

LIFT STRENGTH CAPABILITY OF THAI MALE INDUSTRIAL WORKERS

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Abstract

The objectives of this study were: 1) to measure lift strengths and muscular activities, and 2) to evaluate the ability of industrial workers to quantify the lifting weights. Lift strengths were recorded using the isometric strength measurement system. Muscular activities in left and right erector spinae were measured by electromyogram. Five heights (floor, knee, knuckle, elbow and shoulder), two reaches (normal and maximum), and three horizontal angles (0, 45, and 90 degrees) were used to define 30 strength measurement locations. The results showed that the maximum strength was 498.49 Newton (N). This value was recorded in the maximum reach at the knuckle height and 0 degree horizontal angle. The greatest muscular activity in erector spinae was found in the maximum reach at the floor height and 0 degree horizontal angle. To evaluate the ability of the workers to quantify the lifting weights, the workers lifted the box and then estimated the weight of the box. It was found that the workers slightly overestimated the weights in most cases. The results of this study can be used to design industrial tasks and workstation in such a manner that the industrial workers can work effectively and safely.

Keywords: Lift strength, muscular activity

Introduction

Manual materials handling (MMH) has become a major cause of work hazards to industrial workers (NIOSH, 1997). The Social Security Office of Thailand reported that 59% of work-related injuries for Thai workers found in year 2003 were caused by manual lifting of heavy objects. Lifting is associated with complex trunk motion and is very common in industries (Maiti and Ray, 2003). The workers are often required to exert extensive forces, sometimes in awkward positions, while working. As the work cycles

become repetitive, the same muscles perform the main work movements over and over again. Such situations can lead to an increase in the potential for chronic injury (MacKinnon, 1998). Ergonomic approaches to prevent overexertion of workers have been proposed.

Human strength capabilities are determined to obtain a proper matching between worker performance and task demands. As a result, the majority of the industrial worker population is able to perform a given task and the

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problem of work-related injuries can be alleviated. Another application includes assessing the percentage of maximum strength required by a repetitive task so that fatigue is avoided (Xiao *et al.*, 2005). The benefits of applying the strength data in the early stage of work design are widely recognized.

Strength capabilities are affected by a number of personal and task factors such as age, gender, posture, reach distance, arm orientation, and speed of exertions (Warwick, *et al.*, 1980; Sanchez and Grieve, 1992; Mital and Kumar, 1998). Whilst research on isometric strength is carried out in Thailand (Intaranont *et al.*, 1988; Mamansari and Salokhe, 1996; Niempoog *et al.*, 2007), its usefulness (in terms of work design) is often limited. This is because strengths are measured in limited conditions with only a few experimental variables. For example, in most studies on the exertion of isometric lift strength, subjects adopted a standardized posture in the sagittal plane. Although this allows comparison of studies, it makes data

difficult to relate to real-life design applications.

To date, a few lift strength data on Thai industrial workers exist (Intaranont *et al.*, 1988). The objectives of this study were to determine the isometric lift strengths of a sample of Thai industrial workers and to evaluate the ability of the workers to quantify the lifting weights.

Materials and Method

Subjects

Fifty two male workers participated in this study as experimental subjects. Their work experience ranged from 3 months to 40 years. Most of them were machine shop workers. They were right-handed with no personal recollection of arm, shoulder or back injuries. Their physical characteristics are presented in Table 1. They were compensated for their participation. The subjects were familiarized with the equipment and experimental protocol before the experiment.

Table 1. Physical characteristics of the subjects (n = 52)

Number	Measure	Mean	Standard Deviation
1	Age(years)	29.6	9.5
2	Weight (kg)	63.6	12.2
3	Height (cm)	168.5	6.0
4	Shoulder height (cm)	139.9	5.5
5	Elbow height (cm)	104.4	14.7
6	Functional reach (cm)	82.9	11.2
7	Chest width (cm)	28.8	3.0
8	Chest depth (cm)	20.8	2.6
9	Elbow height, sitting (cm)	65.3	4.4
10	Popliteal height (cm)	45.4	3.7
11	Buttock-knee length (cm)	56.2	3.5
12	Buttock-popliteal length (cm)	44.1	2.5
13	Elbow-fingertip length (cm)	46.4	2.1
14	Abdominal depth (cm)	20.6	3.3
15	Biceps circumference, relaxed (cm)	27.2	2.6
16	Biceps circumference, tensed (cm)	29.7	2.8
17	Hand length (cm)	18.7	0.9
18	Hand breadth at metacarpal (cm)	8.4	0.5
19	Hand thickness (cm)	2.9	0.4
20	Grip breadth, inside diameter (cm)	4.0	0.5

Equipment

Body dimensions were measured by the Martin's type anthropometer. The anthropometer was composed of four connecting brass tubes with a rod-shaped meter (Figure 1). A scale was also used to weigh the subjects.

The lift strengths were measured by the Jackson strength measurement system (Model 32628DL*C), using the default setting for sampling frequency (1,000 Hz) (Figure 2). The system included a load cell with a 1,000-pound capacity, a control unit that measured forces exerted on the load cell, a platform, cable and chain system, and a lift bar.

The muscular activities were collected by

the MEGA electromyogram (ME3000P) (Figure 3). Surface electrodes were placed on the lower back of the subjects. The MEGA electromyogram provided small amplifiers to be attached to the surface electrodes. The amplified signals were sent to an encoder box and then transmitted through the fiber-optic cable to the computer.

To record the electromyography (EMG) signal, the average on-line mode at the frequency of 1,000 Hz was selected and the EMG signal was stored in a personal computer for later analysis. A dark plastic box (40 cm × 60 cm × 30 cm) and known weights were used to test the ability of the subjects to quantify the weights of the box lifted.

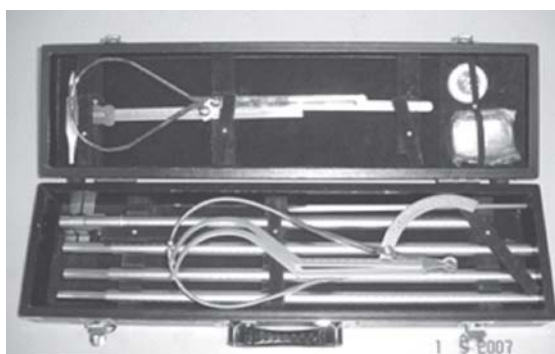


Figure 1. The Martin's type anthropometer



Figure 2. The Jackson strength measurement system

Experiment 1 Measurement of Lift Strengths and Muscle Activities

Experimental Design

The experimental design was a factorial design, with subject being a blocking variable so as to eliminate variability among the experimental subjects. All factors were considered as fixed factors except for subject.

The independent variables were as follows:

1. Height, at five levels: floor, knee, knuckle, elbow and shoulder;
2. Reach, at two levels: normal and maximum;
3. Horizontal angle, at three levels: 0, 45, and 90 degrees relative to the right side of the sagittal plane.

The dependent variables included the isometric lift strength and the normalized EMG value of erector spinae.

Experimental Procedure

Measurement of Maximum Voluntary Contraction (MVC)

Before the strength measurements, the subjects performed maximum voluntary contractions of the erector spinae muscles to provide the normalization level for the EMG readings. The subjects maximally extended their backs

against the back restraint for 5 sec and the EMG values were recorded. Then, the EMG values were averaged and used as the MVC EMG values.

Measurement of Lift Strengths and Muscular Activities

Thirty measurement locations were defined by three work design parameters: height (5 levels), reach (2 levels), and horizontal angle (3 levels). The examples of test posture are shown in Figures 4 - 11. The sequence of measurement locations was randomized among the subjects.

To measure the lift strengths and the muscular activities during exertions, the subjects performed maximal two-handed lift strength exertions on the handle of the measuring system. The subject built up his maximum force within the first two seconds without jerking and held it for another three seconds. Each condition was repeated twice. A rest period of at least two minutes was provided between the successive trials.

The strength data extracted from the last 3 sec were averaged and used as the maximum strength measured at that location. Also, the EMG signals recorded during the last three seconds of strength exertion were averaged and used as the EMG value measured at the particular exertion. The whole experiment was conducted on two consecutive days for each subject.



Figure 3. The MEGA electromyogram



Figure 4. Strength exertion in the normal reach, at the floor height, and 0 degree horizontal angle



Figure 5. Strength exertion in the normal reach, at the knee height, and 0 degree horizontal angle



Figure 6. Strength exertion in the normal reach, at the knuckle height, and 0 degree horizontal angle



Figure 7. Strength exertion in the normal reach, at the elbow height, and 0 degree horizontal angle



Figure 8. Strength exertion in the normal reach, at the shoulder height, and 0 degree horizontal angle



Figure 9. Strength exertion in the maximum reach, at the elbow height, and 0 degree horizontal angle



Figure 10. Strength exertion in the normal reach, at the elbow height, and 45 degree horizontal angle



Figure 11. Strength exertion in the normal reach, at the elbow height, and 90 degree horizontal angle

For data analysis, the EMG values recorded during strength exertions were normalized by the MVC EMG. The strength and normalized EMG values were analyzed by Analysis of Variance (ANOVA).

Experiment 2 the Ability to Quantify the Lifting Weights

Experimental Design

For this experimental session, the experimental design was a factorial design, with subject being a blocking variable. The independent variable was lifting height which was considered as a fixed factor. The dependent variable was the differences between the estimated weights and the true weights.

Experimental Procedure

The subjects were asked to lift a dark plastic box filled with different weights (5 - 20 kg) at five different heights (floor, knee, knuckle, elbow and shoulder). A cover was placed over the box to prevent the subjects from seeing the weights. Before the experiment, the subjects were allowed to familiarize the lifting task with known weights. However, they were not allowed to know the weights used in the experimental session. The adopted posture during lifting was

standing with upright back and flexed elbow. The box was kept close to the body.

The subjects lifted the box with the weight from the starting point (floor, knee, knuckle, elbow, and shoulder) to the finishing point (10 cm above the starting point) and held it for 10 sec before lowering it to the starting point. Then, they estimated the magnitude of the weights. For each height, the lifting was repeated six times and the weight used for each lifting was randomly selected. A rest period of 2 min was provided between trials. The differences between the estimated weights and the true weights at different heights were calculated and then analyzed by ANOVA.

Results and Discussion

Experiment 1

The averages and standard deviations of lift strengths for all conditions are presented in Table 2. The maximum lift strength was 498.49 N (Newtons). This value was found in the maximum reach at the knuckle height and 0 degree horizontal angle. The minimum lift strength was recorded in the maximum reach at the shoulder height and 45 degree horizontal angle. Lift strength at this location was 78.03 N. On average, the strength exerted at the knuckle

Table 2. Isometric lift strengths (N)

Height	Reach	Horizontal angle					
		0 degree		45 degree		90 degree	
		Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
Floor	Normal	254.83	127.64	234.86	113.44	222.95	104.37
	Maximum	237.94	133.26	237.62	123.29	241.38	122.15
Knee	Normal	182.17	87.79	155.24	65.77	149.91	65.34
	Maximum	106.10	61.24	100.30	51.19	100.29	56.00
Knuckle	Normal	364.62	215.67	303.92	176.93	332.73	202.36
	Maximum	498.49	281.19	366.06	193.07	395.31	215.48
Elbow	Normal	198.27	73.52	165.89	66.60	162.76	56.30
	Maximum	98.43	55.87	98.12	58.15	102.64	53.93
Shoulder	Normal	266.89	134.60	206.59	101.49	202.20	101.83
	Maximum	82.43	41.84	78.03	48.94	80.34	60.11

height was greatest, whereas that at the knee height was lowest. The strengths at the knee, elbow, and shoulder height were obviously greater in the normal reach than they were in the maximum reach.

Strength exertion in the normal reach at the elbow height and 0 degree horizontal angle was selected as the normalizing condition since this working condition was common in the industry. The strength measured at this working condition was considered 100%. Table 3 presents the percentage obtained by comparing the averages of every condition with the normalizing factor. Although some differences were less than 10%, some approached 150%. This indicates that strength capability varies considerably depending on exertion condition.

By comparing the normalizing condition with the others, it was possible to determine that there was an increase in strength of 20.17% at the floor height and 90.07% at the knuckle height. The decrease in strength with respect to the normalizing condition was 33.26% at the knee height and 30.56% at the elbow height.

The ANOVA and Tukey's test were used to analyze the strength data shown in Table 2. The result of ANOVA (Table 4) showed that height, reach, and horizontal angle were highly significant ($p < 0.01$). Also, the two-way interactions were highly significant.

The example of recorded EMG signals is displayed in Figure 12. Muscular activities in left and right erector spinae are shown in Table 5. As the horizontal angle increased, the muscular activity in the left erector spinae decreased, but that in the right muscle increased. To compare the muscular activities in different working conditions, the muscle activities in both muscles were averaged and ranked. The average muscular activities was greatest (76.42%MVC) when exerting force in the maximum reach, at the floor height and 0 degree horizontal angle. The average muscular activity was lowest (36.49%MVC) when exerting force in the normal reach at the elbow height and 90 degree horizontal angle. The average muscular activity obtained during strength exertion at the floor and knee heights were greater than those at the knuckle, elbow, and shoulder heights.

The ANOVA (Table 6) revealed that height, reach, horizontal angle, and the interaction between height and reach were highly significant. Stated otherwise, these factors had a highly significant effect on the muscular activities in both muscles.

Tukey's test showed significant difference in muscular activity in left and right erector spinae as height varied (Table 7). The muscular activities in both muscles at the floor and knee height were significantly greater than those at

Table 3. Percent change in strength in different conditions after normalization (%)

Height	Reach	Horizontal Angle		
		0 degree	45 degree	90 degree
Floor	Normal	28.53	18.45	12.45
	Maximum	20.01	19.85	21.74
Knee	Normal	-8.12	-21.70	-24.39
	Maximum	-46.49	-49.41	-49.42
Knuckle	Normal	83.90	53.29	67.82
	Maximum	151.42	84.63	99.38
Elbow	Normal	0.00	-16.33	-17.91
	Maximum	-50.36	-50.51	-48.23
Shoulder	Normal	34.61	4.20	1.98
	Maximum	-58.43	-60.64	-59.48

- = strength value lower than the normalizing factor

the knuckle, elbow, and shoulder height. The deployment of the back is the most important factor allowing for greater muscular activities at the lower height. The muscular activities in both muscles in the normal reach were significantly lower than those in the maximum reach (Table 8). This was due to the mechanical advantage. As the horizontal angle increased, the muscular activity in left erector spinae decreased, whereas that in right erector spinae increased (Table 9).

Experiment 2

The differences between the estimated weights and the true weights are shown in Table 10. The correlation coefficient between the true weights and the perceived weights was 0.94. Although the differences between the estimated weights and the true weights are less than 1 kg, they show an interesting pattern. As the height increased, the difference between the estimated weights and the true weights decreased. This

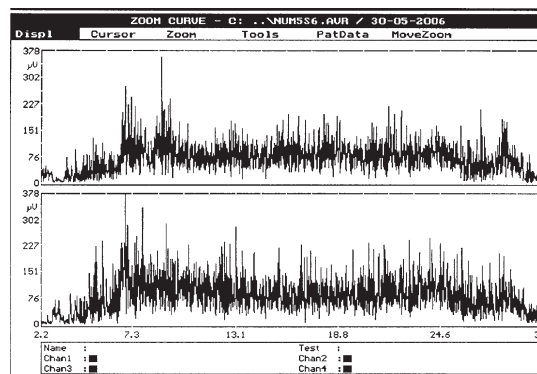


Figure 12. The example of recorded EMG signals.

Table 4. Analysis of variance on lift strength

Source of Variation	Degree of freedom	Adjusted sum of square	Mean square	F- Value	P- Value
Height	4	540.128	135.032	878.43	0.000**
Reach	1	121.158	121.158	788.18	0.000**
Horizontal angle	2	9.312	4.656	30.29	0.000**
Height * Reach	4	159.399	39.850	259.24	0.000**
Height * Horizontal Angle	8	3.602	0.450	2.93	0.003**
Reach * Horizontal Angle	2	1.828	0.914	5.94	0.003**
Height * Reach* Horizontal Angle	8	2.451	0.306	1.99	0.440
Subject	51	500.802	9.820	63.88	0.000**
Error	3,039	467.154	0.154		
Total	3,119				

Note: ** $p < 0.01$

indicates that the subjects tended to overestimate the weights of the box when lifting it from the lower levels, whereas they slightly underestimated the weights of the box when lifting it from the shoulder height. The analysis of variance in Table 11 shows that the height had a significant effect on the difference between the estimated weights and the true weights.

When the subjects estimated the weights of the box lifted, the true weights were overesti-

mated in most cases. The explanation for the overestimation of the box weight could be the size illusion. The size illusion makes an object feel heavier than it actually is (Wiktorin *et al.*, 1996). Another explanation for the overestimated could be the long duration of the lifting and holding (10 s). Perceived muscular effort depends on the duration of work (Gamberale, 1990).

Table 5. The muscular activities in left and right erector spinae (%MVC) during strength exertion

Height	Reach	Horizontal angle	Activity in left erector spinae	Activity in left erector spinae	Average activity in erector spinae	Rank
Floor	Normal	0	73.33	70.10	71.72	4
		45	44.83	80.06	62.45	12
		90	28.41	89.81	59.11	15
	Maximum	0	76.88	75.96	76.42	1
		45	50.68	80.58	65.63	9
		90	42.47	81.66	62.07	13
Knee	Normal	0	71.03	74.06	72.55	3
		45	59.96	80.68	70.32	5
		90	44.17	82.93	63.55	10
	Maximum	0	74.40	76.76	75.58	2
		45	57.45	79.24	68.35	6
		90	38.62	94.14	66.38	7
Knuckle	Normal	0	50.00	42.09	46.05	23
		45	35.67	50.53	43.10	27
		90	20.54	56.56	38.55	29
	Maximum	0	52.25	44.58	48.42	21
		45	38.63	57.89	48.26	22
		90	25.13	66.52	45.83	24
Elbow	Normal	0	50.40	46.94	48.67	20
		45	24.16	56.53	40.35	28
		90	15.14	57.84	36.49	30
	Maximum	0	60.58	59.28	59.93	14
		45	41.15	65.19	53.17	18
		90	22.80	67.70	45.25	26
Shoulder	Normal	0	58.37	52.22	55.30	16
		45	44.22	62.66	53.44	17
		90	22.72	68.21	45.47	25
	Maximum	0	70.47	62.07	66.27	8
		45	50.00	75.11	62.56	11
		90	20.23	79.67	49.95	19

Table 6. Analysis of variance on the muscular activities

Source of Variation	P-Values	
	Left Erector Spinae	Right Erector Spinae
Height	0.000**	0.000**
Reach	0.020*	0.004**
Horizontal angle	0.000**	0.000**
Height * Reach	0.000**	0.000**
Height * Horizontal Angle	0.353	0.278
Reach * Horizontal Angle	0.564	0.998
Height * Reach* Horizontal Angle	0.82	0.970
Subject	0.930	0.881
Error		
Total		

Note: * $p < 0.05$, ** $p < 0.01$

Table 7. Average muscular activities and standard deviations at different heights (%MVC)

Height	Left Erector Spinae		Right Erector Spinae	
	Average	Standard Deviation	Average	Standard Deviation
Floor	52.75	38.74	79.73	44.49
Knee	57.69	30.36	81.16	30.93
Knuckle	37.03	20.82	53.03	20.28
Elbow	40.47	25.26	58.79	22.86
Shoulder	44.34	30.72	66.65	27.29

Table 8. Average muscular activities in different reaches (%MVC)

Reach	Left Erector Spinae		Right Erector Spinae	
	Average	Standard Deviation	Average	Standard Deviation
Normal	42.92	29.15	64.84	31.10
Maximum	48.04	32.10	70.92	33.24

Table 9. Average muscular activities at different horizontal angles (%MVC)

Horizontal Angle	Left Erector Spinae		Right Erector Spinae	
	Average	Standard Deviation	Average	Standard Deviation
0	63.70	34.72	60.37	32.89
45	44.40	24.68	68.61	29.59
90	28.10	19.88	74.52	32.92

Conclusion

In summary, the following conclusions can be drawn:

1) The greatest lift strength was 498.49 N. which was found in the maximum reach at the knuckle height and 0 degree horizontal angle. On the other hand, the lowest lift strength was 78.03 N. which was recorded in the maximum reach at the shoulder height and 45 degree horizontal angle.

2) Lift strength varied with height, reach and horizontal angle. Lift strengths in the normal reach were greater than those in the maximum reach in most cases. Lift strengths at the knuckle height were higher than those at the floor, knee, elbow, and shoulder height. Lift strengths at 0 degree horizontal angle were greater than those at 45 and 90 degree horizontal angles.

3) The average muscular activity in erector spinae was highest (76.42%MVC) when performing maximum lift strength exertions in

the maximum reach at the floor and 0 degree horizontal angle. However, the lowest value (36.49%MVC) was recorded in the normal reach at the elbow height and 90 horizontal angle.

4) The subjects were able to estimate the weights. The correlation between the estimated weights and the true weights was high ($r^2 = 0.94$).

5) This study indicated that there are a wide range of lifting strength capabilities which must be considered when designing industrial work. The amount of force required to complete the task should be such that it is safe for the weakest group of workers.

6) Lifting force exertion required the lower back muscular activity. The lifting task should be carried out in the normal reach since the activity of lower back muscles increased with the increase in reach.

Acknowledgements

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Table 10. Difference between the estimated weights and the true weights at different height levels

Height	Difference between the estimated weights and the true weights (kg)	
	Average	Standard Deviation
Floor	0.967	4.902
Knee	0.615	5.272
Knuckle	0.664	4.739
Elbow	0.240	4.261
Shoulder	-0.046	4.930

Table 11. The analysis of variance on the difference between the estimated weights and the true weights

Source of Variation	Degree of Freedom	Adjusted sum of square	Mean square	F- Value	P- Value
Height	4	231.06	57.76	2.76	0.027*
Subject	52	5,540.24	106.54	5.09	0.00**
Error	1,798	37,655.86	20.94		
Total	1,854	43,427.16			

Note: * $p < 0.05$, ** $p < 0.01$

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