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Maximum Weights of Asymmetrical Loads Acceptable to Industrial Workers for Symmetrical Manual Lifting*

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This paper presents 'maximum acceptable weight of lift' design databases for lifting asymmetrical loads by industrial male and female workers. These databases were developed by first collecting experimental data on experienced and inexperienced workers under identical conditions (Study A) and then applying the trends developed, as a result of data comparison, to the data collected on inexperienced workers in a separate independent study (Study B) dealing with lifting asymmetrical loads. Several different task variables are accounted for in the data. These include the following: 1) lifting height (floor to knuckle, knuckle to shoulder, and shoulder to reach); 2) frequency of lift (2, 4, and 6 lifts/min); 3) box-size (30.48, 45.72, and 60.96 cm long in the sagittal plane); and 4) load asymmetry (indicated by the offset of the center of gravity in the frontal plane: 0, 12.7, and 25.4 cm from the mid-sagittal plane; the 0 cm center of gravity (c.g.) offset indicates symmetrical load).

Introduction

The hazards of lifting materials manually have been outlined in several previous publications.[1-3] It now is accepted widely that ergonomic intervention in the materials handling job design process is a viable means of reducing overexertion injuries resulting from performing such jobs. In order to accomplish this, several researchers have proposed design data bases specifying human work limits for repetitive lifting tasks. The basis for such data is either the subjective fatigue criterion[4] or the physiological fatigue criteria.[5,6]

The subjective fatigue criterion, which utilizes the psychophysical methodology, has been used more widely in designing manual lifting jobs for a given population. The physiological fatigue criteria (heart rate and oxygen uptake), on the other hand, generally are used for assessing physiological stresses in individuals and matching and screening workers. This does not imply, however, that the subjective fatigue criterion cannot be used for worker screening and matching or the physiological fatigue criteria are unsuited for designing manual lifting jobs for a given population.

Much of the subjective fatigue design data for manual lifting jobs are for symmetrical loads (symmetrical objects that have their load c.g. concentric with the geometrical center).[4,7,8] In reality, it is rarely so. The majority of objects that are lifted manually have their load distributed asymmetrically around the available space. Clearly, it is inappropriate to use data developed by lifting symmetrical loads for designing manual lifting tasks that involve asymmetrical load lifting — especially when some scientific studies indicate that the effect of load asymmetry can be very significant.[9,10]

The purpose of this work was to generate maximum weight of asymmetrical loads acceptable to male and female workers for regular work shifts (8-hr work durations) by modifying similar data collected in an independent and separate study on inexperienced student workers. The basis for modification was the ratios of maximum weights of lift acceptable to experienced (industrial) and inexperienced (student) workers at various combinations of task variables. These ratios were developed in the work presented here.

Load asymmetry could be either in the sagittal plane or in the frontal plane. Since the c.g. offset in the sagittal plane (c.g. location away from the body) is biomechanically more stressful than c.g. offset in the frontal plane, workers almost always reorient the object such that the largest box dimension is in the frontal plane (between the hands). The load asymmetry considered here, therefore, was due to the c.g. offset in the frontal plane.

Study A: Comparison of the Maximum Acceptable Weight of Lift Data for Industrial and Non-Industrial Workers

In order to determine the relationships between the lifting capabilities of the two populations, the maximum acceptable weight of lift data on industrial and student workers were collected under identical experimental conditions.

Subjects

Thirty-seven male and 37 female industrial workers, experienced in manual lifting activities, and 37 male and 37 female students, inexperienced in manual lifting activities, were recruited. All subjects were screened for physical ailments, medication and experience. Following the screening procedure, each subject filled a written consent form. Isometric strength and anthropometric measurements were recorded for each subject, next. Standard procedures outlined in the literature were followed for strength[11] and body size[12] measurements. Table I shows the measurements made on student workers, expressed as a percentage of measurements made on industrial workers. As the various ratios indicate, the two populations were very similar in body size and strengths. The data for industrial workers can be obtained from earlier works;[4,8] to obtain data for student workers, data on industrial workers and Table I ratios should be used.

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TABLE I
Average Value of Anthropometric and Strength Measurements of the Student Workers Expressed as a Percent of Respective Industrial Worker Measurements (Study A)

Variable	Mean Males	Mean Females
Age	73.3	66.0
Stature	100.0	98.9
Body weight	86.4	86.0
Shoulder height	100.0	96.5
Iliac crest height	101.5	99.3
Knuckle height	97.9	97.5
Knee height	101.3	99.3
Forearm grip distance	102.5	100.6
Chest width	93.6	91.0
Chest depth	93.4	93.7
Abdominal depth	92.2	92.4
Arm strength	103.4	112.2
Shoulder strength	101.3	110.6
Composite strength	104.9	110.3
Back strength	110.0	98.8

Experimental Design and Procedure

A randomized incomplete block factorial design was used to collect maximum acceptable weight of lift data for the two populations. Three different task variables were included: lifting height (floor to knuckle, knuckle to shoulder, and shoulder to reach); lifting frequency (1, 4, 8, and 12 lifts/min); and box-size (30.48, 45.72, and 60.96 cm long in the sagittal plane). Each subject performed 9 out of 36 possible treatment combinations (3 heights × 4 frequencies × 3 box-sizes) in a random order. Since identical experimental layouts were used for both populations, respective blocks (male or female) from each population performed the same nine treatment combinations.

The psychophysical methodology was used to determine the maximum acceptable weight of lift. Starting randomly with either a very heavy or very light load, subjects made weight adjustments, by adding or removing some weight from the box, to arrive at the maximum acceptable weight of lift. The entire weight adjustment process lasted approximately 20-25 min, at the end of which the weight of the box was measured. This procedure was repeated for each planned treatment for each subject. No rest was provided between successive treatment combinations except the time necessary for changing equipment settings for the immediate next treatment.

The maximum acceptable weight of lift data, collected in the manner described above, were adjusted for the effect of the shift duration. It has been shown that for both industrial[13] and student[14] workers, the psychophysical methodology leads to overestimation of weights that can be lifted for the entire 8-hr shift period. Adjustments, therefore, must be made to the maximum acceptable weight of lift data, obtained after a trial period of 20 to 25 min to reflect the actual weights that can be handled for the entire work period. The actual weight that can be handled repeatedly declines at the rate of 3.4%/hr for industrial males and 2%/hr for industrial females[13]; the rates of decline for male and female students are 2.6% and 1.9%/hr, respectively.[14] All psychophysical data were adjusted by these multipliers to reflect actual weights acceptable to individuals for 8-hr shifts.

Results

Overall, the maximum weight of lift acceptable to male students was 89% of the maximum weight acceptable to industrial males. Females students, on the other hand, accepted 94% of the weight acceptable to industrial female workers.

The maximum weights of lift acceptable to male and female students as a percentage of maximum weights of lift acceptable to male and female industrial workers for various frequency, box-size and lifting height combinations are given in Tables II and III, respectively. In order to determine how each population responded to task variables, changes in maximum acceptable weight of lift with changes in task variable levels for each population were looked at. The pattern of decline in weight with box-size for male students was similar to the pattern of decline for industrial workers

TABLE II
Maximum Weights of Lift Acceptable to Male Students Expressed As a Percentage of Weights Acceptable to Industrial Males

		Frequency of Lift (Lifts per Minute)											
		1			4			8			12		
	Box-Size (cm)	30.48	45.72	60.96	30.48	45.72	60.96	30.48	45.72	60.96	30.48	45.72	60.96
Floor to knuckle height:	$\bar{x}^A$	94	81	87	91	79	83	87	92	98	88	116	122
	S^B	71	117	83	110	61	90	52	89	198	51	138	169
Knuckle to shoulder height:	$\bar{x}^A$	85	69	89	88	89	75	89	82	99	97	86	90
	S^B	88	63	52	85	152	63	100	56	63	111	39	70
Shoulder to reach height:	$\bar{x}^A$	96	88	80	74	99	85	94	94	77	98	106	95
	S^B	102	120	63	69	60	138	96	106	52	96	133	80

$^A\bar{x}$ = Ratio of Averages.
^BS = Ratio of Standard Deviations.

TABLE III
Maximum Weights of Lift Acceptable to Female Students Expressed As a Percentage of Weights Acceptable to Industrial Females

		Frequency of Lift (Lifts per Minute)											
		1			4			8			12		
	Box-Size (cm)	30.48	45.72	60.96	30.48	45.72	60.96	30.48	45.72	60.96	30.48	45.72	60.96
Floor to knuckle height:	$\bar{x}^A$	93	86	95	95	101	88	99	103	105	122	91	81
	S^B	143	70	112	33	75	62	37	120	95	98	68	38
Knuckle to shoulder height:	$\bar{x}^A$	96	86	91	92	87	90	93	99	90	101	93	104
	S^B	130	82	82	132	44	48	130	80	75	191	77	69
Shoulder to reach height:	$\bar{x}^A$	77	106	113	94	102	91	89	86	101	92	110	101
	S^B	92	109	240	103	97	105	189	33	61	212	97	61

$^A\bar{x}$ = Ratio of Averages.
^BS = Ratio of Standard Deviations.

(8% to 9% when box-size increased from 30.48 cm to 60.96 cm); the decline patterns for female students and industrial females were also similar (5% decline when box-size increased from 30.48 to 60.96 cm). Similar patterns were observed in the case of lifting height. The maximum acceptable weight of lift declined by approximately 13% for male students and industrial males when the lifting height changed from the floor to knuckle level to shoulder to reach level. Both for female students and industrial females, the decline in weight was approximately 15% for similar changes in lifting height. For lifting frequency, the response of male students was similar to that of female students (approximately 17% to 18% decline in weight with an increase in frequency from 1 to 12 lifts/min) while the response of industrial males was similar to that of industrial females (approximately 26% decline in weight with an increase in frequency from 1 lift/min to 12 lifts/min).

Thus, the results indicated that responses of inexperienced students and experienced industrial workers to task variables were very similar. It can be concluded, therefore, that if responses (maximum acceptable weights of lift) of student workers to other task variables than those investigated in Study A were known, design data for industrial workers for similar conditions could be generated by using relationships between the lifting capabilities of student and industrial workers given in Tables II and III. The following study (Study B) and the development of maximum weights of asymmetrical loads, in the subsequent section, give a specific example of the use of Tables II and III.

Study B: Maximum Weights of Asymmetrical Loads Acceptable to Inexperienced Student Workers

Subjects

Ten male college students (21 to 23 years of age) voluntarily participated in the study. Before their actual participation in the experiment, each subject completed a personal data and consent form. Subjects suffering from any physical ailment or those on medication were screened. Several anthropometric and strength measurements were made on each subject. The means and standard deviations of the measurements made are given in Table IV. Standard procedures were followed for the measurement of strength[11] and anthropometry.[12] The respective body size and strength data were not significantly different ($p \geq 0.10$) from the values for industrial workers.[4,8,15]

Experimental Design and Procedure

A randomized complete block factorial design was used. Three lifting frequencies (2, 4, and 6 lifts/min) and three load center of gravity offsets (0, 12.7, and 25.4 cm from the mid-sagittal plane in the frontal plane) were investigated. The lifting height was from the floor to knuckle height level, and it was fixed.

Each subject, using the psychophysical methodology, determined the maximum acceptable weight of lift for each treatment combination. These data, however, must be adjusted for the effect of shift duration. As mentioned earlier,[14] the actual weight that can be handled repeatedly by

TABLE IV
Anthropometric (cm) and Strength (kg) Measurements of the Male Students Who Participated in Study B (Asymmetrical Load Lifting Study)

Measurement	Mean	Standard Deviation
Age (years)	22.20	0.63
Body weight	77.31	13.25
Height	178.97	4.89
Shoulder height	145.43	3.90
Knuckle height	78.27	3.42
Knee height	52.45	2.12
Forearm grip distance	38.72	1.91
Chest depth	21.01	1.67
Chest width	32.34	3.15
Arm strength	38.79	7.64
Back strength	89.00	22.48
Composite strength	108.04	28.57
Shoulder strength	45.02	10.16

TABLE V
Maximum Weights of Lift (kg) Acceptable to Male Students for Various Frequency-Load Asymmetry Combinations[A]

Load Asymmetry[B] (cm)	Frequency (lifts/min) 2		4		6	
	$\bar{x}$[C]	S[D]	$\bar{x}$[C]	S[D]	$\bar{x}$[C]	S[D]
0	17.43	5.68	16.36	5.87	15.71	5.89
12.7	16.58	6.03	16.03	5.72	14.51	5.13
25.4	15.99	4.86	14.51	5.44	13.98	6.57

[A]Based on a sample of ten male students; Box-size = 30.48 cm; Height level = floor to knuckle.
[B]c.g. offset from the mid-sagittal plane in the frontal plane.
[C]$\bar{x}$ = Mean.
[D] = Standard Deviation.

male students declines at the rate of 2.6%/hr. For 8-hr shifts, therefore, a reduction of 20.8% (2.6%/hr × 8 hr) in the weight must be made. All psychophysical estimate data were reduced by 20.8% to reflect true capability of male students to handle asymmetrical loads. Table V shows these adjusted data.

Results

The results indicated that lifting asymmetrical loads was physically more stressful than lifting symmetrical loads. The weights of asymmetrical loads acceptable to industrial males, after all adjustments, are tabulated in Table VII.

TABLE VI
Multipliers to Adjust Table V Data for Various Box-Sizes and Height Levels

Lifting Height	Box-Size (cm) 30.48		45.72		60.96	
	$\bar{x}$[A]	S[B]	$\bar{x}$[A]	S[B]	$\bar{x}$[A]	S[B]
Floor to knuckle	1.000	1.000	0.915	1.100	0.860	0.910
Knuckle to shoulder	0.870	0.830	0.920	1.020	0.780	0.870
Shoulder to reach	0.770	0.820	0.720	0.640	0.720	0.640

[A]$\bar{x}$ = Multiplier for the Average.
[B]S = Multiplier for the Standard Deviation.

One sample calculation (average value for industrial males lifting weight in a 45.72-cm wide box at the rate of 4 lifts/min from the knuckle to shoulder height) is shown as follows:

The mean maximum weight of lift acceptable to male students for a frequency of 4 lifts, knuckle to shoulder height, and 12.7-cm load asymmetry is 16.03 kg (Table V). Since industrial males can lift 9.89% more weight, compared to male students, at this frequency (Table II), 16.03-kg value was multiplied by 1.0989 to yield a weight of 17.614 kg. The lifting capability also declines by 8% (Table II) when loads

TABLE VII
Database for Maximum Weights (kg) Acceptable to Male Industrial Workers for Asymmetrical Loads for 8-hr of Lifting

Lifting Height	Load Asymmetry (cm)	Box-Size (cm)	2: 30.48	2: 45.72	2: 60.96	4: 30.48	4: 45.72	4: 60.96	6: 30.48	6: 45.72	6: 60.96
Floor to knuckle	0	$\bar{x}$[A]	18.74	17.15	16.12	17.98	16.45	15.46	17.65	16.15	15.18
		S[B]	6.76	7.43	6.15	5.33	5.86	4.85	7.27	8.00	6.61
	12.7	$\bar{x}$[A]	17.83	16.31	15.33	17.61	16.11	15.14	16.30	14.91	14.02
		S[B]	7.18	7.90	6.53	5.20	5.72	4.73	6.33	6.96	5.76
	25.4	$\bar{x}$[A]	17.19	15.73	14.78	15.94	14.58	13.71	15.71	14.37	13.51
		S[B]	5.78	6.36	5.26	4.94	5.43	4.49	8.11	8.92	7.38
Knuckle to shoulder	0	$\bar{x}$[A]	16.30	17.24	14.62	15.64	16.54	14.02	15.35	16.24	13.77
		S[B]	5.61	6.89	5.88	4.42	5.44	4.64	6.03	7.41	6.32
	12.7	$\bar{x}$[A]	15.51	16.40	13.91	15.32	16.20	13.73	14.18	15.00	12.71
		S[B]	5.96	7.32	6.79	4.32	5.30	4.52	5.25	6.46	5.51
	25.4	$\bar{x}$[A]	14.95	15.81	13.41	13.87	14.66	12.43	13.67	14.45	12.25
		S[B]	4.80	5.89	5.03	4.10	5.03	4.30	6.73	8.27	7.06
Shoulder to reach	0	$\bar{x}$[A]	14.43	13.49	13.49	13.84	12.94	12.94	13.59	12.71	12.71
		S[B]	5.54	4.33	4.33	4.37	3.41	3.41	5.96	4.65	4.65
	12.7	$\bar{x}$[A]	13.73	12.84	12.84	13.56	12.68	12.68	12.55	11.74	11.74
		S[B]	5.89	4.59	4.59	4.26	3.33	3.33	5.19	4.05	4.05
	25.4	$\bar{x}$[A]	13.24	12.38	12.38	12.27	11.48	11.48	12.10	11.31	11.31
		S[B]	4.74	3.70	3.70	4.05	3.16	3.16	6.65	5.19	5.19

Frequency of Lift (Lifts per Minute): 2, 4, 6.

[A]$\bar{x}$ = Mean.
[B]S = Standard Deviation.

TABLE VIII
Multipliers (Ratios) Describing the Relationships Between the Lifting Capabilities of Female and Male Industrial Workers

Height Level		Box-Size (cm)	Frequency of Lift (Lifts per Minute) 2: 30.48	2: 45.72	2: 60.96	4: 30.48	4: 45.72	4: 60.96	6: 30.48	6: 45.72	6: 60.96
Floor to knuckle	$\bar{x}^A$		0.764	0.739	0.726	0.766	0.653	0.715	0.745	0.672	0.705
	S^B		0.407	0.444	0.389	0.518	0.517	0.367	0.497	0.442	0.429
Knuckle to shoulder	$\bar{x}^A$		0.712	0.619	0.718	0.724	0.652	0.732	0.731	0.663	0.745
	S^B		0.320	0.375	0.401	0.295	0.272	0.430	0.457	0.383	0.377
Shoulder to reach	$\bar{x}^A$		0.664	0.677	0.671	0.640	0.658	0.694	0.661	0.658	0.648
	S^B		0.301	0.290	0.309	0.320	0.278	0.365	0.411	0.383	0.461

$^A\bar{x}$ = Multiplier for the Average.
^BS = Multiplier for the Standard Deviation.

maximum acceptable weight of lift decreased significantly ($p<0.01$) when the c.g. offset was either 12.7 cm (by approximately 3%) or 25.4 cm (by approximately 8%). The decline in weight when frequency increased from 2 lifts/min to 4 lifts/min (7.6%) was highly significant ($p<0.01$). Further decline of 3.4%, when frequency increased from 4 lifts/min to 6 lifts/min, however, was not significant ($p\geq0.10$). The interaction between lifting frequency and load asymmetry was also statistically insignificant ($p\geq0.10$).

Maximum Weights of Asymmetrical Loads Acceptable to Industrial Workers

In order to generate 'maximum acceptable weight of lift' database for industrial workers, Table V data were adjusted. The relationships given in Table II indicated that for frequencies of 2, 4 and 6 lifts/min, industrial males on the average, are willing to lift 7.53, 9.89 and 12.36% more weight than male students from the floor to knuckle height in a 30.48-cm box [linear interpolation was used to generate

TABLE IX
Database for Maximum Weights (kg) Acceptable to Female Industrial Workers for Asymmetrical Loads for 8-hr of Lifting

Lifting Height	Load Asymmetry (cm)		Box-Size (cm)	Frequency of Lift (Lifts per Minute) 2: 30.48	2: 45.72	2: 60.96	4: 30.48	4: 45.72	4: 60.96	6: 30.48	6: 45.72	6: 60.96
Floor to knuckle	0	$\bar{x}^A$		14.31	12.67	11.70	13.77	10.74	11.05	13.15	10.85	10.70
		S^B		2.75	3.30	2.39	2.76	3.03	1.78	3.61	3.54	2.83
	12.7	$\bar{x}^A$		13.62	12.05	11.13	13.49	10.52	10.82	12.14	10.02	9.88
		S^B		2.92	3.51	2.54	2.69	2.96	1.73	3.15	3.08	2.47
	25.4	$\bar{x}^A$		13.13	11.62	10.73	12.21	9.52	9.80	11.70	9.66	9.52
		S^B		2.35	2.82	2.05	2.56	2.81	1.65	4.03	3.94	3.17
Knuckle to shoulder	0	$\bar{x}^A$		11.60	10.67	10.50	11.32	10.78	10.26	11.22	10.77	10.26
		S^B		1.79	2.58	2.36	1.30	1.48	2.00	2.75	2.84	2.38
	12.7	$\bar{x}^A$		11.04	10.15	10.00	11.09	10.56	10.05	10.36	9.94	9.47
		S^B		1.91	2.74	2.72	1.27	1.44	1.94	2.40	2.47	2.08
	25.4	$\bar{x}^A$		10.64	9.79	9.63	10.04	9.56	9.10	10.00	9.58	9.13
		S^B		1.54	2.21	2.02	1.21	1.37	1.85	3.07	3.17	2.66
Shoulder to reach	0	$\bar{x}^A$		9.58	9.13	9.05	8.86	8.51	8.98	8.98	8.36	8.24
		S^B		1.67	1.25	1.34	1.40	0.95	1.24	2.45	1.78	2.14
	12.7	$\bar{x}^A$		9.12	8.69	8.61	8.68	8.34	8.80	8.29	7.72	7.61
		S^B		1.77	1.33	1.42	1.36	0.92	1.21	2.13	1.55	1.87
	25.4	$\bar{x}^A$		8.79	8.38	8.31	7.85	7.55	9.97	8.00	7.44	7.33
		S^B		1.43	1.07	1.14	1.30	0.88	1.15	2.73	1.99	2.39

$^A\bar{x}$ = Mean.
^BS = Standard Deviation.

percentages (fractions or multipliers) for frequencies of 2 and 6 lifts/min]. These respective percentages were used to adjust Table V data to reflect the capabilities of industrial males at frequencies of 2, 4, and 6 lifts/min. Standard deviation values were adjusted similarly. Further adjustments were made to these data by adjusting them for other box sizes and height levels. Since Table V did not include any data for 45.72 and 60.96 cm long boxes or knuckle to shoulder and shoulder to reach heights, multipliers to adjust these data were generated from the data gathered on industrial males. Table VI gives these multipliers. The maximum are lifted in 45.72-cm wide box from the knuckle to shoulder height instead of in a 30.48-cm wide box from the floor to knuckle height (various corrections factors are shown in Table VI). The 17.61 kg value therefore was multiplied by 0.92 to yield a value of 16.20 kg (same as shown in Table VII).

In order to generate similar database for industrial female workers, multipliers describing the relationships between the capabilities of industrial female workers and industrial male workers were developed. These multipliers are given in Table VIII. Data given in Table VII then were multiplied by these respective multipliers to yield maximum weights of asymmetrical loads acceptable to female industrial workers (Table IX).

Concluding Remarks

The relationships between the lifting capabilities of the student population and the industrial population were developed by expressing student population capabilities as a percentage of industrial worker capabilities. Overall, student workers lifted less weight than industrial workers. It also was observed that percentage changes in maximum acceptable weight of lift because of various task variables — frequency of lift, box-size and height of lift — were about the same for either experienced or inexperienced workers.

By using the relationships developed, the maximum acceptable weight of lift data for lifting asymmetrical loads, collected on student workers, were adjusted to generate design databases (maximum acceptable weights of lift for asymmetrical loads) for industrial workers. These data, instead of those applicable to symmetrical loads,[1,4,7,8] should be used in designing manual lifting jobs involving asymmetrical loads.

One might argue that since the absolute effect of load asymmetry is much smaller than the effects of other variables, it can be ignored. This argument, however, ignores the fact that manual lifting is a complex activity and a worker's capability is determined by the interactive effect of all task variables and not by the effect of just one variable. Many task variables, when considered alone, have little impact on the capability (presence/absence of handles for example), and yet are acknowledged to reduce the hazards of manual lifting. Asymmetrical loads cause lateral bending moment on the spine. If the overall goal is to reduce spinal stresses and overexertion injuries, the effect of load assymmetry, no matter how small, must be considered.

References

1. **National Institute for Occupational Safety and Health:** *Work Practices Guide for Manual Lifting* (DHHS/NIOSH Pub. No. 81-122). Cincinnati, Ohio: Robert A. Taft Laboratories, 1981.
2. **Mital, A., W. Karwowski, A. Mazouz and E. Orsarh:** Prediction of Maximum Acceptable Weight of Lift in the Horizontal and Vertical Planes Using Simulated Job Dynamic Strengths. *Am. Ind. Hyg. Assoc. J. 47*:288-292 (1986).
3. **Rowe, M.L.:** *Backache At Work.* Rochester, N.Y.: Perinton Press. 1983.
4. **National Institute for Occupational Safety and Health:** *Acceptable Weight of Lift for Extended Work Shifts* by A. Mital, R.L. Shell, C. Mital, N. Sanghavi and S. Ramanan (DHHS/NIOSH Grant Nos. 1-R01-0H-01429-01 & 02). Cincinnati, Ohio: NIOSH, 1984. [Final Report].
5. **Garg, A.:** Physiological Stresses in Warehouse Operations With Special Reference to Lifting Technique and Gender: A Case Study. *Am. Ind. Hyg. Assoc. J. 46*:53-59 (1985).
6. **Khalil, T.M., A.M. Genaidy, S.S. Asfour and T. Vinciguerra:** Physiological Limits in Lifting. *Am. Ind. Hyg. Assoc. J. 46*:220-224 (1985).
7. **Snook, S.H.:** The Design of Manual Handling Tasks. *Ergonomics 21*:963-985 (1978).
8. **National Institute for Occupational Safety and Health:** *Determination and Modeling of Lifting Capacity* by M.M. Ayoub, S. Deivanayagam, N.J. Bethea, S.S. Asfour, G.M. Bakken, D. Liles, A. Mital and M. Sherief (DHHS/NIOSH Grant No. 5-R01-0H-00545-02). Cincinnati, Ohio: NIOSH, 1978. [Final Report].
9. **Mital, A. and I. Manivasagan:** Maximum Acceptable Weight of Lift as a Function of Material Density, Center of Gravity Location, Hand Preference, and Frequency. *Hum. Factors 25*:33-42 (1983).
10. **Mital, A. and M. Ilango:** Load Characteristics and Manual Carrying Capabilities. *Proc. Hum. Factors Soc.*:274-278 (1983).
11. **Chaffin, D.B.:** Ergonomics Guide for the Assessment of Human Static Strength. *Am. Ind. Hyg. Assoc. J. 36*:505-510 (1975).
12. **Roebuck, J.A., Jr., K.H.E. Kroemer and W.G. Thomson:** *Engineering Anthropometry Methods.* New York: Wiley Interscience, 1975.
13. **Mital, A.:** The Psychophysical Approach in Manual Lifting — A Verification Study. *Hum. Factors 25*:485-491 (1983).
14. **National Institute for Occupational Safety and Health:** *Lifting Capacity of Student and Industrial Populations* by A. Mital (DHHS/NIOSH Grant No. 1-R01-0H-01956-01). Cincinnati, Ohio: NIOSH, 1985. [Final Report].
15. **National Institute for Occupational Safety and Health:** *Preemployment Strength Testing* by D.B. Chaffin, G.D. Herrin, W.M. Keyserling and J.A. Foulke (DHHS/NIOSH Contract No. CDC-99-74-22). Cincinnati, Ohio: NIOSH, 1977. [Final Report].

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