handed push force of about 220 N and a continuous push force of about 110 N for distances up to 98.4 ft.

Strindberg and Peterson (1972) measured the force required to start a trolley rolling. It was found that a person could exert, on the average, a pushing force of about 80 percent of his body weight.

Caldwell (1964) studied the body position, strength, and endurance of manual pull. Ten male subjects were used (mean weight 171 lbs, mean height 68.9 in., age range 22-39 years). Strength (response) and endurance were measured for 20 different body positions which were combinations of five elbow angles (95°, 110°, 125°, 140° and 155°) two thigh angles

TABLE 23
Least Horizontal Push Forces That Males Should be Able to Exert
Intermittently and for Short Periods of Time

Force	Applied With	Condition (μ : coefficient of static friction)
100N(25 lbs) Push or Pull	Both hands or one shoulder or the back	With low traction $.2 \leq \mu \leq .3$
200N(45 lbs) Push or Pull	Both hands or one shoulder or the back	With medium traction $\mu \sim .6$
250N(55 lbs) Push	One hand	If braced against a vertical wall (20-60 in) from and parallel to the push panel
300N(70 lbs) Push or Pull	Both hands or one shoulder or the back	With high traction $\mu \geq .9$
500N(110 lbs) Push or Pull	Both hands or one shoulder or the back	If braced against a vertical wall (20-70 in) from and parallel to the panel or if anchoring the feet on a perfectly non-slip ground (like a footrest)
750N(165 lbs) Push	The back	If braced against a vertical wall (23-43 in) from and parallel to the push panel or if anchoring the feet on a perfectly non-slip ground (like a footrest)

Kroemer (1974)

(0° and 20°); and two knee angles (110° and 150°). Each subject was required to pull maximally for a period of 8 seconds for the strength test. For the endurance test, the subject was asked to apply 80 percent of the maximal pull for as long as possible. A green light, which would turn on at 80 percent pull force, was used to assist subjects in maintaining this pull force.

An increase in the knee angle resulted in an increase in strength. The same was true for an increase in elbow angle. Trunk stabilization improved with an increase in the thigh angle. These responses occurred during endurance tests also. It was concluded that a change in body position, control placement, or body stabilization which increased strength would reduce the effort required to maintain a given force under control. In addition, the endurance of the holding response would be proportionately increased. In other words, static strength could be used to predict static endurance with reasonable confidence.

However, Smith and Edwards (1968) indicated that muscular endurance (dynamic endurance) may not be predicted from static strength. Forty male students participated in this study. A grip dynamometer was used to record static strength, static (isometric) endurance, and dynamic (isotonic) endurance. Subjects were given two training sessions each for 14 weeks. A poor correlation was found between strength and pre- and post- training isometric and isotonic endurance.

Strength Norms: Summary

The study by Ayoub and McDaniel (1974) will be used to summarize the research dealing with pushing and pulling forces. Presently, it is the most comprehensive study in this area. Tables 21 and 22 give a summary of the data. However, it should be noted that the data in these tables is for pushing and pulling forces applied with both hands. For other modes of application of pushing and pulling forces, Table 23, which is based on Kroemer (1974) should be consulted.

Capacity Norms: Literature Review

Snook, et al. (1970) and Snook and Ciriello (1974) also studied pushing and pulling capacities, along with lifting and lowering capacities described earlier. The heights used for pushing and pulling approximated the handle heights "commonly" found in industry. The pushing and pulling tasks were simulated on a specially constructed treadmill which was powered by the subject as he or she pushed or pulled against a horizontal bar. Force was the dependent variable and was varied by controlling the resistance of the treadmill belt by varying the amount of electric current flowing into a magnetic clutch. The subjects were encouraged to make force adjustments by starting them with either a very light or very heavy force.

Capacity Norms: Summary

The results of the foregoing studies were summarized by Snook (1978). Tables 24 through 26 present the maximum acceptable forces for pushing and pulling for male and female industrial workers. Only one pulling distance is presented, since objects transported over greater distances are usually pushed. It is important to note that not all of the data presented in Tables 24 through 26 were generated via experimentation. To fill in some gaps that have not been studied, Snook made some assumptions based on his current experimentation (e.g. some of the intermittent task frequencies between 1 minute and 8 hours).

CARRYING

Literature Review

Parts of the studies by Snook, et al. (1970) and Snook and Ciriello (1974) were to determine the maximum rate of walking (miles/hr) acceptable to male and female workers. Rate was used as a dependent variable in the walking tasks. For carrying tasks, subjects determined their own work loads at different walking speeds. The tote box (19 in. x 13.5 in.

TABLE 24
THE MAXIMUM ACCEPTABLE FORCES OF PUSH FOR MALES

Vertical Distance (in)*	100 ft. Push one push every						150 ft. Push one push every						200 ft. Push one push every					
	min.			hr.			min.			hr.			min.			hr.		
	1	2	5	30	8	hr.	1	2	5	30	8	hr.	2	3	5	30	8	hr.
INITIAL FORCE	57"	51	55	64	68	73	48	51	60	64	68	68	46	46	53	57	62	
	37"	12	15	15	17	17	14	14	15	19	19	19	14	12	15	17	17	
	25"	14	15	17	17	19	15	14	17	21	22	22	15	14	17	19	19	
	57"	46	55	62	68	70	44	51	57	62	66	66	44	46	53	57	59	
SUSTAINED FORCE	37"	10	14	15	15	17	12	12	17	19	21	21	12	12	14	15	17	
	25"	29	35	40	42	46	26	33	37	40	44	44	26	29	31	35	37	
	57"	7	9	10	12	12	7	9	9	10	10	10	7	7	9	9	10	
	37"	29	33	40	42	46	29	33	37	40	42	42	26	29	31	35	37	
	57"	9	9	9	10	10	7	9	9	10	12	12	9	9	9	9	9	
	37"	29	33	37	42	44	29	31	35	37	42	42	29	29	31	33	35	
	25"	9	9	9	9	10	7	9	9	10	10	10	7	9	7	9	10	

Snook (1978)

*From floor to hands

TABLE 25
THE MAXIMUM ACCEPTABLE FORCES OF PUSH FOR FEMALES

Vertical Distance (in)*	100 ft. Push					150 ft. Push					200 ft. Push				
	one push every					one push every					one push every				
	1	2	5	30	hr.	1	2	5	30	hr.	2	3	5	30	hr.
53"	$\bar{x}$ 37	40	44	48	51	35	35	42	46	48	33	33	37	39	44
	σ 7	10	9	9	10	5	7	7	7	9	5	5	7	9	7
35"	$\bar{x}$ 42	46	51	55	58	40	42	48	51	55	37	37	42	46	48
	σ 9	10	10	10	10	7	7	7	10	9	7	7	9	9	9
22"	$\bar{x}$ 33	40	44	48	51	31	35	42	44	46	31	33	37	40	42
	σ 7	9	9	9	9	7	7	9	9	9	5	5	5	7	9
53"	$\bar{x}$ 24	26	33	35	40	20	24	29	31	33	19	22	24	26	29
	σ 3	5	5	7	7	5	5	5	5	5	3	5	5	5	5
35"	$\bar{x}$ 24	26	33	35	27	22	24	29	31	33	20	22	24	25	29
	σ 5	5	5	7	7	3	5	5	5	5	5	5	3	5	5
22"	$\bar{x}$ 24	26	31	35	37	22	24	26	29	31	22	22	22	24	26
	σ 5	3	5	3	7	3	3	5	5	7	3	3	5	5	5

INITIAL FORCE

SUSTAINED FORCE

Snook (1978)
*From floor to hands

TABLE 26
THE MAXIMUM ACCEPTABLE PULLING FORCES FOR MALES AND FEMALES

Vertical Distance (in)*	7 ft. pull (initial forces) one pull every						7 ft. pull (sustained forces) one pull every					
	sec.			min.			sec.			min.		
	6	12	48	1	2	5	6	12	48	1	2	5
	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.
Male 57"	42	48	55	57	64	66	26	35	42	42	46	48
	12	14	14	14	15	15	7	10	12	14	15	15
Female 53"	42	42	42	44	48	51	31	31	33	33	37	40
	10	12	10	9	10	12	9	9	9	9	9	10
Male 37"	59	68	77	79	88	92	33	44	55	57	62	66
	15	17	17	19	21	21	9	14	17	15	19	21
Female 35"	57	59	59	62	68	70	40	42	42	44	48	51
	15	15	12	12	15	15	12	10	12	12	12	15
Male 25"	68	77	86	90	99	103	35	48	59	59	66	70
	17	19	21	21	24	24	10	14	17	19	19	22
Female 22"	64	66	66	68	77	79	40	44	44	44	51	55
	17	17	15	15	17	19	12	12	12	12	14	14

Snook (1978)
*from floor to hands

x 5.5 in) was carried for a distance of 7 ft., 14 ft., and 28 ft. The results of these studies are in Tables 27 and 28.

Summary

The only two studies that are available dealing with carrying are Snook, et al. (1970) and Snook and Ciriello (1974). Therefore, Tables 27 and 28 will be used to summarize the data.

TABLE 27
Distribution of Maximum Work Loads (ft.-lb./min.) Acceptable to Male
and Female workers while carrying a 19"Lx13.5"Wx5.5"H Tote
Box at Elbow Height*

Distance Carried (ft.)	Sex	Mean	Std. Devia.	Percent of Population				
				95	75	50	25	5
7	Ind. men	2485	645	1423	2051	2485	2919	3546
	Ind. women	2198	458	1445	1897	2198	2499	2951
	Housewives	1418	359	827	1181	1418	1654	2009
14	Ind. men	3066	865	1643	2484	3066	3648	4488
	Ind. women	2649	662	1560	2213	2649	3084	3737
	Housewives	1596	384	963	1343	1596	1849	2228
28	Ind. men	3070	736	1859	2575	3070	3565	4281
	Ind. women	2744	432	2033	2460	2744	3028	3455
	Housewives	1733	388	1094	1477	1733	1988	2372

Snook, et al. (1970)

Snook and Ciriello (1974)

*Assuming a normal distribution

TABLE 28
Distribution of Maximum Weights (lbs.) Acceptable to Male and Female
Workers While Carrying a 19"Lx13.5"Wx5.5"H Tote Box at Elbow Height*

Distance Carried (ft.)	Sex	Mean (lbs.)	Std. Devia.	Percent of Population				
				95	75	50	25	5
7	Ind. men	58	14	35	49	58	67	81
	Ind. women	38	8	25	33	38	43	51
14	Ind. men	51	12	32	43	51	59	70
	Ind. women	38	8	25	33	38	43	51
28	Ind. men	45	10	28	38	45	52	62
	Ind. women	34	7	22	29	34	39	46

Snook, et al. (1970)

Snook and Ciriello (1974)

*Assuming a normal distribution

Comparison of Load Limits Based on the Biomechanical, Physiological, and Psychophysical Criteria

A direct comparison of the physiological, biomechanical, and psychophysical methods for establishing lifting capacity is difficult because of the procedural differences among the relevant studies. However, an examination of the data per se does address the following questions: 1) under what criterion are there higher acceptable weight limits; and 2) under what conditions are the three criteria similar.

A comparison of the data generated by experimentation based on the three criteria revealed the following:

1. For infrequent lifting, the maximum permissible weight of a load as determined by psychophysical methods is less than the recommended weights based on the biomechanical model. In other words, the acceptable weight limits based on muscle strength testing (Martin & Chaffin, 1972) are usually higher than those based on the psychophysical model (Snook, 1978; Ayoub, et al., 1978; Snook & Irvine, 1967). However, the psychophysical data also indicate that lifting capabilities increase if the time interval between lifts increases. Snook (1978) found that the average acceptable weights for women were 46 lbs. and 57 lbs. for 120 second and 300 second intervals, respectively. These lifting capabilities were comparable to the lifting capabilities of 50 percent of the women under the biomechanical criterion (Martin & Chaffin, 1972).
2. For repetitive lifting, the maximum acceptable weights based on the psychophysical criterion are lower at lower lifting frequencies and higher at higher lifting frequencies than those weights based on the physiological criterion.

Tables 29 and 30 present data based on the three aforementioned criteria. However, the data do not represent a direct comparison of the criteria, for procedural differences among the

TABLE 29
ACCEPTABLE WEIGHT (lbs.) BASED ON PSYCHOPHYSICAL AND
PHYSIOLOGICAL CRITERIA FOR FLOOR TO KNUCKLE HEIGHT

Criteria	Reference	Method of Lift	Lifting Frequency (lifts/min)	Acceptable Weight to 50% Male Population (lbs)
Psycho- physical	Ayoub, et al. (1978)	Free style lift	4.0	64
			6.0	63
			8.0	61
Physio- logical	Garg (1976) (estimate of weight based on metabolic criteria)	Stoop lift	4.0	73
			6.0	35
			8.0	24
		Squat lift	4.0	48
			6.0	18
			8.0	7

TABLE 30

LIFTING CAPABILITIES OF MALE AND FEMALE POPULATIONS
 BASED ON BIOMECHANICAL MODELING (MARTIN AND CHAFFIN, 1972)

Horizontal Distance (in)	Vertical Distance (in)	Lifting Capability (lbs) 50% Population Percentile	
		Male	Female
12	12	112	51
12	59	103	24
24	12	53	20
24	59	46	11
35	12	11	0
35	59	15	0

pertinent studies makes such a comparison difficult. It is recommended that further research be conducted to fill the extant gaps which preclude a true comparison of the three criteria.

Comparison of pushing-pulling and carrying limits based on the foregoing criteria is presently not possible; experimentation in pushing-pulling and carrying has basically followed the psychophysical model. Obviously, further research should strive to generate data representing pushing-pulling and carrying limits based on the physiological and biomechanical models.

Recommendations for Mil-Std-1472B Revision

The preceding literature review and experimental results were used as the basis for recommending changes in Mil-Std-1472B for MMHA. The following is recommended for inclusion in Mil-Std-1472B for the MMHA Section.

5.9.11.3.1.1 Limits. The weight limits in Table 1 shall be used in determining the design weight of items requiring one-man lifting. For two-man lifting, the weight limits would be approximately twice the amount of weight prescribed for each condition in Table 1. The weights lifted should adhere to those presented in Table 1. The weight lifted should be reduced as the box size increases in the sagittal plane. The absence of handles on boxes usually results in a 15 percent reduction in the amount of weight lifted obtained from Table 1. The handles or grasp areas should conform to paragraph 5.9.11.5. The weight limits in Table 2 shall be used in determining the design weight of items requiring one-man lowering. In using Tables 1 and 2 to estimate the recommended weight of lift and lower for a particular height of lift, box dimension, and frequency of lift, locate the mean value (in pounds) pertaining to the particular task variables. For example, if a job requires lifting a 12 inch box (length in the sagittal plane) twice every minute from floor to knuckle, the maximum acceptable weight for 50 percent of the male worker is 61 pounds.

5.9.11.3.1.2. Labeling. Items weighing more than the one-man lift values of Table 1 shall be prominently labeled with weight indication and lift limitation (i.e., mechanical or two-man lift). Where mechanical or power lift is required, hoist and lift points shall be provided and clearly labeled.

5.9.11.3.2. Carrying. The limits in Table 3 shall be used in determining the weight of a 19"x13.5"x5.5" tote box. The weight limits shall correspond to the presented distances that a load is to be carried (i.e. 7, 14, 28 feet). It should be noted that those lifting limits prescribed in Table 1 (paragraph 5.9.11.3.1.1.) are not applicable to tasks where carrying the load is involved.

TABLE 1
Mean and Standard Deviation of the Maximum Recommended Weight of Lift
(lbs.) for Male and Female Workers

Height of Lift	Box Dimension in the Sagittal Plane	MALE WORKERS					FEMALE WORKERS						
		1	2	4	6	8	12	1	2	4	6	8	12
Floor to Knuckle	12	67	61	53	49	46	39	44	41	35	31	29	25
	18	19	21	15	18	17	12	7	3	7	8	7	7
	24	59	57	52	48	43	34	39	30	28	27	26	23
	30	17	19	21	13	14	9	7	7	11	7	5	5
	36	55	51	47	53	39	31	34	28	27	27	25	21
Floor to Shoulder	12	17	15	17	11	18	9	7	5	6	5	6	5
	18	52*	51	48	45	42	36*	29*	29	29	28	28	27*
	24	13	14	12	13	14	14	7	7	3	8	4	2
	30	54*	53	51	49	47	45*	32	32	30	28	26	22*
	36	7	7	13	11	15	10	6	6	7	10	5	4
Floor to Reach	12	51*	51	59	47	45	41*	30	29	28	26	25	22*
	18	11	11	10	8	14	12	6	6	4	5	8	7
	24	48*	47	45	42	40	35*	28*	27	26	25	24	21*
	30	11	11	13	7	8	6	5	5	6	6	4	6
	36	57*	54	47	40	33	19*	29	28	27	25	24	22*
Floor to Reach	18	14	14	13	9	8	4	5	5	5	4	4	4
	24	41*	41	39	38	37	34*	27	26	25	24	23	20*
	30	12	12	8	9	10	8	6	6	7	5	4	5

TABLE 1 (continued)
Mean and Standard Deviation of the Maximum Recommended Height of Lift
(lbs.) for Male and Female Workers

Height of Lift	Box Dimension in the Sagittal Plane	MALE WORKERS						FEMALE WORKERS					
		1	2	4	6	8	12	1	2	4	6	8	12
Knuckle to Shoulder	12	x 53	51	48	44	41	34	32	31	30	28	26	23
		s 15	12	16	14	12	9	5	8	5	5	8	3
	18	x 59	57	53	49	44	31	29	29	29	28	25	20
		s 14	16	19	14	12	9	5	8	5	5	7	3
	24	x 46	45	42	39	36	31	29	28	26	25	23	19
		s 14	16	15	19	16	9	5	6	7	6	5	4
Knuckle to Reach	12	x 49*	47	43	40	36	29*	28*	28	27	25	24	22*
		s 15	15	9	11	8	3	8	8	6	5	7	6
	18	x 55*	53	48	44	40	31*	26	26	25	25	24	23*
		s 9	9	8	7	11	10	4	4	3	4	4	4
	24	x 54*	52	43	44	40	32*	32	31	29	26	24	19*
		s 13	13	7	5	7	4	5	5	6	2	5	5
Shoulder to Reach	12	x 50	49	46	40	33	24	27	26	24	21	19	14
		s 15	5	14	12	9	9	3	5	4	4	5	2
	18	x 45	41	40	38	35	24	25	24	22	20	17	13
		s 12	10	12	17	9	5	3	4	3	4	5	3
	24	x 44	40	39	38	34	24	26	25	23	22	20	13
		s 12	11	11	11	9	5	3	5	4	3	3	2

Ayoub, et al. (1978), Snook (1978)

*Data extrapolated from data generated for the other lifting frequencies

TABLE 2
Maximum Acceptable Weight (lbs.) of Loads for Males and Females for Different
Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift	MALES					FEMALES					
			One Lift Every					One Lift Every					
			9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.
Floor to Knuckle	29.5"	x	40	57	77	90	26	33	44	53	53	53	53
		30"	10	14	21	26	5	5	7	9	9	9	9
		x	40	59	79	95	29	33	46	55	55	55	55
		20"	12	15	22	26	5	7	7	9	9	9	9
	19.5"	x	46	66	90	106	33	37	53	62	62	62	62
		10"	16	19	24	29	5	7	9	10	10	10	10
		x	46	66	90	66	31	37	53	62	62	62	62
		50"	14	19	26	31	5	7	7	10	10	10	10
	14.2"	x	46	68	92	110	31	40	53	64	64	64	64
		20"	15	21	28	33	7	7	10	10	10	10	10
		x	55	77	106	123	37	34	62	73	73	73	73
		10"	17	22	31	58	7	9	9	12	12	12	12
Snook (1978)	19.5"	x	50	73	99	117	35	42	57	68	68	68	68
		30"	15	21	29	34	7	7	9	10	10	10	10
		x	53	75	105	121	35	44	59	70	70	70	70
		20"	15	22	31	56	7	7	10	12	12	12	12
	14.2"	x	62	86	117	156	42	48	66	79	79	79	79
		10"	19	24	34	41	9	9	12	14	14	14	14

TABLE 2 (continued)
Maximum Acceptable Weight (lbs.) of Load for Males and Females for Different
Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift	MALES				FEMALES			
			One Lift Every				One Lift Every			
			9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.
Knuckle to Shoulder	29.5"	x	40	48	55	66	29	31	57	42
		50"	12	14	15	21	5	5	7	9
		x	42	55	64	75	31	33	40	46
		20"	14	17	17	22	7	5	9	9
		x	51	64	75	88	37	37	48	53
		10"	15	19	19	28	9	9	9	10
	19.5"	x	40	48	59	66	29	31	37	42
		50"	12	14	17	21	5	5	7	9
		x	42	55	66	75	31	35	40	46
		20"	14	17	21	22	7	5	9	9
		x	51	64	79	88	37	37	48	53
		10"	15	19	22	28	9	9	9	10
	14.2"	x	44	51	64	75	29	35	40	46
		50"	12	15	19	21	7	7	9	9
		x	46	57	72	81	35	35	44	48
		20"	14	17	21	24	7	7	9	10
		x	55	68	86	97	40	42	51	57
		10"	15	21	24	28	19	7	10	12

Cronek (1978)

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REVIEW OF THE STRENGTH AND CAPACITY DATA FOR MANUAL MATERIAL HA--ETC(U)

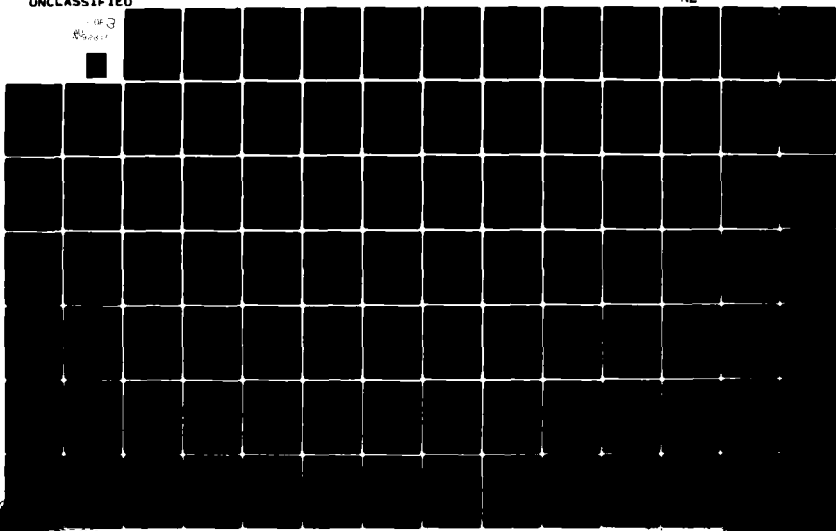
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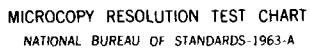
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE 3
Distribution of Maximum Weights (lbs.) Acceptable to Male and Female
Workers While Carrying a 19"Lx13.5"Wx5.5"H Tote Box at Elbow Height*

Distance Carried (ft.)	Sex	Mean (lbs.)	Std. Devia.	Percent of Population				
				95	75	50	25	5
7	Ind. men	58	14	35	49	58	67	81
	Ind. women	38	8	25	33	38	43	51
14	Ind. men	51	12	32	43	51	59	70
	Ind. women	38	8	25	33	38	43	51
28	Ind. men	45	10	28	38	45	52	62
	Ind. women	34	7	22	29	34	39	46

Snook, et al. (1970)

Snook and Ciriello (1974)

*Assuming a normal distribution

In using Table 3 to estimate the recommended carrying weights for a particular distance, locate the value (in pounds) pertaining to the particular carrying distance and percentile of the working population. For example, if a job requires carrying a tote box at elbow height for a distance of 14 feet, the maximum acceptable weight for 25 percent of the male workers is 50 pounds.

5.9.11.4. Horizontal Push and Pull Forces. The horizontal push and pull forces, to be applied initially to an object to set in motion or to be sustained for a period of time, shall not exceed the prescribed limits presented in Tables 4-6. These values were generated while pushing and pulling against a bar set at the indicated vertical heights on a treadmill surface. The posture used for pushing and pulling should be that posture most comfortable to the worker. The static horizontal push and pull forces exorable either intermittently or for short periods of time are presented on Table 7. For optimal pushing forces, the hands should be placed at a height between 38 and 44 inches from the floor on the object to be pushed, and the foot distance from the object's vertical plane should be between 53 and 61 inches. For optimal pulling forces, the bar height (i.e., the gripping surface) should be 37 to 43 inches from the floor, and the foot distance should be 8 to 9 inches from the vertical plane. The foregoing pertains to both males and females. In using Tables 4, 5, and 6 to estimate the recommended dynamic pushing and pulling forces for a particular vertical height from the floor, distance, and frequency, locate the mean value (in pounds) pertaining to those particular task variables. For example, if a job requires pushing a hand truck at a height of 57 inches above the floor once every minute for a distance of 7 feet, the maximum acceptable initial force for 25 percent of the male workers is 101 pounds.

5.9.11.5 Handles and Grasp Areas.

5.9.11.5.1 General. All removable or carried units designed to be removed and replaced shall be provided with handles or other suitable means for grasping, handling, and carrying (where appropriate, by gloved or mittened hand). The provision of handles generally allows for a 15% increase in lifting capacity.

TABLE 4
THE MAXIMUM ACCEPTABLE FORCES OF PUSH FOR MALES

Vertical Distance (in)*	100 ft. Push one push every					150 ft. Push one push every					200 ft. Push one push every				
	min.					min.					min.				
	1	2	5	30	8 hr.	1	2	5	30	8 hr.	2	3	5	30	8 hr.
57"	51	55	64	68	73	48	51	60	64	68	46	46	53	57	62
37"	12	15	15	17	17	14	14	15	19	19	14	12	15	17	17
25"	57	64	73	79	84	55	59	68	73	77	53	53	62	66	70
	14	15	17	17	19	15	14	17	21	22	15	14	17	19	19
	46	55	62	68	70	44	51	57	62	66	44	46	53	57	59
	10	14	15	15	17	12	12	17	19	21	12	12	14	15	17
57"	29	35	40	42	46	26	33	37	40	44	26	29	31	35	37
37"	7	9	10	12	12	7	9	9	10	10	7	7	9	9	10
25"	29	33	40	42	46	29	33	37	40	42	26	29	31	35	37
	9	9	9	10	10	7	9	9	10	12	9	9	9	9	9
	29	33	37	42	44	29	31	35	37	42	29	29	31	33	35
	9	9	9	9	10	7	9	9	10	10	7	9	7	9	10

Snook (1978)

*From floor to hands

TABLE 5
THE MAXIMUM ACCEPTABLE FORCES OF PUSH FOR FEMALES

Vertical Distance (in)*	100 ft. Push one push every					8 hr.	150 ft. Push one push every					9 hr.	200 ft. Push one push every					8 hr.
	1	2	5	30	min.		1	2	5	30	min.		2	3	5	30	min.	
53"	$\bar{x}$	37	40	44	48	51	35	35	42	46	48	33	33	37	39	44		
	σ	7	10	9	9	10	5	7	7	7	9	5	5	7	9	7		
35"	$\bar{x}$	42	46	51	55	58	40	42	48	51	55	37	37	42	46	48		
	σ	9	10	10	10	10	7	7	7	10	9	7	7	9	9	9		
22"	$\bar{x}$	33	40	44	48	51	31	35	42	44	46	31	33	37	40	42		
	σ	7	9	9	9	9	7	7	9	9	9	5	5	5	7	9		
53"	$\bar{x}$	24	26	33	35	40	20	24	29	31	33	19	22	24	26	29		
	σ	3	5	5	7	7	5	5	5	5	5	3	5	5	5	5		
35"	$\bar{x}$	24	26	33	35	27	22	24	29	31	33	20	22	24	25	29		
	σ	5	5	5	7	7	3	5	5	5	5	5	5	3	5	5		
22"	$\bar{x}$	24	26	31	35	37	22	24	26	29	31	22	22	22	24	26		
	σ	5	3	5	3	7	3	3	5	5	7	3	3	5	5	5		

INITIAL FORCE

SUSTAINED FORCE

Snook (1978)
*From floor to hands

TABLE 6
THE MAXIMUM ACCEPTABLE PULLING FORCES FOR MALES AND FEMALES

Vertical Distance (in)*	7 ft. pull (initial forces) one pull every						7 ft. pull (sustained forces) one pull every					
	sec.			min.			sec.			min.		
	6	12	18	1	2	5	6	12	18	1	2	5
	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.
Male 57"	42	48	55	57	64	66	26	35	42	42	46	48
	12	14	14	14	15	15	7	10	12	14	15	15
Female 53"	42	42	42	44	48	51	31	31	33	33	37	40
	10	12	10	9	10	12	9	9	9	9	9	10
Male 37"	59	68	77	79	88	92	33	44	55	57	62	66
	15	17	17	19	21	21	9	14	17	15	19	21
Female 35"	57	59	59	62	68	70	40	42	42	44	48	51
	15	15	12	12	15	15	12	10	12	12	12	15
Male 25"	68	77	86	90	99	103	35	48	59	59	66	70
	17	19	21	21	24	24	10	14	17	19	19	22
Female 22"	64	66	66	68	77	79	40	44	44	44	51	55
	17	17	15	15	17	19	12	12	12	12	14	14

Snook (1978)
*from floor to hands

TABLE 7
Least Horizontal Push Forces That Males Should be Able to Exert
Intermittently and for Short Periods of Time

<u>Force</u>	<u>Applied With</u>	<u>Condition (μ: coefficient of static friction)</u>
100N(25 lbs) Push or Pull	Both hands or one shoulder or the back	With low traction $.2 \leq \mu \leq .3$
200N(45 lbs) Push or Pull	Both hands or one shoulder or the back	With medium traction $\mu \sim .6$
250N(55 lbs) Push	One hand	If braced against a vertical wall (20-60 in) from and parallel to the push panel
300N(70 lbs) Push or Pull	Both hands or one shoulder or the back	With high traction $\mu \geq .9$
500N(110 lbs) Push or Pull	Both hands or one shoulder or the back	If braced against a vertical wall (20-70 in) from and parallel to the panel or if anchoring the feet on a perfectly non-slip ground (like a footrest)
750N(165 lbs) Push	The back	If braced against a vertical wall (23-43 in) from and parallel to the push panel or if anchoring the feet on a perfectly non-slip ground (like a footrest)

Kroemer (1974)

5.9.11.5.2 Location. Handles or grasp areas shall be provided relative to the object's center of gravity (C.G.) in order to prevent swinging or tilting when lifted. Location of the handles should be at least 2.5 inches below the top edge of the container. Further, they shall be located to provide at least two inches (50mm) of clearance from obstructions during handling.

5.9.11.5.3 Nonfixed Handles. Nonfixed handles (e.g., hinged or fold unit) shall have a stop position such that the handle is perpendicular to the surface when held. Furthermore, the handles should be capable of being placed into carrying position by one hand where appropriate.

5.9.11.5.4 Grasp Surface. Where a unit's installation requires that its bottom surface be used as a handfold during removal or installation, a nonslip grasp surface, (e.g., grooved or frictional) shall be provided.

5.9.11.5.5 Handle Dimensions. Handles which are to be used with mittened, gloved, or ungloved hands shall approximately equal the following applicable dimensions: 1.5 inches for grip size, 5 inches in the sagittal plane; and 2.5 inches in the vertical plane.

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APPENDIX

STUDY: Aberg, U. Physiological and mechanical studies of material handling. Ergonomics Research Society Ann. Conf., p. 282, 1961.

KEYWORDS: Maximal load, oxygen intake, pulse rate, mechanical work, electromyogram

METHODS: A series of investigations were carried out in an attempt to find out how large a maximal load can be safely allowed for each lifting action and how often this action can be performed, i.e., what is the maximal instantaneous effort and the long-time average of the mechanically produced work. The experiments were performed both as laboratory and field trials, but the laboratory trials have also had a rather strong practical connection. The following tasks were investigated:

1. Carrying weights in a rucksack while walking on a treadmill
2. Lifting beer cases
3. Baling operations in a pulp factory.

Measurements were made primarily of oxygen intake, pulse rate and the mechanical work produced. Throughout the experiments, a description of the movements was made by means of suitable work study techniques. Electromyograms were taken in some of the tests.

RESULTS: The results supported the earlier findings by Atzler, Cathcart, and others, concerning the maximal load in relation to body weight. In the case of carrying on the back, energy consumption can be separated in two parts: one part caused by the vertical acceleration forces, and one part caused by the balancing of the load. This also seemed valid for other forms of work, e.g., work with a wheelbarrow. The pulp factory experiment showed a marked dependence on the relation between momentary work load and the distribution of pauses. Some of these results point to a serious drawback for older workers who are in the doubly unpleasant situation of working near the upper limit of their ability and at the same time, because of insufficient strength, being compelled to use a method which is inferior from an energy-spending point of view.

SUMMARY: An attempt has been made to answer questions such as: how large of a maximal load can be safely allowed for each lifting action and how often can this action be performed?

This study looks into an important area because carrying and lifting of loads still very frequently occurs even in highly mechanized industries.

CITATIONS: None cited.

- STUDY: Aberg, U., Elgstrand, K., Magnus, P. & Lindholm, A. Analysis of components and predictions of energy expenditure in manual tasks. The International Journal of Product Research, 6(3), 189-196, 1968.
- KEYWORDS: Energy expenditure, model, work study
- METHODS: A relationship between amount of work and human energy expenditure is given in an equation (sometimes called Johansson's rule). This states that for a specific situation, the energy expenditure can be expressed by the formula:
- $$E = E_o + E_t + K \cdot A \dots \text{where } E = \text{total energy expenditure}$$
- E_o = energy expenditure due to basal metabolism, E_t = energy expenditure due to the operation's movement empty handed, A = amount of external work performed, K = a proportionality constant.
- The present paper deals with an attempt to divide the terms E_t and $K \cdot A$ in simple elements which could be easily measured using ordinary work study methods.
- RESULTS: A model for prediction of energy expenditure from physical data was proposed and was tested in a number of industrial cases. The accuracy of the result is in the same order of magnitude as a good work study.
- SUMMARY: As the variables used for predicting the energy expenditure can be easily measured at the same time as the ordinary method and work study is done, a comparatively small extra effort might add another dimension to the design of job and work place.
- CITATIONS: Seven references.

STUDY: Aghazadeh, F. Lifting capacity as a function of operator and task variables. Texas Tech University: Unpublished Thesis, August, 1974.

KEYWORDS: Low back pain (LBP), stepwise regression technique

METHODS: The report concerns itself with the causes and preventative measures of low back pain (LBP). It attempts to fully cover the scope of back injuries by examining the etiology of LBP, conducting experiments in order to determine lifting capacities, formulating and validating mathematical models incorporating operator and task variables, and investigating the effects of box size on lifting capacity. Previous studies which focus on the foregoing problems are also presented, along with a comparison between the previously generated data and the results of the present experiments. Further, a detailed description of the apparatus and techniques used in the present experiments are presented.

RESULTS: An analysis of those factors affecting low back pain indicated that age, sex, weight, height, and reduction of work space and dietary intake contribute to LBP. As far as the preventative measures are concerned, pre-employment screening, training, and ergonomics were underscored. The ability to predict the effects of box size and other variables on the maximum permissible weight by the formulated mathematical models was found to be strong. However, it was shown that the predictive ability of a model was weakened with the addition of variables; the fewer the variables, the greater was the predictive ability of a model. Much of the data generated by the present experiments were used in determining the validity of the proposed models. In addition, it was found that the utilization of data from other relevant studies could serve as a valid procedure in the development of a model.

SUMMARY: In essence, the use of predictive models could provide a more effective means of matching the worker with the right job. This paper indicated that the optimum and simplest predictive model only needed to incorporate back strength and leg strength as variables. This model was found not only to have greater predictive ability, but required less equipment to use, saved money, and was more applicable.

Although the effects of many operator and task variables were examined, further research needs to be conducted on such problem variables as temperature, noise, and humidity.. Furthermore, the presented models only incorporated the floor to knuckle height and three box sizes. Consequently, future research should consider various lift ranges and box sizes when investigating the etiology of LBP.

CITATIONS: 72 references.

STUDY: Alston, W.A., Carlson, K.E., Feldman, D.J., Grimm, Z. & Gerontinos, E. Quantitative study of muscle factors in the chronic low back syndrome. Journal of the American Geriatrics Society, 14(10), 1041-1047, 1966.

KEYWORDS: Chronic low back syndrome, muscle factors

METHODS: Two groups of subjects were chosen. The first group included 32 male patients with low back symptoms and 32 male controls. These normal subjects were matched with the low back patients with respect to age, weight, and height scores from high to low, the scores being independent from each other. The second group included 20 subjects with low back syndrome, and 25 normal subjects matched with similar characteristics. The strength of the trunk flexors and trunk extensors and hamstring muscle tightness were obtained for the first group. These were obtained by measuring the force developed by a maximal isometric contraction. Three determinations were made for flexors and extensors and the average result was considered representative. Then strength of the abdominal and psoas muscles were determined for the second group.

RESULTS:

1. There was a significant difference in the strength in the trunk flexion between normal subjects and those with low back syndrome.
2. A similar difference existed in the strength in trunk extension.
3. No significant difference was noted between the trunk flexion-extension ratios for the controls and the ratios for the patients.
4. The psoas muscle strength was clearly diminished in the patients with low back pain as compared to the controls, but the relationship to total trunk flexion strength and abdominal strength was statistically the same for both normal subjects and those with low back pain.
5. Tightness of the hamstring muscle groups of one or both lower extremities is common in patients complaining of low back pain of this type. The incidence was significantly increased in the patients as compared to the controls.

SUMMARY: In 32 male patients with the chronic low back syndrome and 32 normal male controls, measurements were made of the strength of the trunk flexors and extensors and of hamstring muscle tightness. In another group of 20 similar patients and 25 controls, the strength of the abdominal and psoas muscles was determined. The results led to the following conclusions: Chronic low back pain not associated with demonstrable bone or disc disease is frequently accompanied by generalized weakness of the trunk muscles, but there is a normal relationship between flexor and extensor muscle groups as indicated by the F/E ratio. No selective weakness of

Alston, et al., 1966 (continued)

SUMMARY: (continued)

flexors or extensors of sufficient degree to disturb this ratio was found in this study.

Tightness of hamstring muscle groups of one or both lower extremities is common in patients complaining of low back pain of this type. The incidence was significantly increased in the patients as compared to the controls. The use of back supports and therapeutic exercise as means of eliminating these muscle factors is of great help.

CITATIONS: Five references.

STUDY: Anderson, G.B.J., Ortengren, R. & Nachemson, A. Quantitative studies of back loads in lifting. Paper to the International Symposium: Safety in Manual Materials Handling, Paper #54, Buffalo, New York, July 19-21, 1976.

KEYWORDS: Intervertebral disc pressure, intra-abdominal pressure

METHODS: The intervertebral disc pressure in the third lumbar disc, the intra-abdominal pressure and the myoelectric activity of several muscles of the back have been recorded simultaneously. Four healthy subjects were studied. Lifting was performed with the back straight and knees flexed (leg-lifting) as well as with the back bent and the knees straight (back-lifting). Studies were also made when a load was held at various distances from the body. Static experiments were also studied. They comprised pulling a handle placed 40, 50, or 60 cm above the floor with the back either straight or flexed.

RESULTS: The intervertebral disc pressure was about the same in back-lifting and leg lifting; back-lifting yielded a slight but systematically higher pressure. The distance from the body at which the weight was held was more important than the technique of lifting. In all investigations there were only minor changes in the intra-abdominal pressure. It was not possible to reduce the disc pressure by voluntarily increasing the intra-abdominal pressure. The time-course of the myoelectric activity was about the same in back-lifting as in leg-lifting. The disc pressure values and the intra-abdominal pressure values were about the same when pulling was performed with the back straight and flexed. The myoelectric signal amplitudes were significantly higher when pulling was performed with the knees flexed and the back straight and the handle placed at 40 or 50 cm above the floor. When the handle was at 60 cm, the amplitudes were about the same regardless of the posture of the back.

SUMMARY: Instructions in manual handling are used with increasing frequency to reduce the load on the back during manual work. There are comparatively few investigations, however, in which the load on the back has been measured when different methods of lifting are adopted. Further, the results differ in different investigations. The purpose of the present work is to analyze differences in load on the back when lifting is performed using different techniques.

CITATIONS: None cited.

STUDY: Aquilano, N.J. A physiological evaluation of time standards for strenuous work as set by stopwatch time study and two predetermined motion time data systems. Journal of Industrial Engineering, 19(9), 425-432, 1968.

KEYWORDS: Time standard, predetermined motion time data, work physiology, elemental data, work sampling

METHODS: An experiment was designed to investigate whether workers, while performing moderate to strenuous tasks at time standards set by traditional industrial engineering methods, experience physical demands which are considered 'reasonable' from a physiological point of view and whether the time standards developed for different tasks are consistent in requiring the same levels of energy expenditure. In the experiment, experienced workers performed carton handling tasks while heart rate and oxygen consumption were monitored. To conduct the experiment, time standards based on conventional engineering methods were first developed. The energy costs for performance at these time standards were then obtained and compared to levels suggested by physiological studies. Standard times were obtained by the analysts by multiplying the normal times by an allowance factor which included personal and fatigue time. The physiological level used for comparison in this study was 4Kcal above the sitting rest level. Another assumption was that 4Kcal above the seated rest level corresponds to incentive performance.

Carton handling was selected as the type of work to be performed. A sample of six subjects was selected from a population of about 500. Each subject performed two trials of each of the six tasks at three paces, for a total of 36 runs per subject. The faster pace was set at 128 percent of the standard rate which had been developed previously. The heart rate and the oxygen consumption were monitored both during and previous to the work period.

Regression analysis was performed with work pace as the independent variable and Kcal as the dependent variable.

RESULTS: Using 4Kcal as the physiological level corresponding to 128 percent performance, a comparison was made of the energy expenditure rates. At the incentive pace determined by the standard analysts, wide differences from this level resulted. Performance by individual subjects varied from 32 percent below to 189 percent above this level. At standard pace also, energy demands were high.

Since such large differences were observed in performing the tasks, a simple test was made to determine the extent to which conventional methods were compatible with physiological recommendations. Five of the six subjects performed task 1 and task 3 using empty cartons. This was done to get an estimate of low weight energy expenditure. The figures for energy expenditure showed that energy requirements for body motion alone are in the range of the 4Kcal level.

Aquilano, 1968 (continued)

RESULTS: (continued)

It was concluded that the standard times developed for this study were valid for unladen body movement and are consistent with physiological recommendations. However, as weight is added, a rapid increase occurs in energy requirements.

SUMMARY:

An experiment was designed to investigate whether workers, performing moderate to strenuous tasks at time standards set by traditional testing methods, experience physical demands which are considered 'reasonable' from a physiological point of view or not, and whether the time standards developed for different tasks are consistent in requiring the same levels of energy expenditure or not.

The time standards developed for this study were unacceptable from a physiological point of view. Great differences in energy demands from reasonable levels and a large variance among tasks were observed. The major discrepancy was thought to be in the rest allowances. The study entailed the performance of six carton-handling tasks by experienced workers. At incentive pace, energy expenditure levels ranged from 32 percent below the assumed 4Kcal level to 189 percent above it. At standard time they ranged from 46 percent below to 125 percent above the 4Kcal level.

The study stresses the need for setting standards by methods which take the physiological factors into account. In the moderate to strenuous work situation, time standards based on conventional methods do not seem to work. It can be used to determine and estimate time standards for manual materials handling jobs, applying the work physiology techniques.

CITATIONS: Twelve references.

STUDY: Asmussen, E., Poulsen, E. & Rasmussen, B. Quantitative evaluation of the activity of the back muscles in lifting. Communications from the Danish National Association for Infantile Paralysis, No. 21, 1965.

KEYWORDS: Back muscle, EMG, isometric back strength

METHODS: The measurements of the force produced during isometric contractions of the back muscles were performed by means of a strain guage-dynamometer. The force is measured during an attempted extension of the back in the erect position with a strap around the shoulders across the deltoid muscles. Weights to be lifted were placed in a box with two handles, about 40 cm apart, and weighing 2.5 kg. The subjects were instructed to keep their backs straight although not overextended, and at an angle to the vertical of 45°. Hips and knees were flexed and the feet placed about 50 cm apart. Control experiments showed that the degree of flexion in the knees and the placement of the feet had no influence on the muscle activities of the back under the experimental conditions. The EMG was recorded by means of paired silver electrodes. After measuring the strength of the back muscles, the subject was released from the dynamometer and the lifting operations were started. The subject grasped the two handles of the box containing the weights and assumed the standard position: feet apart, knees bent, back straight and inclined 45° forward. He maintained this position for a few seconds while EMG and IEMG were recorded.

RESULTS: There is a correlation between the weight that is carried in the hands in a forward inclined position and the force that the muscles of the back must develop. This force, probably because of the supporting action of the intra-abdominal pressure, is less than what should be expected. It would be safe to estimate that people with otherwise normal backs are able to hold loads (inclusive weight of head, arms, and part of the trunk) weighing up to 140 percent ($100/\cos 45^\circ$) of their maximum isometric back strength, measured at the height of the shoulders, provided the spine is held in a normal position and the trunk is not inclined more than about 45° forward in the hips. For long lasting holding in this position, the figures must be reduced. For frequently repeated lifts, it must correspondingly be reduced with a factor .8 to .6, depending on the frequency. In practical daily jobs, a further reduction to half of these maximal values must be recommended in order to eliminate the weight of head, arms and trunk and to obviate chronic fatigue. The rule must then be: about 70 percent of maximum isometric back strength for single, short lasting lifts; 55 to 40 percent of isometric strength for lifts repeated 10 to 30 times per minute; and 30 to 35 percent for continued holding of about 1 minute duration.

SUMMARY: As a hypothesis it is assumed that lifting of loads from the ground should be carried out with the spine as nearly as

Asmussen, et al., 1965 (continued)

SUMMARY: (continued)

possible in the habitually curved position. In this position the muscles of the back rather than the ligaments counteract the pull of gravity. In a series of experiments, the pulls exerted by the back muscles when holding loads in a 45° forward tilted position are estimated from the integrated EMG of the muscles and the established relationship between integrated EMG and isometric backward pulls. It was found that the estimated forces were less than the theoretically predicted forces, especially at higher loads. Possible reasons for this difference are discussed. Practical hints for estimating allowable maximal loads from measurements of isometric back strength are given.

CITATIONS: Ten references.

STUDY: Ayoub, M.A. Optimum design for containers for manual material handling tasks. Paper presented at the International Symposium: Safety in Manual Material Handling, Buffalo, N.Y., 1976.

KEYWORDS: Torque, bulk, optimization model, Lagrange multiplier, simplex method

METHODS: Several examples which outline and detail the problems associated with the design of containers were presented. For example, given a container having a particular constant weight, what would its dimensions have to be in order to preclude excessive torque on the lower lumbar region? Or, given a container with fixed dimensions, what would its weight have to be if the torque at the L5/S1 were to be kept constant?

RESULTS: The foregoing examples attempted to emphasize that the design of containers is basically a problem of mechanics. Several models centering on the biomechanical approach were presented as viable approaches for dealing with specific container design problems.

SUMMARY: The elimination of problems arising as a result of hazardous practices in container design is important. However, it should not preclude analysis of other industry-related factors (i.e., consideration of man, task, environment). In light of this, the modeling approach in biomechanics stands to contribute the most, for it offers flexibility in the analysis of problem variables in an integrated and complete fashion.

CITATIONS: Seven references.

- STUDY: Ayoub, M.M. Lifting Capacity of workers. Journal of Human Ergology, 6, 187-192, 1977.
- KEYWORDS: Physiological, psychophysical, biomechanical approaches, task variables
- METHODS: Lifting capacity, in this paper, was defined as the amount of load lifted repeatedly at the rate of one lift/minute in a compact box. With this definition in mind, a comparison of the lifting capacity as determined by the psychophysical and physiological methods for different studies was made.
- RESULTS:
1. Lifting Capacity
It is defined as the amount of load lifted repeatedly at the rate of 1 lift/minute in a compact box. The physiological and psychophysical methods are compared; also, one lifting height is used (from floor to the height of 29 inches above floor, or floor to knuckle height). The lifting capacities using several techniques are given in tabular form.
 2. Effect of Frequency
Several investigations indicated that lifting capacity decreased when the frequency of lift increased. Assuming a linear effect of frequency, there was no agreement between either the physiological or the psychophysical approaches.
 3. Box Size Effects
All psychophysical studies pointed out that as the size of the load increased in the sagittal plane, the mean weight lifted decreased. No data on the box size effects using physiological approaches was available.
The study showed that there were some disagreements in the data obtained between investigators using the same approach and between the different approaches used. These disagreements in the lifting capacity and the task variables were the result of several factors:
 1. Differences in methodologies used.
 2. Differences in the subject population and its characteristics.
 3. The wide variation in the lifting tasks used by the several investigators and the demands of these tasks in terms of strength and endurance.In summary, the author suggested that it is essential to resolve some of these differences by simultaneously using several methodologies in a single study under well-controlled conditions.
- SUMMARY: This paper provided a comparison of the lifting capacity as determined by the following methods:
 1. Physiological method
 2. Psychophysical methodAlso, how this capacity was modified when three basic task variables were considered. These task variables were:
 1. Lifting height
 2. Lifting frequency
 3. Box size lifted

Ayoub, 1977 (continued)

CITATIONS: Thirteen references.

STUDY: Ayoub, M.M., Bethea, N.J., Deivanayagam, S., Asfour, S.S., Bakken, G.M., Liles, D., Mital, A. & Sherif, M. Determination and modeling of lifting capacity, Final Report, HEW Grant Nos. 1R01OH00545-01 and 5R01OH-00545-02, September, 1978.

KEYWORDS: Lifting capacity, psychophysical approach, task variables, job stress index

METHODS: This study was designed to determine the lifting capacity of the male and female industrial population for six different height ranges, four levels of frequency (2, 4, 6, and 8 lifts per min), and three different box sizes (12 in., 18 in., 24 in., in the sagittal plane).

A balanced incomplete block factorial design was used. There were 73 male and female subjects. The dependent variable was the maximum acceptable weight of lift, which was arrived at using the psychophysical approach.

Lifting capacity prediction models were developed. Also, field data were collected to determine the effects of job demands on back injuries and the relationship of job stress index (job demand/individual capacity) and potential injury.

RESULTS: The lifting capacity for males and females differed significantly. There was a linear effect of box size and frequency on the lifting capacity. Sex code was the most important factor in predicting the lifting capacity of males and females. Age had no effect on the lifting capacity, either for males or females.

SUMMARY: Lifting capacity norms and prediction models were developed. These data and models are needed for job design and employee placement/selection.

CITATIONS: One hundred thirty-seven references.

STUDY: Ayoub, M.M., Dryden, R.R., McDaniel, J.W. & Knipfer, R.E. Psychophysical based models for the prediction of lifting capacity of the industrial worker. Paper presented at Automotive Engineering Congress & Exposition, Detroit, paper #760080, February 23-27, 1976.

KEYWORDS: Maximum acceptable lift, psychophysical model, lift ranges

METHODS: Subjects were required to lift tote boxes from the floor to standing knuckle height, knuckle to shoulder height through a range of 50.8 cm, and shoulder to reach height through a range of 50.8 cm. Following the lift to the proper height the box was placed on a table which lowered the box to its starting height. As well as the lifting performance, anthropometric strength, and physiological measurements and parameters were recorded. The measures were taken so as to allow the subjects time to recover between performance measures from fatigue. The comparison of the working heart rate with the resting heart rate was used to determine the number and duration of the rest periods. The procedures followed a psychophysical approach in that the subjects adjusted the weight of the box, but did not know the weight of the box. The instructions given the subject were to adjust the weight to a level which could be lifted repetitively during an 8 hour day. The subjects lifted 4, 6, 8 times respectively for the floor to knuckle, knuckle to shoulder, and shoulder to reach heights. Subjects lifted for a maximum of 45 minutes. Subjects were recruited from industry.

RESULTS: Predictive models of the weight of maximum acceptable lift were developed. A stepwise regression procedure was used to formulate these models. The predictive capability of the models for the upper range of lifting were lower than the models for the lower ranges of lift. Males were found to have higher levels of maximum acceptable lift than females. For 90% levels of males the maximum weight is 155.75 newtons, for the same range of the female population the maximum weight is 84.55 newtons.

SUMMARY: Research was conducted to formulate predictive models of maximum weight of acceptable lift. Using a psychophysical approach models for three ranges of lift were developed. Maximum acceptable weight was lower for women than for men ranging from 49% to 62% of the maximum acceptable weight for men. The predictive models were viewed as having potential as screening methodologies in selecting proper job placement of workers in jobs requiring lifting activities.

CITATIONS: Ten references.

STUDY: Ayoub, M.M. and El-Bassoussi, M.M. Dynamic biomechanical model for sagittal lifting activities. Paper presented at the International Symposium: Safety in Manual Materials Handling, State University of New York at Buffalo, July 1976.

KEYWORDS: Compressive force, shear force, leg lift, back lift

METHODS: Leg lifting and back lifting were compared using different weight loads and different box sizes. The model was used to determine the strain on the musculoskeletal system during these two types of lift. Body segment parameter data, external weight carried, initial and final configurations of the body links and total movement time for each link with its relation to the other links were found and put into the dynamic biomechanical model. The model then produced the angular displacement, velocity, and acceleration for each segment which could be used to calculate tangential and normal accelerations. Next, using the accelerations, the reactive forces and torques could be calculated. The forces and torques allow the shear forces on the spine during the lifting action to be determined.

RESULTS: The lifting comparisons were made in terms of hip torque, compressive and shear forces on the spine at L-4/L-5 and L-5/S-1, and the postures during the lifting action where maximum compressive and shear forces occur. The model simulated both methods of lifting showing each articulation path. The data showed that maximum compressive forces are higher for back lift as compared to leg lift. As the stress increases for the lifting task, the rate of change in stress on L-5 increases at a higher rate for the back lift method. In either method of lift, the most stressful posture occurs right after the lifting action has started. The model also shows how the compressive and shear forces change as the operators posture changes while lifting. The model also simulates the lifting showing the operator's posture as a function of time. The results also show the linear changes in the stresses with increase of the difficulty of the task as the box length is increased.

SUMMARY: The dynamic biomechanical model was used to determine the strain on the musculoskeletal system during the lifting action using leg and back lifts. Compressive and shear forces were found and during the action of lifting, these forces increase rapidly, reach a peak early and gradually decrease in value towards the end of the lift.

CITATIONS: Thirty-three references.

STUDY: Ayoub, M. M. & Lo Presti, P. The determination of an optimum size cylindrical handle by use of electromyography. *Ergonomics*, 4(4), 503-518, 1971.

KEYWORDS: Electromyography, hand size, weight resistance, hand cylinder

METHODS: The task, to determine an optimal size cylindrical handle, consisted of reaching to the handle, the lower edge of which was located 18 in. above the work surface. Each subject was required to grip the handle using his preferred hand in a power grip and then to pull the handle straight down toward the target marked on the flat horizontal surface of a simulated work piece located 12 in. directly below the original static position of the handle. Upon making contact, instructions were to hold for 3 seconds, then return the handle to the original position and release it. This was repeated 5 times. The position of the subject was such that a sagittal plane would pass through the center of the suspended handle and his shoulder joint.

In addition, another task, procedurally identical, but involving the element of fatigue, was performed by each subject. In this investigation "optimum size hand cylinders" meant that diameter of cylindrical handle which resulted in: the maximum ratio between the grip force and the EMG activity of the flexor and extensor muscle groups; the longest work period before the onset of fatigue, the criterion being the working time until the onset of synchronization of action potential on the EMG trace.

A pulley system was designed such that the handle was suspended from one side and counter-balanced by various weights. The tension in the line is referred as the weight resistance. A special dynamometer was designed and built for reading the force exerted by the hand. This was cylindrical with the provision of changing the diameter by stages up to a maximum of 3 in.

A completely randomized block design was used with subjects serving as blocks.

RESULTS: Handle sizes were highly significant. A handle 2.5 in. in diameter resulted in the least muscle activity in performance of the experimental tasks, and the 1.5 and 2 in. handles showed slightly higher electromyographic activity.

Weight effect was also highly significant. More muscle activity was required to produce large force.

It was possible to exert the greatest grip force on the 1.5 in. diameter handle and the least on the 2.5 in. diameter handle. If the ratio of the grip force to the EMG activity is considered, the best efficiency is obtained for the 1.5 in. diameter handle.

Ayoub & Lo Presti, 1971 (continued)

RESULTS: (continued)

Results of the fatigue experiments were similar to the main experiment. A 2.5 in. diameter handle was less desirable as compared to 1.5 in. and 2 in. diameter handles, but was preferred to a 1.25 in. diameter handle.

The handle of best size proved to be that of 1.5 in. in diameter.

SUMMARY:

An experiment was designed using muscle electromyography to determine if an optimum cylindrical handle size exists. First phase of the experiment was concerned with an experimental task of gripping a cylindrical handle and performing a simple task routine to evaluate the optimum size. The second phase was concerned with a fatigue test, using the same handles. Hand size, weight resistance and cylindrical handle diameter were the experimental variables.

Results indicated that the 2.0 in. diameter handle showed least EMG activity, but the 1.5 in. diameter handle was found to be the optimum handle size based on the ratio between force applied and the EMG activity measured. Also, the 1.5 in. diameter handle was found to provide the maximum number of completed task cycles before the onset of fatigue.

This research has application in the design of couplings for industrial containers. Optimal handle size can accompany a container with optimal weight/bulk ratio.

CITATIONS: Fourteen references.

- STUDY:** Ayoub, M.M. & McDaniel, J.W. Effect of operator stance on pushing and pulling tasks. AIIE Transactions, 6(3), 185-195, 1974.
- KEYWORDS:** Pushing and pulling capacities, task configurations, stress on the spine, bar height, shoulder height, foot distance, reach height.
- METHODS:** The subjects were instructed to push against the handle of the apparatus keeping the arms extended at the elbow and the rear leg extended at the knee. They were further instructed to position their left foot approximately 12 in. in front of the right foot while applying their maximum push for 5 sec. In the case of pulling, the rear foot was maintained off the floor.
- The height of the subject was removed as a variable by choosing the bar height (BH) and foot distance (FD) as percentage of the shoulder height or reach height. Reach height (RH) in this study was defined as the distance from the floor to the grip center in overhead reach. Shoulder height (SH) was measured from the floor to the acromion. The foot position distance from the handle was defined as the distance from the vertical plane of the handle to the lateral malleolus. The elbow angle was removed as a variable.
- RESULTS:** It can be concluded that the best position for pushing tasks can be found when the force is applied to the load at a height of approximately 70 percent shoulder height or 50 percent reach height and the rear foot should be located at a distance of approximately 100 percent SH or 70 percent RH.
- For pulling, the hands should apply the forces at a distance of 40 percent of shoulder height above the floor, while the front foot should be at a distance of 10 percent of shoulder height from the plane of force application. Several other findings are also important.
1. Maximum fatigue is found when foot distance is between 70 percent and 80 percent shoulder height or approximately 50 to 55 percent reach height.
 2. The optimum bar height should be as low as possible to yield the longest time.
 3. The female subjects, although unable to achieve pushing forces as high as the males, have been able to maintain the maximum forces for longer periods than the males.
- SUMMARY:** The main objectives of this study were to: 1) investigate the capabilities of man in pushing and pulling tasks as they are affected by the different body configurations, 2) determine if optimum configurations would exist for both the pushing and pulling tasks, and 3) evaluate the stress on the spine during such activities as pushing and pulling tasks.
- CITATIONS:** Twelve references.

STUDY: Ayoub, M.M., McDaniel, J.W. & Dryden, R. Modeling in lifting activities. Paper presented at the American Industrial Hygiene Association Meeting, Boston, Mass., May 1973.

KEYWORDS: Lifting capacity, lifting stresses, human frames, acceptable weight of lift, static and dynamic endurance, back, arm, and leg strength

METHODS: Each subject was instructed to lift a weight from the floor and place it on the lifting machine shelf adjusted to his knuckle height. Each subject was also instructed to adjust the amount of weight in the box so that he was lifting as much weight as he could lift in this manner for a period of a normal working day. Based on the findings of Brown (1970), the subject lifted this box in the manner most comfortable to him.

RESULTS:

- I. Model 1 (2 final models were selected)
 1. Model for males - based on 10 cases:
Predicted maximum lift = $-172.356 + .022 (\text{height})^2 - 2.73 (\text{static end.})^2 + .021 \times (\text{RPI} \times \text{arm st.}) + .053 (\text{RPI} \times \text{back st.}) - 2.513 (\text{fitness/dynamic end.})$;
Multiple R=.9331; Prediction Error=8.78 percent
 2. Model for females based on 15 cases
Predicted maximum lift = $-24.027 + .194 (\text{RPI})^2 + .006 (\text{arm st.} \times \text{leg st.})$; Multiple R=.7443; Prediction Error=6.83 percent

II. Model 2
The following two relationships are used

$$X_t = \frac{X_T}{2\pi} \left[\frac{2\pi t}{T} - \sin \frac{2\pi t}{T} \right] \quad (i)$$

$$\theta_t = \frac{\theta_T}{T} \left[\frac{2\pi t}{T} - \sin \frac{2\pi t}{T} \right] \quad (ii)$$

where

X_t = displacement of time t

X_T = maximum displacement, the distance between initial and terminal points measured in that distance

θ_t = angular displacement of time t

θ_T = maximum angular displacement

SUMMARY: A need exists for generalized models capable of predicting lifting capacities of man and lifting stresses imposed on him while lifting loads. Two types of models are thus discussed here:

1. Performance Models
2. Biomechanical Models

The performance models attempt to develop correlations between physical characteristics and lifting capacities of industrial workers. These models would predict lifting capacities for

Ayoub, et al., 1973 (continued)

SUMMARY: (continued)

several lifting heights with reasonable degree of accuracy. The biomechanical models attempt first to apply Newtonian mechanics to the human frame to provide data on reactive forces and torques on the various joints, links and other critical parts of the human frame. Once these biomechanical models are developed, they can also be used for predictive purposes. Predictive models for performance, as well as biomechanical models, are very useful in gaining insight into the factors and methods in lifting activities that relate to lifting capacity of man. Both types of models attempt to determine lifting capacity of man, given certain physical characteristics and constraints.

CITATIONS: Nine references.

- STUDY:** Ayoub, M.M. & Murthy, D.J.V. Optimum skeletal configuration under static pushing tasks. Unpublished Report, Department of Industrial Engineering, Texas Tech University, August 1967.
- KEYWORDS:** Maximum pushing force, skeletal configuration, crossbar height and the horizontal distance from the ankle joint to the vertical plane through crossbar in terms of subject's shoulder height
- METHODS:** In order to select different skeletal configurations the following two methods were considered:
1. The subject's skeletal configurations were defined by two angles
 - a. the angle between the subject's extended arm and the horizontal plane through shoulders. Range: -30° to 40° , 10° intervals.
 - b. the angle between the rear lower extremity and the floor surface. Range: 60° to 80° , 10° intervals.
 2. The skeletal configuration of the subject was determined by two variables:
 - a. Distance A: the height of the crossbar above the floor surface
 - b. Distance B: defines the location of the ankle joint as measured from the vertical plane passing through the crossbar.
- Distance A: 6 levels, 60, 70, 80, 90, 100 and 110 percent of the shoulder height.
- Distance B: 6 levels, 50, 60, 70, 80, 90, and 100 percent of the shoulder height.
- Each subject was placed in front of the experimental equipment, and, according to a randomized order, a measurement was taken for the horizontal and vertical forces during leaning as well as maximal pushing for each of these configurations. During both leaning and maximal pushing, the subjects maintained:
1. a fully extended arm
 2. full knee extension of the rear lower extremity, and
 3. the front foot was not in contact with the floor.
- RESULTS:** The results reported in this paper are those for method 2 only.
1. Effects of Measurement A (cross-bar height)

As the cross-bar is raised, the leaning horizontal and pushing forces increase. The resultant leaning as well as the resultant pushing force increase as the cross-bar is increased in height. The effects of A on leaning vertical and pushing vertical forces were nonsignificant.
 2. Effects of Measurement B (horizontal distance of rear foot from cross-bar)

While the leaning horizontal and leaning resultant forces increase almost linearly with the increase in B, the pushing horizontal forces increase nonlinearly and level off after B has reached 90 percent of the shoulder height. It appears that the maximum forces due to muscular contraction

Ayoub & Murthy, 1967 (continued)

RESULTS: (continued)

appear when the rear foot is at 80 percent of shoulder height away from the vertical plane through the cross-bar. The effect of B on the leaning and pushing vertical forces were not significant.

SUMMARY:

This paper describes the preliminary work in progress whose purpose is to determine the skeletal configuration that will result in the maximum pushing forces and compare these with those providing the maximum force due to muscular contractions; in addition, it will answer some questions concerning the component that the body weight contributes toward the total pushing force. The ultimate goal is to construct a biomechanical model of pushing and pulling tasks. The program consists of two phases:

1. The Static Phase: Biomechanical analysis of tasks while the subject is pushing or pulling against a stationary load.
2. The Dynamic Phase: Biomechanical analysis of tasks while the subject is pushing or pulling against a load and both the subject and the load is in motion.

CITATIONS: Seven references.

STUDY: Bastina, P.I., Gratsianskaya, L.N., Krasinskaya, G.F., Syromyatnikova, E.N. & Elkin, M.A. The effect of women's health by occupations involving frequent carrying of small weights. Public Health Engineering Abstracts, XLI(g), September 1961.

SUMMARY: The maximal weight of a single load lifted at a time by a woman is set at 20 kg, but the law fails to specify the sum of weight lifted during the whole of a shift. In order to obtain hygienic backgrounds for rating this total weight lifted in the course of one day by women, the authors have examined at two brick works 146 women workers permanently engaged in transporting relatively small loads during the whole of the work day. These women-workers revealed a series of physiological shifts, reproduction disturbances, and a high percentage of occupational diseases of the skeletal and motor systems.

The authors suggest that the total weight shifted per work day by women should be subject to a standard rating, and recommend measures to improve working conditions prevailing at brick works.

CITATIONS: None cited.

STUDY: Block, C. T., Fine, G. T., Nemmer, W. C. & Wiersema, R. G. The effect of force moment on physiological cost while performing a lifting task. Unpublished report. Department of Industrial Engineering, Texas Tech University, 1966.

KEYWORDS: Pulmonary ventilation, heart rate, energy consumption, and fatigue

METHODS: The experiment used a four factor design. Three test positions were administered to each of three subjects in a pre-determined random order sequence. The second replication was taken in the same manner. A total of six tests were recorded in each position. Three female subjects each performed the same lifting tasks while pulmonary ventilation, heart rate, and electrical potential of the sacrospinalis muscle were measured. All tasks performed by the subjects consisted of lifting a 20 lb. weight a total of 7 inches. The time interval from the initiation to the termination of the lift was 0.05 minute and the rest cycle was a constant 0.10 minute. The distance from the fifth lumbar vertebrae to the center of the test weights was the only independent variable introduced in this project. Electrocardiogram and electromyogram readings were made at rest and continuously during the test, and exhaled air volume was recorded at the end of each minute of work.

The exhaled air volume was used as a qualitative measure of O_2 consumption. The difference between pulmonary ventilation at rest and at work is the amount of ventilation which is required by the work. The electrocardiogram was used for pulse rate determination. Changes in configuration and amplitude of the myogram are an indication of muscle fatigue and are read directly from the recorder chart.

RESULTS: The main effect of positioning the test weight from the lumbar spine showed that the larger moment arms resulted in a higher average ventilation rate due to work. This shows that more O_2 was used and thus more energy was required to perform the work at the larger moment arms. Even though all the subjects showed this same upward trend in ventilation rate, there were great differences in the individual rates. This can be attributed to the differences in body chemistry of individuals and to the fact that the individual operators use different groups of muscles in the lifting task.

In regard to time, the ventilation rate increased as the work period progressed. This can be attributed to the fact that the muscles are not getting enough O_2 from the red corpuscles of the blood and therefore must start using the O_2 stored in the muscle fiber. The pulse rate is related to the ventilation rate in that as the muscles go into " O_2 debt" the pulse rate will increase in order to supply O_2 to the blood at a faster rate.

Block, et al., 1966 (continued)

SUMMARY: The established purpose of this project was to demonstrate the physiological cost of various moments of force about the fifth lumbar vertebrae. In addition, this project demonstrated an objective method of measuring energy consumption and fatigue. Pulmonary ventilation, heart beat and electrical potential of the sacrospinalis muscle were selected as measures of physiological cost.

It was observed that a person can fatigue his muscles to the point of strain, or transfer the load onto the lumbar vertebrae causing an injured or slipped disk, without being aware that they have achieved this overloaded condition. Proper training of personnel can allow the muscle load to be shared between the deltoid and sacrospinalis muscles thereby decreasing the proportionate stress each receives.

CITATIONS: Five references.

STUDY: Bobbert, A. C. Optimal form and dimensions of hand grips on certain concrete building blocks. Ergonomics, 4(2), 141-147, 1960.

KEYWORDS: Dimensions, hand-grips, concrete building blocks

METHODS: A series of 29 sets of hand-grips were moulded of clay or wood. They were variations of the 21 hand positions resulting from technical restrictions and functional-anthropometric considerations.

In order to carry out experiments with the different sets of hand-grips, the grips were mounted upon an iron bar and loaded with a weight in such a way that both the distance between the hand-grips and the weight of the original concrete blocks were simulated. Two subjects were studied performing a standard task with this model. The task consisted of lifting and replacing the model over a fixed height and according to a prescribed time schedule. Pulse rate and oxygen consumption during work were measured. Four hand-grips were studied. It was concluded that the work of handling concrete blocks could be increased by fitting them with finger-grips. But as there was no definite correlation between oxygen consumption and pulse rate on one hand and the depth of the finger-grip on the other, maximal lifting power was taken as a criterion on the assumption that high maximal lifting power correlates with good quality of grip.

Each of the 29 sets of hand-grips was then fitted with a spring ergograph. Six subjects, wearing plastic gloves, were asked to pull with each set of grips four times in succession with their maximal force. The mean of the 24 values obtained with each set was called the 'maximal lifting power.'

RESULTS: When comparison was made of the results obtained by measurements of oxygen consumption and pulse rates and by determination of maximal lifting power, it was clear that the latter criterion is superior. The superiority of the maximal lifting power as a criterion also appears from the fact that the lifting power discriminates between 2mm changes in the depth of finger-grips.

The highest values of maximal lifting power (85.7kg) was found with an ideal grip (No. 29). The grip dimensions are (in mm): $a=0$, $b=65$, $c=40$, $x=10$, $y=36$, $z=13$ curved length=80 where

a =distance from thumb-grips to upper face of block,
 b =width of upper face,
 c =distance between finger-grip and upper face,
 x =depth of thumb grip,
 y =thickness of concrete partition between tips of thumb and fingers, and
 z =depth of finger-grip.

For technical reasons grip number 24 was selected. The maximal lifting power of this differed only slightly from the ideal of

Bobbert, 1960 (continued)

RESULTS: (continued)
number 29. The various dimensions are: $a=0$, $b=65$, $c=40$, $x=10$,
 $y=42$, $z=13$, straight length=80, maximum lifting power=81.7kg.

SUMMARY: The optimal form and dimensions of hand grips for handling certain types of concrete building blocks were found by theoretical considerations and laboratory experiments. Such grips were found to reduce the physiological work load considerably. The maximal lifting power proved to be a better criterion for the evaluation of minor changes in dimensions of hand grips than energy expenditure of heart rate during work.

This study has application in modern building practice, where the shape of the concrete block can be changed to reduce the physiological work load. The maximum lifting power can also be applied to determine hand-grips in lifting objects similar to concrete blocks.

CITATIONS: Four references.

STUDY: Brown, J.R. The contributory factors to the development of low back pain in industry. Presented to the American Industrial Hygiene Conference, Miami, Florida, May 1974.

KEYWORDS: Posture, etiology, trauma

METHODS: To uncover some of the causes of lower back pain, a questionnaire was designed which covered aspects such as physical fitness, job satisfaction, postural fatigue, recreational activities and medical care. Of 1000 employees, 509 returned the completed or partially completed questionnaire. The employees were of varied occupation and covered areas like warehouse, hospital, removal and storage, and light industry. Anthropometric data for the subjects was also collected and dated to check if there was a significant difference between the subjects with back injury and general population.

RESULTS: A number of interesting observations were made from the returned questionnaires. There was an excess of 11 percent of back injuries in females (46 percent) over males (35 percent). Those with injuries lasting more than 6 months constituted 5.8 percent of the women and 5.3 percent of the men. Twenty-five percent of the men and 7 percent of the women with back injuries received workmen's compensation. Ten percent of men and women with back injuries received compensation for more than 6 months. Fifty-eight percent of the men and 30 percent of the women took sick leave for back trouble. Only 49 percent of the replies gave the opinion that lifting was the cause of their low back pain. The accident rate, for injuries other than back injury, was 2-1/3 times that of women for men. It was revealed that 21 percent of the men and 30 percent of the women did not engage in athletic games. Forty-eight percent of the total population did not attend lectures or demonstrations on lifting and 37 percent of those with back injuries did not attend. However, it was found that 77 percent of the sample adopted the lifting methods advocated in educational programs. Eighty-two percent of individuals with back injuries used the prescribed method. It is interesting to note that 92 percent of the population returned to their original job following treatment. There was no evidence that people with back injuries changed jobs more frequently than those without. Fifty-two percent of the sample with back injuries did not wear non-skid shoes. Fifty-one percent of the men thought that loads up to 50 lbs. were not unreasonable, but 36 percent of the women thought the load should not exceed 30 lbs. Only 20 percent of the men and 7 percent of the women lifted 50 lbs.

SUMMARY: The results of the questionnaire indicate the variety of factors which may be responsible for development of low back pain in industrial workers. Questionnaires were sent to 1000 workers in a variety of industrial occupations including hospital work. A sample of 509 replies was obtained and a number of observations were made on the incidence, duration and treatment of low back

Brown, 1974 (continued)

SUMMARY: (continued)
pain in industry. An opinion considering the role of accident prevention program and non-skid footwear was obtained.

Most of the individuals did not lift weights greater than they thought to be reasonable.

The questionnaire study was of an exploratory nature and serves as a useful pilot study. It is helpful in the development of further questionnaires and indicates the areas from which useful objective results may be obtained.

CITATIONS: Two references.

STUDY: Caldwell, L.S. Body position and the strength and endurance of manual pull. Human Factors, 6(5), 479-483, 1964.

KEYWORDS: Elbow, thigh, knee-angles, maximum pull force to measure strength, maximum time of holding response in seconds to measure the endurance

METHODS: Prior to actual testing the subjects were given practice in pulling maximally on the handle and in maintaining a goal force as long as possible. The strength and endurance trials were presented as a pair in each practice session. Five such sessions spaced at least 4 hours apart were presented. In each session the subjects were first told to pull as hard as possible without "slamming" the handle and to keep trying to increase the force until the experimenter terminated the trial in 8 seconds. A 3 minute rest period was given and then the subject was required to hold a force proportionate to his own strength as long as possible. In these endurance trials the display amplifier was set so that the green light would turn on at a force equal to 90 percent of the maximum force measured in the immediately preceding strength trial. In the endurance trials the subject was simply instructed to keep the green light on as long as possible. The endurance trial was terminated when the subject ceased responding, or when he was unable to turn the green light on again within 3 seconds.

RESULTS: I. Strength
The effect of thigh and knee positions on the strength of manual pull reflects the importance of body stabilization in the production of control forces. The knee-angle influences the force exorable by the legs against the backrest by varying the output of the toggle formed by the legs between the foot rest and back rest. As the thigh-angle increases the force developed by the legs tends increasingly to wedge the subject into his seat and trunk stabilization is improved. As the elbow-angle increased, there was a progressive increase in strength ($p < .01$). Thus an increase in strength was obtained as body stabilization was improved by either increasing the elevation of the thigh or by straightening the leg, and an improvement in strength was reached as the arm was straightened.

Significant F-ratios were:

thigh-angle ($p < .01$)

knee-angle ($p < .01$)

elbow-angle ($p < .01$)

thigh-angle x subjects ($p < .01$)

knee angle x subjects

thigh-angle x knee-angle ($p < .01$)

II. Endurance

Essentially the same results were obtained as in strength data.

Significant F-ratios were:

thigh-angle ($p < .01$)

Caldwell, 1964 (continued)

RESULTS: (continued)
knee-angle ($p < .05$)
elbow-angle ($p < .01$)
thigh-angle x knee-angle ($p < .01$)

SUMMARY: The purpose of this study was to test the assumption that the control position or body attitude in which an operator can develop the greatest momentary control force - or at which response strength is greatest - is also the position in which a given sub-maximal force can be maintained for the longest time. Since a substantial correlation was obtained between strength and endurance of a sub-maximal response, the "goodness" of various control and body positions for extended performance can be estimated in many cases from existent strength data.

CITATIONS: No references.

STUDY: Caldwell, L.S., Chaffin, D.B., Dukes-Dobos, F.N., Kroemer, K.H.E., Lauback, L.L., Snook, S.H. & Wasserman, D.E. A proposed standard procedure for static muscle strength. American Industrial Hygiene Association, 35(4), 201-206, 1974.

KEYWORDS: Static strength

- METHODS:
1. Static strength is measured according to the following conditions:
 - a. Static strength is assessed during a steady exertion sustained for 4 seconds.
 - b. The transient periods of about 1 second each, before and after the steady exertion are disregarded.
 - c. The strength datum is the mean score recorded during the first 3 seconds of the steady exertion.
 2.
 - a. The subject should be informed about the test purpose and procedure.
 - b. Instructions to the subject should be kept factual and not include emotional appeals.
 - c. The subject should be instructed to increase the maximum exertion (without jerk) in about 1 second and maintain this effort during a 4 second count.
 - d. Inform the subject during the test session about his general performance in qualitative, non-comparative, positive terms. Do not give instantaneous feedback during the exertion.
 - e. Rewards, goal setting, competition, spectators, jeers, noise, etc. can affect the subject's motivation and performance and, therefore, should be avoided.
 3. The minimum rest period between related efforts should be 2 minutes.
 4. Describe the condition existing during strength testing:
 - a. Body parts and muscles chiefly used.
 - b. Body position.
 - c. Body support/reaction force available.
 - d. Coupling of the subject to the measuring device (to describe location of the strength vector).
 - e. Strength measuring and recording device.
 5. Subject description:
 - a. Population and sample selection.
 - b. Current health status medical examination/questionnaire is recommended.
 - c. Sex.
 - d. Age.
 - e. Anthropometry (at least height and weight).
 - f. Training related to strength testing.
 6. Data reporting:
 - a. Mean (median, mode).
 - b. Standard deviation.
 - c. Skewness.
 - d. Minimum and maximum values.
 - e. Sample size.

METHODS: (continued)

In an experimental study the maximum voluntary strength of handgrip was measured along the instruction conditions employed by Kroemer and Howard. A pair of trials separated by a rest of two minutes was given for each instruction condition. No information feedback was provided.

RESULTS: The data were analyzed to determine:

1. The effects of instructions on the time required for each maximum force application.
2. The relationship between instruction conditions and the obtained strength measures.
3. The relationship between strength and method of force generation.

With instructions to apply force as rapidly as possible, 38 percent of the subjects reached their maximum output within the first second, 41 percent took between one and two seconds, 12 percent required from two to three seconds, and 9 percent took more than three seconds.

The instruction to increase gradually to maximum output and then release led to extremely variable performance. Twelve percent attained maximum force within one second; 15 percent took from one to two seconds; 21 percent reached maximum between two and three seconds; 21 percent took from three to four seconds; 6 percent needed from four to five seconds; and 27 percent took more than five seconds.

For "hold" only three percent of the subjects reached maximum output in the first second; 24 percent required between one to two seconds; 29 percent took two to three seconds; 26 percent took three to four seconds; 9 percent required four to five seconds; and the remaining 9 percent reached maximum after five seconds.

For all instruction conditions the times-to-maximum data were skewed toward the longer times. For "Jerk", "Increase", and "Hold", the values were 1.54, 1.84, and 1.67 respectively.

In 31 of the 34 cases maximum force was attained fastest with the "jerk" instruction. In 19 cases the longest times were obtained in the "increase" condition, and in 14 instances longest times were found with "hold" instruction. Differences between instruction conditions were significant. The mean time-to-maximum strength for the "jerk", "increase", and "hold" conditions were 1.4, 4.1, and 2.8 seconds respectively.

There was little difference in the measures obtained with the various instructions. All instruction conditions yielded reliable measures of strength, and differences in reliability did not provide a basis for recommending one procedure over the others.

The results emphasize the necessity for explicit instructions to subjects in strength assessment studies.

Caldwell, et al., 1974 (continued)

SUMMARY: An attempt was made to standardize the procedure for static muscle strength testing. Different sets of instructions were given to subjects to determine their effects on the time required to reach maximum force application, the relationship between instruction conditions and the obtained strength measures, and the relationship between strength and method of force generation.

It was concluded that the results were so similar for the three methods that differences in reliability did not provide a basis for recommending one procedure over the other, and the necessity for explicit instructions to subjects was emphasized.

CITATIONS: Twenty references.

- STUDY: Chaffin, D.B. A computerized biomechanical model - development of and use in studying gross body actions. Journal of Biomechanics, 2, 429-441, 1969.
- KEYWORDS: Biomechanical model, musculo-skeletal system, abdominal pressure.
- METHODS: Chaffin (1969) developed a computerized biomechanical model which can be used to estimate the forces and torques that are created at six major articulations of the body (i.e. wrist, elbow, shoulder, hip, knee, and ankle) as well as at the fourth lumbar through the first sacral spinal vertebrae of a person performing weight-handling tasks. The model has been referred to as the static sagittal plane model (SSP) and evaluated various "static" situations such as when one is holding weight, or pushing or pulling on a nonmoving container. The model can also be used to analyze "slow" moves by formulating the input data to describe a sequence of static positions with very small changes in each successive position. However, a rotation or lateral deviation can not be analyzed. The model treats the body as a series of seven solid links which are articulated at the ankles, knees, hips, shoulders, elbows, and wrists. The body measurements needed as input data are: body stature, body weight, center-of-gravity of the hand to wrist distance, lower arm length, lower leg length, foot length, and elbow height when standing. From these, the link lengths are estimated. The task under analysis is described by two types of data. First, external force that may be exerted against the hands is measured and entered into the program as a vector acting at the c.g. of the hands. The second type of information required to describe the activity is the position of the body. To obtain these data, it is necessary to measure the articulation angles from either a lateral photograph of a person, or from an articulated drawing board body template placed in the "Task" position.
- The above data are sufficient for the model to compute the torques and forces at each of the six major articulations of the body.
- To perform the analysis of the lumbar spinal stress, the following concepts were included in the SSP model:
1. The geometry of an average erect spinal column, proportionally scaled in the model based on the hip-to-shoulder distance.
 2. The curvature change for the column during sagittal rotation of the hips.
 3. The contribution of intra-abdominal pressure in relieving compression on the lumbar spine.
 4. The amount of pressure created by the abdominal pressure was estimated by assuming the following:
 - a. a diaphragm area of 465 sq. cm. and a pelvic area of 517 sq. cm. upon which the abdominal pressure can act.

METHODS: (continued)

- b. the line of action of the force acts parallel to the line-of-action of the normal compressing forces on the lower lumbar spine.
 - c. the force acts through finite moment arm distances from the center of the disks.
5. Additional compressive forces on the lumbar spine due to the abdominal muscles were assumed to be negligible.
 6. The line of action of the muscles of the lower lumbar back were assumed to act parallel to the normal compressing force on the vertebral/disk interface, and with a moment arm of 5.0 cm.

A "muscle strength" evaluation was included in the model.

To test the model, a group of 13 volunteers (10 males, 3 females) were employed in the following tests:

1. Procure anthropometric data
2. Test each subject's voluntary strength for the seven isolated muscle group actions.
3. Have each subject perform a maximum lift with legs and back while holding handles attached to load cells secured to the floor, and at the point of maximum effort take a lateral photograph to enable the measuring of the body position.

The above data were used in the SSP model, which computed estimates of both the major articulation torque and the compressing and shearing forces at the L4/L5 and L5/S1 disk vertebral body end plates during the lifting tasks.

RESULTS:

When the articulation torques produced during the lifting task were compared to the maximum voluntary torques determined by the isolated muscle group strength tests, it was found that the predicted strength limits were not exceeded or equaled during the lifting task. The knee extension torque during the task came the closest, as it ranged from 73 to 95 percent of the tested maximum voluntary knee extension torque. The hip extension torque during the lifting task was found to range from 18 to 75 percent of the subject's maximum voluntary hip extension torque as determined by the prior strength tests. It was concluded from these results that for this particular lifting task the subjects were not limiting their performances due to the muscle group strengths that were tested.

An analysis of the compressing and shearing forces at the lower lumbar spine during the lifting task, as predicted by the model, disclosed that the subjects appeared to limit their compressive forces to a fairly constant magnitude, regardless of their potential hip and knee extension strengths. Similar results were found for the disk/L5 inferior surface, disk/L5 superior surface, and disk/L4 inferior surface.

Chaffin, 1969 (continued)

SUMMARY: A computer model is developed which treats the human body as a series of seven links, from which reactive forces and torques are computed at each articulation during various simulated materials-handling tasks. In addition, an analysis of shearing and compressing forces at the lower lumbar spine is included.

The use of SSP model has disclosed that, in at least one type of lifting circumstance, the strengths of a group of major muscles do not appear to dictate the whole-body lifting capacity. It is proposed that either the limited muscle strength of the back extensors, or the sensing of possible injury to the vertebral column due to excessive compressing forces, inhibits the lifting action.

Further development of the SSP model can be used in analyzing different types of lifting conditions that are encountered in heavy industry and are often the cause of injury to the musculo-skeletal system.

CITATIONS: Thirty-seven references.

STUDY: Chaffin, D.B. Human strength capability and low back pain. Journal of Occupational Medicine, 16(4), 248-254, 1974.

KEYWORDS: Strength, low-back pain

METHODS: The study involved 103 different jobs populated by 411 men and women. Visits to the medical departments were recorded over about a one year period, thus making a total exposure of 17,430 man-weeks, during which time 25 low-back incidences occurred in the study group. The procedure included a job evaluation of the 103 jobs included in the study. This evaluation was done by using an index, the lifting strength rating (LSR), which was simply the largest value of the following:

$$\text{LSR} = \frac{\text{Each weight lifted}}{\text{Predicted lifted strengths for large/strong man}}$$

This predicted strength was determined from a previous study (Chaffin, D.B. & Baker, W.H. A biomechanical model for analysis of symmetric sagittal plane lifting. AIIE Transactions, 2(16) 1970) and a number of high strength requiring jobs ($\text{LSR} > 0.5$) as well as a number of lower strength requiring jobs. Then a strength test was performed with the person in two different lifting postures. First, they were placed in a position wherein their hands were 20 inches in front of the ankle of the leading foot, and 20 inches above the floor. This was referred to as the Standardized Position Strength Test. The second test position required the person's hands to be placed in the location dictating the LSR rating on the job. This was referred to as the Job Position Strength Test. They were asked to slowly apply a lifting force to the handles (which were 18 inches apart). When they reached what they believed to be the level of force they could tolerate on any present or future job, they were asked to hold that load for three seconds. The testing device was designed to average the demonstrated force over a three second period. The computation of the low-back pain incidence rate for each job was simply accomplished by dividing the number of separate incidents for the people on each job by the man-weeks of exposure of the people to the job during the study period.

RESULTS: The first result of interest was simply the distribution of strength among the people participating in the study, which was skewed, with the women having a 58 percent mean strength of the men and a 65 percent of the men's modal value. A ratio of the weight lifted on the job to the mean strengths of the employees on that job (from Job Position Strength test) was formed. And this ratio was referred to as "Strength Ratio". The results indicated a sharp increase in the mean low-back pain incidence rates (by a factor of 3:1) for those jobs populated by persons who did not demonstrate sufficient strength to equal or exceed that required to lift the weight that generates the highest predicted stress on the job.

Chaffin, 1974 (continued)

SUMMARY: The objective of the study was to determine if an isometric strength test of a person's ability to lift weights would correlate with the incidence rate of low-back pain. A strength test was developed and was used to estimate the individual's strength on both a standardized position and on the posture required by the job. Results show that women had a mean strength of 58 percent that of men and 65 percent of the men's modal value. Also the results indicated a sharp increase in the mean low-back pain incidence rates for those jobs populated by persons who did not demonstrate sufficient strength equal to or exceeding that required by the job.

CITATIONS: Twenty-six references.

STUDY: Chaffin, D.B. Biomechanical models of human strength in manual materials handling. Paper presented at International Symposium on Safety in Manual Materials Handling, Buffalo, New York, 1976.

KEYWORDS: Maximum voluntary torque, resultant torque, reactive torque

METHODS: Biomechanical strength models are based on a kinematic linkage representation of the human body. To manipulate the body posture, a set of angles are the inputs of the model. Biomechanical strength modeling involved the comparison of maximum voluntary torque (VT) and the torques (RT, called "resultant torques") resulting from the forces acting at the hand, body segment weights, and any external constraints. Maximum voluntary torques representing the strength of the subject and, therefore, required as input to the model are calculated from data gathered on carefully controlled and dimensional test equipment. A person's voluntary strength (often referred to as "reactive torques") depends upon a number of factors. The major factors are: 1) body position, 2) individual characteristics such as health, prior training, sex, age, etc., 3) motivation, and 4) level of fatigue at the time of exertion. Muscles react to an externally applied force by "pulling" across articulations. The ability of a muscle to produce a torque varies with the included angles of joints across which it is pulling.

RESULTS: By using a polynomial regression analysis of 18 (10 males and 8 females) subject's elbow flexion strength at different positions, the group's average value can be expressed as follows:

$$VT = 336.29 + 2.088\alpha - .015\alpha^2 - 3.364\beta + .019\beta^2 \quad (\text{Eq. 1})$$

where:

VT = Mean max. voluntary elbow flexion reactive torque (inches-pounds).

α = Elbow included angles (degrees).

β = Shoulder vertical abduction angle (degrees).

To account for individual characteristics, the VT predicted above is multiplied by a factor called the "subject strength coefficient" designated C_i and by "left-right adjustment" designated C. An individual's elbow flexion strength is then represented by:

$$VT_i = C_i * C (336.29 + 2.088\alpha - .015\alpha^2 - 3.364\beta + .019\beta^2)$$

where

C_i = Subject strength coefficient.

C = a parameter to account for the difference in right and left elbow strength.

On an average $C_1 = 1.00$ for right elbow, $C_1 = .93$ for left elbow for a right-handed person.

C_i = The ratio of the max. measured strength (reactive torque) of a given muscle group for a selected body position (body angle) of i^{th} subject to the predicted mean strength (Eq. 1) of the same muscle group for the same body position over all subjects considered in population.

SUMMARY: This paper gives a procedure which established the various muscle groups strengths for different body postures. These strengths or voluntary torques are then systematically compared to the

Chaffin, 1976 (continued)

METHODS: (continued)

resultant torques at the joints due to gravity acting on both an object being handled and on the body masses. In doing this, if a specific posture has not been used as an input, the model will iterate through various angles at the joints, keeping the hands and feet in the same relative position. With each iteration of a posture, all the joint voluntary torques are checked to determine the maximum load that can be applied to the hands to cause a resultant torque to equal one of them. This hand load is thus the maximum predicted strength of the body in that posture.

CITATIONS: Twenty-one references.

STUDY: Ciriello, J.M., and Snook, S.H. The effects of size, distance, height and frequency on manual materials handling performance. Proceedings of the Human Factors Society, 22nd annual meeting, pp. 318-322, 1978.

KEYWORDS: Manual materials handling, psychophysical, heart rate, oxygen consumption, frequency, males

METHODS: Fifteen second-shift, male industrial workers from local industries performed 61 variations of lifting, pushing and pulling. To establish the maximum acceptable weight, a psychophysical methodology was employed whereby the test subject controlled the amount of weight or force being handled. The vertical distances of lift were 25, 51, and 76 cm. These distances of lift were studied at three heights: 1. floor level to knuckle height, 2. knee height to elbow height, and 3. knuckle height to shoulder height. Two box lengths (the distance between the hands) of 57 cm and 89 cm were investigated. For each box length, there were three corresponding box widths (the distance away from the body) of 36, 49, and 75 cm. A depth of approximately 14.4 cm was used for all boxes. The boxes had handles located midway on the width dimension. Lifts were performed once every 9, 14, and 60 seconds and once every 8 hours. Dynamic pushing and pulling tasks were simulated on a specially constructed treadmill. Pushing and pulling were performed at three heights: 1. shoulder height (147 cm), 2. a distance midway between knuckle and elbow height (97 cm) and 3. 15 cm below knuckle height (65 cm). Five pushing lengths were studied: 2.1 m, 7.6 m, 30.5 m, 45.7 m, and 61.0 m. Pushing frequencies ranged from once every 15 seconds to once every 3 hours, depending on the length of the push or pull.

RESULTS: The results of this experiment indicated that box size (specifically the width), distance, height and frequency are significant variables to consider when establishing guidelines for maximum acceptable weights.

SUMMARY: Fifteen second-shift, male industrial workers from local industries performed 61 variations of lifting, pushing and pulling tasks to investigate the effects of task frequency, height, distance, and box size. A psychophysical methodology was employed whereby the test subject controlled the amount of weight or force being handled. Measurements of heart rate, oxygen consumption, and body size were also taken. The results indicated that box size, distance, height and frequency are significant variables to consider when establishing guidelines for maximum acceptable weights.

CITATIONS: Ten references.

STUDY: Datta, S.R., Chatterjee, B.B. & Roy, B.M. The relationship between the energy expenditure and pulse rates with body weight and the load carried during load carrying on the level. Ergonomics, 16(4), 507-513, 1973.

KEYWORDS: Load carriage, energy expenditure, pulse rates, peak heart rate

METHODS: Six healthy volunteers were chosen for the experiment. These subjects had an average age of 29.4 years (range 23-40), an average height of 163.3 cm (range 162.0-171.1 cm) and body surface area (B.S.A.) 1.62 m² (range 1.49-1.66 m²). They were asked to carry loads (0, 20, 30, 40, and 50 kg) on their heads in a basket for a period of 12 min. so as to cover a measured distance of 1 km (5 km/hr).

Energy expenditure was determined by collecting the expired gas in a Douglas bag during the final two minute period of walking. The Douglas Bag and accessories were supported by an attendant walking immediately behind the subject at the same speed. The volume of the collected expired gas was measured by passing it into a large calibrated spirometer and the minute ventilation was computed. The oxygen consumption was determined with a Haldane gas analysis apparatus. The heart rate was measured by timing 20 beats with a stop watch with the subject standing still with whatever load he had been carrying immediately after completion of his walk.

RESULTS: The observed energy expenditure in kcal/min (E) for walking with no load and while carrying 20, 30, 40, and 50 kg loads on the head were plotted: 1) separately against the weights of the loads (L) carried as well as the gross weights, i.e., the total of the subject's body weight (W) and the weight of the load itself (L) and 2) the values of peak heart rate (PHR) were also plotted against L and (W+L). The regression equation obtained between energy expenditure (kcal/min) and gross weight (W+L in kg) transported was:

$$E = 0.0943(W+L) - 2.1833$$

and that between the PHR and the gross weight transported was:

$$PHR = 1.2552(W+L) + 24.87.$$

The coefficient of correlation between the energy expenditure and gross weight transported was $r=0.91$ and between the peak heart rate and gross weight transported was $r=0.88$. The correlation between the load carried and the peak heart rate ($r=0.79$) are also between the load carried and energy expenditure ($r=0.89$) were numerically less than the ones described above.

The finding with regard to the relationship of total weight and energy expenditure to the load carried was similar to earlier findings that the energy cost per unit weight is essentially the same regardless of the distribution of total weight between body weight and load.

The regression equations for energy expenditure (E) and peak heart rate to the gross weight transported show that it is possible to predict the values of these physiological parameters,

Datta, et al., 1973 (continued)

RESULTS: (continued)

while carrying loads on the level, with a high degree of accuracy for individuals of similar body type as the subjects chosen for this study.

The applicability of these regressions was verified by an independent series of experiments. There was good agreement between the predicted and observed values. It was noted that the observed values of energy expenditure and peak heart rates tended to be greater than the predicted values for subjects with lesser body weights than the group studied earlier and were less than the predicted ones if the subject's body weight was greater than the body weights of the group studied earlier.

SUMMARY:

In a study of load carriage on the head on the level, high degrees of correlation were obtained with the gross weights transported (viz. body weight and given load) and the energy expenditures, $r=0.91$. Their relationship fits the equation, $E(\text{kcal/min})=0.0943 (\text{body weight} + \text{load carried}) - 2.183$. The gross weight transported was also found to have an equally high correlation with the peak heart rates observed ($r=0.88$) and the regression equation, $\text{PHR}=1.2552 (\text{body weight} + \text{load carried}) + 24.87$, mathematically describes the relationship of the two latter variables.

These equations can conveniently be used for field studies of load carrying in many underdeveloped countries where the common mode of load carriage is identical with that investigated in this study and the average weight of the subjects around 50kg.

CITATIONS: Seven references.

STUDY: Davies, B.T. Moving loads manually. Applied Ergonomics 3(4), 190-194, December, 1972.

KEYWORDS: Initial force, sustained force, lift range

METHODS: Considering the number of industrial accidents attributed to the lifting and handling of materials, it is vital that an attempt be made to construct an objective criterion to facilitate matching the worker with the right job. This paper addresses various industry-related questions, with the intention of giving employers a better idea of the capabilities of industrial workers.

RESULTS: In essence, the report posed the following questions: how much can we expect a worker to lift and carry?; how often can we expect a woman operator to lift a given weight?; and how can we reduce the number of back injuries in industry? These questions were partially answered via the provision of past regulations which dictated manual materials handling practices. For example, in 1958 the Pottery (Health and Welfare) special regulations propounded that a woman or young person must not carry more than 18.1 kg (40 lb) more than 45.7 meters (50 yd) on a level surface. Other regulations prescribed a "heavy" weight as being 35 percent of the worker's body weight. The report also addressed such problems as how dress affects work efficiency, team work coordination in lifting, the use of yokes and harnesses in carrying loads, and the relationship between the pace of moving loads and energy expenditure.

SUMMARY: Considering the variety of prescribed norms governing the handling of manual materials, determination of any single relevant criterion is difficult. However, some reasonable answers, taking into account the multitude of factors which can affect them, may be: 1. a healthy, experienced male should not be expected to lift more than 55 kg (120 lb); 2. a woman's strength is generally about 65% of the strength of adult men; and 3. all workers expected to lift light and heavy loads should be taught the proper techniques of lifting and moving loads.

CITATIONS: Twenty references .

STUDY: Davis, H.L., Faulkner, T.W. & Miller, C.I. Work physiology, Human Factors, 11(2), 157-166, 1969.

KEYWORDS: Work physiology, lifting, rest periods, heart rate, O₂ consumption

METHODS: The authors used heart rate and O₂ consumption to estimate the load placed upon operators performing physically difficult tasks. The energy expenditure was calculated from the O₂ consumption. The people participating in this study were studied under controlled conditions available in the laboratory and then were studied as they performed their normal job. A criterion of 5 cal/min. was considered as an average maximum work load for a healthy young male and this load was not expected to produce an average heart rate exceeding 120 beats/min. About 33 jobs were evaluated using energy consumption and heart rate as the criteria for the severity of the jobs.

RESULTS: It was concluded that it is practically impossible to estimate accurately the difficulty of a job by merely observing it. The number of different factors that have a bearing on task difficulty is very large. One of the studies evaluated the effect of the length of the rest periods on a lifting task (lifting a 40 lb. case from floor level to a table 20 inches above floor at the rate of 6 lifts/min). The results showed that the heart rate continued to rise during the working period when a rest period of 2 minutes was given every 10 minutes, while such an increase did not take place when the rest period was 7 minutes for every 10 minute work period.

SUMMARY: The paper shows that one of the most useful techniques of analysis of different jobs is work physiology, as it is practically impossible to estimate accurately the difficulty of a job by merely observing it.

CITATIONS: Eight references.

STUDY: Davis, P.R. Posture of the trunk during the lifting of weights. British Medical Journal, 1, 87-98, 1959.

KEYWORDS: Posture, lifting, abdominal pressure

METHOD: Three questions are proposed by the author. These questions are: (1) How are heavy weights lifted? (2) What part does the trunk play in this? (3) What damage may be produced? The answers to these questions stem from personal observation of a large number of people engaged in their everyday tasks. Davis then explains these answers through the usage of relevant anatomy.

RESULTS: This paper gives an idea about the different ways of lifting weights. It emphasizes the part played by the trunk in lifting and that the trunk should be straight always, especially in case of heavy loads. The author then classifies the injury of the trunk into two basic types. The anterior, extrusive group of injuries, which includes visceral herniae and prolapses; and the spinal group, including such lesions as the lumbo-sacral strain; prolapsed intervertebral disks at the lumbar and cervical levels, and tears of posterior ligaments and spinal muscles. The mechanisms resisting the different forces in lifting are basically two. The first is the spinal column and its muscles, and the second is the "pneumatic" mechanism created by the abdominal pressure in the abdominal cavity. The author also emphasizes the danger of flexing the spine as it creates high abdominal pressures.

SUMMARY: Davis (through personal observations by workers) examines ways of lifting weights and the part played by the trunk. A review of the literature made it apparent that lesions caused by weight-lifting rarely appear in the limbs, but are not uncommon in the trunk. In giving an anatomical explanation of the observations, Davis divided the analysis into two stages. Firstly, by examining the forces exerted on the trunk when weight-lifting in different positions; and secondly, by examining the mechanisms whereby the trunk may sustain these forces.

In final summary, Davis concluded that there was evidence that two complementary mechanisms are in action when large flexion forces are resisted by the human trunk, these being the spinal column and its muscles on the one hand, and the "pneumatic" mechanism on the other. Each is affected by its own group of disorders, and in theory, it appears that the more flexed the trunk when lifting the more likely it is that damage will occur.

CITATIONS: Five references.

- STUDY:** Drury, C.G. & Pfeil, R.E. A task-based model of manual lifting performance. Proceedings of the seventeenth annual meeting of the Human Factors Society, 457-464, 1973.
- KEYWORDS:** Task factor variables, non-compact object, compact object, acceptable lift, individual variables
- METHODS:** A task-oriented approach has been taken instead of using individual variables in predicting the weight that can be lifted. The model consists of a base weight (WB), which is the maximum (under some criterion) which can be lifted under perfect conditions, multiplied by a series of factors to give the effects of the task variables. For example, the weight lifting capability of females is about 60 percent that of males so that the factor for sex would be 1.00 for males and .6 for females. The model is given as:
- Predicted weight in situation j = $W_p(j) = WB \prod_{i=1}^n \text{factor}_i(j)$
- If the factors such as above affect the maximum weight lifted in a variety of situations, the assumption that all other factors act in the same way justify the above model.
- An experiment to observe the effect of age on lifting non-compact objects was conducted to test the model. A 20 inch cube was used as the lifting object and was lifted into a carrying position from the floor at increasing weights. The carrying position was defined as the metacarpel phalangeal articulation in the anatomical position and ranged from 704 to 823 mm above the floor. The maximum weight chosen by each subject was measured. Forty-five subjects (male) were chosen from five to nine age groups. These age groups were five year intervals from 15-20 years through 55-60 years.
- In order to test the general structure of the model, five subjects were given a random sample of conditions under which to lift a load. The variables were sex, age, height of lift, awkwardness of object. The subject's maximum weight in each condition was measured in exactly the same way as in the experiment. The model was used to predict the weight by multiplying together all the factor values appropriate to each condition.
- RESULTS:** The analysis of variance applied to the weight chosen by the nine age groups showed that age group was a significant effect. Adjacent group means were significantly different. Mean weight lifted was 30.8 kg (non-compact object was used), which appears to be about 60 percent of the weight for compact objects.
- In formulating the prediction model, a base weight of 100 pounds was chosen and the 50th percentile of the population was given a factor value of 1.0. The regression equation was given as:
- Actual weight = 0.967 (Predicted weight) + 3.5 kg
- The correlation coefficient was 0.936, explaining 87.6 percent of the variance of the actual weights.
- The model predicted weight is consistently less than the actual weight.

Drury & Pfeil, 1973 (continued)

SUMMARY: An attempt has been made to devise an empirical prediction model of manual lifting performance, based on task factors rather than individual factors. It was 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 number of task variables. The model was tested using the effects of 5 variables; estimated from the literature, the correlation between the actual and predicted weight was found to be 0.936, explaining about 87.6 percent of the variation.

The model is built to find application in industry where the industrial engineer or safety officer doesn't have enough details about the individual variables to ensure that operations will work within safe limits. This model gives practical limits with task variables and the individual variables are covered by specifying a particular percentile value in the model.

CITATIONS: Twenty-four references.

STUDY: Emanuel, I., Chaffee, J.W. & Wing, J. A study of human weight lifting capabilities for loading ammunition into the F-86H aircraft. Wright Air Development Center Technical Report, AD 97206, August, 1956.

KEYWORDS: Weight-lifting

METHODS: This study consisted of 19 males lifting a container with different weight loads to various heights. The subjects ranged in age from 17 to 28 and selected anthropometric dimensions were measured for comparison. The subjects lifted the container up two steps. The steps were 32 inches wide, 18 inches deep and had two strips of wood placed 9½ inches apart to limit the area in which the container had to be placed. The steps ranged in height from 1 foot to 7 feet with 1 foot increments. The subjects had to lift the box with their entire back held straight at all times, but it did not need to be perfectly vertical. This required subjects to have their knees sufficiently bent to allow them to grasp the handle of the box while holding their arms straight. The subjects then lifted the box off the ground by straightening their legs, and when they were in an erect position, they could then bend their arms and place the box on the step between the guide strips. The test was run in three series. In the first and third series, the subjects began lifting at the 1 foot level, whereas, in the second series, the subjects began lifting at the highest level they could.

RESULTS: The entire sample could lift up to 5 feet, with the lifting capacity for the 50th percentile at 5 feet being 57 pounds, at 4 feet being 81 pounds, at 3 feet being 114 pounds, at 2 feet being 190 pounds, and at 1 foot being 231 pounds, (weights for the 5th, 25th, 75th, and 95th percentile at these heights are also given in this paper). Nine subjects could lift to 6 feet with the mean weight lifted being 46 pounds and only one subject could lift to the 7 foot level with a weight of 50 pounds. Fatigue decrements were not studied.

SUMMARY: Nineteen male subjects were used to test their weight-lifting ability. They lifted weighted containers to various heights, ranging from 1 to 7 feet. The subjects had to lift with their backs straight and also had to keep their arms straight until they were in an erect position so that the greatest share of lifting was done by straightening the knees and legs rather than by using the arms and trunk. The author then concluded the following from the data: 1. Weights could be lifted successfully by the entire sample to platforms from 1 to 5 feet above the floor, but not to 7 feet. 2. Based on the fifth percentile values, the following weights are those which could be lifted by an adequate percentage of the sample at each level: 1 foot, 142 pounds, 2 feet, 139 pounds; 3 feet, 77 pounds; 4 feet, 55 pounds; 5 feet, 36 pounds. 3. Only 9 individuals

Emanuel, et al., 1956 (continued)

SUMMARY: (continued)

could lift any weight according to instructions to 6 feet above the floor; and only one person was able to perform at 7 feet. Therefore, for tasks such as those considered in this study, workers should not be required to lift weights higher than 5 feet above the floor.

The author also stated that the information about lifting capacity at various heights could serve the following two functions in work planning: 1. Tasks can be planned so that a large percentage of young men can accomplish them. 2. It can be estimated whether or not a particular weight lifting job should be performed by machinery.

CITATIONS: Three references.

- STUDY: Ergonomics Guide to Manual Lifting. American Industrial Hygiene Association Journal, 31(4), 511-516, 1970.
- KEYWORDS: Task variables, environmental variables, human variables
- METHODS: Ergonomics Guide is published to provide a service to industry to aid in the evaluation of work situations, such as, significant variables to consider.
- RESULTS: The following significant variables must be considered in any manual material handling (lifting situation):
Task variables: weight, size, configuration of the object; height, distance, rate, and rhythm of lift.
Environmental variables: temperature, humidity and air flow; air contaminants and O₂ deficiencies.
Human variables: age, sex, physique, fitness, and work position.
The following points must be carefully reviewed:
1. Ergonomics Data:
 - A. Weight of lift - for females and males. Biomechanical or psychophysical criteria.
 - B. Frequency of lift - physiological and psychophysical criteria.
 - C. Application of data - the following sequencing should be followed:
 1. Explanation of anthropometric data.
 2. Evaluation of the size and weight of the object being lifted.
 3. Evaluation of the frequency of lift.
 2. Characteristic Injuries:
 - A. Back injuries - excessively heavy objects can cause acute or chronic injury to the back.
 - B. Abdominal hernias - various types of abdominal hernias can occur.
 - C. Accidents - approximately 25 percent of handling accidents are due to lifting.
 - D. Foot injuries - when heavy objects are lifted and carried, there is a risk of injury to the foot bones.
 - E. Aggravation of circulatory and respiratory disorders - manual lifting involves the circulatory and respiratory systems and the risk of aggravating them increases with excessive frequencies of lift.
 3. Industrial Hygiene Practice:
 - A. Industrial uses - manual lifting, occasional or repetitive, is usually found with tasks such as lowering, carrying, pushing and pulling.
 - B. Evaluation of exposure - the weight of lift and frequency of lift.
 - C. Hazards and their recommended control -
 1. Incorrect method of lifting - training.
 2. Older workers - precautions in placement.
 3. New workers - medical screening, training and conditioning.

Ergonomics Guide to Manual Lifting, 1970 (continued)

RESULTS: (continued)

- C. 4. Stressing environments - proper clothing and breathing.
- 5. Awkward working positions - proper work place design.
- 6. Unhealthy or pregnant workers - decrease the weight lifted based on medical advice.

SUMMARY: This guide reflects the current state of the art in laboratory research and industrial experience, and is likely to be changed as new information becomes available. This is published as a service to industry to aid in the evaluation of work situations and to make them aware of ergonomic data, characteristic injuries, industrial hygiene practice, as well as significant variables to consider in manual lifting.

CITATIONS: Twenty-four references.

STUDY: Frederik, W.S. Human energy in manual lifting. Modern Materials Handling, 14(3), 74-76, 1959.

KEYWORDS: Manual lifting, energy consumption, weight, vertical range

METHODS: In this research, some of the factors governing manual lifting were evaluated and studied. Tests were run to determine the energy consumption for lifting weights ranging from 20 to 65 lbs, over a vertical distance of 20 in. in a height range from 0 to 20 inches, 20 to 40, 40 to 60, and 60 to 80. The compounded results were presented on a graph.

RESULTS: The results indicated that the best area for manual lifting is between 40 and 60 inches from floor level for a standing man of average height, and that the ideal weight within the recommended area is about 40 lb. An arbitrary limit for the average hourly caloric output in sustained work was set at 200. From this limit, the maximum number of lifts a man could make under any of the conditions covered in the tests can be determined.

SUMMARY: An ideal weight and ideal vertical range have been devised for manual lifting. Lowered efficiency will result if loads greater or less than the ideal are lifted. If however, lifting cannot be performed in the ideal range, at least an ideal load can be determined for efficient lifting in the range required. If there is no control over weight or lifting range, the physiological limit on the rate of manual lifting can be determined.

CITATIONS: None cited.

- STUDY: Garg, A. A metabolic rate prediction model for manual materials handling jobs., unpublished Ph.D. dissertation, The University of Michigan, 1976.
- KEYWORDS: Metabolic rate, manual materials handling, prediction models, males, females, oxygen uptake, heart rate, ventilation rate
- METHODS: Six subjects were selected for this study, three males and three females. Light, medium and heavy subjects were selected in both male and female categories to cover a wide range of body weight. All subjects were college students of 18 to 22 years of age and in good physical condition. An imbalanced factorial design was used. The following tasks were studied:
1. Lifting and lowering: two vertical height ranges (floor to 32" and 32" - 60") were used for lifting and lowering loads. Two lifting techniques (stoop and squat) were used when lifting and lowering from floor to 32". Load levels of 6 lbs., 33 lbs., 44 lbs., and 55 lbs., and frequencies of 4, 8, and 12 lifts per minute were employed to measure the metabolic costs of lifting and lowering. For lifting, a one hand lift from the floor to a 32" vertical height range was also studied.
 2. Holding, walking, and carrying loads: four techniques were used for holding and carrying loads; load held at arms length against thighs (both hands), load held against waist (both hands), load held at arms length at sides (both hands), and load held at arm length at side (one hand). The load weights employed were 0 lbs., 33 lbs., and 55 lbs. for the first three techniques and 0 lbs., 16.5 lbs., and 27.5 lbs. for one hand at the side. Subjects walked at speeds of two and three miles/hour in a corridor on a finished concrete floor.
 3. Horizontal work: Movement of arms was in the sagittal plane at bench height (32"). Four different body postures were employed; both hands (standing), one hand (standing), both hands (sitting), and one hand (sitting). The horizontal movement of arms from the edge of the bench was 24" and 16" for standing and sitting postures, respectively. Load weights were 6 lbs., 33 lbs., (both hands, standing); 6 lbs., 16.5 lbs., (one hand, standing); 6 lbs., 22 lbs., (both hands, sitting); and 6 lbs., 11 lbs., (one hand, sitting). Frequencies of four and eight lifts per minute were employed.
 4. Lateral arm work: different loads and frequencies were employed.
 5. Pushing: Two height levels were employed, 32" (bench height) and 60" (chin height). The total distances of pushing were 24" and 16" at the bench and chin height, respectively. Average pushing forces were 7 lbs., and 26 lbs. at bench height and 3 lbs., and 23 lbs. at chin height. The pace employed for pushing the load was four and eight times per minute.

Garg, 1976 (continued)

RESULTS: (continued)

Energy prediction models using stepwise regression analysis were developed for the tasks studied. The correlation coefficients and coefficients of variations were 0.98 and 0.08, respectively. Results also showed that most of the variation (80% - 97%) in net metabolic cost of task with a given technique could be explained by first order interactions of body weight and load with the frequency of loading the body.

SUMMARY:

The objective of this research was to develop a model to estimate metabolic energy expenditure rates for a wide variety of manual materials handling jobs. The model was based on the assumption that a job could be divided into simple tasks and that the average metabolic energy expenditure rate of the job could be predicted by knowing the energy expenditures of the simple tasks and the time duration of the job. Over 540 oxygen uptake measurements were made for different variables on six subjects (3 males and 3 females, 18-22 years of age and 122-200 lbs. of body weight). Prediction equations for the net metabolic energy expenditure rate of each task as a function of personal and task variables were developed via stepwise, forward, least square error regression analysis.

CITATIONS: One hundred thirty one references.

STUDY: Goldman, R.F. & Iampietro, P.F. Energy cost of load carriage. Journal of Applied Physiology, 17(4), 675-676, July 1962.

KEYWORDS: Energy cost, grade, load, speed

METHODS: Ten men acted as subjects for the study. The subjects walked on two large (4-man) treadmills which were set at a given grade (3 percent, 6 percent, or 9 percent) and speed (1.5, 2.5, 3.5, or 4 mph). Three standard loads were selected and made up on packboards so that the total weight of load and packing was 10, 20, or 30 kg.

Duplicate Tissot collections of expired air were taken on each subject during the last 15 min. of a 45 min. walk, and oxygen concentrations were measured with a Beckman paramagnetic O₂ analyzer.

Subjects were ranked with respect to percentage of body fat so that the five subjects studied for a given condition represented a cross-section within the relatively narrow range of body fat presented by the group.

RESULTS: The results show that energy cost per unit weight (subject weight plus loads of 10-30 kg) is a constant for a given grade and speed. The following curve-fitting formula was evolved relating progression rate, load, and grade over the ranges 1.5-4.5 mph (S), 0-30 kg load (L), 0-9 percent grade (G).

$$\begin{aligned} \text{Energy cost (70 kg subject, in kcal/min.)} = & 4.3 - 1.1S \\ & -.22S^2 - 6.3G + 8.2GS - .05GS^2 + 3.6G^2S^2 + 4.06LG \\ & -1.77LGS + .003LS^2 + .24LGS^2 - .06LG^2S^2 \end{aligned}$$

Calculations of predicted values for energy cost from this formula are in close agreement with observed values.

Variations in such parameters as stature, stride, physical condition, and skill in adjustment of a load all influence the energy cost of progression. For this reason the energy estimates must be regarded as first approximations. It seems probable that for a given rate of progression and grade, the energy cost per unit weight is essentially the same, regardless of the distribution of total weight between body weight and load within the range 0-30 kg load for a reasonably fit individual.

SUMMARY: The relative contributions of rate of progression (1.5-4 mph), grade (3-9 percent), and load (10-30 kg) to total energy cost were determined. The data obtained were integrated graphically with some of the available-energy cost data in the literature to provide a useful graph for estimating energy expenditure. It was tentatively concluded that for grade walking over the ranges studied, the energy cost per unit weight is essentially the same whether the weight is of the body or the load.

CITATIONS: Three references.

STUDY: Haisman, M.F. & Goldman, R.F. Effect of terrain on the energy cost of walking with back loads and handcart loads. Journal of Applied Physiology, 36(5), 545-548, 1974.

KEYWORDS: Work, manpower assists, load carriage, terrain coefficient

METHODS: Eight soldiers participated in the study. Their characteristics were: nude weight, 75.3 ± 11.5 kg; height, 177.2 ± 2.5 cm; age, 20.9 ± 1.7 years; percentage body fat content, 15.7 ± 4.3 percent. Each subject performed 24 30 minute walks for each of the following conditions: four loads-20 kg carried on the back or 20, 60, or 100 kg cart loads; three terrains-black top for road, dirt road, and grassland; two walking speeds - 0.89 and 1.34 meters/second. The basic cart weighed 20 kg; the overall length was 183 cm, and the axle width was 89 cm; two other carts (identical) were loaded to 60 and 100 kg. Cart balance was checked daily, with a spring balance, to require an upward lift on the handle of 2.3 kg at a height of 1 m. Tire pressures were maintained at 21 newton/cm². Average ambient temperatures during the study were 19.6°db and 15.7°wb.

Energy expenditure was measured by means of Max Planck respirometers for three periods of 5 or 6 minutes, with the collection periods ending at 10, 20, and 30 minutes. Heart rates were counted by palpation of the radial artery immediately before and after each walk.

RESULTS: The following observations were made:

1. At both speeds, energy costs on blacktop show relatively little increase with cart weight. However, energy costs on both uneven terrains increase markedly with increasing cart weight and only the 20 kg cart is equivalent to a 20 kg back load.
2. The slopes of energy cost and cart weight are only approximately linear.
3. Energy cost expressed by kg of total weight of the man and his back load allowed the same general observations as the gross energy cost results.

Heart rate increments show the same overall pattern as the energy cost results but with much greater variability. Terrain coefficients illustrate the reasonably good agreement between speeds for each terrain, except for the 60 kg cart on grass. Energy cost for the 100 kg cart is increased by 1.31 on the dirt road and 1.44 times on the grass compared to the same activity on black top.

With terrain coefficients of 1.0 for blacktop and 1.1 for dirt road, energy cost was predicted from body and load weight and speed. The predicted values overestimated energy cost on the fast speed and underestimated on the slow speed.

Net energy cost of cart pulling was obtained by subtracting the calculated cost of walking from the total cost of cart pulling. The four carts (each of a different design) show a wide spread of net energy cost. It appears that cart design has more effect on energy cost than cart weight.

Haisman & Goldman, 1974 (continued)

SUMMARY: Eight young soldiers carried a 20 kg back load or pulled a hand cart weighing 20, 60, or 100 kg, at two speeds (0.89 or 1.34 m/sec.) on three terrains (black top road, dirt road, or grassland) in a randomized factorial design. Energy cost was measured three times during each 30-minute walk. The results indicated that although on a smooth surface the 100 kg cart was more costly than a 20 kg back pack, on both uneven terrains only the 20 kg cart was equivalent to a 20 kg back load. Nonetheless, the energy cost of moving the 100 kg cart over these uneven terrains, at these speeds, was within acceptable physiological limits for these subjects. This would probably not be true with more difficult terrains such as soft sand or heavy brush.

CITATIONS: Thirteen references.

STUDY: Haisman, M.F., Winsmann, F.R. & Goldman, R.F. Energy cost of pushing loaded handcarts. Journal of Applied Physiology, 33(2), 181-183, 1972.

KEYWORDS: Work, manpower, assists, load carriage

METHODS: Seven soldiers acted as subjects in this study. Each subject performed one 30 minute walk at 1.56 m/s (3.5 mph) with one cart on the treadmill and one walk with another cart on the outside circuit. Energy expenditure was measured three times during each 30-minute walk. Tissot spirometers were used for the treadmill walks and Max Planck respirometers for outdoors. The total weight of clothing and respirometer was about 7 kg. O₂ and CO₂ concentrations of the expired air samples were determined by use of a Beckman E-2 oxygen analyzer and a Beckman LB-1 CO₂ analyzer. Two treadmills were used; each was large enough to accommodate a subject pushing a handcart.

The four handcarts were loaded to achieve a total weight of 50 kg. These carts were obtained commercially and were different from each other. Ambient temperature was controlled in the treadmill chamber, mean db 22.2±0.7°C, mean wb 15.2±1.2°C and wet bulb 11.8±6.2°C. Identical clothing was worn inside as well as outside.

RESULTS: Mean values of energy expenditures for the treadmill and the outdoor circuit closely agreed. Cart A (4 wheeled mail carts) had the lowest values and Cart D (golf carts) the highest; the differences between carts were significant except between A and B (large garden cart.). Analysis of the energy expenditure data, standardized for total body weight by dividing each energy cost by the total weight of the man, his clothing, and respirometer, showed the same pattern of results.

The mean value of energy expenditure for all carts for the treadmill walks was 511±52(sd)w, which was close to the mean for the outdoor circuit 512±45w.

SUMMARY: Seven male volunteers, mean age 21 years, pushed four types of handcarts at 1.56 m/s, on a level treadmill and on an outdoor asphalt circuit. The carts (A, four wheel; B.C.D., two wheel) had the following wheel diameters: A, rear 30 cm, front 15 cm; B, 50 cm; C, 40 cm; D, 35 cm. Each cart was loaded to achieve a total weight of 50 kg. Force measurements of energy expenditure were made during each 30-minute walk. The mean value for all carts for the treadmill walks was 511±52(sd)w, which was closely similar to the mean for the outdoor circuit 512±45w. Cart A was found to require the lowest energy expenditure, 478±37w, and Cart D the highest, 555±41w.

This study attempts to determine the most economical means of carrying heavy loads, in terms of minimal energy cost to the human body and could be useful in developing design criteria for handcarts.

CITATIONS: Ten references.

STUDY: Hamilton, B.J. & Chase, R. B., A work physiology study of the relative effects of pace and weight in a carton handling task. AIIE Transactions, 1 (2), 106-111, June, 1969.

KEYWORDS: Work pace, load weight, physiological stress, heart rate, and energy expenditure.

METHODS: Heart rate and oxygen consumption were used to measure the physiological stress of six male subjects as they were performing experimental tasks of carton handling. The variables in this experiment were load weight and work pace. There were four levels of load weight (10 lbs., 15 lbs., 20 lbs., and 25 lbs.) and work pace (6, 9, 12, and 15 cartons per minute). All six subjects performed the 16 prescribed combinations. Then work output was obtained for each subject at all 16 levels.

RESULTS: Work pace and load weight were found to be linear in their effects on energy expenditure rate and heart rate. The existence of a linear relationship indicates that no optimum work pace exists, using these measures of effort, for the experimental tasks over the range of work paces studied. Also, the interaction of pace and weight was found to be significant in its effects on energy expenditure rate and heart rate. The interaction, however, of pace and subjects was found to be significant for energy expenditure, but not for heart rate.

SUMMARY: Physiological stress of six male subjects was measured as each performed various combinations of experimental tasks of carton handling where the variables were load weight and work pace. The results indicated that the design of the job is a significant factor in determining the physiological cost to the worker. Also the following guideline is offered for job design:
Use heavier weights at slower paces. Pace and subjects were found to be significant in their effects on energy expenditure but not for heart rate, whereas pace and weight were found to be significant in their effects on both.

CITATIONS: Eighteen references.

STUDY: Jones, D.F. Back strains: the state of the art. Journal of Safety Research, 3(1), 28-34, 1971.

KEYWORDS: Back strains, lifting techniques

METHODS: The history of manual lifting techniques and resulting stresses in components of the human trunk are reviewed. Papers by Bradford and Spurling (1975) and Bartelink (1957) are utilized to develop a new hypothesis reflecting the interacting role of the three mechanisms of lifting (spine, muscles, intra-abdominal pressure) to stimulate further research in this field. The hypothesis is based on the idea that the body during lifting is more than a simple crane; actually it is a complex crane with a hydro-pneumatic device installed below the boom. This hydro-pneumatic device is created by the abdominal pressure in the abdominal cavity.

RESULTS: The hypothesis, as presented, places known facts in a relationship which appears to fit the human body more accurately than explanations previously advanced. Jones states that the human body is more complex than the crane we have used to describe it for many years, and that lifting involves dynamic as opposed to static forces.

The technique of lifting that each individual finds most suitable is the safest for him, and our efforts should be directed at emphasizing the need for conditioning of stomach muscles and the neuro-muscular responses necessary for coordinated movement. Also, we should explain to workers the unstable positions, the role of momentum, fatigue, and moment.

SUMMARY: After reviewing literature on manual lifting techniques and resulting stresses, Jones offers a hypothesis of lifting that emphasizes the dynamic aspects of lifting as compared to previous static explanations previously offered. This hypothesis could result in a re-assessment of the tendency to minimize manual involvement in tasks. Further, it could explain unstable positions, the role of momentum, fatigue and moments, and the benefit of maintaining the resultant of forces below and in front of the lumbar spine. Jones proposes that a more complex model be developed including a hydro-pneumatic cylinder and back muscles which can be lengthened or shortened independently to illustrate the effect of poor coordination on the stability of the spine.

CITATIONS: Seventeen references.

STUDY: Jones, D.F. Back injury research: a common thread.
American Industrial Hygiene Association Journal, 33 (9),
596-602, 1972.

KEYWORDS: hip-flex, kinetic, mechanical, dynamic.

METHODS: The contention is made that back pains have nothing to do with the working environment (i.e., the external conditions). Therefore, it is necessary to review some basic principles to determine the etiology of back pains. The analogy which compares the vertebral column with a crane provides the framework by which various lifting techniques could be analyzed. More specifically, this paper compares the hip-flex, kinetic, natural, mechanical, and dynamic lifting models with the supposition that the vertebral column is dynamically comparable to the crane.

RESULTS: A comparison of the aforementioned lifting methods made possible an analysis of the differences between utilizing the trunk like a "fishing pole" or a relatively rigid cylinder when lifting a load. For example, the natural lifting method entails lifting a load with a horizontal back (analogous to a fishing pole), and the kinetic method dictates that the back be maintained as straight as possible with a stable trunk (analogous to a rigid cylinder). Although the natural lifting method is found not to consume as much energy as any of the back straight-knees bent methods, it does impose a greater stress on the vertebral column when heavy loads are lifted.

Anatomical evidence indicates that the vertebral column is laterally and frontally supported by muscle groups. In light of this, the foregoing lifting models stress that in attempting to change the relative position of adjacent vertebrae under load, a worker may readjust the muscles out of sequence or create a temporary weakness in those supporting muscles; the resultant lateral movement of the vertebral column would cause back pain.

SUMMARY: In essence, the report supposes that it is usually not the external force (i.e., the load per se) which causes back injury, but the body's reaction to it. It is the coordinated, sequential adjustment of the vertebrae, along with the supporting muscle groups that will preclude back injuries. This evidence implicates the importance of training, especially before attempting to lift heavy loads. More specifically, the lifting techniques commonly advocated stress training in stabilizing the spinal column through stabilization of the entire trunk.

CITATIONS: Fifteen references.

STUDY: Jørgenson, K. & Poulsen, E. Physiological problems in repetitive lifting with special reference to tolerance limits to maximum lifting frequency. *Ergonomics*, 17(1), 31-39, 1974.

KEYWORDS: Lifting, tolerance limits, maximum frequency

METHODS: Seventy-nine experiments on repetitive lifting of burdens from floor to table have been performed with 4 female and 4 male subjects. For each subject the maximum burden which could be lifted from floor to table height using a correct lifting technique and the maximum oxygen uptake were determined. From the maximum burden which could be lifted, relative burdens of approximately 10 percent, 25 percent, 50 percent and 75 percent were calculated. Each of the eight subjects lifted the calculated weights under three different frequency conditions. The lifting procedure lasted 20 minutes, during which the oxygen uptake and pulse rate were measured. The maximum lifting frequency, which did not demand more than 50 percent of the subjects maximum oxygen uptake, was determined for each relative burden on each of the subjects. These maximum lifting frequencies for all subjects and all relative loads were then plotted against relative burdens.

RESULTS: The maximum lifting frequency of females is approximately 0.7 of that of males at the same relative burden. The difference is probably due to the difference in the capacity of the oxygen transporting system in the two sexes. The load on the circulatory system in lifting and in leg work on a bicycle ergometer was compared by investigating the pulse rate/oxygen uptake relation. It was found that the orthostatic load on the organism was most pronounced when lifting heavy burdens at low frequencies. The efficiency of useful work in lifting was found to be approximately 6 percent.

SUMMARY: Earlier investigations have demonstrated that the back muscle strength is the limiting factor when a single lift is performed. This experiment, however, showed that in repetitive submaximal lifting both the capacity of the oxygen transporting system and the muscle strength in the back act as limiting factors if the accepted physiological limits are not exceeded. Thus, from an ergonomic point of view, it is necessary to know the strength in the back muscles of the worker as well as the maximum oxygen uptake per kg body weight. This should be kept in mind when planning a work place where repetitive lifting is performed.

CITATIONS: Twelve references.

STUDY: Kamon, E. & Belding, H.S. The physiological cost of carrying loads in temperate and hot environment. Human Factors, 13(2), 153-161, 1971.

KEYWORDS: Cartons, grade, metabolic cost, heart rate (HR)

METHODS: This study was concerned with the physiological cost of carrying bulky cardboard cartons; both metabolic cost and HR were measured. Three subjects, who were pretrained and preacclimatized by 10 days of daily walking for 2 hours at 3.5 mph at 45°C, were used. The load was a cardboard carton (40x30x30 cm), weighing 10, 15 or 20 kg. One of the three thermal conditions prevailed in the chamber: neutral, dry bulb (D.B.) 20°C, wet bulb (W.B.) 15°C; warm-dry, 35°C (D.B.), 20°C (W.B.); or hot-dry, 45°C (D.B.), 25°C (W.B.). Air speed was about 75 m/min. In a single experiment, one of four combinations of speed and grade was employed. Speed was 4 or 5 km/hr, grade was 0 to 4 percent.

HR was recorded continuously by an electrocardiogram over the second half of each minute throughout each experiment. Douglas bags were used to collect expired air during the last 2 minutes of each period of the first and third cycle. A Beckman paramagnetic oxygen analyzer (Model C₂) was used to measure oxygen concentration.

The subject was dressed in shorts, rubber shoes and socks. After the subject was hooked up, he sat quietly for about 15 minutes during which resting HR was recorded. Each test lasted for 65 minutes. After entering the chamber, the subject sat down for 5 minutes and then warmed up by walking for 10 minutes at the speed and slope designated for the test. After a second rest of 5 minutes, he went through 3 cycles, each divided into three 5 minute periods. Cycle 1 - walking, carrying the load, sitting; cycle 2 - carrying the load, walking, sitting; cycle 3 - same as cycle 1.

The load was placed on a waist-high shelf at the front of a motor-driven treadmill. The subject was asked to lift the load away from the shelf while walking. After carrying the load for 5 minutes in both hands, he placed it back on the shelf while walking.

RESULTS: The metabolism per meter walked was least at speeds between 65 and 85 m/min. The ambient temperature did not affect the metabolic cost and so the results for all three thermal conditions were averaged for each load at each speed and grade. Ten kg loads added substantially to the metabolism of walking at any of the four combinations of speed and slope. Loads of 15 kg usually required an increase in metabolism proportional to the added weight. The 20 kg loads had different effects on metabolism, depending on the subject and the speed-grade combination. For all three subjects, the smallest relative increase in metabolic cost attributable to the load was found at

RESULTS: (continued)

4 km/hr with 4 percent slope. Without load, the energy cost for the shorter of the two subjects of similar body weight was greater. However, when metabolism was expressed in calories per step, the difference between the two subjects nearly disappeared. The heaviest and tallest subject had a higher metabolic cost for walking. Carrying the load in the hands in front of the body increased both step frequency and metabolic cost. The extra cost of carrying load indicates an efficiency loss, which was greater for heavier loads.

At 20°C, HR for each level of activity levels off, with similar increments for each cycle. Under warmer conditions this pattern changes. At 35°C, the leveling off is delayed and the levels of HR reached are progressively higher for each cycle. At 45°C, steady states were not attained during the last two cycles either while working or resting.

A high degree of linear correlation independent of individual, treadmill slope, speed of walking, and weight of load, but dependent on ambient temperature was indicated in the regression analysis. The regression of heart rate on metabolism is a little steep at the two higher temperatures. These differences in slope would have been accentuated if HR data from the third cycle had been chosen.

SUMMARY:

Cartons weighing 10, 15 and 20 kg were carried by hands in front of the body at speed of 4 and 5 km/hr on level and 4 percent grade at dry ambient temperatures of 20, 35 and 45°C. Three subjects were used; each test involved three 5 minute periods of carrying the load, walking without the load and sitting. At each speed, step rate increased with increase in the weight of the load. The work efficiency decreased. The metabolic cost for each kg of load carried was 1.3 to 2.3 times greater than the cost per kg of body weight without load. Metabolic costs were not significant under the three thermal conditions, but HR increased by 7 to 10 beats/min for each 10°C rise in temperature.

Based on considerations of metabolic and cardiac cost, fatigue, and need for rest periods, 15 kg packages were determined to be preferable to 10 and 20 kg packages for moving large amounts of material by hand.

The study provides useful information in establishing lifting standards under hot environment.

CITATIONS: Fifteen references.

STUDY: Karvenon, M.J. & Ronnholm, N. Electromyographic and energy expenditure studies of rhythmic and paced lifting work. Annales Academiæ Scientiarum Fennicæ (Helsinki), 106(19), 101-115, 1964.

KEYWORDS: Electromyography, ventilation, light lifting, rhythmic, paced, heart rate

METHODS: A weight of 5 kg was lifted to a level of 12 cm higher and back again (from 63 cm to 75 cm) at the rate of 30 cycles/minute. In the experiments with paced work, the subject followed the signals of the metronome. In rhythmic work, the subject carried out a predetermined number of lifts at a rate chosen by himself, starting every 30 seconds and resting at the end of each sequence of lifts. The ventilation was measured during the experiments which lasted 10 minutes. The O₂ content of the expired air was determined by using the Beckman O₂ analyzer. The heart rate was counted by feeling the radial pulse during the work. The action potentials of some muscles of the trunk and upper limbs were recorded using surface electrodes. Four young adult male subjects were used.

RESULTS: When the work was interrupted into sequences of 10 lifts each, starting a sequence every 20 seconds, and carrying it out at a freely chosen pace, the energy expenditure per lift was considerably less than that used for performing the same work at a steady pace of 30 lifts/minute. Electromyographic recordings with the aid of surface electrodes demonstrated that the change from paced to rhythmic work involved major changes in the pattern of the motor innervation of both trunk and upper arm muscles, e.g. the number of action potential in m longissimus in rhythmic work was less than half that in paced work.

SUMMARY: This study shows that breaking the lifting work in short sequences increases its mechanical efficiency. Although the task was very much the same in paced and rhythmic work, the participation of various muscle groups in its performance showed wide differences. The electromyographic patterns differed at each site of recording and according to the character of the work. The electromyographic results emphasize that breaking a paced work in a series of rhythmic sequences is sufficient to alter the pattern of the innervation of the participating muscle groups deeply. The results of this study indicate that purely mechanistic concepts have only a limited application to the problems of light manual work. The energy cost of even a simple type of work cannot be predicted on the basis of general considerations, without exactly defining the rate and rhythm of working.

CITATIONS: Two references.

STUDY: Kellerman, F.T. and Van Wely, P.A. The optimum size and shape of container for use by the flower bulb industry. Ergonomics, 4(3), 219-228, July 1961.

KEYWORDS: Optimum weight, optimum dimensions.

METHODS: In this study, the processes of tulip bulb handling and the requirements of the container for the bulb-growing industry had to be outlined and then the selection of an optimum size and shape container had to follow those guidelines. In the actual experiments, three weights were compared (8.75 kg., 17.5 kg., and 35 kg.). The influence of shape was eliminated by using the same shape basket for all weights. The task consisted of carrying 210 kg. of flower bulbs a distance of 12 m., i.e., in lots of 35 kg. (six times), 17.5 kg. (12 times) and 8.75 kg. (24 times). Heart-rate was recorded continuously during each experiment and used as an index of work-load. The second test required the subjects to carry containers loaded to the same weight, but different sizes and shapes, a distance of 360 m. at a constant speed of 90 m./minute. The subjects were then asked to tell which container was most convenient to carry.

RESULTS: When the subjects were loaded with 8.75 kg., they had the highest average heart rate frequency, whereas there wasn't much difference when they were loaded with 17.5 and 35 kg. When loaded with 35 kg., the subjects had the lowest heart-rates, but it showed a tendency to increase throughout the task instead of reaching a steady state. Consequently, 17.5 kg. was selected as the optimum weight. The optimum container was one that was long and narrow, and due to its small width, its center of gravity was close to the axis of the body, so that it is not strictly necessary to lean the body backwards for maintaining equilibrium.

SUMMARY: This article deals with an investigation into the optimum size and shape of a container and the transport and storage of bulbs in the Dutch Flower Bulb industry. The results of the investigations (both from the working and psychological point of view) were that the optimum weight for untrained people is 17.5 kg. and the optimum dimensions are 100 x 30 x 12 cm. To further facilitate the carrying of the containers, it was suggested that a strap around the neck be used.

CITATIONS: Six references.

STUDY: Konz, S.A. and Bhasin, R. Foot position during lifting. American Industrial Hygiene Journal, 35(12), 785-792, 1974.

KEYWORDS: Tote box, acceleration, vertical, frontal, lateral force, cartwheel, somersault torque

METHODS: The subjects lifted and lowered a 16.5 x 13 x 6 in. tote box filled with sand to 11 lbs. The center line of the box was 18 in. from the body center line (assumed to be perpendicular from the earhole of the subject) at the lower position. At the upper position it was 34 in. from the original body center line. The subjects stood on a force platform while doing the task; the platform measured vertical force, frontal force, lateral force, cartwheel torque, and somersault torque. Vertical acceleration of the box was also measured. Lifting and lowering were measured at four conditions: 1) feet aligned and the upper shelf straight ahead; 2) feet aligned with the upper shelf at 45° angle to the right; 3) left foot ahead with the upper shelf straight ahead; and 4) left foot ahead with the upper shelf at a 45° angle to the right. In all four conditions the foot center lines were 9 in. apart.

RESULTS:

1. Experience: given the overall pattern in the data from the experiment as well as from previous experiments, it seems clear that peak forces increase with experience. This may be due to initial caution of the subject being reduced.
2. Acceleration of the box: acceleration is positive when upward or deceleration is downward. It is negative otherwise. There is little difference among the four conditions.
3. Vertical force: at any specific time in the lift, a typical range among the four conditions for the mean of eight subjects was 10 lbs.
4. Frontal force: perhaps the most noticeable effect is the generally low magnitude of the forces. There is no appreciable difference among the four conditions.
5. Lateral force: forces are lower than either vertical or frontal forces, with little difference among conditions.
6. Cartwheel torque (torque about the frontal axis) during lifting and lowering was different among the four conditions. Some recommendations are:
 - i. for straight-ahead lifting, keep feet aligned.
 - ii. for lifting with a turn, lead with the opposite foot.
 - iii. for straight-ahead lowering, keep the feet aligned.
 - iv. for lowering with a turn, lead with the opposite foot.
7. In the somersault torque (torque about the lateral axis during lifting and lowering) for lifting, there is no appreciable difference among the four conditions. The previous rule of "lead with the opposite foot only when turning" reduces peak torque about 100 in-lb. and the reversal by about 100 in-lb. For lowering, the curves differ during the early part of the move but are the same during the latter portion. Leading with

Konz & Bhasin, 1974 (continued)

RESULTS: (continued)

the opposite foot only when turning reduced peak torque about 100.

Note that, although the torque may be the same for different foot positions, the stress on specific muscles may vary, depending on the lengths of different moment arms. Moving the foot forward 9 in. should give a better (longer) moment arm, so the resulting stress on the muscles and ligaments should be less. This would extend the advantage of leading with the opposite foot when turning. For workers there are thus two pieces of advice:

1. When lifting or lowering straight ahead, align the feet.
2. When turning, have the foot on the side opposite to the turn ahead.

SUMMARY: Approximately 25 percent of compensable industrial injuries are due to incorrect handling of materials; from a safety viewpoint the problem is overstress on muscles and ligaments rather than strain on the cardiovascular system. Eight (8) male subjects lifted and lowered an 11 lb. box at four conditions stated in methods above. Forces were measured with a force platform. When lifting or lowering straight ahead, align the feet. When turning, have the foot on the side opposite the turn ahead. Forces were very "peaked;" peak force on the vertical axis was 60 lbs.

CITATIONS: Seven references.

STUDY: Konz, S. & Desai, G. Lifting forces for nine lifting heights. III Symposium International de Posturographic Paris, September 23-26, 1975.

KEYWORDS: Peak force, peak torque, peak lateral force, somersault torque, cartwheel torque.

METHODS: Two male subjects (height: 174 cm, weight: 66kg) stood on a force platform and lifted a 5 kg box to height of 15, 30, 45, 60, 75, 90, 105, 120, and 135 cm. The center of mass of the box was 40 cm from the center of mass of the subject. Each subject lifted 12 times at each condition. Since the study was safety oriented rather than energy oriented, the peak forces or torques for each axis were the criteria rather than the area under the curve.

Stage I (0 to 1.3 seconds) ends with the grasping of the box; stage II (1.3 to 3.7 seconds) ends with the box on the shelf; stage III (3.7 to 5.0 seconds) ends with the subject standing vertically. The vertical force is the dominant force.

Each of the nine heights was a condition. Two random sequences of the nine conditions were generated. Each subject followed one of these sequences and then to counterbalance serial effects, the same sequence in reverse order. At each condition, each subject made three lifts. Thus there was data for six lifts/subject at each condition.

RESULTS: The vertical force peaks are greater than object weight due primarily to the effect of the body weight, but also due to acceleration. Height of lift did not significantly affect the peak values. In stage I, peak A (-8.7 kg) occurs at .6 seconds and peak B (+4.8 kg) occurs at 1.1 seconds. In stage II, peak C (-4.4 kg) occurs at 1.6 seconds; peak D (+12.7 kg) occurs at 2.2 seconds; and peak E (-6.3 kg) occurs at 3.0 seconds. There is no discernible peak in stage III.

Peak lateral force was 3 kg. Mean peak twist torque was .17 kg-m. Mean peak somersault torque was 4.40 kg-m. Mean peak cartwheel torque was 6.25 kg-m.

SUMMARY: When investigating the characteristics of safe lifting it is important to use the proper criterion. The part of the body injured is the skeletal-muscular system, not the cardiovascular system. What is important from a safety viewpoint, is the stress in relation to the capability over a short time period (less than 5 seconds).

This study investigated only the final location of the object to be lifted and then only for two-handed sagittal plane lifting. The criterion was output from a force platform.

CITATIONS: Seven references.

STUDY: Konz, S, Sunil, D. & Corwin, B. Forces and torques in lifting. Human Factors, 15(3), 237-245, 1973.

KEYWORDS: Tote box, force, torque

METHODS: Five male students, between the 40th and 60th percentiles of height, acted as subjects in the study. Their weight ranged from 150-170 lbs. with a mean of 157. During the experiment, the subject stood on a 6-axis force platform, which resolved the forces and torques into their six components (vertical, lateral, and frontal forces; and twist, somersault, and cartwheel torques). A wooden tote box containing sand was lifted with both hands from a shelf 42 inches high. One variable was the weight of the load. A 16.5 x 13 x 6 inch container with hand grips was filled to 11, 22, or 33 lbs. with sand. The second variable was the distance (16, 18, or 20 inches) between the center of the load on the lower shelf and the rear of the heel of the subject's foot. The third variable was the angle of the turn (the shelf was located directly ahead, at 45° or 90° to the left). A cube design was used with the 15 experimental conditions. Each subject lifted four times at each condition in each of the two replications. A 10 second rest was given between conditions. During the rest period between conditions, the subject was lying down.

RESULTS: Replications did not produce a significant effect on any of the six criteria, so all the means are based on the 40 values for each condition (5 subjects x 4 performances per replication x 2 replications). The mean peak force along the vertical axis over all distances was 50.6 lbs. The effect for weight was significant but the effects for angle and the interactions were not. The mean peak force along the frontal axis was 17.5 lbs. The distance did not have a significant effect. The effects of weight, angle and their interaction were significant. The mean peak force along the lateral axis was 5.9 lbs. Again the distance did not have a significant effect. The effects of weight, angle, and their interaction were significant.

The mean peak twist torque over all distances was 156 in-lbs. Effect of angle and weight were significant. The mean peak cartwheel torque over all distances was 401 in-lbs. Again the effects of weight and angle were significant. The mean peak somersault torque was 680 in-lbs. The effect of angle was not significant, but those of distance and weight were.

SUMMARY: A force platform was used to study the effect of the following variables on lifting: distance of the load from the heel (16, 18, or 20 inches), weight of the load (11, 22, or 33 lbs.), and angle of turn (0, 45, and 90°). Five male students, between the 40th and 60th percentile in height, lifted eight times at each condition. The mean peak force was 50.6 lbs. along the vertical axis, 17.5 lbs. along the frontal axis, and 5.9 lbs. along the lateral axis. The corresponding mean peak torques

Konz, et al., 1973 (continued)

SUMMARY: (continued)
were 156 in-lb. for the twist, 401 in -lbs. for the cartwheel, and 680 in-lb. for somersault torques. Object weight has a significant effect on all six criteria. The effect varied in relation to the weight of the body plus object more closely than to the weight of the object alone. Angle of turn had a significant effect on all criteria except somersault torque. Distance did not have any significant effect on any criteria except somersault torque.

CITATIONS: Thirty-eight references.

STUDY: Kroemer, K.H.E. Human strength: terminology, measurements, and interpretation of data. Human Factors, 12(3), 297-314, 1970.

KEYWORDS: Isometric, isotonic, static strength, dynamic strength, concentric effort, eccentric effort.

METHODS: This paper presents a comprehensive review of some of the problems encountered by human engineers when attempting to apply strength data to human engineering problems. The etiology of these problems centers on the ambiguous terminology and data used among various researchers which hampers the interpretation of experimental data and its application to the dynamic and real-world situations. Consequently, this paper provides the reader with the terminology found within the discipline of human strength testing, along with definitions, measurement techniques, and interpretation and application of strength data. Furthermore, it attempts to establish a relationship between human static force capabilities and dynamic forces.

RESULTS: The clarification of the extant ambiguities in both the terminology and data revealed that strength data are fully relevant to human engineering problems only when the worker exerts maximal static muscle force; the exertion of submaximal forces in certain tasks limit the applicability of strength data.

SUMMARY: This paper attempted to solve some of the problems concerning the use of ambiguous terms and data in the human strength testing discipline. It pointed out the general lack of standardization effect on the comparison and interpretation of results in strength studies conducted by various researchers. The paper emphasizes the need for research to establish relationships between human static force capacities and the abilities to perform dynamic work at maximal and submaximal levels. Presently, there is little evidence that static force data accurately predicts dynamic performance.

CITATIONS: Seventy-six references.

STUDY: Lind, A.R. & McNicol, G.W. Cardiovascular response to holding and carrying weights by hand and by shoulder harness. Journal of Applied Physiology, 25(3), 261-267, 1968.

KEYWORDS: Fatigue, static (isometric) effort, exercise, load carriage, blood pressure (BP), heart rate (HR)

METHODS: Male subjects, with high degree of physical fitness, from VIC's Mine Rescue Service and laboratory workers in the United States were employed in the study. The holding part of the study had two experimental series. In the first series, 10 subjects held weights for 2.5 minutes in three ways: 1) 20 kg in right hand, 2) 20 kg in the left hand, and 3) 20 kg in each hand at the same time. An interval of 20 minutes was provided between conditions. The weights were handed to the subjects to prevent any cardiovascular responses due to postural changes. Blood pressures and heart rates were measured for 2 minutes before and during, and for 5 minutes after weight holding. Blood pressures were recorded by auscultation with a microphone stethoscope at 30 second intervals while heart rate was measured from a continuously recording ECG, counted over a 30 second period.

In the second series of experiments the cardiovascular responses of the subjects were compared when 40 kg were held in the hands and on the shoulders. Ten subjects were examined in the standing position on two occasions; on the first occasion the subjects held 20 kg in each hand simultaneously, for 2.5 minutes. On the second occasion a well padded shoulder harness weighing 40 kg was worn for 15 minutes. Heart rates and blood pressures were recorded as in the first series.

To check and extend the results of previous experiments that 20 kg constituted a weight that quickly induced fatigue when held by hand, whereas 40 kg could be supported on the back for at least 15 minutes without fatigue, the cardiovascular responses produced by supporting a series of different weights in these two ways were examined. First, the BP and HR of eight standing subjects were measured on four occasions when they held in their preferred hand, 5 kg for 5 minutes, 10 kg for 5 minutes, 15 kg for 2.5 minutes, and 20 kg for 2.5 minutes. In addition, measurements were made when they held 10 kg in their left hand for 5 minutes and 10 kg in each hand for 5 minutes.

Cardiovascular events were also compared during actual stretcher carrying by the conventional hand method with the responses when the stretcher was supported by a shoulder harness. Ten men, working in teams of two, were examined in two ways. On one occasion each pair walked at 2 mph on the level, carrying by hand a stretcher and subject (total weight 80 kg) to the point of exhaustion. On the other occasion the same pair were examined when the weights were supported by the shoulder harness. The subjects walked again at 2 mph, but this time stopped after 15 minutes.

RESULTS: All 10 subjects studied were able to hold 20 kg in each hand, separately or together, for 2.5 minutes. During the three work periods, when the subjects held 20 kg in each hand, first separately and then together, large increases in systolic and diastolic blood pressures and heart rates occurred. There was a wide variation in the absolute values reached by individuals, but they all showed the same pattern of response. The increases of systolic and diastolic blood pressure were of the same order, so that the estimated mean blood pressure (diastolic plus $1/3$ pulse pressure) was correspondingly elevated. When the weight was held in the left hand, the increments of heart rate and blood pressure were somewhat greater than when the same weight was held in the right hand. Since all the subjects were right handed, it was assumed that the muscles of their right hand were stronger than their left hands. When the 20 kg weights were held in each hand simultaneously, the increments of mean blood pressure and heart rate were greater than when 20 kg were held in the right hand, but were very similar to those found when 20 kg were held in the left hand. This is in agreement with earlier findings that during two simultaneously sustained contractions, the cardiovascular responses were not additive but corresponded to the level of responses produced by the muscles which were contracting to the higher relative tension.

The cardiovascular responses found when the subjects carried 20 kg in each hand simultaneously were strikingly different from those which occurred when they held the same total load (40 kg) in a shoulder harness. The increase in the mean blood pressure and heart rate rose initially, and thereafter remained steady at their new levels for as long as the weight was held - 15 minutes.

Subjectively, the local effects on the muscles involved in the two types of weight bearing were also very different. Whereas the arm muscles involved were close to fatigue at 2.5 minutes, the muscles involved in shoulder carriage had not fatigued after 15 minutes, and on two occasions when the test period was extended, there was no fatigue after 30 minutes.

In order to establish some dividing line between what constituted a fatiguing and non-fatiguing load for each method of weight carriage, the responses of five subjects were then studied when they held different weights by hand and in the shoulder harness. The changes in HR and BP were measured in eight subjects who held 5 kg, 10 kg, 15 kg, and 20 kg in their right hands. On separate occasions, when the subjects held 5 kg and 10 kg, their BP and HR rose quickly but reached new steady state levels. The level of each steady state depended on the weight held and was independent of the duration. When the subjects held 20 kg, their BP and HR rose steadily and muscle fatigue occurred rapidly. The responses varied holding 15 kg. Thus, for six of the eight subjects, the weight which separated a non-fatiguing load from a fatiguing load for the arm was between 10 kg and 15 kg.

Lind & McNicol, 1968 (continued)

RESULTS: (continued)

A similar pattern emerged on the eight subjects while they carried 40 kg and 120 kg in a shoulder harness. It was concluded that the critical weight was between 80 kg and 120 kg.

For the carrying part of the study, the results for the two males carrying the stretcher (hand and shoulder harness) were strikingly different. The increase in BP and HR was much higher when the stretcher was carried by hand and the subjects stopped because of fatigue, whereas the subjects were not fatigued after 15 minutes of carriage by the shoulder straps.

SUMMARY:

Blood pressures and heart rates were measured when various weights were supported by hand and by a shoulder harness. The responses fell into the following two categories depending on the weight and the strength of the muscle groups: 1) fatiguing responses where blood pressures and heart rates rose progressively throughout, until at fatigue, the BP was very high and 2) non-fatiguing responses whereafter an initial moderate rise, the BP and HR remained stationary.

Hand carriage in excess of 10 kg and shoulder carriage in excess of 80 kg produced the fatiguing type of response.

Stretcher carrying is an extreme example of the tasks where the above findings have any implications. In mining, stretchers may have to be carried by men for distances of a half mile or more underground before any other mode of transportation can be used.

CITATIONS: Twelve references.

- STUDY: Martin, J.B. & Chaffin, D.B. Biomechanical computerized simulation of human strength in sagittal-plane activities. AIIE Transactions, 4(1), 19-28, 1972.
- KEYWORDS: Maximum voluntary torque, torque resultant from lifting task, five major body articulations
- METHODS: Biomechanical strength modeling involves the comparison of maximum voluntary torques to torques resulting from a lifting task. This comparison is made at each of the five major body articulations (ankle, knee, hips, shoulder, and elbow). Maximum voluntary torques are calculated from data gathered on carefully controlled and dimensioned task equipment. The resultant torques on each joint are made up of two components. First, the weight to be lifted creates a torque when displaced a known distance from the joint center. Second, the weights of the body links create torques around the articulations which also must be reacted to by the muscles involved. Also required as input to the program are maximum voluntary torque capabilities of the subject. The model generates force predictions on the basis of subject voluntary strength.
- The ability of a muscle to produce a torque varies with the included angle of the joint across which it is pulling. Curves representing these variations are general population curves which are input to the biomechanical model. Also, subject test torques at specified angles are input to the program. The muscle torque producing capability at the angle of interest (determined by the current body position) is calculated as follows:

$$ST_{\alpha} = PT_{\alpha} \frac{ST_{\alpha 1}}{PT_{\alpha 1}}$$

where

ST_{α} = Subject torque at angle of interest.

PT = Population curve value at angle of interest.

$ST_{\alpha 1}$ = Subject test value at test angle.

$PT_{\alpha 1}$ = Population curve value at test angle.

α = Included articulation angle of interest.

$\alpha 1$ = Included articulation angle at test position.

Subject reactive torque capabilities are determined at all articulations by this method. The model then compares the resultant torques with the respective reactive strength. If the resultant torque exceeds the reactive capability at any articulation, that joint is said to be "critical" under the current loading.

RESULTS: The three tasks evaluated for a subject applying force to a test object can be defined as: lifting, pushing, and pulling. Results for both males and females at the 50 percent and 95 percent levels are considered; 95 percent level capabilities are lower than the corresponding 50 percent level capabilities. Many observations of general interest can be made from the results obtained.

1. Lift capability in standing position decreases nearly linearly with horizontal displacement, regardless of vertical height.
2. Lift capability is greatest when the hands are close to the knees.
3. Lift capability near the body is lower when the load is waist-high as opposed to knee or shoulder-high due to poor mechanical advantage of the arms and back at waist level.
4. Subjects in a seated position demonstrate constant lift capability at the lower vertical heights until the weight is displaced two feet horizontally from the joint.
5. Pushing capability increases generally with an increase in horizontal displacement, with this relationship nearly linear in the upper vertical heights.
6. Pulling as #5.
7. Female lift capability at the 95 percent level is quite low.

SUMMARY: The branch of biomechanics considered in this model involves the study of human physical attributes during non-repetitive short-duration tasks; "short-duration" is considered to be less than 4 seconds. Thus, the predictions involve musculoskeletal system limitations, not cardiovascular system limitations. The evaluation presented in no way applies to the endurance capabilities of men. The output predictions of the model described here are only useful when applied to infrequently occurring (less than once every 5 minutes), single-effort tasks. The model is also only effective for symmetric sagittal plane predictions. It considers equal-extremity actions performed directly in front of the human operator.

CITATIONS: Twenty-one references.

STUDY: McConville, J.T. and Hertzberg, H.T.E. A study of one-handed lifting; Antioch College, Yellow Springs, Ohio and Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, May 1966.

KEYWORDS: One handed lift, box size, psychophysical

METHODS: This study used 30 male volunteers, ranging in age from 18 to 39 years, as subjects. Seventeen anthropometric dimensions for each subject were recorded. Each subject was asked to lift boxes of varying sizes (height remained constant, only width and length changed) using his right hand only with his palm and fingers up. The boxes were lifted from the floor to a table. The subjects had to do this by straightening their legs, pausing in the lift briefly after coming upright, and then making a biceps-flexion lift to the table top. Thirty pounds were put in the box initially. Each subject lifted this initial load and then additional weights were added to the box until each subject had achieved his maximum possible one-handed lifts. The next series of trials were run using different box sizes.

RESULTS: The test results were tabulated and graphed. The maximum weight of the box that subjects were able to lift varied linearly, but inversely, with the width of the box. From the data collected the maximum weight that 95% of the population would be able to lift was expressed by the linear equation: $Y=60-X$, where Y is the weight (lbs.) of the object to be lifted and X is the width (inches) of the object.

SUMMARY: The author stated that the primary objective of this investigation was to determine the optimum size and width of a container that the Air Force population can conveniently lift with one hand. He also concluded that the major result was the formula $Y=60-X$, by which the recommended upper limit for weight and width of a container could be found under ideal conditions.

CITATIONS: Nine references.

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REVIEW OF THE STRENGTH AND CAPACITY DATA FOR MANUAL MATERIAL HA--ETC(U)

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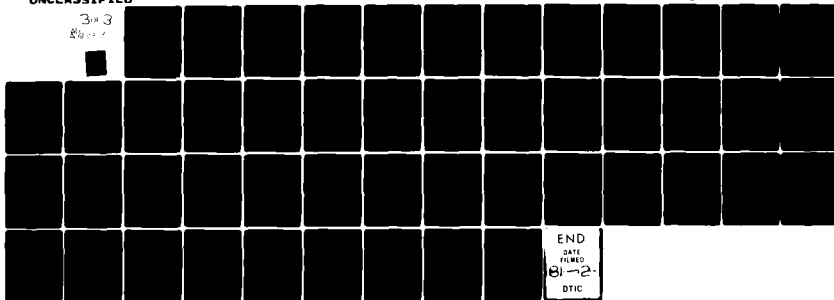
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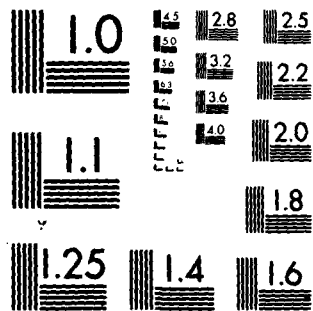
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STUDY: McFarland, R.S. Injury, a major environmental problem.
Arch. Environ. Health, 19, 244-255, August, 1979.

KEYWORDS: Injury, classifications, trends, recommendations

SUMMARY: This paper outlines the extant problems in Manual Materials Handling Activities (MTHA), along with their etiology and prevention. The following outline presents those areas reviewed by the paper.

- I. The problem of accidental deaths and injuries.
 - A. Major classes of accidental deaths.
 - B. The age and sex of accident fatalities.
 - C. Trends in accidental death rates.
 - D. The prevalence of nonfatal injuries.
- II. Research on accidents.
 - A. The problem of definition in accident research.
 - B. Conceptual approaches in accident research.
 1. The epidemiological model.
 2. Systems safety analysis.
- III Current trends in accident research and the development of countermeasures.
 - A. The specific etiology of injury-abnormal exchanges of energy.
 - B. Medical - engineering collaboration in the prevention of injury.
 1. Analysis of motor vehicle injuries.
 2. The "vehicles" of destructive energy in crashes.
 3. The forces involved in motor vehicle crashes.
 4. The determination of injury thresholds..
- IV Applications of biotechnology to the control of injuries.
 - A. Examples illustrating the point of view of biotechnology.
 - B. Contributions of anthropometry to occupational safety.
 - C. Implications of biomechanical information for occupational safety.
 1. Lifting objects varying in weight.
 2. Carrying objects in occupational tasks.
- V Summary - the author states that one of the most important approaches to the prevention of injuries relates to the control of energy at the source, so that it will not impinge on the body. To control energy at the source, the physical stresses in the environment must not exceed the thresholds of human tolerance in potentially hazardous situations.

CITATIONS: Forty-two references.

STUDY: Minard, D., Goldsmith, R., Farrier, P. & Lambiotte, B.
Physiological evaluation of industrial heat stress. American
Industrial Hygiene Association Journal, 32(1), 17-28, 1971.

KEYWORDS: Heart rate, body temperature, heat stress

METHODS: Subjects were volunteers from the work force of the open hearth department of a large steel mill. Two series of subjects were used. Series A consisted of 19 men representing three job categories. Total heart beats were monitored separately during work, during waking hours off, and during sleep. Mean temperature of the skin (t_{sk}) of the anterior chest wall during each period was also monitored. Series B consisted of seven subjects in the open hearth department. The EKG and HR during standard 5-minute exercise at 125 watts work output on a bicycle ergometer were recorded pre-shift and post-shift. Continuous recording of EKG during the shift was made. A measurement of total sweat rate was also made.

RESULTS: Results showed that men in series A expend 31 percent to 36 percent of maximum cardiocirculatory capacity on the job. HR on the job varied inversely with individual work capacity estimated from pre-shift performance on an ergometer. HR gradients to heat levels were nearly as great as to task levels in summer. In winter, HR gradient to heat was only 33 percent of that in summer, but HR responses to task were unchanged.

SUMMARY: Heart rate (HR) and body temperature (t_b) were studied in men on jobs in the open hearth department of a large steel mill. In 19 subjects on various jobs, mean HR for the shift was compared to mean HR off work and during sleep. Results showed that these men expend 31 percent to 36 percent of maximum cardiocirculatory capacity on the job. In 12 tests on five second helpers, continuous EKG records on magnetic tape revealed individual mean HR's for the shift ranged from 99 to 136/minute in summer and 97 to 111/minute in winter. HR on the job varied inversely with individual work capacity estimated from pre-shift performance on an ergometer. Performance decrement was observed for post-shift in two subjects with the lowest work capacity. HR responses, counted each 0.5 minutes of the shift, were analyzed by computer with task effort and heat exposure as independent variables. HR gradients to heat levels are nearly as great as to task levels in summer. In winter, HR gradient to heat was only 33 percent of that in summer, but HR responses to task were unchanged.

CITATIONS: Twenty-five references.

STUDY: Noro, L. Medical aspects of weight carrying. Industrial Medical Surgery, 36(3), 192-195, 1967.

KEYWORDS: Preventive techniques, weight carrying, pathology, accidents, back trouble, aspects of workers.

METHODS: Literature is reviewed with the thought in mind that the duty of an occupational physiologist, biotechnologist or industrial physician is to find the preventive means for back injuries by keeping the work and working environment as healthy as possible and by placing into jobs persons who are physically fit for the tasks involved.

RESULTS: In answering the question "What should be the maximum permissible weight carried by one worker from the health point of view?", it is very difficult, biologically, to find any arithmetical figures in kilos or pounds which could serve as a final norm to limit every individual case. For instance, in addition to the weight of the load, the individual working capacity varies from man to man in the same country and even more between various countries.

In trying to fix a maximum permissible weight, many other factors must be taken into consideration, such as duration of carrying, technique, work breaks, and many environmental factors such as temperature and humidity of air, etc. One must take into consideration the fact that among the workers there are always young and old, men and women, slender and thick, healthy and sick, tall and short. Workers are not 100 percent healthy, and this means that the working capacity differs very much from person to person.

Carrying as a working process always includes lifting, carrying, and lowering of the load. The health effects of this can be acute (sprain of the muscles and the joints, aggravation of circulatory and respiratory organs) or chronic (stress diseases).

Women and young workers need special attention with regard to load carrying due to weak construction of vertebrae, bones, muscles and circulation organs, lower oxygen uptake, etc. Training however, can increase their strength and physical fitness.

From the pathological point of view, lifting is perhaps the most important cause of acute accidents and lower back troubles. The space between the lumbar V and the sacral I vertbrae is especially a weak point in this respect.

A pre-employment screening procedure would be good for workers about to get involved in lifting or carrying heavy loads. A check for circulatory diseases should be made and the general health of the worker should be determined.

Health education should be an important requirement and the management should ensure that the workers are using correct lifting and carrying techniques. Films, lectures etc., should be used for this purpose.

Noro, 1967 (continued)

SUMMARY: Noro reviews literature with the end result being that technologists who deal directly with workers and occupational hazards should be more aware of preventive measures that can be used to protect the workers from accidents.

Industrial physicians should take an active part in health education. Modern ergonomics or biotechnology should be applied as far as possible in lifting and carrying. In particular, management should be trained to ensure that the workers are using correct lifting techniques. Another important point is to strengthen the muscles of the back by regular exercise. In educational work, lectures alone are not enough, and every worker should be given printed material on the right methods. Films should also be available and may be of help in this connection.

CITATIONS: Twenty-one references.

STUDY: Poulsen, E. Prediction of maximum loads in lifting from measurements of muscular strength. Communications from the Danish National Association for Infantile Paralysis, No. 31, 1970.

KEYWORDS: Lifting, maximum load, strength of back muscles

METHODS: It has been described by Asmussen, et al. (1965) that $W = 1.4 \cdot M - \frac{1}{2}$ body weight, in which W = maximum weight of burden and M = backward directed pull of the back muscles as measured at the height of the shoulders. In a state of equilibrium, the torque relative to a frontal axis through the lumbosacral joint will be: $(W \cdot \sin V) \cdot l - M \cdot l = 0$, where V = the angle of body tilt, l = length of the spine from the shoulders to the lumbosacral joint. By solving for W , one gets: $W = M/\sin V$. M can be measured by having the subject pull maximally on a dynamometer; for practical purposes V is assumed to be 45° ; the maximum weight of the burden is $(W - .5 \times \text{body weight})$.

To test the validity of this predictive formula, a series of experiments have been performed on 25 women and 21 men, ages 17 through 60 years, of various occupations, and weighing from 40-90 kg. The experiments will be discussed under two headings.

1. Lifting from floor to an upright position, and
2. Lifting from a fixed shelf to a shelf placed at head height of the subject.

1. Lifting from floor to an upright position

A wooden box, measuring $30 \cdot 35 \cdot 26$ cm with handles placed 20 cm above the bottom at both sides, was loaded approximately with the predicted maximum weight. The subject, with a straight back, bent down by a flexion in the hip and knee joints and grasped the handles. By extending the legs and gradually straightening the back, the subject then lifted the burden from the floor until an upright position was attained. By adding or subtracting weights to the box, the maximum weight that could just be lifted in this way was found.

2. Lifting from a fixed shelf to a shelf placed at head height

A fixed shelf, 82 cm above ground level, and an adjustable higher shelf were used. With the subject standing erect the adjustable shelf was placed over the fixed shelf at the height of the tip of the nose. A small sack with sides measuring $50 \cdot 35$ cm² was loaded with the weight predicted from the formula: $\frac{1}{2}$ (sum of the right and left arm push). The subject grasped the sack and lifted it up to the upper shelf. By adding or subtracting weights to the sack, the maximum weight the subject could just push up on the shelf was found.

RESULTS:

1. Lifting from floor to an upright position

The data collected from the experiment has been plotted against (i) body weight, (ii) the strength of back muscles, and (iii) the maximum load as predicted from the formula described in the methods above. It was found that there is no clear correlation between the maximum load that can be lifted and the body weight of the subject. The equation for the regression

Poulsen, 1970 (continued)

RESULTS:

(continued)

line for women is $y = .46x + 15.2$ kg and for men, $y = .14x + 76.9$ kg in which y is maximum load, and x is body weight, both in kg. The correlation factor, r , is low, for women $r = .28$ and for men even lower, $r = .06$. The relation between the maximum weight that could be lifted and the back muscle strength is also computed; the equation for the regression line is: for women $y = .96x - 7.7$ kg, and for men $y = 1.0x + .42$ kg. The correlation is quite high (women: $r = .78$ and men: $r = .72$). Men are lifting 8 to 10 kg more than women at identical back muscle strength. Also the relation between the maximum load lifted and the load that was predicted from the theoretical formula is calculated. Here the correlation is quite high for both women ($r = .73$) and men ($r = .76$), the men being able to lift heavier burdens than women at identical predicted lifts. The conclusion to be drawn here must be that the maximum weight a person can lift can neither be fixed as a standard load, nor defined as a load related to the person's body weight. A load equal to the actual strength of the back muscle seems to give realistic values, while the determination from the predictive formula where also the weight of head, arms, and trunk of the subject is included does not seem to give a better result than predicted from the back muscle strength alone.

2. Lifting from a fixed shelf to a shelf placed at head height

The maximum load the subject could lift in this way was plotted against the load predicted from the formula. Regression lines for men and for women separately have been calculated and the correlation factor, r , has been determined. It is concluded that men are able to lift more than women and that the regression line for men is placed above that for women. The equations for the regression lines are: for men, $y = .91x + 8.72$ kg, and for women, $y = .72x + 8.27$ kg. The correlation factor r is .66 for men and .62 for women. The maximum load that could be lifted to head height was also plotted against strength of hand grip (average of right and left). The correlation was also fairly high, corresponding to the fact that strength of hand grip correlates highly with strength of arm push.

SUMMARY:

Theoretical predictions of how heavy a burden a person can lift (A) from floor to table height and (B) from a fixed shelf to a shelf placed at head height have been tested in practice. When lifting loads from the floor to table height the strength of the back muscles often will be the limiting factor. When lifting a load from table height to a shelf placed at head height, it is the strength of the arm push that will be the limiting factor.

The prediction formula for (A) is maximum load = (maximum isometric back muscle strength) $\times 1.4 - .5 \times$ body weight. After experiments with 50 men and women it was found that the

Poulsen, 1970 (continued)

SUMMARY: (continued)
correlation between maximum load was highly correlated to both the predicted maximum load to back strength ($r = .7$). For (B) the predictive formula was: maximum load = $1/2 * (\text{sum of right and left maximum isometric arm push})$. After experiments, it was found that the correlation factor r between prediction and actual maximum load was .6. For A the regression lines for maximum load and back muscle strength, and maximum load and predicted maximum load, were different for men and women, men being able to lift heavier burdens than women with the same measured back muscle strength. For B also the regression lines for men and women were different with men lifting more than women with the same measured muscle strength.

CITATIONS: Thirteen references.

STUDY: Ramsey, J.E. & Purswell, J.L. The correlation of mechanical and physiological measures of work movement of the upper limb. AIIE Transactions, 3(2), 97-103, 1971.

KEYWORDS: Mechanical variables, physiological variables, heart rate (HR)

METHODS: The correlation of mechanical and physiological variables reported proceeded from two independent studies. Some subjects were used in a joint experiment. The work task consisted of a seated operator performing a typical motion pattern while carrying a load in his hand. A dead weight shaped to fit the hand with the fingers encircling it was between two targets which defined the length and plane of motion. The work task was paced at a rate of 50 cycles per minute and lasted for 4 minutes.

The seven mechanical measures of work considered were velocity and acceleration of movement, total mechanical energy, force, torque, linear impulse, and angular pulse. The three physiological measures were pulmonary ventilation rate, pulse rate, and oxygen consumption.

A Max Plank gas meter was used to measure the pulmonary ventilation volume. The oxygen analysis was performed using a Beckman E2 oxygen analyzer. Surface electrodes, amplifier, and counter were used to record the heart rate of the subject. An exoskeletal kinematometer was developed and used to continuously monitor the arm motion. The angle of abduction for the upper arm was measured with respect to the midsagittal plane of the body, using the shoulder as a reference point.

RESULTS: Analysis of variance was used and it was found that ventilation rate was highly significant to the variables of weight carried, angle of abduction, distance of reach, and type of work. Heart rate was also sensitive to those variables but not as sensitive as the ventilation rate. Oxygen consumption was sensitive only to distance of reach.

Analysis of variance also indicated that the variables of weight, distance and angle of abduction all had highly significant effects on the mechanical measures of energy, torque and angular impulse.

Increase in ventilation rate/BSA has the highest correlation among the three physiological criteria for every mechanical measure tested and it varied from .531 for shoulder angular impulse to .353 for average shoulder force. Conversely, increase in oxygen consumption/BSA consistently showed the lowest correlation to the mechanical criteria.

SUMMARY: An experimental approach to determine the correlation of some mechanical measures of work with some physiological measures of work, for a task performed by the upper limb, was undertaken. The seven mechanical measures of work were velocity and acceleration of movement, total mechanical energy, force, torque, linear impulse, and angular impulse. The three physiological measures were pulmonary ventilation rate, pulse rate, and

Ramsey & Purswell, 1971 (continued)

SUMMARY: (continued)

oxygen consumption. Pulmonary ventilation rate was found to correlate best with all the mechanical measures, with shoulder angular impulse and average shoulder torque having the highest correlation of the mechanical measures.

This study is an important contribution towards quantifying human capability and measuring human effort for the dynamic work task.

CITATIONS: Twenty-five references.

STUDY: Ronnholm, H. Physiological studies in the optimum rhythm of lifting work. *Ergonomics*, 5(1), 51-52, 1962.

KEYWORDS: Lifting, rhythmic periods, heart rate, energy consumption, blood lactic acid, efficiency.

METHODS: The influence of arranging the work into rhythmic periods was studied by means of comparative experiments. A light lifting work performed with the right hand was chosen for the experiment. Two healthy sportsmen were used as subjects. Energy consumption, heart rate, and blood lactic acid were determined. A typical example of the task is: a weight of 5 kg was put on a table with a height of 63 cm and the work consisted of lifting the weight to another table with a height of 75 cm and lowering it again to the table with a height of 63 cm. The lifting was performed either with regular interruptions (20 lifts/minute) or with a continuous rhythm (10 lifts in a series or free rate, then 30 seconds rest, 10 lifts, 30 seconds rest and so on) during 10 minutes.

After this experiment, trials were made in order to find out the optimum conditions under which least energy was required for a standard work output. The weight, distance and rate of lift were varied.

In order to find the ratio of working time to resting time, the performance was filmed. When lifting rhythmically at a rate of 10 times/minute (12 cm, 5 kg) the time ratio was 1:4; for 20 and 30 times/minute the ratio was 1:1.2 and 1:0.8 respectively.

When lifting at the optimum rate (30 times/minute rhythmically), the subject used on an average 0.56 seconds to lift the weight, kept it in that position for .25 seconds, lowered the weight in .5 seconds and kept it in that position for .19 seconds before the next cycle started.

RESULTS: The results showed that lifting performed with a certain rhythm was much more economical. When the work was performed with regular interruptions at the rate of 20 times/minute, the energy expenditure was 2.38 Kcal/minute. With a continuous rhythm, the energy expenditure was only 1.97 kcal/minute.

In the second case the same work was done with a higher mechanical efficiency. The optimum efficiency was reached at a rate of about 30 lifts/minute. The energy expenditures were 2.4 and 2.04 kcal/minute for rhythmic and non-rhythmic work respectively.

After these, when the distance of lift and the weight lifted were changed, it was observed that with doubling the distance, energy consumption was tripled. The optimum distance was found to be around 12 cm. Optimum load was found to be about 5 kg. Blood lactic acid ranged from 18 to 63 mg percent.

It was observed that to lift 5 kg 20 times/minute is more economical than to lift 10 kg 10 times/minute, either with regular interruptions or rhythmically. It was more economical to lift a load 5 kg 40 times/minute than to lift 10 kg 20 times/minute when performed rhythmically. It was more economical to lift a load of 5 kg over a distance of 24 cm 20 times/minute than to lift it over a distance of 12 cm 40 times/minute.

Ronnholm, 1962 (continued)

SUMMARY: When light lifting work is to be performed, it is possible to do the lifting in two ways: either with regular interruptions or arranging the lifts into work periods with distinct intervals. The essential finding in this study is that physiological considerations of the problem of lifting contribute to ergonomics and may be applied to the solution of practical working situations. When light lifting work is performed rhythmically, efficiency and output may be increased and the work load may be reduced.

CITATIONS: No references.

STUDY: Ronnholm, H., Darvonen, M.J. & Lapinleimu, V.O. Mechanical efficiency of rhythmic and paced work of lifting. Journal of Applied Physiology, 17(5), 768-770, 1962.

KEYWORDS: Lifting, rhythm, pace, energy expenditure, mechanical efficiency

METHODS: The work consisted of relatively light lifting with the right hand. An example of the experiment: a weight of 5 kg was put on a table at the height of 63 cm; the subject had to lift it onto a table 75 cm high and to lower it again to the 63 cm table. The lifting was performed at a rate of 20 lifts/min. In rhythmic work, the subject made 10 lifts at a rate chosen by himself, every 30 sec., resting during the intervals.

In further experiments, the weight, the vertical distance lifted, and the rate of lifting were varied. In all experiments with rhythmic work, however, the work has started every 30 sec. Work at different rates was filmed at the rate of 16 frames/sec., and the time spent for the different movements was studied from the film.

The ventilation was measured with the aid of Miller-Franz apparatus during each 10 minute experiment and in some cases also 5 minutes during recovery. Oxygen in the expired air was determined with Beckman oxygen analyzer, model C. The heart rate was counted by feeling the radial pulse during work. In some experiments, blood lactic acid was determined.

RESULTS: A time study was made from the films. When the rate was speeded up from 10 to 30 lifts/min, the actual lifting became only a little faster, mostly cutting the pauses shorter. At each frequency both the lifting cycles and the pauses were shorter in rhythmic than in paced work.

In paced work at 20 lifts/min. the total energy expenditure was 2.38 kcal/min. In rhythmic work the energy expenditure was markedly less, only 1.97 kcal/min. These values include the energy required for standing upright (1.58 kcal/min.). One of the subjects attained the optimum efficiency at the rate of 30 lifts/min. while the other attained it at the rate of 20 lifts/min. The mechanical efficiency of rhythmic work was much greater than that of paced work. It was observed that at a high rate of lifting, as the rhythmic work approaches the character of paced lifting, the difference in the mechanical efficiency of the two types of work also tends to disappear. When the vertical distance is increased, the difference in mechanical efficiency between rhythmic and paced work tends to disappear. The difference was greatest at about 12 cm. The mechanical efficiency was much higher in rhythmic than in paced work at 5 kg load. The difference disappeared with loads of 2 kg and 10 kg.

For all tasks, the heart rate was slower in rhythmic than in paced work. Lactic acid determinations ranged from 18 to 63 mg/100 ml.

Ronnholm, et al., 1962 (continued)

SUMMARY: Weights of from 2 to 10 kg. were lifted to levels 5 to 44 cm higher and back again at the rate of 10 to 40 cycles/minute. The optimum rate in terms of energy efficiency was 20 to 30 lifts/minute. With this rate, a load of 5 kg, and a lift of 12 cm, about half as much energy was expended when the subjects were permitted rapid, rhythmic completion of lifting and a compensatory pause during each 30 sec. of scheduled work as when the same amount of work was performed at equal intervals throughout. The difference between rhythmic and paced work diminished to zero as the number of lifts were increased to 40/minute. At loads of 2 and 10 kg and also over the distance of 5 and 44 cm, paced and rhythmic work required equal energy expenditure. The heart rate was also slower in rhythmic than in paced work. The difference was largest (16/minute) when lifting 5 kg over 12 cm at the rate of 30 lifts/minute.

The introduction of an element of rhythm thus resulted in a saving of physiological effort under strictly defined conditions. This study attempts to determine an optimum speed at which the mechanical efficiency of the work is highest.

CITATIONS: Five references.

STUDY: Smith, L.E. & Edwards, D.K. Prediction of muscular endurance (work performance) from individual differences in initial and post training increments in static strength. Human Factors, 10(4), 345-350, 1968.

KEYWORDS: Static strength, muscular endurance, isometric endurance, isotonic endurance, pre- and post-training effects

METHODS: Static Strength Test: Following adjustments of the handle of a calibrated Stoelting dynamometer for individual differences in size of hand grip, each subject, who was seated, completed five maximal contractions with 2 minute rest intervals between each contraction.

Isometric Endurance Test: The subject was encouraged to sustain statically a maximum isometric contraction for two minutes; immediately following which he relaxed his grip for approximately a quarter second and completed one rapid maximal contraction.

Isotonic Endurance Test: Using the same body and limb position, equipment, and recording device that was employed in the static strength test, the subject completed a 6 minute alternating maximal grip-rest-grip-rest cycle of exercise. During the 6 minute test the subject alternated work and rest cycles (each 3 minutes in length).

RESULTS: It was found that an individual's static strength training program is a poor prediction of his post-training increments in strength performance, i.e., the correlation between static strength and post-training increment in strength was found to be only .169. Similarly in the present study static strength did not discriminate among individuals in regard to their potential in work performance as witnessed by the low correlations between strength and pre- and post-training isometric endurance viz r 's = .270 and .408, and pre- and post-training isotonic endurance .374 and .303. Also, there is no radical comparative disagreement in results in reference to the prediction of work performance from individual differences in strength, i.e., correlations between strength increment and pre- and post-isometric and isotonic endurance ranged from .110 to .492. The inter- and intra-relationships between individual's isometric and isotonic "endurances" are predominantly low with non-significant correlations ranging from .242 to .338. However, although there was little relationship between pre-isotonic and isometric endurance (r = .242), pre-isotonic endurance was found to be a significant predictor of post-isotonic and initial isometric work capacity (r 's = .741 and .743).

Therefore, it is quite apparent as a result of the wide scatter of correlations, one cannot predict from the strength measure how individuals will perform endurance activities.

Smith & Edwards, 1968 (continued)

SUMMARY: The object of the study was to determine the pre- and post-training changes upon the interrelationships between strength, isometric endurance, and isotonic endurance. A controversial research topic is the current problem concerning the relationship of individual differences in strength as a predictor of muscular endurance. Also in question are individual differences in static strength performance as a reliable predictor of work capacity prior to and following a significant increase in strength.

CITATIONS: Twelve references.

STUDY: Snook, S.H. The effects of age and physique on continuous work capacity. Human Factors, 13(5), 467-679, 1971.

KEYWORDS: Work capacity, age, physique, lifting, lowering, pulling, pushing, carrying, walking, heart rate

METHODS: The basic tasks of lifting, lowering, pushing, pulling, carrying and walking were varied according to height distance and rate of work, resulting in a total of 54 separate tasks. The lifting and lowering heights correspond to the muscles which actually do the work, whereas the pushing and pulling height approximates handle heights commonly found in industrial situations. All tasks, except walking, were performed at high, medium, and low rates of work which were determined empirically during pilot studies. Heart-rate was chosen as a dependent variable. Telemetry equipment was used for this purpose and measurements of heart-rate were recorded only during high and intermediate rates of work. Force was another dependent variable for all tasks, except walking, and was adjusted by varying the weight of the object being handled. Rate was the dependent variable for the walking task.

Twenty-eight subjects, divided into two age groups, were required to handle an industrial tote box 13.5 x 19 x 5.5 in. with two 7 x 1-5/8 in. handles, and varied the weight of the box by adding or subtracting loose lead shot. Pushing, pulling, and walking were simulated on a specially constructed treadmill. The treadmill was powered electrically during walking and manually, by the subject, during pushing and pulling. Strain gauges measured the force of pull and push. Forty-one anthropometric measurements were made of each subject at the beginning and at the end of the experiment. These were used to compute ectomorphy, endomorphy, mesomorphy, density, body type, specific gravity, and for estimates of lean body mass. Subjects were instructed to adjust their work load to a comfortable level (very light or very heavy) and starting forces were randomly used. The adjustments for the two cases were averaged. Each task was performed for about 40 minutes in a controlled environment.

RESULTS: All force measurements for lifting, lowering, pushing, pulling, and carrying tasks were subjected to a three-factor analysis of variance (age by task by rate). No significant force differences were found between the two age groups.

The work-rate measurement applied only to the walking task. All walking-rate measurements were subjected to a two-factor analysis of variance - age by replication. No significant work-rate differences were found among the age groups or replications. All heart-rate measurements for lifting, lowering, pushing, and carrying tasks were subjected to a three-factor analysis of variance (age by task by rate).

No significant heart rate differences were found between the two age groups. Significant differences were found among tasks, rates, and task by rate interaction. Heart-rate measurements

Snook, 1971 (continued)

RESULTS: (continued)
for walking were subjected to a two-factor analysis of variance (age by replication). No significant heart-rate differences were found among the age groups or replications.

SUMMARY: The following hypotheses were investigated: 1) continuous work capacity does not decrease with increasing age, and 2) physique has a greater effect on continuous work capacity during slower, heavier tasks than during faster, lighter tasks. Twenty-eight male subjects, 14 between 25 and 35 years of age, and 14 between 45 and 60 year of age, performed 54 manual handling tasks for a duration of 40 minutes. Three lifting, three lowering, four pushing, one pulling, and six carrying tasks were performed at three different rates of work. Three replications of a walking task were also performed. The continuous work capacity of each subject for each task was measured by a psychophysical technique which required subjects to adjust their work loads to the maximum they could perform without feeling uncomfortable. Heart rate was monitored continuously during task performance. The age hypothesis was tested by subjecting both work load and heart rate data to analysis of variance. The physique hypothesis was tested by correlating work load data with each of the 41 anthropometric measurements obtained from each subject. The results supported the age hypothesis. The physique hypothesis, however, was supported only by the results of the younger group of subjects.

CITATIONS: Thirty-seven references.

STUDY: Snook, S.H. The design of manual handling tasks. The Ergonomics Society lecture given at the Cranfield Institute of Technology, Bedfordshire, England, April 6, 1978.

KEYWORDS: Back injuries, lifting task, psychophysical, physiological, strength, endurance.

METHODS: This paper discusses the prevention of low back injuries by designing the job to fit the worker. The author describes seven studies, six of which used psychophysical methodology. In the first study, heart rate and oxygen consumption were measured for 30 male industrial workers selected from three age groups. They performed different lifting tasks which varied in height, frequency, and object weight. The classification of lifting height used in this study was based upon the muscles that actually performed the lift. The second study was concerned with the maximum weight of lift and psychophysical methodology was used. The third study investigated lifting frequency and also used a psychophysical methodology. The fourth study investigated other types of manual handling tasks in addition to lifting, such as lowering, pushing, pulling and carrying. Using a psychophysical approach. The fifth study was the same as the fourth except it used all female workers so that the differences in sex could be investigated. The sixth study had to do with the effects of heat stress on manual handling tasks. The seventh study expanded and refined the manual handling data base by also looking at variables such as object length, object width, lifting distance, pushing height, and pulling height. In addition, questionnaires were sent to the Loss Prevention representatives of the Liberty Mutual Insurance Company to obtain data on tasks producing low back injury.

RESULTS: The author stated that in view of the differences in strength and endurance of all the people used, a good way to evaluate a manual handling task is in terms of the population that can be expected to perform the task without overexertion or excessive fatigue. For example, 18 kg. is the maximum acceptable weight for 75 percent of the male industrial workers lifting a large object (75 cm. width) through a 76 cm. distance from the floor to knuckle height once every minute (all the data is given in tabular form). Results from the questionnaires revealed that about one-quarter of the jobs (where the workers have worker's compensation with this company) involve manual handling tasks that are acceptable to less than 75% of the workers, and one-half of the low back injuries were associated with these jobs. No significant reduction in low back injuries was found in employers who used medical histories, medical examinations, or low back x-rays to select the worker for the job or for the employers who trained their workers to lift properly.

Snook, 1978 (continued)

SUMMARY:

This paper reviews seven studies which were done previously. It explains how the experiments were done and tabulates all the data from the experiments. The studies investigated lifting, lowering, pushing, pulling, carrying and walking, and had the following variables: height, distance, and frequency of task; size and weight of the object; differences in worker sex, age, and physique; and the effects of heat stress. Six of the seven studies used a psychophysical methodology. In addition, the effectiveness of the studies was investigated by analyzing randomly selected back injuries. The author then concluded that the proper design of manual handling tasks can reduce up to one-third of industrial back injuries, and, therefore, job design appears to be significantly more effective than selecting the worker to fit the job, or training the worker to lift properly.

CITATIONS: 42 references.

STUDY: Snook, S.H. & Ciriello, J.M. Low back pain in industry. American Society of Safety Engineers Journal, 17(4), 17-23, April, 1972.

KEYWORDS: Back injury, cause, prevention, recommendations

METHODS: A literature search was conducted to determine what is currently known about low back pain in industry.

RESULTS: Low back pain is characterized by intermittency, but there is no real agreement as to its cause. The six major theories that have been offered as the cause of lower back pain are: sciatic nerve theory, sacroiliac joint theory, psychoneurosis theory, disc theory, muscle spasm theory, and facet joint theory. There have been conflicting studies on lower back pain as related to age, experience, seasonal variations, body height, and sex. It seems that no one really knows the cause of lower back pain or if there is a certain group of people it affects. Since the cause of lower back pain is not known, it is very difficult to prevent it, but attempts have been made through selection, instructions, job design, and physical fitness. There is also disagreement about the usefulness of low back x-rays for job selection in pre-employment programs and whether or not there is a correct, safe way to lift. Job design is another area where attempts are being made to reduce the number of lower back pain injuries. However, there is disagreement in what kind of jobs produce back injury and even when back injury occurs. One thing that is agreed upon by the references the authors used is that physical fitness is important in preventing lower back pain.

SUMMARY: The author's conclusions are that, as indicated by his literature search, the problems of low back pain are far from being solved and that they may never be solved completely. He also seemed to agree with Rowe (J. Occup. Med 11(4): 161-169, 1969) that it appears impossible to prevent backache, but that it may be possible to reduce low back disability. The most promising method in preventing the backache or reducing the disability appeared to be physical fitness, followed by job design, selection, and instruction; in decreasing order.

CITATIONS: Thirty-seven references.

STUDY: Snook, S.H. & Ciriello, J.M. Maximum weights and work loads acceptable to female workers. Journal of Occupational Medicine, 16(8), 527-534, 1974.

KEYWORDS: Maximum acceptable weight of lift, females, physiological, work rate

METHODS: The six basic manual handling tasks were lifting, lowering, pushing, pulling, carrying, and walking. Sixteen housewives and 15 industrial workers were used as subjects. Independent variables were: height of lift, tote box weight, frequency of lift. Dependent variables were: force (except for walking), rate (for walking), heart rate. All tasks except walking were performed at fast, moderate, and slow rates of work.

RESULTS: Comparison of the results with earlier studies shows that the average weight handled by industrial man was significantly greater than the average weight handled by industrial women - which in turn was significantly greater than the average weight handled by housewives. The sex differences in object weight were greater for the lifting, lowering, and carrying tasks than they were for the pushing, pulling, and walking tasks. Sex differences in object weight were also greater at low rates of work than at high rates of work; although women handled significantly less weight than men, they expressed similar or significantly higher heart rates.

SUMMARY: An ergonomic study was designed and conducted to determine maximum weights and work loads acceptable to female workers. The results are used to predict the maximum weights and work loads that are acceptable to various percentages of the female population. The purpose of this study was thus to determine whether the sex differences demonstrated with traditional laboratory tests would also occur with actual manual handling tasks used in industry.

CITATIONS: Fifteen references.

STUDY: Snook, S.H. & Irvine, C.H. Maximum acceptable weight of lift. American Industrial Hygiene Association Journal, 28(4), 322-329, 1967.

KEYWORDS: Human variables, task variables, tote box, lift

METHODS: Seven human and task variables are considered in the study. These are: sex, age, training, physical fitness, size of the object to be lifted, height from which and to which the object is lifted, and frequency of lift. None of the previous six studies investigated or held constant all seven of the variables identified above.

Nine male subjects, between 25 and 27 years, were instructed to adjust the weight of the tote box until they felt that it was the maximum amount they could lift comfortably without straining themselves once every 15 minutes. Subjects performed push-up, pull-up, and deep-knee bend exercises for one week prior to their participation. Eighteen 50-minute, thirteen 12-minute, three 15-minute, and three 30-minute sessions of repeated lifting were performed by each subject before any measurements were recorded for analysis. The object lifted was a tote box, 13-1/2 x 19 x 5-1/2 inches with two 7 x 1-5/8 inches handles. The subject varied the weight of the box by adding or removing loose lead shot with a small scoop. The box weighed 10 lbs. and contained a false bottom which could hold a maximum of 40 lbs. of lead shot. Weight of the "empty" box was varied between 10, 20, and 30 lbs.

Each subject made a total of 18 judgements; six for the floor level to knuckle height lift, six for the knuckle to shoulder height lift, and six for the shoulder to arm reach height. For one-half of the judgements the initial total weight of the box was 30 lbs.; for the other half 100 lbs. was the initial weight.

Subjects made only one judgement per lifting height in a single day.

RESULTS: The median weight for the six trials per lifting height was obtained for each subject and the mean and standard deviations were used to get the values of 90 percent, 75 percent, 25 percent, and 10 percent of population. The following observations were made:

1. With only one exception, standard deviations are considerably smaller than in the two Air Force studies.
2. There is a small difference between the three lifting heights when compared with previous studies.
3. Results for the floor to knuckle height lift are somewhat less than for equivalent lifts in other studies.
4. Results for the knuckle to shoulder height lift are in general agreement with equivalent lifts of other studies.
5. Results for shoulder to reach height are somewhat greater than for equivalent lifts in other studies.

Snook & Irvine, 1967 (continued)

SUMMARY: It was concluded that 50 lbs. is the maximum weight of a compact object that should be lifted by unselected, adult male workers. The maximum amount of weight that an individual can be expected to lift comfortably and without strain is discussed. Six previous studies have been reviewed. The approach used in two Air Force experiments is identified as a variation of the psychophysical method of magnitude production. An improved experimental design is described which includes the following advantages: 1) the control of additional variables not considered in previous studies; 2) experimental controls and statistical procedures found necessary for use in psychophysical experiments; 3) instructions and tasks which are more applicable to industrial situations; and 4) subjects who are experienced industrial workers, older, and better conditioned to the lift-task.

The study attempts to find a safe weight to protect individuals against injuries due to lifting and is useful in developing recommendations for maximum permissible safe weights.

CITATIONS: Twelve references.

STUDY: Snook, S.H. & Irvine, C.H. Maximum frequency of lift acceptable to male industrial workers. American Industrial Hygiene Association Journal, 29(6), 531-536, 1968.

KEYWORDS: Frequency, lift, tote box, psychophysical methodology

METHODS: Of the numerous psychophysical methods designed for determining thresholds, a combination of the methods of adjustment and tracking was chosen as the most practical for long term, continuous tasks. Eight male subjects were required to lift an industrial tote box (19 inches long, 13.5 inches wide, and 5.5 inches deep) repeatedly through a 20 inch vertical distance. A device was designed to lower the tote box automatically after each lift.

There were two independent variables: tote box weight and height of lift. The empty tote box weighed 20 lbs. During one-half of the trials, the tote box weighed 35 lbs., and 50 lbs. during the remaining half. Three levels of height were used: floor to knuckle, knuckle to shoulder, and shoulder to functional arm reach. Within each height level, the tote box was lifted through the standard 20 inch vertical distance. The subject was paced by a repeating timer which activated a combination light and buzzer. Control of the timer was given to the subject so that he could adjust the frequency of lift according to his feelings of fatigue. The subject was instructed to imagine that he was working on a piece of work, getting paid for the number of lifts, but working a normal 8-hour shift that allows him to go home without feeling bushed.

The initial frequency was randomly varied (3, 4, 5 or 6 seconds between lifts). These values were chosen because they cannot be maintained for any length of time and consequently, subjects had to decrease the frequency of lift in order to follow the instructions correctly. Each subject performed for test sessions of 4 hours each. Five minute periods of repeated lifting were performed during the first session; 12 minute periods during the second session; 15 minute periods during the third session; each subject performed three 1-hour periods of repeated lifting, separated by a 15 minute rest period.

RESULTS: During the early minutes of the test session, subjects overestimated the frequency of lift and had to slow down. In 90 percent of the tests during the last four days subjects made no further adjustments in lifting frequency after 40 minutes of the test had elapsed. In the remaining 10 percent of the tests, small adjustments, if any, were made.

To permit direct comparison between the 35 lb. and 50 lb. weights of lift, the frequencies were converted into foot-pounds per minute. There were significant differences among the three heights and the two weights. All three heights of lift were significantly different from each other. Replications were not significantly different, however.

Snook & Irvine, 1968 (continued)

SUMMARY: This study utilized a psychophysical approach to determine maximum frequencies of lift acceptable to male industrial workers. Eight subjects were required to lift continuously either a 35 lb. or a 50 lb. tote box through a 20 in. distance at each of three different heights. The lifting task was paced by a repeating timer which the subject controlled according to his subjective feelings of fatigue. Visual cues were minimized as much as possible. Non-significant differences among three replications of the experiment lend strong support for the psychophysical methodology. Negative correlations between selected frequency of lift and subject height and weight are very similar to those reported by other investigators.

This study supplements an earlier attempt by the authors to define the maximum frequency of lift that 90 percent of the healthy male industrial workers can perform without showing signs of excessive fatigue.

CITATIONS: Sixteen references.

STUDY: Snook, S.H. & Irvine, C.H. Psychophysical studies of physiological fatigue criteria. Human Factors, 11(3), 219-300, 1969.

KEYWORDS: Fatigue, psychophysical methodology, heart rate (HR)

METHODS: The study has two parts: 1) laboratory study and 2) field study.

Laboratory Study:

Of the numerous psychophysical methods designed for determining thresholds, a combination of the methods of adjustment and tracking was chosen as the most practical for long term continuous tasks. Subjects were required to lift an industrial tote box (19x13.5x5.5 in.) repeatedly through a 20 in. vertical distance. Tote box weight and height of lift were two independent variables. The tote box weighed 35 lbs. during the first half trials and 50 lbs. during the remaining half. Three height levels were used: floor to knuckle, knuckle to shoulder, and shoulder to functional arm reach. The subject was paced by a repeating timer which activated a combination light and buzzer. Control of the time was given to the subject so that he could choose the frequency according to his sensation of fatigue. The initial frequency was randomly varied (3.4, 5 or 6 seconds between lifts) and the subject was asked to lift on a piece rate system for an 8 hour shift such that he can go home without becoming tired.

The experiment was replicated three times for a total of 18 tests. Nine males performed as subjects. Each subject performed 10 test sessions of 4 hours each, one test session every other day. Five minute periods of repeated lifting were performed during the first session, 12 minute periods during the second session, 15 minute periods during the third session, and 30 minute periods during the fourth session. During the first four sessions, subjects were instructed in the correct methods of lifting. During the remaining six sessions each subject performed three 1 hour periods of repeated lifting, separated by 15 minute rest intervals.

A continuous recording of work heart rate was obtained from the subject's EKG signal and was telemetered by a small FM transmitter. The final frequency of lift selected by each subject was also recorded.

Field Study:

During the field study, 12 workers from a shoe factory participated. Subject ages ranged from 22 to 37. The task consists of placing a shoe upper on a shoe last, securing it by pulling the strings of the upper over pins on the last, and placing the last into a mold where the sole is attached. Eleven of the 12 workers operated six machines and the twelfth worker operated only four machines but at a faster pace.

Heart rate was recorded for each worker, while he was performing the string lashing task.

Snook & Irvine, 1969 (continued)

RESULTS: Laboratory Study:

1. There were no significant heart rate differences among the three replications.
2. There were no significant heart rate differences among the two weights of lift (35 lbs. and 50 lbs.).
3. There were significant heart rate differences among the three heights of lift. Floor to knuckle height lift was significantly different from the other two, but the other two were not significantly different from each other.

Field Study:

The mean heart rate for 12 workers was 100 beats/minute (while performing the task). There were no significant heart rate differences between the field and laboratory results.

The heart rate, as a fatigue criterion, has shown consistency in both the laboratory and field studies, and this lends strong support for the use of psychophysical methodology in future studies of fatigue criteria.

SUMMARY:

A laboratory experiment and a field study were conducted using psychophysical methods for determining fatigue criteria. Heart rate was measured during these studies as an indication of the physiological level of functioning and was compared with fatigue criteria suggested by other investigators. The consistency of the results in the field study and three replications of the laboratory study demonstrated the reliability of the psychophysical and methodology.

Oxygen consumption criteria--There remains some doubt as to whether maximum continuous work capacity can be expressed as a percentage of maximum oxygen uptake.

Energy Expenditure Criteria--It is quite adequate for leg tasks, but slightly high for arm tasks (Lehmann's criterion).

CITATIONS: Thirty-five references.

STUDY: Snook, S.H., Irvine, C.H. & Bass, S.F. Maximum weights and work loads acceptable to male industrial workers. American Industrial Hygiene Association Journal, 31(5), 579-586, 1970.

KEYWORDS: Lifting, lowering, pushing, pulling, carrying, walking, psychophysical methodology, work load

METHODS: The six basic manual materials handling tasks of lifting, lowering, pushing, pulling, carrying and walking were varied according to height, distance, and rate of work for a total of 54 separate tasks. Carrying heights represented both straight-arm and bent-arm methods of carrying. All tasks except walking were performed at high, medium, and low rates of work. The dependent variable was force for all tasks except walking; for lifting, lowering and carrying tasks, force was adjusted by varying the weight of the object being handled. For pushing and pulling tasks, force was adjusted by varying the resistance against which the force was applied.

During lifting, lowering, and carrying tasks, subjects were required to handle an industrial tote box, 13-1/2 x 19 x 5-1/2 inches with two 7 x 1-5/8 inch handles. A special device was used to automatically lower the tote box after each lift. The device was modified to lift the tote box after each lowering operation. Pushing, pulling, and walking tasks were simulated on a specially constructed treadmill. During walking the treadmill was electrically powered, but during pulling and pushing, it was manually powered by the subject. Strain gauges on the stationary bar measured the horizontal force and acceleration of push and pull. The subject controlled the resistance of the treadmill belt by varying the amount of electric current flowing into a magnetic clutch built into the treadmill.

Twenty-eight males served as subjects and were instructed to adjust their work load to the maximum amount that they could perform without strain or discomfort, and without being tired, weakened, overheated, or out of breath. Three subjects performed simultaneously. Each task was performed for 40 minutes in a controlled environment between 68° and 72°F and 40 percent to 55 percent relative humidity. All subjects wore cotton scrub suits and safety shoes with neolite heels and soles.

RESULTS: Maximum acceptable weights of lift and lower were tabulated. The mean and standard deviation for each task was used to predict the weights that 10 percent, 25 percent, 50 percent, 75 percent, and 90 percent of the male industrial population can be expected to lift and lower.

Two different forces were recorded during pushing and pulling tasks. The force required to get an object in motion is called initial force and is greater than the force required to keep the object in motion, i.e., the sustained force. These forces and work loads for 7-foot push and pull are also tabulated.

Maximum weights and work loads acceptable to subjects when performing carrying tasks are tabulated along with the maximum walking rates selected by the subjects.

Snook, et al., 1970 (continued)

RESULTS: (continued)

There was no significant difference between maximum acceptable weights of lift and lower. However, work load was significantly greater for lowering than lifting. The initial force for pushing was significantly greater than the initial force for pulling, but there was no significant difference between work load and sustained force.

When carrying the tote box, subjects handled a significantly greater weight with the straight arm carry than with the bent arm. The differences among the three replications of walking task were not significant and the mean walking rates were close to 3 mph.

SUMMARY:

An ergonomic study was conducted to determine man's physical capacities while performing manual materials handling tasks. Twenty-eight subjects (industrial) performed three lifting, three lowering, four pushing, one pulling, one walking, and six carrying tasks in a controlled environment of 68° to 72°F and 40 percent to 55 percent R.H. Each task was performed at three different rates of work. A psychophysical methodology was used. The subjects controlled their own work load by adjusting the force variable.

The results are used to predict the maximum weights and work loads that are acceptable to different percentages of the male industrial population.

This investigation develops data by investigating actual manual handling tasks and makes an attempt to develop maximum continuous work capacity criteria with the use of psychophysical methodology.

CITATIONS: Twelve references.

Also see: Snook, S.H., Irvine, C.H., and Ross, S.F. Maximum weights and work loads acceptable to male industrial workers while performing lifting, lowering, pushing, pulling, carrying, and walking tasks. Paper presented at the American Industrial Hygiene Conference in Denver, Colorado, May 13, 1969.

STUDY: Soule, R.G. & Goldman, R.F. Energy cost of loads carried on the head, hands, or feet. Journal of Applied Physiology, 27(5), 689-690, 1969.

KEYWORDS: Mechanical loads, steady-state exercise, work efficiency

METHODS: Ten men between the ages of 20 and 23 were selected. The subjects walked for 20 minutes at speeds of 4, 4.8, and 5.6 km/hr in an environment of 22°C, 50% RH, wearing the standard U.S. Army fatigue uniform (weight 3.5 kg) under each of the following conditions: 1) carrying no load, 2) carrying a load of 4 kg on each hand (total 8 kg), 3) carrying a load of 7 kg on each hand (total 14 kg), 4) carrying a load of 14 kg on the head, and 5) carrying a load of 6 kg on each foot (total 12 kg). The two different hand loads consisted of a pair of boxing gloves wrapped with strip lead. The load on the head consisted of a helmet liner, a steel helmet, and a lead weight brazed in the helmet. The load for the feet was made by filling standard U.S. Army double-walled "vapor-barrier" boots with mercury. During each of the 20 minute test periods, three 2-minute gas samples were collected using a 350-liter Tissot gasometer; collections were made for minutes 7 and 8, 11 and 12, and 15 and 16. Samples of expired air were analyzed for oxygen and CO₂ with a Beckman E2 paramagnetic oxygen analyzer and a Beckman LB-1 CO₂ analyzer. Resting oxygen consumption and maximum oxygen uptake were determined for each subject.

RESULTS: The total energy cost for each condition was tabulated. With increase in speed, there was an increase in mean total cost of each load.

It was observed that weight may be carried in the hands and on the head without a great increase in energy cost over equivalent body weight increases. However, when the weight is carried on the feet, energy cost is greatly increased; at 4 km/hr the oxygen uptake per kg of weight per minute is about four times that per kg of body weight and clothing. Furthermore, the energy cost for the weight on the feet at the walking speeds of 4.8 and 5.6 km/hr is about six times that per kg of body weight. Each of these energy cost cases is highly significant.

SUMMARY: Ten subjects walked for 20 minutes on a treadmill at 4, 4.8, or 5.6 km/hr carrying: 1) no load, 2) 4 kg on each hand, 3) 7 kg on each hand, 4) 6 kg on each foot, or 5) 14 kg on the head. Energy cost per minute per kg of total weight agreed, for the no load condition, with previous studies. The cost per kg of weight carried on the head was 1.2 times the expected cost per kg of the no load condition at all speeds. At 5.6 km/hr, the cost/kg of load carried in the hands was 1.9 times the no load cost for both 4 and 7 kg loads. It was the same for the 7 kg load at slower speeds also. However it was 1.4 times for the

Soule & Goldman, 1969 (continued)

SUMMARY: (continued)

4 kg load. The cost/kg of load carried on the feet was 4.2 times the no load cost per kg at 4 km/hr, 5.8 times at 4.8 km/hr, 6.3 times at 5.6 km/hr.

An attempt has been made to study the relative efficiencies of the different techniques of carrying load and investigate the maximum loads that can be placed in areas such as wrist or helmet radios, in spike proof boots, and the relative energy costs incurred.

CITATIONS: Fourteen references.

STUDY: Strindberg, & L. Petersson, N.F. Measurement of force perception in pushing trolleys. Ergonomics, 15(4), 435-438, 1972.

KEYWORDS: Pushing, psychophysical methods, body weight

METHODS: Ten male untrained subjects, between 19-29 years of age were studied. Their mean height was 184 cm ($SD=+6$) and mean weight 72 kg ($SD=+8$). All subjects wore tennis shoes. Three identical 'Post be hallare 69' trolleys measuring 1715 mm (height) X 800 mm (width) X 1200 mm (length) were used and their starting positions were indicated on the floor (concrete). Three mechanical dynamometers with different weight ranges were used for the measurement of required starting force with different loads. Cardboard containers filled with notepaper and envelopes were used as load in most cases. Twenty-five kg lead rods totalling around 300 kg were used for the heavier weights (the weights varied from 100-800 kg).

The force required to start a trolley rolling was measured for the 3 trolleys with weight increments of approximately 25 kg.

The maximal pushing ability test was made with an empty trolley (98 kg) and with a trolley loaded with 700 kg. The psychophysical method of estimation was used in order to study the relation between the perceived force and the physical force needed in pushing trolleys. Seven different weights were used for the test trolley. The subjects had to estimate the force necessary to start seven different heavy trolleys and to indicate this force in comparison to the maximal value they thought themselves capable of exerting in the pushing.

RESULTS: The results verified previous studies in that a person on the average was able to push a trolley of this type on a horizontal surface with approximately 80 percent of his body weight.

The perceived force was plotted as a function of the physical force measured. The three curves for the different trolleys were in agreement. Up to a force of 130N, perceived force was about equal to the physical force, but beyond that it increased more rapidly.

Subject's estimate of the necessary starting force in comparison to the maximal value they thought themselves capable of exerting in pushing increased exponentially. Results were also used for individual analysis of subject estimation capability by dividing the median of estimated maximal force by the measured maximal force. This figure correlated well with subject height, such that tall persons underestimated their strength and short persons overestimated it.

SUMMARY: The force perception in pushing trolleys was studied by the psychophysical method of magnitude estimation. It was found that forces beyond a certain critical value (130N) were

Streindberg & Peterson, 1972 (continued)

SUMMARY: (continued)

experienced as being greater than they actually were. It was also found that a person on the average can exert a maximal pushing force expressed in kp which corresponds to approximately 80 percent of his body weight in kg. Tall persons seemed to underestimate their maximal force and short persons to overestimate it.

This study was an attempt to determine what man himself regards as an appropriate load and his perception of the varying degrees of loading involved in trolley handling.

CITATIONS: Four references.

STUDY: Thomas, D.P. The effect of load carriage on normal standings in man. Journal of Anatomy, 93(1), 75-86, 1959.

KEYWORDS: Load carriage, standing posture

METHODS: Ten male students, aged 18-21 years, acted as subjects. Their heights and weights ranged from 170.6 to 188.9 cm and 59.75 to 84.75 kg respectively. Four bony hand marks were marked: 1) the lateral side of the greater tuberosity of the right humerus; 2) the lateral side of the greater trochanter of the femur; 3) the knee joint immediately above the head of the right fibula; and 4) the lateral malleolus of the right fibula. The subjects stood on a rigid platform with heels 20 cm apart, in a comfortable posture. Each subject was photographed under the following conditions: 1) normal standing, without load; 2) carrying an empty carrier; 3) carrying 12 kg attached to the carrier high on the back; 4) carrying 24 kg as in (3); and 5) carrying 24 kg attached to the carrier low on the back. The load of 24 kg was moved over a distance 30 cm between the 'high' and 'low' positions. For the experiments the subjects wore only trunks and vest. Subjects were photographed twice, but not on the same day, about half a minute after they had been placed in position. This was repeated for each condition and subject. The film negatives were projected on a white screen and measurements were taken directly from it using a grid. The vertical height above the platform, and the horizontal distance from the plumbline were measured for each of the four workers.

The analysis of the results was performed by comparing the positions of the four anatomical markers on each subject under varying load conditions.

RESULTS: The results showed a highly significant forward displacement of the shoulders with loading. The unloaded carrier, however, made no significant difference to the position of any of the markers. The position of the hip marker did not move significantly for the varying load conditions, but the position of the knee marker moved progressively backwards with increasing load carriage. There is, therefore, a highly significant realignment of the body segments with the carriage of loads above a certain minimum weight in the standing position.

There were highly significant differences in position between normal standing and carrying the carrier plus 12 kg, between carrying 12 kg and 24 kg and between carrying 24 kg in the low as compared to the high position. Thus the heavier the load, provided that it exceeded the weight of the carrier (4.25 kg), the further forward the subject leaned, and for the same weight, the lower position on the back caused the shoulder to be displaced further forward.

The position of the shoulder was also compared using the angular displacement from a vertical line through the hip

Thomas, 1959 (continued)

RESULTS: (continued)

marker, but the levels of significance between different effects were virtually the same. Similarly the position of the hip marker was checked, but it did not change significantly with the varying load.

It was found that the angle between the shoulder-hipline and the vertical, and the angle between the ankle-hipline and the vertical showed no significant correlation with either the weight or the height of the subjects during load carriage. There was no evidence that the posture of the subjects when loaded was significantly related to their height or weight.

There was a significant interaction between loads and subjects, implying that the effects of the load differ significantly from subject to subject.

SUMMARY:

The effect of load carriage on the normal standing posture has been studied using a miniature camera photographic technique. The displacement from the vertical line of marked anatomical landmarks was measured on enlarged negative images, during normal standing and when loads of 12 and 24 kg were carried. It was found that there was a highly significant change in the position of the hip. There was a highly significant backward displacement of the knee, while the position of the knee was not affected.

It was concluded that a highly significant re-alignment of the body position takes place during load carriage above a certain minimum weight.

A weight of 24 kg was found to cause further forward displacement of the shoulder when it was carried low on the back than when it was carried high on the back.

It is suggested that the trunk acts as a counterbalance, altering its inclination according to the position of the load on the back, so that the vertical projection of the center of gravity remains relatively undisturbed.

CITATIONS: Nine references.

- STUDY:** Tichauer, E.R. A pilot study of the biomechanics of lifting in simulated industrial work situations. Journal of Safety Research, 3(3), 98-115, 1971.
- KEYWORDS:** Lifting stress, task severity, lumbar spine, surface myograms, force platform, kinesiometer, biomechanical profile of lifting, heel height, bulk/weight ratio
- METHODS:** A system consisting of a force platform (a simplified version of Green's model (1957)), a kinesiometer, an oscillographic recorder and a fourteen channel analog tape recorder, was constructed to permit the simultaneous analog recording and storage of mechanical, biomechanical and myographic data in form of biomechanical profile. The profile was representative of the magnitude and sequencing of mechanical and physiological events associated with a lifting task. The force platform provides displacement in absolute terms of the center of mass of the body-load aggregate of the subject along the abscissa of the mid-sagittal plane, changes in force on the load cell related to acceleration of the center of masses of the body-load aggregate along the ordinate of the mid-sagittal plane, and location of the combined center of mass of all of the objects on the platform at any instant. The kinesiometer provides a continuous recording of the location of anatomical landmarks in their respective sagittal planes. The following are thus known:
1. The location in space of the center of mass of the object manipulated.
 2. The location in space of the center of mass of the body-load aggregate.
 3. By mathematical derivation, the location of the center of mass of the human subject.
 4. The distance between the anatomical landmark selected and any of the aforementioned centers of mass.
 5. By computational derivation, acceleration at any instant of the center of mass of the object handled, of the center of mass of the human body-object aggregate, and of the center of mass on the human body on the platform.
- Based on the above information, the lifting stress acting at any point on an anatomical structure is computed using the "moment concept."
- The objects to be manipulated and lifted under experimental conditions were boxes, constructed in three different dimensions, three boxes for each dimension weighing 5, 10 and 15 pounds, respectively. Thus nine different weight/bulk ratios were obtained with only three levels of weight. Load levels were determined on the basis of the mean weight of objects commonly handled in activities of daily living and in light work in industry.
- To validate the moment concept (the rationale was that torque to either the lumbar spine or to the hip joint would produce stresses in both the sacrospinalis and gluteus maximus muscles), a board was constructed holding weights of 5, 10 and 20 pounds,

Tichauer, 1971(continued)

METHODS: (continued)

respectively so as to produce torques on the lumbar spine of a magnitude of inch-pounds. Distance from the deepest part of the lumbar curvature to the center of mass of the load was 14 inches, 20 inches, and 26 inches, respectively. These moments simulated the effects of weight/bulk ratios.

A walking experiment was also conducted to bring in the realism of an industrial situation.

RESULTS:

Observations were taken during 60 1-hour tests. It was seen that the mean height of the integrated e.m.g. gathered over the sacrospinalis muscle is roughly proportional to the moment exerted on the lumbar spine rather than to the weight of the object held. It was shown that when workers are mobile, the surface myograms of gluteus maximus and sacrospinalis muscles are reliable indices of the moment exerted on both lumbar spine as well as on the hip joint. The increase in moment while the weight remained constant demonstrates that the nature of task changes from high to medium heavy. This proves that weight considered alone is meaningless as an indicator of the severity of a lifting task, but that torque is the true index.

It was concluded that the surface myogram over gluteus maximus could be developed into an acceptable indicator of biomechanical stress on the lumbar spine during walking. A good correlation between the walking speed and the mean height of the surface myogram was also found.

Also, biomechanical lifting profiles were obtained from two different lifting techniques. It was observed that minor variations in heel height of shoes affected the sacrolumbar angle and also altered the general lordotic configuration of the vertebral column during lifting. It was concluded that heel height as well as lumbo-sacral angle are major factors influencing the magnitude of any biomechanical bending moment acting on the lumbar spine and thus may vary substantially the severity of a lifting task, even if the load does not change. This is more significant in women than in men.

SUMMARY:

A methodology for the application of kinesiology to lifting and materials handling situations was theoretically validated and confirmed by practical "spot testing". Two kinesimeters and a force platform were constructed for the experimentation. It was established that the weight/bulk ratio of the object handled is a major determinant of the severity of a lifting task and this together with lifting technique determines the bending moment acting on the vertebral column. It was found that even minor variations in the heel height of the working shoes affect the lordosis of the vertebral column, and the same was true for minor changes in posture due to lifting techniques. It was shown that lifting techniques which increased the sagittal bending moment on the lumbar spine, produced large myoelectric responses from the gluteus maximus. Also, any increase in sagittal bending moment

Tichauer, 1971 (continued)

SUMMARY: (continued)

increased the time necessary to lift and reduced the pace when walking with the object in hand.

It was shown that weight limitations on lifting are valueless and irrelevant because they do not consider weight/back ratio of the object handled, nor do they consider the protection of individuals with pre-existing impairment.

The results of this study provide a basis for developing quantitative relationships between weight/bulk ratio and work tolerance. Also important is the development, in many classes of back injuries, of satisfactory methods of rehabilitative treatment which would enable the patient to successfully handle work situations within a normal environment and without further impairment to his health. The results can be applied to explore the possibility of developing rules and revision of legislation to protect rehabilitees from further disability resulting from poorly designed work situations.

CITATIONS: Forty-nine references.

STUDY: Tichauer, E.R., Milter, M. & L. Nathan, I.M. Lordosimetry: a new technique for the measurement of postural response to materials handling. American Industrial Association Journal, 1, 1-12, 1973.

KEYWORDS: posture, lordosimetry, lumbosacral adjustments, ectomorphs, endomorphs

METHODS: Ten women served as subjects to determine whether a causal relationship between spinal curvature and the loads lifted could be established. The supposition was made that via the mapping techniques of the spinal curvature, both the magnitude and location of the spinal response to lifting stress could be defined. The variables examined were subject body type, weight of load, and bulk/weight ratio of the load. The subjects, classified as either ectomorphic or endomorphic, were required to hold boxes of several sizes (i.e., small and large) and weights (i.e., 5 lbs, 10 lbs., 15 lbs.) for durations of time ranging from two minutes to ten minutes. A stylus of the lordosimeter mapped the spinal curvature while the loads were held.

RESULTS: The processed data revealed substantial variations in the measured parameters. It is conjectured that each subject can assume a nearly infinite number of postural configurations when standing at rest, provided that stable balance is maintained. Changes in lumbosacral angle and slope of the line of best fit were determined for all subjects holding large and small boxes of the three weight levels and the two time intervals. The deliberate choice of packages of similar weights but different bulk was intended to assess the significance in lifting tasks of bulk/weight ratio as well as weight alone. However, no direct relationship could be developed between spinal response and weight alone. Lordotic response to each weight level was affected by the box size.

In the no-load condition, the average lumbosacral angle is close to 130 degrees, and the range of its variation is less for the ectomorphs. Lumbosacral adjustments of the lowest movement (lightest small package) occur randomly for both body types, but with a narrower range for the ectomorphs. Generally, in reaction to light load application, ectomorphs tend to arch, and endomorphs tend to straighten. At greater levels of loading, the ectomorphs tend to arch consistently, but the endomorphs respond randomly by either arching or straightening. Changes in slope of the best fit are negative for both groups of two and ten minute durations. The variation of slope is greater for endomorphs, making their trends more random than the ectomorphs.

Tichauer, et al., 1973 (continued)

RESULTS: (continued)

The range of ectomorphic arching at two minutes is substantially reduced at ten minutes. Endomorphs, however, do not show different behavioral patterns of lumbosacral adjustment in time.

It was found that subjects were unable to hold the heavier large box for the assigned ten minute term, although weights of ten or fifteen lbs. are not considered severe by current lifting standards.

The large load produced effects markedly different from the small load. At the two minute interval, the ectomorphs showed reduced range of adjustment for the lower range of movements; as the moments increased so did the range of adjustments. The endomorphs showed a random variation in arching at the low range of moments for the two and ten minute tasks. In the high range, the response became more uniform for the endomorphs. For all subjects, body tilt adjustments were positive with the large box. For the long duration task with the heaviest load, all subjects showed the broadest spread of lumbosacral adjustments.

At the critical task level with incipient failure, the subjects maintained balance with large excursions in random directions.

SUMMARY:

The objective of this pilot study is to determine whether through lordosimetry a quantifiable causal relationship can be found between spinal curvature changes and the loads that cause them.

A device was designed and constructed which maps the configuration of the vertebral column. It was used to record changes in spinal configuration and general posture of a group of female subjects engaged in the holding of loads of different weights and bulk/weight ratios. This new apparatus provides a potentially useful procedure of the simple measurement of postural reaction to physical work stress during manual materials handling in industrial practice.

In the course of the study, measurements and procedures were standardized; the effects of body type, load bulk, and load weight on postural reaction were discussed.

CITATIONS: Eighteen references.

- STUDY: Tichauer, E.R., Yagoda, H.P., Weinstein, J.M. & Wall, R.A. Design criteria for packages and containers: A report on the state of the art, submitted to NIOSH, Cincinnati, Ohio, October 15, 1972.
- KEYWORDS: Manual materials handling, design criteria, loads, exertion, containers
- METHODS: The report evaluates research needs for the development of criteria for recommended standards for the design of packages and containers, i.e., for size, shape, weight and labeling of packages or containers to reduce all kinds of resulting injuries. An attempt has been made to review pertinent literature, determine gaps in research, and make recommendations of actions necessary to fill such research gaps.
- RESULTS: The findings of Tichauer and his associates include information procured from a literature search as well as from information obtained from international organizations and government organizations. Research was conducted by biomechanical techniques into the physical response of the back as well as other structures of the body in the efforts required by manual-materials handling. Recommendations are offered concerning the marking of containers, regarding standards development, and regarding identification of organizations with capabilities in ergonomics and biomechanics.
- SUMMARY: Finally, it must be stated that all research results currently available in the U.S.A. concern themselves with "lifting" per se and not with the relevance of container design and container handling methods in the maintenance of occupational safety and health.
- There is not sufficient data available for the formulation of reliable standards as related to container design, labeling, and handling. Loosely formulated standards would not protect the working population, would be unenforceable, and could lead to alienation between governmental agencies, labor, and management. It is, therefore, necessary to proceed along the slower, but both in the long run as well as in the short run, more fruitful avenue of purposeful and accelerated research in this field and to produce draft standards as soon as the information to support them becomes available.
- CITATIONS: Twenty-five references.

STUDY: Troup, J. D. C. Relation of lumbar spine disorders to heavy manual work and lifting. Lancet, 857-861, April 17, 1965.

KEYWORDS: Lifting, lumbar spine disorders, biomechanics

METHODS: Troup's paper is concerned with low-back disorders which are among the major causes of absenteeism in industry and account for much disability both in industry and at home. Troup discusses the prevalence of back injuries, their etiology, significance of x-ray changes, the biomechanics of lifting, pathological changes, lifting regulation, and training programs.

RESULTS: The paper points out that the data on the extent of the low-back problem, though incomplete, indicate that, considered together, these disorders form a massive group and that the cost in terms of sickness and injury benefits, the charge on the National Health Service, and loss of productivity and earnings is enormous. The paper also discusses the significance of x-ray screening of workers as a valid procedure pointing out that it is not always a good method. The author then compares the two methods of lifting (stooping and squatting) showing that without adequate physical training, the flexed knee or "kinetic" lift is not necessarily the safest method. Also, he indicates that in lifting the greatest stresses arise at the beginning of the lift-together with an increase in intra-abdominal pressures. He stresses the importance of training in lifting.

SUMMARY: The data on the extent of the low-back problem, though incomplete, indicate that, considered together, these disorders form a massive group. Unfortunately, none of the figures on back injuries and manual handling accidents are comparable. The way in which the necessary information is collected and analyzed is not adaptable enough to provide the required information. For instance, back-injury rate in different industries cannot be compared, because of varying efficiency in reporting accidents.

A move toward standardization in reporting accidents is apparent, based on the incidence of accidents causing "three day plus" incapacity. This is logical and such a process is essential for purposes of comparison, but in relation to back injuries, it tends to exclude useful information, since the spine can be irreversibly damaged without necessarily causing immediate incapacity. Information on the incidence of both trivial and serious injuries is therefore equally valuable. With more efficient reporting, the frequency with which particular tasks are associated with back injuries can be correlated with the relative frequency with which each task is performed in the course of a day's work. In this way the relative dangers can be assessed.

Unfortunately, knowledge of the physiology of lifting and similar heavy work is in its infancy. The stresses produced in the spine during actual maneuvers, the mechanics of the movement involved, and the forces exerted, have only recently been given attention, and so far for only a limited number of tasks. But investigations of this kind are essential before

Troup, 1965 (continued)

SUMMARY: (continued)
dangers inherent in some types of manual work can be properly understood and the safest methods for performing them can be devised. The selections of manual tasks for analysis must wait until more is known of the epidemiology of low-back disorders.

CITATIONS: One reference.

Troup, 1965 (continued)

SUMMARY: (continued)

dangers inherent in some types of manual work can be properly understood and the safest methods for performing them can be devised. The selections of manual tasks for analysis must wait until more is known of the epidemiology of low-back disorders.

CITATIONS: One reference.

STUDY: Troup, J.D.C. & Chapman, A.E. The strength of the flexor and extensor muscles of the trunk. Journal of Biomechanics, 2, 49-62, 1969.

KEYWORDS: Maximal push and pull, turning moment of the trunk, dynamic strength, hip flexion/extension

METHODS: A. Measurements of static strength

The maximal forces exerted while pushing and pulling were measured using a special apparatus which was designed so that subjects applied forces manually, their upper limbs horizontal, with their trunks vertical and their pelvis held firmly between anterior and posterior padded bars. Forces were measured in two postures: standing and sitting. The apparatus could be adjusted to suit the dimensions of the subject. Subjects were asked first to exert a submaximal force to accustom themselves to the apparatus, keeping elbows and knees extended. The two maximal exertions were made, subjects being asked to hold the maximum for about 1 second. The results were recorded to the nearest kg. Taking into account the time of response of the galvanometer, the duration of the exertion was 3 to 4 seconds.

B. Measurement of the ability to flex and extend the trunk while overcoming the effect of gravity

The ability to achieve and hold postures at the extremes of the range of flexion and extension of the trunk and hips was measured in two tests: sit and reach, inclined and prone trunk raising. They were tests of dynamic strength only in as much as movement was required of the subject in performing them.

C. Measurements of mobility

The ranges of sagittal movement of the lumbar spine and hips were estimated from observations made on subjects in fully flexed and fully extended postures. Lumbar movement was calculated indirectly by estimating the range of movement between the thoracolumbar region and the femora and subtracting from it the range of movement at the hip joints.

D. Anthropometric measurements

The following were measured: weight, to the nearest kg; stature, to the nearest cm; trochanter height; sitting height and reach height.

RESULTS: A. Measurement of static strength

The forces exerted by the males were significantly greater than those exerted by the females, both in absolute terms and when expressed as a proportion of the body weights of the two sexes. Flexor forces were consistently less in magnitude than extensor forces and flexor turning moments were similarly less than extensor turning moments. The flexor forces exerted were somewhat greater standing than sitting, but with the difference in handle/bar heights in the two postures, the flexor turning moments were greater in the standing position. The converse applied to the extensor forces and moments, the latter being similar in the two postures.

RESULTS: (continued)

B. Sit and reach, inclined test

1. The mean distances between fingertips and the plantar surface of the feet achieved in the performance of this test were closely similar in the two sexes.

2. Prone, trunk raising: The mean vertical distances moved at C7 in the performance of prone, trunk raising were 35.6 cm for both sexes. When the mean scores were expressed as a proportion of the mean sitting height, the ratios were .57 and .53 for females and males respectively.

C. The relationships between variables

All the forces and all the turning moments in the static tests of strength correlated significantly with each other for both sexes. Flexor forces correlated as well with each other as with extensor forces, and the same applied to flexor and extensor moments. Forces and moments correlated well with each other also, particularly those concerning the same maneuver. The sit and reach, inclined (S.R.I.) and prone trunk raising (P.T.R.) tests of strength correlated significantly with each other in the male subjects ($p < .01$) but not in the females.

The individual measurements of static strength were significantly related to subjects' weight, particularly with the male subjects. But there was no significant association between weight and either the S.R.I. or the P.T.R. tests.

The relationship between the range of sagittal movement of the hips and the static tests of strength was of no significance although there were three exceptions in male subjects in whom there were negative correlations at comparatively low levels of significance. On the other hand the degrees of lumbar flexion/extension correlated significantly in both sexes with the flexor forces and moments in the seated position and with extensor forces and moments standing in the females. Hip flexion/extension correlated significantly with both the S.R.I. and the P.T.R. tests particularly with the males; and in both sexes, lumbar flexion/extension was significantly associated ($p < .001$) with the S.R.I. and P.T.R. tests of strength.

SUMMARY:

Disorders of the lumbar spine are widespread in industrial communities, and the amount of incapacity they cause is considerable. There is thus a need for objective methods of assessing individual capacity for work involving the spine and trunk. This investigation was planned to provide data on the flexor and extensor turning moments on the trunk during maximal static contractions in two postures, standing and sitting. The tests were devised to measure subjects' ability to maintain postures at the extremes of flexion and extension while overcoming the effect of gravity on the trunk. In addition the

Troup & Chapman, 1969 (continued)

SUMMARY: (continued)
ranges of sagittal movements of the lumbar spine and hips were measured together with subject's weight, stature, sitting height, and the lengths of their upper and lower limbs.

CITATIONS: Forty references.

STUDY: Whitney, R.J. The strength of the lifting action in man. Ergonomics, 1(2), 101-128, 1958.

KEYWORDS: Strength, type of lifting, foot placement, type of grasp

METHODS: The strength of the lifting action was measured under the following defined conditions:

1. The subject was instructed to exert a steady, maximum lifting force on a horizontal bar placed in a frontal plane. The duration of the steady force was three seconds.
2. The bar was of circular cross section, 3.2 cm diameter and the span of the two-handed symmetrical grasp was maintained at 40 cm throughout.
3. Subjects were instructed to employ a closed grasp throughout, and both overhand and underhand grasps were investigated.
4. Three grasp heights were investigated, viz. 12.5, 25.0, and 50.0 cm above ground level.
5. Foot stance was maintained at 20 cm throughout.
6. Foot placement was investigated at three distances of heel contours from the frontal plane, viz. 30, 40, and 50 cm.
7. In each lifting effort the subject was instructed to adopt one of two types of lifting action - either derrick (stooping) or knee action (squat).

The apparatus consisted of a force platform and recording equipment. The subjects employed in these experiments were male student volunteers between the ages of 18 and 20 years. Eight subjects, of statures from 172.6 to 192.3 cm and of body weights from 63.9 to 84.0 kg, were investigated. For the lifting experiments all subjects wore shorts, singlet, thin socks and rubber-soled plimsolls. The routine of the experiments was designed to randomize with time the variables of the experiment as far as practical. Each subject completed the whole set of lifting actions over three separate days. On each experimental day the subject performed six separate "blocks" of lifting actions at one grasp height and two further blocks of actions at another grasp height. The six blocks of actions included all combinations of foot placement, grasp (overhand or underhand) and lifting action (derrick or knee) at the one grasp height.

- RESULTS:
1. The most important variable determining the maximum lifting force was the distance of the feet from the frontal plane including the grasp axis. The force decreases rapidly with increase of this distance.
 2. The maximum lifting force also decreased with increase of grasp height, but the influence of grasp height was much less than that of foot placement distance.
 3. None of the other variables considered, apart from subject-to-subject variation, had an appreciable effect on the maximum lifting force, in particular lifting actions.

Whitney, 1958 (continued)

RESULTS: (continued)

4. In all lifting operations the turning moment exerted on the body by the lifting effort has to be counterbalanced by an opposing moment produced by the body weight. It was suggested that in most practical lifting operations the maximum lifting force is limited by the maximum counterbalancing moment which the body weight can provide, and that only exceptionally with the inherent muscular strength of body extension being the limiting factor. This appeared to be the chief reason why the heavier subject could exert a greater maximum lifting force under specified conditions.

SUMMARY: The maximum isometric force exorable on a horizontal bar situated in a frontal plane was found to vary, for either young male subjects and for the different lifting conditions observed, from 15 to 120 kg. Increase of foot placement distance from 30 cm to 50 cm effected the largest reduction in lifting force. The reduction produced by increase of grasp height from 12.5 cm to 50 cm was very much less, and the effect of type of grasp (overhand or underhand) and type of lifting action (using or not using knee extension) was generally small. It appeared that the magnitude of the lifting force was largely determined by the magnitude of the force moment which the body mass could exert to counterbalance the reaction of the lifting force upon the body.

CITATIONS: Twenty-six references.

