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Biomechanical Analysis of Manual Lifting Tasks by Saudis

Ibrahim M. Jomoah
Department of Industrial Engineering, Faculty of Engineering,
King Abdulaziz University, Jeddah, Kingdom of Saudi Arabia
ijomoah@kau.edu.sa

Abstract– **An empirical study was conducted to determine the biomechanical forces developed in human body during material handling tasks, such as manual lifting, where serious injuries might occur. The sample workforce consisted of Saudis, since Saudi industries are progressively replacing the expatriates with qualified nationals to meet the rising unemployment. A two-dimensional static biomechanical model was used for calculating the mechanical stresses on major joints of the musculoskeletal system and then the effects of "load" and "lifting technique" on the spinal loading during lifting actions were examined. Three different weights and three lifting techniques were considered. Compressive and shear forces were computed using four different objective functions. Results indicated that the objective function for one active muscle yielded consistently higher values of compressive forces and the objective function for ten muscles yielded the lowest. Correlations of heights, weights, age groups and lifting techniques with compressive and shear forces were computed too.**

Index Term– **Manual materials handling, biomechanical analysis, lifting techniques, compression forces, shear force, Saudis.**

I. INTRODUCTION

A. Manual Material Handling

Almost every occupational setting requires some form of material handling. Space limitations, varied nature of the activity, and the reluctance to make substantial investment in automated equipment are in favor of manual handling of materials. Invariably, the ability of individuals to perform these activities, either frequently or occasionally is a deciding factor. Handling excess loads might result in severe chronic or acute injuries. The direct costs of manual-handling related injuries have risen to approximately 15 billion dollars annually in the United States and the indirect costs was estimated to be as much as four times the direct costs [1-3].

The European Union (EU), UK, Canada and Australia, as well as KSA, find the severity and costs of manual material-handling related injuries unacceptably high and a cause for serious concern [4-11]. The need to control the costs and severity of injuries caused by handling different kinds of materials has led to development of guidelines for designing these jobs. The most notable among these guidelines are the "ILO 1962 Guide of the Maximum Permissible Weight to be Carried by One Worker" and "the 1988 Guide of the Maximum Weight in Load Lifting and Carrying" [12,13], the "1981 Work Practices Guide for Manual Lifting" developed by the National Institute for Occupational Safety and Health (NIOSH) [14], the "1991 Revision of NIOSH's 1981 Work Practices Guide for Manual Lifting" [15], and the most recent "Draft on Manual Lifting from the Health and Safety Executive (HSE)", United Kingdom [16]. These guidelines are, however, limited to only manual lifting activities [17]. Generally, Manual Materials Handling (MMH) creates special problems for any worker. Laborers engaged in jobs that require lifting, lowering, carrying, pushing, and pulling of heavy materials, run into increased rates of musculoskeletal injuries, especially on the backside. Fortunately, awareness has been created among the world community of workers about the problems associated with MMH.

It is becoming increasingly important to our modern society to realize that the health and quality of life of a large proportion of our population are greatly reduced because of acute and chronic musculoskeletal disorders. Praemer et al. [18] summarized the occurrence of musculoskeletal conditions in the United States. They reported that musculoskeletal impairments were present in about 12% of persons in 1988.Back and spine impairments accounted for about half of these impairments. Further data collected by the authors revealed that there were 32 million musculoskeletal injuries in the United States during 1988, and the incidence of injury was higher for males than females (158.4 per 1,000 vs. 108.9 per 1000).

Leigh et al. [19] further reported that the total cost of occupational injuries and illnesses in the United States was $155.5 billion. This is nearly 3 percent of the gross domestic product in 2000. It surpasses the cost of AIDS, and is nearly equal to the cost of cancer or heart and circulatory diseases. Injuries account for about 85% of these costs, with musculoskeletal injuries (and particularly low back injuries) generating the large majority of these.

A follow-up review by the U.S. National Research Council in 2001 [20] concluded that work-related musculoskeletal injuries continue to account for about one-third of all workers compensation cost commenting that a similar estimate was presented by the European Agency for safety and Health at work in 2000. Furthermore, Sie [5] reported that workers compensation in Minnsota (USA) cost business and industry $ 1.585 billion in 2004. Also, Schneider and Irastorza [6] commented that many studies reported that one third of the total sick leaves caused by MSDs, and further reported that during 2006 in Germany, MSDs generated a loss of more than 400 million work days and productivity loss of about €36 billion.

In the occupational setting, back problems appear to remain the most frequent and expensive occupational injury reported. According to Murphy and Volinn [21] almost 2% of workers each year have a work-related back problem that costs in the United States over $ 8 billion annually in medical and lost wage compensation. In another report, about 60% of people in USA, attributed their sufferings from lower-back injuries to overexertion;. worthynoting that back injuries resulted in more lost job time than any other injuries [21].

Although the precise relationships are unknown, a considerable amount of evidence points to the workload as an important factor. Workers involved in heavy lifting, for example, have been found to have about six to eight times as many low back injuries as those performing more sedentary work [23,24]. However, in a review performed in 1998 by the U.S. National Research Council of the epidemiological evidence assembled by Bernard [25], who analyzed about 600 previous studies for NIOSH in USA, concluded that there are workplace interventions that can prevent many different types of work related musculoskeletal problems.

Regrettably, only a few other countries have data on the magnitude of occupational injuries due to MMH. For example, according to Sweden's National Board of Occupational Safety and Health [26] the most common types of injury to workers in that country were strains and sprains due to over-exertion of the body. Overexertion accounted for almost 18% of injuries, while about 12% of personal injuries to workers were skeletal. When the injuries were classified by occupation, the category 'materials, goods, and packaging' accounted for more than 23% of the all injuries, the largest proportion of any one type. Other countries reported similar findings, too. In 1982, the Health and Safety Commission [4] reported over 70,000 injuries due to MMH in the UK [8]. During the financial year 1986-1987 there were at least 11,000 MMH injuries, half of which resulted in more than 3 days absence from work. In 1988-89, 27.5% of the reported accidents in the UK involved MMH activities. The costs of these accidents, including decline in productivity, medical treatment and individual sufferings, exceeded ₤90 million. Rawin and O'Halloran [10] reported that according to the Australia's State Electricity Commission of Victoria (SECV) estimates, about 34% of the compensation costs were paid to workers suffering from injuries due to MMH. In Luxembourg, data from the Association of d'Assurance Centre Les Accidents showed that acute back disorders accounted for 2% of occupational accidents reported i.e., 286 out of the 15559 cases reported. Out of these, 181 cases (78%) of back disorders involved lifting/lowering and carrying and 26 cases (11%) resulted from pushing/pulling loads. The total annual costs of musculoskeletal diseases exceeded ₤25 billion [27].

The factors affecting MMH such as physique, anthropometry, strength, physical fitness, spinal mobility, age, gender, training and selection, static work, posture, handling techniques, loading characteristics, handling, coupling, repetitive handling, load asymmetry, environment, spatial strains, safety aspects, protective equipment, task duration, work organization, etc. were discussed in details by Ayoub [2] and Ayoub and Metal [1] who discussed problem of MMH in details, including the injury frequency and cost. They proposed, in agreement with other researchers, four design approaches for MMH to quantify the relationships between the imposed stresses and the resulting strain; and thereby, control of overexertion injury and back problems. These are biomechanical, physiological, psychological and epidemiological approaches. The biomechanical approach estimates the mechanical stresses (compressive forces, shear forces and abdominal pressure) acting on the major joint of the human body. There are various biomechanical models in the literature [6,31-50] evaluating the static/dynamic MMH tasks in two or three-dimensional spaces.

B. Current Situation and Needs in KSA

The Kingdom of Saudi Arabia (KSA), from the time of discovery of petrol, has been making big leaps towards industrialization and economic development. Within a short period, the Kingdom was transformed from a desert country to an industrialized one. Now it is one among the top countries advanced commercially and industrially. The Kingdom is considered to be one of the most developed in petrochemical industries. The industrial development in other industrial sectors is quite impressive, too [51,52]. In line with the industrial growth the Kingdom was in dire need for technically qualified manpower, enormously. This predicament forced the Saudi companies to import technically qualified manpower in bulk quantities from other countries. Simultaneously the Saudi government and the corporate sector were fast advancing with nurturing human resources from within the nation. Saudization had had to be enforced, for the Saudi citizen to be in the right place to serve his country. Besides, this was necessary for avoiding the potential problem of unemployment, since Saudi schools and universities have been producing thousands of technically qualified graduates every year. Now, thanks to the well-planned developmental programs, Saudi citizens are entering the factory gates in huge numbers, with great confidence, ahead of foreigners. However, such programs, of economic development in industry, agriculture and other trades have not been paralleled with programs of workers safety and health protection; meanwhile, the impact of such development programs on worker's safety and health may be aggravated due to the following facts [53]:

(a) The diversification of economic activity from nearly complete dependence on oil production to a wide spectrum of basic, secondary and supporting industries. This involves introduction of new technologies, usage of potentially toxic chemicals, more exposure to industrial hazards and exposure to physical and psychological stresses which requires more stringent assessment of the work environment and worker's health.

(b) The rapid increase in the types and the size of new industrial activities requires similar increase in implicating adequate safeguards for workers safety and health, mostly through development of industrial safety and health facilities and manpower.

(c) The expected changes in composition of workers from largely expatriate to mainly Saudi should encourage the immediate development of the industrial safety and health services.

Thus, there has been a need for a study to realize the current problems related to manual material handling, in comparison with the previous times when Saudi workers were few in number. In most of the industrialized countries such studies are conducted, in collaboration with labor departments, not only as part of monitoring safety of workers, but to oblige with the government laws on occupational safety and health, too.

C. Study Objectives

The goal of the study was set on the above premises. It was felt imperative to make such a study in Saudi industries which could provide reference information for the concerned people. It was also expected that the results of the research could help in designing a comprehensive manual on material handling. Such guidelines could help the employers to ensure that right people are recruited for the right jobs in companies, so that production efficiency is enhanced. Therefore, the scope of this study was the Saudi males and the specific objectives were oriented to:

- utilize a pre-developed two-dimensional static biomechanical model in calculating the mechanical stresses (compressive and shear forces) acting on the major joints of the musculoskeletal system using different objective functions for manual symmetric lifting tasks, and
- examine the effects of weight of load lifted (5, 15 and 25 Kg) and lifting technique (squat, stoop and free-style) on the spinal loading for the lifting activities performed by the Saudis.

II. MATERIALS AND METHODS

Students and technicians in the KAU College of Engineering were randomly selected from the students' academic records and the technicians' payment rolls. All the participants were young Saudi males, who came from different ethnic origins such as urbanite class, rural tribes, Yemenis and Asians.

A. Equipment

The following equipment was used for the study: (a) a wooden box (41.6*41.6*25 cm^3) made locally with cover and handles, (b) a 35mm camera with a holder (c) a wooden table 78 cm height, (d) different weights, (e) a foot scale, (f) a measuring tape, and (g) an Ergo-Edge Version 1.0 computer software designed by Innovative Ergonomics, Inc. for biomechanical modeling for use in analyzing worker productivity and safety [54].

B. Experimental Procedure

At the outset, the subject was briefed on the objectives of the study. Since he voluntarily participated in the experiment, he was then asked to read, fill in, and sign the consent in a preplanned and pretested study form. The following anthropometric parameters were then measured: body weight, body height, sitting shoulder height, buttock-popliteal length, knee height, shoulder-elbow length, elbow-fingertip length, foot length, chest width, chest depth, and abdominal depth. The subject then was asked to lift the wooden box with unknown weights. He was asked to add/drop weights to determine the acceptable weight of lift for him for 8 hours working day. This was called the acceptable weight of lift (AWL).

The two factors considered for the experiment were lifting technique with three levels (stoop, squat, and free style) and the weights to be lifted with three levels (5 kg, 15 kg, and 25 kg). Thus there were nine treatments (without replications) with assigned codes from 1 to 9. To randomize the experimental runs, weights were put inside the boxes and kept jumbled so that the box picked by the subject would weigh 5, 15 or 25 kg. In each run the subject was asked to pick the box containing the weights, on the floor to the wooden table in front of him, by any one of the three lifting techniques specified above.

The lifting action was video-graphed during each experiment. From these video images, five angles (ankle, knee, hip, shoulder, and elbow) were measured (Figure 1) and entered to the computer software for computing the compressive and shear forces using four different objective functions. The assumptions made for the four objective functions were:

Objective function #1: (One Active Muscle)

In this option the following assumptions were made: (a) Only one muscle was counteracting the moment developed and the forces on the spine; either the *erector spinae* muscle or the *rectus abdominus* muscle, and (b) The effects of abdominal pressure were assumed to be negligible.

Objective function # 2: (One active muscle and abdominal pressure)

In this option the following assumptions were made: (a) Only one muscle was counteracting the moment developed and the forces on the spine; either the *erector spinae* muscle or the *rectus abdominus* muscle, and (b) The effects of abdominal pressure were taken into account

Objective function # 3: (Ten muscles to minimize muscle intensity)

In this option it was assumed that: (a) The human body tried to minimize the maximum intensity of the contracting muscles; muscle intensity was defined as the tension force per unit area of the muscle, (b) Five pairs of muscle were counteracting generating moments and forces on the spine; these muscles were : *erector spinae*, *latissimus dorsi*, *external oblique*, *internal oblique*, and *rectus abdominus*, (c) The effects of abdominal pressure were assumed to be negligible, and (d) Dimensions of the muscles were obtained at the L4/L5 disk level.

Objective function # 4: (Ten muscles to minimize compression)

In this option it was assumed that: (a) The human body tried to minimize the compression force of the contracting muscles; the user selected the maximum muscle intensity allowed; muscle intensity was defined as the tension force per unit area of the muscle, (b) Five pairs of muscle were counteracting the moment and the forces on the spine. These muscles were: *erector spinae*, *latissimus dorsi*, *external oblique*, *internal oblique*, and *rectus abdominus*, (c) The effects of abdominal pressure were assumed to be negligible, and (d) Dimensions of the muscles were obtained at the L4/L5 disk level.

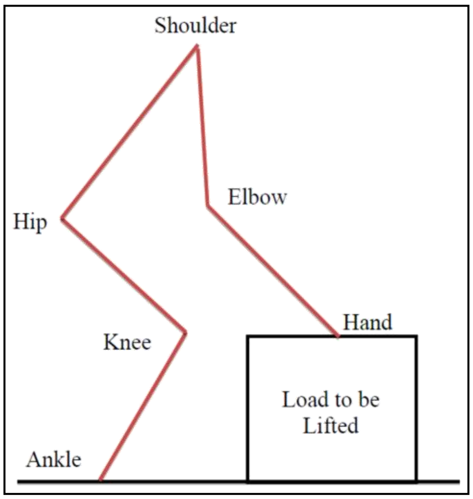

Fig. 1. The Linkage System that Represents the Human Body while Lifting and the Measured Angles between the Links

C. Statistical Analysis

Means and standard deviations were determined by using the Microsoft Excel and the compressive and shear forces were determined by using Ergo-Edge [54]. Correlations were, also, computed as described in Hayter [55] using Excel 2000 software.

III. Results and Discussion

A. Characteristic of the Studied Sample:

Table 1 shows the means and standard deviations of age, stature, weight, and some other anthropometric measures of the population sample of the study. The subjects participated in the study were all males, aged 19 to 40 years old with a mean age of 28 years, thus represent the youth of the Saudi population [56]. Their heights ranged from 160 to 182 cm and weights from 50 to 90 kg.

TABLE I
MEANS, STANDARD DEVIATIONS AND RANG OF SOME ANTHROPOMETRIC MEASURES OF THE SUBJECTS INVOLVED IN THE STUDY (N=60)

Parameters	Mean	Std. Dev.	Range
Age (Years)	28	5.0	19 – 40
Stature (cm)	170	4.7	160 – 182
Weight (Kg)	71	9.0	50 – 90
Sitting Shoulder Height (cm)	90.7	9.5	75 – 104
Buttock-Popliteal Length (cm)	50.6	5.7	42 – 59
Knee Height (cm)	51.6	3.2	47 – 58
Shoulder-Elbow Length (cm)	33.3	3.0	29 – 39
Elbow-Fingertip Length (cm)	43.6	2.7	40 – 50
Foot Length (cm)	25.65	1.5	23 – 29
Chest Width (cm)	35	4.8	29 – 45
Chest Depth (cm)	28.3	5.9	22 – 46
Abdominal Depth (cm)	26.1	5.3	19 – 38

Table II presents the sample classified according to ethnic origin, education level, monthly income, marital status, smoking habits, job type, sports activities, involvement in MMH activities and previous history of back pain or injury. Ethnic origin may have influence on the anthropometric characteristics of the studied subjects and body built and consequently, on their strength and physique. The majority of the participants (55%) were urbanite (not associated with tribes), followed by tribal subjects (35%) and a few percentage of Yemenis and Asian subjects (10%), but no Arabic or African originated subjects. Meanwhile one half of the examined subjects (30 : 50%) had Bachelor degrees, while 26 subjects (43.3%) had secondary school education, 3 subjects (5%) had technical and/or administrative institutes education, and one subject just had elementary school education. Also, 18 subjects (30 %) had monthly income SR<3000, 17 subjects (28.3%) SR3001-6000, 16 subjects (26.7%) SR6001-9000, 7 subjects (11.7%) SR9001-12000, and 2 subjects SR>12000. Moreover, the relatively young age of the subjects had impact on their marital status, since 34 subjects (56.6%) were singles and 25 subjects (41.7%) were married and only one subjects (1.7%) was divorced. Also, most of the subjects (42 subjects: 70%) were non-smokers, and similar proportion were involved in office work, 8 subjects (13.3%) involved in field work and 9 subjects (15%) in both office and field work; while only 10 subjects (16.7%) were involved in Manual Materials Handling (MMH) activities, and only 20 subjects (33.3%) performed sports. Consequently, 23 subjects (38.3%) practiced back pain or injuries.

TABLE II
DISTRIBUTION OF THE STUDIED SAMPLE ACCORDING TO SOME ECOLOGICAL, ECONOMIC, SOCIAL, OCCUPATIONAL AND HEALTH CHARACTERISTICS OF STUDIED PARAMETERS THAT MIGHT HAVE IMPACT ON MMH

Parameters	Class (1)	Number (%)	Class (2)	Number (%)	Class (3)	Number (%)
Ethnic Origin	Urbanite	33 (55%)	Hordes	21 (35%)	Yemeni & Asians	6 (10%)
Educational Level	Elementary	1 (1.7%)	Secondary	29(48.3%)	Bachelor	30 (50%)
Monthly Income (SR)	< 3,000	18 (30%)	3001-6000	17 (28.3%)	6001->12,000*	25 (41.7%)
Marital Status	Married	25 (41.7%)	Single	34 (56.6%)	Divorce	1 (1.7%)
Smoking Habits	Non-Smokers	18 (30%)	Smokers	42 (70%)		
Job Type	Office	42 (70%)	Field	9 (15%)	Office/Field	9 (15%)
MMH Activities	Involved	10 (16.7%)	Not-Involved	50 (83.3%)		
Back Pain/Injuries	Present	23 (38.3%)	Not Present	37 (61.7%)		
Sports	Perform	20 (33.3%)	Do Not Perform	40 (66.7%)		

* [16 subjects (26.7%) income SR 6,001-9,000; 7 subjects (11.7%) income SR 9,001-12,000; and 2 subjects (3.3%) income SR>12,000]

B. Compressive and Shear Forces

Table 3 shows the means and standard deviations of the compressive and the shear forces according to types of treatments investigated in this study. The treatments were combinations of weights (3 levels: 5, 15, and 25 kg) and lifting technique (3 levels: stoop, squat, and free style), resulting in a set of 9 treatments. Each of the 60 selected subjects performed all the 9 treatments, which means that a total of 540 experimental runs were conducted. It is clear that the compressive forces computed using the objective function for one active muscle (CF1) were consistently at higher levels compared to the other objective functions, whereas the compressive forces computed using the objective function of ten muscles to minimize compression (CF4) showed the lowest level values. The mean values of all the compressive forces computed were between 4200 and 5840 N. The corresponding Maximum Permissible Limit (MPL) and Action Limit (AL) were 6377 and 3434 N, respectively.

Also, the shear forces were much lower than the corresponding compressive forces. The compressive forces for treatments 7, 8 and 9 were higher than the values for the others treatments (Table3). Treatments 4 (15 kg with stoop technique) and 7 (25 kg with stoop technique) resulted in the highest values of shear forces, while treatment 2 (5 kg with squat technique) yielded the lowest values. The range of shear forces obtained was 540 to 570 N. It may be noted that the objective function didn't have any effect on the shear forces. In other words, the shear forces principally depend on the side-to-side movements of the body and not on the upright lifting movements.

TABLE III
MEANS AND STANDARD DEVIATIONS OF COMPRESSIVE FORCES (CF) AND SHEAR FORCES ACCORDING TO TREATMENT NUMBER AND TECHNIQUES

Trtm. No.	Load (kg)	Tech.	CF1		CF2		CF3		CF4		SF	
			Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	5	Stoop	5398	494	4559	500	5276	528	4289	388	559	77.3
2	5	Squat	5590	548	5149	657	5457	577	4468	435	540	51.3
3	5	Free	5482	505	4708	502	5358	532	4357	395	559	60.5
4	15	Stoop	5532	420	4686	460	5392	477	4406	349	574	49.4
5	15	Squat	5634	488	5234	530	5509	529	4482	389	548	45.7
6	15	Free	5545	477	4823	536	5410	536	4408	378	565	50.1
7	25	Stoop	5667	442	4839	442	5530	496	4497	349	578	50.7
8	25	Squat	5862	437	5655	474	5721	511	4656	347	551	50.8
9	25	Free	5744	490	5147	538	5639	547	4564	389	564	49.0
Overall Means			5604	497	4977	616	5484	530	4457	394	560	56.0

(Sample Size at each treatment = 60 participants)

Table IV shows the means and the standard deviations of the compressive and the shear forces according to the levels of the load lifted. The compressive forces increased with the increase of the load. Furthermore, the shear forces increased too, but the rate of increase was small in the range of 15 to 25 kg.

Table 5 presents the means and the standard deviations of the compressive and the shear forces according to lifting technique. It shows that the mean values of compressive forces for the squat technique were higher than in the case of other lifting techniques. The differences were almost negligible between the three lifting technique used in this study. The mean values of shear forces developed while using stoop technique were found to be the highest and the mean shear forces were the lowest while using squat technique.

TABLE IV
MEANS AND STANDARD DEVIATIONS OF COMPRESSIVE FARCES (CF) AND SHEAR FORCE (SF) ACCORDING TO LEVEL OF LOAD LIFTED BY THE EXAMINED SUBJECTS

Load (Kg)	CF1		CF2		CF3		CF4		Overall		SF	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	S.D.	Mean	Mean	S.D.
5	5490	519	4805	609	5364	548	4371	411	5008	522	553	64
15	5571	462	4914	558	5437	514	4432	372	5089	477	563	49
25	5758	461	5214	589	5630	521	4572	366	5294	484	564	51

TABLE V
MEANS AND STANDARD DEVIATIONS, OF COMPRESSIVE FORCES (CF) AND SHEAR FORCE (SE) ACCORDING TO LIFTING TECHNIQUES

Technique	CF1		CF2		CF3		CF4		Overall		SF	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Free-Style	5591	500	4893	555	5469	549	4443	395	5099	500	563	53
Squat	5695	505	5346	599	5562	549	4535	399	5285	513	546	49
Stoop	5532	464	4696	480	5399	509	4397	370	5006	456	570	61

Table VI presents the overall means and standard deviations for the compressive and the shear forces of the participants according to treatment. The mean of compressive forces calculated using objective function CF1 (one active muscle) was higher than the compressive force calculated using objective functions. The maximum values of the compressive force were obtained while using objective function for one muscle (FC1) and the minimum values were obtained using objective function for ten muscles (CF4).

TABLE VI
MEANS AND STANDARD DEVIATIONS OF COMPRESSIVE FORCES (CF) AND SHEAR FORCE (SF) ACCORDING TO TREATMENTS

Treatment No.	Load (kg)	Technique	CF1		CF2		CF3		CF4		SF	
			Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	5	stoop	5419	515	4450	447	5331	506	4301	403	547	57
2	5	squat	5672	401	5295	530	5581	395	4520	321	501	49
3	5	Free	5536	507	4805	515	5446	499	4400	401	534	63
4	15	Stoop	5502	420	4710	426	5413	413	4368	332	546	55
5	15	Squat	5797	380	5434	425	5703	374	4612	304	516	41
6	15	Free	5410	331	4787	532	5323	326	4302	267	534	42
7	25	Stoop	5525	314	4763	383	5435	309	4387	254	542	57
8	25	Squat	5839	259	5604	331	5745	255	4651	209	500	54
9	25	Free	5625	456	5078	597	5713	435	4464	357	537	50

(Sample Size at each treatment = 60 participants)

C. Contributing Factors

Table 6 presents the means and the standard deviations of the compressive and the shear forces of the participants according to their ages. Since the sample size of the participants (n=60) was relatively small for the wide range of their ages (19-40 years), no specific trend could be predicted from the scatter of the data .However, the means of the compressive force for the age range 25-35 years was the minimum, while the mean shear force for the age range 27-40 years was higher than that of the age range 19-26 years.

The compression and the shear forces of the participants classified according to height and weight groups are presented in Tables (VIII) and (IX), respectively. Both the compression and the shear forces showed increase by participants' heights (Table VIII) while the shear forces only increased by the increase of weights (Table IX).

TABLE VII
MEANS AND STANDARD DEVIATIONS, OF COMPRESSIVE AND SHEAR FORCES ACCORDING TO AGE OF PARTICIPANTS

Age (Years)	Sample Size	Compressive Forces		Shear Forces	
		Mean	S.D.	Mean	S.D.
19	1	5578	540	529	79
21	2	5164	687	509	31
22	3	5585	673	522	54
23	4	5289	775	496	59
24	5	5322	633	548	34
25	5	5009	641	530	46
26	7	5051	723	547	39
27	7	5095	631	598	59
28	5	5092	653	590	25
29	3	5174	631	565	45
30	2	5414	675	588	31
31	2	4702	634	631	33
32	4	5067	634	556	42
33	1	4678	486	595	19
34	3	4924	672	578	39
36	3	5053	642	590	32
37	2	5249	623	552	80
40	1	4712	546	565	9
Overall	60	5120	639	561	42

TABLE VIII
MEANS AND STANDARD DEVIATIONS, OF COMPRESSIVE FORCES (CF) AND SHEAR FORCE (SF) ACCORDING TO HEIGHT OF PARTICIPANTS

Height (cm)	Sample Size	CF1		CF2		CF3		CF4		Overall		SF	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
160 – 164	5	5333	416	4738	476	5220	462	4234	328	4881	421	488	49
165 – 169	29	5462	471	4894	615	5300	542	4344	378	5000	502	565	49
170 – 174	17	5707	397	5035	571	5614	390	4543	308	5225	417	553	51
175 – 179	6	6009	502	5264	625	5915	494	4776	395	5491	504	584	47
180 – 184	3	6076	382	5288	619	5957	399	4827	305	5537	426	616	42
Overall	60	5717	434	5044	581	5601	457	4545	343	5227	454	561	48

TABLE IX
MEANS AND STANDARD DEVIATIONS OF COMPRESSIVE FORCES (CF) AND SHEAR FORCES (SF) ACCORDING TO WEIGHT OF PARTICIPANTS

Weight (Kg)	Sample Size	CF1		CF2		CF3		CF4		SF	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
50 –59	4	5249	445	4699	501	5175	497	4204	351	473	43
60 –69	22	5765	457	5152	561	5666	455	4580	364	530	31
70 –79	23	5511	455	4891	573	5335	554	4382	361	576	39
80 - 89	11	5598	557	4911	725	5505	549	4467	443	618	50
Overall	60	5542	479	4913	590	5420	514	4408	380	549	41

Table X shows the range of motions of body links and the maximum and the minimum for all the sample angles. It displays the minimum hip angle which is equal to zero, but it can be negative value, too. However negative values were not accepted by the software.

Worthynoting that using ANOVA analysis, the significance of the age, the height, the weight and the body angles (Tables VII-IX) on the compression and shear forces of the participants showed that all the considered parameters were significant (Table XI).

TABLE X
BODY ANGLES AND RANGE OF MOTION OF BODY LINKS (DEGREES)

Body Angles	Maximum	Minimum	Range of motion
Ankle	112	68	44
Knee	150	56	94
Hip	57	0	57
Shoulder	-68	-136	68
Elbow	-30	-104	74

TABLE XI
TEST OF SIGNIFICANT FOR COMPRESSIVE AND SHEAR FORCES

Parameters	Compressive force (N)	Shear force (N)
Age (years)	Significant	Significant
Height (cm)	Significant	Significant
Weight (kg)	Significant	Significant
Ankle (degrees)	Significant	Significant
Knee (degrees)	Significant	Significant
Hip (degrees)	Significant	Significant
Shoulder (degrees)	Significant	Significant
Elbow (degrees)	Significant	Significant

D. Acceptable Weight of Lift

Table 12 shows the means, the standard deviations, the maximums and the minimum for the acceptable weight of lift (AWL) as selected by the subjects participated in the study according to age group. It is clear that the weight that can be handled by subject in 8-hours jobs is 12.4 kg if the weight selection is left to their option. The average load ranged from 10 kg to13 kg. It was noticed that the subject aged 20-30 could handle more weight than the others. The maximum weight handled was 20 kg.

TABLE XII
MEANS, STANDARD DEVIATIONS, MAXIMUM AND MINIMUM FOR THE ACCEPTABLE WEIGHT OF LIFT

Age (years)	No.	Mean	Standard deviation	Maximum	Minimum
15-19	1	13.0	0.0	13	13
20-24	14	12.1	4.5	20	5
25-29	27	13.0	3.3	19	5
30-34	12	12.1	3.9	17	5
35-39	5	10.6	3.2	16	7
40-44	1	10.0	0.0	10	10
Total	60	12.4	3.74	20	5

E. Correlation Matrix of the Tested Parameters

Table 13 shows the correlation coefficient for the main parameters of the study. It shows that there is a good correlation between the knee angle and the compressive forces (CF2) (one active muscle and abdominal pressure), the weight with the shear forces, and strong correlation between the compressive forces option with each others.

TABLE XIII
CORRELATION FOR MAIN PARAMETERS INVESTIGATED IN THE STUDY

	AGE	HEIGHT	WEIGHT	LOAD	ANKLE	KNEE	HIP	SHOULDER	ELBOW	CF1	CF2	CF3	CF4	SF	AWL
AGE	1														
HEIGHT	-0,06	1													
WEIGHT	0.43	0.48	1												
LOAD	0	0	0	1											
ANKLE	-0.07	0.02	-0.04	-0.04	1										
KNEE	0	0.03	0.05	0.14	-0.53	1									
HIP	0.02	0.07	0.04	-0.26	-0.01	-0.18	1								
SHOULDER	-0.06	0.02	0	-0.21	-0.01	-0.19	-0.34	1							
ELBOW	-0.02	-0.11	-0.14	0.52	-0.14	-0.23	-0.14	-0.11	1						
CF1	-0.20	0.40	-0.02	0.22	-0.09	-0.30	0.02	0.43	0.47	1					
CF2	-0.16	0.22	-0.07	0.27	-0.35	-0.69	-0.10	0.30	0.49	0.82	1				
CF3	-0.29	0.40	-0,02	0.20	-0.06	-0.26	0.07	0.38	0.43	0.92	0.74	1			
CF4	-0.19	0.41	-0.01	0.21	-0.10	-0.31	0.05	0.43	0.46	0.99	0.81	0.91	1		
SF	0.34	0.34	0.75	0.08	-0.15	-0.32	-0.44	-0.25	-0.13	-011	-0.20	-0.12	-0.11	1	
AWL	-0.05	0.39	0.22	0	-0.02	-0.02	0.06	0.00	-0.09	0.16	0 08	0.15	0.17	0.21	1

IV. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from this study:

1. The compressive forces computed using the objective function for one active muscle (CF1) generated consistently high values. Whereas the compressive forces computed using the objective function of ten muscles to minimize compression (CF4) are much lower.
2. A good correlation exists between the combination of height, weight and load with the compressive and shear forces. When the height increases the compressive forces increase too. When the weight increases the shear force also increases. Similarly, when the loads increase both the compressive and shear forces increase too.
3. The means of the compressive and the shear forces for the squat technique are higher than those for the other lifting techniques.
4. The compressive and the shear forces computed for persons involved in MMH activities are less than the compressive and the shear forces computed for persons not involved in these activities.
5. The means of the acceptable weight of lift for Saudi males for 8 hours working day is 12.4 kg.
6. The means of shear forces for ages 27 to 40 years are higher than those for ages 19 to 26 years.

The research in this area in KSA is limited. Therefore, it is recommended to conduct a series of studies to cover the different factors affecting the biomechanical stresses on the human body during MMH activities. Different ages, sex, ethnic origins, socio-economic factors, lifting techniques, weights handled, etc. should be investigated. Furthermore, three-dimensional analysis may be used, and dynamic functions may be tested, considering extending the age of the examined subjects to 60 years old and include the Saudi females. Meanwhile, testing the impact of environmental factors on the process of lifting, such as the effect of heat, humidity, noise, illumination, etc. is recommended.

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REFERENCES

[1] M.M. Ayoub, A. Mital, *Manual Materials Handling.* Taylor and Francis, London, 1989.

[2] M.M. Ayoub, "Problems and Solutions in Manual Materials Handling: The State of the Art," *Ergonomics, 35(7/8),* 713-728, 1992.

[3] A. Mital, A.S. Nicholson and M.M. Ayoub, *A Guide to Manual Material Handling*. Taylor and Francis, London, 1993.

[4] J.R. Brown, *Lifting as an Industrial Hazard*, Labour safety Council, Ontario, Canada, 1971.

[5] J.B. Sie, "An Evaluation of Manual Materials Handling of Drywell Materials Using Drywell Charts at Tamarock Materials Inc.," M.S. Thesis, the Graduate College of Wisconsin-Stout, USA, 2006.

[6] E. Schneider, X. Irastorza, *Work-related Musculoskeletal Disorders in EU – Facts and Figures.* European Agency for Safety and Health at Work, ISBN 978-92-9191-261-2, 2010.

[7] Eurofound (2010), Changes over Time - First Findings from the Fifth European Working Conditions Survey. Available: http://www.eurofound.europa.eu/survey/euros/ index.htm.

[8] Health and Safety Commission of the UK. *Proposals for Health and Safety (Manual Handling of Loads) Regulations and Guidance*. HMSO, Health and Safety Commission, London; 1982.

[9] Australian Council of Trade Union, *Guidelines on Manual Handling*. Victoria: ACTU/VTHC Occupational Health and Safety Unit, 1983.

[10] R. Rawi, P. O'Halloran, Effective Control of Manual Handling Injury in the Electricity Company. *Proceedings of the International Ergonomics Association, Australia, Sydney;* 266-268, 1988.

[11] GOSI. Annual Report – General Organization for Social Insurance in the Kingdom of Saudi Arabia. *www.gosi.gov.sa.*, 2012.

[12] International Labour Organization (ILO), *Maximum Permissible Weight to Be Carried by One Worker, Information Sheet No. 3*, Geneva, Switzerland, 1962.

[13] International Labour Organization (ILO), Maximum Permissible Weight in Load Lifting and Carrying, Occupational Safety and Health Series, Geneva, Switzerland, No. 59, 1988.

[14] National Institute for Occupational Safety and Health (NIOSH): *A Work Practices Guide for Manual Lifting*, Technical Report No. 81-122, U.S. Dept. of Health and Human Services, USA, 1981.

[15] NIOSH, 1991. *Revisions in NIOSH Guide to Manual Lifting.* Cincinnati: National Institute for Occupational Safety and Healtth, 1991.

[16] Heallth and Safety Commission, 1991. *Handling Loads at Work – Proposals for Regulations and Guidance,* London: Health and Safety Executive, 1991.

[17] I.M. Jomoah, *A Comprehensive Study of Static and Dynamic Stresses for Symmetric and Asymmetric Lifting Activities.* Ph.D. Dissertation, University of Miami, Coral Gables, Florida, USA; 1994.

[18] A. Praemer, S. Furner, and D.P. Rice, *Musculoskeletal Conditions in the United State*, American Academy of Orthopedic Surgeons, Rosemont, IL, 1-199, 1992.

[19] J.P. Leigh, S. Markowitz, M. Fahs, and P. Landrigan, *Costs of Occupational Injuries and Illnesses.* The University of Michigan Press, Ann Arbor, 2000.

[20] National Research Council: *National Research Council, Musculoskeletal Disorders and the Workplace: Low Back Pain and Upper Extremities.* National Academy of Sciences, Washington, DC, 2001.

[21] P.L. Murphy, and E. Volinn, "Is Occupational Low Back Pain on the Rise?" *Spine*, 7, 691-697, 1999.

[22] D.B. Chaffin, G. Andersson, and B.J. Martin, *Occupational Biomechanics (4th ed.).* John Wiley & Sons; 2006.

[23] D.B. Chaffin, and K.S. Park, "A Longitudinal Study of Low-Back Pain as Associated with Occupational Weight Lifting Factors," *Am. Ind. Hyg. J., 34,* 513-525, 1973.

[24] A. Burdorf, and G. Sorock, "Positive and Negative Evidence of Risk Factors for Back Disorder," *Scand. J, Work Environ Health , 23* , 243-256, 1997.

[25] B.P. Bernard, Ed. *Musculoskeletal Disorders and Workplace Factors. A Critical Review of Epidemiological Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back Pain*, Cincinnati: US Department of Health and Human Services CDC (NIOSH), DHHS(NIOSH) Publication No. 97-141, 1997.

[26] National Board of Occupational Safety and Health: *Occupational Injuries in Sweden.* National Board of Occupational Safety and Health, Sweden; 1983.

[27] F. Metzler, Epidemiology and Statistics in Luxembourg. *Ergonomics, 28,* 21-24, 1985.

[28] C.C. Chang, S. Hsiang, P.G. Depsey, and R.W. McGorry, A Computerized Video Coding System for Biomechanical Analysis of Lifting Tasks. International Journal of Industrial Ergonomics, 32(4), 239-250, 2003.

[29] P. Wu, Maximum Acceptable Weights for Asymmetric Lifting of Chinese Females. Applied Ergonomics, 34(3), 215-224, 2003.

[30] R. Maiti, and G. Ray, Determination of Maximum Acceptable Weight of Lift by Adult Indian Female Workers. International Journal of Industrial Ergonomics, 34(6), 483-495, 2004.

[31] K.G. Davis, and M.J. Jorgensen, Biomechanical Modeling for Understanding of Low Back Injuries: A Systematic Review. *Occupational Ergonomics, 5(1):* 57-76, 2005.

[32] S.A. Lavender, W.S. Marras, S.A. Ferguson, R.E. Splittstoesser, and G. Yang, Developing Physical Exposure-Based Back Injury Risk Models Applicable to Manual Handling Jobs in Distribution Centers. *J. Occupational and Environmental Hygiene. 9(7):* 450-459, 2006.

[33] C.J. Lin, S.J. Wang, and H.J. Chen, A Field Evaluation Method for Assessing Whole Body Biomechanical Joint Stress in Manual Lifting Tasks. *Industrial Health*, 44, 604-612, 2006.

[34] C.R. Dickerson, R.E. Hughes, and D.B. Chaffin, Experimental Evaluation of a Computational of shoulder Musculoskeletal Model. *Clin. Biomech (Bristal, Avon) 23(7),* 886-894, 2008.

[35] A.S. Merryweather, M.C. Loertscher, and D.S. Bloswick, A Revised Back Compressive Force Estimation Model for Ergonomic Evaluation of Lifting Tasks. *Work: A Journal of Prevention, Assessment and Rehabilitation, 34(3):* 263-272, 2009.

[36] N. Arjmand, D. Gagnon, A. Plamonlon, A. Shirazi–Adl, and C. Lariviere, Comparison of Trunk Muscle Forces and Spinal Loads Estimated by Two Biomechanical Models. *Clin Biomech (Bristol, Avon) 24(7):* 533-541, 2009.

[37] T.R. Waters, and A. Garg, Two-dimensional Biomechanical Model for Estimating Strength of Youth and Adolescents for Manual Material Handling Tasks. *Applied Ergonomics, 41(1):*1–7, 2010.

[38] S. Iyer, B.A. Chritiansen, B.J. Roberts, M.J. Valentine, R.K. Manoharan, and M.L. Bouxsein, A Biomechanical Model for Estimating Loads on Thoracic and Lumbar Vertebrae. *Clin Biomech (Bristol , Avon) 25(9):* 853-858, 2010.

[39] T.R. Waters, and A. Garg, Two-dimensional Biomechanical Model for Estimating Strength of Youth and Adolescents for Manual Material Handling Tasks. *Applied Ergonomics, 41(1):*1–7, 2010.

[40] H.S. Jung, A Survey of the Optimal Handle Position for Boxes with Different Size and Manual-Handling Positions. *Applied Ergonomres, 41(1)*: 115-122, 2010.

[41] N. Arjmand, A. Plamondon, A. Shirazi-Adl, C. Lariviere, and M. Parnianpow, Predictive Equations to Estimate Spinal Loads in Symmetric Lifting Tasks. *J. Biomech., 44(1):* 84-91, 2010.

[42] S.A. Olson, J.L. Marsh, D.D. Anderson, and L.L. Latta, Designing a Biomechanics Investigation: Choosing the Right Model. *J Orthop Trauma 26(12):* 672-677, 2010.

[43] R. Parida, and P.K. Ray, Biomechanical Modeling and Evaluation of Construction Jobs for Performeance Improvement. *Work: A Journal of prevention, Assessment and Rehabilitation . 41(supplement 1):* 5959-5965, 2012.

[44] S.O. Ismaila, and O.E. Charles-Owaba, A Quantitative Approach for Establishing Safe Weight of Lift. *Engineering Review, Ožujak, 32(1),* 2012.

[45] A.R.J. Pinder, and M.G. Poocock, Prediction of Maximum Acceptable Weight of Lift from the Frequency of Lift. *International Journal of Industrial Ergonomics,* 2012.

[46] C.C. Chang, X. Xu, G.S. Faber, I. Kingmac, and J. Dennerleinb, Assessing manual lifting tasks based on segment angle interpolations. *Work: A Journal of Prevention, Assessment and Rehabilitation* 41, 2360-2363, 2012.

[47] R. Parida, and P.K. Ray, Biomechanical modeling and evaluation of construction jobs for performance improvement. *Work: A Journal of Prevention, Assessment and Rehabilitation* 41, 5959-5965, 2012.

[48] N. Singh, R. Belokar, and R. Walia, Physiological evaluation of manual lifting tasks on Indian male workers. *International Journal of Engineering and Advanced Technology*, 2(1), 2249-8958, 2012.

[49] N. Arjmand, A. Plamondon, A. Shirazi Adl, M. Parnianpowr, and C. Leriviere, Predictive Equations for Lumbar Spine Loads in Load–Dependent Assymmetric One- and two– Hand Lifting Activities. *Clin Biomech (Bristo-Avon) 27(6):* 537-549, 2013.

[50] A.J. Beek, S.E. Mathiassen, and F.A. Rurdor, Efficient Assessment of Exposure to Manual Lifting Using Company Data. *Applied Ergonomics, 44(3*): 360-365, 2013.

[51] Ministry of Economy and Planning: *Ninth Development Plan 1430-1434 (H).* Kingdom of Saudi Arabia, 2010.

[52] Ministry of Economy and Planning: *Statistical Year Book No. 47 (1431-1432).* Kingdom of Saudi Arbia, 2011.

[53] M.H. Noweir, *Occupational Health in Saudi Arabia.* WHO Consultation Assignment Report , Project EM/ OCH/75/E/R/10.94/22, 11 January- 9 February, 1994.

[54] Ergo-Edge: *Computer Software, Version 1.0.* Innovative Ergonomics Inc. NY.

[55] A.J. Hayter, Probability and Statistics for Engineers and Scientists. PWS Publ. Co., Boston, MA, USA, 1996.

[56] M.H. Noweir, A.O. Bafail, and I.M. Jomoah, Anthropometric Norms of Saudi Population. A Final Repent of the Research Project No. (103/417). King Abdulaziz Universty, Jeddah, Kingdom of Saudi Arabia, 2003.