International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 16, Issue 12 (December 2020), PP. 17-25

Evaluation of Repetitive Lifting Tasks Performed In Cement Industries

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Abstract – *Lifting is the most common task performed in industrial, healthcare as well as in domestic settings. This research work aims at addressing the biomechanical effects of performing lifting tasks for male subjects working in industry. The peripheral body loads as a result of musculoskeletal stress, due to lifting tasks have been analyzed using four different lifting postures. A field approach is adopted which involve six industries performing a variety of lifting tasks. A questionnaire comprises of body discomfort chart is administered to 109 respondents. The perceived stresses was assesed along with the computer generated stresses. Anthropometric variables of 109 workers from six different industries is collected. The posture was simulated and analyzed using a human modelling system (ManneQuin Pro). The force and torque for fifteen anatomical regions of the body was calculated. It was observed the lower back were exposed to high stresses and there was a need to re-design the lifting methods. The results were further compared with the perceived pain in the body and it was observed that in stoop lifting task, the trunk region is exposed to high musculoskeletal loading.*

Keywords: *Digital Human Modelling, Lower Back Pain, Lifting Task, Muscle stresses, Musculoskeletal Disorders*

Date of Submission: 28-01-2020 Date of Acceptance: 26-01-2021

I. INTRODUCTION

Industrial sector plays a key role in developing economy of any country. While the developed countries have moved towards automation, a large number of developing as well underdeveloped countries rely on Manual Material Handling (MMH). Lifting heavy loads plays a vital role in manufacturing operations regardless of advancement in automation and mechanization [1]. MMH such as lifting heavy loads comes in combination with many other task variables such as pushing, pulling, twisting and lowering of weight. These all pose risk of musculoskeletal disorder in the trunk region [2-4]. A task which demands handling materials manually can be classified as a high risky job if the task variables exceeds that of defined by NIOSH [5-7]. An injury occurred as a result of performing lifting task affects labor productivity as well as impose economical burden on the industry.

Workplace and task design factors are of utmost important to insure comfort as well as safety of workers and heavily depend on the ergonomic analysis of biomechanical factors [8-10]. In these biomechanical factors, force and the movement of the body are the primary factors that are taken under consideration for task analysis [11, 12]. Through joint kinematics and dynamics, the biomechanical effects can be analyzed. This gives the basic understanding of what happens to human body in terms of mechanical load [13, 14]. Objectives of ergonomics include achieving functional effectiveness of facilities which a labor uses and maintaining or enhancing human wellbeing by proper design of facilities and environment [15, 16]. In this regard some standards are followed, and most widely used standards are ISO standard 11228-1 25 kg, MMH 27 kg and NIOSH 23 kg [17]. These standards determine maximum weight limit for labors. Values are required to be adjusted according the main factors affecting the health and safety of labors. These factors are lifting frequency, lifting duration, load properties, posture of labors and working environment [18]. When the maximum acceptable load is lifted then its result is quantifiable stress and strain acting on spine [19-21]. Depending on posture of labor performing lifting task, bending moment and torque as well as force acting on body linkages while lifting can be evaluated using biomechanical models [22, 23]. It has been identified that most prominent among all injuries related to lifting task is Lower Back Pain (LBP) [24]. As per the reports of different studies, all work related tasks which involve lifting account for 33% of back pain. While performing lifting task when bad lifting techniques and heavy load is lifted then lower back pain may be caused by an injury to L5/S1 compression disc of human spine [25]. The purpose of this study is to biomechanical effects of lifting tasks on male subjects which are involved in heavy load lifting as well as to determine musculoskeletal regions of the body which are affected as a result of these loads.

II. METHODOLOGY

LBP’s starts generally from performing tasks which are repetitive in nature. In situation where it is impossible to avoid repetitive tasks, Injuries can be minimized by taking steps like remodeling workplace to minimize movements, enhancing grip, making the loads lighter as well as educating the workers about handling techniques. For the achievement of goals i.e. mimization of LBPs, the study is proceeded in three steps. In the first step, anthropometric data of workers, working in cement industry, were obtained. Then, a study was conducted based on questionnaire. In the last step, using HumanCAD software, 3D Mannequin was developed for stress analysis of postures[9]. Antropometric data was obtained from workers and provided to HumanCAD software as input for 3D mannequines modelling, as presented in this paper in section 4. Manniquine is postured in such a way to represent the true loading condition on workers for analysis.

Workers' Anthropometric Data

Bone calipers and gauges were used for collection of the anthropometric data of more than 110 labor as tabulated in Table 1. Ten anthropometric variables were measured with minimum and maximum range. For the mannequin to precisely replicate the actual worker’s anthropometry, all possible errors in measurement process were removed for the purpose that mannequin mimic accurately the real-life labors.

Table 1. Workers’ anthropometric data

S. No.	ID	DISCRIPTIONS	Minimum(cm)	Maximum (cm)	Mean (cm)	SD (cm)
1	S	Stature	156.41	178.01	166.13	6.63
2	HL	Hand length	16.32	20.21	18.57	1.08
3	SP	Span	158.22	176.52	167.77	5.62
4	SE	Shoulder Elbow Length	31.76	37.36	13.71	1.78
5	K	Knee height	48.79	57.67	52.79	2.56
6	F	Forearm Length	41.67	49.63	34.76	2.52
7	HB	Hand Breadth	07.09	8.86	7.94	0.59
8	FS	Fingertip to Shoulder Length	64.45	79.67	71.9	4.33
9	H	Hip Breadth	30.24	40.01	34.04	2.86
10	W	Weight	60.00	73.00	66.5	2.50

Questionnaire Survey

For the development of questionnaire, literature was studied and the questions about LPBs were identified. Following relevant information was included in the questionnaire:

(a) Workers’ personal information including age, working experience, height, weight.
(b) Information relating to task including weight and size of objects handled, working hour, posture, handling frequency, etc.
(c) Information related to lower back pain including, nature of pain, injuries and causes of LBPs.

Generally, workers in cement industry are illiterate, therefore, the workers were asked the questions by the researchers and responded answers were recorded on the spot. These targeted workers were involved in different MMH activating including frequent bending, pushing, lifting, and were using excessive force. Prior to our research study, permission was granted by factories management and the study center at our university has acknowledged the factory management. Anthropometric data as well as additional information was collected voluntarily.

The worker information related to age, height, weight and work experience was collected as shown in Table 2. This is the essential part of our research study to collect data of labors regarding discomfort and pain in different parts of their bodies. Frequencies and level of discomforts of different body parts are shown in Table 3.

Table 2. Working experience and physical information of labours

Age (years)	20-25	26-30	31-35	36-40	> 40
	30	35	25	9	10
Height (cm)	< 165	165 to 175	>175		
	55	30	24		
Weight (Kg)	< 60	61 to 70	70 to 75	> 80	

	35	45	26	3	
Work Experience	< 1 year	1 to 5 years	5 to 8 years	> 8 years	
	20	60	20	9	

In Table 3, anatomical regions of labors and values for perception of discomfort for the respective region of the body are presented. The verbal perception of discomfort of the body parts were assessed based on no pain, mild pain, moderate pain and severe pain as discomfort levels. The body part with highest perceived discomfort level were found out to be the lower back, upper back, thorax and neck. Other relatively low affected body parts were elbow, hip, thigh, arm, palm, shank, pelvis and shoulder. Less severe pain cases noted were on hip thigh with 11.65% value.

Table 3. Body parts associated with WMSDs

	No pain		Mild pain		Moderate Pain		Severe Pain	
	N	%age	N	%age	N	%age	N	%age
Neck	31	30.0970	23	22.3301	30	29.12621	25	24.27184
Shoulder	20	19.41748	32	31.06796	36	34.95146	21	20.38835
Elbow	29	28.15534	36	34.95146	30	29.12621	16	15.53398
Hip Thigh	33	32.03883	40	38.83495	24	23.30097	12	11.65049
Upper Back	11	10.67961	24	23.30097	34	33.00971	32	31.06796
Lower Back	11	10.67961	20	19.41748	30	29.12621	40	38.83495
Arm	15	14.56311	36	34.95146	30	29.12621	16	15.53398
Palm	41	39.80583	24	23.30097	36	34.95146	8	7.76699
Shank	65	63.1068	16	15.53398	18	17.47573	10	9.708738
Pelvis	33	32.03883	24	23.30097	32	31.06796	20	19.41748
Thorax	23	22.3301	30	29.12621	26	25.24272	30	29.12621

Digital Human Modelling

For biomechanical analysis, digital human models were used with computer-generated representations of human beings as are shown in Fig. 1- 4. HumanCAD software was used to design mannequin to mimic the posture of industrial workers with real loading conditions. The static and biomechanical loads on different anatomical regions of the body were analyzed using the software.

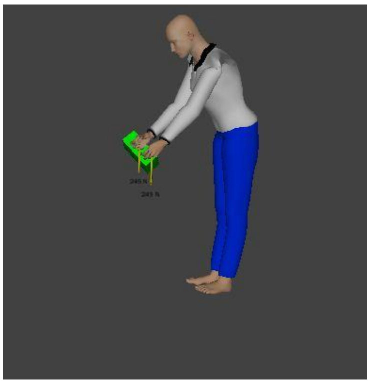

Fig. 1 Step A:
Initial position to lift the bag

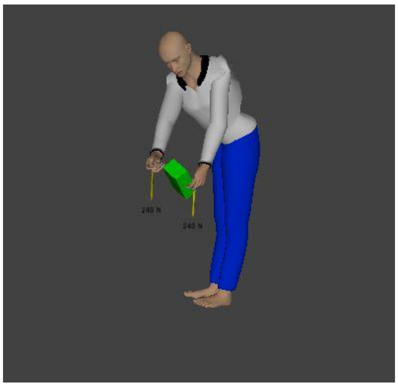

Fig. 2 Step B
Lifting of the cement bag initiated

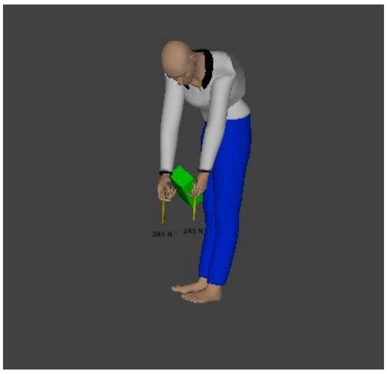

Fig. 3 Step C
Trunk twisted to approach final position

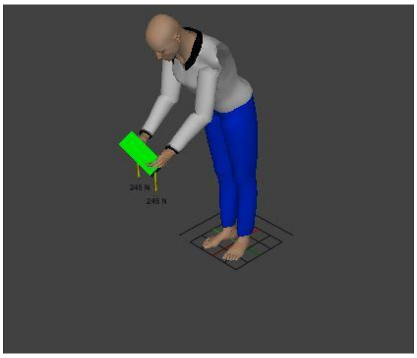

Fig. 4 Step B
Cement bag unloading

III. RESULTS

Static biomechanical loadings including force generated and torque in 15 different regions of the body are presented for four different lifting scnerios.

1. Initial postion

Static biomechanical stresses on different body parts of labors are shown in Table 4 and plotted in Fig. 5, in which the highest force applied on pelvis is 359.049 N. While the second most load bearing region is thorax with 268.708 N force. The maximum positive torque which on thorax is 314.213 Nm, whereas 39 Nm positive torque acts on the pelvis is the second largest torque.

Table 4. Static Biomechanical Forces

	Force (N)	Torque (N.m)
Head	65.629	0
LeftArm	24.356	93.309
LeftFoot	17.682	1.145
LeftForearm	10.518	74.064
LeftPalm	7.317	23.358
LeftShank	49.872	1.145
leftThigh	121.998	2.777
Pelvis	359.049	323.684
RightArm	25.267	82.626
RightFoot	17.682	1.094
RightForearm	11.429	69.756
RightPalm	252.317	20.023
RightShank	49.872	1.094
RightThigh	121.998	2.626
Thorax	268.708	314.213

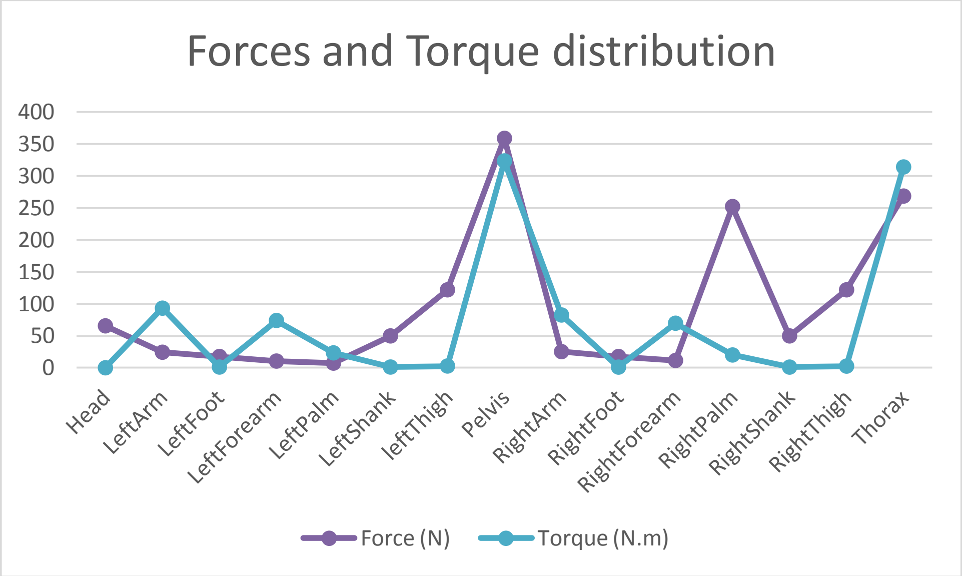

Fig. 5 Static biomechanical graph

Static biomechanical stresses on different body parts of labors are shown in Table 5 and plotted through a line graph in Fig. 6, in which the highest applied force on pelvis is 359.049 N while second most load bearing region is thorax which is 268.708 N force. The maximum positive torque which acts on the thorax is 322.031 Nm whereas 39 Nm is the positive torque which act on the pelvis is the second largest torque.

Table 5. Static biomechanical forces

	Force (N)	Torque (N.m)
Head	65.629	0
LeftArm	24.356	75.441
LeftFoot	17.682	1.234
LeftForearm	10.518	44.926
LeftPalm	7.317	13.126
LeftShank	49.872	4.038
leftThigh	121.998	12.094
Pelvis	359.049	356.301
RightArm	25.267	136.264
RightFoot	17.682	1.159
RightForearm	11.429	74.729
RightPalm	252.317	21.072
RightShank	49.872	3.7
RightThigh	121.998	9.096
Thorax	268.708	322.031

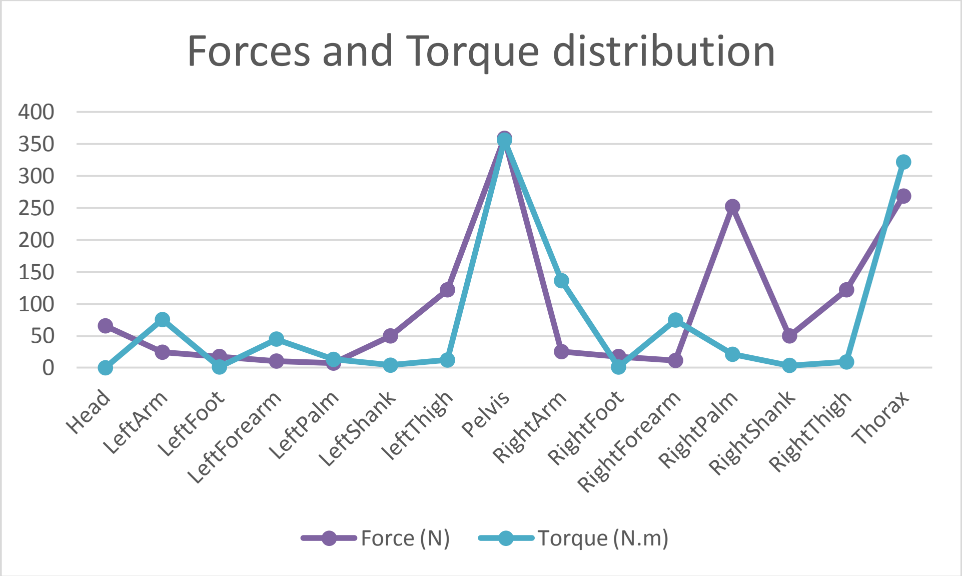

Fig. 6 Graph of static biomechanical

Static biomechanical stresses on different body parts of labors are shown in Table 6 and plotted through a line graph in Fig. 7, in which the largest force applied on pelvis is 268.708 N whereas second most load bearing region is thorax with 268.708 N force. The maximum positive torque which act on the thorax is 261.287 Nm while 258.228 Nm positive torque acting on pelvis is the second largest torque.

Table 6. Static biomechanical forces

	Force (N)	Torque (N.m)
Head	65.629	0
LeftArm	24.356	37.561
LeftFoot	17.682	1.234
LeftForearm	10.518	22.095
LeftPalm	7.317	12.376
LeftShank	49.872	4.038
leftThigh	121.998	12.094
Pelvis	359.049	258.228
RightArm	25.267	58.387
RightFoot	17.682	1.159
RightForearm	11.429	34.295
RightPalm	252.317	12.346
RightShank	49.872	3.7
RightThigh	121.998	9.096
Thorax	268.708	261.287

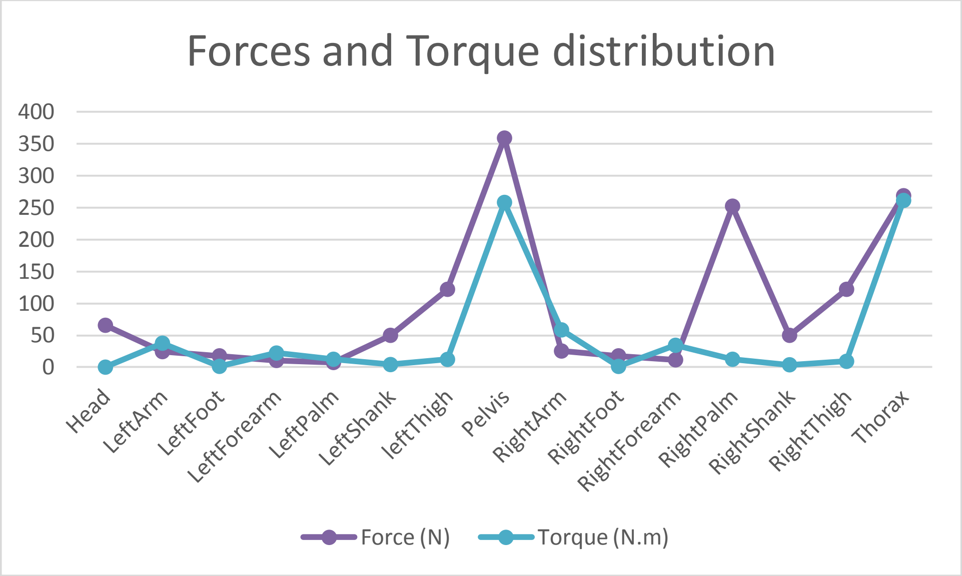

Fig. 7 Static biomechanical graph

In Table 7, the static biomechanical stresses on different body parts of labors are shown in which the highest applied force on pelvis 268.208N while the second most load bearing region is thorax with 268.708 N force. The maximum positive torque which act on the thorax is 317.074 Nm while 39 Nm positive torque which act on the pelvis is the second largest torque. The data has been shown through a line graph in Fig. 8.

Table 7. Static biomechanical forces

	Force (N)	Torque (N.m)
Head	65.629	0
LeftArm	24.356	100.905
LeftFoot	17.682	1.234
LeftForearm	10.518	58.903
LeftPalm	7.317	18.115
LeftShank	49.872	4.038
leftThigh	121.998	12.094
Pelvis	359.049	342.811
RightArm	25.267	102.589
RightFoot	17.682	1.159
RightForearm	11.429	70.471
RightPalm	252.317	20.232
RightShank	49.872	3.7
RightThigh	121.998	9.096
Thorax	268.708	317.074

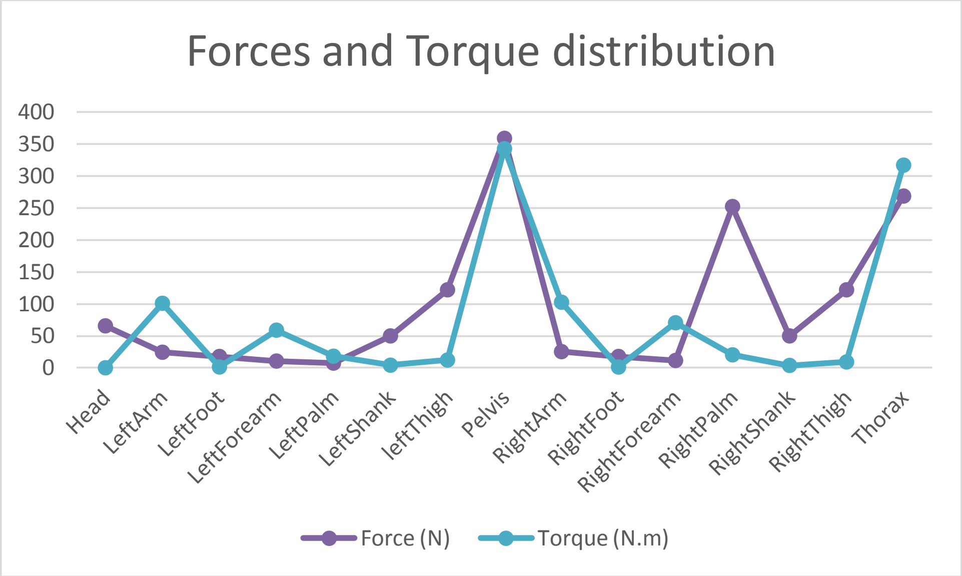

Fig 8 Static biomechanical graph

NIOSH Calculations

As per NIOSH 1991 equation, the safe value for manual lifting is lifting Indices is less than or equal to 1. By using the formula of Recommended Weight Limit RWL=LC*HM*VM*AM*FM*CM, we first calculate RWL then by dividing cement bag by the RWL gives LI. For 50 kg mass of cement bag, the lifting Indices is 2.9 which is considerably large and is not within safety limits.

IV. DISCUSSION

As per the recommendations of NIOSH, for lifting-related low back, lifting tasks with lifting index greater than or equal to 1 shows a high risk. Hence, such lifting tasks should be reshaped, resized, modified or redesigned to get lifting index less than or equal to 1. In this study, the lifting index evaluated is 2.09 at the origin which is extremely hazardous for the health of labors. Due to posture in Figure 1, the torque on the pelvis is 323.684 N.m and on the thorax, the torque is 314.213 N.m while torque due to posture on Figure 2 is 356.301N.m 0n pelvis and 322.031 N.m on the thorax. Similarly, in Figure 3 the torque on the pelvis is 258.2288 N.m and 261.287 N.m on the thorax and in Figure 4 the torque on the pelvis is 342.811 N.m and on thorax 317.074 N.m. Musculoskeletal disorders are found due to various risk factors which include contact stress, vibration, force, repetition and jobs which put labor muscles under redundant physical forces. There is no doubt that most lifting tasks performed at cement industries pose high risk for the health of labors. In this research, we have found that majority of labors has musculoskeletal disorder symptoms which ranges from small pain to severe pain. The frequent musculoskeletal disorder complaints from labors were lower back pain, back pain and upper back pain. Also, neck pain and thorax pain were the second most complained musculoskeletal disorder problem from labors. Improper twisting and stretch out bending are often indicated as causes. To put the observations on more technical bases the workers postures were simulated through HumanCAD mannequin pro to study the stresses on different body parts which unevenly distribute.

V. CONCLUSION

The purpose of this study is to show the dependency of body discomfort on the nature of lifting tasks. Also, lifting posture employed while performing the lifting task and lifting frequency are also observed to determine those body parts which can experience discomfort. Other factor which results in discomfort are lifting duration, working environment, load properties and physiological factors. The results of our study clearly show that labors performing lifting tasks in an industry are predisposed to lower back injuries and lower back pain. Repeated stress on shoulders of labors performing lifting tasks predisposes them to shoulder tendinitis. The connection between spinal lordosis, lower back pain and spinal kyphosis is not included and is recommended as a subject of further research.

All lifting tasks performed by labors in the industry not meeting the ergonomics standards need to be redesigned for the incorporation of engineering controls. Also, the criteria for labor selection must be used for workers' identification who can perform stressful lifting tasks without significant increase in risk of work related injuries. However, the selection criteria must base on research studies, theoretical considerations or empirical observations which include job related strength testing and aerobic testing. This is also mandatory to Job Security Index (JSI) procedures while allocating lifting tasks to labors in an industry. Further research include the same research study used for female labors in industries when there is a gender equality environment.

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Muhammad Ihtiram Ullah. "Evaluation of Repetitive Lifting Tasks Performed In Cement Industries." *International Journal of Engineering Research and Development*, vol. 16(12), 2020, pp 17-25.