DEVELOPMENT AND EVALUATION OF HEAD LOAD MANAGER FOR CONSTRUCTION WORKERS

BY

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CERTIFICATE – I

This is to certify that this thesis entitled **"Development and evaluation of head load manager for construction workers"** submitted for the degree of **Doctor of Philosophy**, in the subject of **"Family Resource Management"** to the CCS Haryana Agricultural University, is a bonafide research work carried out by **Ms. Garima Yadav** under my supervision and that no part of this dissertation has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged.

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LIST OF ABBREVIATIONS

ABS	:	Acrylonitrile butadiene styrene
AHR	:	Average Heart Rate
BMI	:	Body Mass Index
BPDS	:	Body Part Discomfort Score
CCR	:	Cardiac Cost of Recovery
CCW	:	Cardiac Cost of Work
CED	:	Chronic Energy Deficiency
CM	:	Conventional Method
DHLM	:	Developed Head Load Manager
EER	:	Energy Expenditure Rate
FEA	:	Finite Element Analysis
HLC	:	Head Load Carrier
HLH	:	Head Load Harness
HLM	:	Head Load Manager
HR	:	Heart Rate
LBM	:	Lean Body Mass
MMH	:	Manual Material Handling
MSDs	:	Musculoskeletal Disorders
MSS	:	Musculoskeletal Symptoms
NIOSH	:	National Institute for Occupational Safety
OSHA	:	Occupational Safety and Health Administration
OWAS	:	Ovako Working Posture Analysis System
PCW	:	Physiological Cost of Work
PFI	:	Physical Fitness Index
REBA	:	Rapid Entire Body Assessment
RPE Scale	:	Rating of Perceived Exertion Scale
RWL	:	Recommended Weight Limit
TCCW	:	Total Cardiac Cost of Work
VAD Scale	:	Visual Analogue Discomfort Scale
WMSDs	:	Work Related Musculoskeletal Disorders

CHAPTER–I

INTRODUCTION

The construction industry is the second largest employer of the country after agriculture. As per the projections it is expected to employ over 67 million workforce by 2022 (Economic Survey of India, 2017-18). It has contributed to 7.54% to the national Gross Value Added (GVA) in 2018-19 registering a growth of 8.7% (Economic Survey of India, 2018-19). Due to modernization and industrialization, there is a rise in construction industry. Development in small towns and cities has opened up avenues for employment opportunities and a large number of workers are getting employed in construction industry. In India, a large proportion of construction workers is unskilled with most of them being migrants. Construction workers are usually hired on project to project basis and may spend only a few weeks or months at any one project. Yadav *et al.* (2016) reported that most of the labourers in construction industry (71%) work on temporary basis.

Construction work is featured by high labor turnover, constantly changing work environment and conditions on-site and different types of work being carried out simultaneously. Construction workers are gradually more affected as compared to other industries. They face different physical, chemical, and biological environments, thereby developing various health problems like respiratory problems, musculoskeletal disorders and pain in different body parts, mostly back and shoulder pain. Their work comprises of hard physical labor under difficult conditions like adverse weather conditions. The nature of work, working hours, low wages, poor living conditions with lack of basic amenities , separation from family, lack of job security and lack of access to proper occupational health services make the situation worse (Shah and Tiwari, 2010; Gaurav *et.al,* 2005, Adsul *et.al*, 2011).

Health hazards in the construction industry can be grouped under mechanical and non-mechanical hazards. Mechanical hazards include accidental issues from impact, penetration from scrap metal and sharp objects and crushing. Non- mechanical hazards are a major cause of occupational diseases and physical problems. Non-mechanical hazards associated with machinery and equipment can include harmful emissions, contained fluids or gases under pressure, chemicals and chemical by-products, electricity, and noise. All of these can cause serious injury if not adequately controlled. Death and injury from accidents in the Indian construction sector are widespread. India has the world’s highest accident rate among construction workers. A survey by the Indian Labour Organization (ILO 2009) found that 165 out of every 1000 workers are injured in the construction sector. Data suggest that the possibility of an accident is five times more likely in the construction industry than in the manufacturing industry, and the risk of a major injury is 2.5 times higher. British Safety

Council study revealed that not only the construction workers in India lack legal protection, but the on-site deaths are also 20 times higher than those in Britain with 25% of the deaths happening due to falling from a height, and nearly 80% of the workers working in an unsafe environment.

Throughout the world, over 90% of construction workers are male. In some developing countries, the proportion of women is higher and they tend to be concentrated in unskilled occupations. In India, with over 35million people engaged in the construction sector, women comprise nearly 30 percent of the workforce. Almost 65 percent of the women works as construction laborers since their families are already in the workforce or male members of their family are employed there (Choudhri, 2019).

Women perform various unskilled jobs like cleaning building sites, carrying bricks, gravel, mortar, and water up to the skilled carpenters and masons. Irrespective of the number of years they work; they are not upgraded from unskilled to skilled category in comparison to their male counterpart (Jhabvala and Kanbur, 2002). As they are unskilled and have no training before the recruitment, they are unaware of the ergonomic risks related to the work. Since they are much more involved in Manual Material Handling (MMH), they are required to work for longer durations without any rest. They are not provided any equipment for carrying a heavy load more than the recommended value. Many a times they have to carry a heavy load on their head for a long distance. As per Madhok (2005) women carried 9-12 bricks (each weighing 2.5 kg) on their heads. During earthwork, women carried 15 kg of mud on their head and walked 30 feet to deposit the mud and return. In an activity of one hour, this was repeated 180 times.

Yadav *et al.* (2016) revealed that 59% of the female construction workers carried heavy load on their head with the weight greater than 20 kg. The safe load limit for an adult female worker has been described as 30 kg (Dwivedi, 2000) which is higher than the recommended weight limit (RWL) of 23 kg suggested by NIOSH committee. The RWL for Indian women should be 15 kg (Maiti *et al.*, 2004 a). Mitra *et al.* (2012) performed biological analysis of spine during stoop and squat lifting and stated that lifting loads over a prolonged period of time, creates a risk of lower back injury. In India, most of the materials and equipments are manually handled by women construction workers usually in ergonomically hazardous postures. They are mostly engaged in MMH tasks that require lifting, loading, carrying, pushing, and pulling activities (Sahu *et al.*, 2008). Such activities require frequent bending, twisting and other awkward postures which may predispose them to musculoskeletal disorders (Gangopadhyay *et al.*, 2008).

The study of manual load carrying is an important area of investigation. The emphasis on ergonomics in manual load carrying tasks arises from the potential risks of work-related health problems and injuries. Much of the recently reported work relates to either physiology or biomechanics of load carrying confined to industrial set up, household working or military activities. Some studies on physiology (Abe *et al.*, 2008; Bastien *et al.*, 2005; Llyod *et al.*, 2011) report that energy expenditure during walking increases linearly with the quantum of the load being carried. Few bio-mechanical studies report spinal loading during manual load carrying that results in degeneration of the disc and musculoskeletal disorder (Vuuren *et al.*, 2005).

Although several researchers have contributed to the design of work systems involving manual handling of tasks under different working conditions, there is a constant need to study the effect of physical environment on the performance of the persons engaged in MMH jobs in both open and closed environments and workplaces from the perspective of ergonomic design of such jobs and the workplaces. As manual handling involves considerable physical work demands with considerable risk of physical stress and deterioration of health and fitness, an evaluation of physical environment in this context assumes significance for a better ergonomic design of workplace for the development or exacerbation of musculoskeletal symptoms (Elders and Burdorf, 2001; Hoozemans, 2001; Kramer *et al.*, 2009). As environmental conditions vary widely across the workplaces, it is imperative that empirical investigative research is carried out for development of a general approach for mitigation of such disorders.

The tools and technologies are either gender-neutral or male-oriented. The technologies are not oriented addressed the needs of women. In this view, there is a need to empower women with the application of ergonomics. With this motto, it becomes important to educate and create awareness among women to carry out their occupational activities effectively and safely. Several studies have been done to reduce the different hazards faced by women construction workers, by providing some ergo solutions to carry load on the head without much difficulty some of the ergo solutions include Load Carrier for labour (Panchal, 2011), Vajra (Vessel Desk) (Lohar, 2011) and Head Load Manager (Mrunalini, 2011). However, the technology has not reached to the end users till now.

Considering the above facts, the present investigation was planned to overcome the problems of female workers, mostly engaged in the MMH task involving a high risk of injury with the following specific objectives:

Objectives

1. Assessment of existing head load managers for construction workers
2. To design and develop head load manager for construction workers
3. Ergonomic assessment of the developed head load manager
4. Feasibility testing of the developed head load manager

Scope of the study

In the present study, an effort has been made to study the work profile of construction women workers and ergonomic assessment of the existing head load managers on the basis of which a new head load manager was designed and developed.

An overview of literature reveals that researchers have done the research on the farm women mostly by providing them head load manager but not on the women construction workers. Several types of research have been done on ergonomic parameters on farm women and feasibility testing of ergo solutions which were provided to them. The aim of this research work is to design an ergo tool head load manager that is based on the anthropometry of female construction workers followed by its ergonomic assessment and feasibility testing.

CHAPTER–II

REVIEW OF LITERATURE

A brief review of past literature and researches relevant to the present study have been incorporated in this chapter. It reflects the status of the studies regarding the problems and helps to find out the research gaps leading to the necessity for this study. It includes analysis and interpretation of results from different research that forms a basis for this study. The pertinent literature related to various aspects dealt in this study has been presented under following subheads:

1. Assessment of existing head load managers for construction workers
2. Design and development of head load manager for construction workers
3. Ergonomic assessment of the developed head load manager
4. Feasibility testing of developed head load manager

1. Assessment of existing head load managers for construction workers

Madhok (2005) found that in 15 minutes, about 55 bundles, each weighing 7-8 kg, passed through the hands of women. Women carried 9-12 bricks (each weighing 2.5 kg) on their head. While doing earthwork, women carried 15 kg. of mud on their head and walked 30 feet to deposit the mud and return. This activity was repeated 180 times in an hour.

Sharma and Singh (2012) inferred that carrying the water load is safe only through the head mode. Carrying load on shoulder and waist may result in injuries. Considering the cardiovascular, muscular, biomechanical stress and psychophysiological evaluation, they concluded that load carrying through the head mode should be around 15 kg while for shoulder and waist mode should not be more than 10 kg at a walking speed of 3.5 kmph.

Gaikwad and Zend (2012) tested head load manager, a technology developed by ANGRAU AICRP H.Sc. Hyderabad for load carrying activity, in the selected brick kilns of Parbhani city. There was a significant reduction in the physiological cost of work (10%) and body discomfort rating when brick carrying activity was performed with head load manager but work output per hour was reduced by 16.62 percent. Head load manager was recommended for reduction of drudgery with certain improvements.

Chawada *et al.* (2012) reported that a total of 118 female construction workers participated in the study with mean age of 22 years. Mean daily wages of the female worker were ₹120 while of the male were ₹245, double than that of female workers. Major health complaints reported were fatigue/weakness (61 %), backache (30 %), cough (17.5 %), fever (17 %), skin itching (10.5 %) and diarrhoea (7 %). They were not even using the government medical facility due to lack of awareness and knowledge. No safety measures were provided to female workers at most of the construction site, whereas, only at two construction sites female workers were provided ‘gloves’. Some (6%) of the working females reported chewing tobacco daily or smoking ‘bidi’. The living conditions were barely enough to provide any privacy for female workers.

Manhas (2014) conducted a study in Kathua District of J&K on the physical health status of 120 female construction workers between the age group of 20-40 years. The result showed that majority of the female workers had a moderate level of health problems related to various body parts namely eyes, musculoskeletal system, skin, and genitourinal tract and at the same time they also had lower level of health problems related to respiration, cardiovascular system, digestive tract and nervous system, redness, pain, irritation and watery eyes. Digestion related problems included diarrhea, acidity, and constipation. Skin rashes and lesions, muscular pains and joint aches were also frequently reported. Nervous problems included feeling of dizziness, fainting spells, headaches and cold sweats. Statistically, there was a significant difference in the physical health of the two age groups (20-40 & 30-40 years). Comparatively, women in the 30-40 years age group faced more problems in eyes, nervous system, genitourinal system and encountered more incidence of illness than the younger age group.

Mala (2015) in a study in Tripura in found that 46 percent of the respondents were in the age group between 30–40 years. Most (76%) of the respondents were married. Forty four percent respondents carried bricks, cement, and stones. About one-fourth of them (22%) filtered sand at the work sites, carried water for construction purpose (20%) or assisted the masons at the work site (14%). Women faced instability in work, got poor remuneration and faced discrimination in the payment of wages and virtual absence of enforcement of protective labor legislation.

Muslim and Nussbaum (2015) reported that musculoskeletal symptoms (MSS) on MMH workers were mostly at the lower back (72.2%), feet (69.4%), knees (64%), shoulders (47.2%), and neck (41.7%). Logistic regression indicated that MSS in the lower back were associated with longer work hours/day, MSS in the hands were associated with load mass, and MSS in the ankles/feet were associated with stature and load bearing frequency. MSS was reported to occur with day to day activity, but only a few workers pursued medical treatment.

Ray *et al.* (2015) reported that the workers got only 90 minutes of rest during an 8-hour schedule because of which they felt physically tired at the end of work. Majority (84.5%) of the masons helpers reported highly tired at the end of work. The major reason behind their tiredness was place, fixed shift schedule and time of work, as they have to work beyond their shift schedule on an average of 25 times per month. Around 40 percent of the masons felt problem related to work in an uneven worktop, 30 percent on an even worktop, and 20 percent in a semi-slippery worktop. Around 60 percent of the masons helpers worked on an uneven top. Climate, repetitive work, going up, suddenly changing position, amount of work, and not an expert in adopting ergonomic posture were the main causes of danger at the work place that resulted in bending pain (96.7%) among the ground-level workers. Ground-level workers did MMH activities in general condition, 96.7 percent workers stressed because of squatting, stooping, lowering, repetitive work, going up, grasping, holding, stretching and due to a mix of all the factors. Evaluation of these danger factors might be coped through biomechanical observations and work-caused risks were highly connected with causes producing dangerous effect.

Jena (2015) observed that 38 out of 40 women farm workers (95.00%) had musculoskeletal disorder. Carrying load (10 kg to 40 kg) by women farm workers was an everyday activity which contributed to musculoskeletal disorders. Body part discomfort showed that lower back was the most affected body part, as 87.5 per cent women farm workers complained of back pain, followed by neck pain (72.5 per cent) and knee and foot pain. Energy consumption (kJ/min) increased to 0.5 to 6 % with harness as compared to carrying load directly on head. This is due to additional weight of intervention and minor inconvenience of wearing harness.

Sarkar *et al.* (2016) reported that ninety-five percent of workers encountered MSD in at least one part of the body in the past 12 months. As per OWAS results, 83% of the analyzed work postures of the workers required immediate corrective measures for the safety. The most destructive posture was carrying a heavy overhead load. Carrying load more than 120 kg increased the odds of lower back and neck pain by 4.52times and 4.55times, respectively.

Mrunalini (2016) found significant difference between the conventional and head load manager model for physiological and body pain score while doing head load activity at the farm yards, market yards and construction site. HLM 1 and HLM 2 recorded less physiological workload, body pain and drudgery perception score than the Conventional Method.

Chhajed *et al.* (2016) studied about different head load technologies and found that the load carrying ability (to hold or do something) of these devices was not acceptable. Female workers found it uncomfortable to walk with load, taking up a lot of space for its weight. Workers earned Rs. 5 for each round. It became hard for them to afford anything costing more than Rs. 200. Therefore, cost of the product was also an important factor for workers. These technologies were gender neutral but both male/female had quite different needs that made both of them uncomfortable while performing the task.

Yadav *et al.* (2016) revealed that head load carrying activity was performed by a majority (74%) of women labourers, followed by those engaged in breaking bricks (14%) and cleaning activity (12%). Most of them carried concrete mixer and cement mixer. About two-third of the respondents lifted load by bending their back whereas only 28 percent of them lifted load by bending their knees.

Yadav *et al.* (2016) revealed that at construction site majority of the respondents were illiterate (93%) and hailed from Madhya Pradesh (45%). The majority of the respondents (71%) were employed on a temporary basis. Most of the respondents (36%) were residing away from the construction site followed by those living in the vicinity of the site (33%) and within the premises of construction site (31%). The labourers reported having no toilet facility (72%) and medical facility (77%).

Gahlot (2017) revealed a significant decrease in grip strength of both hands (4.63kg) in right hand and 3.65 kg in left hand after performing *nikasi* activity with help of wooden trolley. It might have happened because for transporting heavy load workers had to put force of hands that might have resulted in grip fatigue.

2. To design and develop head load manager for construction workers

Kizildağ (2013) studied the finite element modeling of the nonlinear behavior of shear links under various loading and boundary conditions. Shear links are designed for dissipation of large amounts of energy in case of overloading, therefore, construction of buildings with eccentrically braced frames is suitable for earthquake resistant design. Shear links are modeled and analyzed in finite element program ANSYS Workbench with 2-D and 3-D elements. The material properties are calibrated based on the cyclic behavior of steel.

Hassan (2013) investigated the structure analysis of cast iron for dry clutch disc of amphibious vehicle. Finite element analysis is used to predict the maximum stress that can be applied to the disc. The main focus that needs to be considered is the torque produced from the engine. The finite element analysis was to predict the maximum stress that can be applied to the disc.

Patil and Sarange (2014) discussed finite element analysis technique to analyze the effect of temperature and cutting forces (Horizontal and vertical force) on the tip of tool using 3D model of a single-point cutting tool in ANSYS software. This software could also predict temperatures, distribution of von Mises stresses and deformation of tip of single point cutting tool using tool forces. It also estimated the tool wear and residual stresses on machined surfaces, optimization of cutting tool geometry and cutting conditions. The study further showed a constitutive workflow stress model used to characterize workflow stress in deformation zones which were based on an estimation of the normal stress distribution over the tool. The tool forces over the tool can either directly be entered in FEA software or used in determining distribution of stresses and deformation at the tooltip.

Baby *et al.* (2015) studied the flywheel to analyze the change in stress values due to change in parameters. She used ANSYS to study different parameters like speed, the outer diameter of the flywheel, number of spokes, the diameter of spoke and material to study the change in stress behaviour. The results obtained paved the way to study the stress behavior on the flywheel in different parameters.

Warkade and Jain (2016) designed a clutch plate model by CATIA software and studied the design and analysis of friction clutch plate. He used ANSYS software for static structural analysis. Experimental work was also performed to observe the strength and deformations of the clutch plate.

Pawar *et al.* (2016) worked on a 3D model of broach tool and the workpiece that were developed using finite element (FEM) software ANSYS. They considered the linear type toothed broach tool. The developed model gave an idea about the force and deformation analysis of structural steel broach tool, which is applied, to the copper alloy, magnesium alloy, titanium alloy, aluminum alloy. The FEM results showed that maximum equivalent elastic strain was 0.92209 mm/mm and maximum plastic strain was 0.90307mm/mm is observed for the aluminum alloy.

Ghimire *et al.* (2017) carried out work on sheet metal. Sheet metal parts were used to manufacture a wide range of products by bending and cutting the sheets into appropriate shapes by means of the physical process of shearing. The metal sheet was analyzed before fatigue failure with the help of a software-based analysis. The study further explored the phenomena of spring-back associated with the metal sheet during its deformation. Finite element analysis for the same was carried out in ANSYS Workbench 16.0.

Wang *et al.* (2017) studied metal Al solid and fluid conversion carried out by using crucible resistance furnace and observing the phenomenon of metal Al solid and fluid conversion. The experimental results showed that the melting point of metal Al was between 650^0C and 660^0C, and after the melting point, the metal aluminum began to melt when it maintained for a long period of time, however, when the temperature is higher than the melting point, the aluminum will melt very quickly.In addition, ANSYS simulation, due to the heating rate was faster, the solid Al melted completely at 670^0C in 5430seconds, much longer than the actual experiment.

Aprajita and Gandhi (2018) studied the aluminium alloy and ABS plastics, as both of these have low weight and are highly durable. Comparison was done on the basis of deformation and von Mises stress by putting a load of 60kg on it. Comparison of all these parameters was done with the help of simulating software ANSYS. Results revealed that both the materials were suitable for the development of HLM but ABS was preferred in making the HLM due to its low cost, lighter weight and fulfilment of all the minimum requirements.

3. Ergonomic assessment of the developed head load manager

Chauhan (2004) conducted a study on ergonomic assessment to estimate the physiological cost of activities performed by women in construction work. In his study 40 construction women workers were selected from Pantnagar, Rudrapur and Kashipur block of district Udham Singh Nagar of Uttarakhand. Results indicated that at construction site majority of load-carrying activities were being performed by women. Postural analysis showed that when brick load was carried, the respective angle in deviation of older and younger groups was 2.50 & 1.30 degrees in upper part and 1.80 & 0.70 degrees in lower part. The angle of deviation during transportation of mortar was 1.60 degrees in upper part and 0.80 degrees in lower part in younger group and 2.8 degrees and 1.7 degrees in older group. The amount of load and heart rate in 28 different activities revealed that during transportation of bags of cement or sand on head weight of bags was 50kg and heart rate increase was the highest in this activity i.e. 138 beats/min among older age group and 135beats/min in younger group. During transportation of bags on shoulder in older group, heart rate was 140beats/min while in younger group it was 132beats/min.

Maiti (2008) conducted a study on female workers to highlight the occupational risk factors related to building construction activities in India. A whole day work-study was conducted on 11 adult female workers performing concreting operation. During asymmetric lifting, the average field working heart rate (HR) was calculated as 124.1 ± 12.5 beats/min, equivalent to $45.03 \pm 6.93\%$ of VO2 max level. These working HR were significantly ($p \leq 0.005$) correlated with pause time and lifting frequency, but not with lifting time. A method was proposed to determine the average steady pause time (P.T) from fluctuating working HR and the lifting frequency was calculated as 6.1 lifts min-1. This type of load handling task showed lower work efficiency and higher relative HR (%RHR). The required resting time was calculated as 61.47 percent, whereas the actual rest time (R.T.) in the field was 23.56 ± 10.28 percent. Using Neibel and Frivalds equation, the rest allowance (RA) due to muscular fatigue and environmental load were calculated as 50.46 percent and 45.02 min/h, respectively. These results showed that the workers were not getting sufficient rest in the field. Modification work parameter, in optimum condition, the RWL value could be achieved as 7.19 kg, which was much lesser than the actual lifted load of 12.02 kg. Therefore, modification of workplace and work methods was suggested to compensate the health hazard conditions.

Choi (2008) investigated the ergonomic issues in the Wisconsin construction industry. Results indicated that majority of the respondents (33%) had sprain/strain related injuries. Back injury followed with 25% and cuts with 24%. Other type of injuries reported were contusion (5%), burns (4%), fracture (2%) and Carpal Tunnel Syndrome (2%). Most common source of injury was over exertion (28%) followed by motion /position (26%) and slip & trip (22%). The study also showed that the construction workers were usually walking/working on ground & ladder and spent significant amount of time for manual lifting and carrying heavy materials.

Sharma *et al.* (2008) reported that the construction workers were involved in activities like excavation, cutting of stones and carrying of stones/cement /soil. Female workers were engaged in carrying activities from one site to other site. A total of 81.8 percent of the female and 54.17 percent of the male workers were suffering from shoulder ache or back pain or both. About 84.5 per cent of the female and 62.3 percent of the male workers reported to have blisters, skin itching and discoloration of skin. Among the workers, 63.6 percent of the female and 68.75 percent of the male reported eye injuries and eye infection. About 27.30 percent of the female workers and 29.9 percent of male workers complained about difficulty in breathing.

Sett and Sahu (2009) studied the female labourers working in manual brick manufacturing units. The results revealed that 32 percent of them were suffering from chronic energy deficiency, gynecological problems (74%), skin diseases (68%) and respiratory problems (85%). The female brick carriers carried heavy load (beyond their lifting capacity) and the awkward posture adopted by them in the field was the main cause of health related problem.

Chattopadhyay *et al.* (2009) carried out study on ergonomic evaluation of postural stresses of male and female construction labourers employed in unorganized sectors in West Bengal. Results indicated that MMH and equipment handling task imposed maximum physical exertion and discomfort in both male and female construction labourers. The analysis of working postures further revealed that most of their working postures were highly unsafe.

Kaminskar and Antanaitis (2010) carried out cross sectional survey of construction workers. Construction employees from Lithuanian small and medium companies of construction industry were randomly selected and invited to complete a survey on different discomforts of the body parts. The questionnaire included questions about stratification of musculoskeletal disorders in neck, shoulders, elbows, wrists, hands, upper back, hips, knees, and ankles/feet. The specific symptoms lasted for few days. Results indicated that construction workers felt pain and discomfort in the lower back. Workers also suffered from pain and discomfort in ankles/feet (range: 12%-22.99%) followed by neck (range: 6.25%-19.63%), shoulder (range: 12%-16.61%) and knees (range 4.55%-14.63%).

Nimbarte *et al.* (2010) carried out study on neck disorders among construction workers. Fifteen healthy participants (10 males and 5 females) with no history of musculoskeletal abnormalities participated in the study. Results indicated that the average maximum neck flexion and extension angles were 54.6° (± 10.1°) and 46.3°(± 9.0°) respectively. Further, it was concluded that lifting and holding weights at shoulder height resulted in increased activity in the superficial neck flexors and upper trapezius which may be a source of neck musculoskeletal disorder prevalent among construction workers.

Sahu and Sett (2010) conducted a study on female workers in unorganized sector. Modified Nordic questionnaire and body part discomfort scale was used for the study of workers to identify the musculoskeletal disorders and the zones of discomfort in different body parts. Maximum discomfort was found on the head (9.2±1.63), neck (8.8±1.21), trunk (8.4±1.61) and low back (8.2±1.59) in the brick carrying activity

Singh and Kumar (2010) studied the effect of mechanical lifting aid in a single task lifting using revised NIOSH lifting equation. The study was carried out on 30 industrial workers with no history of acute illness or low back pain. NIOSH lifting equation was used to calculate manual and mechanical lifting; RWL (recommended weight limit) and LI (lifting index). Results indicated that mechanical lifting aid proved to be beneficial as it not only saved task time by increasing frequency of lifting but also reduced the physiological stress associated with the worker by bringing lifting index within limits as per revised NIOSH listing equation.

Bhattacharya and Biswas (2011) studied working postures and associated health status of construction workers. Working postures were assessed using OWAS and REBA methods. Body part discomfort scale was applied on the workers to identify the musculoskeletal disorders and the zone of discomfort in different body parts. Results indicated that 38 percent workers had pain feeling at any one body part among neck, shoulder, wrist, hand, elbow, upper back, lower back, knee, ankle/feet and head.

Yadav *et al.* (2016) reported that after carrying the head load, highly significant increase was observed in pulse rate (27.9 b.min-1), HR (32.7 b.min-1), EER (6.4 kJ.min-1). On the basis of RPE, load carrying was perceived as moderately heavy activity (3.7). Grip strength of right hand (19.7%) as well as left hand (15.4%) was reduced after performing the activity. Deviation in spinal angle in terms of lumbar region by 2.7 percent (exterior posterior) and cervical region by 3.1 percent (anterior posterior) was observed during carrying the load on head. This study also revealed that women workers had to work in a very high temperature, humid weather, dirt etc. so that they suffered many health problems due to unsuitable work place environmental conditions.

Gahlot (2017) reported that an increase in heart rate (55.45 b min-1), energy expenditure rate (8.8kJ/min) and percent increase in oxygen consumption rate (76.72%) was observed. TCCW was observed 3587.85 beats and PCW was 59.79 bpm after performing nikasi activity. Female nikasi workers gave nikasi activity a mean score of 4.40 which indicated that nikasi workers felt heavy exertion after the activity because they had to carry 80.45 kg weight on wooden trolley and to perform loading and unloading of bricks also. This heavy load carrying in high temperatures contributes to the increased exertion felt by the workers.

Sinha *et al.* (2017) revealed that the female workers worked for an average of 9.2 hours per day with a continuous working of 4.1 hour. REBA analysis revealed that brick lifting was the most tedious activity as its activity score was 12 followed by brick landing (11) and brick carrying (9). Further, the risk assessment scale depicted that pain was felt in the upper arms, neck, thighs, head, shoulders, wrists, lower back, feet, lower arms, ankles, mid back, legs, upper back, fingers, buttock and palm. Numbness was felt in fingers and palms;

stiffness in neck and feet; tingling sensation in palms and weakness in upper arms, thighs, feet, legs, shoulder and upper back.

4. Feasibility testing of developed head load manager

Panchal (2011) designed a product named Load Carrier for Labour with an aim to improve the working condition of labourers and workers at many places globally like construction site, factories, ports, railway stations, etc and got Core 77 design award. The cost of the product was ₹300 per piece. The product allowed carrying the load in three modes viz. on back, shoulders and in the form of pushing cart.

Singh (2011) reported that Panchal introduced the product "Load Carrier for Labour" (LCL) which is amazingly simple and costs just Rs.300 to make. It is usually made of cane with metal and plastic fitting. Where cane is abundantly available it can be made from cane elsewhere it is possible to produce it out of materials like metal and plastic. A big advantage of the product is that it can be used for all three modes of carrying loads – on the back, on the head, and as a trolley. The mode can be switched in just a minute by using two knobs on the device. The total weight of the device is only 2 kg. Ergonomically, the load is distributed on the shoulders and at the lumbar, supported by softer material.

Lohar (2011) developed Vajra which is a vessel desk like device that distributes load of a worker from his head to shoulders with the help of a vertical support assembly. Its lower part is fitted to the body with the help of flexible belts and the upper part can be fitted and removed as per requirement with no need to balance the objects. It reduces cumulative trauma like headache, backache and other body strains. It can take the weight up to 75 kg and costs Rs. 700/-.

A device "Relief" for women labourer developed by Priya (2012) is quite similar to the one developed by Panchal (2011). It can be used to carry a load of 20- 30 kg per trip at one time and costs Rs.700.

Sidharth (2013) developed an improvised load carrying device for substituting the traditional way of carrying bricks on the head. In this version of load carrying device, the weight is distributed over the shoulders and the upper back. The hands rest in an ergonomically comfortable position on the supports provided contributing to balancing the weight on the platform. This device is made from stainless steel which is high in strength and at the same time very light.

Kumari (2014) tested head load manager, a technology developed by Mrunalini (2011), for head load carrying activity by rural women. Its ergonomic evaluation revealed that it was effective in reducing the physiological and biomechanical stress and WMSDs but discomfort at shoulders increased. User's assessment indicated that the HLM needed modifications to make it user-friendly.

Yadav (2015) tested head load manager, a technology developed by Mrunalini (2011), for construction women labourer engaged in head load carrying activity. Head load manager was not acceptable by the women labourer as it was difficult to handle while carrying a heavy load on the head and hence needed modifications.

Jena (2015) developed a harness that was made up of aluminium material to make it sturdy and light weight. There is a horizontal distance adjustment at shoulder level up to 3cm. The upper load carrying platform is detachable so that it can be lifted with convenience. Belt arrangement is given at waist and chest level for secure fastening. Cushion padding is provided on both harness and belt at the point of contact with the body.

The review of several researches conducted so far revealed that many researches have been done on construction sites. From the above literature review it can be concluded that most of the women labourer were engaged in unskilled work and the time duration performed by them was 6-8 hours per day. They faced several problems like joint pain, neck pain and skin related problems. Most of them performed activities in incorrect posture while performing their activity in construction industry. They performed the activity manually which was the main reason for their MSDs.

Several researchers felt that there was need to develop a technology to reduce the load from head. They had attempted to reduce the work load of the workers while carrying load by developing different tools. The basic focus of all the interventions was to distribute the load to maximum body parts so that the stress could be distributed from the head to shoulders. Therefore the present study entitled "Development and evaluation of head load manager for construction workers" was taken up with the aim to assess the existing head load managers for construction workers, design a head load manager and ergonomic assessment of developed head load manager and its feasibility testing for the reduction of musculoskeletal problems.

CHAPTER–III

MATERIALS AND METHODS

This section encompasses the methods, techniques and various tools used for the study. The study was carried out in four phases as given below:

Phase 1: Assessment of existing head load managers

Phase 2: Experimental Work (Design and DHLM)

Phase 3: Ergonomic assessment of D HLM

Phase 4: Feasibility testing of D HLM

The study procedure followed has been described under the following subheads:

3.1 Locale of the study

3.2 Sampling procedure

3.3 Variables and their measurement

3.4 Tools and techniques of data collection

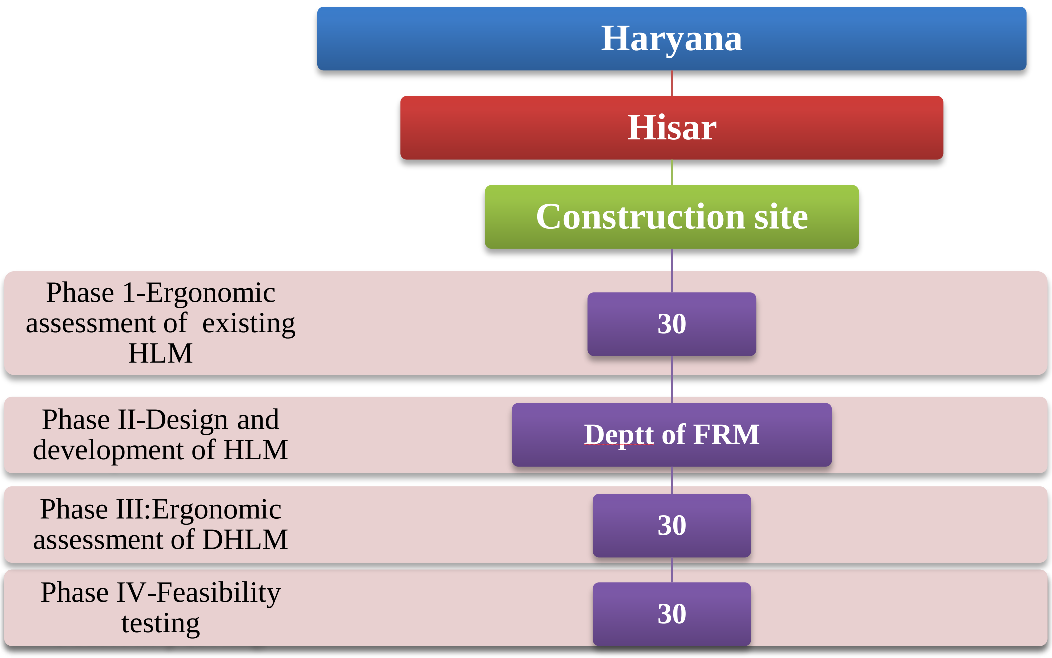
3.5 Analysis of data

3.1 Locale of the study

The present study was conducted in Hisar city of Haryana state. Different construction sites from Hisar city were selected purposively. A minimum of 3-4 female workers working in a project at the construction site was the criteria for the selection of construction sites.

3.2. Sampling procedure

For **Phase 1 and Phase 3** a sample of 30 physically fit women respondents falling in the age group of 20-40 years with willingness to cooperate were selected for the study.



3.3 Variables and their measurement

The variables selected and their measuring tools/techniques used are given in Table 3.1:

Table 3.1: Variables and their measurements

Variables	**Measurement**
Independent variables	
Work parameters	
Time spent (hrs.)	Stopwatch
Weight of load (kg)	Weighing scale
Distance travelled (km)	Pedometer
Environment parameters	
Temperature (ºC)	Thermometer
Relative humidity (%)	Hygrometer
Noise (dB)	Sound meter
Light (lux)	Lux meter
Dependent variables	
Physiological parameters	
Pulse rate (beats/min)	Pulse Oxymeter
Energy expenditure (kJ/min)	Varghese *et al.*,1994
Heart rate (beats/min)	Polar Heart Rate Monitor
Perceived exertion (score)	Rating of Perceived Exertion scale (Varghese *et al.*,1995)
Biomechanical parameters	
Grip strength (kg)	Grip dynamometer
Spinal angle (degree)	Inclinometer, Goniometer
Overall body discomfort(score)	Visual Analogue Discomfort Scale
Musculoskeletal discomfort(score)	Human Body Map(Corlette & Bishop,1976)
	OWAS (Karhu *et al.*1977)
	REBA (Hignett and McAtamney,2000)

Independent variables

Work parameters

- **Time spent (hrs.):** It is the measurable period over which an action or process continues.
- **Weight of load (kg):** It is the vertical pull of the earth to the load.
- **Distance travelled (km):** It is the length of path covered by respondents involved in carrying head load.

Environment parameters

- **Temperature (ºC):** It is the extent of coldness or hotness of the atmosphere. Comfortable range of atmospheric temperature in the workplace should be between 20 and 25º C.
- **Relative humidity (%):** It is the index of amount of water vapours in the air. Basically, it is the saturation percentage of air, that can be less than or equal to 100. Relative humidity of 40-50 percent makes one comfortable in winters, while in summers 40-60 percent is normal.
- **Noise (dB):** It is an unwanted sound which is not liked by an individual. The sound intensity is the sound pressure level and is measured in units of decibels (dB).
- **Light (lux):** It refers to the general lighting conditions in the work place where workers work. To perform the task comfortably, it should be within the range of 500-1000 lux.

Dependent variable

Physiological parameters

- **Pulse rate (beats/min)/ Heart rate (beats/min):** The heart rate is referred to as the primary indicator of the strain or the physiological reaction of a specific person to the stress of the environment and the work. The rate of heart beat (b^{-min}) was determined by using Polar heart rate monitor.
- **Energy expenditure (kJ/min):** Energy expenditure during work was calculated from the value of average heart rate (AHR) by using the regression equation as per Varghese *et al.* (1994).
- **Perceived exertion (score):** It is based on physical sensation a person experiences during an activity including increased heart rate, increased sweating and muscle fatigue. It was calculated with the help of RPE scale given by Varghese *et al*., 1995.
- **Biomechanical parameters**
- **Grip strength (kg):** It is the stress experienced by the grip muscles during or after an activity. It was measured using grip dynamometer.
- **Spinal angle (degree):** It is recorded as the amount of deviation in the normal angle of spine on carrying head load as compared to the resting condition.
- **Overall body discomfort (score):** It is used to determine the discomfort during the activity and doesn't attempt to measure the severity and intensity of the pain.
- **Musculoskeletal discomfort (score):** It is the amount of physical discomfort faced by the respondent in performing a particular work.

3.4 Tools and techniques of data collection

Data were collected during four phases using various tools and techniques as given below:

Phase I: Assessment of existing head load managers

This phase comprised a field survey to study the socio-economic, work profile and ergonomic assessment of the respondents carrying the head load and the work-related musculoskeletal discomfort faced by them. The field survey was conducted with the help of an interview schedule. The activity profile of the workers was examined on the basis of nature, working pattern, weight carried by them at the construction site. A well-structured interview schedule was prepared (Annexure-I).

An ergonomic experiment was carried out on 30 respondents to find the reduction in physiological & biomechanical stress and WMSDs by the use of ergo solutions: Head Load Manager, Head Load Carrier, Head Load Harness (Fig. 3.1).

1. **Head Load Carrier:** HLC was developed by Kumari (2014) for transporting fodder. The HLC is fixed to the user's body with the help of belt. Load could be lifted on it with the help of some other person as farm workers used to do in their normal routine. Finally, the handles are held by keeping the upper arms parallel to the body. While landing the load they could drop it directly on the ground as per their general routine.
2. **Head Load Manager:** Mrunalini (2011) developed the technology named Head Load Manager for transporting manure, seeds, harvested grains, vegetables, fodder and biomass fuel from home, farm and handling of sand, cement at the domestic construction sites. Its first prototype made of GI sheet metal was made in 2009-10, 2nd prototype of stainless steel sheet metal was developed in 2010-11 and 3rd and 4th prototypes of stainless steel tube and cane were made in 2011-12. Its cost was estimated to be Rs 800-1000.
3. **Head Load Harness:** Head Load Harness was developed by Jena (2015) and was useful in eliminating the load to be placed on head. It was a harness of backpack type, easy to mount, convenient to load with little interference in natural movement and facilitated reduced loading on cervical spine. It was made of iron flats with cushion on sides that comes in contact with body. A belt arrangement for fastening and support were given at waist and chest.

Head Load Carrier **Head Load Manager** **Head Load Harness**

Fig. 3.1: Existing Head Load Managers

Experimental procedure:

The selected 30 respondents were given a cement mixture of weight 15 kg to carry for a fixed distance of 200m in four cycles. In the first cycle, they were allowed to carry the load by the existing method as they used to do in their daily routine and their ergonomic parameters were studied. As maximum women were engaged in this industry at construction sites. After that, a proper rest period was given to them till their resting heart rate came to normal. Then they were given the HLC to carry the load and the resultant parameters were recorded again. The same procedure was repeated for the other ergo solutions HLM and HLH. These parameters were then compared to obtain the percentage change in values. The experiment was conducted in the month of September for assessment of various parameters under phase 1

An observation sheet/ worksheet comprising various ergonomic parameters (Annexure-II) was employed using various scales to assess the work-related discomfort of respondents in carrying load on the head. In this phase, details pertaining to the head load were gathered and the ergonomic assessment was done to check the effect of carrying head load on the physiological, biomechanical and environment parameters on the respondents. The experimental procedure was as follows:

A. Physical parameters

Body mass index (BMI): BMI was derived by measuring weight and height of the subjects using Quetelet's Index using the following formula given by Garrow (1981) and the corresponding presumptive diagnosis against score is given in Table 3.2.

$$\text{Quetelet's Index} = \frac{\text{Weight (kg)}}{\text{Height}^2\ (\text{m}^2)}$$

Table 3.2: Grading of health status on the basis of BMI

Scores	Presumptive Diagnosis
16.0	CED* grade- III (Severe)
16.0-17.0	CED* grade- II (Moderate)
17.0-18.5	CED* grade-I (Mild)
18.5-20.5	Low weight Normal
20.5-25.0	Normal
25.0-30.0	Obese grade-I
30.0	Obese grade- II

*CED= Chronic energy deficiency

Body type was estimated to be ectomorphic, mesomorphic and endomorphic using the scores of Quetelet's index as given in Table 3.3.

Table 3.3: Interpretation of body type on the basis of BMI

Body Type	Quetelet's Index Score	Description
Ectomorph	<21.5	Slender, very thin body
Mesomorph	21.5-25	Athletic type body
Endomorph	>25	Abdominal physical type

Body composition: Body composition refers primarily to the distribution of muscles and fat in the body. Body composition is often represented as a two compartment system:

Fat weight: Body fat content was measured by using specially designed skinfold calipers.

Lean body weight: Lean body mass (LBM) was derived by subtracting fat weight from body weight.

Estimation of body fat by skin folds measurements

- **Biceps** skinfold was the bulkiest portion of the upper front inside arm of the respondents.
- **Triceps** skinfold was the bulkiest front of the upper backside arm of the respondents.
- **Subscapular** skinfold was just below the bulging portion of the subscapular bone of the respondents.
- **Suprailiac** skin fold was just above the iliac bone.

To calculate body fat and LBM, the following formulae were used. The log of the sum of skinfolds was calculated and measured as:

Body density (D) = 1.599-(0.0717x log of sum of skinfolds)

Percent fat = (4.95-4.5/D) x 100

$$\text{Fat weight} = \frac{\text{Body weight x \% Fat}}{100}$$

Lean body mass (kg) = Body weight-fat weight.

B. Physiological parameters

These were used to determine the workload on construction women in the form of cardio-respiratory responses and were measured in terms of heart rate (HR), energy expenditure rate (EER), and physiological cost of work (PCW) during the head load carrying activity. The workload on women after completion of the activity was found out on the basis of HR and EER as given by Varghese *et al*. (1994) in Table 3.4.

Table 3.4: Workload classification

Physiological Workload	Variables of Physiological cost	
	HR (b.min^{-1})	EER(kJ.min^{-1})
Very light	Up to 90	Up to 5.0
Light	91-105	5.1-7.5
Moderately heavy	106-120	7.6-10.0
Heavy	121-135	10.1-12.5
Very heavy	136-150	12.6-15.0
Extremely heavy	>150	>15

Heart rate (HR): Heart rate of the subject was measured with the help of heart rate monitor at rest, during the period of the activity and recovery thereafter. Values of resting, working and recovery heart rate were averaged out each time to make a final assessment. From the values of heart rate, following parameters were calculated using their respective formulas:

Energy expenditure rate (EER) (kJ.min^{-1}) = 1.59 × Avg. Working HR (b.min^{-1}) – 8.72

Cardiac cost of work (CCW) (beats) = (Avg. working HR – Avg. Resting HR) ×Duration of activity

Cardiac cost of recovery (CCR) (beats) = (Avg. Recovery HR–Avg. Resting HR) × Duration of recovery

Total cardiac cost of work (TCCW) (beats) = CCW + CCR.

Physiological cost of work (PCW) (b.min^{-1}) = TCCW / Total time of the activity.

The average scores of all the 30 respondents were computed using mean and standard deviation and were recorded to obtain the final values.

C. Biomechanical parameters

Stress on the musculoskeletal system of the women laborers while carrying the load on the head was assessed in terms of grip fatigue and musculoskeletal discomfort of body parts using the following tools and techniques:

Grip strength: It is the stress experienced by the grip muscles during or after an activity. It was measured using grip dynamometer before start of the activity separately with right and left hand. After completion of the activity, the grip strength was again measured. The grip fatigue was calculated using the following formula:

Grip fatigue (%) = Sr-Sw x 100 /Sr

Sr = Strength of muscles at rest.

Sw = Strength of muscles at work.

Reduced muscular strength during activity is an indicator of muscular fatigue because of the activity.

Musculoskeletal discomfort: It was assessed by studying postural discomfort during work using flexicurve, REBA, and Human Body Map**.**

Flexi curve: It was used to measure the angle of deviation (degree) between the normal spinal curve and maximum deviated posture. The flexi curve was mounted to the contour of the spine and immediately drawn on a plain paper to measure the angle of deviation. The angle of bent of the back during the performance of the activity was measured and compared with the normal bent of the back and the angle of the deviation was determined by subtracting the normal angle of bent from the angle of bent during the bending

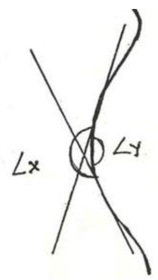


Fig. 3.2: Identification of spinal Angle

posture.

Required angle = x

Measured angle = y

Required angle (x) = 360-y

In addition to flexi curve, the postural deviation was also measured using tool viz. REBA.

REBA: REBA (Rapid Entire Body Assessment) given by McAtamney and Hignett, 2000 is a survey method developed for ergonomic investigation of workplace where work-related entire body disorders are reported. It uses the diagram of body posture including movement of arms, wrists, neck, trunk, and legs by a scoring method including the scoring table to evaluate the level of exposure of risk factors (Annexure-III). A coding system is used to generate an action list which indicates the level of interventions required to reduce the risk of injury due to physical loading on the operator. A video of load lifting, carrying and unloading task was taken, then it was observed to fill observation sheet and then the tasks were numbered to suggest corrective action and necessary changes as given in Table 3.5.

Table 3.5: REBA action sheet

Action level	Score	Interpretation
1	1	Negligible risk
2	2-3	Low risk, change may be needed
3	4-7	Medium risk, further investigation, change soon
4	8-10	High risk, investigate and implement change
5	11+	Very high risk, implement change

Human body map: It is used to measure the localized discomfort, musculoskeletal discomfort, and intensity of pain in different body parts resulting from the postural discomfort. Body part discomfort score (BPDS) was obtained using a modified Human Body Map given by Corlett and Bishop, 1976 (Fig.3.2). In this technique, the body is divided into a number of regions. After performing the work, subjects are asked to indicate discomfort in body parts on a 5-point continuum ranging from 1-5 *i.e.* very mild (1), mild (2), moderate (3), severe (4), and very severe discomfort (5). The weighted mean score are derived to reach the conclusion.

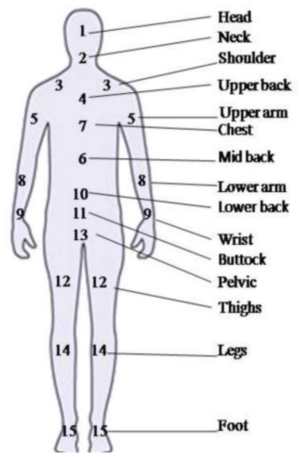


Fig. 3.3 Human Body Map

D. Environmental parameters

Temperature: It is the degree of hotness or coldness of the atmosphere. For work, the comfortable range of atmospheric temperature is taken to be about 20 °C to 24 °C with an average of 23°C.

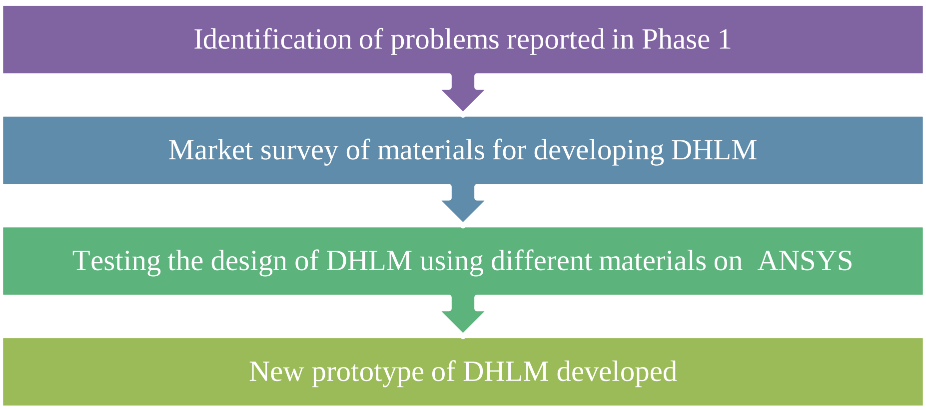
Relative humidity: It is an index of the amount of water vapours in the air. It is simply the percentage saturation of air, which is less than or equal to 100. Relative humidity of 40-50 percent makes one comfortable in winters while in summers 40-60 percent is normal.

Noise: It is an unwanted sound which is not liked by an individual. The sound intensity is the sound pressure level and is measured in units of decibels (dB). The recommended level fall between 60-80dB.

Light: light intensity was measured with the help of lux meter and the unit of measurement of light is lux, and1 lux = 1 lumen per sq. m. The recommended value lie between 250-500lux

Phase II: Experimental Work (Design and development of HLM)

The problems reported in Phase 1 were utilized for designing and development of head load manager. A new modified prototype of the model was developed on the basis of head load manager developed by Murnalini (2011) and named as Developed Head Load Manager (DHLM). The schematic presentation is as under:



There was a need to make DHLM at local level but cane/bamboo was not locally available, therefore, a market survey was conducted. The materials selected on the basis of survey were: stainless steel, gray cast iron and aluminium alloy. Stainless steel, gray cast iron and aluminium alloy could be used to manufacture DHLM due to its low weight. However, their bearing strength was required to be checked. Hence, Analysis System (ANSYS), a simulating software, was used to check their amount of deformation, von-Mises stress, intensity and safety factor by applying different load of 10, 20, 30 and 40 kg on it.

Analysis System (ANSYS)

Analysis system (ANSYS) Mechanical software is a comprehensive FEA (Finite Element Analysis) tool for structural analysis, including linear, nonlinear and dynamic studies. It is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetics for engineers. So ANSYS, which enables to simulate tests or working conditions, enables to test in virtual environment before manufacturing prototypes of products. Furthermore, determining and improving weak points, computing life and foreseeing probable problems are possible by 3D simulations in virtual environment. With the new technology, the scope of interpretation of results has also increased significantly over what was available even 10 years ago because of the availability of various graphing tools. FEA involves three stages:

(1) *Pre-processing*, in which the basic geometry is created and the relevant loads, boundary conditions and material properties are defined. A pre-processor generates an FE file for further processing.

(2) *Analysis*, in which the associated equations are solved and results are generated. The output file from the pre-processor is input to the finite element solver. The solver also generates a series of output files for interpretation of results.

(3) *Post-processing* is the stage where the results are transferred into a form that is easy to interpret. All the solver generated files will be analyzed and necessary graphs and tables will be created. The disadvantages associated with FEA are that the responses of the structure or the results are highly dependent on the boundary conditions and loads specified and, depending on the complexity of the problem; the calculation can consume significant computer resources.

ZW3DCAD

ZWCAD is budget-friendly, DWG file format-compatible Computer Aided Design (CAD) software for MCAD (Mechanical Computer Aided Design) and AEC (Architectural, Engineering & Construction) industries. It is a reliable solution crafted for designers looking for an accessible and affordable drafting application with all the functionality of AutoCAD. The application brings the microinnovations required to deliver smart and efficient design.

It provides a wide range of compact and lightweight drafting features that make it operate faster and overcome key CAD challenges. Some of its key features include 3D solid modelling, dimensioning, creating and editing 2D geometric objects, file sharing, and plotting. In addition, ZWCAD comes with other innovative, customizable, collaborative features including tool palettes, design center, and API customization to boost the efficiency of users.

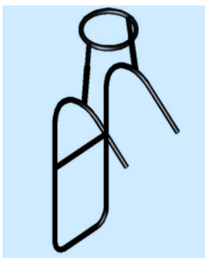


Fig. 3.4: 3D Model of DHLM

Process of testing

i. 3D Model

ii. Comparison of Stainless steel, Cast iron and Aluminum alloy

i. 3D Model

The 3D model of DHLM was made on the ZW3DCAD. The rod used to craft was assumed to have a diameter of 1.5cm.

ii) Comparison of Stainless steel, Cast iron and Aluminum alloy

For making the comparison, load was assumed to be of 10, 20, 30, 40 kg. The 3D model from ZW3DCAD was imported to ANSYS and the results were compared. The comparison was made on the basis of total deformation, von Mises stress and safety factor of all the three materials.

1) Deformation

When a sufficient load is applied to a metal or other structural material, it causes the material to change shape. This change in shape is called deformation. A temporary shape change that is self-reversing after the force is removed, so that the object returns to its original shape, is called elastic deformation. In other words, elastic deformation is a change in shape of a material at low stress that is recoverable after the stress is removed. This type of deformation involves stretching of the bonds, but the atoms do not slip past each other. When the stress is sufficient to permanently deform the metal, it is called plastic deformation.

In tensile tests, if the deformation is elastic, the stress-strain relationship is called Hooke's law:

$$s = Ee$$

$$e = \frac{\Delta L}{L}$$

$$E = ds/de$$

Where, s is tensile stress of the material, E is theYoung’s modulus and e is the change in length of the material as a fraction or percentage of total length.

2) Von Mises stress

Von Mises stress is widely used by designers, to check whether their design will withstand given load condition or not. Using this information an engineer can say his/her design will fail, if maximum value of von Mises stress induced in the material is more than strength of the material. It works well for most of the cases, especially when material is ductile in nature.

For a solid body having yield stress of $\sigma 1$, $\sigma 2$ and $\sigma 3$ in all the three axis, the von Mises stress, σ_v could be expressed by the following equation:

$$\sigma_v = \frac{\sqrt{(\sigma 1 - \sigma 2)^2 + (\sigma 2 - \sigma 3)^2 + (\sigma 1 - \sigma 3)^2}}{\sqrt{2}}$$

3) Safety factor

Safety factor (SF), also known as Factor of safety (FoS), is a term describing the structural capacity of a system beyond the expected loads or actual loads. Essentially, this means how much stronger the system is than it usually needs to be for an intended load. Safety factors are often calculated using detailed analysis because comprehensive testing is impractical on many projects, such as bridges and buildings, but the structure's ability to carry load must be determined to a reasonable accuracy.

$$\text{Safety factor} = \frac{\text{Material strength}}{\text{Design load}}$$

Table 3.6: Application of the safety factor in practical sense based on yield strength (Juvinall & Marshek (2000)

Factor of Safety	Application
1.25 - 1.5	Material properties known in detail. Operating conditions known in detail. Loads and resultant stresses and strains known with high degree of certainty. Material test certificates, proof loading, regular inspection and maintenance. Low weight is important to design.
1.5 – 2	Known materials with certification under reasonably constant environmental conditions, subjected to loads and stresses that can be determined using qualified design procedures. Proof tests, regular inspection and maintenance required.
2 - 2.5	Materials obtained for reputable suppliers to relevant standards operated in normal environments and subjected to loads and stresses that can be determined using checked calculations.
2.5 – 3	For less tried materials or for brittle materials under average conditions of environment, load and stress.
3 – 4	For untried materials used under average conditions of environment, load and stress.
3 – 4	Should also be used with better-known materials that are to be used in uncertain environments or subject to uncertain stresses.

Phase III: Ergonomic assessment of DHLM

Field experiment for ergonomic assessment of DHLM

Field experiment was conducted for ergonomic assessment of the head load carrying task. An observation sheet/ work sheet comprising various ergonomic parameters (Annexure-II) was employed using various scales to assess the work related discomfort of women workers in carrying load on head.

In this phase, details pertaining to the head load were gathered and the ergonomic assessment was done to check the effect of head load carrying on the physiological, biomechanical and environment parameters of the respondents. The experimental procedure is as follows:

Experimental procedure

The selected 30 respondents were given a cement mixture of weight 15 kg to carry for a fixed distance of 200m in two cycles. In the first cycle, they were allowed to carry the load by the existing method as they used to do in their daily routine and their ergonomic parameters were studied. After that, a proper rest period was given to them till their resting heart rate came to normal. Then they were given the DHLM to carry the load and the resultant parameters were recorded again. The experiment was conducted in the month of December for assessment of various parameters.

Table 3.7: Physical and activity Parameters

Parameters	**Name of instrument/formula**
Physical parameters	
Body weight	Weighing scale
Body height	Anthropometer
Body temperature	Clinical thermometer
Blood pressure	Sphygmomanometer and stethoscope
Body mass index	Quetelet's index
Body composition	Lange skin fold calipers
Activity parameter	
Work parameters	
Time spent (hour)	Stop watch
Weight of material (kg)	Weighing scale
Distance travelled (km)	Pedometer

Physiological parameters

Physiological parameters are the scientific study of functions in living system. These include how organisms, organ systems, organs, cells, and bio-molecules carry out the chemical or physical functions that exist in a living system. Following physiological parameters were studied during study:

Table 3.8: Physiological parameters

Parameters	**Name of instrument/formula**
Heart rate	Polar heart rate monitor
Oxygen consumption rate	Oxylog (oxygen consumption, 1/min.) = 0.0155x HR- 1.2248 (Singh and Gite, 2007)
Physical Fitness Index	Step -stool ergometer
Energy expenditure	1.59x AHR (bpm)-8.72 (Varghese *et al.* 1994)

a. **Heart rate:** The heart rate is referred to as the primary indicator of the strain or the physiological reaction of a specific person to the stress of the environment and the work. The rate of heart beat (b^{-min}) was determined by using Polar heart rate monitor.

b. Oxygen consumption rate: The term oxygen consumption means the amount of oxygen consumed by whole body per unit. It was measured by using formula given by Singh and Gite, *et al.* (2007):

c. Physical fitness index: Step stool ergometer is a wooden stool having the following dimensions:

Length	45 cms
Breadth	30 cms
Height	24 cms

Procedure for step stool test:

Selected subject was given rest for some time; the resting heart rate was then measured with heart rate monitor. After the complete rest, the selected subject was asked to perform the stepping activity on the step-stool ergometer for a maximum of 5 minutes with a uniform stepping rate of 30steps/min. During the stepping activity, the heart rate was recorded every 1 min. for a period of 5 min. Physical Fitness Index was calculated by using the following formula:

$$\textbf{Physical Fitness Index} = \frac{\textbf{Duration of stepping (sec)}}{\textbf{Sum of } \mathbf{1^{st}, 2^{nd}} \textbf{ and } \mathbf{3^{rd}} \textbf{ min recovery HR}} \mathbf{\times 100}$$

Table 3.9: Interpretation of health status of the subjects as per PFI

Scores	Physical fitness of the subjects
Upto 80	Poor
81-100	Low average
101-115	High average
116-135	Good
136-150	Very good
Beyond 150	Excellent

The VO_2 max was estimated by using the following formula to determine the physical fitness of the respondents and was grouped according to the classification given by Varghese *et al.* (1995).

$$\mathbf{VO_2} \textbf{ Max (l/min) = 0.377 X step stool test (PFI) – 12.767}$$

Table 3.10: Classification of physical fitness as per Varghese *et.al* (1995)

VO_2(l/min)	Level of Physical fitness
Upto15.0	Poor
16.0-25.0	Low average
26.0-30.0	High average
31.0-40.0	Good
41.0-45.0	Very good
Beyond45.0	Excellent

d. Energy expenditure: Energy expenditure during work was calculated from the value of average heart rate (AHR) by using the regression equation given by Varghese *et al.* (1994):

Energy expenditure (kJ/min.) = 1.59 x AHR (bpm)-8.72

Biomechanical parameters: Biomechanics is the use of body according to principles of laws of mechanism. During work, it also applies engineering principles in order to gain a greater understanding of human performance. In simple words, biomechanics is concerned with how the human body applies forces to itself and object with which it comes into contact, and how the human body is affected by external forces i.e. mainly use of proper body posture while working in day today living. In this study, following biomechanical parameters were used:

Table 3.11: Biomechanical parameters

Parameters	Name of instrument/formula
Posture	REBA (Hignett and McAtamney 2000) and OWAS (Kivi and Mattila, 1991),VAD scale
Angle of deviation	Inclinometer, Goniometer, Flexi curve
Grip strength	Grip dynamometer

Posture: Posture is a position of body and body parts at particular situation. It may also be defined as the orientation of body segments in the space. The posture of the workers in different activities was measured by REBA and OWAS methods. REBA has been described earlier (Phase 1).

a. OWAS: OWAS (Ovako Working Posture Analysis) given by Karhu *et al.*, 1977 is a simple observational method for postural analysis especially that of back, lower and upper extremities and load (Annexure-IV). Video during different activity, showing different movements of worker was recorded and cropped after every 10 seconds to get snapshots for analysis of posture. The snapshots were analyzed to fill the score of OWAS sheet. The OWAS method uses the concept of number to represent posture with an associated coding system. The jobs with the involvement of high risk were numbered higher and those with the less risk involvement were numbered low and thereafter immediate corrective actions and necessary changes were recommended

Table 3.12: OWAS Action Sheet

OWAS category	Description
Action category 1	Work postures are usually considered with no particular harmful effects on musculoskeletal system. No action is needed to change work posture.
Action category 2	Work postures have some harmful effects on musculoskeletal system. Light stress, no immediate action is necessary, but changes should be considered in future planning.
Action category 3	Work postures have distinctly harmful effects on musculoskeletal system. The working method involved should be changed as soon as possible.
Action category 4	Work postures with extremely harmful effects on musculoskeletal system. Immediate solutions should be found to change this posture.

b. Visual Analog Discomfort (VAD) scale: For the assessment of overall discomfort rating, VAD scale, an adaptation of Corlett and Bishop (1976) was used. It is used to determine the discomfort during the activity and doesn't attempt to measure the severity and intensity of the pain. It is a 10 point scale, 0 being the lowest point showing no discomfort and 10 being the uppermost point showing the extreme discomfort. The weighted mean score was derived to reach the conclusion.

Table 3.13: Visual Analogue Discomfort scale

0	1	2	3	4	5	6	7	8	9	10
No Discomfort	**Visual Analogue Discomfort Scale**									Extreme discomfort

c. Angle of deviation: Postural analysis of the lumbo-sacral region during the performance of the activity was done with the help of inclinometer and goniometer. The angle of bend of the back during the performance of the activity was measured and compared with the normal bend of the back. Angle of deviation was determined by subtracting the normal angle of bend from the angle of bend during the bending posture. It gave the angle of deviation of the back bone.

∟x- The required angle.

∟y - The measured angle.

Angle of deviation is, therefore, 360-∟y.

Flexi curve: It was used to measure the angle of deviation (degree) between the normal spinal curve and maximum deviated posture. The flexi curve was mounted to contour of the spine and immediately drawn on a plain paper to measure the angle of deviation. The angle of bent of the back during performance of the activity was measured and compared with the normal bent of the back and angle of deviation was determined by subtracting the normal angle of bent from the angle of bent during the bending posture.

d. Grip Strength: Described earlier in phase 1.

Psycho-physiological Parameters

Psycho-physiology is the branch of psychology that deals with the physiological basis of psychological process. Psychophysics quantitatively investigates the relationship between physical stimuli and the sensations and perceptions they affect. Psychophysiology has been described as "the scientific study of the relation between stimulus and sensation" or, more completely, as "the analysis of perceptual processes by studying the effect on a subject's experience or behavior of systematically varying the properties of a stimulus along one or more physical dimensions" (Promila, 2010). Following parameters were evaluated during study:

Table 3.14: Psycho-physiological Parameters

Parameters	Name of instrument/formula
Musculo-skeletal discomfort assessment	Human body map , VAD Scale (Overall Discomfort Rating) (Corlett and Bishop (1976)
Perceived exertion	RPE (Varghese *et al.*, 1995)

In addition to cardio-respiratory and biomechanical responses, the psycho-physical responses of the workers while performing activity were also recorded in terms of human body map, VAD, Nordic scale and RPE as given below:

a. **Musculo-skeletal discomfort assessment:** Incidences of musculoskeletal problems during the activity were identified with the help of human body map, and VAD scale.

Rating of Perceived Exertion (RPE): The RPE scale given by Varghese *et al*., 1995 was used to measure the intensity of exertion. It is subjective expression of feelings of workers towards the activity i.e. how easy or difficult the subject finds his activity. It was based on physical sensation a person experiences during an activity including increased heart rate, increased sweating and muscle fatigue. This scale now has been accepted as a practical method for rapid appraisal of all occupational work. In this scale, scores were assigned at 5-point continuum ranging from 1-5 as below:

Table 3.15: Rating of Perceived Exertion scale

1	2	3	4	5
Very light exertion	Light exertion	Moderately heavy exertion	Heavy exertion	Very heavy exertion

The weighted mean score was derived to draw the inference.

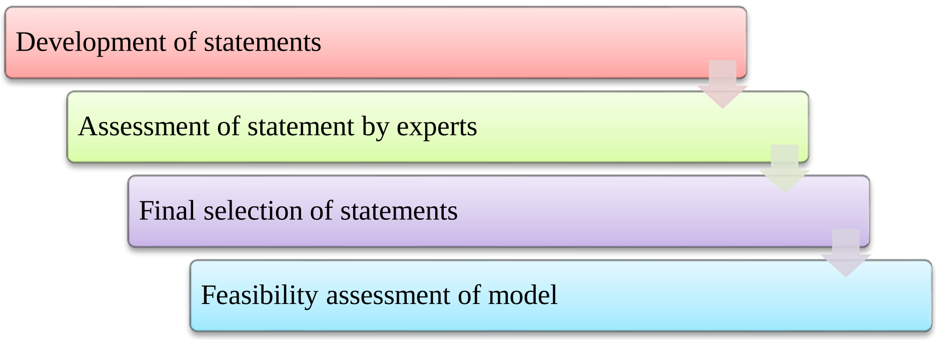
Phase 4: Feasibility testing of DHLM

Feasibility testing of the DHLM was done using the modified scale of Rogers and Shoemaker (1962). On the basis of various attributes i.e. relative advantage, compatibility, simplicity/complexity and practicability and data were analysed in terms of the weighted mean score. Several statement were prepared by the researcher relevant to above parameters which were given to 30 experts comprising faculty members of I. C. College of Home

Science, CCS, HAU, Hisar, for final selection of statements for testing the feasibility of DHLM on the basis of ranks. The statements given the highest rank by the experts were selected (Annexure-V).

Data were also analysed with the help of user assessment sheet which includes ergonomic aspects to make the product more convenient to the users.

Responses of the respondents were recorded using interview schedule which comprised of different statements categorized under five main headings i.e. musculoskeletal factors, physical stress factors, work output factors, tool factors and acceptability factors (Annexure-VI). The responses of the women were recorded on 3 point scale. The qualitative scores were quantified by assessing scores i.e. strongly agree – 3, agree – 2 and disagree – 1.



3.5. Analysis of data

Personnel information was analyzed by using frequency and percentage.

Frequency and percentage: Frequencies and percentages were calculated to generate personnel information, work pattern of the respondents at construction site. The frequency is the number of times a particular value for a variable (data item) has been observed to occur. A percentage expresses a value for a variable in relation to a whole population as a fraction of one hundred.

The experimental data were coded and tabulated by mean, standard deviation, weighted mean score.

Weighted mean: Weighted mean was calculated to assess VAD, RPE and feasibility testing of DHLM encountered by women labourer while working at construction site. The frequency in each of the category was multiplied by assigned code. The resulting sum of each aspect was divided by the total number of respondents. In this way, the weighted mean score for each aspect was calculated.

Correlation: It was employed to find out the relationship between different variables.

ANOVA test was used to compare head load carriage using Conventional Method, HLC, HLM and HLH.

The paired t-test was employed to compare different ergonomic parameters while carrying the head load by using SPSS.

CHAPTER–IV

RESULTS

This chapter presents the findings of the study. For a comprehensive presentation this chapter has been grouped under the followings phases:

Phase I: Assessment of existing HLMs for construction workers

Phase II: Design and development of HLM for construction workers

Phase III: Ergonomic assessment of the DHLM

Phase IV: Feasibility testing of DHLM

Phase I: Assessment of existing HLMs for construction workers

Demographic profile includes:

a) **Socio-personal profile of the respondents**
b) **Work profile of the respondents**
c) **Material carried by the respondents**

Ergonomic Assessment:

a) **Anthropometric and physical parameters of the respondents**
b) **Physiological parameters before and after carrying the head load**
c) **Comparison of spinal angle after carrying the head load**
d) **Comparison of the grip strength**
e) **Comparison of Body Part Discomfort**
f) **REBA analysis for different stages of head load carrying the task**
g) **Environmental conditions while carrying the head load**
h) **Correlation between anthropometric and physiological parameters**
i) **Comparison between physiological parameters**
j) **Comparison between grip strength**
k) **Comparison between different body part discomfort**

a. Socio-personal profile of the respondents

Age: The result in Table 4.1 shows that 66.67 percent of the respondents were in the age group of 30-40 years followed by those having age between 20-30 years (33.33).

Marital status: Majority of the respondents (63.33%) were married, followed by those who were single (23.33%), or divorced (13.34%).

Educational level: Majority of the respondents were illiterate (60%), followed by those who could read and write only (40%).

Family type: Table 4.1 unfolds that a large number of the respondents were having a nuclear family (70%) followed by joint family (30%) system.

Native place: Majority of the respondents working at construction sites belonged to the state of West Bengal (30%), followed by Uttar Pradesh (20%), Madhya Pradesh (16.67%), and Haryana (13.33%).

Table 4.1: Socio-personal profile of the respondents

n=30

Variables	**Category**	**Total f (%)**
Age	20-30 years	10(33.33)
	30-40 years	20(66.67)
Marital status	Married	19(63.33)
	Single	7(23.33)
	Divorced/separated	4(13.34)
Educational level	Illiterate	18(60.00)
	Read & write	12(40.00)
Family type	Joint	9(30.00)
	Nuclear	21(70.00)
Native place	Madhya Pradesh	5(16.67)
	Uttar Pradesh	6(20.00)
	West Bengal	15(30.00)
	Haryana	4(13.33)

b. Work profile of the respondents

Pattern of employment: Data in Table 4.2 show that huge majority of the respondents (60%) were employed on the daily wage, followed by temporary basis (23.33%), and those who were engaged on a permanent basis (16.66%).

Wages received per day: More than half of the respondents (60%) received wages in between ₹250-350. Remaining respondents (40%) received wages between ₹350-450 per day.

Pattern of wage payment: Maximum number of the respondents (50%) reported wage payment pattern as daily basis followed by those who were getting on a weekly basis (30%) and monthly basis (20%).

Table 4.2: Work profile of the respondents **n=30**

Variables	**Categories**	**Total f (%)**
Pattern of employment	Permanent	5(16.67)
	Temporary	7(23.33)
	Daily wage	18(60.00)
Wages received per day	250-350	18(60.00)
	350-450	12(40.00)
Pattern of wage payment	Daily	15(50.00)
	Weekly	9(30.00)
	Monthly	6(20.00)

c. Material carried by the respondents

Table 4.3 shows that the material carried by the respondents on their head was concrete mixture (30%) bricks (23.33%), cement (20%) and water (16.67%). Ten percent of the respondents carried other material like sand, gravel, etc. Majority of the respondents (60%) carried the heavy load on the head ranging between 10-20 kg, followed by those who carried the weight greater than 20 kg (23.33%), whereas only a few (16.67%) reported carrying less than 10kg.

Table 4.3: Material carried by the respondents at construction sites

n=30

Variables	**Categories**	**f(%)**
Type of material	Water	5(16.67)
	Bricks	7(23.33)
	Concrete mixture	9(30.00)
	Cement	6(20.00)
	Other material (sand,gravel,etc.)	3(10.00)
Weight of material	<10 kg	5(16.67)
	10-20 kg	18(60.00)
	>20 kg	7(23.33)

Ergonomic assessment

a. Anthropometric and physical parameters of the respondents

Results in Table 4.4 reveal the anthropometric and physical parameters of respondents selected for the study. The mean age of the respondents was 31.96 ± 4.89 yrs; the height of the respondents was 155.43 ± 7.02 cm with a mean weight of 52.36 ± 4.68 kg. The mean waist circumference of the respondents was 72.03±8.60 cm, waist back length was 38.33±3.26 cm, vertical reach 194.10±8.66 cm and head breadth was 14.36±1.10 cm, respectively. Different body fold measurements were also recorded. The mean of their biceps skinfold was 1.76±0.31mm while those of triceps, subscapular, and suprailiac were 1.65±0.37 mm, 1.91±0.41 mm and 2.01±0.43 mm, respectively.

Mean body mass index was 21.78±2.63kg/m^2 with mesomorph body type, mean body fat percentage was 0.83±1.23, mean LBM (Lean body mass) of the respondents was 34.01±5.05 kg and total body fat was 14.08±2.09 kg, respectively. An average female worker worked for 6-8 hours per day and travelled a distance of 2-3 km in one hour at the construction site.

Table 4.4: Anthropometric and physical parameter of the respondents

n=30

Parameter	**Mean ± S.D**
Age (yr.)	31.96 ± 4.89
Height (cm)	155.43 ± 7.02
Weight(kg)	52.36 ± 4.68
Waist circumference(cm)	72.03±8.60
Waist Back Length(cm)	38.33±3.26
Vertical Reach(cm)	194.10±8.66
Head breadth(cm)	14.36±1.10
Biceps skinfold(mm)	1.76±0.31
Triceps skinfold(mm)	1.65±0.37
Subscapular skinfold(mm)	1.91±0.41
Suprailiac skinfold(mm)	2.01±0.43
BMI (kg/m^2)	21.78±2.63
Body fat percentage	0.83±1.23
Lean body mass(kg)	34.01±5.05
Total body fat(kg)	14.08±2.09

b) Physiological parameters before and after carrying the head load

Table 4.5 gives the comparison of different physiological parameters before and after carrying the head load. It was found that working heart rate before activity was 120.14 b/min whereas while after using Conventional Method was 137.67 b/min. The working heart rate while using head load harness was 133.77 b/min and while using head load manager and head load carrier was 134.86 b/min,132.80 b/min respectively. Recovery heart rate before activity (107.51b/min) was always lesser as compared to after activity. Recovery heart rate in head load manager 120.18 b/min was found higher followed by head load harness 119.29 b/min, Conventional Method 119.08 b/min and head load carrier117.49 b/min. Energy expenditure 10.38 kJ/min before activity was low while after activity in Conventional Method was higher i.e 13.16 kJ/min. The head load manager, head load harness, head load carrier had approximately same value of 12.72 kJ/min, 12.54 kJ/min, 12.39 kJ/min respectively after the activity. The total cardiac cost of work after activity was found higher in Conventional Method 3170.10 beats followed by head load manager (3006.90beats), head load carrier (2970.10 beats), head load harness (2937.00beats) in comparison to before activity (2039.22 beats). Physiological cost of work was also higher in Conventional Method (52.83b/min) followed by head load manager (50.11b/min), head load harness (48.95b/min) and head load carrier 47.83 b/min as compare to before activity (33.98 b/min).

Table 4.5: Physiological parameters before and after carrying the head load

n=30

Parameters	Before Activity	After Activity			
		Conventional Method	HLC	HLM	HLH
Working Heart Rate ($b.min^{-1}$)	120.14	137.67	132.80	134.86	133.77
Recovery Heart Rate ($b.min^{-1}$)	107.51	119.08	117.49	120.18	119.29
Energy Expenditure ($kJ.min^{-1}$)	10.38	13.16	12.39	12.72	12.54
Total Cardiac Cost of Work (TCCW) (beats)	2039.22	3170.10	2970.10	3006.90	2937.00
Physiological Cost of Work ($b.min^{-1}$)	33.98	52.83	47.83	50.11	48.95

*HLC-Head load carrier
*HLM-Head load manager
*HLH-Head load harness

Fig. 4.1: Carrying head load with Head Load Manager, Head Load Carrier and Head Load Harness

c) Comparison of spinal angle after carrying the head load

Table 4.6 represents the deviation in spinal angle while carrying the head load with the help of Conventional Method, HLC, HLM and HLH. It was seen that the deviation of cervical angle of the spinal cord in Conventional Method was 187^o while there was no change in the cervical angle after using head load carrier (182^o), head load manager (182^o) and head load harness (182^o) respectively. It was seen that a deviation in the lumbar angle of the spinal cord in Conventional Method was 189^o, followed by head load harness 188^o, head load manager 186^o, head load carrier 186^o while the resting angle was 183^o.

Table 4.6: Comparison of spinal angle after carrying the head load

n=30

Spinal angle (degree)	Resting	Conventional Method	Head load carrier	Head load manager	Head load harness
Cervical angle (degree)	182	187	182	182	182
Lumbar angle (degree)	183	189	186	186	188

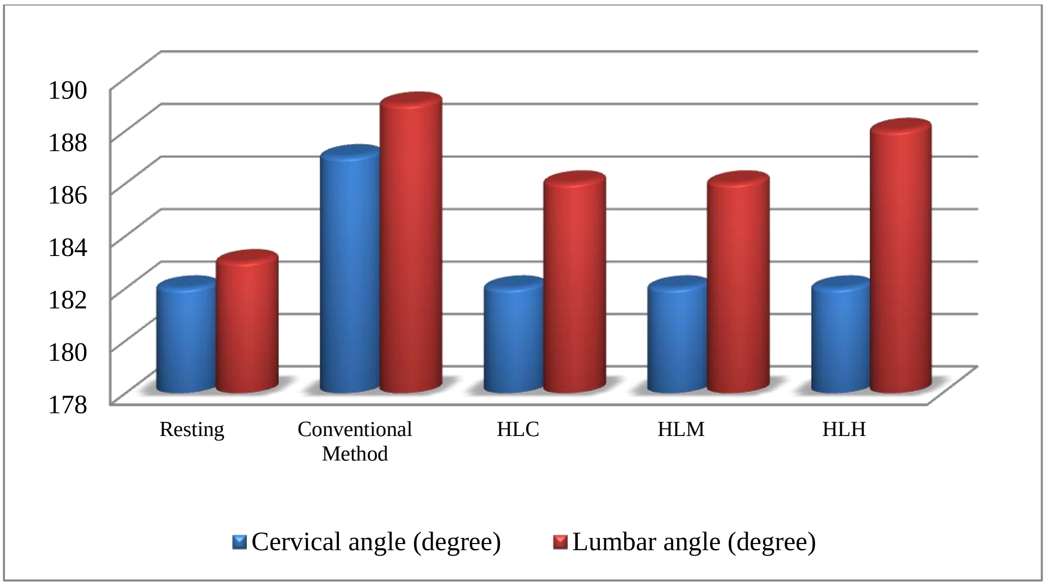


Fig: 4.2 Comparison of spinal angle after carrying the head load

d) Comparison of the grip strength

Table 4.7 depicts the grip strength of the respondents after performing the load carrying activity performed through four methods. Results reveal that grip strength was 19.29±4.89 kg, 18.16±3.61 kg, 17.60 ±3.27 kg, and 16.21± 3.30 kg for the right hand in the head load carrier, head load harness, Conventional Method, and head load manager respectively. For the left-hand, grip strength was 18.68±4.27 kg, 17.60±3.99 kg, 15.77±2.55 kg, 15.57±2.80 kg, in head load carrier, head load harness, head load manager, and Conventional Method respectively.

Table 4.7: Comparison of the grip strength

n=30

Parameters		Right				Left			
		CM	**HLC**	**HLM**	**HLH**	**CM**	**HLC**	**HLM**	**HLH**
Grip Strength (kg)	**At rest**	20.37± 3.08	20.37± 3.08	20.37± 3.08	20.37± 3.08	21.68± 4.32	21.68± 4.32	21.68± 4.32	21.68± 4.32
	After work	17.60± 3.27	19.29± 4.89	16.21± 3.30	18.16± 3.61	15.57± 2.80	18.68± 4.27	15.77± 2.55	17.60± 3.99
Reduction in strength (%change)		2.77 (13.59%)	1.08 (5.30%)	4.16 (20.42%)	2.21 (10.84%)	6.11 (28.18%)	3.00 (13.83%)	5.91 (27.68%)	4.08 (18.81%)

*CM-Conventional Method
*HLC-Head load carrier
*HLM-Head load manager
*HLH-Head load harness

e) Comparison of Body Part Discomfort

Body part discomfort Score (BPDS) was studied through the use of Human Body Map (Corlett & Bishop, 1976) at 5-point continuum.

For the discomfort level in different body parts while carrying the load on their head with the help of different methods, weighted mean score of discomfort of different body parts was calculated individually and is presented in Table 4.8.

In Conventional Method, severe discomfort was felt in the head, lower back (4.19 each), neck (3.93), feet (3.84), shoulders (3.81), buttocks (3.75) and upper back (3.61). Discomfort in the wrists (3.39), upper arms (3.32), mid back (3.20), chest (3.17), and knee (3.16) was moderately heavy whereas light discomfort was felt in the thighs (2.97), legs (2.64), lower arms (2.58) while carrying the load (Fig. 4.2).

While performing the activity with the help of head load carrier, mild discomfort was felt in the legs (2.60), shoulders (2.54), upper back (2.37), feet (2.41), upper arms (2.18), mid back (2.07), neck (1.54), and lower arms, thighs (1.52 each). Very mild discomfort was felt in the knee (1.43), buttocks (1.39), lower back, head (1.30 each), chest (1.08), and wrists (1.01).However, carrying the heavy load with the help of head load manager, very heavy discomfort was felt in the shoulders (4.67) and moderate discomfort was felt in upper back (3.64), and lower back (3.59) mild discomfort was perceived in the feet (2.76), legs (2.70), thighs (2.68), wrists (2.37), mid back (2.35), knee (2.33), upper arms (2.25), neck (2.24), lower arms (2.22). head (2.20), buttocks (2.15), and chest (2.03) felt.

Though carrying the heavy load with the assistance of head load harness, moderate discomfort was felt in the upper back (3.50) while mild discomfort was felt in the wrists (2.60), legs (2.52), knee, shoulders (2.50 each), mid back (2.36), thighs (2.29), lower back (2.25), buttocks, chest (2.23 each), upper arms (2.20), lower arms(1.99), neck (1.64),feet(1.50) and head (1.30).

Table 4.8: Level of Body Part Discomfort using different methods

n=30

Sr. No.	Body parts	Conventional Method	Head load carrier	Head load manager	Head load harness
1.	**Head**	4.19	1.30	2.20	1.30
2.	**Neck**	3.93	1.54	2.24	1.64
3.	**Shoulders**	3.81	2.54	4.67	2.50
4.	**Upper back**	3.61	2.37	3.64	3.50
5.	**Mid back**	3.20	2.07	2.35	2.36
6.	**Lower back**	4.19	1.30	3.59	2.25
7.	**Chest**	3.17	1.08	2.03	2.23
8.	**Upper arms**	3.32	2.18	2.25	2.20
9.	**Lower arms**	2.58	1.52	2.22	1.99
10.	**Wrists**	3.39	1.01	2.37	2.60
11.	**Buttocks**	3.75	1.39	2.15	2.23
12.	**Thighs**	2.97	1.52	2.68	2.29
13.	**Knee**	3.16	1.43	2.33	2.50
14.	**Legs**	2.64	2.60	2.70	2.52
15.	**Feet**	3.84	2.41	2.76	1.50

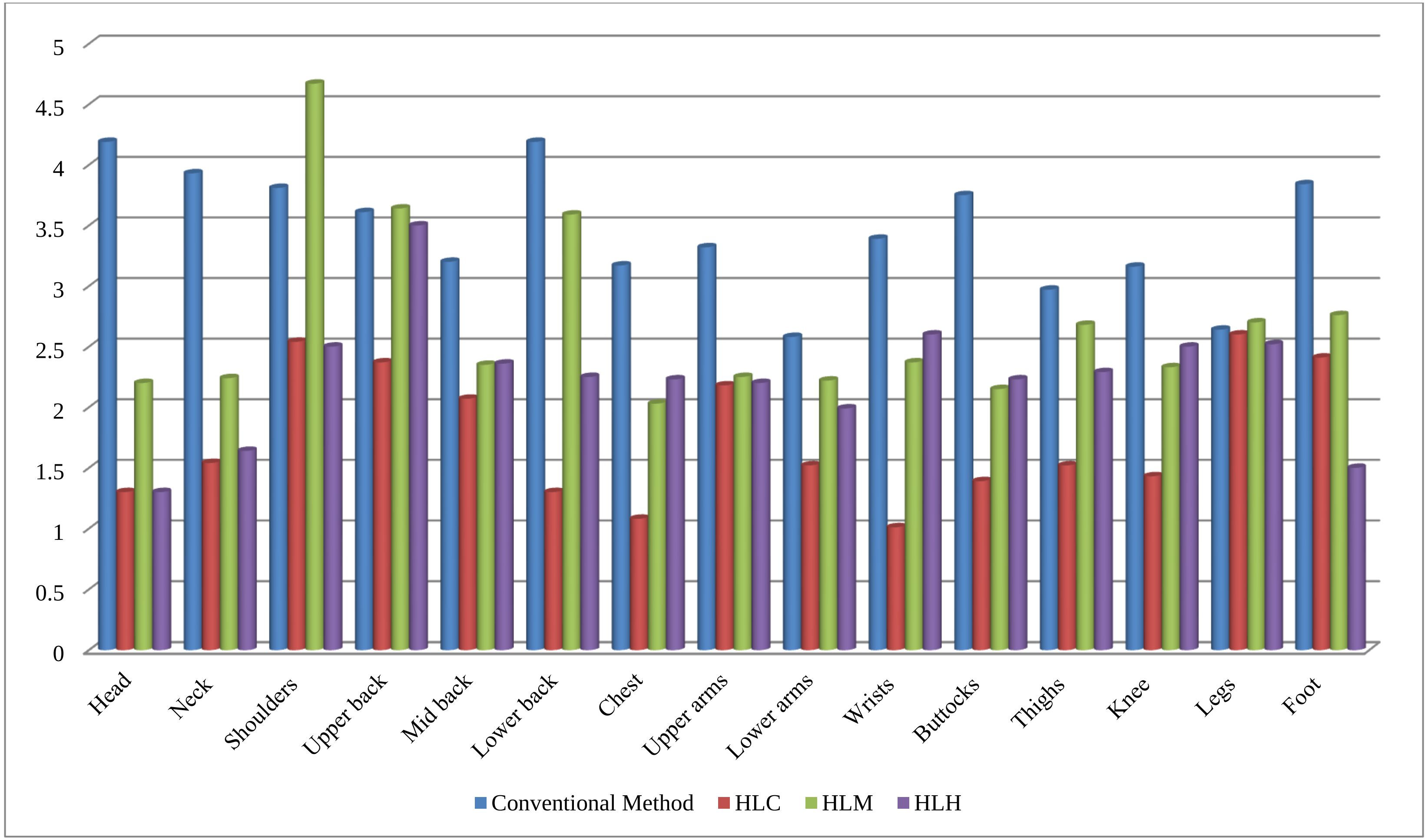


Fig 4.3: Body Part Discomfort

f) REBA analysis for different stages of head load carrying the task

The head load carrying activity was divided into three stages: lifting, carrying and landing the load. Each stage was analysed carefully through REBA and results are presented in Table 4.9.

Table gives the overall REBA score while performing the activity with the use of different methods to them. It was found that in lifting activity, score was 13 in Conventional Method followed by head load carrier, head load harness (12 each), 11 in head load manager respectively indicating that the job had very high risk and there was need to implement the change.

While in the carrying activity, the score was 12 in Conventional Method followed by head load carrier (11) and head load manager, head load harness (10 each), which indicated that the job was very highly risky and there is need to implement the change.

Even though in landing activity, the score was 12 in head load manager followed by head load carrier, head load harness (11each) and Conventional Method (10), it indicated that the job had very high risk and there was need to implement the change.

Table 4.9: REBA analysis for different stages of head load carrying the task

n=30

Stages	Conventional Method	HLC	HLM	HLH
Lifting	13	12	11	12
Carrying	12	11	10	10
Landing	10	11	12	11

*HLC=Head load carrier
*HLM=Head load manager
*HLH=head load harness

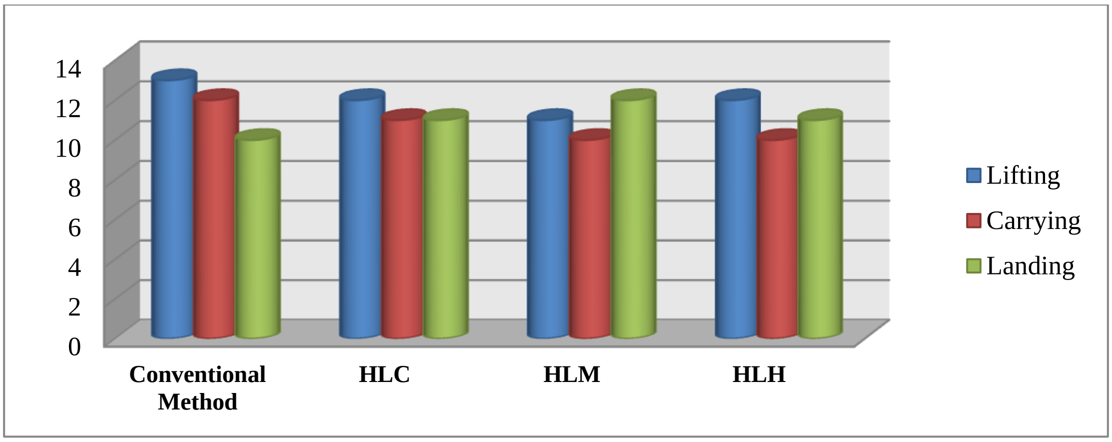


Fig 4.4: REBA analysis

g) Environmental conditions while carrying the head load

Table 4.10 shows the environmental conditions while carrying load on the head. The experiment was conducted in the month of September having an average temperature of 34. 26^{0}C during carrying the head load which was much higher than the recommended value whereas the average level of humidity was 48.16 % which was within the recommended value but on the lower side. The noise level at the construction site was 90.43dB which was more than the recommended value and light was found 386.60lux which was within the limit. Hence, it may be inferred that the environment in which the respondents had to work was hot and dry.

Table 4.10: Environmental conditions while carrying the head load n=30

Parameters	(Mean $\pm$ SD)	Recommended value*
Temperature (^{0}C)	34.26$\pm$2.60	20-24
Humidity (%)	48.16$\pm$11.89	40-60
Noise (dB)	90.43$\pm$6.61	60-80dB
Light (lux)	386.60$\pm$327.61	250-500lux

*Grandjean (1978)

h) Correlation between anthropometric and physiological parameters

Table 4.11 illustrates the correlation between the anthropometric and physiological parameters. It was found that there was no correlation between BMI and working heart rate, recovery heart rate and physiological cost of work while performing the head load carrying activity using different methods. From the perusal of Table it may be inferred that there is a correlation between the working heart rate and age while using head load manager. There was also correlation found in the age and physiological cost of work for head load carrier and head load manager. Table also shows the correlation between the physiological cost of work of head load carrier and total body fat.

Table 4.11: Correlation between anthropometric and physiological parameters

Parameters		BMI	Age	Total Body Fat
Working Heart Rate (b.min^{-1})	**Conventional Method**	0.12	0.35	0.35
	Head load carrier	0.27	0.29	0.33
	Head load manager	0.06	0.40*	0.11
	Head load harness	0.12	0.12	0.03
Recovery Heart Rate (b.min^{-1})	**Conventional Method**	0.58	0.16	0.01
	Head load carrier	0.13	0.34	0.16
	Head load manager	0.01	0.01	0.002
	Head load harness	0.06	0.09	0.01
Physiological Cost of Work (b.min^{-1})	**Conventional Method**	0.06	0.12	0.15
	Head load carrier	0.26	0.38*	0.39*
	Head load manager	0.09	0.47**	0.21
	Head load harness	0.14	0.09	0.13

*Significant at 0.05 level.
**Significant at 0.01 level.

i) Comparison between physiological parameters

Table 4.12 shows physiological parameters of the respondents. The working heart rate (120.14 b/min) of the respondents before activity was significantly lesser than the

Conventional Method (137.67 b/min), head load carrier(132.80 b/min),head load manager (134.86 b/min), and head load harness(133.77 b/min). However, no significant difference was observed in the Conventional Method, head load carrier, head load manager, and head load harness. On the other hand, recovery heart (107.51b/min) was also significantly lesser than the other methods. No significant difference was found among the Conventional Method (13.07 kJ/min), head load carrier (12.39 kJ/min), head load manager (12.72 kJ/min), and head load harness (12.54kJ/min) in respondents energy expenditure. But rate of energy expenditure before activity (10.44kJ/min) was significantly lower than the other methods. There was no significant difference found in the total cardiac cost of work (TCCW) and physiological cost of work of the respondents while performing activity using Conventional Method, head load carrier, head load manager, and head load harness but before activity significantly lower difference was found for both the parameters compared to other methods.

Table 4.12: Comparison between physiological parameters

Parameters	Before Activity	Conventional Method	HLC	HLM	HLH
Working Heart Rate ($b.min^{-1}$)	120.14^{a}	137.67^{b}	132.80^{b}	134.86^{b}	133.77^{b}
Recovery Heart Rate ($b.min^{-1}$)	107.51^{a}	126.86^{b}	128.21^{b}	129.55^{b}	124.72^{b}
Energy Expenditure ($kJ.min^{-1}$)	10.44^{a}	13.07^{b}	12.39^{b}	12.72^{b}	12.54^{b}
Total Cardiac Cost of Work (TCCW) (beats)	2062.55^{a}	3171.66^{b}	2923.72^{b}	3053.77^{b}	2964.27^{b}
Physiological Cost of Work ($b.min^{-1}$)	34.37^{a}	52.86^{b}	48.72^{b}	50.89^{b}	49.40^{b}

j) Comparison between grip strength

Table 4.13 elucidates the correlation between the respondents after performing the activity with the assistance of four different methods. For the right hand, it was found that there was a significant difference between Conventional Method and head load manager and head load harness. A significant difference was observed between head load carrier and head load manager. For the left hand, there was a significant difference between Conventional Method and head load manager. Significant difference was also observed between head load carrier and head load manager as also depicted in the Table 4.13.

Table 4.13: Comparison between grip strength

Variables		Right	Left
Conventional Method	**Head load carrier**	0.55^{NS}	0.61^{NS}
	Head load manager	2.59^{*}	3.52^{*}
	Head load harness	1.95^{*}	1.69
Head load carrier	**Head load manager**	2.03^{*}	2.91^{*}
	Head load harness	1.39^{NS}	1.07^{NS}
Head load manager	**Head load harness**	0.64^{NS}	1.83^{NS}

*Significant at 0.05 level

k) Comparison between different body part discomforts

Table 4.14 depicts the comparison between different body part discomforts while performing activity with the help of Conventional Method, head load carrier, head load manager, and head load harness. No significant discomfort was found in the head load carrier and head load manager with respect to shoulder discomfort; head load carrier and head load harness in the head , neck, and shoulder discomforts, head load manager and head load harness in the neck and shoulders discomfort.

Table 4.14 shows that upper back discomfort in Conventional Method, head load carrier, head load manager and head load harness was significantly different whereas head load carrier, head load manager head load harness were non- significantly different in this regard. In mid-back, upper back and upper arm discomfort, head load carrier, head load manager head load harness were non- significantly different whereas Conventional Method, head load carrier, head load manager and head load harness were significantly different. On the other hand, in lower back discomfort all variables were significantly different with each other with respect to in lower arms discomfort, head load manager and head load harness were non-significantly different and other variables were significantly different.

A perusal of Table indicates that in buttocks and thigh, almost all the variables were significantly different but head load harness and head load manager were non- significantly different. For legs and feet, all the variables were non-significantly different with each other.

Table 4.14: Comparison between different body part discomforts

Variables		Head	Neck	Shoulders	Chest	Wrist	Upper Back	Mid Back	Lower Back	Upper Arms	Lower Arms	Buttocks	Thighs	Knees	legs	Feet
CM	**HLC**	2.88*	2.39*	1.43*	2.09*	2.35*	1.07*	2.89*	1.14*	1.06*	2.69*	1.44*	1.72*	0.04^{NS}	0.43^{NS}	1.13*
	HLM	1.98*	1.69*	1.44*	1.13*	1.02*	0.97*	1.60*	1.07*	0.36*	1.59*	0.28	0.82*	0.05^{NS}	0.92^{NS}	0.84*
	HLH	2.88*	2.29*	1.31*	0.93*	0.79*	1.05*	1.93*	1.12*	0.59*	1.51*	0.67*	0.66*	0.12^{NS}	0.34^{NS}	0.83*
HLC	**HLM**	0.90*	0.70*	0.00^{NS}	0.95*	1.33*	0.10^{NS}	1.29*	0.07^{NS}	0.70*	1.09*	1.16*	0.90*	0.09^{NS}	1.35^{NS}	0.28^{NS}
	HLH	0.00^{NS}	0.10^{NS}	0.12^{NS}	1.15*	1.56*	0.02^{NS}	0.95*	0.01^{NS}	0.47*	1.17*	0.77*	1.06*	0.08^{NS}	0.08^{NS}	0.29^{NS}
HLM	**HLH**	0.90*	0.60^{NS}	0.12^{NS}	0.20*	0.22	0.08^{NS}	0.33*	0.05^{NS}	0.22^{NS}	0.07^{NS}	0.39^{NS}	0.16^{NS}	0.18^{NS}	1.26^{NS}	0.01^{NS}

*CM-Conventional Method

*HLC-Head load carrier

*HLM-Head load manager

*HLH-Head load harness

*Significant at 0.05 level

Phase II

Design and development of head load manager for construction workers

Stainless steel, Gray cast iron, and Aluminium alloy were compared to obtain a low cost, durable and lightweight product. From Table 4.15, it may be observed that Stainless steel had the density of 7750/m^3, Gray cast cast iron had density 7200kg/m^3, and Aluminium alloy had density 2770kg/m^3. A 3D model was made with the help of ZWCAD software for further analysis. Their strengths were checked with the help of simulating software ANSYS by applying the force 98N, 196N, 294N, and 392N. The hollow rod for the manufacture of developed head load manager was assumed to have a diameter 1.5cm. The use of software reduced the unnecessary wastage of time and money and gave the information about the strength, durability, and risk involved in making the product. Comparisons had been made on the basis of the amount of total deformation occurred, von Mises stress created, the intensity of material and safety factor of the material after applying a load of 10,20,30, and 40 kg on it.

Table 4.15: Properties of materials

Parameters	Density	Young's Modulus	Tensile yield strength	Tensile ultimate strength
Stainless steel	7750kg/m^3	1.93e+05 MPa	207 MPa	586 MPa
Gray cast iron	7200kg/m^3	1.1e+05 MPa	190 MPa	240 MPa
Aluminium Alloy	2770kg/m^3	71000 MPa	280 MPa	310 MPa

Comparison of total deformation of the materials

Table 4.16 shows the total deformation of the materials when a different amount of force was applied to the 3D model. From the Table, it can be concluded that all the values are very minute for any metals. Hence, all the materials were suitable for manufacture on the ground of deformation.

Table 4.16: Comparison of total deformation (mm) of the materials

Load (kg)	Stainless Steel	Gray cast iron	Aluminium Alloy
10	0.17	0.30	0.46
20	0.34	0.60	0.92
30	0.49	0.89	1.39
40	0.68	1.20	1.84

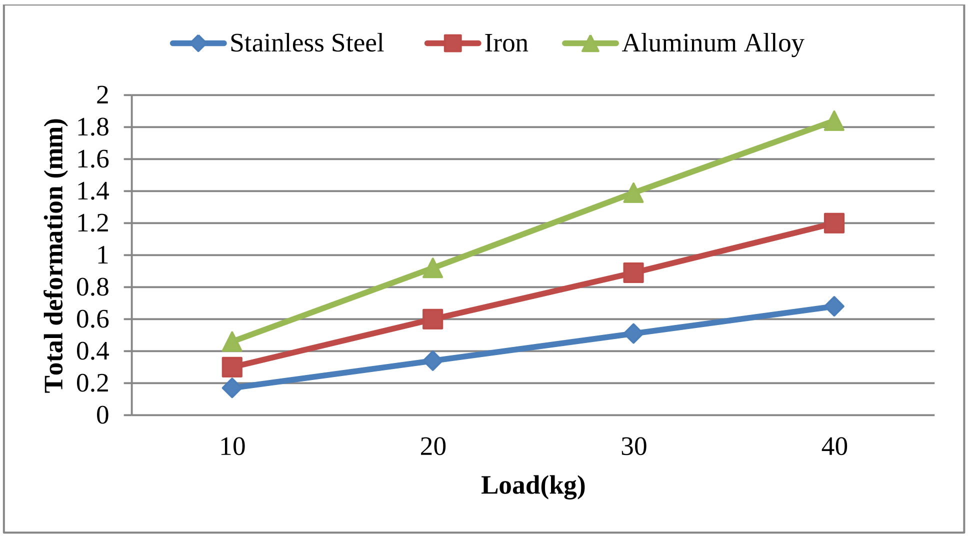


Fig 4.5: Total deformation of the materials

Comparison of von-Mises stress of the materials

From Table 4.17, it was concluded that the von Mises stress in all the three materials, i.e. Stainless steel, Gray cast iron and Aluminium alloy had the value less than the tensile strength of the materials. Hence it was safe for the industrial production of the product. Tensile strength for the stainless steel gray cast iron and Aluminium alloy was 207MPa, 190MPa and 280MPa, respectively.

Table 4.17: Comparison of von-Mises (MPa) stress of the materials

Load (kg)	Stainless Steel	Gray cast iron	Aluminium Alloy
10	12.78	12.74	12.82
20	25.57	25.48	25.64
30	38.31	38.23	38.46
40	51.15	50.97	51.28

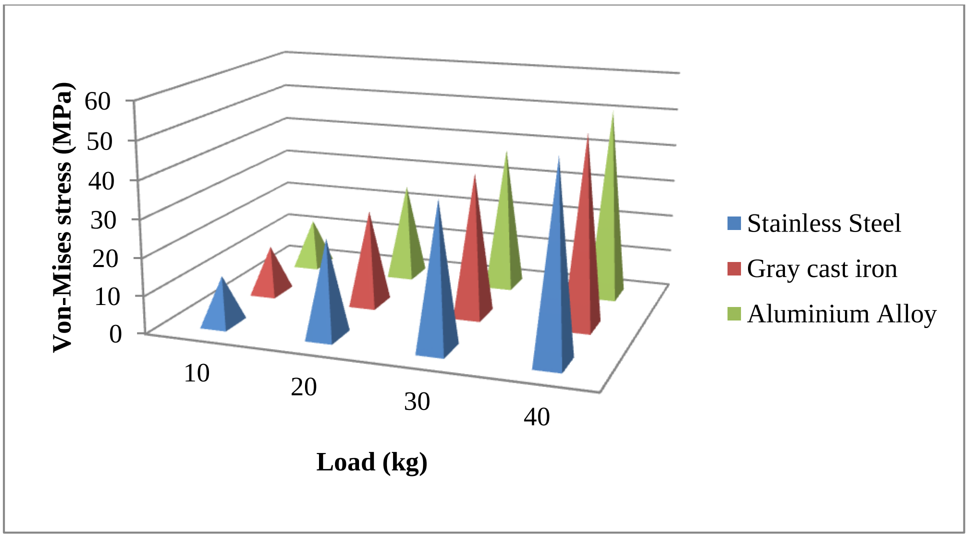


Fig 4.6: von-Mises stress of the materials

Comparison of the safety factor of the materials

Table 4.18 elucidates the safety factor of the materials. At a load of 10kg, 20kg, and 30kg any of the material did not involve any risk of manufacture. According to yield strength (Juvinall & Marshek, 2000) at 10kg load, material should also be used with better-known materials that are to be used in uncertain environments or subject to uncertain stresses.

Table 4.18: Comparison of the safety factor of the materials

Load (kg)	Stainless Steel	Gray cast iron	Aluminium Alloy
10	16.18	14.91	21.84
20	8.09	7.45	10.92
30	6.52	4.96	7.28
40	4.04	3.72	5.46

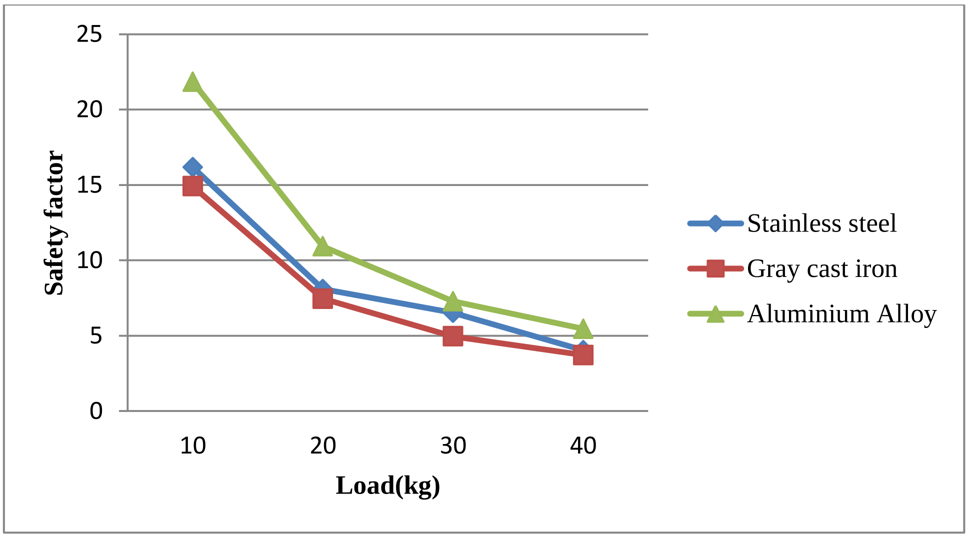


Fig 4.7: Safety factor of the materials

From the above Tables it can be concluded that all the materials i.e. stainless steel, gray cast iron, and Aluminium alloy were fit for making the product. All of them had an acceptable level of deformation and von Mises stress. But the safety factor of gray cast iron was lower than stainless steel and Aluminium alloy which could be overcome by keeping the load less than 40 kg. Since gray cast iron material was cheaper and easily available in the market than stainless steel and Aluminium alloy, it could be preferred because our main requirement was to make a cheaper, light weight and durable product. Hence, gray cast iron material was preferred in making the final product.

Development features for DHLM

The product was made on the basis of the anthropometric dimensions, ANSYS analysis, and availability of the material. A new modified prototype of the model was developed on the basis of head load manager developed by Murnalini (2011) .The product developed to decrease the discomfort while carrying bulky loads on the head was designated as Developed Head Load Manager (DHLM).

Considerations for development of the product were as follows:

1. Distribution of the load on both the shoulders and head of the female workers carrying the load to minimize the stress.
2. Hands not to be raised above shoulder level to hold the materials.
3. The product should be multipurpose in order to accommodate various materials.
4. Flexibility in the dimensions to accommodate a large number of users.
5. Convenient fixation of the product to the users body so that they could easily carry and drop the load without any disturbance.

Table 4.19 indicates the changes made in the dimensions of DHLM on the basis of anthropometric measurements, and the amount of load being lifted by female workers at the construction site. Overhead frame height was made adjustable so that weight could be supported by the head along with the shoulders and used by every female worker. Frame width was reduced so that it might fit perfectly to the user's body. Width of the overhead frame or the neck support was reduced to fit the handles in between the acromioclavicular joints. Length of the back frame was reduced to remove the unnecessary hurdle at the lower back region.

Table 4.19: Design specifications of different Head Load Managers

Dimensions of parts	**HLM**	**HLC**	**HLH**	**DHLM**
Overhead frame height (cm)	24.5	19	29	15
Frame (round diameter) (cm)	19.5	17	29	19
Frame width (cm)	25	23	30	24
Length of the back frame (cm)	40.8	31	30	34
Handle length (cm)	22	40	36	20
Weight(kg)	0.5	0.4	3	0.5

Additional features of DHLM to improve the functionality

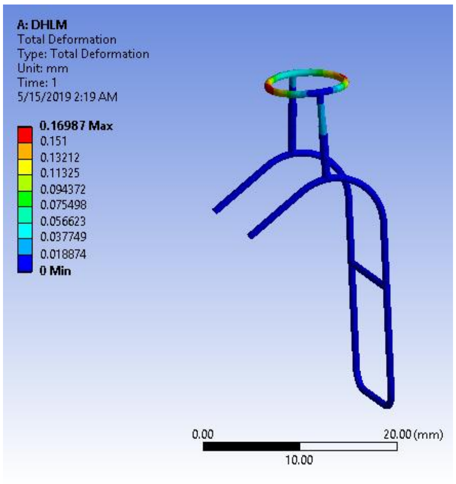
Belts were used for loading and unloading the materials. Padding was done under the shoulder, and at the back to provide proper support and cushioning for comfort of the female worker while carrying the load by reducing the jerks and contact stresses. To avoid slipping of hands iron rod was covered with cotton tape. Velcro tape belts were provided at the waist level that allowed DHLM to fix properly to the body. Handles were made just above the elbow level because for short distance big handle may cause problem to the workers for loading and unloading of materials.

Operation of the Developed Head Load Manager

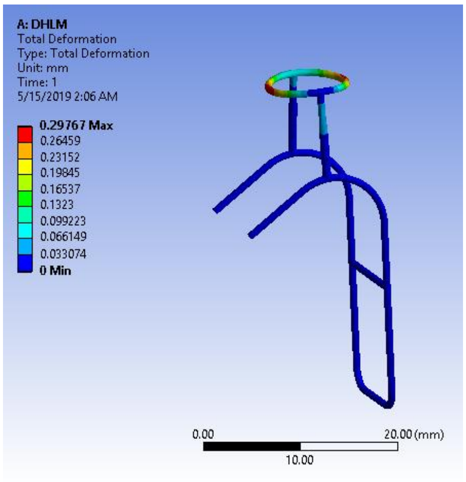
Before use, the worker can fix the DHLM to the body with the help of a belt provided in the frame. The load can be placed over it by another worker as per the routine practice prevalent at the construction site. Finally, the user can hold the handles of the DHLM by keeping the upper arms parallel to the body. After performing the load carrying task, the user can unload the material directly on the ground as per the existing practice. The overhead frame of the DHLM is adjustable and the workers can adjust the height according to their convenience.

Fig.4.8: Developed Head Load Manager

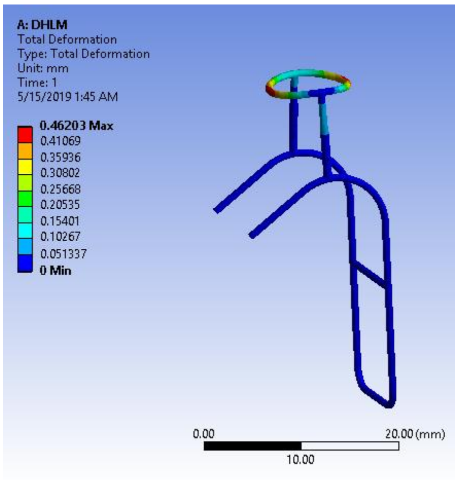
Plate No. 4.1: Total Deformation at 10 kg



Stainless Steel

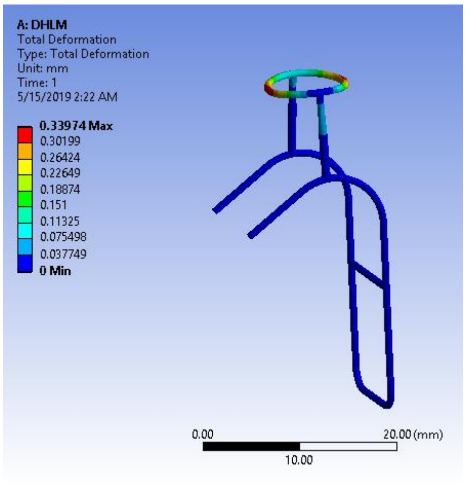


Grey Cast Iron

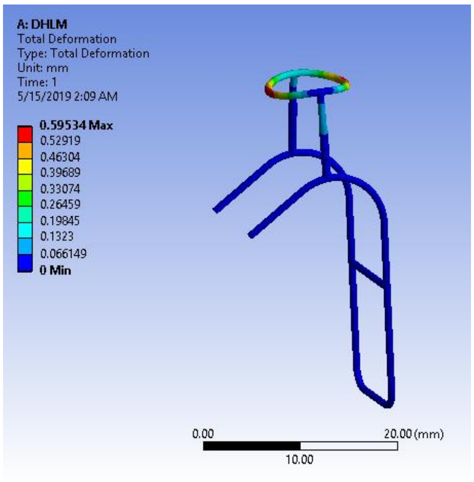


Aluminium Alloy

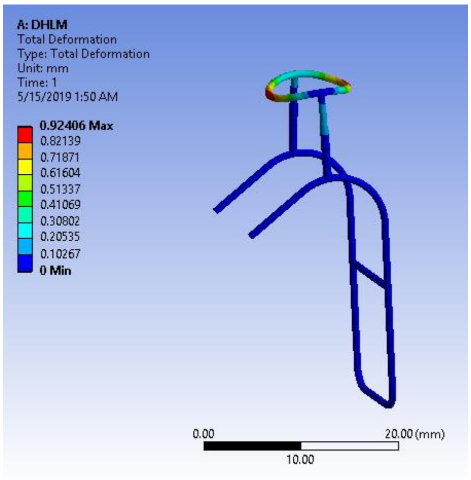
Plate No. 4.2: Total Deformation at 20 kg



Stainless Steel

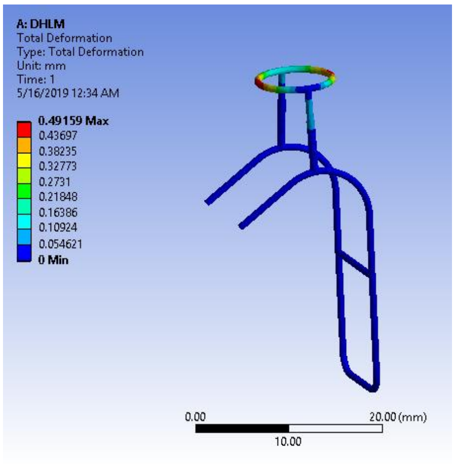


Grey Cast Iron

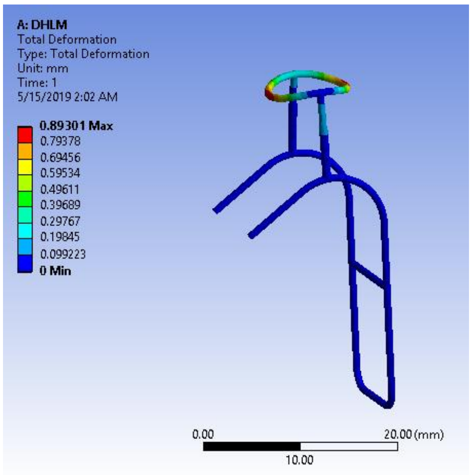


Aluminium Alloy

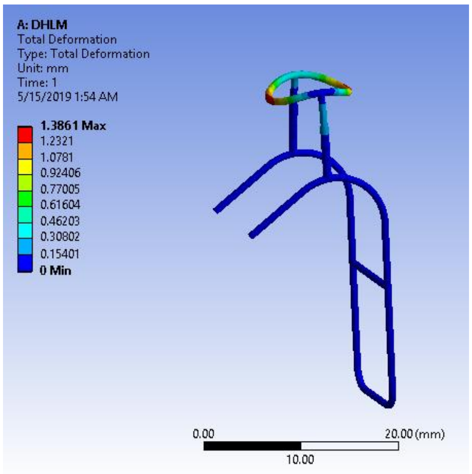
Plate No. 4.3: Total Deformation at 30 kg



Stainless Steel

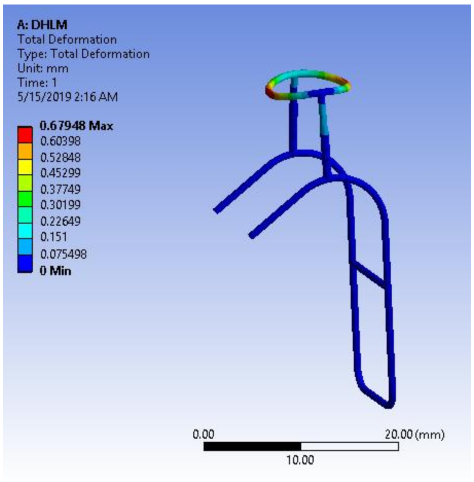


Grey Cast Iron

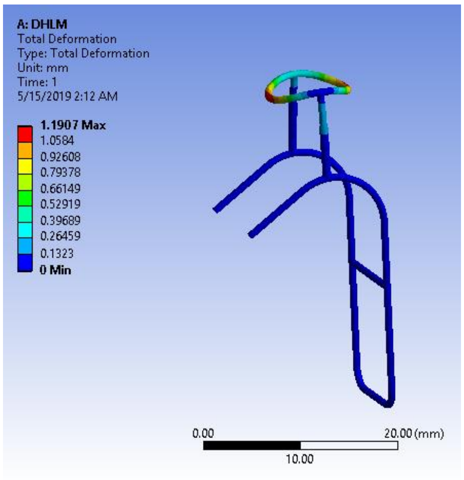


Aluminium Alloy

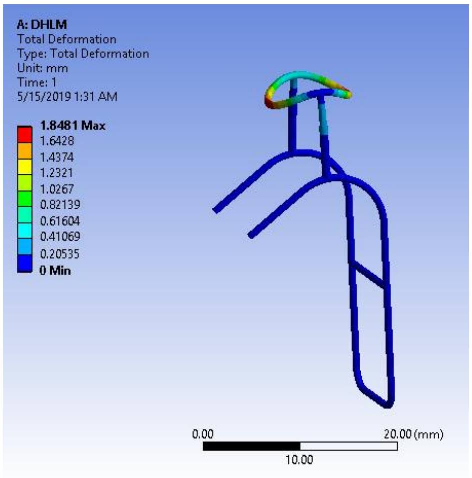
Plate No. 4.4: Total Deformation at 40 kg



Stainless Steel

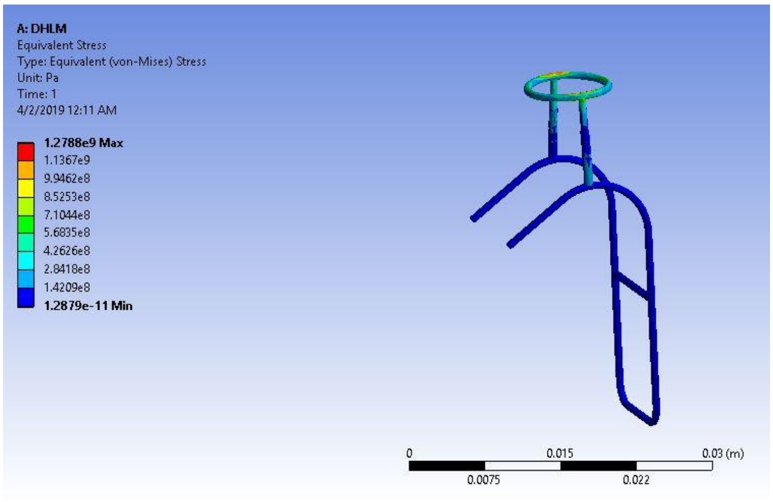


Grey Cast Iron

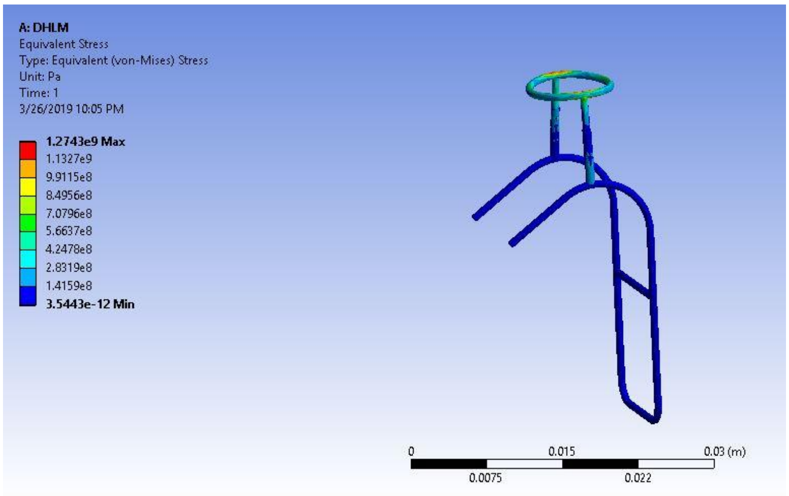


Aluminium Alloy

Plate No. 4.5: vVon-mMises stress of the materials at 10kg



Stainless Steel



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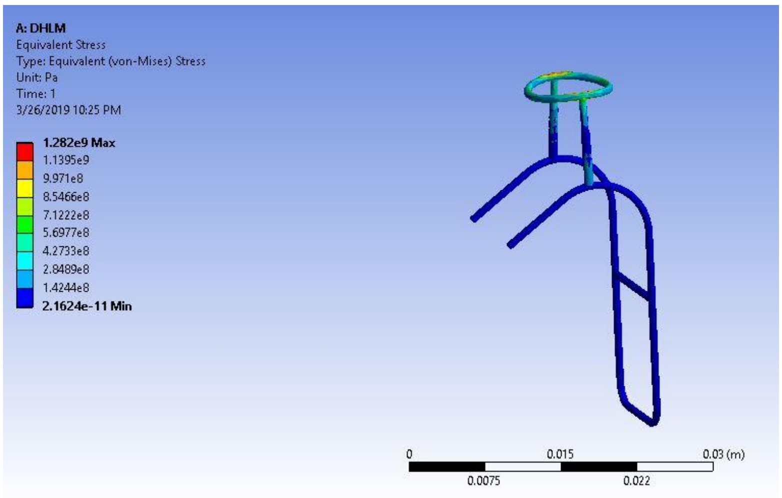
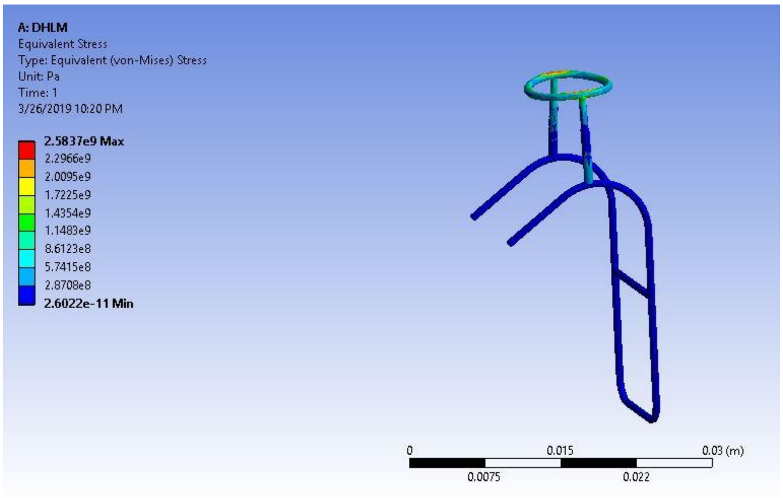
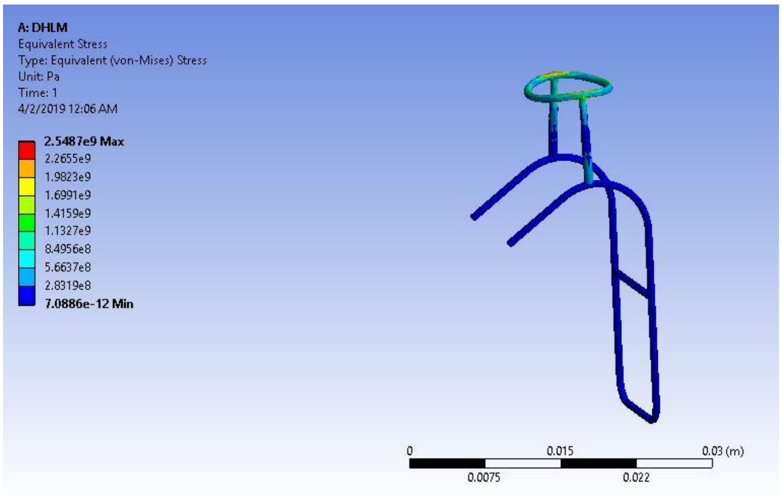


Aluminium Alloy

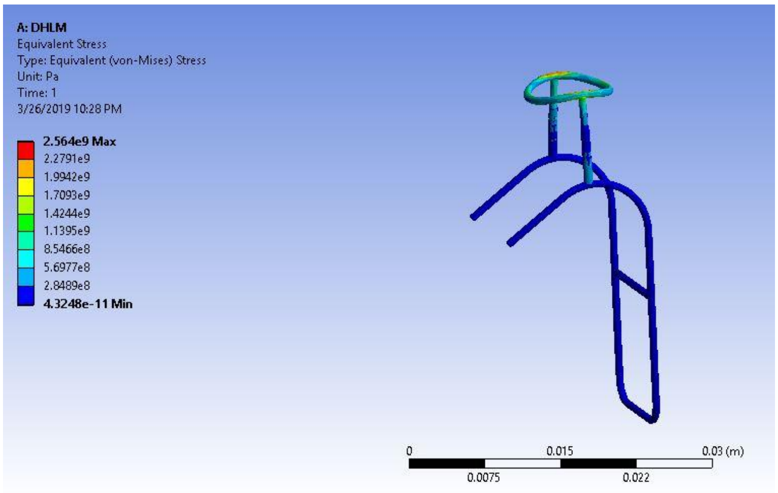
Plate No. 4.6: vVon-Mmises stress of the materials at 20kg



Stainless Steel

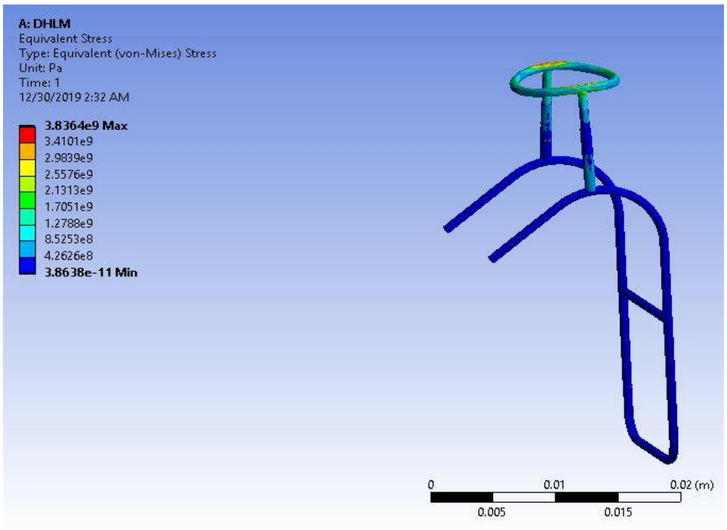


Grey Cast Iron

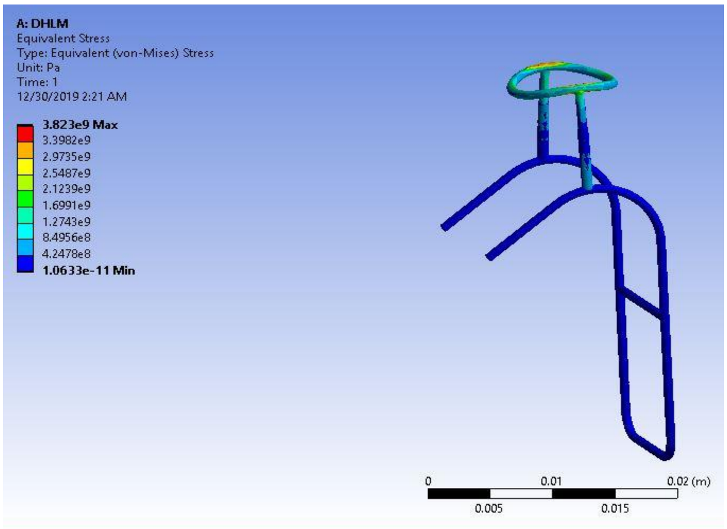


Aluminium Alloy

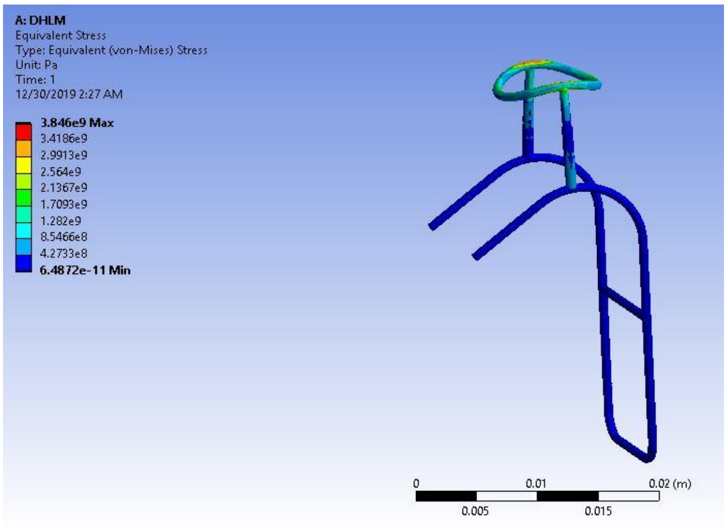
Plate No. 4.7: vVon-mMises stress of the materials at 30kg



Stainless Steel

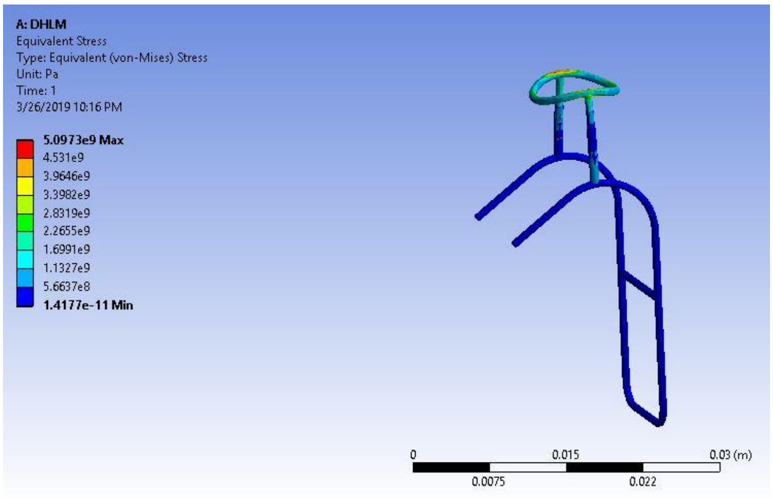


Grey Cast Iron

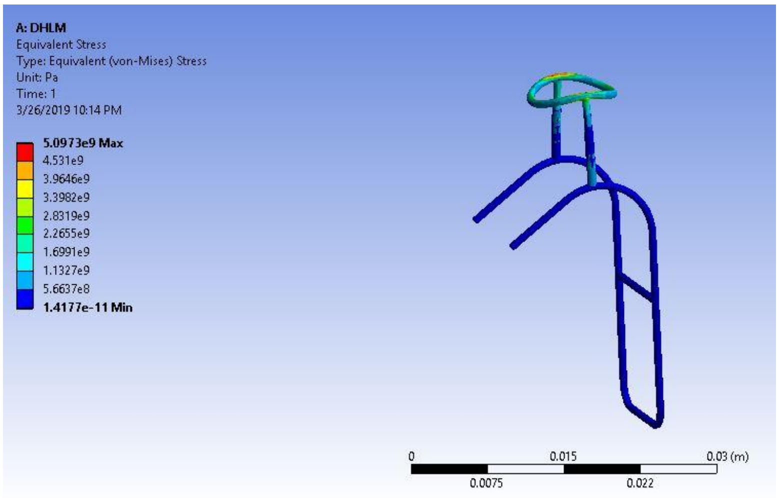


Aluminium Alloy

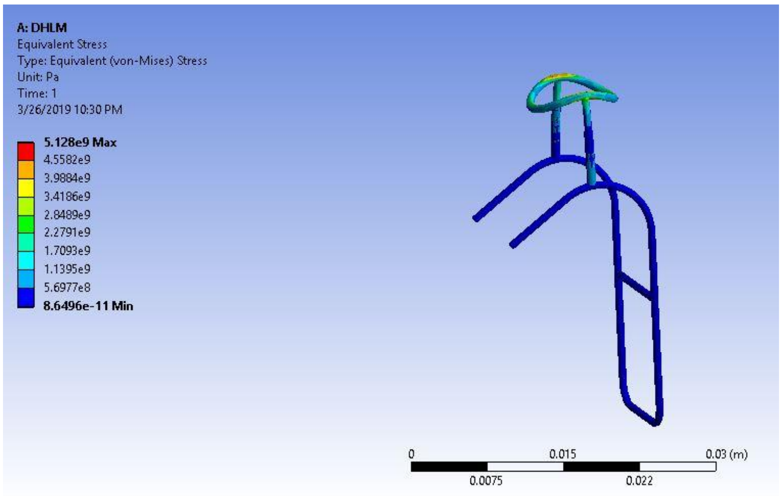
Plate No. 4.8: vVon-Mmises stress of the materials at 40kg



Stainless Steel

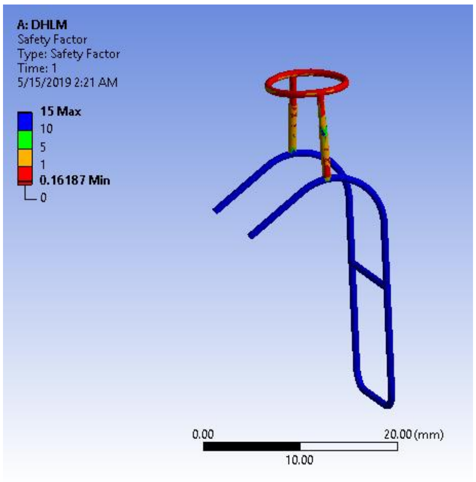


Grey Cast Iron

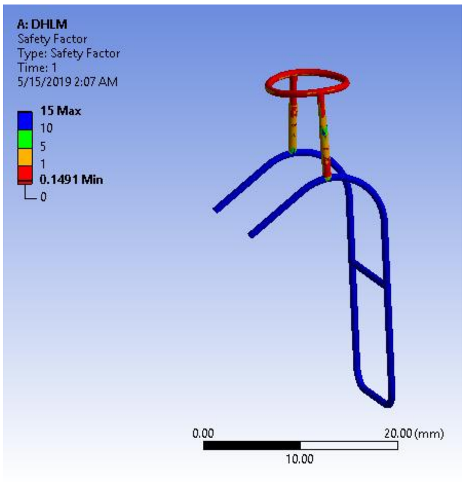


Aluminium Alloy

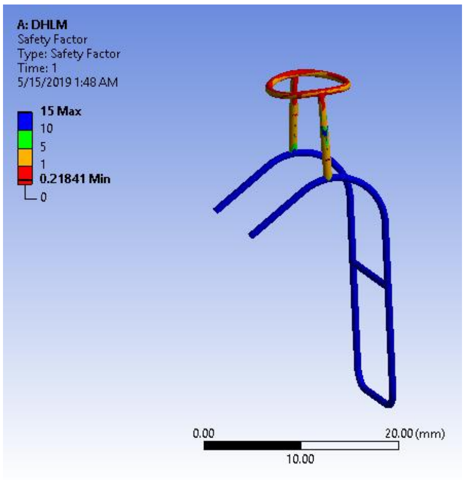
Plate No. 4.9: Safety factor of the materials at 10 kg



Stainless Steel

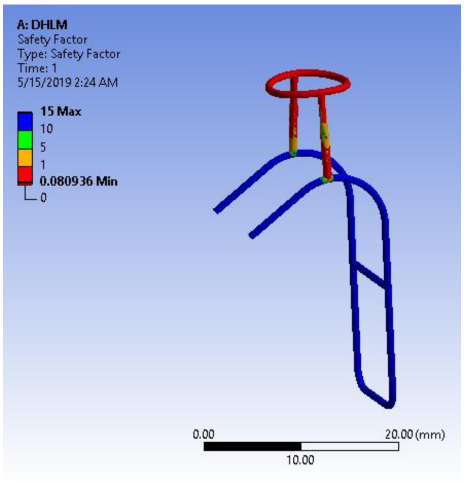


Grey Cast Iron

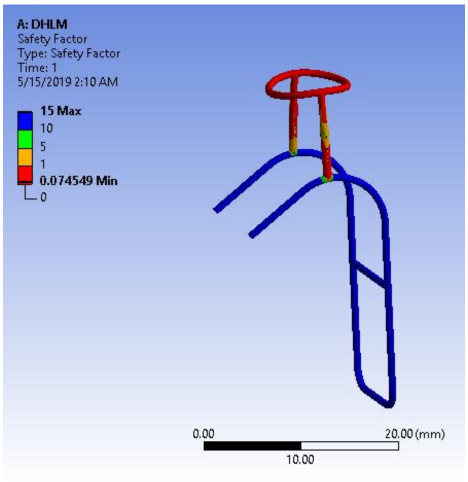


Aluminium Alloy

Plate No. 4.10: Safety factor of the materials at 20 kg



Stainless Steel



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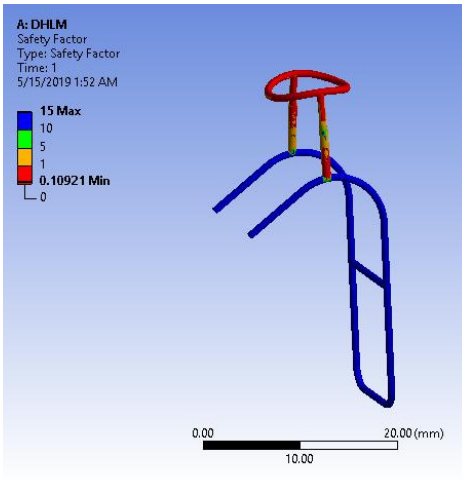
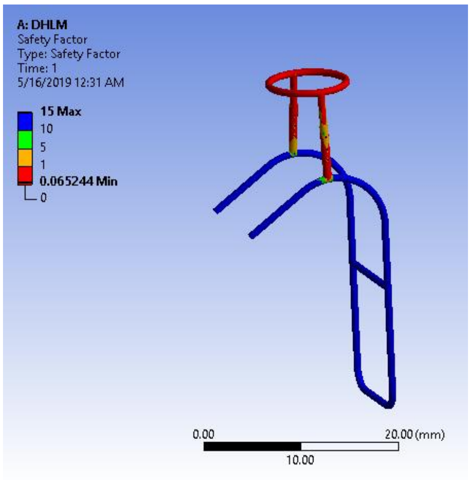


Aluminium Alloy

Plate No. 4.11: Safety factor of the materials at 30 kg



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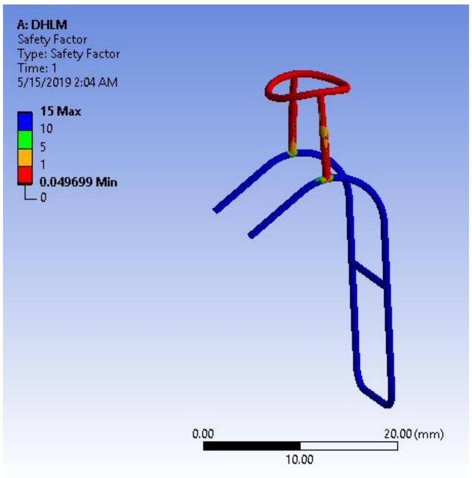

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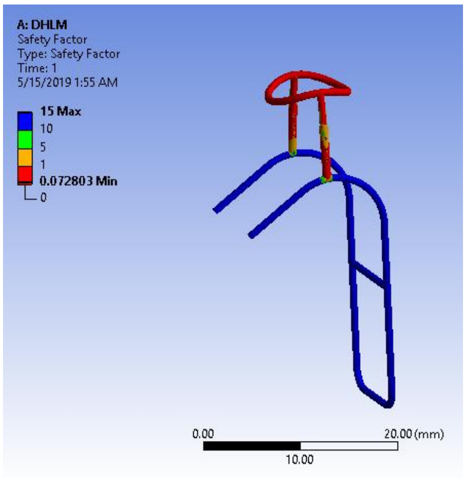
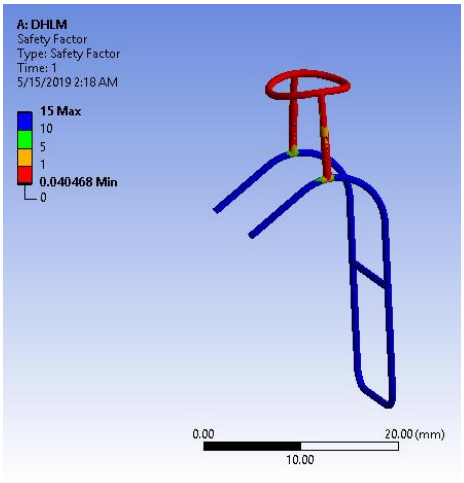


Aluminium Alloy

Plate No. 4.12: Safety factor of the materials at 40 kg



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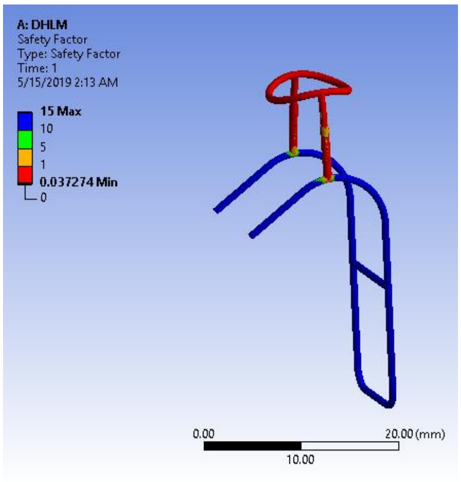

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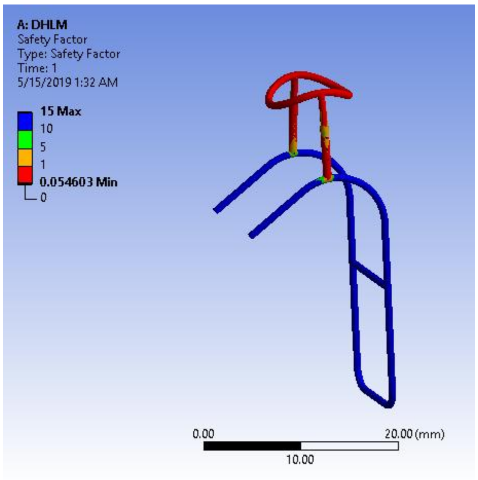


Aluminium Alloy

Phase III

Ergonomic assessment of the Developed Head Load Manager

This section includes the physical, physiological, biomechanical and psycho-physiological parameters of the respondents involved in carrying cement mixture on their head. These parameters of the respondents were recorded from time of start of the activity until its completion.

Table 4.20 depicts that an average female selected for the study was of middle age (31.36 yr.), having 48.73 kg body weight, 155.16 cm height, LBM 35.57kg leading to a BMI of 20.30 kg/m^2 indicating mesomorph body. The respondents were having good physical fitness index (120.57%) and VO_2 was 32.69l/m.

Table 4.20: Personal profile and health status of the selected respondents

n=30

Physical characteristics	**Mean $\pm$ SD**
Age (yr)	31.36 $\pm$ 5.24
Weight (kg)	48.73 $\pm$ 6.66
Height (cm)	155.16 $\pm$ 6.73
BMI (kg/m^2)	20.30$\pm$2.96
LBM(kg)	35.57$\pm$4.11
PFI (%)	120.57$\pm$4.62
VO_2(l/m)	32.69$\pm$1.74
Body type	Mesomorph

Comparison of the physiological parameters in the Conventional Method of carrying the head load and DHLM

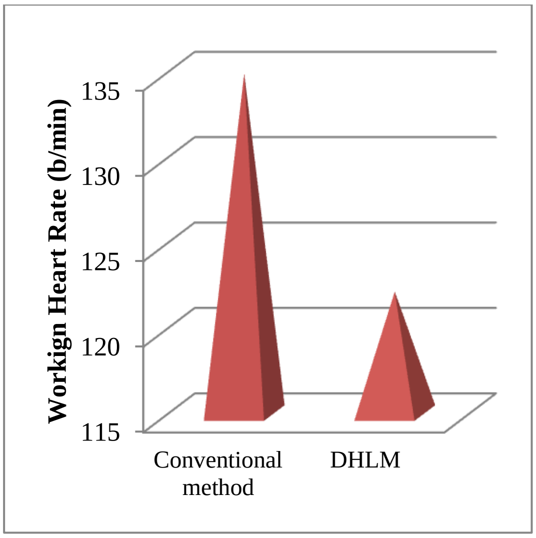
Data in Table 4.21 show the physiological responses of the selected female construction workers for ergonomic evaluation. The Table shows the comparison of physiological parameters as working heart rate, recovery heart rate, energy expenditure, oxygen consumption rate, total cardiac cost of work (TCCW), and physiological cost of work (PCW) of female workers while performing head load carrying activity with the Conventional Method and with developed head load manager. Findings reveal that the mean working heart rate of the respondents with the Conventional Method was 134.89b/min and with developed head load manager, it was 122.10b/min and mean recovery heart rate of the respondents was 118.35b/min, 107.51b/min with the Conventional Method and developed head load manager, respectively. It was observed that performing the activity with developed head load manager led to a reduction of 12.79b/min in working heart rate and 10.84b/min in recovery heart rate. Energy expenditure decreased in developed head load manager to the extent of 2.03kJ/min with 18.08 percent decrease when compared with the Conventional Method. Oxygen consumption rate was also decreased up to 23.25 percent with developed head load manager.

It can also be observed that TCCW decreased to 821.55beats with 27.58 percent decrease. Similarly, PCW decreased by 13.69b/min recording a decrease of 9.91 percent. All the values were found statistically significant at 0.05 level of significance. It might be concluded that developed head load manager, when compared to the Conventional Method, was found efficient to reduce the physiological exertion of the female workers in head load carrying activity at the construction site.

Table 4.21: Comparison of the physiological parameters in the Conventional Method of carrying the head load and Developed head load manager **n=30**

Parameter	Methods adopted		Difference	% Change	t-value
	Conventional Method	DHLM			
Working Heart Rate ($b.min^{-1}$)	134.89	122.10	12.79	9.48	6.15*
Recovery Heart Rate ($b.min^{-1}$)	118.35	107.51	10.84	9.15	8.47*
Energy Expenditure ($kJ.min^{-1}$)	12.72	10.69	2.03	18.08	6.15*
Oxygen Consumption($kJ.min^{-1}$)	0.86	0.66	0.20	23.25	6.15*
Total Cardiac Cost of Work (TCCW) (beats)	2978.11	2156.56	821.55	27.58	6.51*
Physiological Cost of Work ($b.min^{-1}$)	49.63	35.94	13.69	9.91	6.51*

*DHLM=Developed head load manager
*Significant at 0.05 level



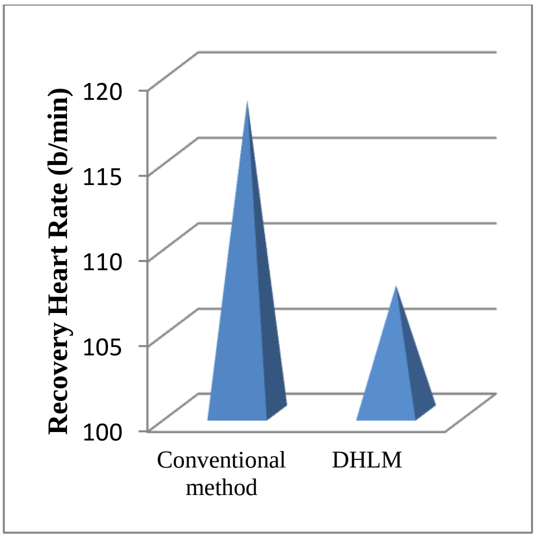


Fig 4.9: Comparison of working heart rate with Conventional Method and DHLM

Fig 4.10: Comparison of recovery heart rate with Conventional Method and DHLM

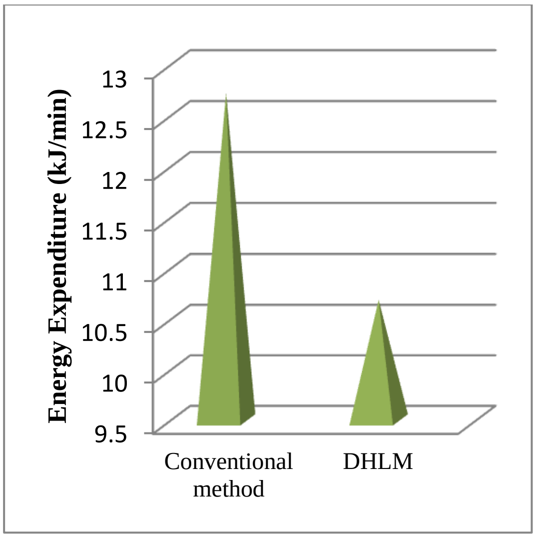


Fig 4.11: Comparison of Energy Expenditure with Conventional Method and DHLM

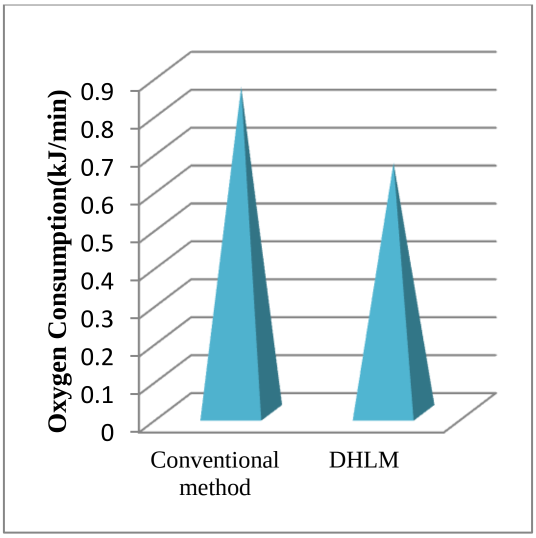


Fig 4.12: Comparison of Oxygen Consumption with Conventional Method and DHLM

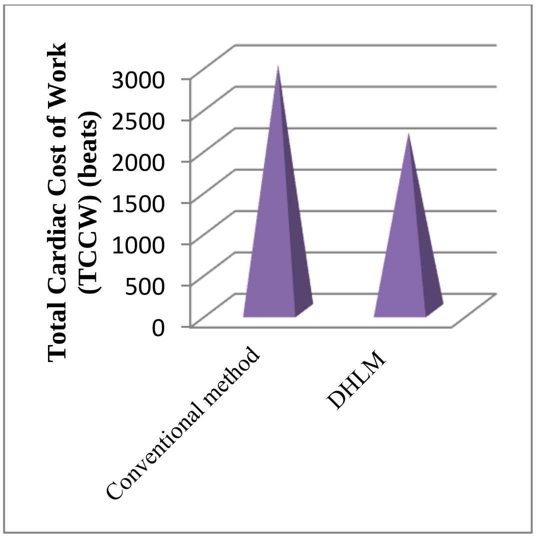


Fig 4.13: Comparison of TCCW with Conventional Method and DHLM

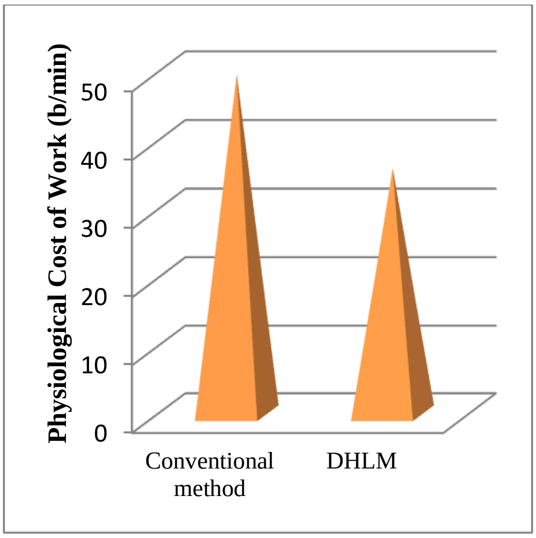


Fig 4.14: Comparison of PCW with Conventional Method and DHLM

Fig.4.15: Carrying head load with the help of Developed Head Load Manager

Biomechanical Parameters

Comparison of the grip strength in carrying head load with the Conventional Method and Developed head load manager

Table 4.22 illustrates the comparison of the grip strength of the hands of female workers while performing head load carrying activity with Conventional Method and developed head load manager. While performing head load carrying activity with the Conventional Method, reduction in grip strength in the right hand was 25.18 percent and in the left hand, it was 32.70 percent. Whereas, when activity was performed with the developed head load manager, reduction of grip strength in the right hand was observed to be 14.61 percent and in the left hand, it was 17.68 percent.

Paired 't' test was applied to test the difference in grip fatigue of hands of the respondents while performing the activity with the Conventional Method and developed head load manager, and it was found significant at 0.05 level of significance. Therefore, it can be concluded that grip strength was found less in both the hands in head load carrying activity when performed with developed head load manager compared to the Conventional Method.

Table 4.22: Comparison of the grip strength in the Conventional Method of carrying the head load and Developed head load manger n=30

Parameters	Grip strength						
	Conventional Method			Developed head load manager			t-value
	At rest	After activity	Reduction in strength (% change)	At rest	After activity	Reduction in strength (% change)	
Right hand(kg)	22.51 ± 2.70	16.84± 2.34	5.67 (25.18%)	22.51 + 2.70	19.22+ 2.51	3.29 (14.61%)	3.65*
Left hand(kg)	19.17 ± 3.76	12.90 ± 1.39	6.27 (32.70%)	19.17 ± 3.76	15.78 ± 2.31	3.39 (17.68%)	6.1*

RH: Right hand
LH: Left hand
*Significant at 0.05 level

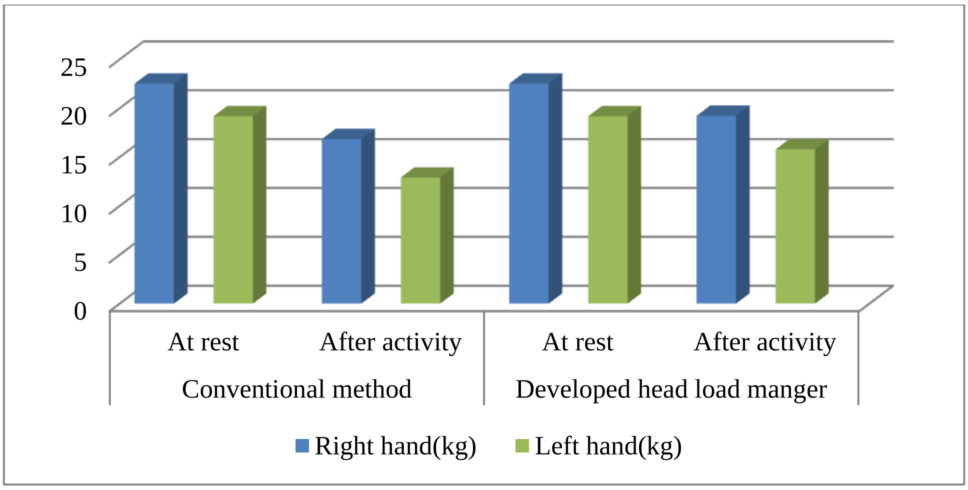


Fig. 4.16: Comparison of the grip strength in Conventional Method of carrying head load and Developed head load manger

Comparison of spinal angles in the Conventional Method of carrying the head load and Developed head load manager

Table 4.23 represents that the deviation in the lumbar region of the spinal cord was higher in case of Conventional Method (2.67%) than by using developed head load manager (0.53%). In the cervical region, the deviation was observed only in the case of Conventional Method (2.16%), whereas no deviation in cervical angle was observed by using developed head load manager.

Table 4.23: Comparison of spinal angles in the Conventional Method of carrying the head load and Developed head load manager n=30

Spinal angle	Resting	Methods		Deviation from resting		% age deviation from resting	
		Conventional Method	DHLM	Conventional Method	DHLM	Conventional Method	DHLM
Lumbar angle (degree)	187	192	186	5	1	2.67	0.53
Cervical angle (degree)	185	189	185	4	0	2.16	0

*DHLM=Developed head load manager

REBA analysis for different stages of head load carrying task

The head load carrying activity was divided into three stages: lifting, carrying and landing the load. Analysis of working posture of respondents was done using REBA.

REBA analysis while performing the activity with the Conventional Method

Load lifting activity: While lifting the load from ground to head, women adopted a very bad posture as their back was bent at 120 degree that was two times greater than the maximum angle of bend (60^0) given in the assessment sheet, upper arm was at 90^0 to the body, and wrist was extended and twisted. The REBA score for load lifting activity was calculated as 12 which indicated that the task involved very high risk requiring the need to implement the change.

Load carrying activity: During load carrying, hands of the respondents remained raised above shoulder level, wrists remained extended, neck remained flexed and their back was extended and twisted as they walked. The REBA score was 15 which indicated that the job involved very high risk and there was a need to implement the change.

Landing activity: This part of head load carrying activity involved sudden flexion of neck and vertebrae with the load. The sudden shift of load resulted in jerk in lower vertebrae and cervical region. The activity got the score of 14 which indicated that the task was highly risky, warranting need to implement the change.

REBA analysis while performing the activity with developed head load manager

Load lifting activity: While lifting the load from ground to head, women adopted a very bad posture as their back was bent at 60 degrees given in the assessment sheet, upper arm was at 45^0 to the body, and wrist was extended and twisted. The REBA score for load lifting activity was calculated as 4 which indicated that the task involved medium risk, further investigation, there is a need for change in the near future.

Load carrying activity: During load carrying, hands of the respondents remained raised above shoulder level, wrists remained normal, neck stayed at angle 20^0 and their back was straight as they walked. The REBA score was 2 which indicated that the job involved low risk and there is change may be needed.

Landing activity: This part of head load carrying activity involved no sudden flexion of neck and vertebrae with the load. The shift of load resulted in no jerk in lower vertebrae and cervical region. The activity got the score of 1 which indicated that the task held negligible risk.

Table 4.24: REBA analysis for different stages of head load carrying task

n=30

Stages	Conventional Method Score	Remarks	DHLM Score	Remarks
Lifting	12	Very high risk, implement change	4	Medium risk, further investigation, change soon
Carrying	15	Very high risk, implement change	2	Low risk, change may be needed
Landing	14	Very high risk, implement change	1	Negligible risk

*DHLM=Developed head load manager

OWAS analysis for different stages of head load carrying task

Ovako Working Posture Assessment system (OWAS) analysis of each stage of head load carrying activity was done by observing the activity in parts while performing the activity with the Conventional Method. Table 4.25 shows that the posture adopted in lifting the load (4) was most critical and there is a need for an immediate solution to change the posture. Carrying posture got the action category of 2 indicating that correction is required in the near future. Landing posture got the action category of 2 interpreting that working method involved should be changed in the near future. According to OWAS analysis, load lifting was the critical part of the activity and the corrective measure was needed immediately as respondents' back was bent forward and twisted, both arms were below shoulder level and knees bent either in standing or squatting position. Load carrying was not found to be severe, corrective measures were needed in the near future as they walked with back straight, hands raised above shoulder. Load landing was not much severe as its action category indicated that corrective measures were needed in the near future. While landing the load women used to bend their back forward keeping their legs straight and hands raised above shoulder level.

OWAS analysis of activity performed using developed head load manager is given in Table 4.25. The posture adopted in lifting the load and carrying the load were assigned to the action category 2 implying that correction was required in the near future. Landing posture got the action category of 1 interpreting that no corrective measure was required.

Table 4.25: OWAS analysis for different stages of head load carrying task

n=30

Stages	Conventional Method	DHLM
Lifting	4	2
Carrying	2	2
Landing	2	1

*DHLM=Developed head load manager

Psycho-Physiological Parameters

Visual Analogue Discomfort (VAD) scale experienced by respondents in different stages of head load carrying task

Results of Table 4.26 elucidated the mean score of the visual analogue discomfort scale for overall body discomfort and depiction of overall discomfort in different stages of head load carrying task while performing the activity with Conventional Method and developed head load manager. The findings of VAD score indicated that in Conventional Method load carrying activity obtained 7.7 mean scores indicating that the overall discomfort was found to be high and ranked I. In load lifting activity, the overall mean score attained was 5.3 which indicated moderate discomfort for overall body discomfort and stood II. Whereas the landing activity ranked III with the mean score as 2.5 indicating mild discomfort.

While using developed head load manager, the load lifting activity mean score was found to be 4.1 indicating moderate discomfort with rank I. Load landing activity ranked II with mean score at 2.5 indicating mild discomfort. On the other hand, load carrying activity obtained mean score as 1.4 indicating no pain as overall body discomfort and ranked III.

Table 4.26: Visual Analogue Discomfort (VAD) scale experienced by respondents in different stages of head load carrying task **n=30**

Activity	Conventional Method			Developed head load manager		
	WMS	**Rank**	**Overall discomfort**	**WMS**	**Rank**	**Overall discomfort**
Load lifting	5.3	II	Moderate	4.1	I	Moderate
Load carrying	7.7	I	High Discomfort	1.4	III	No pain
Load landing	2.5	III	Mild	2.5	II	Mild

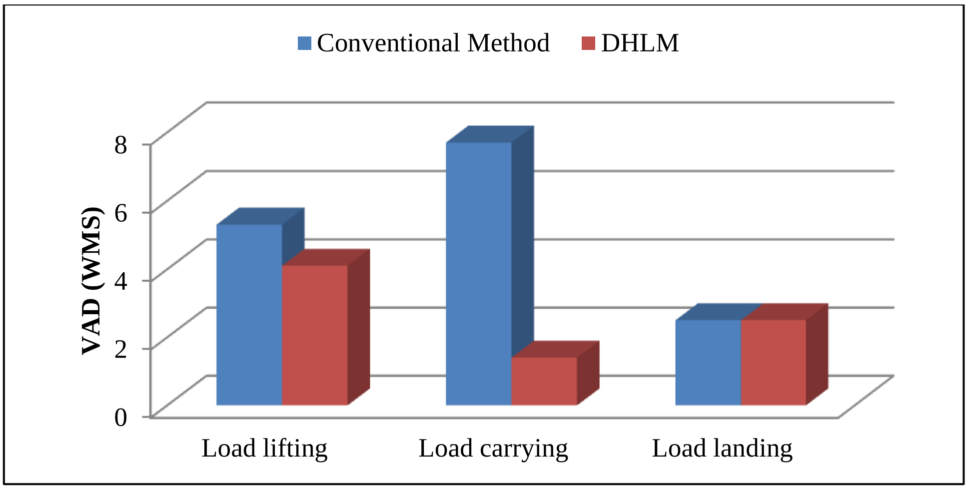


Fig. 4.17: Visual Analogue Discomfort

Comparison of Body Part Discomfort

The musculoskeletal discomfort faced by respondents in carrying the head load by Conventional Method and by using developed head load manager was studied with the help of body part discomfort score given by the respondents for different body parts while performing the activity. Table 4.27 shows that there was a significant reduction in the discomfort at head, neck, shoulders, upper back, upper arms, mid back, chest, lower arms, wrists, lower back, buttocks, thighs, knee, legs, and feet.

Table 4.27: Comparison of Body Part Discomfort **n=30**

Sr. No.	Body parts	Conventional Method	Developed head load manager	t-value
1	Head	4.19	1.19	31.86*
2	Neck	3.93	1.39	25.86*
3	Shoulders	3.81	1.56	17.70*
4	Upper back	3.61	1.40	20.48*
5	Upper arms	3.32	1.45	18.65*
6	Mid back	3.20	1.58	4.87*
7	Chest	3.17	1.20	20.34*
8	Lower arms	2.58	1.28	13.82*
9	Wrists	3.39	1.09	23.64*
10	Lower back	4.19	1.28	21.43*
11	Buttocks	3.75	1.22	20.42*
12	Thighs	2.97	1.33	15.02*
13	Knee	3.16	1.30	15.69*
14	Legs	2.64	1.79	6.57*
15	Feet	3.84	1.96	15.76*

*DHLM=Developed head load manager
*Significant at 0.05 level

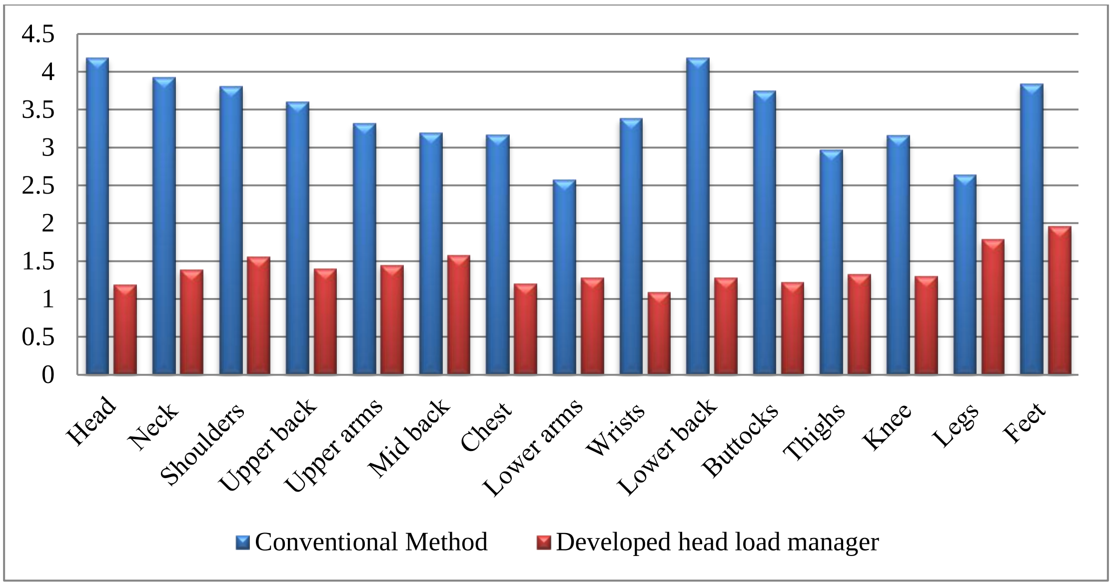


Fig. 4.18: Body Part Discomfort

Rating of perceived exertion (RPE) for different stages of head load carrying task

RPE is a subjective and reliable tool to measure the intensity of exertion felt by the respondents for the activity on a 5 point scale. Findings of Table 4.28 highlighted the rating of perceived exertion felt by the respondents while performing different head load carrying task by Conventional Method and using developed head load manager. Results showed that load carrying ranked 1 with the highest mean score 4.1 in a Conventional Method which means respondents perceived load carrying activity as very heavy exertion. RPE score of 3.4 was obtained for load lifting activity and it was considered as moderately heavy exertion activity and ranked II. Load landing activity obtained 3.2 mean scores and regarded as moderately heavy exertion and ranked III.

Whereas while using developed head load manager load lifting activity ranked I with a mean score of 2.4 which indicated that respondents perceived light exertion. Load landing activity ranked II and load carrying ranked III with mean score 1.6 and 1.5 respectively indicating that the respondents perceived very light exertion.

Table 4.28: Rating of perceived exertion (RPE) for different stages of head load carrying the task **n=30**

Activity	Conventional Method			Developed head load manager		
	WMS	Rank	Activity type	WMS	Rank	Activity type
Load lifting	3.4	II	Moderately heavy exertion	2.4	I	Light exertion
Load carrying	4.1	I	Heavy exertion	1.5	III	Very light exertion
Load landing	3.2	III	Moderately heavy exertion	1.6	II	Very light exertion

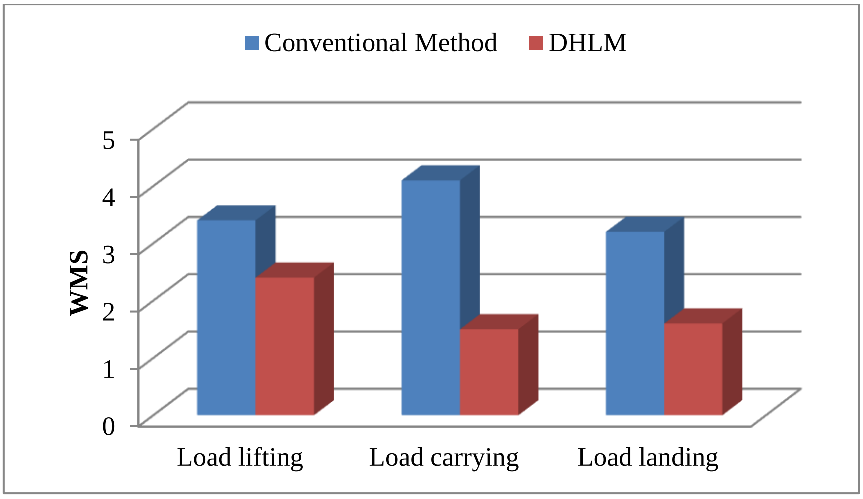


Fig. 4.19: Rating of Perceived Exertion

Environment conditions while carrying the head load

The environmental conditions while carrying the load on the head are represented in Table 4.29. The experiment was conducted in the months of December having an average temperature of 21.56 ^{0}C during carrying the head load which was higher than the recommended value whereas the average level of humidity was 52.93% which was within the recommended level of temperature. Noise level of 92.90db was also found higher than the recommended value and the light was 361.33 lux which was within the recommended value. So the use of earplugs is recommended while working at construction sites.

Table 4.29: Environmental conditions while carrying the head load

n=30

Parameters	**(Mean $\pm$ SD)**	**Recommended value***
Temperature (^{0}C)	21.56$\pm$ 2.38	20-25
Humidity (%)	52.93$\pm$9.50	40-60
Noise (dB)	92.90$\pm$ 3.86	60-80dB
Light(lux)	361.33$\pm$ 332.47	250-500lux

*Grandjean (1978)

Phase IV

Feasibility testing of the developed head load manager

Feasibility testing of the developed head load manager was calculated with the help of a modified scale of Rogers and Shoemaker (1962). On the basis of various attributes i.e. relative advantage, compatibility, simplicity/complexity, practicability. Data were analyzed in term of the weighted mean score. Data were also analyzed with the help of user assessment sheet which included ergonomic aspects to make the product more convenient to the users.

a. Assessment Sheet for Using the Developed Head Load Manager (DHLM)

b. Feasibility testing of the Developed Head Load Manager (DHLM)

a. Assessment Sheet for Using the Developed Head Load Manager (DHLM)

Table 4.30 depicts that practicability ranked at the top with a weighted mean score (WMS) of 2.31, followed by WMS (2.15) of relative advantage ranked II, compatibility and simplicity/complexity ranked III with WMS (2.07). Respondents reported that developed head load manager was practicable as efficiency is reduced while carrying bricks with the use of developed head manager (2.50), maintains body posture comfortably at standing posture, body movement with the use of developed head load manager get restricted (2.37 each), less fatigue and exhaustion while carrying out the activity (2.20), suitable for carrying load up to 20kg (2.10). Regarding relative advantage, respondents reported it 'most feasible' as developed head load manager provided more comfort while carrying heavy load (2.53), reduced pain in the lower back and mid back (2.47), can be used for multiple activities like carrying fodder and water pots on their head easily (2.27). Pain in the arms and shoulders is reduced by using developed head load manager because arms were not extended too much while carrying load (2.20), saves time and energy (2.06), suitable for the short and long distance (2.03), more comfortable as compared to the Conventional Method (1.93), heavy weight can be carried with comfort for longer duration (1.73). As far as compatibility was concerned, it was observed as 'most feasible' because developed head load manager is light in weight (2.20), designed as per anthropometry of the user (2.13), very portable, and the material used for developed head load manager is coarse & hard (2.10), easy to wear (1.97), based on the need of the user (1.93). Simplicity/ Complexity was also found as 'most feasible' by the respondents because developed head load manager increased the efficiency of the worker (2.33) because they did not get tired easily, functioning is easy to understand (2.20), care and maintenance of developed head load manager is less cumbersome (2.13), can be used by every worker at large scale if it is provided by the contractor (1.93), while some of the respondents faced difficulty in adjusting the upper part of the developed head load manager (1.77).

Table 4.30: Assessment Sheet for using the Developed Head Load Manager (DHLM)

n=30

Statements	**Strongly Agree**	**Agree**	**Disagree**	**WMS**
Relative Advantage				
Provides more comfort while carrying a heavy load	20	6	4	**2.53**
Reduces pain in the lower back and mid back	19	6	5	**2.47**
Pain in the arms and shoulders is reduced by using DHLM	15	6	9	**2.20**
Suitable for short and long distance	10	11	9	**2.03**
Heavy weight can be carried with comfort for a longer duration	6	10	14	**1.73**
More comfortable as compared to the Conventional Method	7	14	9	**1.93**
Saves time and energy	12	8	10	**2.06**
Used for multiple activities	15	8	7	**2.27**
				Rank =(II) 2.15

Compatibility				
Based on the need of the user	9	10	11	**1.93**
Portable	11	11	8	**2.10**
Easy to wear	12	5	13	**1.97**
Light in weight	15	6	9	**2.20**
Designed as per anthropometry of the user	9	16	5	**2.13**
Material used for DHLM is coarse & hard	13	7	10	**2.10**
				Rank =(III) 2.07
Simplicity/ Complexity				
Functioning is easy to understand	14	8	8	**2.20**
Care and maintenance of DHLM is less cumbersome	12	10	8	**2.13**
Difficulty in adjusting the upper part	8	7	15	**1.77**
Used by every worker if it is provided by the contractor	10	8	12	**1.93**
Increases the efficiency of the worker	16	8	6	**2.33**
				Rank =(III) 2.07
Practability				
Body movement get restricted	17	7	6	**2.37**
Less fatigue and exhaustion while carrying out the activity	15	6	9	**2.20**
Efficiency reduced while carrying bricks	18	9	3	**2.50**
Maintains body posture comfortably at a standing posture	17	7	6	**2.37**
Suitable for carrying load upto 20kg	13	7	10	**2.10**
				Rank =(I) 2.31

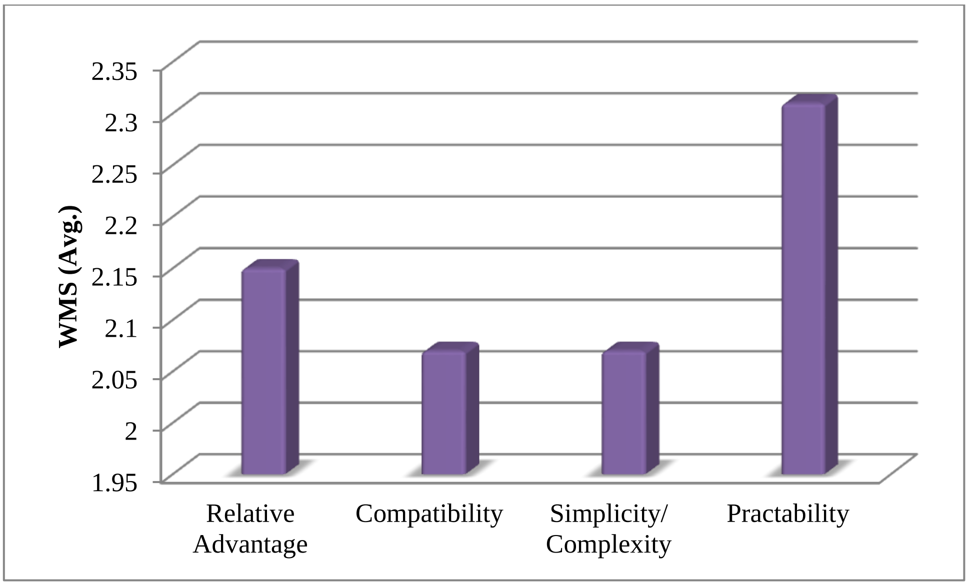


Fig. 4.20: Weighted mean score of DHLM

b. Feasibility testing of the Developed Head Load Manager (DHLM)

Table 4.31 presents the opinion of female workers about developed head load manager. The results revealed that on the basis of physical stress, developed head load manager was accepted with 73.11 percent score. Respondents were feeling less tired and exhausted after performing the head load carrying activity with developed head load manager. Percentage gained score of grip strength (65.00%) indicated that developed head load manager was helpful in reducing the pain in arms. On the basis of acceptability, developed head load manager was acceptable by the workers at 64.89 percent because it is a good replacement to the existing tool and is cheaper also. Tool factor parameter obtained 28.33 score and gained 62.96 percent score clearly reflecting that the workers liked the overall appearance of DHLM and it was found easy to use and durable. On the basis of musculoskeletal stress factor, developed head load manager was accepted at 61.27 percent score. Developed head load manager was helpful in correcting the posture of the workers, and strain felt on lower back was less. Work output parameter gained score of 60.89 percent. The developed head load manager was found acceptable by the respondents as they could work more efficiently.

Table 4.31: Feasibility testing of the Developed Head Load Manager (DHLM)

n=30

Factors Assessed	Attainable score	Attained Score	% Score gained	Feasibility
Musculoskeletal stress factors	65	33.70	61.27	Acceptable
Grip fatigue	10	6.50	65.00	Acceptable
Physical stress	10	10.96	73.11	Acceptable
Work output	15	9.13	60.89	Acceptable
Tool factor	45	28.33	62.96	Acceptable
Acceptability	15	9.73	64.89	Acceptable

CHAPTER–V

DISCUSSION

The research work carried out in accordance with the specified objectives and following the described methodology has been discussed in this chapter in context of the results obtained in the study. It has been discussed in four sections as under:

Phase I: Assessment of existing head load managers for construction workers

Phase II: Design and development of head load manager for construction workers

Phase III: Ergonomic assessment of the developed head load manager

Phase IV: Feasibility testing of developed head load manager

Phase I: Assessment of existing head load managers for construction workers

Demographic profile

Demographic profile of the respondents in the study shows that 66.67 percent of the respondents were between the age group of 30-40 years followed by those having age between 20-30 years (33.33). Bharara *et al.* (2012) who conducted a survey in Punjab state also reported that about half of the women construction workers (55.00%) were in the age group of 21-30 years, followed by 37.50 percent between the ages of 31-40 years. Yadav *et al.* (2016) reported that almost half of the women labourers (47%) having age group of 30-40 years worked at construction site. They belonged to nuclear family and most of them were illiterate. Rai and Sarkar (2012) reported that majority of women in construction industry were young, i.e. between the age of 16-40 years. Tiwary *et al.* (2013) also observed that majority of the respondents (60.80%) were married, belonged to nuclear family and were largely illiterate (79.20%). Majority of the respondents (63.33%) in this study were married, single (23.33%), or divorced (13.34%). Majority of the respondents were illiterate (60%), followed by those who could read and write only (40%). Yadav *et al.* (2016) also reported that majority of the respondents were illiterate (93%), followed by the respondents who could read and write only (7%). Regarding family type a large number of the respondents were having a nuclear family (70%), followed by joint family (30%). Majority of those working at construction sites belonged to the state of West Bengal (30%), followed by Uttar Pradesh (20%), Madhya Pradesh (16.67%), and Haryana (13.33%). Vandana (2012) also reported that in Haryana, 100 percent women labourer in agriculture sector were residents of Haryana while most of the construction labourer were migrants from Chhattisgarh (42%) and Madhya Pradesh (31%). Similarly, Nandal (2004) reported that in Haryana most of the workers in construction industry come from other states and constitute a higher percentage of female workforce. Yadav *et al.* (2016) reported that majority of the respondents working at construction sites belonged to the state of Madhya Pradesh (45%), followed by Uttar Pradesh (28%), West Bengal (16%) and Bihar (11%).

Majority of the respondents (60%) in this study were employed on daily wage basis, temporary basis (23.33%), or those who were engaged on a permanent basis (16.66%). Basu *et al.* (2009) stated that in unorganized sectors, the workers were recruited temporarily on daily basis. More than half of the respondents (60%) received wages between ₹250-350, while 40 percent received wages between ₹350-450 per day. Half of the respondents (50%) reported wage payment pattern on daily basis followed by those who were getting on a weekly basis (30%) and monthly basis (20%). Similar study by Yadav *et al.*(2016) also showed that majority of the respondents (71%) were employed on temporary basis, followed by 21 percent of those who were permanent (with same contractor for the last 5years) and those who were engaged on daily wage basis (8%). More than half of the respondents (59%) received wages between ₹ 250-300, while the remaining respondents (41%) received between ₹200-250 per day. Tiwary *et al.* (2013) reported that 57.2 percent workers earned below ₹5000 per month .Maximum number of the respondents (58%) received wages on weekly basis followed by those who were getting on monthly (27%) and daily basis (15%). According to Kumar (2013), majority of the construction workers received wages on daily basis.

The material carried by the respondents on their head was concrete mixture (30%) followed by those who carried bricks (23.33%) cement (20%) and water (16.66%). Ten percent of the respondents carried sand, gravel, etc. Majority of the respondents (60%) carried a heavy load on head ranging between 10-20 kg, followed by those who carried weight greater than 20 kg (23.33%), whereas, only a few (16.66%) reported carrying less than 10kg. Rajanna (2015) also revealed that in construction industry, more than two third of women construction workers have to work in multiple types of construction works like water feeding, material supply, mixing cement and stone shaping. Similar observations were recorded in a study by Mala (2015) that majority (44%) of the respondents carried bricks, cement and stones. One fourth of the respondents reported filtering sand at the work sites, while one fourth of the respondents assisted masons in the work and carried water for construction site. Kaila *et al.* (2011) revealed that 1.9 percent of men and 2.1 percent of women were suffering from hip osteoarthritis. Almost half the men and a quarter of the women repeatedly handled heavy loads at work. Subjects who had manually handled loads >20 kg had a 1.8-fold increased risk of hip osteoarthritis compared to non-exposed references, when age, body mass index, traumatic fractures, and smoking were accounted for. Yadav *et al.* (2016) also revealed that most of the labourer carried concrete mixture (30%) on their head with a slight difference of bricks (27%) followed by cement (24%) and water (9%). Majority of the women labourer (59%) carried heavy load weighing greater than 20 kg.

Ergonomic Assessment

a. Anthropometric and physical parameters

An experiment was conducted for ergonomic assessment of head load carrying activity by allowing the thirty selected respondents to carry cement mixture. The ergonomic parameters of the respondents were recorded from the time of start of the activity till its completion. The experiment was carried out in month of September.

The mean age of the respondents was 31.96 $\pm$ 4.89 years; the height of the respondents was 155.43 $\pm$ 7.02 cm with a mean weight of 50.86 $\pm$ 5.37kg. The mean waist circumference of the respondents was 72.03$\pm$8.60 cm, waist back length was 38.33$\pm$3.26 cm, vertical reach 194.10$\pm$8.66 cm and head breadth was 14.36$\pm$1.10 cm, respectively. Different body fold measurements were also taken during the study. The mean of their biceps skinfold was 1.76$\pm$0.31mm, triceps 1.65$\pm$0.37 mm, subscapular 1.91$\pm$0.41 mm and suprailiac 2.01$\pm$0.43 mm, respectively.

Mean body mass index was 21.16$\pm$2.81kg/m^2 with mesomorph body type, mean body fat percentage was 0.83$\pm$1.23, mean LBM of the respondents was 34.01$\pm$5.05 kg and total body fat was 14.08$\pm$2.09 kg, respectively. An average female worker worked for 6-8 hours per day and travelled a distance of 2-3 km in one hour at the construction site. In a similar study, Yadav *et al.* (2016) also reported that women selected for the study were of middle age (31.40yr), with mean height 149.60cm and mean weight 50.30kg. LBM was 50.01kg leading to BMI 22.05kg/m^2 with mesomorph body type, respectively.

b. Physiological parameters

The comparison of different physiological parameters before and after carrying the head load revealed that working heart rate before the activity was 120.14b/min whereas working heart rate while using Conventional Method, head load harness, head load manager was 137.67 b/min, 133.77 b/min and 134.86 b/min respectively. It was observed to be lesser in head load carrier (132.80b/min). Recovery heart rate before activity (107.51b/min) was lesser as compared to other methods. Recovery heart rate in head load manager (120.18 b/min) was found higher followed by head load harness (119.29b/min), Conventional Method (119.08 b/min) and head load carrier (117.49 b/min). Energy expenditure before activity was low (10.38 kJ/min) while in Conventional Method, it was higher i.e. 13.16 kJ/min. The head load manager, head load harness and head load carrier had the approximately same value of 12.72 kJ/min, 12.54 kJ/min and 12.39 kJ/min respectively. The total cardiac cost of work (3170.10 beats) was found higher in Conventional Method followed by head load manager (3006.90 beats), head load carrier (2970.10 beats) and head load harness (2937.00 beats). It had a low value of 2039.22 beats before activity. Physiological cost of work after the activity was also higher in Conventional

Method (52.83b/min) followed by head load manager (50.11b/min), head load harness (48.95 b/min), head load carrier (47.83b/min) while before activity it was 33.98 b/min.

No significant difference was observed in the working heart rate, resting heart rate, energy expenditure, total cardiac cost of work, physiological cost of work while using head load carrier, head load manager and head load harness. It might be due to the reason that it was not comfortable to carry heavy load for a short distance because the task included frequent loading and unloading of materials. Since these ergo solutions reduced bodily discomfort to some extent hence some reduction could be seen as compared to Conventional Method. Yadav *et al.*(2016) also revealed that there was an increase in pulse rate (27.9 $b.min^{-1}$), heart rate (32.7 $b.min^{-1}$), and energy expenditure (6.4 $kJ.min^{-1}$), inferring that body had to work more while carrying load on head using Conventional Methods. On the basis of the classification given by Varghese *et al.* (1994) for energy expenditure and heart rate, the workload of carrying head load was determined to be heavy. Maiti (2008) reported that average maximum HR while carrying concrete mixture was 187beats/min.

c) Biomechanical Parameters

It was observed that the deviation of cervical angle of the spinal cord in Conventional Method was 187^0 while there was no change in the cervical angle after using head load carrier (182^0), head load manager (182^0) and head load harness (182^0). It was found that there was a deviation in the lumbar angle of the spinal cord in Conventional Method to the extent of 189^0, followed by head load harness 188^0, head load manager 186^0, head load carrier 186^0 while the resting angle was 183^0. Sharma and Singh (2012) reported that while carrying the load on head, a deviation of 1.7^0, 2.8^0 and 3.1^0 was observed with a load of 15 kg, 20kg and 25 kg respectively. Gauvreau *et al.* (2011) analyzed that during walking, load on the head caused significantly larger upper trunk extension and smaller flexion of the head relative to the trunk. The amplitude of motion of the upper trunk and of the head relative to the trunk, as measured by the standard deviation of walking angles, was found to decrease as a result of carrying load on the head and compensated by increased motion at the sacrum. Kumar *et al.* (2004) emphasized that there was evidence of degenerative disc disease in the vertebral MRI of the workers involved in load carrying activity. Chattopadhyay *et al.* (2009) reported that forward bending back was the most common and frequent repeated awkward posture carried out by labourer during performance of most of the construction works. Other stressful working postures found during different joint motions were neck flexion or extension, shoulder flexion or extension, hands at or above head, elbow flexion, sometimes backward bending or twisting of back during lifting of heavy loads, radial or ulnar deviation of wrist and bending knees.

Regarding grip strength of the respondent after performing the load carrying activity, it was found that grip strength was 19.29 kg, 18.16 kg, 17.60 kg, and 16.21 kg for the right hand in the head load carrier, head load harness, Conventional Method, and head load manager respectively. For the left-hand, grip strength was 18.68 kg, 17.60 kg, 15.77 kg, 15.57 kg, in head load carrier, head load harness, head load manager and Conventional Method respectively. The handle provided in HLC were longer which were creating difficulty in loading and unloading of the materials to the construction workers. In case of HLM no belt was provided to the workers for firm holding as well as no cushioning was provided on the shoulders to provide undue pressure while carrying the material. On the other hand HLH was too heavy for construction workers to hold and carry the material on it especially for short distance.

In lifting activity, REBA score was 13 in Conventional Method followed by head load carrier, head load harness (12 each), and head load manager (11), respectively which indicated that the job was very highly risky and there was need to implement the change. While in the carrying activity, the score was 12 in Conventional Method followed by head load carrier (11) and head load manager, head load harness (10 each), which indicated that the job was very highly risky and there was need to implement the change. Even though in landing activity, score was 12 in head load manager, followed by head load carrier, head load harness (11each) and Conventional Method (10), the same indicated that the job was very highly risky and there was need to implement the change. Scores obtained illustrated that workers were working in poor posture and they were more prone to injury or discomfort due to adoption of poor working posture. The postural stress due to the awkward posture is the key reason for musculoskeletal discomfort (Brown, 1976). Sahu and Sett (2010) analysed the working postures and revealed that most of the working postures adopted by women were unsafe and ranked under REBA action level 3 and 4. Yadav (2015) also reported that on the basis of REBA and VAD, load carrying was identified as the most critical stage of head loading activity

In Conventional Method, severe discomfort was felt in the head, lower back (4.19 each), neck (3.93), feet (3.84), shoulders (3.81), buttocks (3.75) and upper back (3.61). Discomfort in the wrists (3.39), upper arms (3.32), mid back (3.20), chest (3.17) and knee (3.16) was moderately heavy whereas light discomfort was felt in the thighs (2.97), legs (2.64), lower arms (2.58) while carrying the load. This is due to the bad posture adopted by workers that they faced problems in their lower back. Moreover, since load was not properly distributed so they felt pressure on their shoulders. While performing the activity with the help of head load carrier, mild discomfort was felt in the legs (2.60), shoulders (2.54), upper back (2.37),feet (2.41),upper arms (2.18), mid back (2.07), neck (1.54), lower arms and thighs (1.52 each). Very mild discomfort was felt in the knee (1.43), buttocks (1.39), lower back, head (1.30 each), chest (1.08) and wrists (1.01).

However, while carrying the heavy load with the help of head load manager, very heavy discomfort was felt in the shoulders (4.67) and moderate discomfort was felt in upper back (3.64) and lower back (3.59). Discomfort in feet (2.76), legs (2.70), thighs (2.68), wrists

(2.37), mid back (2.35), knee (2.33), upper arms (2.25), neck (2.24), lower arms (2.22), head (2.20), buttocks (2.15), and chest (2.03) was sensed mild. While carrying the heavy load with the assistance of head load harness, moderate discomfort was felt in the upper back (3.50) while mild discomfort was felt in the wrists (2.60), legs (2.52), knee, shoulders (2.50 each), mid back (2.36), thighs (2.29), lower back (2.25), buttocks, chest (2.23 each), upper arms (2.20), lower arms (1.99), neck (1.64), feet (1.50) and head (1.30). The reason behind this might have been that the head load manager was not comfortable to carry the load as no load was supported by the head and handle length of the product was too short. Hence the respondents had to raise their lower arms above elbow level to hold it leading to pain in shoulders. Suthar *et al.* (2011) also reported that 77 per cent of tribal women, aged between 20-50years, had pain in their neck due to head load carrying activity. Likewise, Lloyd *et al.* (2010a) also concluded that head loading is characterized by significant neck pain and though it may have an advantage in terms of balance and stability. Its long term use does not protect from health problems. Chattopadhyay *et al.* (2009) also found that low back problem was more common in both male and female labourer (BPD- 8.6 in males and 9.1 in females). Qutubuddin *et al.* (2013) reported that the workers involved in loading, unloading and carrying experienced pain in the shoulder, neck, hand/wrist and elbows. Bagchi *et al.* (2014) reported that the female brick carriers who carried a heavy load to and from the field and the brick kiln, suffered from more discomfort and pain in the head, neck, shoulder and trunk regions. Sahu and Sett (2010) reported that female brick carriers felt more pain on upper parts of their body such as head, neck, shoulders etc. This is so because female workers had to carry heavy load (50.31 ± 1.01kg) on their head and covered the shortest distance (0.6 ± 0.13 km) from the field to the kiln top.

d) Environmental Parameters

Workplace environment refers to condition at the place where workers devote most of their working time. Therefore, comfortable work environment is the key for workers to perform their task in an efficient way. They have to work in all types of seasons having extreme temperatures. The experiment was conducted in the month of September and the average temperature was observed to be 34.26^{0}C during carrying the head load which was much higher than the recommended value i.e. 20-25^{0}C whereas the average level of humidity was 48.16 % which was within the recommended value but on the lower side i.e. 40-60%. The noise level at the construction site was 90.43 dB which was more than the recommended value i.e. 60-80 dB. Light was found to be 386.60 lux which was within the recommended limits i.e. 250-500 lux. Hence, it describes that the environment in which the respondents had to work was hot and somewhat dry carrying thermal discomfort to the workers while carrying load during this season. Oberoi (2008) reported that the environmental parameters like temperature, ventilation, humidity, air quality, lighting, noise etc. in which the workers perform their tasks may have an effect on health of the workers.

Phase II: Design and development of head load manager for construction workers

Among the three materials selected to develop the HLM stainless steel had a density of 7750/m^3, Gray cast cast iron had a density 7200kg/m^3, and Aluminium alloy had a density of 2770kg/m^3. A 3D model was made with the help ZWCAD software for further analysis. Comparisons were made on the basis of the amount of total deformation occurred, von Mises stress created, the intensity and safety factor of the material after applying a load of 10,20,30, and 40 kg on it. The total deformation of the materials was recorded by applying different amount of force to the 3D model. All the values which were recorded in ANSYS were very minute. The deformation was of elastic nature and acceptable. Hence, all the three materials were suitable for manufacture on the ground of deformation. The study done by Warkade (2016) represented the design and analysis of friction clutch plate which was modelled by CATIA software followed by static structural analysis using ANSYS software. Experimental was performed to observe the strength and deformations of clutch plate. Results revealed that maximum deformation was found in the outer area of plate, while minimum deformation was found in the center position of the plate. Similarly, sheet metal parts are used to manufacture a wide range of products by bending and cutting the sheets into appropriate shapes by means of the physical process of shearing. Ghimire *et al.* (2017) worked on sheet metal. The metal sheet was analysed with the help of ANSYS Workbench. He also studied the phenomenon of spring-back, associated with the metal sheet during its deformation with the help of ANSYS Workbench.

The von Mises stress in all the three materials i.e. Stainless steel, Gray cast iron and Aluminium alloy had a value less than the tensile strength of the materials. Hence, the materials were safe for the industrial production of the product. Tensile strength of stainless steel was 465MPa; gray cast iron 140MPa and Aluminium alloy was 124-290MPa. The available literature suggests that for a design to be functional, the maximum value of von Mises stress should be lesser than the strength of the material. Hence, all these materials were safe for the industrial production of the DHLM. At a load of 10kg, 20kg, and 30kg any of the material did not involve any risk of manufacture. Impact loads require a safety factor of at least 2 (Shigley & Mischke, 2001). The products made from Stainless steel, Gray cast iron and Aluminium alloy had very high safety factor and did not involve any risk of manufacture. Patil (2014) discussed the technique available to analyze the effect of temperature and cutting forces (Horizontal force, vertical force) on the tip of tool using 3D model of a single-point cutting tool in ANSYS software. This software could also predict temperatures, distribution of von Mises stresses and deformation of tip of single point cutting tool using tool forces. It could also estimate the tool wear and residual stresses on machined surfaces, optimization of cutting tool geometry and cutting conditions. Pawar *et al.* (2016) worked on a 3D model of broach tool and the work piece which were developed by using finite element analysis (FEA) software ANSYS. They considered the linear type toothed broach tool. The developed model gave an idea about the force and deformation analysis of structural steel broach tool, which is applied, to the copper alloy, magnesium alloy, titanium alloy, Aluminum alloy. The FEA results showed that maximum equivalent elastic strain was 0.92209 mm/mm while maximum plastic strain was 0.90307mm/mm for the Aluminum alloy. Kumari (2014) developed a prototype model of HLC made from cane but other materials were also sought for its development at local level. Hence, ANSYS (simulating software) was used to compare Al-alloy and ABS material to find out the better one on the basis of weight, durability and cost. ABS material was found appropriate for being lighter in weight, low cost and more durable, hence, recommended for development of HLC at local level.

Modification in technology

Although the head load carrier, head load manager and head load harness were effective in reducing the WMSDs to some extent but it was not comfortable to carry the load for frequent loading and unloading task. Different types of loads were unable to be lifted on it. It caused acute stress on the shoulders and head. Since handle length of HLM was too short, the respondents had to raise their lower arms above elbow level to hold it which caused static posture and fatigue. The concave shape of HLC was not suitable for carrying brick and cement mixture and HLH was very heavy and not good for lesser weight i.e. 20kg. Therefore, modifications were required in shape and dimensions of the product. Therefore, modifications were made in the technology on the basis of anthropometric dimensions of women construction workers, dimensions of the load lifted by them as well as limitations observed by the researcher. A new modified prototype of the model was developed on the basis of head load manager developed by Murnalini (2011). The modified technology was named as Developed Head Load Manager (DHLM) with changes given below:

- Overhead frame height was made adjustable so that weight could be supported by head along with the shoulders according to the height of the workers,
- Frame width was reduced so that it may fit perfectly to the user’s body.
- Width of the overhead frame or the neck support was reduced to fit the handles in between the acromioclavicular joints.
- Length of the back frame was reduced to remove the unnecessary hurdle at the lower back region.

Some additional features were also added to improve the functionality of HLC and eliminate the weak points on HLM as follows:

- The shape of overhead platform was made up of round shape.
- Velcro tape belts were provided at the waist level that allowed the developed head load manager to fix properly to the body.
- Padding was done under the shoulder, and at the back to provide proper support and cushioning for comfort of the female worker while carrying the load by reducing the jerks and contact stresses.

Sharma and Singh (2012) inferred that carrying the water load is safe only through the head mode. Carrying a load on shoulder and waist may result in injuries. By considering the cardiovascular, muscular, biomechanical stresse and psychophysiological evaluation, they concluded that carrying the load through the head model should be around 15 kg while for shoulder and waist mode should not be more than 10 kg at the walking speed of 3.5 kmph. Sidharth (2013) developed an improvised load carrying device for substituting the traditional way of carrying bricks on the head. In this version of load carrying device, the weight is distributed over the shoulders and the upper back. The hands rest in an ergonomically comfortable position on the supports provided, thereby contributing to balancing the weight kept on the platform. This device was made from stainless steel which is high in strength and at the same time very light. Kumari (2014) introduced a modified technology named as Head Load Carrier (HLC) which had several improved as well as additional features to eliminate the problems faced by users while using it. These included change in dimensions, viz. in the height and width of overhead platform, width of the back frame and length of handles. Overhead platform shape was changed from circular ring to concave platform. Cushioning was done at shoulders, back and below head platform. Broad belts were provided at the waist level to keep the HLC closer to the body. Flexibility in the height of overhead platform was provided to accommodate larger population.

Phase III: Ergonomic assessment of the developed head load manager

An average female selected for the study was middle aged (31.36 yr.), having 48.73 kg body weight, 155.16 cm height leading to a BMI of 20.30 kg/m^2 indicating mesomorph body. The respondents were having good physical fitness index (120.57%) and VO_2 score was 32.69 l/m.

Physiological parameters

Findings reveal that the mean working heart rate of the respondents with the Conventional Method was 134.89b/min and with developed head load manager was 122.10b/min. The mean recovery heart rate of the respondents was 118b/min and 107b/min with the Conventional Method and developed head load manager, respectively. It was observed that performing the activity with developed head load manager led to a reduction of 12.79 b/min in working heart rate and 10.84b/min in recovery heart rate. Energy expenditure decreased in developed head load manager to the extent of 1.31kJ/min with 10.29 percent decrease in comparison to the Conventional Method. Oxygen consumption rate was also decreased up to 23.25 percent with developed head load manager. This would be due to the reason that the overhead platform shape was changed from circular ring to concave platform and cushioning was done at shoulders, back and below head platform. Moreover, Velcro belts were provided at the waist level to keep the DHLM closer to the body and adjustable height of overhead platform was provided to accommodate larger population.

It was observed that TCCW decreased to 821.55 beats with 27.58 percent decrease. Similarly, PCW decreased by 13.69b/min recording a decrease of 9.91 percent. All the values were found statistically significant at 0.05 level of significance. It might be concluded that developed head load manager, when compared to the Conventional Method, was found efficient to reduce the physiological exertion of the female workers in head load carrying activity at the construction site. Similarly, Gaikwad and Zend (2012) tested head load manager, a technology developed by ANGRAU for load carrying activity, in the selected brick kilns of Parbhani city. There was significant reduction in physiological cost of work (10%) and body discomfort rating when brick carrying activity was performed with head load manager. However, work output per hour was reduced by 16.62 percent. Head load manager was recommended for reduction of drudgery with certain improvements. Mrunalini (2016) found significant difference between the conventional and head load manager model for physiological and body pain score. HLM 1 and HLM 2 recorded less physiological workload, body pain and drudgery perception score than the Conventional Method. Kumari (2014) reported that significant reduction was observed in the working HR (10 $b.min^{-1}$), EE (1.7 $kJ.min^{-1}$) PCW (11 $b.min^{-1}$) but no significant difference was observed in TCCW by using HLM in comparison to the existing method.

Biomechanical Parameter

The comparison of the grip strength of the hands of female workers while performing head load carrying activity with Conventional Method and developed head load manager revealed that while performing head load carrying activity with the Conventional Method, reduction in grip strength in the right hand was 25.18 percent and in the left hand was 32.70 percent. Whereas, when the activity was performed with the developed head load manager, reduction of grip strength in the right hand decreased to the extent of 14.61 percent and in the left hand to an extent of 17.68 percent. Reduction was observed in the grip strength of respondents after employing Developed Head Load Manager (DHLM) because the hands were not required to be raised above shoulder level, there reducing the fatigue of hands.

A remarkable difference was observed in the spinal angle as there was no deviation from resting in the cervical region and slight deviation was observed in the lumbar region which was lesser than the existing method. By using DHLM, the load was distributed totally on both the shoulders but not at all on head. Hence, the strain at cervical region was eliminated to some extent. According to OWAS analysis, while performing the activity with the Conventional Method, load lifting was the critical part of the activity and the corrective measure was needed immediately as respondents back was bent forward and twisted, both arms were below shoulder level and knees bent either in standing or squatting position. Load carrying was not found to be severe, corrective measures were needed in the near future as they walked with back straight and hands raised above shoulder. Load landing was not much severe as its action category indicated that corrective measures were needed in the near future. While landing the load, women used to bend their back forward keeping their legs straight and hands raised above shoulder level. Whereas, when activity was performed using the developed head load manager, data illustrated that the posture adopted in lifting the load and carrying the load got the action category 2, each implying that correction is required in the near future. Landing posture got the action category of 1 implying that be no corrective measure was required. The reason for this change of working method and corrective working posture that reduce the risk of MSDs and pain in the body parts was adopted by the workers. Sarkar (2016) reported that ninety-five percent of workers encountered muskuloskeletal disorder in at least one part of the body in the past 12 months. As per OWAS results, 83% of the analyzed work postures of the workers required immediate corrective measures for the safety. The most destructive posture was carrying a heavy load overhead. Carrying more than 120 kg increased the odds of low back and neck pain by 4.52 times and 4.55 times, respectively.

The musculoskeletal discomfort faced by respondents in carrying the head load by Conventional Method and by using developed head load manager was studied with the help of body part discomfort score given by the respondents for different body parts while performing the activity. There was a significant reduction in the discomfort at head, neck, shoulders, upper back, upper arms, mid back, chest, lower arms, wrists, lower back, buttocks, thighs, knee, legs, and feet. The reason was the modification in the length of the back frame that reduced the unnecessary hurdle at the lower back region and the adjustable height of overhead frame that reduced the shoulder pain. Muslim and Nussbaum (2015) reported that musculoskeletal symptoms (MSS) on manual material handling workers were mostly at the lower back (72.2%), feet (69.4%), knees (64%), shoulders (47.2%), and neck (41.7%). Logistic regression indicated that musculoskeletal symptoms in the lower back were associated with longer work hours per day, MSS in the hands were associated with load mass, and MSS in the ankles/feet were associated with stature and load bearing frequency. MSS was reported to affect with day to day activity, but only a few workers pursued medical treatment.

Results on Rating of Perceived Exertion felt by the respondents of different head load carrying task in Conventional Method and developed head load manager showed that load carrying was ranked I with the highest mean score of 4.1 in Conventional Method implying that respondents perceived load arrying activity as very heavy exertion. RPE score of 3.4 was obtained for load lifting activity and it was considered as moderately heavy exertion activity and ranked II. Load landing activity obtained 3.2 mean score and was regarded as moderately heavy exertion with rank III. Whereas, while using developed head load manager, load lifting activity ranked I with a mean score of 2.4 which indicated that respondents perceived light exertion. Load landing activity ranked II and load carrying ranked III with mean score 1.6 and 1.5 respectively conveying that respondents perceived very light exertion.

Environmental conditions

The experiment was conducted in the month of December having an average temperature of 21.56^{0}C during carrying the head load which was higher than the recommended value. The average level of humidity was 52.93% which was within the recommended level of temperature. Comfortable range of atmospheric temperature in the workplace should be between 20 and 25º C. Relative humidity of 40-50 percent makes one comfortable in winters, while in summers 40-60 percent is normal. Noise level of 92.90db was also found higher than the recommended value i.e. 60-80dB and the light was 361.33 lux which was within the recommended value i.e. 250-500lux

Phase IV: Feasibility testing of developed head load manager

Feasibility testing of the developed head manager was done with the help of modified scale of Rogers and Shoemaker (1962). On the basis of various attributes i.e. relative advantage, compatibility, simplicity/complexity, practicability, the results show that practicability got the first rank (2.31), relative advantage (2.15), while compatibility, simplicity/complexity got the same rank (2.07).

Head load manager was acceptable to the women workers as it was not difficult to handle while carrying heavy load on the head. They did not feel pressure on the shoulder as cushioning is provided at the back. They were able to maintain their body posture in standing position whereas frequent shifts in posture were needed while using the head load manager. Cushioning is also provided at lower back in DHLM so that a respondent does not feel pressure on the lower back. Handles of DHLM were made according to the anthropometric measurements of the respondents that pose no discomfort to their arms and are comfortable for them. Shape of upper ring was appropriate for keeping heavy load. Material used in DHLM did not hurt the body and was durable. DHLM is tied with Velcro tape so that it keeps closer to the body. DHLM remains stable on the head and DHLM is not required to be held while placing load on the head. The cost estimation of the DHLM was approximately ₹500. Mrunalini (2011) developed the technology named Head Load Manager for transporting manure, seeds, harvested grains, vegetables, fodder and biomass fuel for home, farm and handling of sand, cement at the domestic construction sites. Its cost was estimated to be ₹800-1000. Singh (2011) reported that Panchal introduced the product “Load Carrier for Labour” (LCL) which is amazingly simple and costs just ₹300 to make. It is usually made of cane with metal and plastic fittings. Where cane is abundantly available it can be made from cane, elsewhere it is possible to produce it using metal and plastic. A big advantage of the product is that it can be used for all three modes of carrying loads – on the back, on the head, and as a trolley. The mode can be switched in just a minute by using two knobs on the device. The total weight of the device is only 2 kg. Ergonomically, the load is distributed over the shoulders and at the lumbar region support is provided by a softer material. Vajra developed by Lohar (2011) is a vessel desk like device which distributes the load of a worker from head to shoulders with the help of a vertical support assembly. Its lower part is fitted to the body with the help of flexible belts and the upper part can be fitted and removed as per requirement with no need to balance the objects. It reduces cumulative trauma like headache, backache and other body strains. It bear the weight up to 75 kg and costs Rs. 700/-. A device “Relief” for women labourer developed by Priya (2012) is quite similar to the one developed by Panchal (2011) and can be used to carry a load of 20- 30 kg per trip at one time and costs Rs.700.

DHLM can be fixed to the body with the help of a belt provided in the frame. Padding was done under the shoulder and at the back to provide proper support for comfort of the female worker while carrying the load by reducing the jerks and contact stresses. The load can be placed over it by another worker as per the routine practice prevalent at the construction site. Finally, the user can hold the handles of the DHLM by keeping the upper arms parallel to the body. The cotton tape on the iron rod helps in providing a firm grip. After performing the load carrying task, the user can unload the material directly on the ground as per the existing practice. The overhead frame of the DHLM is adjustable and the workers can adjust the height according to their convenience.

CHAPTER–VI

SUMMARY AND CONCLUSION

The construction industry is the second largest employer of the country after agriculture. As per the projections it is expected to employ over 67 million workforce by 2022. It has contributed to 7.54% to the national Gross Value Added (GVA) registering a growth of 8.7% (Economic Survey of Index, 2017-18). In India, a large proportion of construction workers is unskilled and most of them are migrants. Women workers are much more involved in manual material handling (MMH), they are required to work for longer durations without any rest. Several studies have been done to reduce different hazards faced by women workers, by providing some ergo solutions while carrying load on head without much difficulty. However, the technology has not reached the users till now.

Considering the above facts, the present investigation was planned to assess and address the problems of female workers, mostly engaged in the manual material handling task carrying a high risk of injury, with the following specific objectives:

Objectives

1. Assessment of existing head load managers for construction workers
2. To design and develop head load manager for construction workers
3. Ergonomic assessment of the developed head load manager
4. Feasibility testing of the developed head load manager

Methodology

The present study was conducted in four phases:

Phase I: Assessment of existing head load managers

The present study was conducted in the month of September in the Hisar city of Haryana state. Different construction sites from Hisar city were selected purposively. The field survey was conducted with the help of an interview schedule. Head load activity while carrying cement mixture was selected for the experimental work as maximum women were engaged in this activity at construction site. An ergonomic experiment was carried out on 30 respondents to find the reduction in physiological, biomechanical stress and work-related musculoskeletal disorder by the use of ergo solutions viz; Head Load Manager, Head Load Carrier and Head Load Harness.

Phase II: Experimental Work (Design and development of HLM)

The problems reported in Phase 1 were utilized for designing and development of head load manager. The materials selected for development of head load manager were Stainless steel, Gray cast iron and aluminium alloy. The 3D model of DHLM was developed and tested in the virtual environment of a simulating software namely ANSYS (Analysis system) for their load bearing ability by applying different loads of 10, 20, 30 and 40 kg on it.

Phase III: Ergonomic assessment of developed HLM

Field experiment was conducted in the month of December on selected 30 physically fit women workers. Details pertaining to the head load were gathered and the ergonomic assessment was done to check the effect of head load carrying on the physiological, biomechanical and environmental parameters on the respondents.

Phase 4: Feasibility testing of developed HLM

Feasibility testing of the developed head load manager was calculated with the help of modified scale of Rogers and Shoemaker (1962), on the basis of various attributes, i.e. relative advantage, compatibility, simplicity/complexity and practicability. Data were also analysed with the help of User Assessment Sheet that included ergonomic aspects to make the product more convenient to the users.

MAJOR FINDINGS

Phase I: Assessment of existing head load managers for construction workers

Work profile

- Out of the total sample, majority of the respondents were in the age group between 30-40 years (66.67%), were married (63.33%), illiterate (60%), belonged to nuclear family (70%) and hailed from West Bengal (30%).Majority of the respondents (60%) were employed on daily basis. More than half of the respondents (60%) received wages in between ₹250-350 and a majority (50%) were getting their wages on daily basis. Material carried by the respondents on their head was concrete mixture (30%) with the slight difference of bricks (23.33%), cement (20%), and water (16.67%) and (10%) other material like sand, gravel, etc. Majority of the respondents (60%) carried the head load between 10-20 kg.

Ergonomic Assessment

- An experiment was conducted for ergonomic assessment of head load carrying activity by allowing the thirty selected respondents to carry cement mixture. The mean age of the respondents was 31.96 years, mean height 155.43cm, mean weight 50.86 kg.
- The working heart rate (120.14 b/min) of the respondents before activity was significantly lesser than the Conventional Method (137.67b/min), HLC (132.80b/min), HLM (134.86b/min), and HLH (133.77 b/min). On the other hand, recovery heart rate (107.51b/min) was also significantly lesser than the other methods. Rate of energy expenditure before activity was significantly lower than the other methods.REBA score indicated that the job was very highly risky and there was need to implement the change in the working posture of female construction workers.

Phase II: Design and development of head load manager for construction workers

- Stainless steel, Gray cast iron, and Aluminium alloy were compared to obtain the low cost, durable and lightweight product. A 3D model was made with the help ZWCAD software for further analysis. Their strengths were checked with the help of simulating software ANSYS by applying the force 98N, 196N, 294N, and 392N. The hollow rod with a diameter 1.5cm was used for construction of developed head load manager.
- All the materials i.e. stainless steel, gray cast iron and Aluminium alloy were suitable for making the product. All of them had an acceptable level of deformation and von Mises stress. Since Gray cast iron material was cheaper and easily available in the market compared to stainless steel and Aluminium alloy, it was preferred over them as focus of the study was on making a cheaper, light weight and durable product. Hence, gray cast iron material was preferred in making the final product. The product was made on the basis of availability of the material, the anthropometric dimensions and ANSYS analysis. The product developed to decrease the discomfort while carrying bulky loads on head was designated as Developed Head Load Manager (DHLM).

Phase III: Ergonomic assessment of the developed head load manager

- After using Conventional Method and developed head load manager for carrying the cement mixture, highly significant decrease was observed in WHR (12.79 $b.min^{-1}$), RHR (10.84 $b.min^{-1}$) and EER (2.03 $kJ.min^{-1}$). Oxygen consumption rate also decreased up to 23.25 percent after using DHLM. TCCW and PCW decreased by 821.55 beats and 13.69b/min, respectively.
- Significant difference was found in grip strength of both hands. REBA, OWAS and VAD indicated that workers faced no significant problems while carrying load with the help of DHLM.
- There was a significant reduction in the discomfort perceived at various region of the body like head, neck, shoulders, upper back, upper arms, mid back, chest, lower arms, wrists, lower back, buttocks, thighs, knees, legs, and feet.

Phase III: Feasibility testing of the developed head load manager

- Feasibility testing of the developed head load manager was done with the help of modified scale of Rogers and Shoemaker (1962) on the basis of various attributes i.e. relative advantage, compatibility, simplicity/complexity and practicability. The result showed that practicability got the first rank (2.31) and relative advantage got 2.15, while compatibility and simplicity/complexity got the third rank (2.07 each).
- Head load manager was acceptable to women workers as it was easy to handle while carrying heavy load on the head. They did not feel pressure on the shoulder as cushioning has been provided at the back. DHLM is tied with Velcro tape so that it keeps closer to

the body. DHLM remains stable on the head and holding of DHLM while placing load on the head is not required and this helps in giving rest to hands. The cost estimation of the DHLM was approximately ₹500.

RECOMMENDATIONS FROM THE PRESENT STUDY

- Use of personal protective devices like gloves, helmet, ear plugs etc. should be provided by the contractor to workers at construction site to protect them from injuries like neck, shoulder, back and head injury, hearing loss etc.
- Training programs should be organised by the government and non-government organisations for addressing the issues of occupational health risks like musculo-skeletal problems.
- In order to more objectively find out the effects of load carrying on health of construction workers, such type of studies can be synergistically conducted with medical professionals in future to study the effect of biomechanical stress etc.

IMPLICATIONS OF THE STUDY

- The study provides a drudgery reducing technology in the form of developed head load manager to women workers engaged in construction industry so that they can easily carry heavy loads up to 20 kg without developing any shoulder and neck pain.
- Occupational hazards and work related musculoskeletal disorders can be reduced with the help of developed head load manager.
- The study will be helpful to educate construction workers in order to make them aware about occupational health problems and ways of their prevention through training on various aspects relative to construction Industry.
- The study will also be useful to researchers to conduct detailed ergonomic research on male workers engaged in manual material handling tasks and other activities performed at construction site in order to explore suitable ergonomic interventions and offer practicable solution.
- The findings of the study will be helpful for the manufacturers and product designers to develop a DHLM on mass scale for the benefit of workers engaged in construction industry, thereby reducing the incidence of occupational hazards.

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ANNEXURE-I

INTERVIEW SCHEDULE

Name of the respondents ____________________

1. Socio-personal profile of women worker at construction sites

Sr. No.	Question	Possible response	Response code
1.	**Age**	1. 20-30 yrs 2. 30-40 yrs 3. 40-50 yrs	
2.	**Marital status**	1.Married 2.Single 3.Divorced/separated	
3.	**Family type**	1. Joint 2. Nuclear	
4.	**Educational level**	1.Illiterate 2.Read & write	
5.	**Native place**	1. M.P 2.U.P 3. W.B 4.Bihar	

2. Work profile of women worker at construction sites

Sr. No.	Question	Possible response	Response code
1.	**Pattern of employment**	1. Permanent	
		2. Temporary	
		3. Daily wges	
2.	**What is your wage per day?**	1. □ 250-350	
		2. □ 350-450	
3.	**How do you receive your wages?**	a. Daily	
		b. Weekly	
		c. Monthly	

3. Work assessment

1. What type of materials do you carry?

(a) Water (b) Bricks (c) Cement (d) Concrete mixture (f) Any other

2. What was the total weight of the load carried?

i) <10kg ii) 10-20kg iii) >20kg

4. Anthropometric Parameter:

Anthropometric parameter	
Age	
Weight	
Height	
Waist circumference	
Head circumference	
Hip circumference	
Systolic blood pressure	
Diastolic blood pressure	
Biceps skinfold	
Triceps skinfold	
Subscapular skinfold	
Suprailiac skinfold	
BMI	
Body fat percentage	
Lean body mass	
Total body fat	

ANNEXURE-II

Personal profile

NAME	AGE	HEIGHT	WEIGHT
1			
2			
3			
4			
5			

A. Physical Parameter:

1. Weight
2. Height
3. BMI
4. PFI

5. Body Composition

Sr. No.	BICEPS	TRICEPS	SUBSCAPULAR	SUPRAILLAIC
1				
2				
3				
4				
5				

B. Physiological responses

STEP STOOL TEST

Name of the subject	At rest HR	Step test HR			Recovery HR		
		1	2	3	1	2	3
1							
2							
3							
4							
5							

Other parameters from HR:

Condition	Pulse rate	Exhale capacity	Energy Expenditure Rate
Before carrying load			
After carrying load			

RPE scores while carrying head load:

Posture	Discomfort score
Lifting	
Carrying	
Landing	
Overall activity	

C. Biomechanical responses

Work sheet for grip strength

Respondent	Right hand		Left hand	
	Pre	Post	Pre	post
1				
2				
3				
4				
5				

Spinal angle:

S. No.	**Before activity**		**After activity**	
	Cervical	**Lumbar**	**Cervical**	**Lumbarr**
1				
2				
3				
4				
5				

Postural analysis:

III: REBA scores while carrying head load

Posture	**Score A (neck+trunk+leg+adjust)**	**Score B (upper arm+adjust+lower arm+wrist+adjust)**	**Final score C**	**Action category**
Lifting				
Carrying				
Landing				

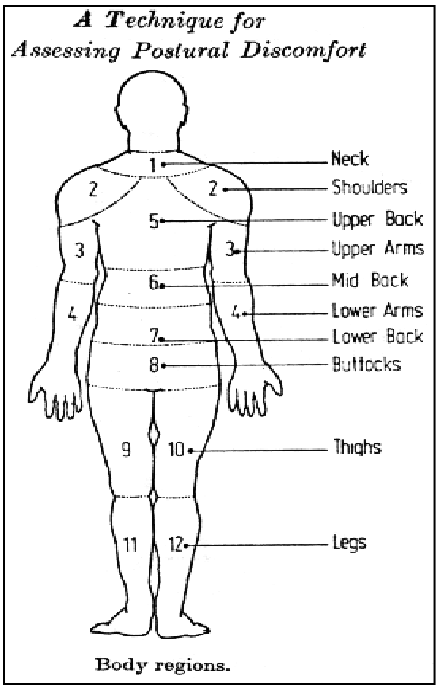
IV: OWAS scores while carrying head load

Posture	**Back**	**Upper limb**	**Lower limb**	**Load**	**Final score**	**Action category**
Lifting						
Carrying						
Landing						

V: VAD scores while carrying head load

Posture	**Discomfort score**
Lifting	
Carrying	
Landing	

VI: Body Part Discomfort Score after performing the load carrying activity



<u>Discomfort Scores</u>

1-very mild

2-mild

3-moderate

4-severe

5-very severe

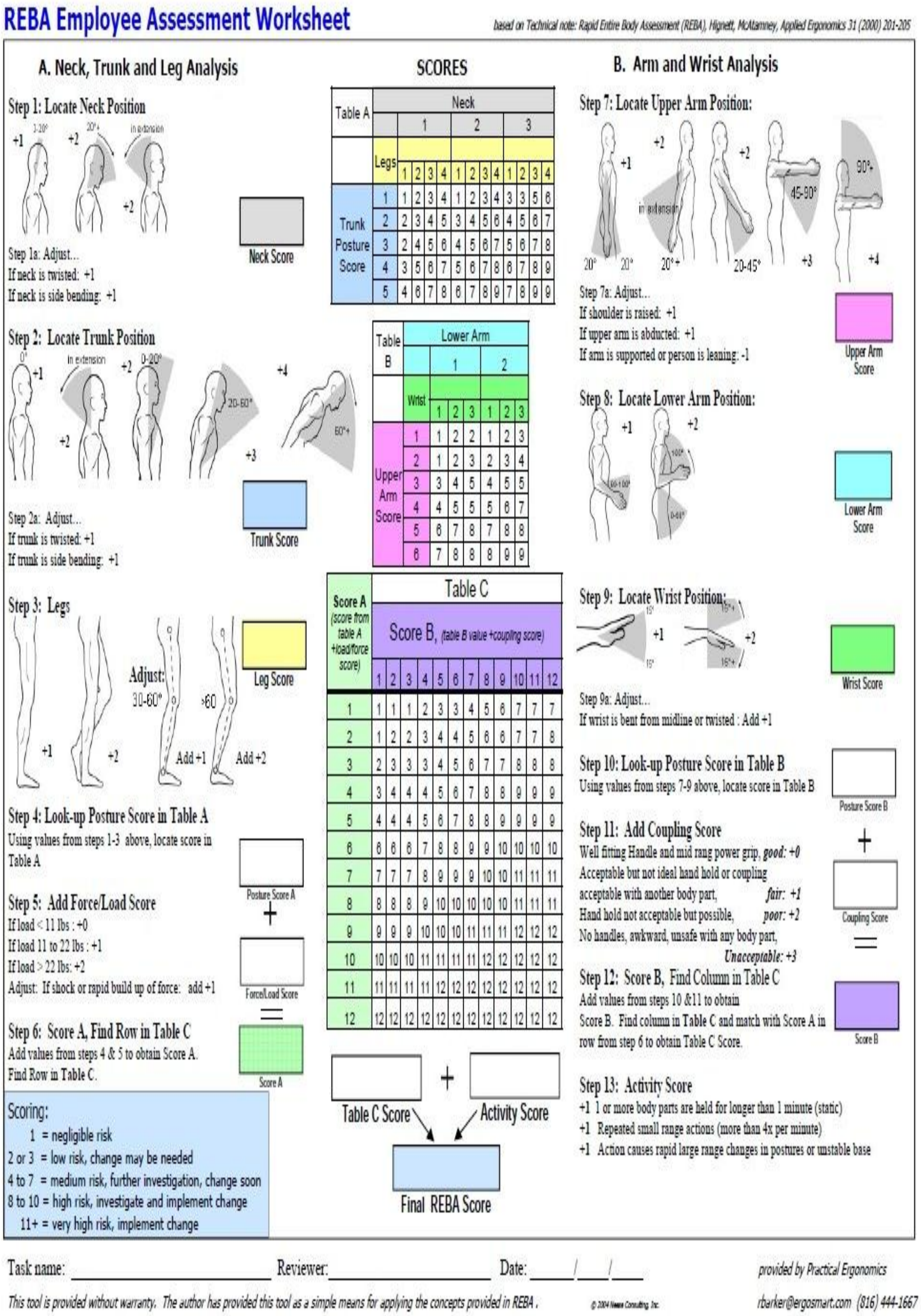
	Head	**Neck**	**Shoulder**	**Upper Back**	**Upper Arms**	**Mid Back**	**Chest**	**Lower Arms**	**Wrist**	**Lower Back**	**Buttock**	**Thigh**	**Pelvic**	**Leg**	**Foot**
Discomfort score															

D. Environmental Parameters:

Parameters	**Reading**
Temperature	
Humidity	
Noise	

ANNEXURE-III

REBA observation sheet



REBA Employee Assessment Worksheet

based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 10-20° +2 20°+ in extension +2

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Neck Score

Step 2: Locate Trunk Position

0° +1 in extension +2 0-20° +2 20-60° +3 +4 60°+

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 3: Legs

+1 +2 Adjust: 30-60° Add +1 >60 Add +2

Leg Score

Step 4: Look-up Posture Score in Table A

Using values from steps 1-3 above, locate score in Table A

Posture Score A

+

Step 5: Add Force/Load Score

If load < 11 lbs : +0
If load 11 to 22 lbs : +1
If load > 22 lbs: +2
Adjust: If shock or rapid build up of force: add +1

Force/Load Score

=

Step 6: Score A, Find Row in Table C

Add values from steps 4 & 5 to obtain Score A.
Find Row in Table C.

Score A

Scoring:

1 = negligible risk
2 or 3 = low risk, change may be needed
4 to 7 = medium risk, further investigation, change soon
8 to 10 = high risk, investigate and implement change
11+ = very high risk, implement change

SCORES

Table A

Table A		Neck 1				Neck 2				Neck 3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B

Table B		Lower Arm 1			Lower Arm 2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C

Score A (score from table A +load/force score)	Score B, (table B value +coupling score) 1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score

Final REBA Score

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

+1 +2 in extension +2 45-90° +3 90°+ +4 20° 20° 20°+ 20-45°

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 8: Locate Lower Arm Position:

+1 +2 100°+ 60-100° 0-60°

Lower Arm Score

Step 9: Locate Wrist Position:

15° +1 15° 15°+ +2 15°+

Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1

Wrist Score

Step 10: Look-up Posture Score in Table B

Using values from steps 7-9 above, locate score in Table B

Posture Score B

+

Step 11: Add Coupling Score

Well fitting Handle and mid rang power grip, *good: +0*
Acceptable but not ideal hand hold or coupling acceptable with another body part, *fair: +1*
Hand hold not acceptable but possible, *poor: +2*
No handles, awkward, unsafe with any body part, *Unacceptable: +3*

Coupling Score

=

Step 12: Score B, Find Column in Table C

Add values from steps 10 &11 to obtain Score B. Find column in Table C and match with Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score

+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Task name: ____________ Reviewer: ____________ Date: ___/___/___

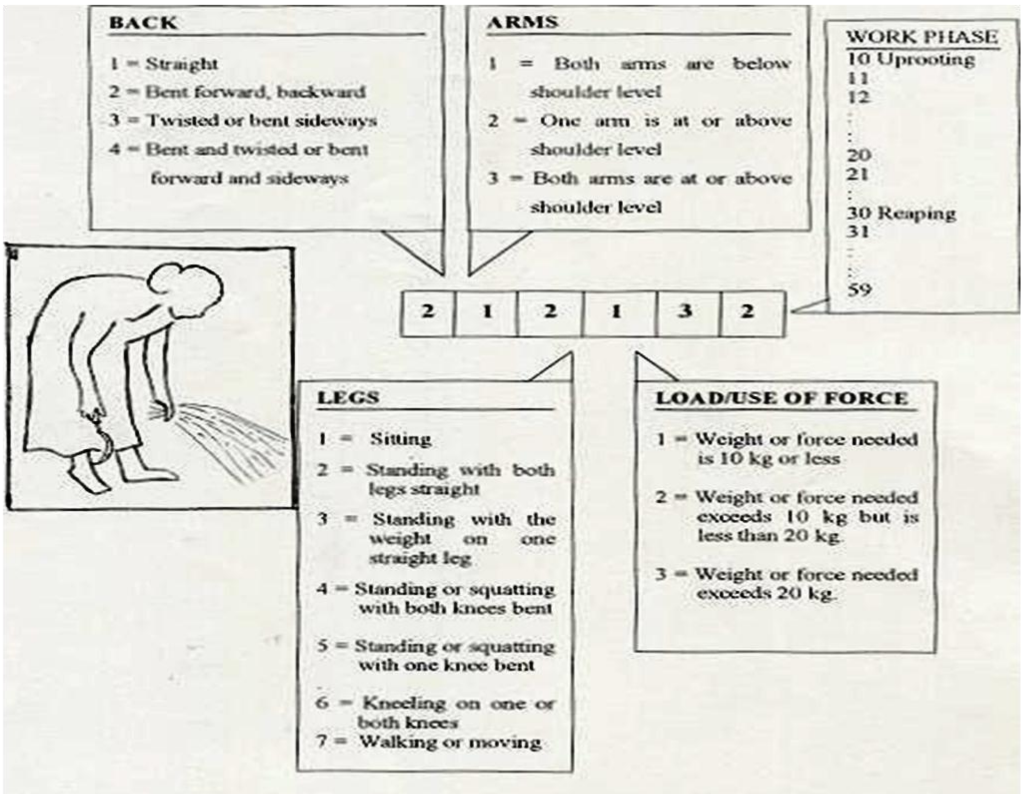
provided by Practical Ergonomics

This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in REBA.

rbarker@ergosmart.com (816) 444-1667

ANNEXURE-IV

OWAS Observation sheets



BACK	ARMS	1			2			3			4			5			6			7			LEGS
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	USE OF FORCE
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	
	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2	
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3	
	2	2	2	3	2	2	3	2	3	3	3	4	4	3	4	4	3	3	4	2	3	4	
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	2	3	4	
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1	
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1	
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	4	1	1	1	
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4	
	2	3	3	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4	
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4	

ACTION CATEGORIES

1. No corrective measures
2. Corrective measures in the near future
3. Corrective measures as soon as possible
4. Corrective measures immediately

ANNEXURE-V

Feasibility of Developed Head Load Manager (DHLM)

Sr. No.	**Statements**					
Musculoskeletal stress factors		SA	A	UD	DA	SDA
	I feel					
1.	I am able to maintain comfortable body posture at standing position while using DHLM. (+)					
2.	Too frequent shifts in the postures were needed while using the DHLM. (-)					
3.	Twisting of trunk while doing the activity was minimized with the use of the DHLM. (+)					
4.	Relieved of lifting the load on my head while using DHLM (+)					
5.	Movements of my hands were restrained while using head load manager. (-)					
6.	High contact stress of the frame on acromioclavicular joint causes pain in shoulders. (-)					
7.	Pressure on low back as DHLM was hurting on lower back. (-)					
8.	Short handles of DHLM resulted in awkward posture leading to pain in arms. (-)					
9.	Lesser discomfort in mid back region (+)					
10.	More discomfort at cervical region (-)					
11.	No pains & cramps in the lower region of my body after performing the activity. (+)					
Grip fatigue						
	I feel					
14.	Arms are less tired due to elimination of its extended posture (+)					
15.	Hands are more fatigued (-)					
Physical stress factors						
	I feel					
16.	Less tiredness while performing the activity with DHLM (+)					
17.	Less exhausted with DHLM (+)					
18.	The activity is light enough when I use the DHLM in comparison to existing method. (+)					
Work output						
	I feel					
19.	The DHLM is effective as per time cost. (+)					

20.	Output reduces while carrying load of high volume. (-)					
21.	Load can be carried comfortably for longer time. (+)					
Tool factors						
	I feel					
22.	The DHLM facilitated me to carry the load easily onto it. (+)					
23.	It is difficult to carry the DHLM on my back and shoulder.(-)					
24.	Size of the DHLM is not comfortable to fasten well to my body. (-)					
25.	Shape of the upper ring/ platform is not appropriate for keeping the load of high volume. (-)					
26.	Material used for DHLM is coarse & hard and hurting my body. (-)					
27.	The load was adjusted properly with DHLM. (+)					
28.	DHLM is not functional for carrying loads of cylindrical shape. (-)					
29.	It is drudgery to tie the DHLM with a cloth to keep it closer to the body. (-)					
30.	It is easy to attach and detach the DHLM to your body. (+)					
Acceptability						
	I feel					
32.	DHLM with modifications is a good replacement to the existing tool / technique. (+)					
33.	I shall possess the DHLM if available. (+)					
34.	Developed head load manager is costly (-)					

SA: Strongly agree, A: Agree, UD: Undecided, DA: Disagree, SDA: Strongly disagree

Gained score = Attained score / Max attainable score X 100

<40 Not Acceptable

40-60 Needs modification

60-80 Acceptable

80-100 Highly acceptable

ANNEXURE-VI

Assessment Sheet for Using the Developed Head Load Manager (DHLM)

Sr. No.	Statements	Strongly Agree	Agree	Disagree
	Relative Advantage			
1.	Provides more comfort while carrying heavy load			
2.	Reduces pain in the lower back and mid back			
3.	Pain in the arms and shoulders is reduced by using DHLM			
4.	Suitable for short and long distance			
5.	Heavy weight can be carried with comfort for longer duration			
6.	More comfortable as compared to the Conventional Method			
7.	DHLM can replace the traditional method of carrying the load			
8.	DHLM saves time and energy			
9.	DHLM can be used for multiple activities			
	Compatibility			
1.	It is based on the need of the user			
2.	DHLM is very portable friendly			
3.	DHLM is easy to wear			
4.	DHLM is light in weight			
5.	DHLM designed as per anthropometry of the user			
6.	The material used for DHLM is coarse & hard			
	Simplicity/ Complexity			
1.	DHLM functioning is easy to understand			
2.	Care and maintenance of DHLM is less cumbersome			
3.	There is difficulty in adjusting the upper part of the DHLM as per user requirement			
4.	DHLM can be used by every worker if it is provided by the contractor			
5.	Increases the efficiency of the worker			
	Practability			
1.	Body movement with the use of DHLM gets restricted			
2.	Less fatigue and exhaustion while carrying out the activity with DHLM			
3.	Efficiency is reduced while carrying bricks with the use of DHLM			
4.	It maintains body posture comfortably in standing posture			
5.	Suitable for carrying load up to 20kg			

ABSTRACT

Title of thesis	:	Development and Evaluation of Head Load Manager for Construction Workers
Full name of the degree holder	:	GARIMA YADAV
Admission Number	:	2015HS10D
Title of degree	:	Doctor of Philosophy
Name and address of Major Advisor	:	Dr. Kusum Rana Principal Extension Specialist, KVK-Jhajjar CCS HAU, Hisar-125004
Degree awarding university	:	CCS Haryana Agricultural University, Hisar
Year of award of degree	:	2019
Major subject	:	Family Resource Management
Total number of pages in thesis	:	**80 + vi + IX**
Number of words in abstract	:	**600**

Key words: Construction workers, Manual material handling, WMSDs, Ergonomic evaluation, Developed Head Load Manager

Women construction workers at construction sites are primarily involved in various unskilled tasks like cleaning building sites, carrying bricks, gravel, mortar and water up to the skilled masons. The present study was conducted on women workers at construction sites to indicate work complexity in actual field conditions and ergonomic assessment of existing ergo solutions to address their issues related to musculoskeletal disorders. In Phase I, work profile of 30 women workers of 20-40 years of age engaged in head load carrying activity was evaluated and their ergonomic assessment done by providing them with existing ergo solutions, viz. HLM, HLC, HLH. In Phase II, the problems reported in Phase I were utilized for designing and development of Head Load Manager with the help of simulating software ANSYS. In Phase III, ergonomic assessment of 30 women workers was done by providing them the modified Developed Head Load Manager. In Phase IV, feasibility testing of the Developed Head Load Manager was done with the help of modified Rogers and Shoemaker Scale and User Assessment Sheet. The study revealed that majority of the respondents were in the age group of 30-40 years (66.67%), married (63.33%), illiterate (60%), belonged to nuclear family (70%), and hailed from West Bengal (30%). Majority of the respondents (60%) were employed on daily basis. More than half of the respondents (60%) received wages in between ₹250-350, and 50% were getting their wages on daily basis. The WHR (120.14b/min) of the respondents before activity was significantly lesser than that observed with Conventional Method (137.67 b/min), HLC (132.80b/min), HLM (134.86b/min) and HLH (133.77b/min). On the other hand, RHR (107.51b/min) was also significantly lesser in comparison to the other methods with respect to grip strength of right hand. In Phase II, Stainless steel, Gray cast iron, and Aluminium alloy were compared to obtain a low cost, durable and lightweight product. A 3D model was created with the help of ZWCAD software and their strengths were compared with the help of ANSYS by applying a force of 98N, 196N, 294N, and 392N. All of them had an acceptable level of deformation and von Mises stress. Gray cast iron material was preferred in making the final product, as it was cheaper than stainless steel and Aluminium alloy. The product was modified to decrease the discomfort while carrying bulky load on head and was designated as Developed Head Load Manager (DHLM). During Phase III, ergonomic assessment was done on 30 respondents and a highly significant decrease was observed in WHR (12.79b/min), RHR (10.84b/min) and EER (2.03kJ/min). Oxygen consumption rate also decreased up to 23.25 percent with DHLM. TCCW and PCW decreased by 821.55 beats, 13.69 b/min while using DHLM. Grip strength of right hand (14.61%) as well as left hand (17.68%) were reduced after performing the activity with DHLM. There was a significant reduction in the discomfort at head, neck, shoulders, upper back, upper arms, mid- back, chest, lower arms, wrists, lower back, buttocks, thighs, knee, legs, and feet. On the basis of various attributes i.e. relative advantage, compatibility, simplicity/complexity and practicability, practicability got the first rank (2.31) followed by relative advantage (2.15), while compatibility and simplicity/complexity got the third rank (2.07) each. The DHLM was acceptable to the women workers as it was found easy to handle, reduced their physiological and biomechanical stress and contributed to reduce their overall discomfort while carrying heavy load on the head. The findings of the study shall be helpful for the manufacturers and product designers to develop a prototype DHLM on mass scale for the benefit of workers engaged in construction industry, thereby mitigating the incidence of occupational hazards.

MAJOR ADVISOR **DEGREE HOLDER**

HEAD OF THE DEPARTMENT

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B.Sc. (Home Science)	CCS HAU, Hisar, Haryana	2013	70.2	FN, HDFS, FRM, TAD, EECM

List of publications :

i. Yadav, G., Singh, K. 2015. Health status of female teachers and their coping strategies. National Conference On Women In 21st Century:Working Towards Empowerment. p. 32-34.

ii. Yadav,G., Singh, K., Rana, K.,Yadav,B. 2016. Health issues among women labourers at construction sites. *IJIRSET* **.5**(8).

iii. Yadav, G., Singh, K., Rana, K.,Mehta, M., & Mamta. 2016. Ergonomic assessment of women labourers in head load carrying activity at construction sites in Haryana. *IJHRM* .**5**(5).29-34.

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Papers presented:

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ii. Yadav, G. and Singh, K. 2015. Ergonomic Assessment of Women Labourers in Head Load Carrying Activity at Construction Sites, 13th International Conference on Humanizing Work and Work Environment, IIT, Mumbai, India (Dec 07-09, 2015).

iii. Yadav,G., Singh, K., Rana, K. 2016. WMSDs of Women Labourers in Head Load Carrying Activity at Construction Site in. 14th International Conference on Humanizing Work and Work Environment, NIT Jalandhar, Punjab, India (Dec 08-11, 2016).

iv. Yadav, G., Singh, K., Rana, K. and Yadav, B. 2017. Work-related health hazards of women labourers. International conference on Emerging areas of environmental science and engineering (EAESE - 2017) GJUS&T, Hisar, Haryana, India. February 16-18, 2017.

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GARIMA YADAV

UNDERTAKING OF COPYRIGHT

I **Garima Yadav,** Admission No. **2015HS10D** undertake that I give copyright of my thesis entitled,**" Development and Evaluation of Head Load Manager for Construction Workers"** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar.

I also undertake that the patent, if any, arising out of the research work conducted during the programme shall be filed by me only with due permission of the competent authority of CCS HAU, Hisar.

SIGNATURE OF THE STUDENT