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Original Article

Effect of Lifting Weight, Height and Asymmetry on Biomechanical Loading during Manual Lifting

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ABSTRACT

Introduction: In India, physical manual activities in asymmetrical postures overtax the human musculoskeletal system, which may exceed workers' physical limitations. Thus the purpose of this study was to examine the physical stresses experienced by the subject, based on subjective and biomechanical loading estimates while lifting weights to various heights, in an asymmetric direction and propose the safe limit for manual lifting.

Methods: A laboratory experiment was conducted utilizing twelve male subjects in the age group of 20 to 25 years who lifted 5 different weights between 10 to 20 kg from below the knee to various lifting heights (below the knee to ear level). The lifting task was performed in three asymmetric angles (45, 90, and 135-degree) using free-style lifting techniques. An ANOVA technique was used to analyze the influence of three parameters (Lifting weight, lifting height and asymmetric angle) on two responses; subjective estimates and biomechanical loading. The subjective estimate was obtained using workload assessment by body discomfort chart. The biomechanical loading (loading rate) was estimated from ground reaction force data, obtained from the force plate.

Results: Both the responses; subjective estimates and biomechanical loading followed a consistent pattern in predicting physical stress. The result revealed that lifting weights with higher destination heights and asymmetry angles increased the physiological workload and discomfort. Experiments have shown that the loading rate is reduced by 8 to 10% for each increase in the 45-degree angle of asymmetry.

Conclusion: In general, safe lifting of 15 kg weight up to ear level and 15 kg weight up to shoulder level are recommended for 45- and 90-degree asymmetry respectively to prevent any chronic injuries. A maximum of 12.5 kg lifting weight up to shoulder level is also proposed.

Keywords: Asymmetric posture, Loading rate, Manual material handling, Workload assessment.

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Introduction

Construction workers are frequently exposed to forceful and repetitive exertions with awkward postures, which lead to work-related musculoskeletal disorders (WMSDs) such as strains, tendonitis, and back and wrist injuries.[1] Moreover, Back pain is the most prevalent and costly musculoskeletal disorder as a result of poor working conditions.[2] In the construction field, the worker experiences frequent bending and/or twisting of the body, lifting the load above and below the shoulder and knee level.[3] Considering the presence of heavy equipment, physically demanding tools, and changing work environments, the job sites in the construction industry are more crucial to society, the economy and the business environments.[4]

Asymmetry occurs when an external load is handled in a non-sagittal plane. A lifter must usually twist his or her trunk off the sagittal plane while performing an asymmetric lifting task. Twisting the trunk in asymmetric lifting is hazardous in several investigations[5]. Large compression spinal force combined with axial shear torsional force impacted the intervertebral discs as well as trunk muscular activity during asymmetric lifting.[3,6] Second the maximal voluntary isometric strength was reduced during asymmetric lifting, also average upward acceleration and peak velocity or human lifting capability were lower in asymmetric lifting.[4,7,8,9] Third, poor posture stability and asymmetric muscular stresses on the spine can be caused by asymmetric lifting.[7]

In the building construction field, Indian workers often employ two hand lifting techniques while twisting their torsos, especially during loading and unloading in restricted workplaces or for irregular material handling. Restricted workplaces may cause low back pain. The study investigated that lifting at a low height, such as below the knee or even from the floor, results in twice the amount of spinal loading[10]. It is commonly agreed that the cause of lower back pain and injury is frequently related to the posture of lifting, the load, muscle fatigue, etc.[11,12]

In the literature, the loading conditions resulting from symmetric lifting are well documented, yet free-style asymmetric lifting above the subject's waist-level height has not been intensively studied.[13] It was also observed that previous studies of asymmetric lifting were limited to a 90-degree asymmetric angle, but none of the studies investigated lifting task parameters at a 135-degree asymmetric angle.[5,14] In line with this motivation, the purpose of the present experimental study is to evaluate the risk of asymmetrical lifting for two lifting task parameters; weight load and destination heights based on subjective and biomechanical loading estimates while lifting objects asymmetrically. The lifting task was considered similar to the task used in the construction industry in India. The present ergonomic study may help workers to avoid hazards that cause injuries, illnesses, and fatalities in the construction field. The construction industry's safety and health performance might be considerably improved if appropriate and acceptable information about workplaces, manual jobs, and ongoing training and education is provided.

Methods

In the present study twelve healthy male university students (mean age 23.5 ± 1.78 years, weight 70.67 ± 2.57 kg, and height 1.76 ± 0.027 m), were participated in the study. The inclusion and exclusion criteria were designed to reflect a healthy and working population. None of the participants had experience in manual lifting tasks, and none had a history of neurological disorders, back pain, or any other musculoskeletal injury. The subject's mean height and weight were found to be approximately the same due to the closed age group. Before the experiment, each subject reviewed and signed an informed consent form approved by the University's Institutional Review Board. All of the subjects had been trained for the task before the actual experiment began. The remuneration was given to the subject for their participation. The lift's origin was in the sagittal plane, and asymmetrical lifting was investigated at 45°, 90°, and 135° departures from the sagittal plane to the right.

The lifting cycle began with the pan being lifted (dimension 30×30×25 cm) of a concrete-cement mixture, from the below knee height (origin) to a bench at the desired destination level. Subjects performed a lifting task with 5 different lifting weights, in which 10, 12.5, 15, 17.5 and 20 kg, the pan was lifted to 5 different vertical lifting heights; below the knee, knee, waist, shoulder and ear level of the subjects. The subjects were restricted to move their feet during the lifting cycle. For asymmetric lifting, the individual completed an initial symmetric lifting, then a desired asymmetric body turn to the right, and finally placed the container on the table. This manual lifting task was found to be consistent with the building construction industry for performing the concreting operation.

Experimental Setup

The experimental study was performed in the Biomechanics Lab of the National Institute of Technology Rourkela; NIT Rourkela.[15] The study was carried out using laboratory simulated experiments in September 2019. The Kistler's multiaxial force platform (500×590×50 mm) measures GRFs and was used in this study (model AA9260). The analog output from the force platform passed through an internal amplifier and reached Kistler's data acquisition system (type 5691A1), where data was collected with a sampling frequency of 1000 Hz to generate a digital signal. The Nyquist theorem was used to determine the sampling frequency. For smoothing data, the Butterworth filter was used, which attenuated frequencies over the set cut-off frequency while allowing frequencies below the cut-off to pass through. Finally, the data was reflected in Bioware software.

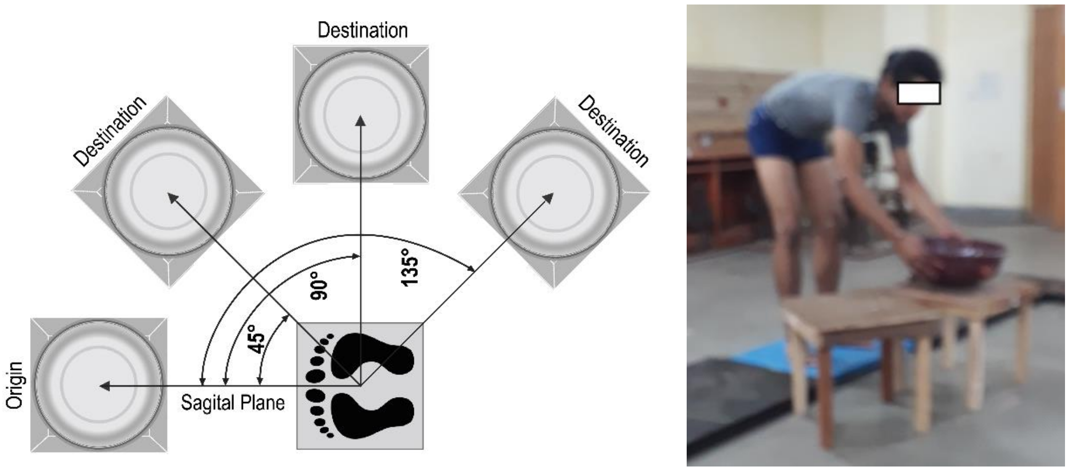

Figure 1. Schematic diagram and Laboratory set-up of the force plate

Biomechanical Evaluation

The manual lifting task was evaluated using data obtained from the force plate and subjective workload assessment chart. The vertical ground reaction force (GRF) (F_z) beneath feet produced during lifting was measured using force platforms. Fz always thrusts the body upward through the feet. The setup arrangement is shown in figure 1. The ratio of peak loading and time to peak loading during human activities is referred to as the loading rate (LR). Loading rate (LR) was calculated by determining the time required for the vertical force to rise by lifting the weight from the origin to the destination. The peak rate of vertical GRF (LR) indicates the possibility of chronic damage as a result of these activities.[16]

$$LR = \frac{F_{zmax} - F_{zmin}}{t_2 - t_1} \quad \text{(Equation 1)}$$

F_{zmax} and F_{zmin} are the peaks and the lower value of F_z of one lift and (t_2-t_1) is the time between these values. Finally, the magnitude of the loading rate obtained from GRF was compared to subjectively evaluated physical discomfort and overall workload.

The Subjective evaluation was performed by giving a questionnaire to each subject, figure 2.[17] The questionnaire includes a chart for measuring physical discomfort as well as a rating scale for the total workload. After executing the lifting task for each test condition, the subject was asked to rate the level of discomfort in each of the body parts, figure 2. The degree of discomfort is measured on a five-point scale that ranges from no sensation or soreness (zero) to extreme pain or soreness (4). Following the discomfort assessment, the subject was asked to rate the overall workload for the task. The overall workload scale is also a five-point scale, with '1' being very light and '5' being very hard. The physiological workload was thought to be a major risk factor for WMSD.[7]

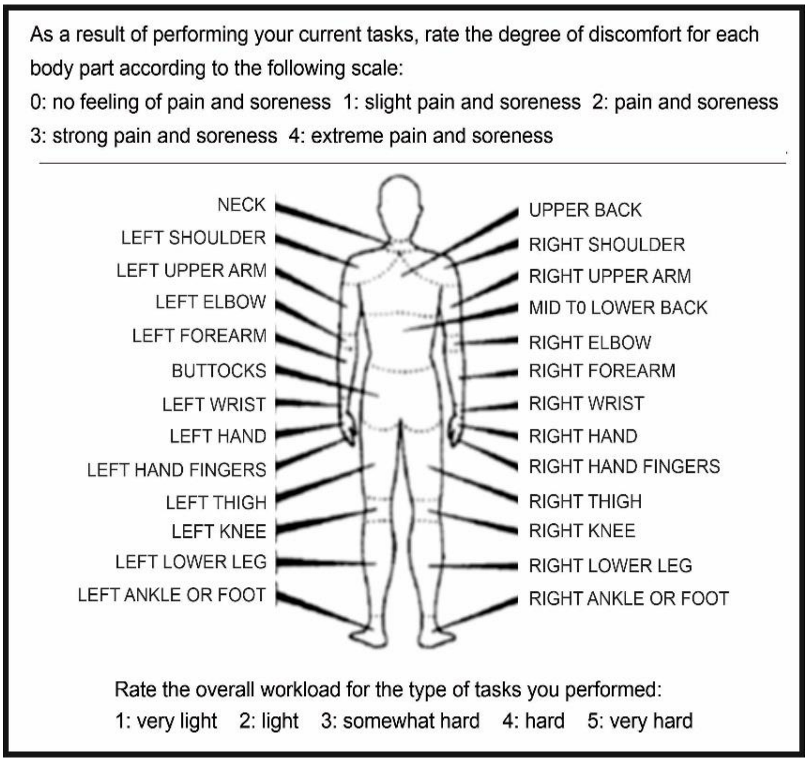

Figure 2. The body discomfort and overall workload questionnaire.[17]

Test Procedure

The weight was lifted using an open circular-shaped plastic pan with no handles. To make lifting easier, the weight of the concrete mixture (cement, sand, and grit) was placed in the pan. The pan is similar to that used in construction fieldwork. Before the lifting task, the subjects were given thorough instructions and requested to complete two to three trials while standing on a force plate.

Each participant was required to lift a load in 75 different combinations of lifting parameters (5 weights, 5 destinations and 3 asymmetrical angles) in an asymmetrical freestyle. A total of these 75 lifting tasks were randomly assigned to each subject during data collection to prevent *order* effects. After each lifting task, a sufficient rest period was given to allow the muscles to recuperate. The subjects were told to lift the weight with both hands while keeping their feet in the sagittal plane. During the lifting cycle, the subject was instructed to maintain a fixed, symmetrical foot position. The Fz was measured for each test condition for all the subjects against a time scale (in seconds).

Response Data Analysis

A repeated measures ANOVA was performed using the statistical package for social sciences (SPSS Inc., Chicago, USA, version 16) to evaluate the subject's response. The loading rate and overall workload were tested for the effect of lifting asymmetry, lifting weight, lifting heights and additional contrast tests (pairwise tests) for significant asymmetry effects. A p-value of 0.05 was considered significant. The repeated-measures design was well suited because each subject's assessments were collected repeatedly for all of the test situations. Wilcoxon signed-ranks test was also carried out on all the data to determine whether the independent variables had a significant effect on the dependent variables. For interpreting the ANOVA, two further statistical measures were used: partial eta squared and the observed power. Partial eta squared (η^2p) is a way to measure the effect size of different variables and to understand the major effects or interactions[18]. An observed power of 0.95 in the range of 0 to 1 indicates a 5% possibility of detecting a false positive result.

Results

Within-subject test of statistical analyses was performed to determine the general effects of lifting weight, lifting height and asymmetry angle on the loading rate and overall workload.

Table 1. Within-subjects effect of test parameters on Loading Rate and Overall Workload

Sources	Loading Rate					Overall Workload				
	df	F	Sig.(*p*)	η^2p	O.P	df	F	Sig.(*p*)	η^2p	O.P
W	4	10535.25	.00	.99	1.0	4	509.17	.00	.98	1.0
H	4	29785.34	.00	1.0	1.0	4	330.10	.00	.97	1.0
A	2	9523.67	.00	.99	1.0	2	165.32	.00	.94	1.0
W * H	16	2127.95	.00	.995	1.0	16	14.07	.00	.56	1.0
W * A	8	27.04	.00	.711	1.0	8	11.48	.00	.51	1.0
H * A	8	446.85	.00	.97	1.0	8	45.47	.00	.81	1.0
W * H * A	32	29.36	.00	.73	1.0	32	20.37	.00	.65	1.0

W- Lifting weight, H- Lifting Height, A-Asymmetry, df- degree of freedom, O.P-observed power

Table 1 interprets the main effects and interaction effects for the judgment of responses. The ANOVA result revealed that all the main and interaction effects are statistically significant. The results show that the highest contribution comes from the individual variables, followed by the contribution of the interaction variable, with a high value of observed power (O.P). The table clearly showed that each increase in lifting asymmetry significantly impacted the loading rate and overall workload (p<0.05). This effect was consistent for lifting weight and lifting height conditions.

The vertical reaction force was measured for all 12 subjects for all experimental conditions. One such sample plot of one subject lifting the weight of 17.5 Kg at shoulder height for one minute has been shown in Figure 3.

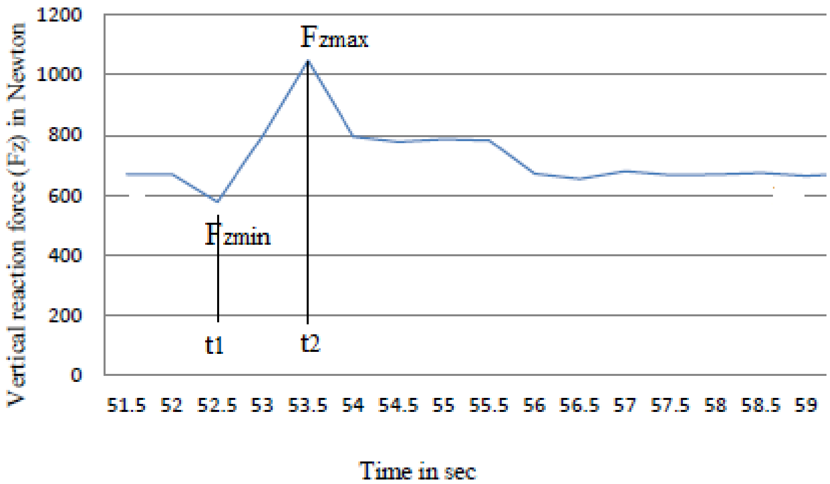

Figure 3. Vertical force-time graph of sample reading

The value of the mean loading rate and overall workload of all 12 subjects was plotted as shown in figures 4 & 5. The plot indicates that the loading rate was significantly increased with increasing lifting weight and also by increasing destination heights for all three asymmetry angles. There is no significant difference in loading rate predictions between the knee and waist height for all the asymmetric lifting weights (p>0.05). When the destination was raised above this lifting height to ear height, however, the loading rate increased dramatically (p<0.05). Moreover, when subjects lifted different weights to below knee height, no significant effect was detected (p>0.05). It has also been seen that the least loading rate was observed for lifting the smallest (10 kg) weight and that there was no significant difference in loading rate for all other asymmetric lifting heights (p>0.05). This was also confirmed by the least overall workload, figure 5. Plot 4 demonstrated that there is a substantial reduction in loading rate with an increase in lifting asymmetry irrespective of lifting weight and lifting height (p<0.05).

The mean overall workload for all 12 individuals was plotted in Fig. 5. It was interesting to find that the mean loading rate and the overall workload rating were well correlated to some extent. The overall workload yields an almost similar rating between the knee and waist height for all of the asymmetric lifting weights (p>0.05). The rating of overall workload showed a significant rise while lifting asymmetrically more than about 12.5 kg weight (p<0.05). The result also clearly demonstrated that the overall workload increased with an increasing asymmetric angle for all lifting weights and heights (p<0.05).

The mean degree of discomfort for each body part was calculated for all 12 individuals. From the subjective rating of discomfort for 45-degree asymmetry, it was observed that lifting above 15 kg weight irrespective of lifting height, brings pain in the upper arms and back. The intensity of pain increased with increasing weight and lifting heights. In the case of 90-degree asymmetry, it was observed that lifting above 15 kg weight at shoulder height causes extreme pain (rating 4) in both arms and knees. An increase in lifting weights to 20 kg, raised this pain in the back and wrist. Further, lifting weights between 15 to 20 kg at ear height brings intense pain (rating 4) in the shoulder. In the case of 135-degree asymmetry, lifting 15 kg weight to shoulder height causes strong pain (rating 3) in the shoulders, upper arms and mid to lower back. Extreme pain (rating 4) was experienced in the upper arms when lifting the same weight at ear height. Moreover, a further increase in weight brings intense pain to ear height.

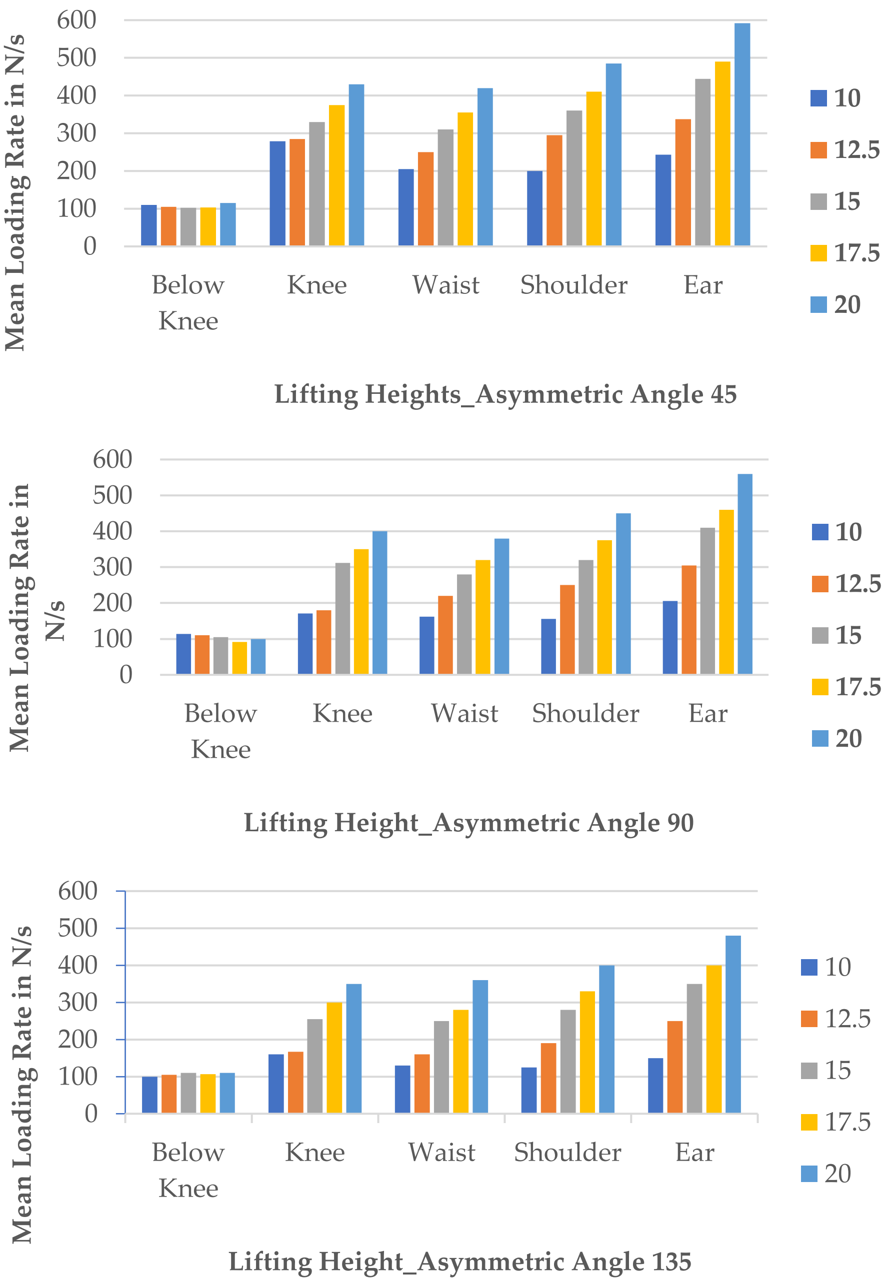

Figure 4. Mean loading rate plot with variation in weight (Kg) and asymmetric lifting height

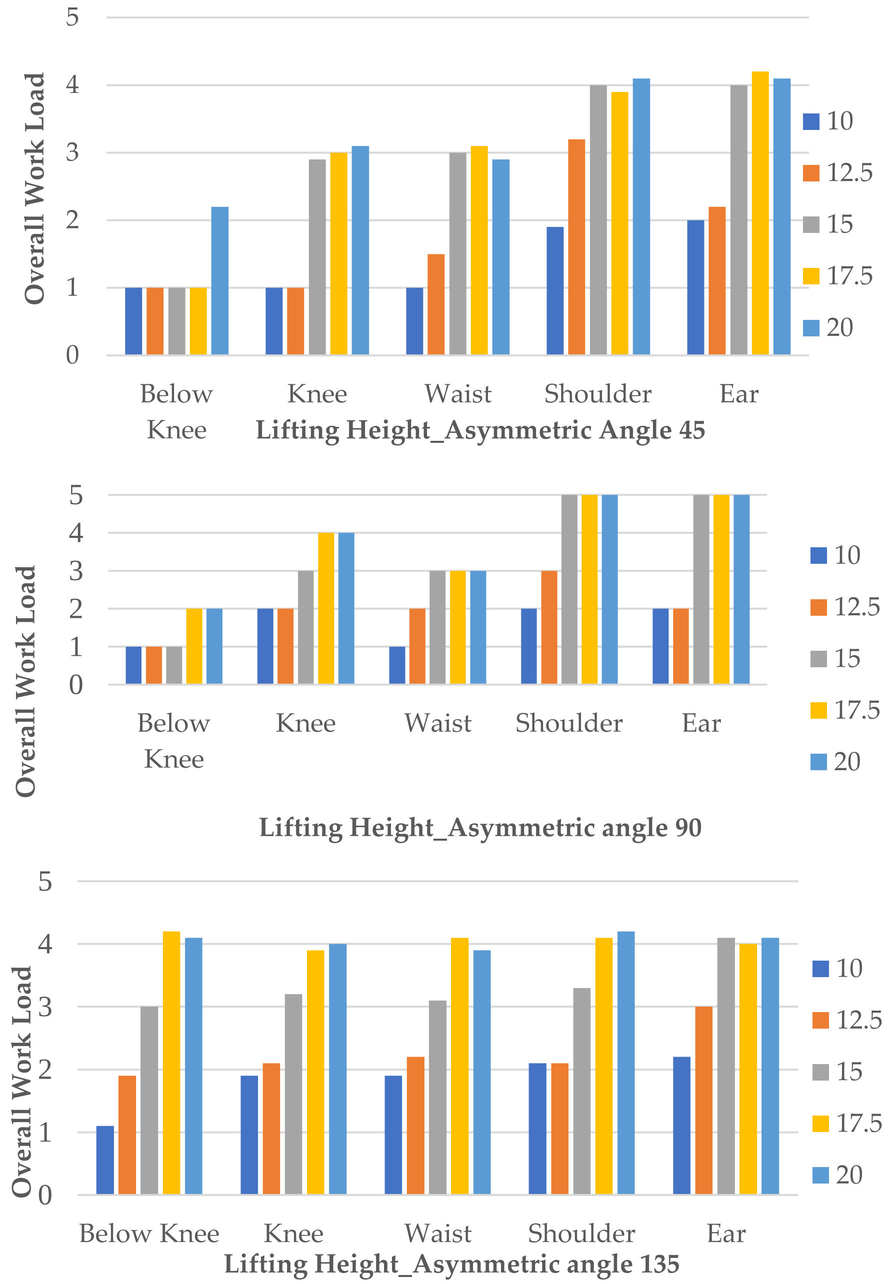

Figure 5. Mean workload plot with variation in weight (Kg) and asymmetric Lifting height.

Discussion

One of the prime beneficiaries of ergonomics is the construction industry, with its physically demanding work. Excessive physical demands beyond one's capabilities may lead to productivity, safety and health issues in construction. The study's major goal is to reduce worker fatigue as well as the danger of subsidence by employing the most optimal lifting parameters during lifting tasks. The present study will mimic occupational conditions adopted in the building construction field. The results can help further progress in the existing occupational lifting guidelines and raise awareness of musculoskeletal or chronic stresses in the workplace as a worldwide problem.

In the present study, lifting weight and lifting height had a major impact on the loading rate. Based on the result obtained, in general, the heavier weights did produce a higher loading rate than the lower ones throughout the process of lifting despite the lifting height. It has been observed that lifting weights with higher vertical lifting heights and asymmetry angles increased the physiological workload and discomfort. From the body discomfort and overall workload responses, the biggest complaints rated by subjects are mid to lower back followed by the upper arm and then shoulder, forearm and knee, among the other body parts. While lifting the weight from the origin, trunk flexion was rare, and lifting was primarily accomplished through knee flexion. This lifting becomes more stressful, at the shoulder or ear height, due to the dynamic trunk motion. Lifting while bending creates a variety of back problems. It multiplies the weight of the object being lifted by the upper body's weight. Bending and/or extending your upper body increases the effective load on your back, causing lower-back stress and muscular fatigue. The most prevalent movements that produced back injuries were bending and twisting. When the subject lifted the weight in a restricted posture, without moving both feet, such confined workspaces increase low back pain in the subjects' bodies[19]. During asymmetric lifting, lateral bending action on the lumbar column and a rotation of each vertebra on its adjacent vertebra happen. This vertebral rotation has a high risk of injury.[20] Aside from the rotational consequences, imbalanced back muscle loading can provide highly concentrated stress, which can overstrain a specific muscle or muscles required to support the column.[20]

In the present study, various combinations of factors were explored to determine the least and the most exerting task conditions. For example, when the lifting weight was increased from 12.5 to 20 kg, for the same lifting height, the mean loading rate increased by about 32 to 40%. Similarly, when the lifting height was increased from knee to ear height for the same lifting weight, the loading rate increased by around 24 to 30 percent. This outcome applies to each asymmetric angle studied. The result revealed that there is no significant difference in loading rate for lifting the smallest (10 kg) weight irrespective of lifting heights. Thus lifting 10 kg weight from origin to ear height for an asymmetrical angle up to 135-degree is safe, as the spinal force generated was less than the recommended limit according to the NIOSH lifting criterion.[21] From the observed data, it is interesting to find that the mean loading rate and the overall workload rating are well correlated to some extent. Both are predicated on the idea of subjects exerting more effort when performing dynamic lifting tasks.

In the previous study by the author, the experiment was conducted for a symmetric posture with the same lifting weight and height conditions.[22] The result found a higher loading rate and less perceived discomfort as compared to the present asymmetric lifting study. In asymmetrical lifting tasks, the subject had to lift the pan and then turn the body through given degrees before placing the lifting weight on the table. Therefore, the cycle time for asymmetrical lifting was longer than for symmetrical lifting, leading to the occurrence of a lower loading rate. According to the findings of the present study, each increase in the 45-degree asymmetric angle reduces the loading rate by 8 to 10%. The results from the present study are consistent to some extent with the results of previous asymmetric studies.[23-25] This study revealed that asymmetric lifting led to a lower loading rate while the overall workload increased as compared to symmetric lifting. Regardless of whether the lift origins are on the left or right side, the revised NIOSH Lifting Equation reduces lifting weight limits by around 10% for every 30 degrees of asymmetry involved in the lift.[23] Several studies have shown reductions in maximum acceptable weights ranging from 8 to 22% when the load is asymmetrically applied to the trunk.[24,25]

The recommended weight limit is a weight limit below which virtually all healthy employees may accomplish for an extended period without increasing their risk of low back pain, according to the revised NIOSH lifting equation.[21] Although the loading rate and overall workload rating are two independent variables, the study found that they followed a similar pattern in predicting physical stress as a result of lifting tasks. Therefore, the safe limit for various task parameters has to be established to prevent/reduce injuries to workers engaged in lifting tasks. The safe limit has been proposed based on results obtained from loading rate and subjective rating, assuming alarming levels for perceived difficulty and workload as rating '2'. For example, if the weight is to be lifted from the origin to all given vertical destinations, then the weight should not exceed 15 kg at a 45-degree asymmetric angle. For a 90-degree asymmetric angle, this is restricted up to shoulder level. In the case of a 135-degree asymmetric angle, a maximum of 12.5 kg weight is permissible to lift safely up to shoulder level to prevent any chronic injuries.

Limitations of the Study

The majority of the construction workers in India are male, specifically lifting tasks in a constraint posture. Therefore, only male participants in a similar age range were chosen as the study's subjects. The study's limitations are that it did not take into account the participants' other existing health conditions, as well as their physical attributes like height, weight, and BMI. The authors believe that these factors contribute to the participants' different physical characteristics, such as height and weight. Analysis of these factors' effects on the physical capabilities of the subjects requires much more in-depth research. Another limitation of this study is that the participants were all male university students with no experience in manual lifting tasks. Investigating a broader spectrum of the population would result in a reliable generalization of our findings.

Conclusion

The workers were exposed to various risk hazards which affect health and safety issues in the building construction works. There has been a paucity of research on the physiological and subjective workloads of Indian male construction workers. This assessment of the physiological and subjective workload of MMH operations is essential for recommending remedial measures and assisting in the implementation of ergonomic guidelines for construction workers.

Even though both responses are distinct, the study found that they followed a consistent pattern in predicting physical stress as a result of lifting tasks. The physiological demands were shown to be increased while lifting loads with a greater vertical distance. Experiments have confirmed that the loading rate decreases linearly as the angle of asymmetry increases. Each increase in the 45-degree asymmetric angle reduces the loading rate by 8 to 10%. The subjects are most susceptible to pain in the lower back followed by the upper arm and then shoulder, forearm and knee. In general, safe lifting of 15 kg weight up to ear level and 15 kg weight up to shoulder level are recommended for 45- and 90-degree asymmetry respectively to prevent any chronic injuries. A maximum of 12.5 kg lifting weight up to shoulder level is also proposed.

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