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Reduction of discomfort in pushing an industrial trolley using ergonomics

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Abstract: Poor design of industrial trolleys lead to more compressive stress on the low back of industrial workers. The research work reported in this paper recommends a handle height of an industrial trolley for use by the local population, which reduces the compressive stress on the low back. Experiments were conducted in a laboratory on five subjects of varying stature 165, 173, 174, 175 and 182 cm, with five different handle heights 90, 95, 100, 105 and 110 cm. A four wheeled trolley has been used to conduct the experiments. Caster wheels diameters of 100,125 and 150 mm made of polyurethane were used. It is found that a handle height of 110 cm allows the users to exert minimum force during the initial pushing. A biomechanical model was employed to calculate the compressive force experienced by L5/S1 disc and it is found that the compressive load will be the least when the handle height is 110 cm. Optimization of handle height using Genetic Algorithm approach, Heart rate analysis and EMG analysis confirm that a handle height of 110 cm and a wheel diameter of 150 mm will reduce the discomfort of industry workers pushing trolleys.

1. Introduction
Biomechanical hazards created by forces and movements are to be avoided or reduced to improve the occupational health of industry workers. Identification and assessment of biomechanical hazards are required to be done by occupational safety and health professionals. Boocock et al. found that biomechanical responses to a variety of loads and gradients must be considered, while acknowledging the broader range of factors associated with load movement to set suitable limits for push/pull activities [1].

Lee et al. conducted experiments using a cart with three different heights of exertion 660, 1090 and 1520 mm and two different moving speeds 1.8 and 3.6 km/h. Pushing a cart resulted in lesser-back loading than pulling. For the weights of subjects ranging from 50 to 80 kg, for forces 98, 198 and 294 N subject body weight affected the lower-back loadings more significantly in pulling, (50% increase as body weight increase from 50 to 80 kg) than in pushing (25% increase) [2].

Ciriello et al. reported that a well-designed trolley should be used to transfer heavy weights with pushing forces that are acceptable to a high percentage of males. Many parameters in manual handling tasks in industries violate good ergonomics design. Efforts should be taken to minimize the hand

distance from the body, decreasing loads of lifting, lowering and carrying, decreasing frequencies of tasks, decreasing the distance of travel. These redesign strategies will help in reducing the costs of compensation claims of manual material handling [3].

Al-Eisawi et al. investigated experimentally the initial forces applied to push a trolley with five male and five female university students on the carpet surface. Two different loads 73 kg and 181 kg were used on the trolley. A horizontal handle was used in three different heights: knuckle, elbow and shoulder height. The most direct horizontal push occurred at the elbow height. The forces were somewhat downward for knuckle height and upward for the shoulder height. The smallest vertical forces were measured at elbow height [4].

Don B. Chaffin described how injurious stresses on the low back can be predicted by biomechanical models during the early phases of designing materials handling tasks in industry. It is shown that these biomechanical models can be used to simulate novel materials handling tasks, and thus be used to guide the design of such tasks to reduce various low back stresses. These simulations provide a scientific basis for specific ergonomics guidelines meant to reduce the risk of future low back pain in industry [5].

Genetic algorithms (GAs) are stochastic global search and optimization methods that mimic the metaphor of natural biological evolution. GAs operate on a population of potential solutions applying the principle of survival of the fittest to produce successively better approximations to a solution. At each generation of a GA, a new set of approximations is created by the process of selecting individuals according to their level of fitness in the problem domain and reproducing them using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals from which they were created, just as in natural adaptation

Genetic Algorithm differs from the classical algorithms, as it generates a new population in each generation. The algorithm selects individuals from the current pool of individuals and generates child population for the next iteration using crossover and mutation operators. Over successive generations, the population evolves towards an optimal solution. GA can be used to solve optimization problems wherein the objective functions are discontinuous, non-differentiable, stochastic or highly nonlinear [6].

From the information collected through the literature presented above, it can be seen that the optimum handle height has to be found for the group of people working in a particular region based on their anthropometric data. The research work reported in this paper focuses specifically on finding the minimum forces for pushing a trolley at different handle heights with the handle fixed at an angle of 110 degrees to the base of the trolley. Experiments were conducted in laboratory with five university student volunteers as subjects using a four wheeled trolley and the recommended handle height and wheel diameter are reported. A biomechanical model is employed to verify the results and it is shown that a handle height of 110 cm offers the lowest compressive loads experienced by L5/S1 discs of the users while pushing the trolley. Optimization of handle height using Genetic Algorithm (GA), Heart rate analysis and EMG analysis are used for validating the results.

2. Methodology
2.1. Subjects
Five male students participated as subjects in laboratory experiments on the trolley. Subjects were properly informed and consents were taken from the subjects. The age and weight per unit height

details of the subjects are presented in Table 1. The subjects have no history of musculoskeletal disorders.

2.2. Trolley

A four wheeled trolley has been used to conduct the experiments. The height of the handle is adjustable from 90 to 110 cm. Caster wheels of 100, 125 and 150 mm diameter made of polyurethane were fitted to the trolley. The front wheels are fixed and non-rotatable whereas the two rear wheels were 360 degrees swiveling. All the wheels were oriented in forward direction before starting every experiment. The trolley handle is welded firmly at an angle of 110 degrees to the base structure. The overall dimensions of the trolley are: 70 x 50 x 68 cm. Figures 1 & 2 show the side view and front view of the set up respectively.

Table 1. Age, height and weight of five subjects

Subject. No	Age (yrs.)	Stature (cm)	Weight (kg)
1	19	165	68
2	19	173	59
3	18	174	61
4	19	175	85
5	19	182	58

2.3. Force measurement

A SHIMPO FGV-500/1000 HXY force gauge is used to measure the push force. This force gauge is attached to the horizontal push bar of the trolley exactly at the midpoint where a M10 Hexagonal internal threaded nut is welded firmly in order to fasten the force gauge to it.

2.4. Heart rate measurement

Polar RS100 heart rate monitor was used for recording continuous heart rate. Polar Coded Transmitter sends the heart rate signal to the wrist unit to avoid cross talk with other nearby electronic signals. The wrist unit displays and records the subject's heart rate during the push trials. The watch has the accuracy$\pm$ 0.5 seconds / day at 25 °C / 77 °F temperature. The Heart rate Monitor has the accuracy$\pm$ 1% or 1 bpm, in a steady state condition and the measuring range between 15-240 beats/minute (bpm).

Figure 1. Side view of the set up

Figure 2. Front view of the test set up

2.5. Surface electromyography (sEMG)

Precision bipolar EMG sensors SX230 (Biometrics Ltd. London (UK)) were used in this study. These sensors have integral electrodes with a fixed electrode distance of 20mm. Six of these sensors were placed over the bulk muscles on each subject under this study. Three on the left side namely flexor digitorum, deltoid and upper trapezius. The EMG signals were acquired real time and saved during the trials into the micro storage device kept in the slot available in the DataLOG unit and simultaneously transmitted via Bluetooth to the laptop. The DataLOG MWX8 (portable) was configured to the host PC (laptop) for acquiring data. The small, light weighted, battery operated unit incorporates a color graphics LCD, joystick, micro SD card interface, and provides a real-time wireless data transfer via Bluetooth linked to laptop. Biometrics analysis software v8.51 was synchronized to the DataLOG and the data was acquired in real time then saved to the laptop computer. The raw data saved was further analyzed.

2.6. A theoretical model for bio-mechanical analysis

The theoretical model proposed by Lee et al. [2] has been employed for biomechanical analysis: The variables considered for the biomechanical model are: subject's body weight, subject's stature, hand force, handle height and various interactions of these variables. The stature/ handle-height relationship is bio-mechanically more important to the compressive forces than the subject's stature alone. This ratio represents the relative height of the handle compared with the stature. Therefore a new variable, height factor, which represents this ratio is defined and used instead of stature and handle height as follows:

Height factor, H = (stature - handle height)/stature

The following is the relationship between the peak compressive force at the L5/*S1* disc and the independent variables as given by Lee et al.[2]:

Y$_{pushing}$ = 298 + 16.62W - 2261.86H + 0.0254WF + 12.67FH

Where   Y$_{pushing}$ = peak compressive force at L5/S1 disc in pushing
            W = subject weight (kg)
            H = height factor
            F = horizontal hand force (N)

2.7. Optimization using Genetic Algorithm (GA)

Genetic Algorithm (GA) tool box of Matlab was used to find the optimized height of the handle. The objective function was formulated considering a mathematical relationship relating force applied by different subjects using different handle heights, the mathematical model proposed by Lee et al.[2] and by specifying lower and upper limits for the handle height.

2.8. Task and procedure

Subjects were clearly instructed about the experimental procedure. Each subject was allowed to perform test trial runs in order to familiarize with the experiment before recording the actual data. Three trials were conducted for each subject at every handle height. Each subject has to push the trolley at his own normal walking speed through a distance of 15m. The starting and finishing lines were indicated on the cemented floor. A human voice is used to alert the subject for initial pushing and the subject has to walk straight. The push forces are recorded and entered in the computer system. Three trials are conducted and the average push forces are found. Heart rates and EMG forces are recorded.

3. Results and discussions

3.1. Initial Push forces

Figures 3 and 4 show the effect of handle heights on forces required for pushing a trolley loaded with 125 kg and 156 kg by 5 subjects of varying stature and heights. The push force required to push the trolley at 110 cm handle height at a load of 125 kg as well as 156 kg was found to be the minimum. The forces exerted by different subjects were different at 110 cm handle height depending on the stature of subjects.
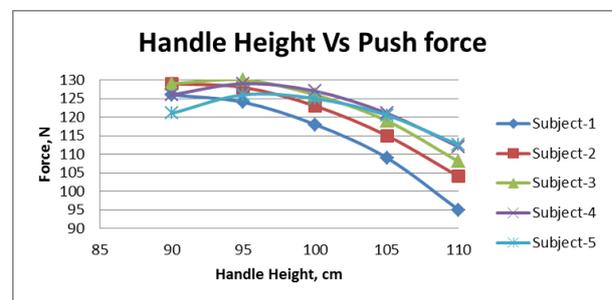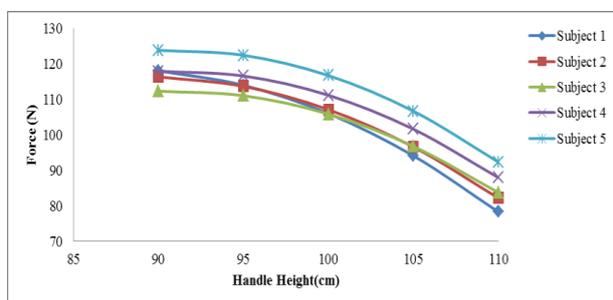

Figure 3. Initial push force in N, at a load of 125 kg

Figure 4. Initial push force in N, at a load of 156 kg

The uses of manual material handling devices like four wheeled trolleys which are poorly designed consume a lot of energy from the industrial workers. Arun et al. [7] reported that it is not clear what handle heights would be optimal for pushing and pulling. The present laboratory experiment results revealed that 110 cm handle height is the recommended value for the subjects tested which permits the minimum push forces for transporting loads as seen in Figures 3 and 4. If the handle height is less than this value, the subjects have to exert more forces during pushing. The reason could be that when the handle is situated at a height of 110 cm, the subjects are occupying comfortable postures at elbow

level and with minimum effort they are able to overcome the inertia forces. The results agree with the findings of Ferreira et al. [8]: The optimum height of the handle should be between 91 cm and 112 cm. Handle heights should not be less than 91 cm since taller workers would stoop. A handle height which is more than 112 cm would cause more discomfort to shorter workers.

3.2. Compressive forces at L5/S1 interface

The theoretical model proposed by Lee et al. [2] for biomechanical analysis has been employed and the experimental results are verified. The results of the biomechanical analysis are presented in Figures 5 and 6,   which show the compressive forces acting on the L5/S1 interface while 5 subjects were pushing trolleys loaded with 125 kg and 156 kg.
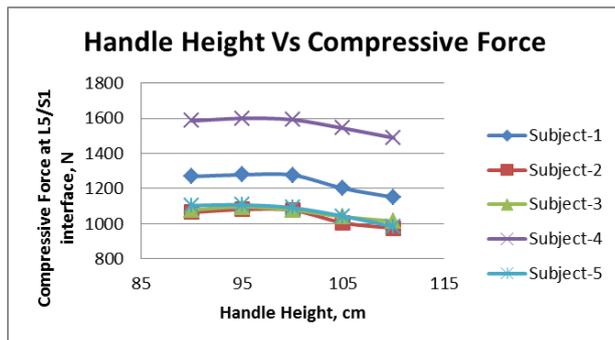
Figure 5. Compressive force at L5/S1 interface in N while pushing a trolley with 125 kg load for different handle heights.
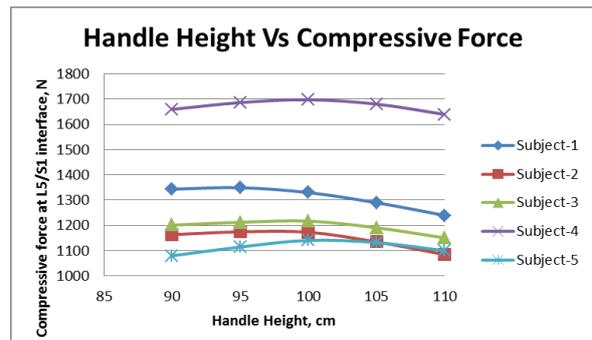
Figure 6. Compressive force at L5/S1 interface in N while pushing a trolley with 156 kg load for different handle heights.

The results shown in Figures 5 and 6 indicate that the compressive force acting at the L5/S1 interface is the least at a handle height of 110 cm validating the experimental results reported in Figures 3 and 4. The trends of the resulting curves do not exactly match with the curves of the experimental study. In Figure 5, there is no variation in the compressive force on the spinal column between 90 cm and 100 cm of handle height and the compressive forces reduce from 100 cm to 110 cm. Subject 4 is experiencing the highest compressive force on the low back and subject 5 is experiencing the lowest compressive force in while pushing 125 kg as well as 156 kg load. The reason for this is evident from Table 1; subject 4 has the highest weight and experiences the highest compressive load in the low back and subject 5 has the lowest weight and suffers the lowest compressive load in the low back. This finding is in agreement with the findings of Lee et al. [2] that low body weight lowers the compressive load at L5/S1 interface.

3.3. Optimization of handle height

The optimum value is obtained through Genetic Algorithm and Figure 7 shows the convergence of the value of load acting at L5/S1 interface ($Y_{pushing}$) in Newtons. The optimum handle height is obtained as 109 cm after 300 generations in Figure 8. These results validate the findings through experimental studies.
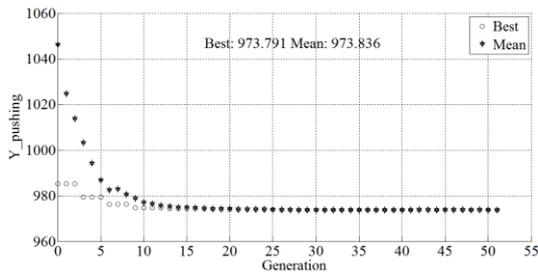
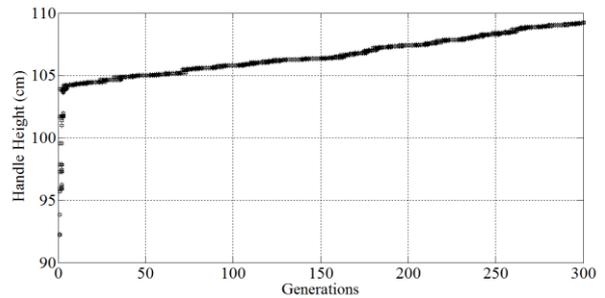**Figure 7.** Convergence of load acting on L5/S1 interface ($Y_{pushing}$) in Newtons

Figure 8. Optimum handle height

3.4. Effect of wheel diameter on push force
The relation between push force and wheel diameter is shown in Figures 9 and 10. The force required for pushing decreases with the increase in wheel diameter of the trolley. It is seen that the push force exerted by subject 5 is the lowest; the stature of subject 5 is the highest as shown in Table 1. It appears that a wheel diameter of 150 mm is recommended.
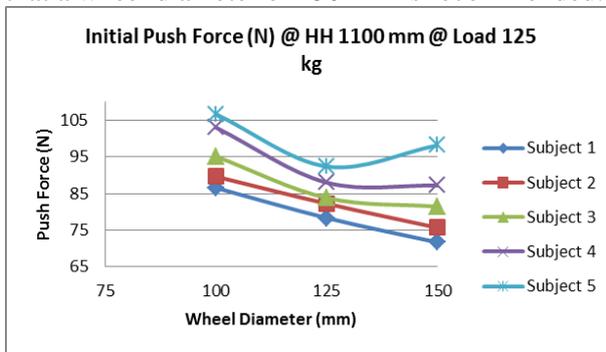
Figure 9. Initial push force in N at a handle height of 110 cm with a load of 125 kg for different wheel diameters
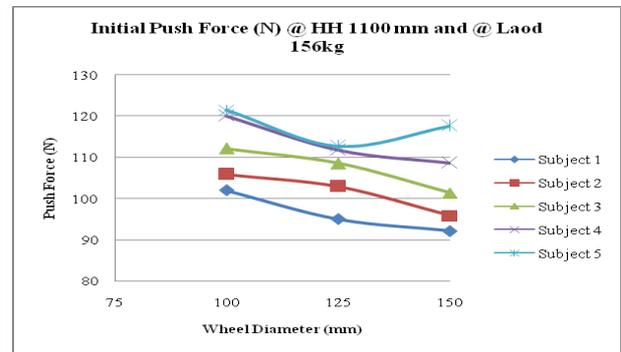
Figure 10. Initial push force in N at a handle height of 110 cm with a load of 156 kg for different wheel diameters

3.5. Compressive forces at L5/S1 interface based on wheel diameter
The effects of increasing the wheel diameter of the trolley on the compressive stresses in the low back of the subjects for different subjects are shown in Figures 11 & 12.
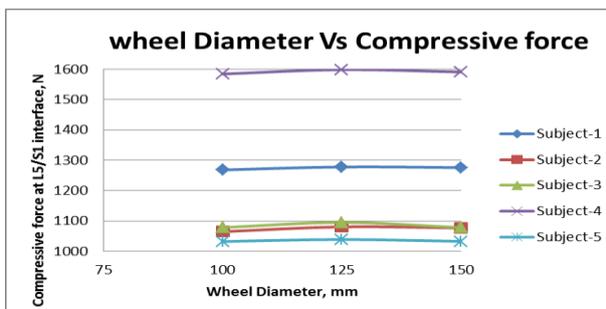

Figure 11. Compressive force at L5/S1 interface in N for different wheel diameters while pushing a load of 125 kg with a handle height of 110 cm.
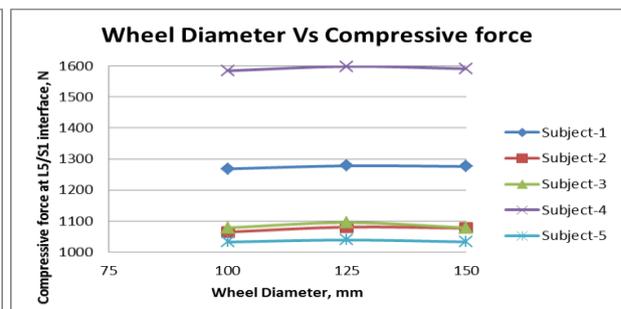

Figure 12. Compressive force at L5/S1 interface in N for different wheel diameters while pushing a load of 156 kg with a handle height of 110 cm.

The compressive forces experienced by subjects at L5/S1 interface appear to be same for different wheel diameters as seen in Figures 11 and 12. This could be due to the fact that the stature and weight of the subject influence the compressive forces acting on the spinal column.   The highest compressive load on the spine experienced is about 1600 N, which is well below the NIOSH guideline which permits up to a compressive load of 3400 N at L5/S1 interface reported by Thomas et al. [9].

3.6. Effect of handle height on heart rate
The effects of handle heights on heart rate are shown in Figures 13 and 14 while subject-1 pushed trolley loaded with 125 kg as well as 156 kg having 100,125 and 150 mm wheel diameters. The heart rates are the lowest at the handle height of 110 cm.
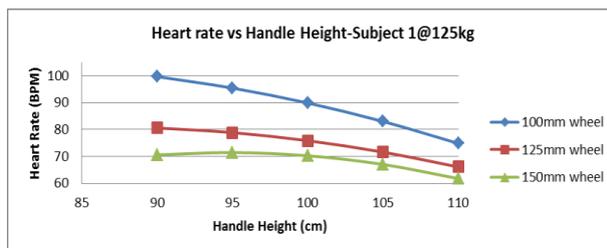
Figure 13. Heart rate in BPM for different handle heights while pushing 125 kg load using different wheel sizes.
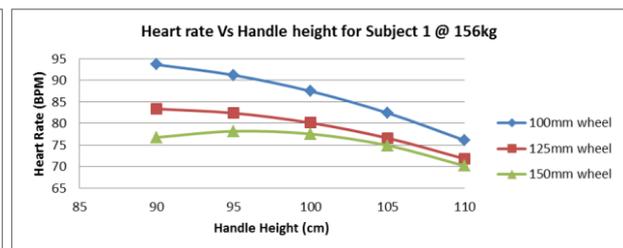
Figure 14. Heart rate in BPM for different handle heights while pushing 156 kg load using different wheel sizes.

3.7. Effect of wheel diameter on muscle activities
Muscle force in % mvc while a trolley loaded with 125 kg as well as 156 kg fitted with 100,125 and 150 mm diameter wheels pushed by 5 subjects are shown in Figures 15 and 16. The muscle activities are less when a wheel diameter of 150 mm was used.
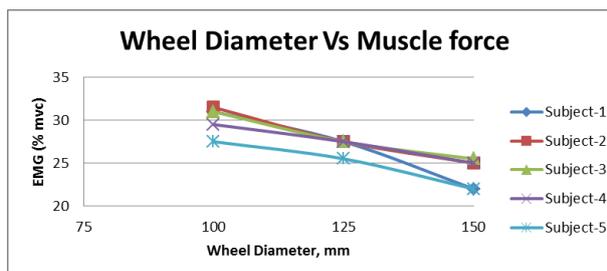

Figure 15. Muscle force in % mvc while pushing a load of 125 kg at a handle height of 110 cm using different wheel diameters.
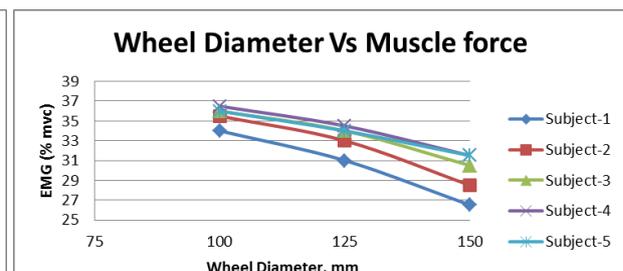
Figure 16. Muscle force in % mvc while pushing a load of 156 kg at a handle height of 110 cm using different wheel diameters.

4. Conclusions
According to the present research, it is found that a handle height of 110 cm is the recommended value for the population whose anthropometric data provides the range of weight from 58 to 85 kg and stature from 165 to 182 cm. At 110 cm handle height, the subjects are found to exert lesser force so that they could push the trolley with minimum effort to overcome the inertia. A biomechanical analysis was performed using the biomechanical model. The results of this analysis confirm the findings of the experimental study. The optimum handle height was found to be 110 cm giving the lowest compressive load at L5/S1 disc through the biomechanical analysis. A wheel diameter of 150 mm reduces push force. Optimization through Genetic Algorithm, Heart rate analysis and EMG studies confirm that a handle height of 110 cm and a wheel diameter of 150 mm will reduce the

discomfort experienced by workers pushing industrial trolleys. Even though the experiments are conducted using local population, the results are applicable to global population with similar anthropometric data.

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