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Biomechanical Evaluation of Three Lifting Techniques

Gutierrez

Faculty, Industrial Engineering Department De La Salle University(gutierreza@dlsu.edu.ph)

ABSTRACT: *. The study aims to to evaluate how different lifting postures (stoop lift, squat lift, and semi-squat lift) affect the compression of the spine. Squat lift has been promoted in training, as opposed to stoop lift. However, squat lift cannot be done on large and bulky loads because it affects the balance of the person doing the lift. Straddle or semi squat lift is another type of lift that uses leg muscles but also faces the same problem. This study will consider the effect of object weight to the balance of the person. Low back pain (LBP) and injuries associated to manual lifting activities are frequent in industry. Manual handling and lifting are the major causes of work related pain. Its cost is huge and cannot be directly quantified [1]. LBP can be a disabling disease. It causes severe emotional, physical, economic and social stress that negatively affects the families of those afflicted [2]. Aside from the monetary and social costs mentioned above, the prevalence of back pain in the adult population explains the focus that researchers in occupational health are giving into this concern. Researches conducted in many parts of the world including the United States, Europe, and Russia indicate that 40-80% of adult population is expected to experience this disease [3]. As such, many studies have dealt with finding ways to determine its causes and possible cures. One of the criteria for estimating occupational back disorders is the compression of the back resulting from overexertion [4]. According to McGill [5], injury occurs due to failure of a tissue when load exceeds its strength. Tissue failure is exhibited by tissue irritation like vertebral fracture or ligament avulsion. The intervertebral disc is the part of the spine that bears the most weight in lateral and anterior shears, axial compression and flexion [6]*

Keywords: *Low back pain, squat lift, semi-squat lift, stoop lift, biomechanics.*

1. INTRODUCTION

In most manufacturing companies we see posters on the proper lifting technique- “squat lift”. Teaching workers on the correct lifting technique is the widely acceptable method of intervention. However, most people do not normally use this lifting technique. Instead they use the stoop method, which it is considered as the incorrect lifting method. The following studies will try to shed light on the practice of training workers in “safe” lifting techniques and whether individual characteristics and preferences need to be considered when attempting to improve the safety of manual handling operations in the industry.

Limerick and Abernethy [7] studied the lifting behaviour with respect to the weight load. The authors evaluated the two types of lifting technique: the squat and stoop lift. Thirty-nine subjects (20 female and 19 males with age ranges from 18- 26 years old) lifted loads of varying mass. The mass of the load varied from 2.5 kg to 10.5 kg with 2 kg increments. Angular motion in the sagittal plane of ankle, knee, hips and lumbar vertebral joints was estimated from two-dimensional video images. Anthropometric data from those subjects who exhibited stooped postures at the start of extension were compared to the other subjects using ANOVA. The results showed that when the load mass was heavy, only patterns involving a semi-squat posture at the start of extension was observed. However, when the load mass was light, both stooped and semi-squat patterns occurred.

On the other hand, Rabinowitz, Bridger and Lambert [8] made a study on evaluating two modalities to improve the safety of industrial manual handling operators. Lifting techniques and the use of an abdominal belt using biomechanical, physiological and subjective means. Ten healthy male subjects with no history of back pain or injury participated in the study. The stadiometer was used to measure the spinal shrinkage before and after a lifting session. Telemetric pulse monitor was used to measure the subjects heart rate every 5 seconds during a lifting session. For the lifting task, subjects were asked to lift a beer crate (36 cm x 27 cm x 30 cm) from a standing position on the floor onto a 75 cm high surface then lowered to the starting position again. Based on the biomechanical measures, there was a significant difference in spinal shrinkage under all lifting conditions compared with shrinkage during 15 min of quiet standing (4.36+-2.24 vs. 1.13+ 1.18 mm) there were no significant differences in shrinkage between the conditions. On the other hand, the subjects heart rate is higher during the squat lift compared to stoop lift (123 beats/min vs. 97 beats/min). With respect to subjective measures, nine out of 10 subjects perceived the stoop lift to demand less exertion than the squat lift. While the squat lift was perceived to be the safest lift by 90% of the subjects, 60% regarded this lift as the least preferred method (with or without the belt). Although, all subjects believed that the safest method involved the use of a belt, 50% rated the belt as their least preferred lifting condition.

Hagen, Sorhagen and Harms-Ringdahl [9] conducted a study on the influence of different weight/ frequency combinations on thighs and lower trunk movements during sagittal symmetric repetitive lifting employing squat and stoop techniques. Ten experienced male forest workers volunteered to participate in this study. Their mean age was 30.6 years with a standard deviation of 4 years. The lifting task consisted of a repetitive sagittal symmetric lowering and lifting of a box (0.36 x 0.36 x 0.25 mm with side handles 0.21 above the bottom edge). Each subject performed 5 submaximal bouts with different weight/frequency combinations using both the stoop and the squat techniques. Kinematic data were collected with electrolytic liquid level sensors. The result showed that the lifting weight or frequency did not influence the motion ranges in stoop lifting. For all subjects and weight or frequency combinations the standard deviation of the mean of thigh and lower trunk motion ranges was significantly higher for squat than for stoop. The study indicates that “movement strategies” to reduce the demand on the quadriceps muscles were used in these lifting bouts. The variations in motion ranges were greater in squat than stoop lifting.

Giat and Pike [10] studied the stoop and squat lifting method using biomechanical and an electromyographic analysis. The stoop and squat lift was performed in which the following variables were compared: the peak moment about the knee, peak EMG of knee extensors, total mechanical work and the duration of the lift. Eight subjects were asked to use both lifting method, lifting small objects of 2.27, 4.54 and 6.81 kg. The discriminant analysis showed that the moment about the knee was the variable which maximally distinguished the two lifting methods. It was concluded that people prefer the stoop lifting method to the squat lifting method because of the greater demand the squat lift imposes on the knee extensors.

2. METHODOLOGY

The Ergonomics laboratory located at STRC 218 of De La Salle University-Manila was used in conducting the study since the Ergomaster software is housed there. An initial survey was conducted to gather the 10 subjects. The purpose of the survey is to screen subjects to make sure that they do not have prior injuries in the back, neck and knees. The subjects used for this study has an age range of 18-20 years. Advanced age can be attributed to weaker spines. All subjects used for this study are physically fit and non-smokers.

All the subjects had their weight and height measures taken. This was to assure that the respondents were under the normal scale in the body mass index. The subjects must not also be active and experienced in doing physical activities. These criteria were adapted from the study of Rixon et al [11]. This was done to avoid muscle contraction biases among the factors since their study shows that muscle contraction vary through weight, gender and muscle experience when doing these lifting activities.

The research design of Rixon et al [11] included two groups of subjects: men (n = 15; age: 23.1 ± 2.4 years; height: 177.5 ± 8.3 cm; weight: 81.3 ± 12.0 kg) and women (n = 15; age: 23.4 ± 3.1 years; height: 166.8 ±7.1 cm; weight: 69.2 ± 26.7 kg) and were free of injuries to the joints of the lower limbs and back.

This study only focused on manual lifting tasks specifically for two handled lifting technique. For the lifting task, subjects were asked to lift a box (40 cm x 28 cm x 30 cm) with cutout so that subjects can have a good coupling of the box. The box was then filled with books to vary the weight (5 and 10 kg). The subjects are asked to lift the load from the floor onto a 70 cm high table surface.

After screening out the subjects, they were then brought to the physical ergonomics room to perform the procedures by using three different lifting postures to lift the 5 kilogram and 10 kilogram weights. The different lifting postures are as follows:

1. Squat- Back is positioned upright while bending the knees to reach the weight to be lifted
2. Stoop- Back is bended while the knees remain intact to reach the weight to be lifted
3. Straddle (Semi-squat)- Back is slightly bended on an angle while bending the knees to reach the weight to be lifted

To assess the fatigue level of the respondents after each lifting posture, a subjective fatigue self-rating was used as measure of how tired or weakened the subject felt after lifting. The subjective fatigue rating scale is adapted from the study of Banks [12]. The subjective fatigue rating scale directs the participant to indicate the level of fatigue you experienced while doing the lifting task by placing an ‘X’ in the appropriate box with numerical levels from 0-10. Numerical interpretations of the subjective fatigue-rating instrument are as follows:

Table 1.Interpretation of Subjective Fatigue Rating

System Fatigue Rating	Level of Fatigue
0	Not at all
1 to 3	Mild Fatigue
4 to 6	Moderate Fatigue
7 to 9	Severe Fatigue
10	Unable to Continue

Aside from the subjective fatigue rating, the Ergomaster software was also used. The Ergomaster software has a 2D Biomechanic calculations. The 2D Biomechanical calculations are based on a sophisticated 2-dimensional static model. The results include both shear and compressive forces. Anthropometric measurements and angles at the various joints are also calculated.

Other factors that cause low back pain such as whole body vibration, static postures, prolonged sitting and trauma of the back will not be evaluated in this study. Lastly, the speed and lifting duration will not be included in this study.

3. RESULTS AND ANALYSIS

The table below shows the total compressive forces acting on the L5/S1 spinal disc.

Table 2. Compressive Forces at Different Lifting Position and Weight of Object

Type of Lift	Semi Squat Lift		Squat Lift		Stoop Lift	
Weight of Object	5 kg	10 kg	5 kg	10 kg	5 kg	10 kg
Male 1	2516.37 N	3252.98 N	2584.97 N	3413.07 N	2353.65 N	2931.40 N
Female 1	1707.16 N	2191.19 N	1507.05 N	1946.92 N	1581.92 N	2096.64 N
Male 2	2829.88 N	3741.91 N	2036.04 N	2716.11 N	2606.18 N	3296.81 N
Female 2	1871.00 N	2411.96 N	1499.89 N	1866.63 N	1951.89 N	2584.79 N
Male 3	3077.51 N	3884.05 N	3211.06 N	4113.19 N	2986.28 N	3617.76 N
Female 3	1945.25 N	2627.42 N	1805.74 N	2340.91 N	1971.18 N	2657.76 N
Male 4	3419.62 N	4504.53 N	2313.51 N	3038.94 N	3280.77 N	4317.66 N
Female 4	1847.43 N	2298.77 N	1968.69 N	2472.50 N	2126.87 N	2783.51 N
Male 5	2798.97 N	3726.41 N	2782.00 N	3812.78 N	2934.08 N	3822.85 N
Female 5	2332.76 N	2926.41 N	2228.34 N	2812.24 N	2338.41 N	2953.94 N

As can be seen in the table it was evident that male subjects specifically Male Subjects 3, 4 and 5 sustained total compressive forces greater than the action limit (those in red fonts). According to the notes of the Ergomaster Software, the action limit is the load weight above which musculoskeletal injury incidence and severity rates increase moderately. It is defined by the following criteria: (1) Compressive forces acting on the L5/S1 spinal disc should not exceed 3425 N (770lb), (2) Twenty five percent of the female workers and one percent of male workers do not have the muscle strengths to be capable of performing the work, (3) Metabolic rates would exceed 3.5 kcal/minutes when integrated over an eight hour day and (4) Lumbosacral torque equal to or greater than 163 N-m (120 ft-lb) is considered hazardous to all but the healthiest of workers as proposed by OSHA.

Comparing the three lifting postures, the stoop lifts with 10-kg weight generated total compressive forces exceeding the action limit. In the study of Nachemson and Elfstrom [13], the disc compression force is higher when lifting 20 kg with bent back and knees straight with value of 3270 N as compared to 2100 N of disc compression when lifting 20 kg with back straight and knees bent. This is also evident in this study. Highest compressive force is obtained when the lifting position is stoop while lowest value is achieved when doing the squat lift. This is due to the fact that when doing a stoop lifting posture, the lifter bends his back while keeping the legs in an upright position thus to lift the weight, the forces are all concentrated in the back. Similarly, when one lifts in a squat posture, the legs are bended while the back is kept upright, thus in lifting the weight all the forces are concentrated on the legs.

The weight of the object also plays an important factor in disc compression of the spine because the load is translated to the intervertebral discs and causes them to compressed. The compressive forces are apparently higher in the 10 kg weight as compared to the 5 kg weight.

Table3. Subjective Fatigue Ratings of Ten Subjects on Lower Back

Lower Back		***Lifting Posture***		
Subjects		**Squat**	**Semi-squat**	**Stoop**
Female	1	3	4	6
Female	2	4	5	7
Female	3	3	4	6
Female	4	2	3	5
Female	5	3	5	7
Male	1	2	4	6
Male	2	3	3	5
Male	3	1	5	4
Male	4	2	3	6
Male	5	3	4	5

Comparing the three lifting postures it is evident that subjects still preferred the squat lifting technique as compared to the stoop lift because it garnered the lowest subjective fatigue rating resulting to an overall mild fatigue assessment. The stoop lift resulted to an overall moderate fatigue assessment. Table 3 only validates the findings in the Ergomaster Software that lowest compressive forces were apparent in the squat lift as compared to the stoop lift technique.

According to Kroemer and Grandjean [14], in Germany disc disorders were the cause of 20 percent of absenteeism and 50 percent of premature retirements. Clearly, lower back pain is among the most common causes of injury and disability in many industrial populations.

One way of ensuring our safety is to understand our body and discover the proper way of doing things. The round back leads to heavy pressures on the front edge of the disc and increases the risk of rupture. The straight back ensures that the loads on the disc are evenly distributed, thus reducing wear and tear on the fibrous ring of the disc [14].

4. CONCLUSION

This study demonstrates how the different lifting postures (stoop, semi-squat and squat) affect the total compressive forces. Squat lift proves to be the safest lifting postures as shown in Table 2, which resulted in the lowest total compressive forces as compared to the stoop lift. This finding was also validated through the subjective fatigue assessment given to the subjects. The subjects rated a mild fatigue assessment for the squat lift and a moderate fatigue assessment for the stoop lift technique. It is therefore suggested that when training workers on the proper lifting technique, the squat lift is the preferred method. However if the objects are bulky and large the squat lift can affect the balance of the person doing the lift. Therefore, for further studies, it is suggested the object shapes and weight be varied to determine the effect on the lifter. Also, the use of surface EMG can be used together with the Ergomaster Software so as to determine the muscle activity and determine the load of the spine.

Lifting and other load handling is often associated with over-exertions of the lower back. Trouble can be avoided by proper lifting techniques ('do pull the load close to the body; don't bend or twist') and by work design, especially by keeping the load light.

There are several factors that affect the fatigability of the lifter. In this study, it found out that lifting posture and lifting weight primarily contribute to the fatigue of the lifter. This is in line with the study of Davis, K.G. et al. [15], Kroemer and Grandjean [14] and Nachemson and Elfstrom [13].

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