Designing safe lifting of centrifugal-pump casing in a medium scale factory in Agra

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Abstract: This study concerns with the repetitive asymmetric lifting task of centrifugal-pump casings (CPC) in a medium scale factory in Agra. CPC are lifted to drilling machine from six heights, as six CPC are stacked in a column. Task variables of revised NIOSH lifting equation are noted down from the factory site to compute lifting index for all six heights. HM and AM are found to be less or more constant, however VM, DM and FM vary with respect to vertical travel distance. Lifting turns out to be physically stressful for all six heights. In fact, it becomes increasingly stressful with respect to increase in vertical travel distance. Task is redesigned to make it safer by reducing asymmetry to an extent. To assess risks involved in the lifting task physiologically, factory site lifting is simulated in the Industrial Kinesiology Lab (DEI). Experiments are conducted on 10 male workers. Heart rate is recorded before and after each experiment. A mismatch between the results of revised NIOSH lifting equation and physiological results is observed. Heart rate of subjects after the experiments is found to fall in the safer range. Re-sults raise questions on the applicability of revised NIOSH lifting equation.

1 Introduction

Even after the advances in the manufacturing automation in the last three decades, manual material handling (MMH) tasks, which mainly include lifting, pushing, and pulling activities, are still common in small scale and medium scale industrial units. The stressfulness of a MMH task is evaluated by comparing job demands to human abilities or scientific norms established in the literature. Greater the departure from human capabilities or the norms, higher is risk of ergonomic hazards. Such departures are not uncommon in a developing country like India, wherein a manual worker, having limited job opportunities, is available at lesser cost, and yearns to increase his earnings by subjecting himself to extreme work conditions. Factor like long working hours, improper rest breaks etc. increase workers' risks to ergonomic hazards.

Manual lifting has been recognized as a major source of low back pain by researchers and organizations. In 1981, National Institute of Occupational Safety and Health (NIOSH) first published a Lifting Equation to compute the Recommended Weight Limit (RWL) [10]. It was revised in 1991 to apply to a larger percentage of lifting tasks, and the resulting equation was published as Revised NIOSH Lifting Equation [11, 13], which computes RWL as illustrated below.

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$$RWL = LC \times HM \times VM \times DM \times FM \times AM \times CM \quad (1)$$

Where,

$LC(Load\ Constant) = 23$ kg

$HM(Horizontal\ Multiplier) = \frac{25}{H}$

$VM(Vertical\ Multiplier) = 1 - (.003\ |\ V - 75\ |)$

$DM(Distance\ Multiplier) = .82 + \left(\frac{4.5}{D}\right)$

$AM(Asymmetric\ Multiplier) = 1 - (.0032)A$

All distances are measured in centimeters. Frequency Multiplier (FM), and Coupling Multiplier (CM) are noted from the standard tables. Notations stand for their usual meanings. LC is the safe load limit of 23 kg under optimal conditions. Value of each multiplier ranges from 0 to 1. In Europe and North America, revised NIOSH lifting equation is well established, but its applicability across different countries is under question [5].

Manual lifting workers are at a higher risk of cardiovascular diseases due to physical and mental stress induced by higher job demands placed on them [4], which could lead to adverse physiological conditions such as increased heart rate, elevated blood pressure levels, excessive sweating and higher intake of oxygen. Heart rate is, among the many vital signs (respiration rate, blood oxygen saturation, arterial blood pressure etc.), one of the most commonly measured and monitored [3]. The body responds by increasing the heart rate such that any kind of task that goes on for an extended period of time can cause stress to the level of heart failure. It is of interest to the ergonomics field to see how physical and mental demands in a work place can affect heart rate. Since heart rate is extremely sensitive to different kinds of stress, measuring heart rate can be a good way to assess risk of manual lifting tasks.

In a survey of industries in Agra, we identified places where heavy and repetitive lifting is carried out on a continuous basis. This paper focuses on lifting of centrifugal pump casings (CPC) in a medium scale factory in Agra, where centrifugal pumps weighing 35 kg are manufactured. Centrifugal pumps are designed to increase the pressure of a fluid through interaction with rotational kinetic energy. Casing, stuffing box and impeller are the three critical components of a centrifugal pump. The purpose of casing is to help balance the hydraulic pressure on the shaft of the pump and have stationary diffusion vanes surrounding the impeller periphery that convert velocity energy to pressure energy [7]. To perform drilling operation on CPC, six CPC are stacked over each other near drilling machine in the workshop (Figure 1a). Two/three such stacks can be seen near drilling machine at any given point of time during working hours. Each CPC weighs 15 kg and its outside diameter is 40 centimeters. The worker lifts each casing from the stack one by one starting with the one placed on the top of the stack and places it on drilling machine platform which is at 92 centimeters height from the floor. Workers perform free style lifting for 8 hours per day with 30 minutes flexible lunch break. After drilling operation CPC is lowered and placed on ground.

2 Methodology

The experiments are performed in the Industrial Kinesiology (IK) Lab, DEI on 10 male industrial workers (age range 18-40 years, 7 years minimum work experience). Workers are given a brief demonstration of equipment for monitoring heart rate (BioHarnessTM Physiology Monitoring System with AcqKnowledge® Software, BIOPAC® Systems, Inc., Goleta, CA), procedures, and experimental risks prior to investigations. A signed consent for this study is taken from each subject. All subjects are healthy and not currently under any medications. Anthropometric and other data are also noted down viz. age, height, weight and job-experience in years.

We simulated factory site lifting of CPC in the IK Lab by recording actual values of task variables of revised NIOSH lifting equation such as H, V, D, A, F (Figure 1b). Lifting indexes are calculated for 6 different heights of CPC. Environmental parameters are also simulated. Each subject performs a 10 minute repetitive free style lifting with 20 seconds pause after each lifting. The heart rate (bpm) is recorded before and after lifting using BioHarnessTM (Figure 1c). A snapshot of ECG Raw is shown in Figure 1d. The experimental tasks are intended to simulate mental and physical stress, and are designed as closely as possible to a realistic work place situation.

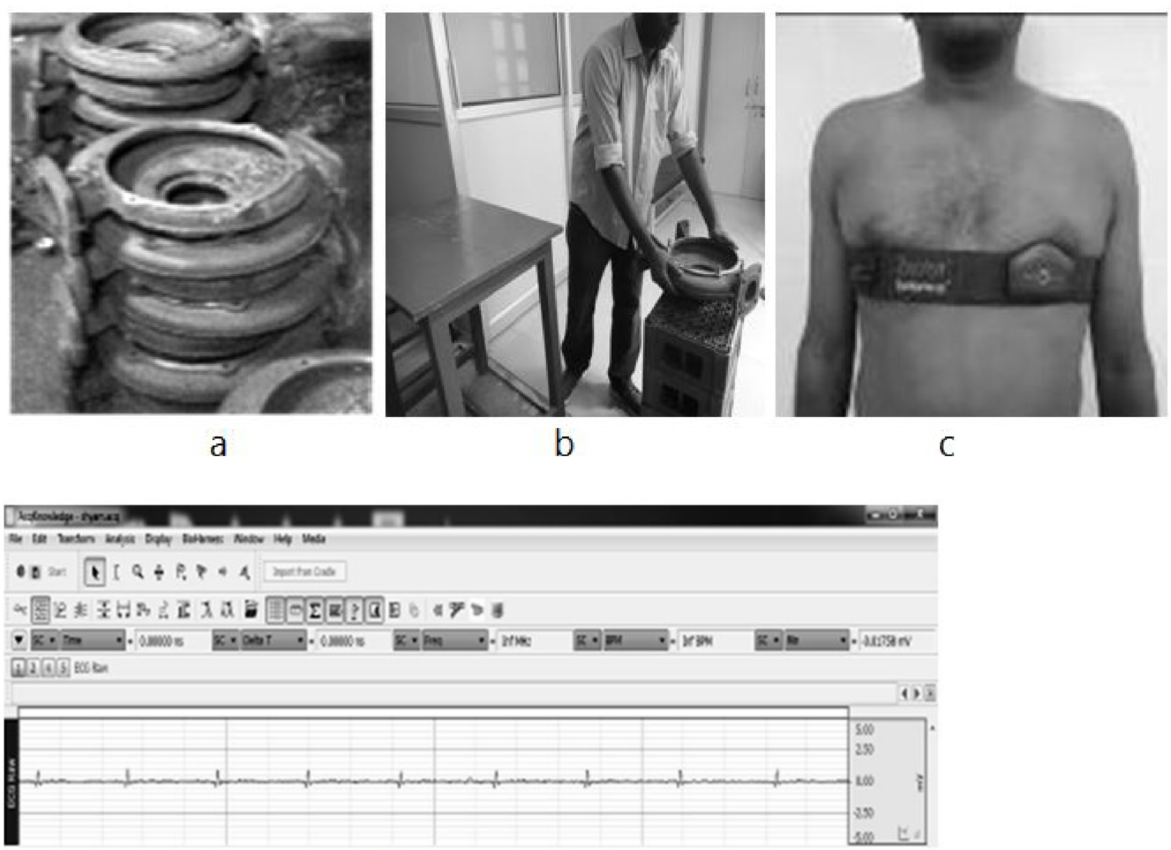

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Fig. 1 (a) stack of CPC at factory site, (b) simulation of lifting of CPC in IK Lab, (c) heart rate recording using BioHarness^{TM}, (d) snapshot of ECG Raw post experiment

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3 Results

Pre-test heart rate and post-test heart rate are measured for each of 10 subjects. The average value of pre-test heart rate is 75.8 bpm and that of post-test is 109.8 bpm (Table1). Lifting indexes are computed as 2.47, 2.33, 2.20, 2.05, 1.88 and 1.72 for six heights of CPC (from floor) which are 6.5 cm, 19.5 cm, 32.5 cm, 45.5 cm, 58.5 cm, 71.5 cm respectively (Table 2). Table 2 also illustrates improvement in RWL with 45 degree asymmetry.

Table 1 Heart rate before and after lifting

Physiological Parameters	before Lifting	After Lifting
Heart Rate (bpm)	75.8±6.18	109.8±11.27

Table 2 Lifting index with different heights of lifting

Height in cm	6.5	19.5	32.5	45.5	58.5	71.5
Average Lifting Index for asymmetric angle 90°	2.47	2.33	2.20	2.05	1.88	1.72
Average Lifting Index for asymmetric angle 45°	2.04	1.92	1.81	1.69	1.56	1.41

4 Discussion and Conclusion

As per the results of revised NISOH lifting equation this lifting task is unsafe, and becomes increasingly stressful with respect to increase in vertical travel distance (D). Hence workers are exposed to ergonomic hazards [11]. As already mentioned a casing weighs 15 kg, and since it is in one unit so its weight cannot be reduced. Value of HM is the least in comparison to other multipliers but it cannot be improved due to the size of the casing (the outside diameter of casing is 40 cm). However it is possible to increase values of VM and DM by reducing the vertical travel distance (D). It may be done by incorporating suitable changes in workplace design and layout design. One possible solution can be lifting CPC from a raised platform of suitable height so that the required vertical travel distance (D) can be obtained. Reducing angle of asymmetry from its existing value of 90 degree to about 45 degree is a more economically viable solution to improve upon the RWL. It requires a rearrangement of workplace in terms of creating some open space near drilling machine to lift CPC with 45 degree asymmetry. It also requires a smaller investment in terms of training of lifting workers to lift CPC with 45 degree asymmetry. RWL improves significantly with 45 degree angle of asymmetry (Table 2). Asymmetry cannot be reduced beyond 45 degree due to bigger size of casing. It is interesting to observe that by reducing angle of asymmetry to 45 degree, lifting index values significantly reduce for all heights of CPC, and therefore ergonomics risks reduce significantly. Further FM and CM values are already very close to one, so there is no need to alter coupling type and frequency of lift.

Physiological measures in terms of heart rate provide interesting results (pre-test heart rate is 75.8 bpm and post-test heart rate is 109.8 bpm). A workload of 33% of the aerobic capacity is recommended as the maximum energy expenditure for an eight hour work day [1, 10]. Its corresponding heart rate is 105 bpm with a range of 95 to 115 bpm [9]. Other studies suggest that the average heart rate over an eight hour industrial work shift should not exceed 110 bpm [2, 12, 8]. Therefore the physiological results show that it is a safe lifting characterized with variable heights.

It is evident from the above discussion that physiological results do not match with the results of revised NIOSH lifting equation. Lifting turns out to be safer as per the results of heart rate studies, while LI values suggest that it is a physically stressful task. Therefore the most important conclusion of this study is that revised NIOSH lifting equation is not able to assess the risks involved with lifting of CPC. Physiological (heart rate) results in general truly assess the risks involved with a MMH task.

Small and medium scale industries can be motivated to implement safe guidelines for their workers by taking such case studies and showing positive results. It is usually possible to alter one or other task variables of revised NIOSH lifting equation to redesign a safer lifting task while meeting the constraints posed by the task. However this case study raises questions on the applicability of revised NIOSH lifting equation in determining the risks involved in manual lifting. It is therefore suggested to verify the results of revised NIOSH lifting equation using other approaches.

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