Dissertation
on

Fractional Factorial Analysis of Lifting and Carrying Tasks to Determine the Effect of Different Parameters and their Interactions

Submitted in partial fulfillment of the requirement for
the award of degree of

MASTER OF ENGINEERING

in

CAD/CAM AND ROBOTICS

Submitted By

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DECLARATION

I hereby declare that the thesis entitled "***Fractional Factorial Analysis of Lifting and Carrying Tasks to determine the effect of different parameters and their interactions***" is an authentic record of my study carried out as requirements for the award of degree of **ME (CAD/CAM & Robotics)** at **Thapar University, Patiala**, under the guidance of **Dr. Ajay Batish,** Associate Professor, **Mr Anirban Bhattacharya,** Lecturer, Department of Mechanical Engineering, Thapar University, Patiala during **July 2007 to June 2008.**

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CONTENTS

ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) developed a lifting equation in 1981 to indicate ‘‘safe’’ occupational lifting limits. This equation was revised in 1991. The equation uses a series of lifting multipliers (parameters) to calculate corresponding recommended task weight limits. Due to the nature of risk factor interactions, the limits obtained from the NIOSH equation may not be appropriate for all lifting tasks. This laboratory experiment will examine the effect of lifting parameters and their interactions as follows: lifting frequency; vertical lifting distance; and load weight. In this simulation study, four different subjects were taken to lift the weights in different combinations of lifting parameters, in which different lifting frequencies, with different load weights and different vertical lifting heights (knee, waist, shoulder, and maximum reach) will be considered. The subjects will do symmetric lifting for a period in sagittal plane adopting free-style lifting technique. The recorded working heart rates will be normalized based on the maximum heart rate obtained during maximum aerobic power measurement. Then, stepwise linear regression analysis will be performed to identify the best predictive model using important parameters.

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ABBREVATIONS

MMH - Manual Material Handling

NIOSH - National Institute of Occupational Safety and Health

RULA - Rapid Upper Limb Analysis

MSD - Musculoskeletal Disorder

RWL - Recommended Weight Limit

ANOVA - Analysis of Variance

S/N - Signal to Noise ratio

DoF - Degree of Freedom

DOE - Design of Experiments

TMED - Taguchi Method of Experimental Design

HRE - Hormone Response Element

ACGIH - American Conference of Government Industrial Hygiene

WMSD - Work-related Musculoskeletal Disorder

NOTATIONS

SS	**-**	Sum of Squares
CI	**-**	Confidence Interval
CF	**-**	Correction Factor
OA	**-**	Orthogonal Array
A	**-**	Lifting Load
B	**-**	Frequency
C	**-**	Obstruction
D	**-**	Vertical Height
Su	-	Slope up
Sd	-	Slope down
No	-	No obstruction

CHAPTER 1: INTRODUCTION

1.1 Introduction

Manual material handling (MMH) creates special problems for different workers world wide. Labourers engaged in jobs which require lifting/lowering, carrying and pushing/pulling of heavy materials have increased the rates of musculoskeletal injuries, especially to the back. In developing countries, MMH is used in a very restricted sense. Mostly the apparent and well-established aspects of working conditions and work place design are being considered in industry. The reasons for the present state of affairs are many: lack of awareness both on the part of employers and employees, age old practices in vogue, resistance to and risk of change, lack of awareness about the benefits that will accrue, initial expenditure etc. are some of the probable reasons. It is generally accepted that there are three factors that affect the maximum acceptable weight an individual can carry: worker, task, and environment factors. Examples of worker factors include gender, age, and experience/training. Examples of task factors include carrying distance, frequency of load carrying, carrying positions, load orientation, object size, shape, and material. Examples of environment factors include temperature and confined space.

Manual materials handling (MMH) is the principle source of work injuries in our country. Statistics show that four out of five of these injuries affect the lower back. (About 70 to 80 percent of the adults at sometime during their life’s experience low back pain). It is most occurred among workers in their 30s and 40s at recurring intervals. According to the National Safety Council's 1992 Accident Facts, back injuries which account for 31 percent of all worker-compensation cases, are the top disabling worker injuries in the U.S. There were 5.2 million persons disabled by low back pain, among them 2.6 million were temporarily disabled, and the other half were chronically disabled (Frymoyer and Gorden, 1989). Although the total estimated cost attributed to low back pain varies from $16 billion to more than $ 50 billion, at least 85 percent of the total is caused by recurrent and chronic disability (Donajkowski, 1993).

The most frequent (36% of all claims) and costly (35% of total cost) category of compensable loss in the USA is manual materials handling (MMH) (Leamon and Murphy, 1994; Murphy *et al.,* 1996; Dempsey and Hashemi, 1999). MMH is also associated with the largest proportion (63–70%) of compensable low back disability claims (Snook *et al.,* 1978; Bigos *et al.,* 1986; Murphy and Courtney, 2000). A small percentage of the most costly low back claims (10%) are reported to be responsible for a large percentage of the total cost of low back claims (86%) (Hashemi *et al.,* 1997). Acceptable loads and limits in MMH have been analysed and established using a wide spectrum of techniques including physiological, biomechanical, subjective, observational, focus groups, psychophysical, postural analysis and a combination of the above (Kemper *et al.,* 1990; Kivi and Mattila, 1991; Waikar *et al.,* 1991; Burdorf *et al.,* 1992; Waters *et al.,* 1993; de Looze *et al.,* 1994; Winkel and Mathiassen, 1994., 2005). Many workplace factors have been found to be relevant to low back injuries. In general, a strong association has been found for repeated bending and twisting, as well as frequent heavy physical work. Twisting has been reported 9 to 18 percent of low back pain, bending in 12 to 14 percent.

In another study, it indicates that more than half of all compensable low back pain has been related to manual material handling task. Lifting has been involved in 37 to 49 percent of all cases, pushing 9 to 16 percent, pulling 6 to 9 percent, and carrying 5 to 8 percent. Moreover, some studies have related the handling of heavy loads to an increased incidence of low back injuries. For example, Chaffin and Park reported that the incidence of low back injury is increased when the load to be lifted is greater than 35 pounds (Chaffin and Park, 1973). In Luxembourg data from the association accounted for 2 % of occupational accidents reported (or 286 out of 15559 reported) of these 181 cases (or 78%) of back disorders involved lifting/lowering and carrying and another 26 cases (another 11%) resulted from pushing/pulling loads.

From an epidemiological perspective, the NIOSH "Work Practices Guide for Manual Lifting" (1981) cites, studies revealed that frequency rates (number of injuries per man-hour) and severity rates (number of hours lost due to injury per man-hour on job) of musculoskeletal injuries increase significantly when: (1) heavy objects are lifted and carried out, (2) the object is bulky, (3) the object is lifted from the floor, and (4) objects are frequently lifted. Therefore, the reduction of risk of such injuries has been of major concern to practitioners of occupational safety and health, federal agencies, insurance companies, and researchers. The best way to reduce the cost of injury is prevention from its occurrence. Therefore, it is important to find and understand the modalities that will most likely cause an injury so that they might be avoided.

Load carrying, a basic task executed by manual workers consists of lifting an object, carrying it through some distance and then putting it down, still remains an indispensable resource in many industrial operatios. Although load carrying is considered less risky for causing injuries than lifting, previous studies have found a high incidence of back injuries among workers whose job requires heavy carrying (Magnusson *et al.,* 1987; Noro 1967). Till date, numerous studies have been conducted on manual lifting. Studies on load carrying have been relatively few. So there is need to review carrying task.

1.2 Objectives and Issues

The National Institute for Occupational Safety and Health (NIOSH) developed a lifting equation in 1981 (Revised in 1991) to indicate ‘‘safe’’ occupational lifting limits. The equation uses a series of lifting multipliers (parameters) to calculate corresponding recommended task weight limits. Due to the nature of risk factor interactions, the limits obtained from the NIOSH equation may not be appropriate for all lifting tasks. It also provided analytical procedures to calculate recommended weight for specified two-handed, symmetrical lifting tasks in terms of action limit (AL), an approach for controlling the hazards of low back injury from manual lifting. In 1991, this lifting equation was revised, and the revised lifting equation retained all four multiplicative weighting factors used in 1981 (horizontal, vertical, distance, and frequency) and added two new factors (asymmetry and coupling) for a total of six multipliers. The relative magnitude of each multiplier indicates relative contribution of each task factor of RWL calculation (Waters *et al.,* 1994). The weightings are expressed as coefficients that serve to decrease the load constant, which represents the maximum recommended load weight under ideal conditions. Karwowski (1992) pointed that in NIOSH lifting equation the interaction effect of different multipliers calculated in multiplicative manner might not be appropriate for all lifting tasks to indicate the associated risk factors due to various kinds of interactions associated among risk factors. Dempsey and Fathallah (1999) also suggested that the interactions calculated from 1991 NIOSH equation were unlikely adequate to accommodate the effects of interactions. Lavender *et al.,* (2003) showed that peak L5/S1 moment was depended upon the interaction effect of lifting speed, initial lifting height and load weight. They also mentioned that NIOSH guidelines could not account the biomechanical spinal loading for low-lying object lifting, which was better fitted with consideration of interaction effects. The authors also emphasized that consideration of interaction effects could explain the co-contraction effects of different muscles that would be happening during lifting at higher frequencies and could provide better prediction. McKeana and Potvin (2001) mentioned the significant interaction effects of lifting parameters on trunk extensor muscle activity.

Maiti and Ray (2004) showed that after considering the interaction effect of lifting frequency and load weight on working heart rate provided a better predictive equation. These results suggest the importance of interaction effects, and it may not be sufficient to define the interaction effects as a mere multiplication factor.

Manual material handling (MMH) exposures are complex in nature. Jobs in a variety of sectors (e.g., manufacturing, service, transportation) often require workers to perform multiple types of MMH tasks and in different stress demanding situations. Therefore, the effect of these lifting parameters variations may better be explained in a separate study on the effect of interaction factors, which is not just a mere result as multiplication operation. In the present work, we plan to research the effect of interactions effect of these lifting parameters variations by using a parameterization approach as the effect of interaction factors, may not just be a mere result as multiplication operation. Therefore the purpose of the study is to evaluate the main effects of tasks, loads and heights, and their interactions during lifting and lowering operatios by using factorial analysis of variance. This factor analysis parameterization approach will be used to study the effects of various factors at appropriate levels and their interactions among variables. Plots of significant factors will be used to determine the best-fit relationship between the response and the model parameters.

1.3 Overall Methodology of the Study

The full factorial design is referred as the technique of defining and investigating all possible conditions in an experiment involving multiple factors while the factorial design investigates only a fraction of all the possible combinations. Although these approaches are widely used, they have certain limitations: (1) they are inefficient in time and cost when the number of the variables is large; (2) they require strict mathematical treatment in the design of the experiment and in the analysis of the results; (3) the same experiment may have different designs thus produce different results; further, determination of contribution of each factor is normally not permitted in this kind of design. The Taguchi method has been proposed to overcome these limitations by simplifying and standardizing the fractional factorial design. The methodology involves identification of controllable and uncontrollable parameters and the establishment of a series of experiments to find out the optimum combination of the parameters which has the greatest influence on the performance and the least variation from the target of the design.

Procedure for application of Taguchi method

The brief procedure of application of Taguchi method is as under:

- Establishment of objective function.
- Selection of factors and/or interactions to be evaluated.
- Identification of uncontrollable factors and test conditions.
- Selection of number of levels for the controllable and uncontrollable factors.
- Selection of the appropriate Orthogonal Array.
- Assignment of factors and/or interactions to columns.

- Execution of experiments according to trail conditions in the array.
- Analyse results.
- Confirmation experiment.

Establishment of objective function

The objective of the present work is to study the effect of main factors and the interactions effect of the identified lifting parameters such as Load Weight, Lift Frequency, obstructions en route and Vertical Lift Height. The main effects and the interactions effects will be studied to study the suitability of the NIOSH Lifting equation for analyzing various Manual Material Handling tasks. Therefore the purpose of the study is to evaluate the main effects of tasks, loads and heights, and their interactions during lifting and lowering operatios by using factorial analysis of variance.

The response function of the trial conditions would be Heart Rate, Blood Pressure, and Postural Analysis using RULA (Rapid Limb Upper Assessment)

1.4 Organization of the Thesis

The thesis has been divided into six chapters. Brief description of the contents of each chapter is as under:

Chapter 1 Introduces the manual material handling systems. Objectives and scope of the study and overall methodology adopted have also been briefly outlined.

Chapter 2 Covers an extensive literature review on the subject and its related areas. Literature review has been divided into the following categories:

1 .Manual Material Handling
2. Lifting Task
3. Lifting and Carrying Task
4. Analysis Using NIOSH lifting Equation
5. Any Other Method Repeated In Literature for Review of MH Tasks
6. Use of Design of Experiments (DOE) for Measuring Interaction Effect

Chapter 3 Discusses the design of the study, its phases and procedural steps. A brief description of the, methodology, tools and techniques used have been covered in this chapter.

Chapter 4 Presents the analysis and results of the experimental study done with four different subjects identified from the Thapar University workshop. Brief Results after Analysis of Variance (ANOVA) and plots are also outlined in this chapter.

Chapter 5 Covers the final analysis using Taguchi Signal to Noise Ratio conversion of data for each of the four subjects. The Signal to Noise (S/N) ratio consolidates several repetitions into one value which reflects the amount of variation present. The values of all the results according to Taguchi array parameter design layout are presented in this chapter.

Chapter 6 Summarizes the results of various ergonomic experimental studies described in Chapter 3, 4 and 5. This chapter synthesizes the broad findings of the study, results of the Analysis of Variance (ANOVA) and plotting analysis. It also presents the summary of results, conclusions of the study covering its usefulness, work done, areas explored and scope for further work.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Ergonomics is one of the most important concept because it is directly related to human safety in working environment. A comprehensive review of literature on diverse aspects of application ergonomics mainly (lifting and carrying tasks) is presented here. It helps to identify the area to be explored in further studies. Thrust areas of research and limitations of existing approaches are highlighted. Need for further research is explored.

2.2 Review of Literature

Ergonomics is now being recognized as a separate and vital subject in industrial working. It has a very wide domain ranging from physical factors like measurements to physiological, psychological and finally the human-human interactions. Each one of these areas has become a separate branch of study. Work is being done in all these areas. In India, however, very limited research is being carried out.

2.3 Categorization of Literature Review

The review of literature has been divided into following categories:

1 .Manual Material Handling
2. Lifting Task
3. Lifting and Carrying Task
4. Analysis Using NIOSH lifting Equation
5. Any Other Method Reported in Literature for Review of MH Tasks
6. Use of Design of Experiments (DOE) for Measuring Interaction Effect

2.3.1 Manual Material Handling

The emphasis on ergonomics in manual material handling (MMH) tasks arises from the potential risks of workplace accidents and injuries. The tasks include diverse activities such as lifting, lowering, holding, pushing, pulling, carrying, and turning of weights.

Gagnon Micheline (1990) evaluated two tasks (lifting and lowering) performed at five different heights (from 15 to 185 cm) with five different loads (from 3.3 to 22.0 kg).Cinematography techniques and two AMTI force platforms were used to collect the data. Dynamic and planar segmental analysis was performed to calculate the net muscular moments at the joints, and work was calculated from the integration of muscular power. Finally, the results revealed the deviation of height of handling from the waist level to be a significant factor. Handling at lower heights was considerably more demanding but the work was shared by several joints, mainly by the hips and lower back (about 70%) on the other hand, in handling above the waist, the work efforts were concentrated on the upper limbs (about 80%).

André Plamondon (1996) conducted a study to determine whether experts differ from novices in their handling strategies and to determine the effects of these differences in joint motions and net reaction moments at the trunk (L5/S1) and knees.The external forces were obtained from two AMTI force platforms, and two 16 mm Locam cameras coupled with two mirrors were used to obtain the three-dimensional kinematic data. Results showed that both groups minimized trunk asymmetries of posture and efforts; however, the experts' strategies appear safer overall because they reduce trunk asymmetry, asymmetrical efforts on the knee and stress on the femoropatellar joint.

St-Vincent (2004) conducted an ergonomic analysis of the job of stocker in a warehouse superstore. Manual materials handling activities are performed during an average of 74% of the work shift duration. During a shift, stockers perform an average of 200 handling operatios and the total average cumulative weight is 2000 kg. The merchandise handled is often fragile and unstable. The pallet jack, the stockers' only equipment, is used on average 54times during a work shift.

Denis (2005) carried out an ergonomic study in two warehouse superstores of a leading company. Results indicate that an imbalance between the amount of stock and the available storage space results in three types of consequences: (1) risk factors related to the development of musculoskeletal disorders (2) Increased risks of accidents, particularly related to loss of balance and falls from heights; and (3) Impacts on productivity and quality of service offered to customers in the form of time wasted, stock losses and customer dissatisfaction.

2.3.2 Lifting Task

The **NIOSH WPG (1981)** contained a summary of the lifting related literature before 1981; analytical procedures and a lifting equation for calculating a recommend weight for specified two handed, symmetrical lifting and an approach for controlling the hazards of low back injury from manual lifting.

Freivalds Andris (1981) developed a biomechanical model consisting of seven rigid links joined at six articulations for evaluation of the job-related stresses imposed upon a worker by means of reducing the high incidence rates of manual material handling injuries in industry. Results indicated effects of the common task variables. Larger load and box sizes increased the rise times and peak values of both vertical ground reaction forces and predicted L_5/S_1 compressive forces.

Ekholm Jan (1986) investigated the muscular load on the ankle and knee in 72 different packing work postures. The principle used was as follows; if the load moment about a joint is divided by the counteracting maximum muscular moment, a muscular strength utilization ratio (MUR) is obtained. The MUR was calculated for a large, an average-sized and a small man depending on whether they were all either strong, of mean strength, or weak, thus giving nine MUR values for each posture.

Genaidy (1988) generated ergonomic software that can be used in the design and evaluation of manual lifting tasks so as to minimize the risk of injury. Specifically, this study is aimed at developing a microcomputer-based model for the design and evaluation of frequent manual lifting tasks built upon the concept of job severity index. The microcomputer-based software package is intended to be used by non-experts in the field of manual materials handling. Possible engineering and administrative controls are implemented in the software if human lifting abilities are exceeded.

Granata (1995) demonstrated the influence of different types of lifting belts on trunk motion, muscle activity and spine loading during symmetric and asymmetric lifting exertions. In vivo measurements were achieved representing lifting dynamics, applied trunk moments. Dynamic spinal loads were determined from a validated biomechanical model of lifting. Dynamic trunk motions, lifting moments and modeled spinal loads were examined as a function of three belt styles (elastic, leather, and orthotic) and compared with results from a no-belt condition. Lifting belts reduced peak trunk angles, velocities and acceleratios in the sagittal, lateral and transverse planes. However, only the elastic belt successfully reduced trunk motions in all three dimensions.

Ayoub (1995) presented a two dimensional whole-body lifting simulation model. Computerized human motion simulation allows generation of dynamic human motions on computers. Biomechanical stresses can be estimated using the motions generated on a computer without actually collecting joint coordinate data. The model assumes that humans perform lifting activities based on minimization of physical work, subject to various constraints.

Larivière Christian (1996) evaluated the validity of two biomechanical dynamic three-dimensional (3D) multisegment models. Four cameras and two force platforms were used to get the data from 66 static and 108 dynamic trials. The triaxial net moments at L5/S1 of both models were compared. Good agreement was observed between the two models for the moments of the static tasks but great disparity was observed for the moments of the dynamic tasks (up to 78 Nm in extension). Both models were sensitive to different task parameters (movement or load asymmetry, movement rate, load magnitude).

Wang (1996) developed an automated system of evaluating the possible risk of low back injury in MMH task. The system applies computer vision technique to identify the working posture, then incorporating biomechanical model and anthropometric data to calculate the low back compression force. By comparing with the specified standard limits, the system can indicate the risk level of the task.

Zhan Xudong (1999) provided the description of a lifting strategy in qualitative terms. A quantitative static descriptor or index differentiates the starting postures but not the primary moving segments. This technical note proposes an index that quantitatively characterizes different dynamic postural strategies employed during sagittal plane lifting.

Larivi_ere Christian (2001) evaluated if chronic low back pain patients performed manual material handling tasks differently from control subjects. A 12-kg box was lifted (freestyle) from the floor to the hips (1) in front (symmetric task) or (2) to a shelf located at 90 degree on the right (asymmetric task) and was lowered back to the floor. A 3D biomechanical analysis involving the assessment of L5/S1 loading, posture of segments, inertial parameters, and EMG was performed. There was no difference between the groups for postural (trunk and lower limb angles), inertial (trunk velocity and acceleration), and L5/S1 loading (moments and compression) variables. The patients showed abnormally low left lumbar erector spine (symmetric task, lowering) or high left thoracic erector spine (all tasks) EMG activation.

Kollmitzer (2001) investigated effects of stance condition on postural control during lifting. Any voluntary motion of the body causes an internal perturbation of balance. Nineteen healthy subjects repeatedly lifted and lowered a load between a desk and a shelf. The base of support was varied between parallel and step stance. Ground reaction force and segmental kinematics were measured. In parallel stance postural response consisted of axial movements in the sagittal plane. Such strategy was accompanied by increased posterior shear forces after lift-off. Lifting in step stance provided extended support in anterior/posterior direction. The postural control mechanisms in the sagittal plane are less complex as compared to parallel stance. However, lifting in step stance was asymmetrical and thus accompanied by distinct lateral transfer of the body. Lateral shear forces were larger as compared to parallel stance. Both lifting techniques exhibit positive and negative aspects. We cannot recommend either one as being better in terms of postural control.

Allan Wrigley (2004) demonstrated the ability of principal component analysis to identify differences in lifting technique. Principal component analysis was applied to sixteen kinematic and kinetic waveforms describing the two-dimensional motion of the trunk and load. The principal component scores for each variable were used as the dependent measures in a one-way ANOVA to determine group differences. Significant group differences ($p < 0.05$) were found for five of the principal component scores capturing associated kinematic waveform patterns related to the control and placement of the box on the shelf, and associated kinetic waveform patterns related to the relative timing of extension moment generation in the sacral and thoracic regions. Principal component analysis was able to identify important biomechanical differences where traditional analysis failed.

Shin Gwanseob (2005) examined the responses in trunk kinematics and ground reaction forces of older and younger subjects during lifting. Age-related changes in trunk kinematics in lifting have received little attention despite a documented increased risk of musculoskeletal injury with age. A lumbar motion monitor was used to measure the subjects' trunk kinematics and a force platform was used to measure the ground reaction forces during the lifting motion. The results of this study showed that age had a significant ($p<0.05$) effect on the transverse plane (axial twisting) trunk kinematics variables (peak velocity and peak acceleration) but did not affect ground reaction forces or other trunk kinematics variables.

Ciriello Vincent M. (2005) studied the effects of high frequency (20 lifts/min) on MAWs (maximum acceptable weights) of lifting. The results confirmed that MAWs of lifting with the large box was significantly affected by frequency. The effects of lifting with an extended horizontal reach decreased MAW 22% and 18% for the mid and center lift and the effects of the 20 lifts/min frequency resulted in a MAW that was 47% of a 1 lift/min MAW. Incorporating these results in future guidelines should improve the design of MMH tasks for female workers.

Reisera Raoul (2006) determined the effects of lifting from a sloped floor surface (both facing up and down) on the lumbar region and compare with the level surface. Secured in a milk crate, the men lifted 25 kg while the women lifted 15 kg. A top-down inverse-dynamics model calculated the net moment at L5/S1.Subject-selected foot placement relative to the crate was significantly affected by lifting condition ($p<0.001$) with subjects tending to stand further from the load as slope changed from down hill to up hill. Maximum L5/S1 moments were not affected by lifting condition ($p= 0.330$). However, the static contribution from mass location significantly increased when facing up hill ($p<0.001$).

Maduri (2006) described two regions of spine motion, a neutral zone where lumbar rotation can occur with little resistance and an elastic zone where structures such as ligaments, facet joints and intervertebral disks resist rotation. In vivo, the passive musculature can contribute to further limiting the functional neutral range of lumbar motion. Movement out of this functional neutral range could potentially put greater loads on these structures. In this study, the range of lumbar curvature rotation was examined in twelve healthy, untrained volunteers at four torso inclination angles. The lumbar curvature during straight-leg lifting tasks was then defined as a percentage of this range of possible lumbar curvatures. Subjects were found to remain neutrally oriented during the flexion phase of a lifting task.

2.3.3 Lifting and Carrying Task

Louhevaara Veikko (1989) simulated the local muscle and circulatory strain in manual handling, continuous parcel lifting, carrying and holding tasks in the laboratory. Heart rate, blood pressure and the overall RPE indicated that average circulatory strain in the tasks was low. Strain was significantly higher during lifting than holding, and the difference was accentuated if a subject used the leg lift technique. There were only few differences in local and circulatory strain due to sex.

Andres Robert (1991) developed a sagittal plane dynamic model to predict L5/S1 compressive force and required coefficients of friction during dynamic cart pushing and pulling. Predicted ground reaction forces were compared with those measured by a force platform, with correlations up to 0.67. Predicted erector spine and rectus abdomens' muscle forces were compared with muscle forces derived from RMS-EMGs of the respective muscle groups, using a static force build-up regression relationship to transform the dynamic RMS-EMGs to trunk muscle forces. Although correlations were low, this was attributed in part to the use of surface EMG on subjects of widely varied body mass. The biodynamic model holds promise as a tool for analysis of actual industrial pushing and pulling tasks, when carefully applied.

de Looze (1996) studied the effect of weight and inversely related frequency on spinal load in two bricklaying tasks: building the skin and the floor of a steel ladle. No differences in integrated compression were observed among four out of five combinations of weight and frequency (both in skin and floor building).

Kirkeskov Jensen Lilli (2004) measured the effect of a participatory ergonomics implementation strategy consisting of information, education, and facilitation on the use of new tools and working methods in the floor laying trade. There was a reduction in the degree of self reported pain in the knees among the floor layers using the new working methods weekly or daily compared to those using them never or occasionally. The musculoskeletal complaints did not increase from any other region and the quality and the productivity of the work were not decreased.

Plamondona Andre (2005) presented a study on **"**In-the-hole (ITH) drilling" a heavy repetitive mining task, which has been identified as having a relatively high incidence and severity rate of musculoskeletal injuries. The purpose of this study was to examine how the load experienced by ITH drill operators changed when lifting a vertical drilling rod (1.61 m,35 kg) using two rod heights and four different foot positions. It was found that the vertical height of the rod had the most significant impact on back loading, while the effect of the initial foot positioning relative to the rod was limited by the technique adopted by the drillers. Moreover, it was found that some of the subjects used techniques less strenuous for the back than others. Finally, the asymmetrical lifting component was found to be the most negative aspect of lifting an ITH drill rod compared to a standard symmetrical lift (NIOSH).

Swei-Pi Wu (2005) examined the effects of container width, carrying rate, and distance on the maximum acceptable weight carried (MAWC) and the resulting responses (heart rate and rating of perceived exertion) to a 1-h work period of carrying tasks. The results obtained lead to the conclusions; the container width significantly affected the MAWC, heart rates and overall RPE values. Although the heart rates increased with the container width, the MAWC and the overall RPE values did not decrease with the container width.

Hoozemans Marco (2006) quantified the relative effect of the magnitude and direction of the exerted push force and of trunk inclination on the mechanical load at the low back using a regression analysis for correlated data. Results show that the magnitude and direction of the exerted push force and the trunk inclination significantly and independently affect low back load. It is concluded that for the ergonomic evaluation of pushing tasks, the inclination of the trunk should be considered, in addition to the magnitude and direction of exerted forces.

Songa Young (2006) suggested, when three axial (isometric) complex moments were applied, 'extension + lateral bending right + twisting counter-clockwise' induced high co activation of about 349N (about 50% of the total muscle force), and the magnitude of the antagonistic moment was 21.9Nm (about 41% of the external moment).Results from this study will be useful for diagnostic, preventive, and rehabilitative purposes in the analysis of manual materials handling tasks.

Raisona (2006) developed a human body model that permitted a non-invasive determination of the joint efforts produced by a seated subject performing maximum ramp pushing efforts. The joint interactions during these experiments were provided by a dynamic inverse model of the human body, using symbolically generated recursive Newton–Euler formalism. The theoretical investigation was presented in two steps, with increasing complexity and relevance:

1. Quasi-static analysis: this approximates internal joint efforts, using static equations at each sample, without taking the postural chain dynamic effects into account.
2. Dynamic analysis: this takes the dynamic effects into consideration and thus presents the advantage of a more relevant description of the motion as well as a more accurate determination of the forces and torques produced at each joint during the transient effort.

Gheldof Els (2006) conducted the study on the role of work-related physical factors and psychological variables in predicting the development of and recovery from short-term and long-term LBP. Odds ratios (ORs) were calculated using simple or multiple logistic regression analysis and categorized result (LBP, high pain severity) according to OR, CI.

Liu Bor-Shong (2007) suggested that the effect of walking speed was strongly significant for all physiological indices (MANOVA results). In addition, as might be expected, there was a significant interaction between load position and walking grade on oxygen consumption. However, carrying heavy loads close to the trunk can affect lung function. Thus, load placement is an important factor in physiological response to load carriage, and optimum choice of upper or lower position when distributing items in a backpack may be dependent on the walking grade.

2.3.4 Analysis of Lifting Tasks using NIOSH Lifting Equation

The National Institute for Occupational Safety and Health (NIOSH) developed a lifting equation in 1981 to indicate ‘‘safe’’ occupational lifting limits. This equation was revised in 1991. The equation uses a series of lifting multipliers (parameters) to calculate corresponding recommended task weight limits. Due to the nature of risk factor interactions, the limits obtained from the NIOSH equation may not be appropriate for all lifting tasks.

Lee Kwan (1994) performed the psychophysical experiment and the validation experiment in sagittal plane where lifting frequency and lifting height varied. Young male college students and field workers participated in the experiment. The load constant obtained in this investigation was about the same as the one recommended in the NIOSH equation, which means that young, healthy, Korean males are well protected by the NIOSH equation.

Russell Steven (2004) compared the results of the NIOSH, ACGIH TLV, Snook, 3DSSPP and WA L&I lifting assessment instruments when applied to a uniform task (lifting and lowering milk cases with different capacities).The reasons for instrument differences are presented so that practitioners can better select the methods they need and interpret the results appropriately.

Saurin Tarcisio Abreu (2005) presented an ergonomic assessment on the operation of two types of suspended scaffolds (traumatic type injuries). They are referred to as light scaffold and heavy scaffold—the difference lying in their dimensions a number of gears. The assessment criteria were: workers’ perceptions of effort; body posture assessment (OWAS method); heart rate elevations (HRE); percentage of the available heart rate range (PHRR); scaffolds’ speed and, repetitiveness of movement in the scaffolds’ levers. For instance, HRE was 52 beats per minute (bpm) and PHRR was 50.7% on average for workers operating the light scaffold. Concerning the heavy scaffold, HRE was 45 bpm and PHRR was 42.2% on average. All of those values are substantially higher than the acceptable limits of 35 bpm for HRE and 33% for PHRR proposed in the literature. Failures in the scaffolds' design as well as the lack of attention directed towards ergonomics in regulations were determined to be relevant root causes for detected poor working conditions.

Ciriello Vincent (2005) investigated maximum acceptable initial and sustained forces while performing a 7.6m pushing task at a frequency of 1 per minute on a magnetic particle brake treadmill versus pushing on a high-inertia pushcart. The results revealed that the maximum acceptable sustained forces of pushing determined on the high inertia cart were significantly higher (21%) than the forces determined from the magnetic particle brake treadmill. These results were countered by an 18% decrease in maximum acceptable forces for the criterion magnetic particle brake treadmill task, perhaps due to secular changes in the industrial population.

Jones (2006) compared and examined some facts:

(1) Compared the results of 5 ergonomic risk assessment methods calculated with quantified physical exposure information,

(2) Examined the effect of multiple definitions of the posture and exertion variable on the risk assessment methods,

(3) described the variability in risk assessment scores between workers,

(4) Examined the ability of risk assessment component scores to differentiate between facilities with significantly different levels of exposure, and

(5) Examined the association between risk output and recorded incidence rates.

(6) Quantified physical exposure information was used to calculate the RULA, REBA, ACGIH TLV, Strain Index and OCRA procedures based on multiple posture and exertion variable definitions. Posture and exertion variable definition was observed to have a significant effect on the component scores and/or risk output of all methods assessed. Meaningful variability in risk assessment scores was observed between workers. Components of all assessments, with the exception of the ACGIH TLV, differentiated between facilities assessed. Average risk index scores of the SI and OCRA procedures were observed to increase as recorded incidence of injury increased; however statistical significance was not demonstrated.

Bagchi Tapan (2006) examined the effect of lifting parameters and their interactions as follows: lifting frequency, vertical lifting distance, and load weight. The recorded working heart rates were normalized based on the maximum heart rate obtained during maximum aerobic power measurement. MANOVA result showed that the main effects were significantly ($p<0.0001$) related with normalized working heart rate and the interaction effects of different lifting parameters contributed 10.01% of total variance of normalized working heart rate. Factorial design was applied to verify the interaction effects.

Pennestrı (2006) presented a musculo-skeletal model of the upper limb. The limb is modeled as a three-dimensional 7 degrees-of freedom system, linked to the shoulder, which has been considered as frame. The upper limb model is made up of four links corresponding to the most important body segments: the humerus, the ulna, the radius and the hand, considered as a single rigid body. Particular attention has been paid to the modeling of joints in order to mimic all the possible arm and forearm movements (including prono-supination). The model also includes 24 muscles. The kinematic analysis has been performed including an ergonomics index to take into account the posture and joint physical limits. Moreover an optimization criterion based on minimum activation pattern has been included in order to find muscular activation coefficients. The results of the proposed methodology concerning muscular activations have been compared to those coming from processed EMG signals, which have been acquired during experimental tests.

2.3.5 Other Methods Reported in Literature for Review of MH Tasks:

Devadasan (2003) provided a modified orthogonal array-based model for enabling the researchers and practitioners to exploit the technique, “design of experiments” in an agile manufacturing environment. The characteristics of Taguchi’s off-line models and agile manufacturing were studied. A theoretical model of modified orthogonal array-based experimentation was designed.

d’Errico Angelo(2004) interviewed a cohort of automobile manufacturing employees at baseline, one and six years later about work history, physical and psychosocial exposures at work, upper limb symptoms, injury and medical history, and demographics. Differences in exposure between 1- and 6-year follow-up were analysed by Wilcoxon matched-pairs signed-ranks test. Large and significant decreases in work pace and physical effort were observed from baseline, although an upper extremity composite index was quite stable in the total population. One-year test–retest reliability was fair to good for the composite exposure index (ICC = 0.58), whole-body vibration, handling parts, and tool use, but poor for the other variables considered.

Yeowa Paul (2004) applied the effectiveness of ergonomics in reducing rejection cost of the manual component insertion (MCI) lines in a printed circuit assembly (PCA) factory.

Kogi Kazutaka (2006) reviewed participatory methods for ergonomic workplace improvement. The review covered participatory programmers for managers and workers in small enterprises, home workers, construction workers and farmers. To meet diversifying ergonomic needs, participatory steps reviewed are found to usually follow a good-practice approach easily adjustable according to local needs and focus on low-cost improvements. Typical areas include materials handling, workstation design, physical environment and work organization.

Cooper (2006) carried out a detailed analysis of the loads applied by the ambulance workers when loading/unloading ambulance stretchers. The postures and forces exerted by the ambulance workers are analysed using biomechanical assessment software to examine if the work loads at any stage of the process are harmful. Kinetic analysis of each stretcher loading system is performed. Comparison of the kinetic analysis and measurements shows very close agreement for most of the cases. The force analysis results are evaluated against derived failure criteria.

Davida Geoffrey (2006) developed the Quick Exposure Check (QEC, an observational tool) to assess exposure to risks for work-related musculoskeletal disorders and provided a basis for ergonomic interventions. The tool is based on epidemiological evidence and investigations of OSH practitioners' aptitudes for undertaking assessments. It has been tested, modified and validated using simulated and workplace tasks, in two phases of development, with participation of 206 practitioners. The QEC allows the four main body areas to be assessed and involves practitioners and workers in the assessment.

Escorpizo Reuben (2006) presented a conceptual model of work productivity—within the area of paid work and within the context of work-related musculoskeletal disorders

(WMSD) and discussed the two sub components of work productivity (absenteeism and presenteeism). An accurate measurement of work productivity is crucial to initiating, evaluating, and monitoring work disability management like employee wellness and ergonomics programs, and clinical interventions in WMSD.

Santos Javier (2006) suggested Modeling and 3D simulation tools could help to improve ergonomics in Small and Medium Enterprises (nonrepetitive manufacturing processes).

Linda To (2006) developed a corporate model for ergonomic assessment and improvement. The model is unique as it is intended to be used by production engineers and safety representatives in cooperation (Volvo Sweden). The process for assessment of musculoskeletal risks is standardised and participatory, which also supports identification of solutions. Interviews, questionnaires, observation and document studies were used to evaluate the use of the model. The model was found to improve participation and collaboration among stakeholders; provide a more effective ergonomic improvement process; visually represent the ergonomics situation in the company; and give legitimacy to and awareness of ergonomics.

Vink Peter (2006) focused on the positive aspects of ergonomics in improvement of the working environment. It consists of a part that studies the literature on success factors in the process towards higher productivity and greater comfort, the formulation of a model and a hypothesis, which is illustrated by four cases. The model distinguishes the success factors in ‘goal’, ‘involvement’ and ‘process’. Goals: evidence is found in the literature that a positive approach has benefits in terms of shareholder value and productivity, and for comfort. Involvement: the literature shows that participation of end-users and management contributes to success. Process: in the process it is essential to have a good inventory of the problems, a structured approach, a steering group responsible for the guidance, and end-users involvement in testing of ideas and prototypes.

2.3.6 Use of Design of Experiment for Measuring Interaction Effect

Lewandowski Henry (1989) presented a computer program that addresses the need for an automated system able to design the experimental matrices for the orthogonal arrays that are required by Taguchi's Method. The program was written to design simple arrays as well as complex multi-level arrays with two-way interactions.

Hefin Rowlands (2000) presented the results of the application of the Taguchi method for optimizing the production process of retaining a metal ring in a plastic body in a braking system.

Antony Jiju (2001) presented a step by step approach to the optimization of production process (of retaining a metal ring insert in a plastic body by hot forming method) through the utilization of taguchi methods of experimental design. The experiment enabled the behavior of the system to be understood by the engineering team in a short period of time and resulted in significantly improved performance.

Jiju Antony (2005) proposed methodology Taguchi Method of Experimental Design (TMED) to optimize the three responses for a double-sided surface mount technology of an electronic assembly. Multiple signal-to-noise ratios are mapped into a single performance statistic through neuro-fuzzy based model, to identify the optimal level settings for each parameter. Analysis of variance is finally performed to identify parameters significant to the process. It can be applied to those areas where there are large data sets and a number of responses are to be optimized simultaneously.

Antony Jiju (2006) provided an excellent resource for those people who are involved in the design optimization of a new product with the help of an application of Taguchi method of experimental design (TMED). The optimal settings of the critical design parameters are determined. The optimal settings have resulted in increased customer satisfaction, improved market share and low defect rate in the hands of customers. Manufacturers may use this method to optimize processes (either design or manufacturing) without expensive and time-consuming experimentation.

CHAPTER 3: EXPERIMENTAL DESIGN

Manual material handling (MMH) exposures are complex in nature. Jobs in a variety of sectors (e.g., manufacturing, service, transportation) often require workers to perform multiple types of MMH tasks and in different stress demanding situations. Load lifting and carrying, a basic task executed by workmen engaged in manual material handling consists of lifting an object, carrying it through some distance and then putting it down, still remains an indispensable resource in many industrial operatios.

To evaluate the main effects of factors like load weight, frequency of lift, carrying distance, and heights, and their interactions during lifting and lowering operatios factorial analysis of variance with repeated measures on some important response variables has been used in this study. This factorial analysis is used to discover the simple patterns of different factor effects and their interactions among variables. In present study, different statistical procedures were applied to indicate the quantitative contribution of individual lifting parameters as well as their interaction effects for certain response conditions such as heart rate, blood pressure and posture Rapid Upper Limb Analysis (RULA) score.

In the present work, the effect of various factors of these lifting parameters variations and their interactions were studied using a parameterization approach developed by Taguchi. Experimental design based on Taguchi methodology is a powerful and effective approach to achieving this goal.

3.1 Experimental Details

Four male workers, having at-least seven years of working experience in an engineering workshop participated in laboratory simulation study. They were selected with no history of chronic or acute illness, not having hypertension or any other major health issues, and not under any prescribed medication. They were instructed not to take any stimulant for at-least 2 hours prior to participate and throughout the experiment. The subjects were clothed in their traditional dress as they regularly do in their place of work. Demographic records of the subjects are given in Table 3.1.

Table 3.1: Demographic records of the subjects

Age (years)	Height (cm)	Body Weight (Kgs)	Knee Height (cm)	Waist Height (cm)	Shoulder Height (cm)
35 ± 5	172 ± 5	70 ± 10	72 ± 5	110 ± 5	148 ± 5

3.2 Experimental set-up

The effect of four different lifting and carrying parameters (viz. lifting frequency, load weight, obstructions en route and vertical lifting distance) was studied in a laboratory simulation condition. In this study the effect of four different lifting frequencies (30, 35 and 40 per every 30 minutes), three load weights (13, 18 and 23 kg), obstructions en route (no obstruction, slope up, slope down) and three vertical lifting heights (knee, waist, and shoulder) were considered as treatments. The maximum reach point was identified as the highest location to which the subject could lift the load without hyper-flexing the body, and generally it was near the eye–ear line level. The other lifting parameters like horizontal distance of 25 cm, origin of lift at ground level, etc., were kept constant (Table 3.2). The subjects were doing sagittally bi-symmetric lifting following free-style posture. The container, used by the subject during lifting was rectangular shaped with steel wire rod grip, made up of GI sheet. A mixture of student jobs used in the University Workshop was used as the load material for this experiment. The container and the load material were the same as used in the field. In this study, a 30 min work period was allotted based on a pilot study done in the laboratory, and this was decided as the subject’s maximum performance level at the highest work stress condition. One hour respite breaks were given between two sets of experiments, to fully recover the previous work-stress. The subjects relaxed during this break either by sitting on a chair or walking a few steps. For this study, an experimental space was created inside the welding shop of the Thapar University Workshop. The laboratory experiment generally started in the morning till about the lunch time. The sequences of modes of lifting were selected randomly keeping the higher workloads before longer breaks to avoid previous work-stress effects onto the next workload. The heart rate, blood pressure and Rapid Upper Limb Analysis (RULA) score (posture at origin of lift) were considered as the response variables.

Table 3.2: Description of different Lifting Parameters used in the Lab study

S.No.	Lifting Criteria	Magnitudes/Types
1	Nature of Loading	Sagittally symmetric
2	Nature of Lifting	Free style
3	Origin of Lifting	Ground
4	Carry Distance	30 feet
4	Horizontal Distance	25 centimeter
5	Nature of Coupling	Round steel wire grip
6	Container Type	Rectangular – GI sheet container

3.3 Factors of Interest and their levels with ranges

By brainstroming through a cause and effect diagram, the list of factors of interest that may have an impact on the heart rate, posture and blood pressure were identified (See Table 3.3). Some of the factors were set as constant charateristics during the experimental study while the following major factors were varied each at three different levels.

Table 3.3: Control Factors and there Levels

Factor	Levels			
	Unit	Level-1	Level-2	Level-3
Load Weight, A	Kg	13	18	23
Frequency, B	No/30min	30	35	40
Obstructions enroute C		No	Slope Up	Slope Down
Vertical Height, D		Knee	Waist	Shoulder

It was also decided to study the effect of following interactions between the main factors.

- Load vs. Frequency (A x B)

- Load vs. Vertical Height (A x D)
- Frequency of Lift vs. Vertical Height (B x D)

In the present experiment each subject carried three different loads with varying frequencies and with the following levels of obstructions en route:

- **NO OBSTRUCTION**- No obstructions en route
- **SLOPE UP-** With an 30^0 upward angle of inclination with the floor level.
- **SLOPE DOWN-** With an 30^0 downward angle of inclination with the floor level

The subject was required to grasp the load weight container from the ground level using free style lifting technique and place it at the distance as the trail treatment conditions. The experiment was conducted in the welding shop of the Central Workshop of Thapar University Patiala. The obstructions en route were designed to meet the experiment requirement.

3.4 Establishment of objective function

The objective of the lifting and carrying task optimization was to determine the best set of the parameters of the lifting task to exert the lowest stress on the workmen to minimize the risk of subsidence. The stress state of the workmen heart rate, blood pressure, and posture (RULA) score were used as the output for the Factorial Experimental analysis to describe such tasks.

3.5 Design of Experiments and Selection of Orthogonal Array System:

Degrees of Freedom (dof):

The selection of which Orthogonal Array to use depends upon:

1. The number of factors and interactions of interest
2. The number of levels for the factors of interest

Dof for each factor is (Say factor A, Load Weight)

$$v_A = k_A - 1$$

Where k_A is the number of levels of factor A

Dof for interaction is (Say factor A and B)

$$v_{A\times B} = (v_A)(v_B)$$

The interactions studied in the present experiment are as follows;

1. A x B - Lift Load, Frequency
2. A x D - Lift Load, Vertical Height
3. B x D - Frequency, Vertical Height

The minimum required dof in the experiment is the sum of all the factor and interaction dofs. In the present experimental setup there are three levels for all four factors. The number of degree of freedom associated with these four factors and three two-level interactions are 20 as shown in Table 3.4. As the degree of freedom required for the experiment is 20 so the orthogonal array that is to be selected should have degree of freedom higher than 20. The most suitable orthogonal array that can be used for this experiment is L27. The degree of freedom due to error contribution is six for this experiment.

Table 3.4: Degree of Freedom

Factor	A	B	C	D	A x B	A x D	B x D	TOT
Degree of Freedom	2	2	2	2	$2\times2=4$	$2\times2=4$	$2\times2=4$	20

3.6 Orthogonal Array

The assignment of main factors and the desired interactions could be easily done by using Linear Graphs or Triangular Tables. In this experiment, the assignment of factors and interactions was carried out using MINITAB. The treatment conditions as suggested by MINITAB using Taguchi Linear Graphs for this particular experiment are listed in Table 3.5.

Table 3.5: Subject Analysis Table

S.NO	Lift Load(A)	Frequency (B)	Obstructions (C)	Vertical Height(D)	RULA Score	Heart Rate-after	BP-Systolic
1.	13	30	No	Knee			
2.	13	30	Slope down	Waist			
3.	13	30	Slope up	Shoulder			
4.	13	35	No	Waist			
5.	13	35	Slope down	Shoulder			
6.	13	35	Slope up	Knee			
7.	13	40	No	Shoulder			
8.	13	40	Slope down	Knee			
9.	13	40	Slope up	Waist			
10.	18	30	Slope up	Knee			
11.	18	30	No	Waist			
12.	18	30	Slope down	Shoulder			
13.	18	35	Slope up	Waist			
14.	18	35	No	Shoulder			
15.	18	35	Slope down	Knee			
16.	18	40	Slope up	Shoulder			
17.	18	40	No	Knee			
18.	18	40	Slope down	Waist			
19.	23	30	Slope down	Knee			
20.	23	30	Slope up	Waist			
21.	23	30	No	Shoulder			
22.	23	35	Slope down	Waist			
23.	23	35	Slope up	Shoulder			
24.	23	35	No	Knee			
25.	23	40	Slope down	Shoulder			
26.	23	40	Slope up	Knee			
27.	23	40	No	Waist			

3.7 Measurement System

The heart rate and blood pressure was measured using a hand device available in the market. The RULA score for postural analysis was measured using the 'ErgoMaster' software available in the Laboratory. Other equipment used for the experiment included stop watch and a measuring tape.

3.8 Performing the Experiment

The first step in the experiment is to lift the load from the origin on horizontal plane and carry it to a destination 30 feet away. The treatment conditions were completely randomized to eliminate any sources of bias creeping into the experiment. In all 27 trials for each subject were conducted for analysis purposes.

3.9 Analysis of results

The values of all the results according to Taguchi array parameter design layout are presented in Chapter 4 and 5.

Signal-to-noise ratio. The Taguchi method uses the signal-to-noise ratio (S/N) to express the scatter around a target value. A high value of S/N implies that the signal is much higher than the random effects of the noise factors. The noise is usually due to the uncontrollable factors, which exist in the environment, often cannot be eliminated and cause variations in the output. Hence, in the context of this study, the noise is attributed to different subjects used for experimental analysis.

From the quality point of view, there are three possible categories of the quality characteristics. They are:
(1) Lower is better (LB);
(2) Nominal is better (NB);
(3) Higher is better (HB)

In this design situation, the heart rate and blood pressure changes is the type of ‘‘lower is better’’, which is a logarithmic function based on the mean square deviation (MSD), given by

$$S/N_{LB} = -10\log(MSD) = -10\log[(\frac{1}{r}\sum_{i=1}^{r} y^2{}_i)$$

Where r is the number of tests in a trial (noise of repetitions regardless of noise levels)

$\sum_{i=1}^{r} y^2{}_i$ = summation of all response values under each trial

Computation of average performance:

Average performance of a factor at certain level is the influence of the factor at this level on the mean response of the experiments. To compute the average performance of the factor A at level 1 (denoted as A1), results for trials including factor A1 were added and then divided by the number of such trials:

Analysis of variance

The knowledge of the contribution of individual factors is critically important for the control of the final response. The analysis of variance (ANOVA) is a common statistical technique to determine the percent contribution of each factor for results of the experiment. It calculates parameters known as sum of squares (SSs), pure SS, degree of freedom (Dof), variance, F-ratio and percentage contribution of each factor. Since the procedure of ANOVA is very complicated and employs a considerable of statistical formulae, only a brief description is given as following:

The Sum of Squares (SS) is a measure of the deviation of the experimental data from the mean value of the data. The total deviation equals SS of all results minus correction factor (CF), are expressed as:

Before the test data is collected some notation in order to simplify the mathematical discussion is:

Let ‘A’ be a factor under investigation

$$SS_T = \sum_{i=1}^{N} (y_i - \overline{T})^2$$

Where N = Number of response observations, $\overline{T}$ is the mean of all observations y_i is the i, *th* response

Factor Sum of Squares (SS_A) - Squared deviations of factor (A) averages from overall average

$$SS_A = \left[\sum_{i=1}^{k_A} \left(\frac{A_i^2}{n_{Ai}} \right) \right] - \frac{T^2}{N}$$

Where

A_i =Average of all obseravtions under A_i level = A_i / n_{Ai}

T = sum of all observations

$\overline{T}$ = Average of all observations = T / N

n_{Ai} = Number of obsernations under A_i level

k_A= Number of levels of factor A

Error Sum of Squares (SS_e) - Squared deviations of observations from factor (A) averages

$$SS_e = \sum_{j=1}^{k_A} \sum_{i=1}^{n_{Ai}} \left(y_i - \overline{A}_j \right)^2$$

Orthogonal Arrays (OA) plays a critical part in achieving the high efficiency of the Taguchi method. OA is derived from the full factorial design of the experiment by a series of very sophisticated mathematical algorithms, finite fields, geometry and error-correcting codes. The algorithms ensure that the OA to be constructed in a statistically independent manner that each level has an equal number of occurrences within each column, and for each level within one column, each level within any other column will occur an equal number of times as well. Then, the columns are called orthogonal to each other. OA's are available with a variety of factors and levels in the Taguchi method. Since each column is orthogonal to the others, if the results associated with one level of a specific factor are much different at another level, it is because changing that factor from one level to the next has a strong impact on the quality characteristic being measured. Since the levels of the other factors are occurring an equal number of times for each level of the strong factor, any effect by these other factors will be ruled out. The Taguchi method apparently has the following strengths:

- Consistency in experimental design and analysis
- Reduction of time and cost of experiments
- Robustness of performance without removing the noise factors.

4.1 Statistical Analysis

The calculated dependent variables were: (1) change in heart rates, (2) blood pressure and the (3) postural RULA score. The independent variables are the vertical height of lift, weight, frequency, and obstructions en route. To examine the influence of the independent variables, repeated measures analysis of variance (ANOVA) were conducted. To avoid compounding alpha error, by conducting f-test for all factors and interactions was carried out. An alpha level of .05 was used for all statistical tests, and conformation tests were conducted at optimized conditions.

4.2 Results

For each subject three types of reports have been generated to assess the affect of various factors and/or interactions. In the end the results of all the four subjects have been used to summaries a consolidated response in the form of signal to noise ratio has been calculated. The subject specific reports are as under:

1. The experimental data report.
2. The classification data table
3. The ANOVA calculation table

The tables are followed by plots of significant factors and their interactions when compared to the response values. The required calculations have been carried out using an Excel Worksheet and the plots were created using MINITAB software.

4.2.1 Results for Subject 1

The results for subject 1 wherein the three response variables for each of the 27 trials conducted are shown in Table 4.1 below. The ANOVA analysis for heart rate, blood pressure and RULA score are shown in Tables 4.2, 4.3 and 4.4 respectively. The respective plots for the significant factors and their interactions are shown in figure 4.1, 4.2 and 4.3.

Table 4.1: Trial Results for Subject 1

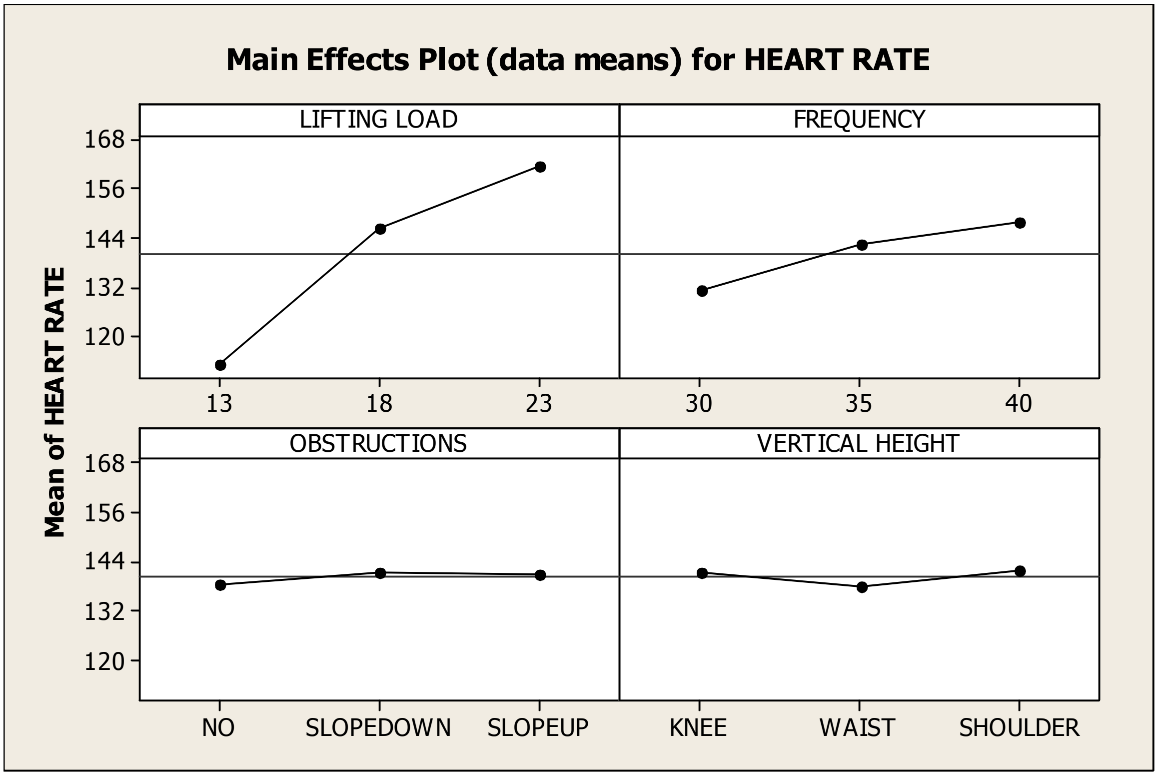
S.NO	Lift Load(A)	Frequency(B)	Obstructions(C)	Vertical Height(D)	RULA Score	Heart Rate-after	BP Systolic
1.	13	30	No	Knee	2	92	162
2.	13	30	Slope down	Waist	2	99	169
3.	13	30	Slope up	Shoulder	3	115	175
4.	13	35	No	Waist	3	96	163
5.	13	35	Slope down	Shoulder	3	116	170
6.	13	35	Slope up	Knee	4	124	169
7.	13	40	No	Shoulder	4	120	169
8.	13	40	Slope down	Knee	4	126	166
9.	13	40	Slope up	Waist	5	129	169
10.	18	30	Slope up	Knee	4	135	169
11.	18	30	No	Waist	4	140	170
12.	18	30	Slope down	Shoulder	4	142	175
13.	18	35	Slope up	Waist	5	133	171
14.	18	35	No	Shoulder	4	156	174
15.	18	35	Slope down	Knee	4	151	164
16.	18	40	Slope up	Shoulder	6	143	183
17.	18	40	No	Knee	5	157	170
18.	18	40	Slope down	Waist	5	159	173
19.	23	30	Slope down	Knee	6	145	168
20.	23	30	Slope up	Waist	6	157	175
21.	23	30	No	Shoulder	5	154	174
22.	23	35	Slope down	Waist	6	169	174
23.	23	35	Slope up	Shoulder	7	163	184
24.	23	35	No	Knee	5	172	169
25.	23	40	Slope down	Shoulder	7	167	186
26.	23	40	Slope up	Knee	7	169	183
27.	23	40	No	Waist	7	159	177

Table 4.2: ANOVA for Subject 1 (Heart Rate)

HEART RATE												
			A1			**A2**			**A3**			
			1017			1316			1451			
			LL1=13			LL2=18			LL3 = 23			**LL1**
		92					**135**		**145**		Knee	1267
B1	Fre1=30		**99**		**140**					**157**	Waist	
1179				**115**		**142**		**154**			Shoulder	
				124		**151**		**172**			Knee	**LL2**
B2	Fre 2=35	**96**					**133**		**169**		Waist	1241
1280			**116**		**156**					**163**	Shoulder	
			126		**157**					**165**	Knee	
B3	Fre 3=40			**129**		**159**		**159**			Waist	**LL3**
1325		**120**					**143**		**167**		Shoulder	1276
		No	Sd	Su	No	Sd	Su	No	Sd	Su		
		1246				1274				1264	**T=**	3784
		D1				**D2**				**D3**		

Source	**SS**	**dof**	**Variance**	**F test**	**F crit**	**SS'**	**C (%)**	**Significance**
Lifting load(A)	10962.3	2	5481.148	224.569	10.93	10798.26	78.09313	Yes
Frequency (B)	1242.296	2	621.1481	25.44917	10.93	1078.255	7.797956	Yes
Obstructions(C)	73.40741	2	36.7037	1.503794	10.93			
VH(D)	44.74074	2	22.37037	0.91654	10.93			
A XB	261.4815	4	65.37037	2.6783	9.15			
B X D	153.037	4	38.25926	1.567527	9.15			
A X D	943.7037	4	235.9259	9.666161	9.15	615.6214	4.452182	Yes
Error	146.4444	6	24.40741					
Total	13827.41	26				13827.41	100	
e-pooled	1476.37	18	82.02058			1950.897	9.656732	

Figure 4.1: Plots of factors & interactions for Subject 1 (Heart Rate)



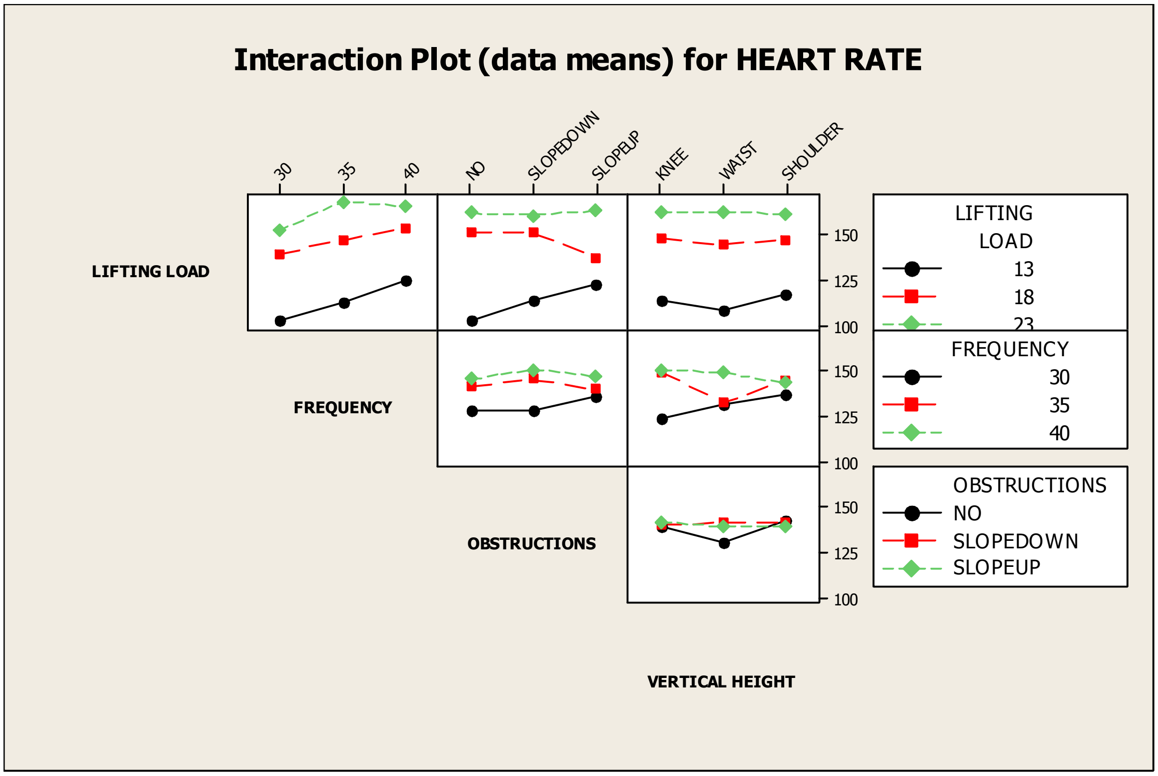


Table 4.3: ANOVA for Subject 1 – Response B.P.

BLOOD PRESSURE												
			A1			A2			A3			
			1512			1549			1590			
			LL1=13			LL2=18			LL3 = 23			LL1
		162					**169**		**168**		knee	1525
B1	Fre1=30		**169**		**170**					**175**	waist	
1537				**175**		**175**		**174**			shoulder	
				169		**164**		**174**			knee	LL2
B2	Fre2=35	**163**					**171**		**169**		waist	1536
1538			**170**		**174**					**184**	shoulder	
			166		**170**					**183**	knee	
B3	Fre3=40			**169**		**173**		**177**			waist	LL3
1576		**169**					**183**		**186**		shoulder	1590
		No	Sd	Su	No	Sd	Su	No	Sd	Su		
		1533				1540				1578	T=	4651
		D1				D2				D3		

Source	SS	dof	Variance	F test	F critical	SS'	C (%)	Significance
Lifting load(A)	338.2963	2	169.1481	70.26154	10.93	327.8095	32.48259	Yes
Frequency (B)	109.8519	2	54.92593	22.81538	10.93	99.36508	9.84607	Yes
Obstructions(C)	268.963	2	134.4815	55.86154	10.93	258.4762	25.61236	Yes
VH(D)	130.2963	2	65.14815	27.06154	10.93	119.8095	11.87191	Yes
A XB	88.37037	4	22.09259	9.176923	9.15	67.39683	6.678341	Yes
B X D	33.03704	4	8.259259	3.430769	9.15			
A X D	25.92593	4	6.481481	2.692308	9.15			
error	14.44444	6	2.407407					
Total	1009.185	26				1009.185	100	
e-pooled	73.40741	14	5.243386			422.8995	13.50872	

Figure 4.2: Plots of significant factors and interactions for Subject 1 (B.P.)

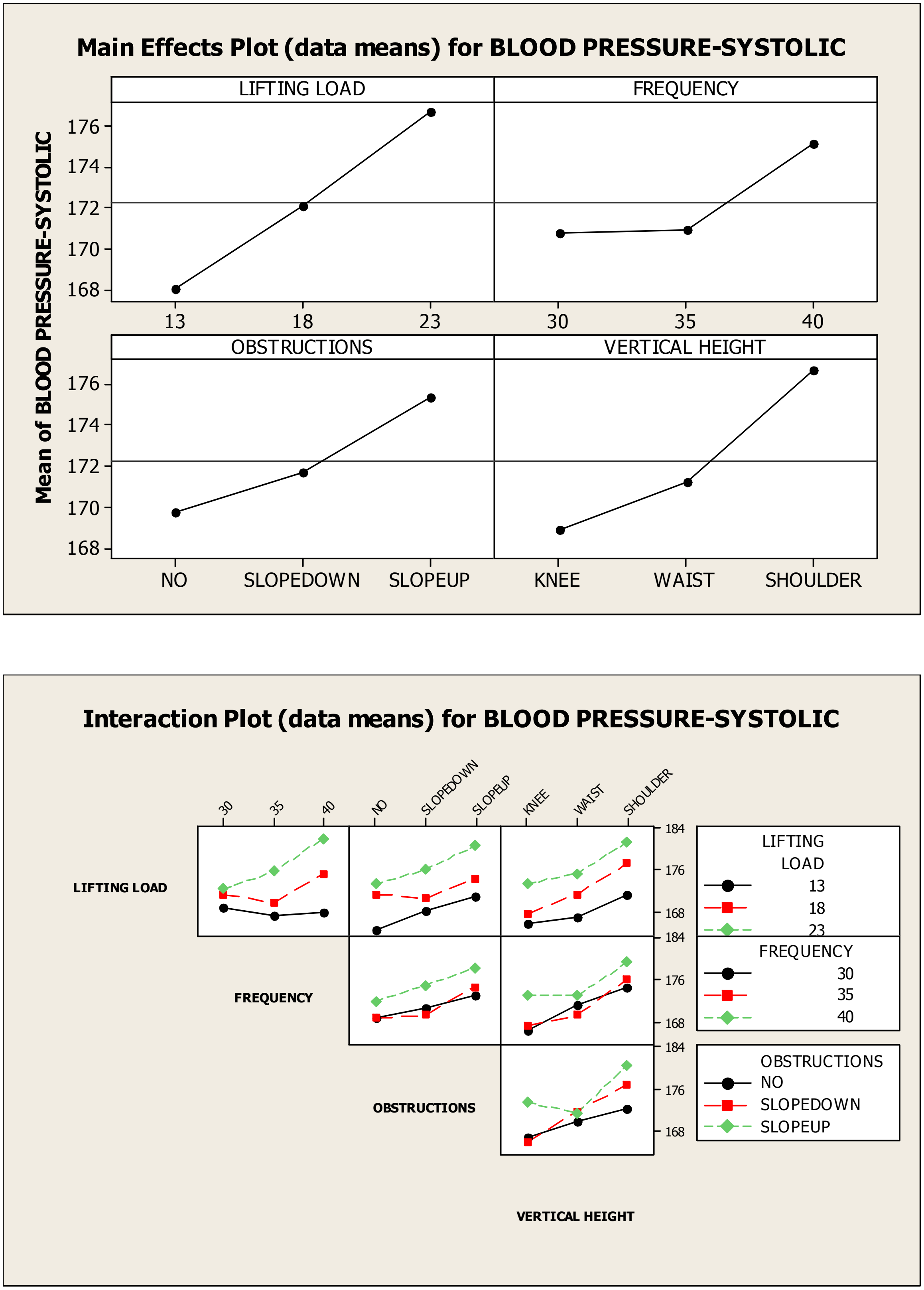
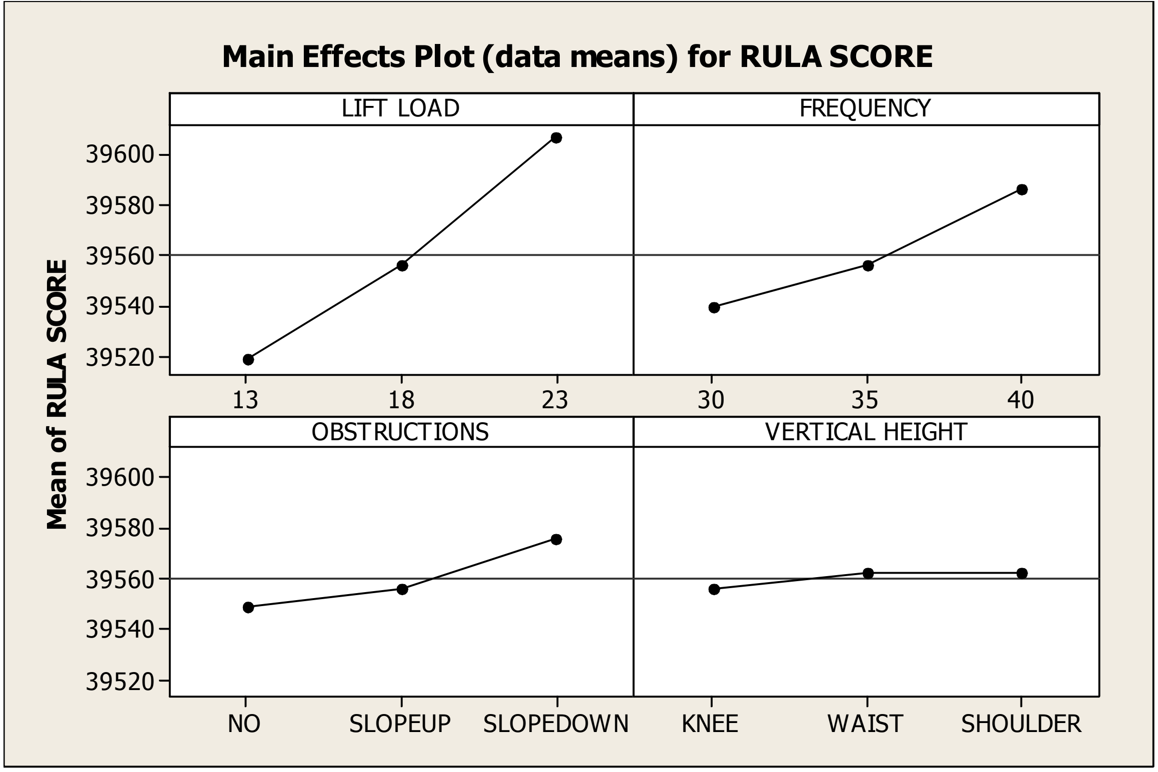


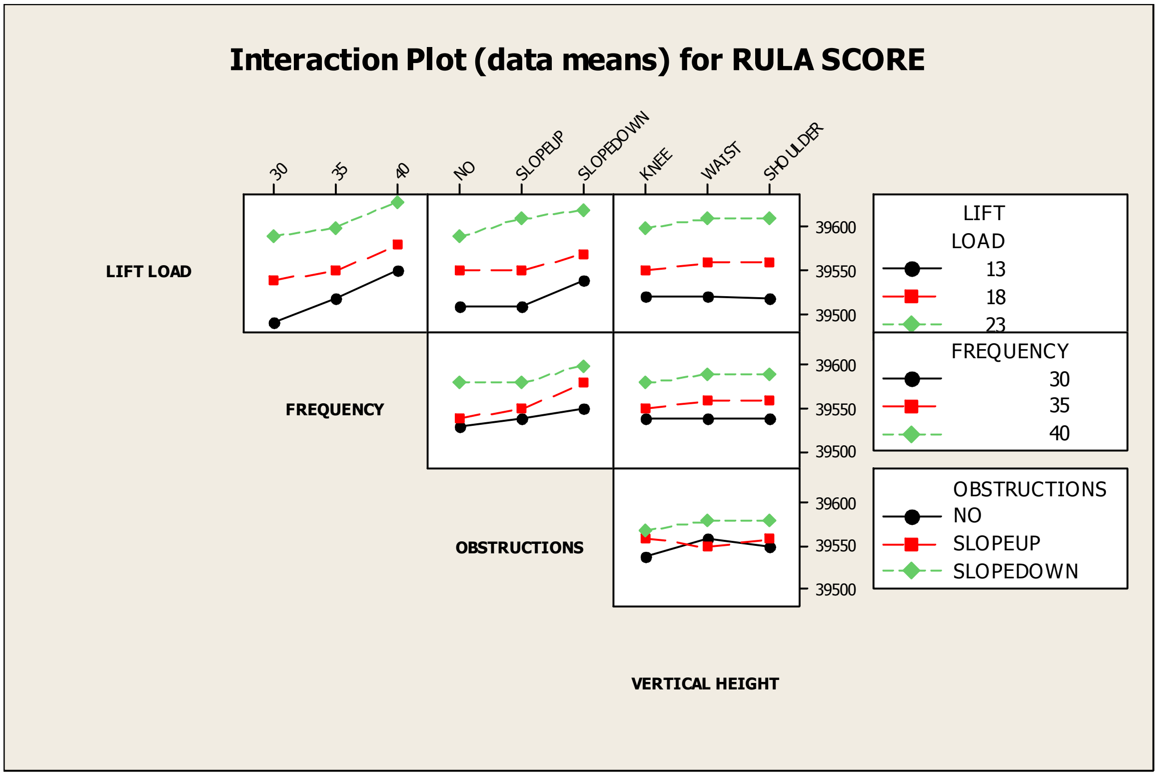
Table 4.4: ANOVA for Subject 1 – Response RULA Score

RULA SCORE												
				A1		**A2**			**A3**			
				30		41			56			
				LL1=13		LL2=18			LL3 = 23			**LL1**
		2					**4**		**6**		knee	41
B1	Fre1=30			**2**	**4**					**6**	waist	
36			**3**			**4**		**5**			shoulder	
			4			**4**		**5**			knee	**LL2**
B2	Fre2=35	**3**					**5**		**6**		waist	43
41				**3**	**4**					**7**	shoulder	
				4	**5**					**7**	knee	
B3	Fre3=40		**5**			**5**		**7**			waist	**LL3**
50		**4**					**6**		**7**		shoulder	43
		No	Su	Sd	No	Sd	Su	No	Sd	Su		
		39				41				47	**T=**	127
		D1				**D2**				**D3**		

Source	SS	dof	Variance	F test	F critical	SS'	C (%)	Significance
Lifting load(A)	37.85185	2	18.92593	170.3333	10.93	37.19342	66.859	Yes
Frequency (B)	11.18519	2	5.592593	50.33333	10.93	10.52675	18.92292	Yes
Obstructions(C)	0.296296	2	0.148148	1.333333	10.93			
VH(D)	3.851852	2	1.925926	17.33333	10.93			
A XB	0.592593	4	0.148148	1.333333	9.15			
B X D	0.592593	4	0.148148	1.333333	9.15			
A X D	0.592593	4	0.148148	1.333333	9.15			
error	0.666667	6	0.111111					
Total	55.62963	26				55.62963	100	
e-pooled	5.925926	18	0.329218			7.909465	15.52005	

Figure 4.3: Plots of significant factors and interactions for Subject 1 (RULA Score)





The results of the 27 trials for Subject 1 are presented below:

The significant factors and their interactions for Subject 1 are listed below in Table 4.5

Table 4.5: Results for Subject 1

Response Type	**Significant Factors and Interactions**
Heart Rate	• Load Weight • Interaction between Load Weight and Vertical Lift Height
Blood Pressure	Vertical Height
RULA Score	Frequency

a) Estimated value for Heart Rate

The table 4.6 shows mean values for each signficant factor at its each level for heart rate.

Table 4.6: Mean values for Heart Rate

Level	$\overline{A}$	$\overline{D}$
1	109	138.4
2	146.2	141.5
3	161.2	140.4

Mean Heart Rate for easy conditions of work (low stress levels)

$$\overline{\mu}_{A_1D_1} = \overline{A}_1 + \overline{D}_1 - \overline{T} = 109 + 138.4 - 140.1 = 107.3$$

Mean Heart Rate for most difficult work conditions (High stress levels)

$$\overline{\mu}_{A_3D_2} = \overline{A}_3 + \overline{D}_2 - \overline{T} = 161.2 + 141.5 - 140.1 = 162.6$$

Confidence Interval around the estimated heart rate

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}}$$ Where $F_{\alpha v_1 v_2} = F\ ratio$

$\alpha = risk$ $\qquad$ $confidence = 1 - \alpha$

$v_1 = dof\ for\ mean\ which\ is\ always = 1$

$v_2 = dof\ for\ error = v_e$

$n_{eff} =$ Number of tests under that condition using the participating factors

The F ratio is determined from the F-Tables used in ANOVA.

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}} = \sqrt{\frac{2.93 \times 82.02}{5.4}} = 6.67$$

$$n_{eff} = \frac{N}{1 + dof_{A\&D}} = \frac{27}{1+2+2} = 5.4$$

So the confidence interval around the estimated heart rate is

$$107.3 - 6.67 < 107.3 < 107.3 + 6.67$$

$$100.63 < 107.3 < 113.97$$

b) Estimated value for Blood Pressure

The table 4.7 shows mean values for each signficant factor at its each level for Blood Pressure

Table 4.7: Mean values for Blood Pressure

Level	$\overline{A}$	$\overline{B}$	$\overline{C}$	$\overline{D}$
1	168	170.7	169.4	170.3
2	172.1	170.8	170.6	171.1
3	176.6	175.1	176.6	175.3

Mean Blood Pressure for easy conditions of work (low stress levels)

$$\overline{\mu}_{A_1B_1C_1D_1} = 161.6$$

Confidence Interval around the estimated blood pressure

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}}$$

The F ratio is determined from the F-Tables used in ANOVA.

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}} = \sqrt{\frac{2.93 \times 5.24}{3}} = 2.26$$

$$n_{eff} = \frac{N}{1 + dof_{A,B,C\&D}} = \frac{27}{1+2+2+2+2} = 3$$

So the confidence interval around the estimated blood pressure is 161.6 ± 2.26

c) Estimated value for Posture (RULA) score

The Table 4.8 shows mean values for each signficant factor at its each level for RULA Score.

Table 4.8: Mean values for RULA Score

Level	$\overline{A}$	$\overline{B}$
1	**3.3**	4.0
2	4.5	4.5
3	6.2	5.5

Mean RULA score for easy conditions of work (low stress levels)

$$\overline{\mu}_{A_1B_1} = 3.3 + 4.0 - 4.70 = 2.6$$

Mean RULA score for difficult conditions of work (high stress levels)

$$\overline{\mu}_{A_{31}B_3} = 6.2 + 5.5 - 4.70 = 7.0$$

Confidence Interval around the estimated RULA Score

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}}$$

The F ratio is determined from the F-Tables used in ANOVA.

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}} = \sqrt{\frac{2.93 \times 0.33}{5.4}} = 0.42$$

$$n_{eff} = \frac{N}{1 + dof_{A\&D}} = \frac{27}{1+2+2} = 5.4$$

So the confidence interval around the estimated RULA Score is 2.6 ± 0.42

Some other observations from the plots could also be made:

- The obstructions en route has no or little impact on the heart rate condition during this experiment.
- For placing the load weight at knee, waist, or shoulder height level, it was observed that the best heart rate condition exists for waist height while there is no appreciable difference when placing the load at knee level or shoulder level.

- Load Weight and Frequency makes the most significant on the stress levels on this subject where stress level is measured through the combined effect of heart rate, blood pressure and RULA score.
- Interaction between Load weight and Vertical Height has been found to be significant while no other factor makes any significant impact on stress levels.

4.2.2 Results for Subject 2

The results for subject 2 wherein the three response variables for each of the 27 trials conducted are shown in Table 4.9 below. The ANOVA analysis for heart rate, blood pressure and RULA score are shown in Tables 4.10, 4.11 and 4.12 respectively. The respective plots for the significant factors and their interactions are shown in figure 4.4, 4.5 and 4.6.

Table 4.9: Response values for Subject 2

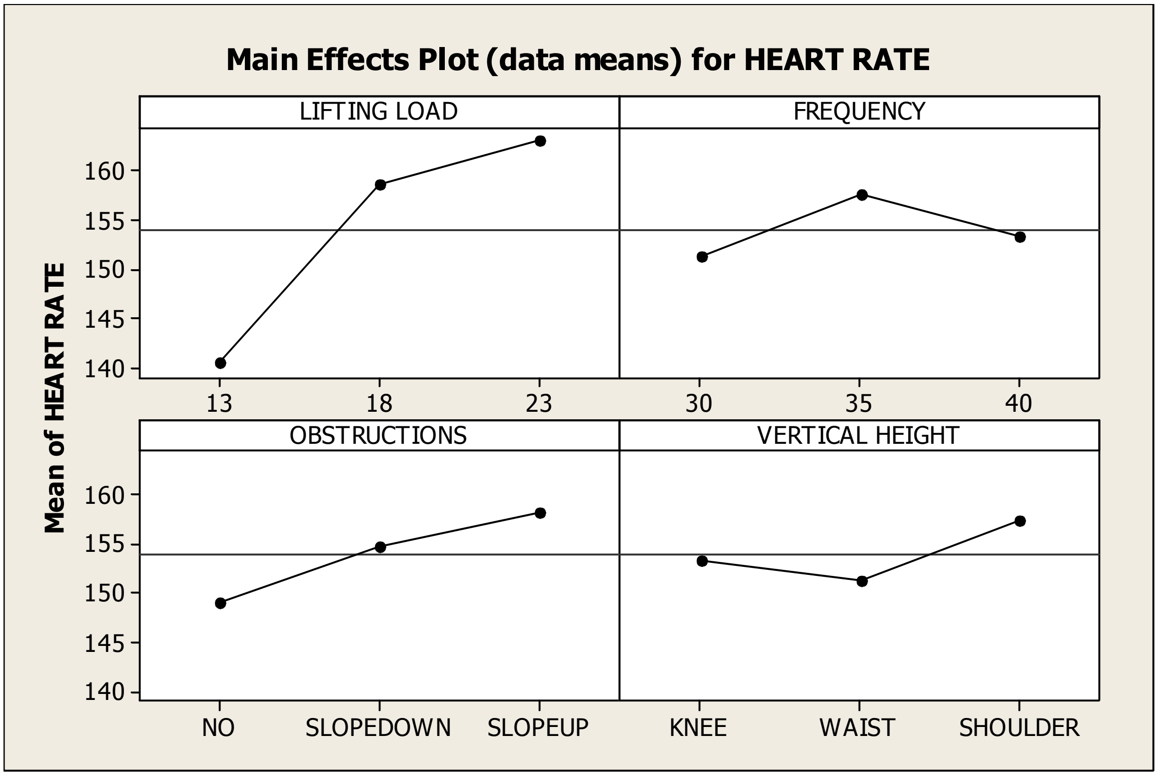
S.NO	Lift Load(A)	Frequency (B)	Obstructions(C)	Vertical Height (D)	RULA Score	Heart Rate-after	Systolic
1.	13	30	No	Knee	2	125	147
2.	13	30	Slope down	Waist	3	132	153
3.	13	30	Slope up	Shoulder	4	145	160
4.	13	35	No	Waist	3	138	138
5.	13	35	Slope down	Shoulder	4	142	167
6.	13	35	Slope up	Knee	4	142	160
7.	13	40	No	Shoulder	4	145	165
8.	13	40	Slope down	Knee	4	143	160
9.	13	40	Slope up	Waist	5	152	152
10.	18	30	Slope up	Knee	4	157	157
11.	18	30	No	Waist	5	153	153
12.	18	30	Slope down	Shoulder	5	161	161
13.	18	35	Slope up	Waist	6	167	167
14.	18	35	No	Shoulder	5	161	167
15.	18	35	Slope down	Knee	4	154	154
16.	18	40	Slope up	Shoulder	5	163	175
17.	18	40	No	Knee	4	154	152
18.	18	40	Slope down	Waist	6	157	160
19.	23	30	Slope down	Knee	5	159	156
20.	23	30	Slope up	Waist	6	167	162
21.	23	30	No	Shoulder	6	162	163
22.	23	35	Slope down	Waist	6	171	162
23.	23	35	Slope up	Shoulder	6	164	170
24.	23	35	No	Knee	5	179	162
25.	23	40	Slope down	Shoulder	7	174	169
26.	23	40	Slope up	Knee	7	166	165
27.	23	40	No	Waist	7	165	160

Table 4.10: ANOVA for Heart Rate (Subject 2)

HEART RATE AFTER												
			A1			**A2**			**A3**			
			1264			1427			1507			
			LL1=13			LL2=18			LL3 = 23			**LL1**
		125					**157**		**159**		knee	1364
B1	Fre1=30		**132**		**153**					**167**	waist	
1361				**145**		**161**		**162**			shoulder	
				142		**154**		**164**			knee	**LL2**
B2	Fre2=35	**138**					**167**		**171**		waist	1402
1418			**142**		**161**					**179**	shoulder	
			143		**154**					**166**	knee	
B3	Fre3=40			**152**		**157**		**165**			waist	**LL3**
1419		**145**					**163**		**174**		shoulder	1432
		No	Sd	Su	No	Sd	Su	No	Sd	Su		
		1367				1393				1438	**T=**	4198
		D1				**D2**				**D3**		

Source	**SS**	**dof**	**Variance**	**F test**	**F critical**	**SS'**	**C (%)**	**Significance**
Lifting load(A)	3408.074	2	1704.037	489.4574	10.93	3398.19	77.218	Yes
Frequency (B)	244.963	2	122.4815	35.18085	10.93	235.07	5.3414	Yes
Obstructions(C)	258.0741	2	129.037	37.06383	10.93	248.19	5.6397	Yes
VH(D)	286.7407	2	143.3704	41.18085	10.93	276.85	6.2911	Yes
A XB	133.7037	4	33.42593	9.601064	9.15	113.93	2.5890	Yes
B X D	23.7037	4	5.925926	1.702128	9.15			
A X D	24.59259	4	6.148148	1.765957	9.15			
error	20.88889	6	3.481481					
Total	4400.741	26				4400.741	100	
e-pooled	69.18519	14	4.941799			767.4709	2.9196	

Figure 4.4: Plots for main factors and Interactions (Subject 2)



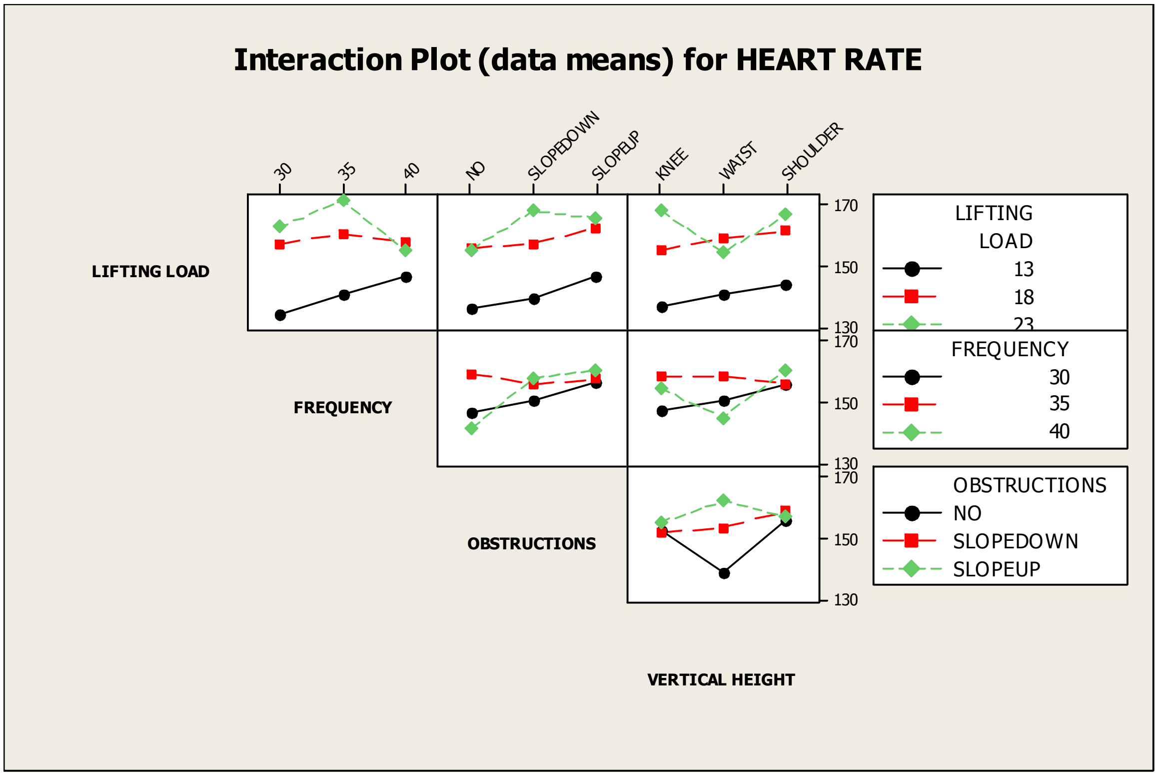
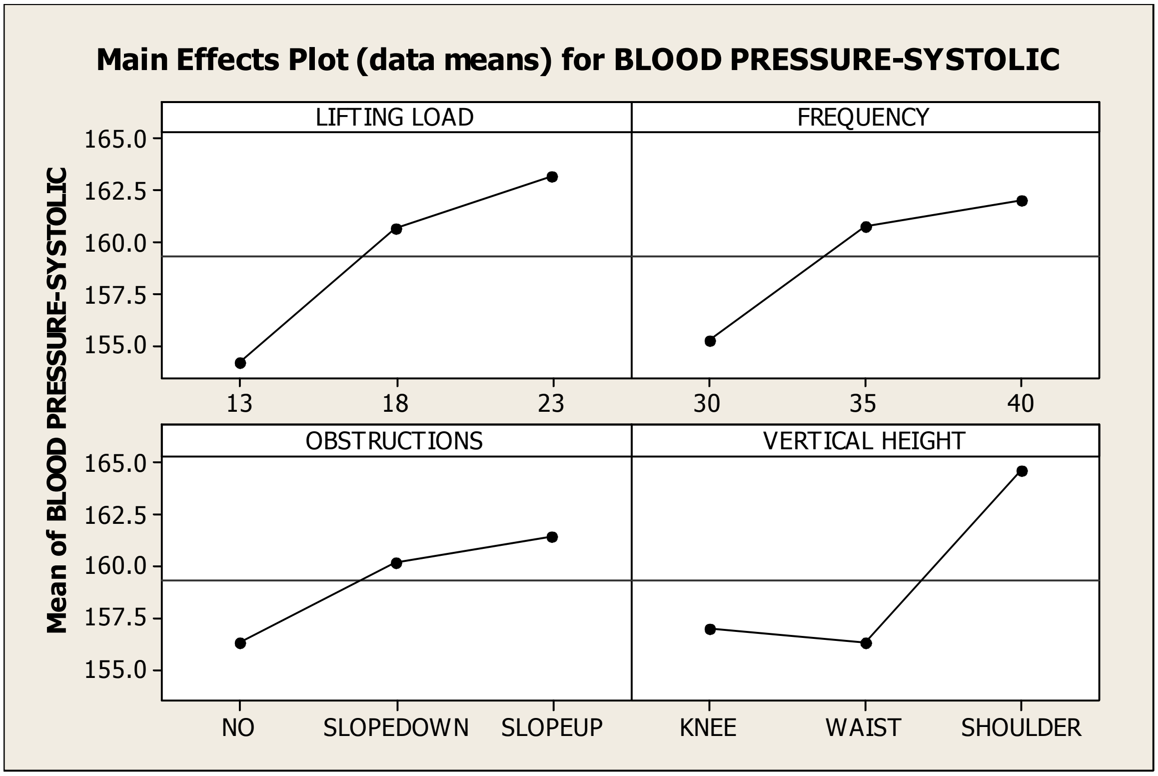


Table 4.11: ANOVA for Blood Pressure (Subject 2)

Blood Pressure Systolic												
			A1			A2			A3			
			1441			1471			1469			
			C1=13			C2=18			C3 = 23			C1
		147					163		156		knee	1424
B1	Pon1=30		153		160					162	waist	
1434				160		170		163			shoulder	
				160		159		162			knee	C2
B2	Pon2=35	158					165		162		waist	1451
1470			167		167					170	shoulder	
			160		152					165	knee	
B3	Pon3=40			171		160		160			waist	C3
1477		165					175		169		shoulder	1506
		No	Sd	Su	No	Sd	Su	No	Sd	Su		
		1434				1456				1491	T=	4381
		D1				D2				D3		

Source	SS	dof	Variance	F test	F critical	SS'	C (%)	Sig
Lifting load(A)	62.51852	2	31.25926	17.58333	10.93	49.61905	4.985911	Yes
Frequency (B)	118.2963	2	59.14815	33.27083	10.93	105.3968	10.59067	Yes
Obstructions(C)	388.0741	2	194.037	109.1458	10.93	375.1746	37.69897	Yes
VH(D)	183.6296	2	91.81481	51.64583	10.93	170.7302	17.15562	Yes
A XB	152.3704	4	38.09259	21.42708	9.15	126.5714	12.71838	Yes
B X D	65.25926	4	16.31481	9.177083	9.15	65.25926	7.767394	Yes
A X D	14.37037	4	3.592593	2.020833	9.15			
Error	10.66667	6	1.777778					
Total	995.1852	26				995.1852	100	
e-pooled	90.2963	14	6.449735			840.1693	9.08305	

Figure 4.5: Plots for main factors and Interactions - B.P. (Subject 2)



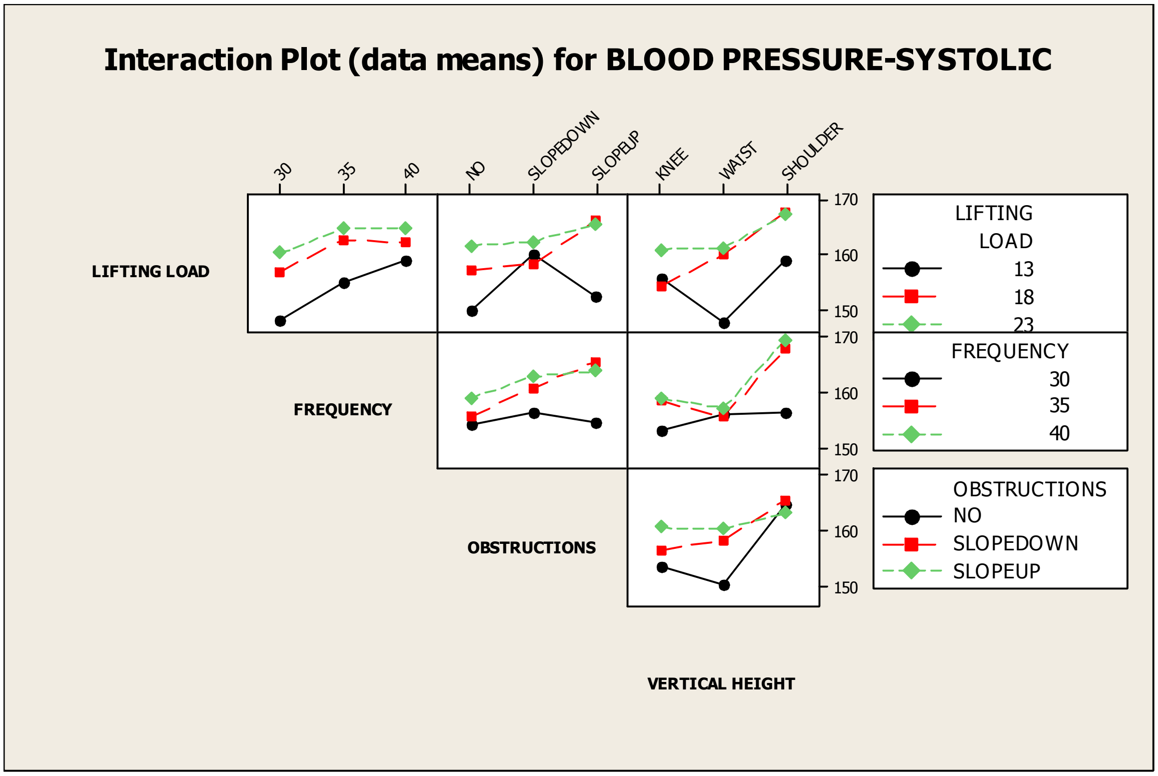
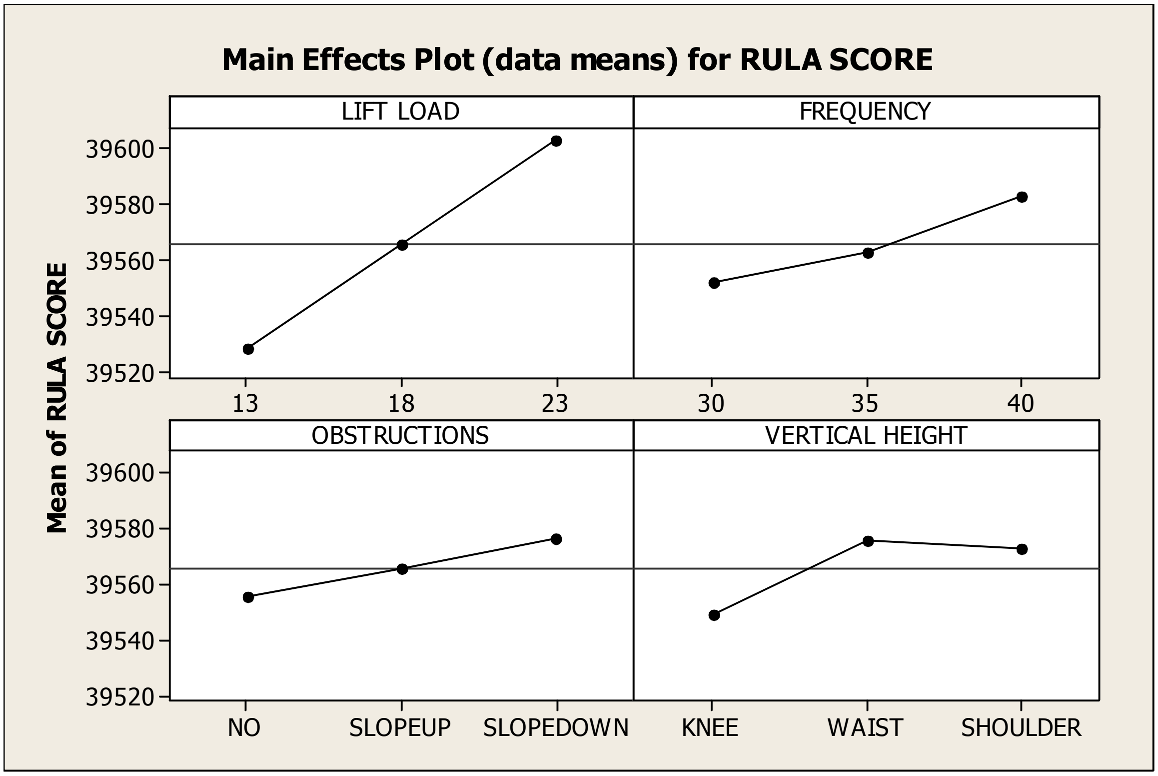


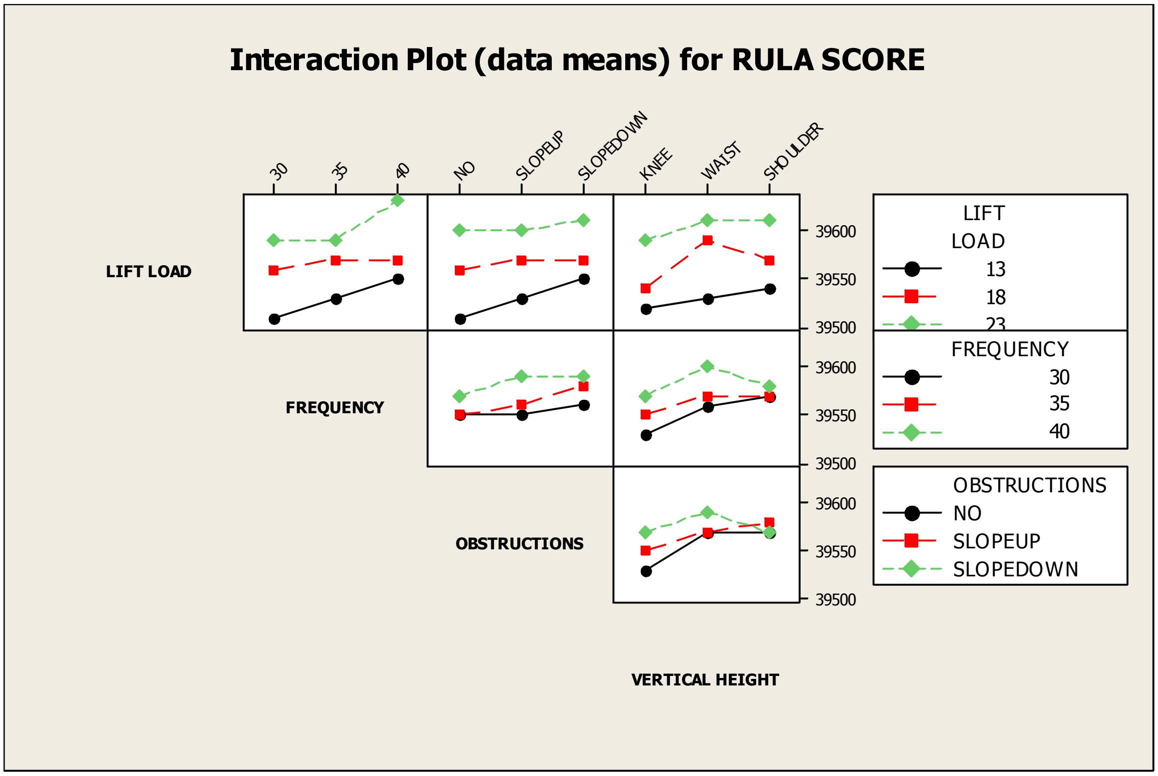
Table 4.12: ANOVA for RULA Score (Subject 2)

RULA SCORE												
			A1			**A2**			**A3**			
			33			44			55			
			LL1=13			LL2=18			LL3 = 23			**LL1**
		2					**5**		**5**		knee	40
B1	Fre1=30		**3**		**4**					**6**	waist	
40				**4**		**5**		**6**			shoulder	
				4		**4**		**5**			knee	**LL2**
B2	Fre2=35	**3**					**6**		**6**		waist	45
43			**4**		**5**					**6**	shoulder	
			4		**4**					**7**	knee	
B3	Fre3=40			**5**		**5**		**7**			waist	**LL3**
49		**4**					**6**		**7**		shoulder	47
		No	Sd	Su	No	Sd	Su	No	Sd	Su		
		40				43				49	**T=**	132
		D1				**D2**				**D3**		

Source	SS	dof	Variance	F test	F critical	SS'	C (%)	Significance
Lifting load(A)	26.962	2	13.481	182	10.93	26.641	62.011	Yes
Frequency (B)	5.629	2	2.8148	38	10.93	5.3086	12.356	Yes
Obstructions(C)	1.851	2	0.9259	12.5	10.93	1.8518	16.816	Yes
VH(D)	5.629	2	2.8148	38	10.93	5.3086	12.356	Yes
A XB	1.037	4	0.2592	3.5	9.15			
B X D	0.370	4	0.0925	1.25	9.15			
A X D	1.037	4	0.2592	3.5	9.15			
Error	0.444	6	0.0740					
Total	42.96	26				42.962	100	
e-pooled	2.888	18	0.1604			11.012	13.275	

Figure 4.6: Plots for main factors and Interactions – RULA Score (Subject 2)





The results of the 27 trials for Subject 2 are presented below:

The significant factors and their interactions for Subject 1 are listed below in Table 4.5

Table 4.13: Results for Subject 2

Response Type	Significant Factors and Interactions
Heart Rate	• Load Weight (Major Impact) Minor Significance: Frequency, obstructions and height
Blood Pressure	All the four factors + Interactions between A x B and B x D
RULA Score	• Load • Frequency • Vertical Height • Interaction between A x B

a) Estimated value for Heart Rate

The table 4.14 shows mean values for each signficant factor at its each level for heart rate.

Table 4.14: Mean values for Heart Rate

Level	$\overline{A}$	$\overline{B}$	$\overline{C}$	$\overline{D}$
1	140.4	151.2	152.4	151.9
2	158.5	157.5	155.8	154.8
3	167.4	157.6	159.1	159.8

Since Factor B and C has no significance, hence ignored.

Mean Heart Rate for easy conditions of work (low stress levels)

$$\overline{\mu}_{A_1D_1} = \overline{A}_1 + \overline{D}_1 - \overline{T} = 140.4 + 151.9 - 155.5 = 136.8$$

Mean Heart Rate for most difficult work conditions (High stress levels)

$$\overline{\mu}_{A_3D_3} = \overline{A}_3 + \overline{D}_3 - \overline{T} = 167.4 + 159.8 - 155.4 = 171.8$$

Confidence Interval around the estimated heart rate

The F ratio is determined from the F-Tables used in ANOVA.

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2}V_e}{n_{eff}}} = \sqrt{\frac{2.93 \times 4.95}{5.4}} = 2.68$$

$$n_{eff} = \frac{N}{1 + dof_{A\&D}} = \frac{27}{1+2+2} = 5.4$$

So the confidence interval around the estimated heart rate is

$$134.12 < 136.8 < 139.48$$

b) Estimated value for Blood Pressure

The significant factors as per the ANOVA table are:

- Frequency
- Obstruction en route
- Load Weight
- Interaction of Load and Vertical Height

The table 4.15 shows mean values for each signficant factor at its each level for Blood Pressure.

Table 4.15: Mean values for Blood Pressure

Level	$\overline{B}$	$\overline{C}$	$\overline{D}$
1	157.6	158.2	159.3
2	163.3	161.2	161.8
3	164.1	165.7	164.0

A1B1	148.3
A1B2	161.7
A1B3	165.3
A2B1	164.3
A2B2	163.7
A2B3	162.3
A3B1	160.3
A3B2	164.7
A3B3	164.7

Mean B.P. For easy conditions of work (low stress levels)

$$\overline{\mu}_{B_1C_1D_1AB_1} = \overline{B}_1 + \overline{C}_1 + \overline{D}_1 + \overline{A_1}\overline{B}_1 - 3\overline{T}$$

$$\overline{\mu}_{B_1C_1D_1AB_1} = 157.6 + 158.2 + 159.3 + 148.3 - 3 \times 161.7 = 138.3$$

Confidence Interval around the estimated blood pressure

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}}$$

The F ratio is determined from the F-Tables used in ANOVA.

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}} = \sqrt{\frac{2.93 \times 13.05}{2.45}} = 3.95$$

$$n_{eff} = \frac{N}{1 + dof_{B,C,D,A \times B}} = \frac{27}{1+2+2+2+4} = 2.45$$

So the confidence interval around the estimated blood pressure is 138.3 ± 3.95

c) Estimated value for Posture (RULA) score

The Table 4.16 shows mean values for each signficant factor at its each level for RULA Score.

Table 4.16: Mean values for RULA Score

Level	$\overline{A}$	$\overline{B}$	$\overline{D}$
1	3.7	4.4	4.4
2	4.9	4.8	4.8
3	6.1	5.4	5.4

Mean RULA score for easy conditions of work (low stress levels)

$$\overline{\mu}_{A_1B_1D_1} = 3.7 + 4.4 + 4.4 - 2 \times 4.9 = 2.7$$

Confidence Interval around the estimated RULA Score

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}}$$

The F ratio is determined from the F-Tables used in ANOVA.

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}} = \sqrt{\frac{2.93 \times 0.13}{3.85}} = 0.31$$

$$n_{eff} = \frac{N}{1 + dof_{A,B,D}} = \frac{27}{1+2+2+2} = 3.85$$

So the confidence interval around the estimated RULA Score is 2.7 ± 0.31

Some other observations from the plots could also be made:

- The obstructions en route has little impact on the stress levels of this subject during the experimental trail conditions.
- Load Weight and frequency are the two foremost important factors affecting the workmen during Lifting and Carrying Tasks
- Interactions between Load Weight and Frequency were found to be significant and needs further elaboration.
- Similarly interaction between Load Weight and Vertical Height of load at destination needs further analysis.
- For placing the load weight at knee, waist or shoulder height level, it was observed that the best heart rate condition exists for waist height
- Load Weight and Frequency makes the most significant on the stress levels on this subject where stress level is measured through the combined effect of heart rate, blood pressure and RULA score.

4.2.3 Results for Subject 3

The results for subject 3 wherein the three response variables for each of the 27 trials conducted are shown in Table 4.17 below. The ANOVA analysis for heart rate, blood pressure and RULA score are shown in Tables 4.18, 4.19 and 4.20 respectively. The respective plots for the significant factors and their interactions are shown in figure 4.7, 4.8 and 4.9.

Table 4.17: Response values for Subject 3

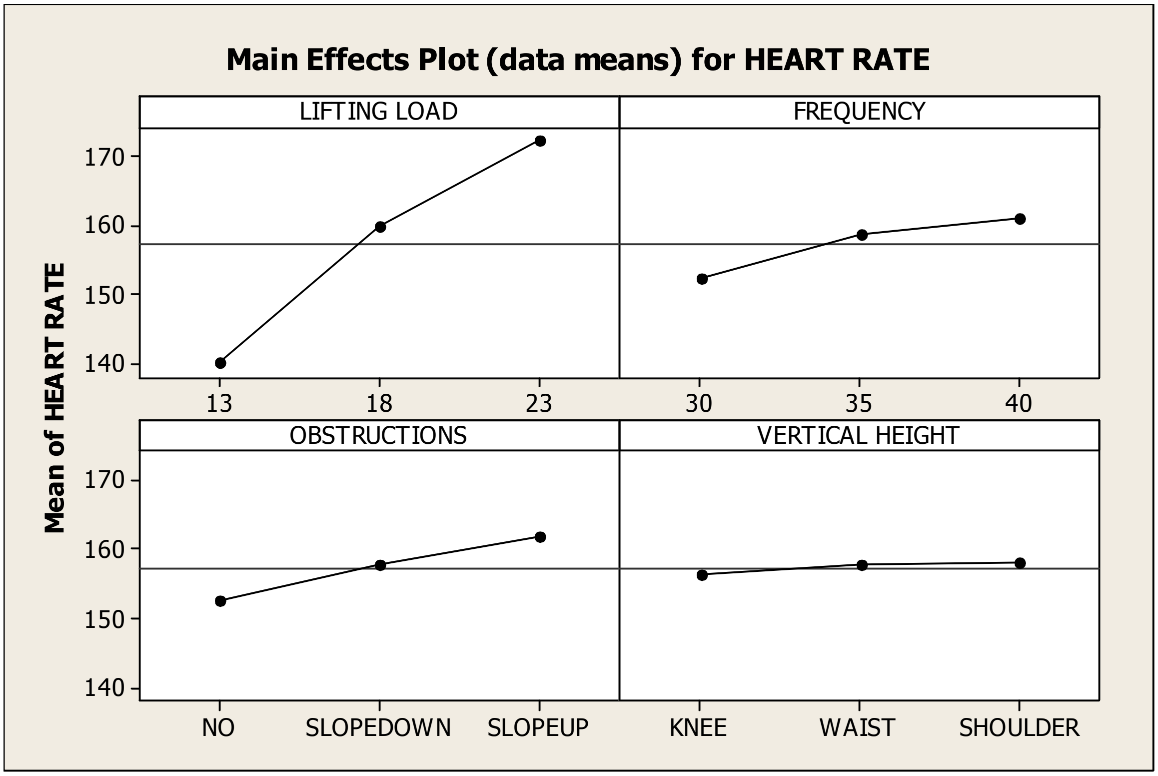
S.NO	Lift Load (A)	Frequency (B)	Obstructions (C)	Vertical Height (D)	RULA Score	Heart Rate-after	Systolic
1.	13	30	No	Knee	2	127	155
2.	13	30	Slope down	Waist	2	135	158
3.	13	30	Slope up	Shoulder	3	140	162
4.	13	35	No	Waist	2	137	159
5.	13	35	Slope down	Shoulder	3	139	167
6.	13	35	Slope up	Knee	3	142	173
7.	13	40	No	Shoulder	2	144	157
8.	13	40	Slope down	Knee	3	147	169
9.	13	40	Slope up	Waist	3	149	173
10.	18	30	Slope up	Knee	5	162	162
11.	18	30	No	Waist	4	157	153
12.	18	30	Slope down	Shoulder	5	159	159
13.	18	35	Slope up	Waist	5	163	163
14.	18	35	No	Shoulder	6	154	159
15.	18	35	Slope down	Knee	4	160	160
16.	18	40	Slope up	Shoulder	6	169	168
17.	18	40	No	Knee	5	153	159
18.	18	40	Slope down	Waist	6	161	163
19.	23	30	Slope down	Knee	5	163	163
20.	23	30	Slope up	Waist	6	169	165
21.	23	30	No	Shoulder	6	159	159
22.	23	35	Slope down	Waist	6	179	177
23.	23	35	Slope up	Shoulder	7	183	183
24.	23	35	No	Knee	6	172	185
25.	23	40	Slope down	Shoulder	7	176	179
26.	23	40	Slope up	Knee	7	180	181
27.	23	40	No	Waist	7	169	172

Table 4.18: ANOVA for Heart Rate (Subject 3)

						HEART RATE						
			A1			**A2**			**A3**			
			1260			1438			1550			
			LL1=13			LL2=18			LL3 = 23			**LL1**
		127					**162**		**163**		knee	1406
B1	Fre1=30		**135**		**157**					**169**	waist	
1371				**140**		**159**		**159**			shoulder	
				142		**160**		**172**			knee	**LL2**
B2	Fre2=35	**137**					**163**		**179**		waist	1419
1429			**139**		**154**					**183**	shoulder	
			147		**153**					**180**	knee	
B3	Fre3=40			**149**		**161**		**169**			waist	**LL3**
1448		**144**					**169**		**176**		shoulder	1423
		No	Sd	Su	No	Sd	Su	No	Sd	Su		
		1372				1419				1457	**T=**	4248
		D1				**D2**				**D3**		

Source	**SS**	**dof**	**Variance**	**F test**	**F critical**	**SS'**	**C (%)**	**Significance**
Lifting load(A)	4752.889	2	2376.444	398.5342	10.93	4744.667	81.60761	Yes
Frequency (B)	357.5556	2	178.7778	29.98137	10.93	349.3333	6.008485	Yes
Obstructions(C)	17.55556	2	8.777778	1.47205	10.93			
VH(D)	402.8889	2	201.4444	33.78261	10.93	394.6667	6.788212	Yes
A XB	234.8889	4	58.72222	9.847826	9.15	218.4444	3.757214	Yes
B X D	4.888889	4	1.222222	0.204969	9.15			
A X D	7.555556	4	1.888889	0.31677	9.15			
error	35.77778	6	5.962963					
Total	5814	26				5814	100	
e-pooled	65.77778	16	4.111111			720	1.838474	

Figure 4.7: Plots for main factors and Interactions (Subject 3)



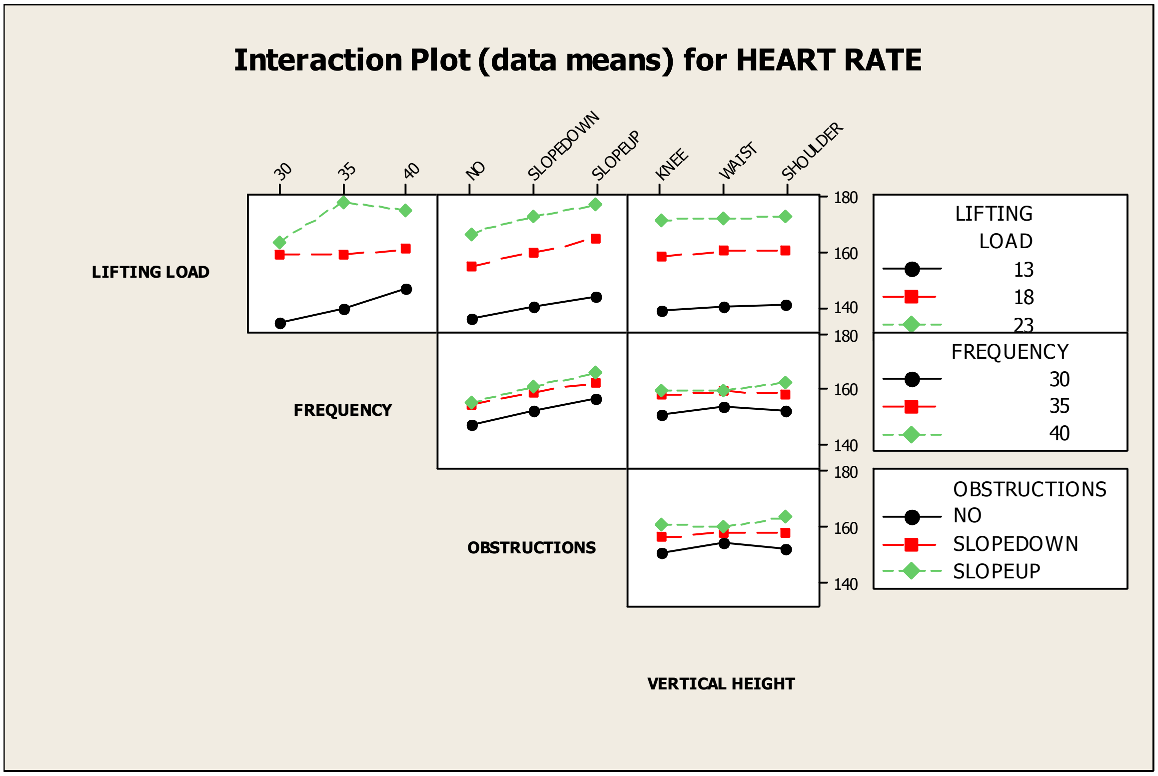
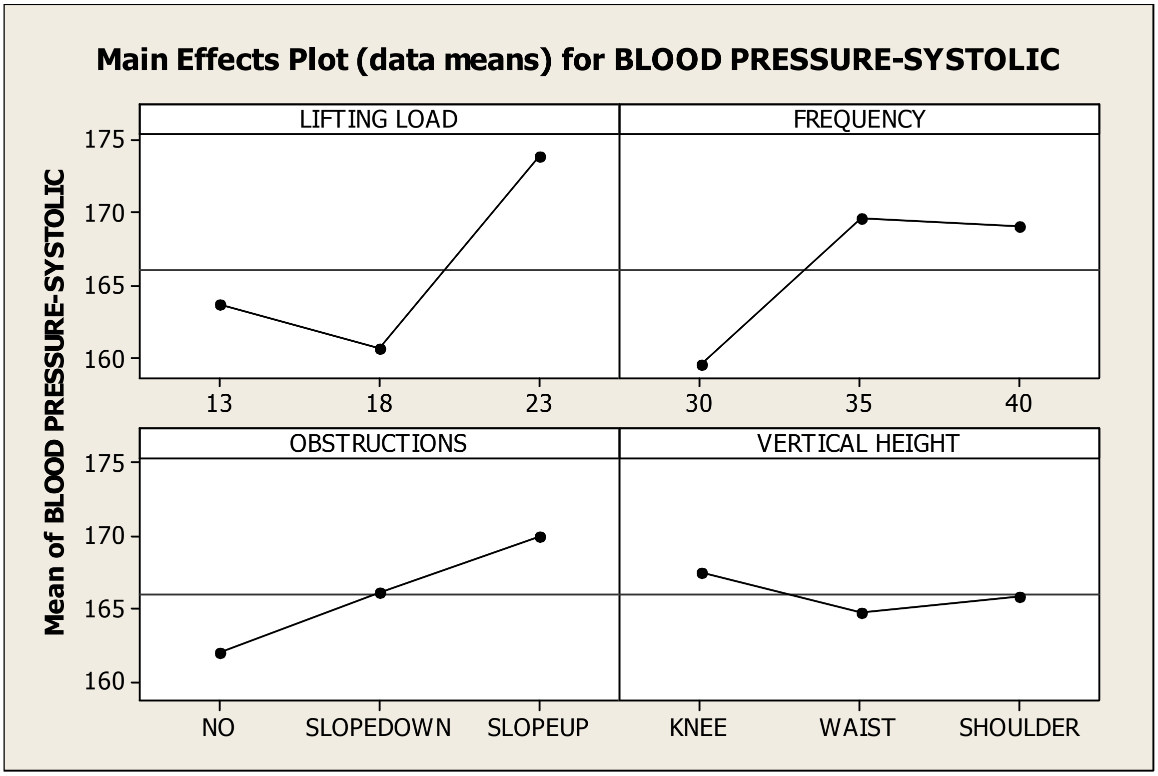


Table 4.19: ANOVA for Blood Pressure (Subject 3)

BLOOD PRESSURE										
	A1			**A2**			**A3**			
	1469			1452			1564			
	LL1=13			LL2=18			LL3 = 23			**LL1**
155					**165**		**163**		knee	1507
	158		**153**					**165**	waist	
		162		**159**		**159**			shoulder	
		169		**161**		**185**			knee	**LL2**
159					**165**		**177**		waist	1485
	167		**159**					**183**	shoulder	
	169		**159**					**181**	knee	
		173		**163**		**172**			waist	**LL3**
157					**168**		**179**		shoulder	1493
No	Sd	Su	No	Sd	Su	No	Sd	Su		
1458				1496				1531	**T=**	4485
D1				**D2**				**D3**		

Source	**SS**	**dof**	**Variance**	**F test**	**F critical**	**SS'**	**C (%)**	**significance**
Lifting load(A)	809.5556	2	404.7778	79.77372	10.93	790.5	39.23726	Yes
Frequency (B)	523.5556	2	261.7778	51.59124	10.93	504.5	25.04136	Yes
Obstructions(C)	27.55556	2	13.77778	2.715328	10.93			
VH(D)	296.2222	2	148.1111	29.18978	10.93	296.2222	14.70329	Yes
A XB	232.8889	4	58.22222	11.47445	9.15	194.7778	9.66799	Yes
B X D	46.88889	4	11.72222	2.310219	9.15			
A X D	47.55556	4	11.88889	2.343066	9.15			
error	30.44444	6	5.074074					
Total	2014.667	26				2014.667	100	
e-pooled	152.4444	16	9.527778			719.6667	11.3501	

Figure 4.8: Plots for main factors and Interactions - B.P. (Subject 3)



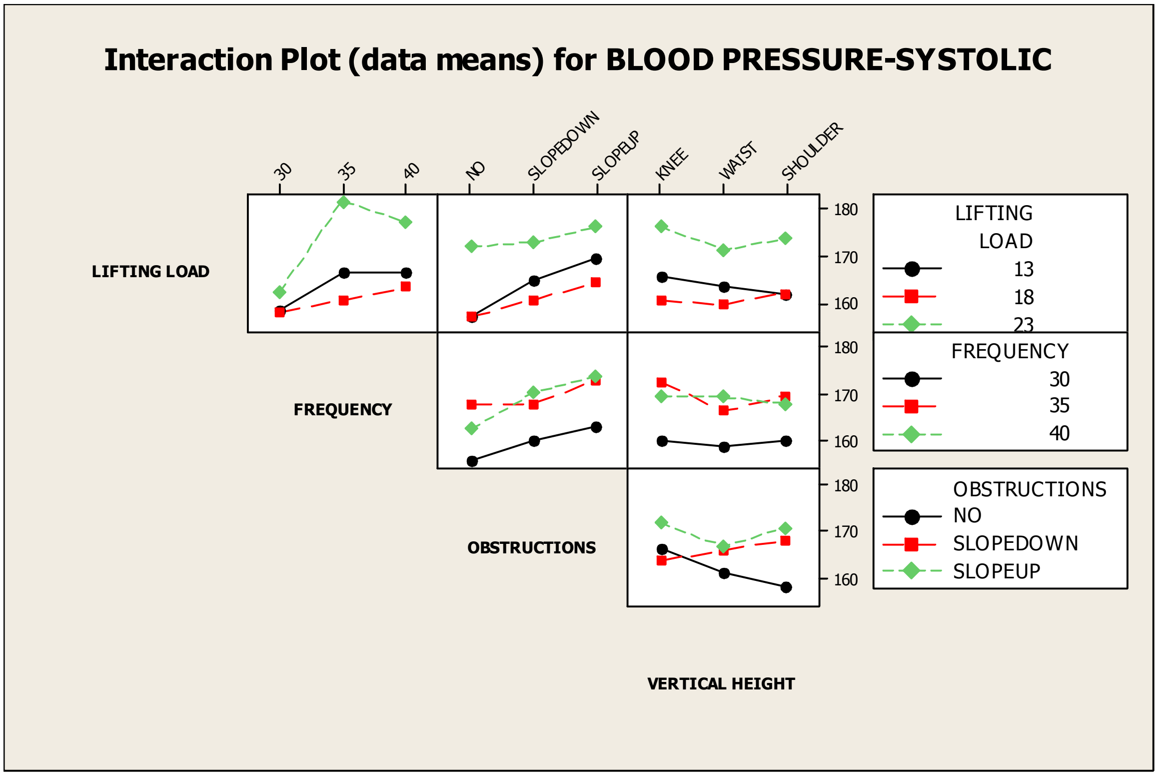
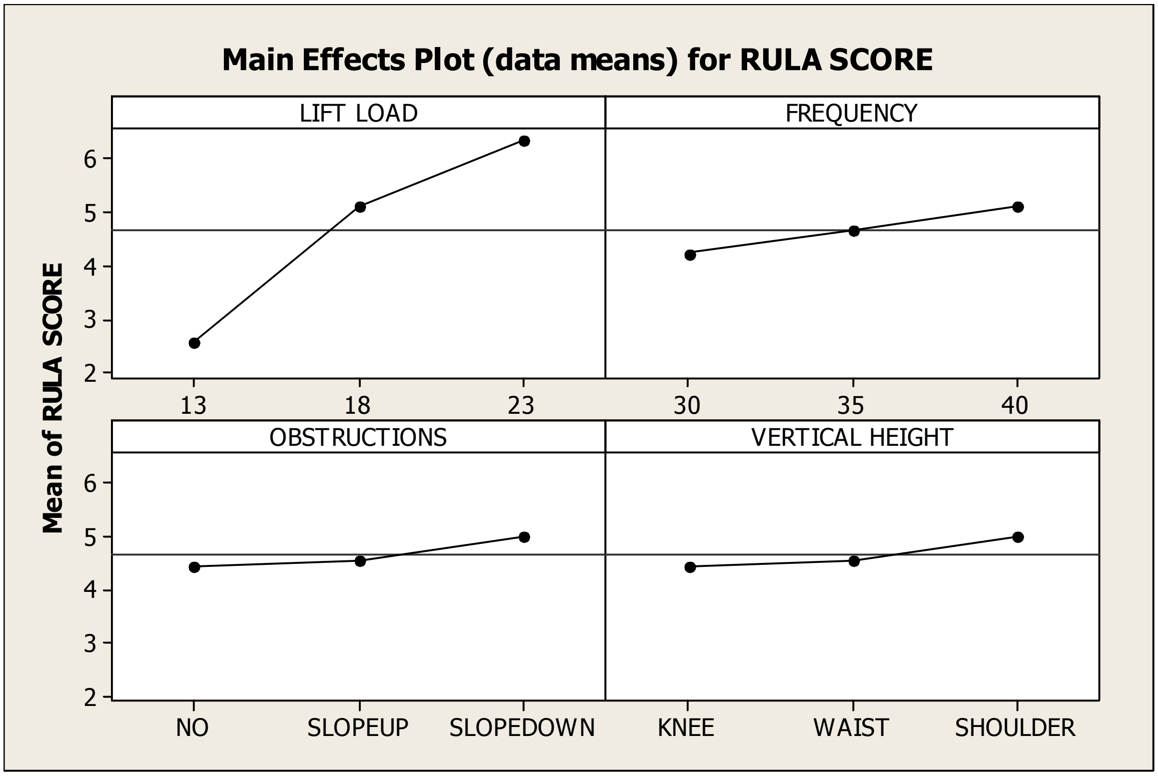


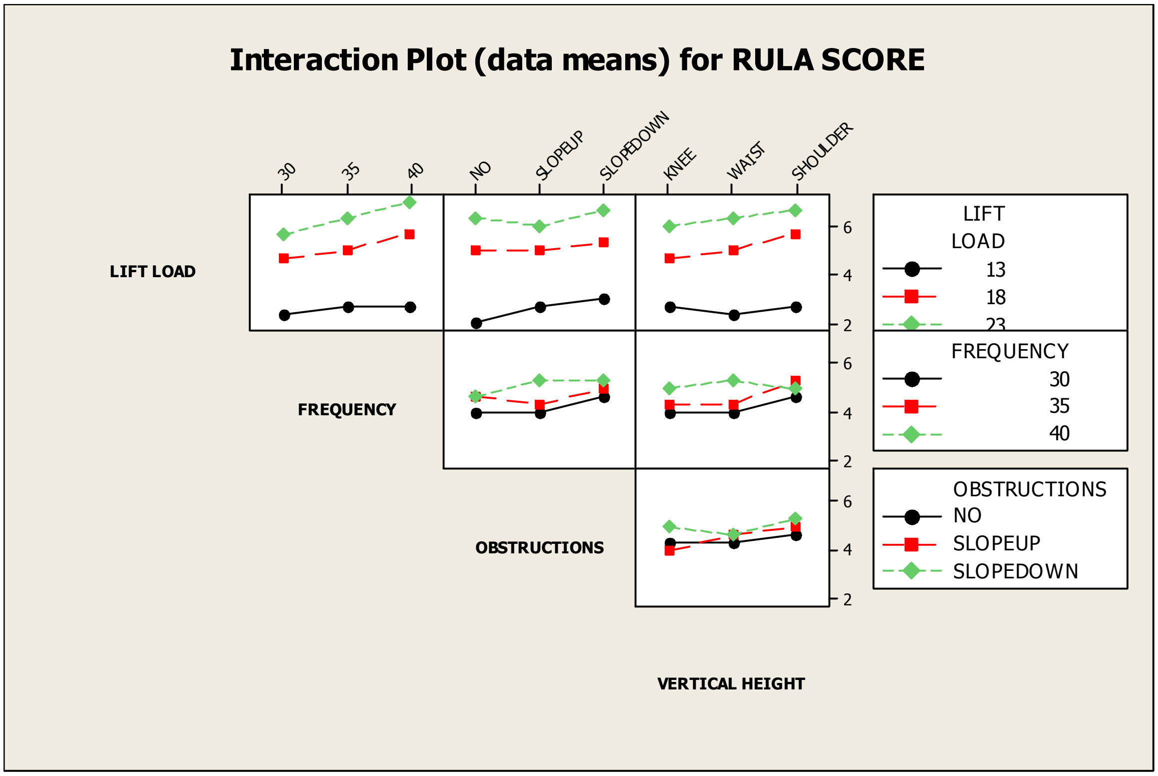
Table 4.20: ANOVA for RULA Score (Subject 3)

RULA SCORE												
			A1			**A2**			**A3**			
			23			35			57			
			LL1=13			LL2=18			LL3 = 23			**LL1**
		2					**5**		**5**		Knee	40
B1	Fre1=30		**2**		**4**					**6**	Waist	
38				**3**		**5**		**6**			Shoulder	
				3		**4**		**6**			Knee	**LL2**
B2	Fre2=35	**2**			**5**				**6**		Waist	36
31			**3**				**6**			**7**	Shoulder	
			3		**5**					**7**	Knee	
B3	Fre3=40			**3**		**6**		**7**			Waist	**LL3**
46		**2**					**6**		**7**		Shoulder	39
		No	Sd	Su	No	Sd	Su	No	Sd	Su		
		34				41				40	**T=**	115
		D1				**D2**				**D3**		

Source	SS	dof	Variance	F test	F critical	SS'	C (%)	significance
Lifting load(A)	66.07407	2	33.03704	63.71429	10.93	64.37037	55.88424	Yes
Frequency (B)	12.51852	2	6.259259	12.07143	10.93	12.51852	10.86817	Yes
Obstructions(C)	0.962963	2	0.481481	0.928571	10.93			
VH(D)	3.185185	2	1.592593	3.071429	10.93			
A XB	21.25926	4	5.314815	10.25	9.15	21.25926	18.45659	Yes
B X D	2.814815	4	0.703704	1.357143	9.15			
A X D	5.259259	4	1.314815	2.535714	9.15			
error	3.111111	6	0.518519					
Total	115.1852	26				115.1852	100	
e-pooled	15.33333	18	0.851852				14.791	

Figure 4.9: Plots for main factors and Interactions – RULA Score (Subject 3)





The results of the 27 trials for Subject 3 are presented below:

The significant factors and their interactions for Subject 1 are listed below in Table 4.5

Table 4.21: Results for Subject 3

Response Type	**Significant Factors and Interactions**
Heart Rate	• Load Weight • Lift frequency • Vertical Height • Interaction of Load Weight and Frequency
Blood Pressure	• Load Weight • Lift frequency • Vertical Height • Interaction of Load Weight and Frequency
RULA Score	• Load Weight • Lift frequency • Interaction of Load Weight and Frequency

a) Estimated value for Heart Rate

The table 4.22 shows mean values for each signficant factor at its each level for heart rate.

Table 4.22: Mean values for Heart Rate

Level	$\overline{A}$	$\overline{B}$	$\overline{D}$
1	140.0	152.3	152.4
2	159.7	158.7	157.7
3	172.2	160.9	161.9

A1B1	134.0
A1B2	139.3
A1B3	146.7
A2B1	159.3
A2B2	159.0
A2B3	161.0
A3B1	163.7
A3B2	178.0
A3B3	175.0

Since Factor C has no significance, hence ignored.

Mean Heart Rate for easy conditions of work (low stress levels)

$$\bar{\mu}_{A_1B_1D_1\,(AB)_1} = \bar{A}_1 + \bar{B}_1 + \bar{D}_1 + (\bar{A}_1\bar{B}_1) - 3\bar{T} = 106.7$$

Confidence Interval around the estimated heart rate

The F ratio is determined from the F-Tables used in ANOVA.

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}} = \sqrt{\frac{2.93 \times 4.1}{2.45}} = 2.21$$

$$n_{eff} = \frac{N}{1 + dof_{A,B,D\&AB}} = \frac{27}{1+2+2+2+4} = 2.45$$

So the confidence interval around the estimated heart rate is 106.7 ± 2.21

b) Estimated value for Blood Pressure

The table 4.23 shows mean values for each signficant factor at its each level for Blood Pressure

Table 4.23: Mean values for Blood Pressure

Level	$\bar{A}$	$\bar{B}$	$\bar{D}$
1	163.2	159.9	162.0
2	161.3	169.4	166.2
3	173.8	169.0	170.1

A1B1	158.3
A1B2	165.0
A1B3	166.3
A2B1	159.0
A2B2	161.7
A2B3	163.3
A3B1	162.3
A3B2	181.7
A3B3	177.3

Since Factor C has no significance, hence ignored.

Mean Blood Pressure for easy conditions of work (low stress levels)

$$\overline{\mu}_{A_2B_1D_1\,(AB)_1} = \overline{A}_2 + \overline{B}_1 + \overline{D}_1 + (\overline{A}_1\overline{B}_1) - 3\overline{T} = 143.2$$

Confidence Interval around the estimated Blood Pressure

The F ratio is determined from the F-Tables used in ANOVA.

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2}V_e}{n_{eff}}} = \sqrt{\frac{2.93\times 9.5}{2.45}} = 11.36$$

$$n_{eff} = \frac{N}{1+dof_{A,B,D\&AB}} = \frac{27}{1+2+2+2+4} = 2.45$$

So the confidence interval around the estimated RULA Score is 143.2 ± 11.36

c) Estimated value for Posture (RULA) score

The Table 4.24 shows mean values for each signficant factor at its each level for RULA Score.

Table 4.24: Mean values for RULA Score

Level	$\overline{A}$	$\overline{B}$
1	2.5	3.3
2	3.9	3.9
3	6.3	4.4

Mean RULA score for easy conditions of work (low stress levels)

$$\overline{\mu}_{A_1B_1} = 2.5 + 3.9 - 4.3 = 2.1$$

Some other observations from the plots could also be made:

- Load Weight and frequency are the two foremost important factors affecting the workmen during Lifting and Carrying Tasks
- The interaction between Load carried and the frequency of lift significantly affects the stress measured in terms of heart rate, blood pressure or RULA score
- The Lifting equation developed by NIOSH which does not consider such interactions may need modifications to include some of the important interactions.
- The obstructions en route has little impact on the stress levels of this subject during the experimental trial conditions.

- Interactions between Load Weight and Frequency were found to be significant and needs further elaboration.
- Similarly interaction between Load Weight and Vertical Height of load at destination needs further analysis.
- For placing the load weight at knee, waist or shoulder height level, it was observed that the best heart rate condition exists for waist height

Load Weight and Frequency makes the most significant on the stress levels on this subject where stress level is measured through the combined effect of heart rate, blood pressure and RULA score.

4.2.4 Results for Subject 4

The results for subject 3 wherein the three response variables for each of the 27 trials conducted are shown in Table 4.25 below. The ANOVA analysis for heart rate, blood pressure and RULA score are shown in Tables 4.26, 4.27 and 4.28 respectively. The respective plots for the significant factors and their interactions are shown in figure 4.10, 4.11 and 4.12.

Table 4.25: Response values for Subject 4

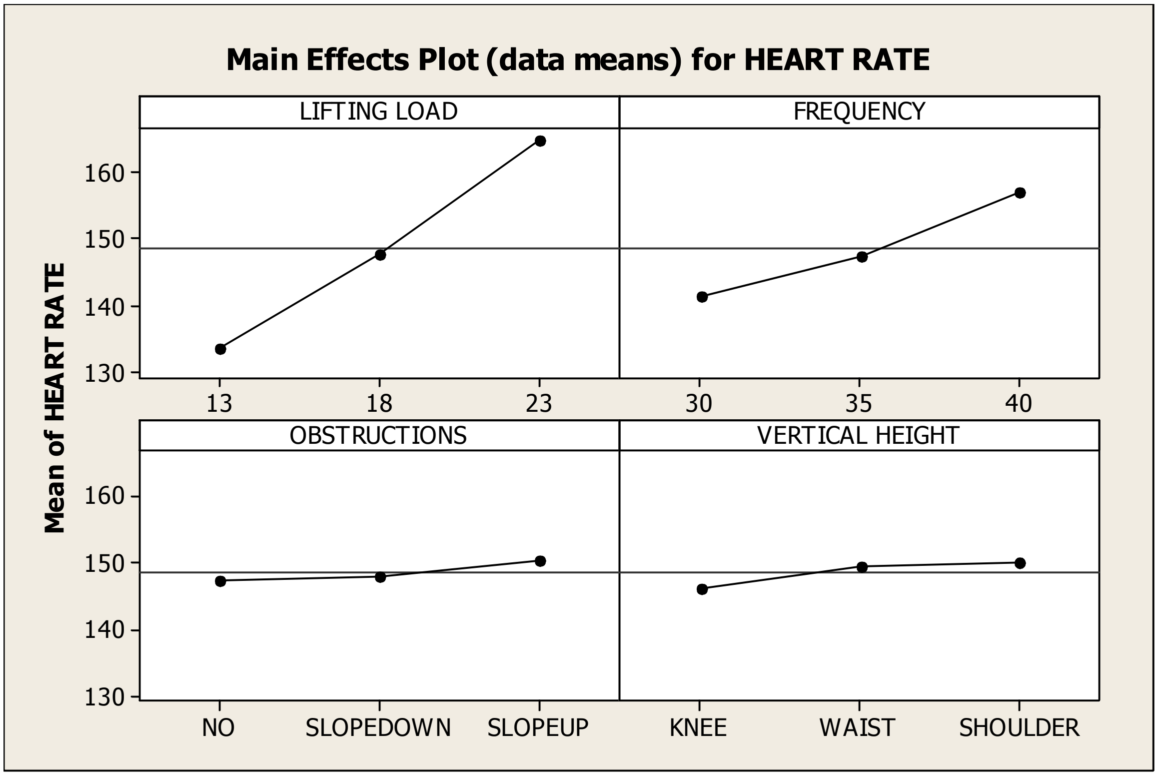
S.NO	Lift Load	Frequency	Obstructions	Vertical Height	RULA Score	Heart Rate-after	BP-systolic
1.	13	30	No	Knee	2	123	135
2.	13	30	Slope down	Waist	3	129	142
3.	13	30	Slope up	Shoulder	3	135	151
4.	13	35	No	Waist	3	127	127
5.	13	35	Slope down	Shoulder	3	135	135
6.	13	35	Slope up	Knee	3	138	138
7.	13	40	No	Shoulder	4	133	133
8.	13	40	Slope down	Knee	4	139	139
9.	13	40	Slope up	Waist	4	142	142
10.	18	30	Slope up	Knee	5	138	138
11.	18	30	No	Waist	4	143	159
12.	18	30	Slope down	Shoulder	5	145	162
13.	18	35	Slope up	Waist	6	147	165
14.	18	35	No	Shoulder	5	139	159
15.	18	35	Slope down	Knee	5	142	142
16.	18	40	Slope up	Shoulder	6	162	162
17.	18	40	No	Knee	6	153	153
18.	18	40	Slope down	Waist	6	159	159
19.	23	30	Slope down	Knee	5	147	159
20.	23	30	Slope up	Waist	6	153	153
21.	23	30	No	Shoulder	6	159	162
22.	23	35	Slope down	Waist	6	163	160
23.	23	35	Slope up	Shoulder	7	169	166
24.	23	35	No	Knee	6	167	153
25.	23	40	Slope down	Shoulder	7	173	180
26.	23	40	Slope up	Knee	7	169	178
27.	23	40	No	Waist	7	183	174

Table 4.26: ANOVA for Heart Rate (Subject 4)

HEART RATE												
			A1			**A2**			**A3**			
			1201			1328			1483			
			LL1=13			LL2=18			LL3 = 23			**LL1**
		123					**138**		**147**		knee	1316
B1	**Fre1=30**		**129**		**143**					**153**	waist	
1272				**135**		**145**		**159**			shoulder	
				138		**142**		**167**			knee	**LL2**
B2	**Fre2=35**	**127**					**147**		**163**		waist	1346
1327			**135**		**139**					**169**	shoulder	
			139		**153**					**169**	knee	
B3	**Fre3=40**			**142**		**159**		**183**			waist	**LL3**
1413		**133**					**162**		**173**		shoulder	1350
		No	Sd	Su	No	Sd	Su	No	Sd	Su		
		1327				1332				1353	**T=**	4012
		D1				**D2**				**D3**		

Source	SS	dof	Variance	F test	F critical	SS'	C (%)	Significance
Lifting load(A)	4432.519	2	2216.259	391.1046	10.93	4404.762	70.40276	Yes
Frequency (B)	1122.296	2	561.1481	99.02614	10.93	1094.54	17.49439	Yes
Obstructions(C)	76.74074	2	38.37037	6.771242	10.93			
VH(D)	42.2963	2	21.14815	3.732026	10.93			
A XB	227.7037	4	56.92593	10.04575	9.15	172.1905	2.752177	Yes
B X D	41.25926	4	10.31481	1.820261	9.15			
A X D	279.7037	4	69.92593	12.33987	9.15	224.1905	3.58331	Yes
error	34	6	5.666667					
Total	6256.519	26				6256.519	100	
e-pooled	194.2963	14	13.87831			757.2169	5.767361	

Figure 4.10: Plots for main factors and Interactions (Subject 4)



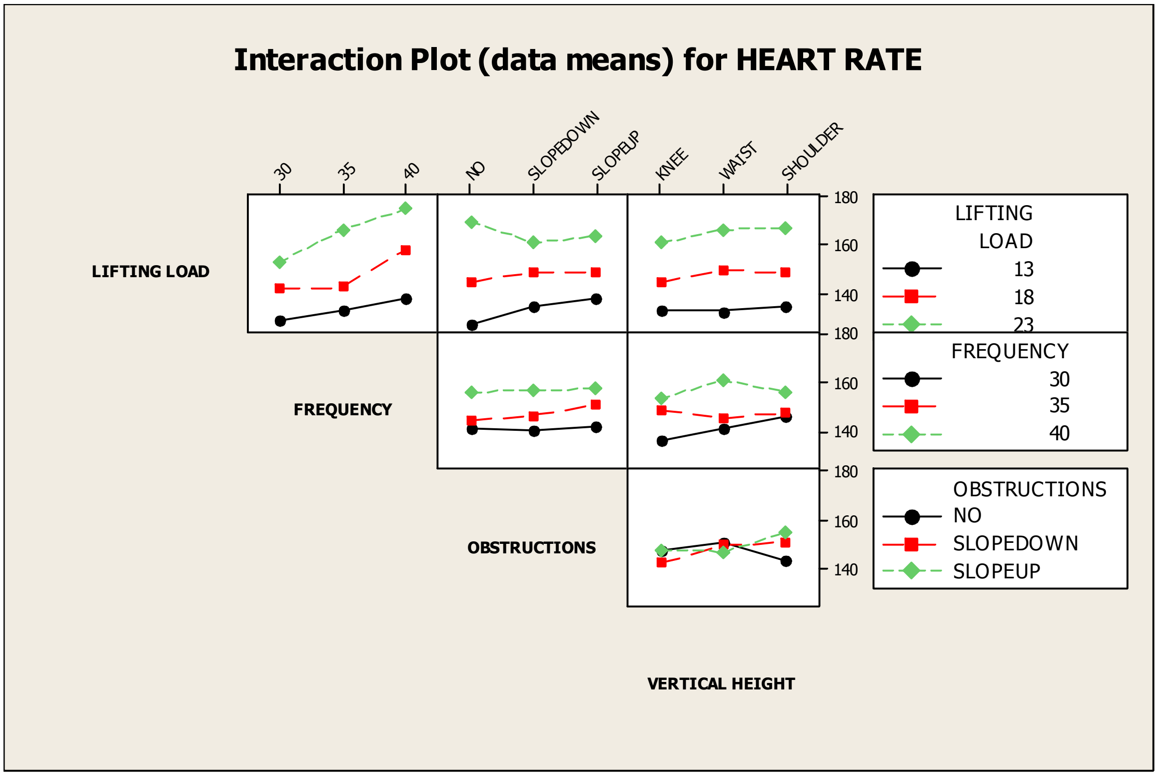


Table 4.27: ANOVA for Blood Pressure (Subject 4)

BLOOD PRESSURE												
			A1			**A2**			**A3**			
			1326			1432			1504			
			LL1=13			LL2=18			LL3 = 23			**LL1**
		135					**151**		**159**		knee	1384
B1	Fre1=30		**142**		**159**					**172**	waist	
1393				**151**		**162**		**162**			shoulder	
				149		**163**		**153**			knee	**LL2**
B2	Fre2=35	**139**					**165**		**160**		waist	1437
1405			**151**		**159**					**166**	shoulder	
			145		**151**					**178**	knee	
B3	Fre3=40			**167**		**159**		**174**			waist	**LL3**
1464		**147**					**163**		**180**		shoulder	1441
		No	Sd	Su	No	Sd	Su	No	Sd	Su		
		1379				1421				1462	**T=**	4262
		D1				**D2**				**D3**		

Source	**SS**	**dof**	**Variance**	**F test**	**F critical**	**SS'**	**C (%)**	**Significance**
Liftingload(A)	1781.63	2	890.8148	88.75277	10.93	1745.397	51.98645	Yes
Frequency (B)	320.963	2	160.4815	15.98893	10.93	284.7302	8.480656	Yes
Obstructions(C)	224.963	2	112.4815	11.20664	10.93	188.7302	5.621306	Yes
VH(D)	382.7407	2	191.3704	19.06642	10.93	346.5079	10.3207	Yes
A XB	393.4815	4	98.37037	9.800738	9.15	321.0159	9.561421	Yes
B X D	52.37037	4	13.09259	1.304428	9.15			
A X D	141.037	4	35.25926	3.512915	9.15			
error	60.22222	6	10.03704					
Total	3357.407	26				3357.407	100	
e-pooled	253.6296	14	18.1164			1327.28	14.02947	

Figure 4.11: Plots for main factors and Interactions - B.P. (Subject 4)

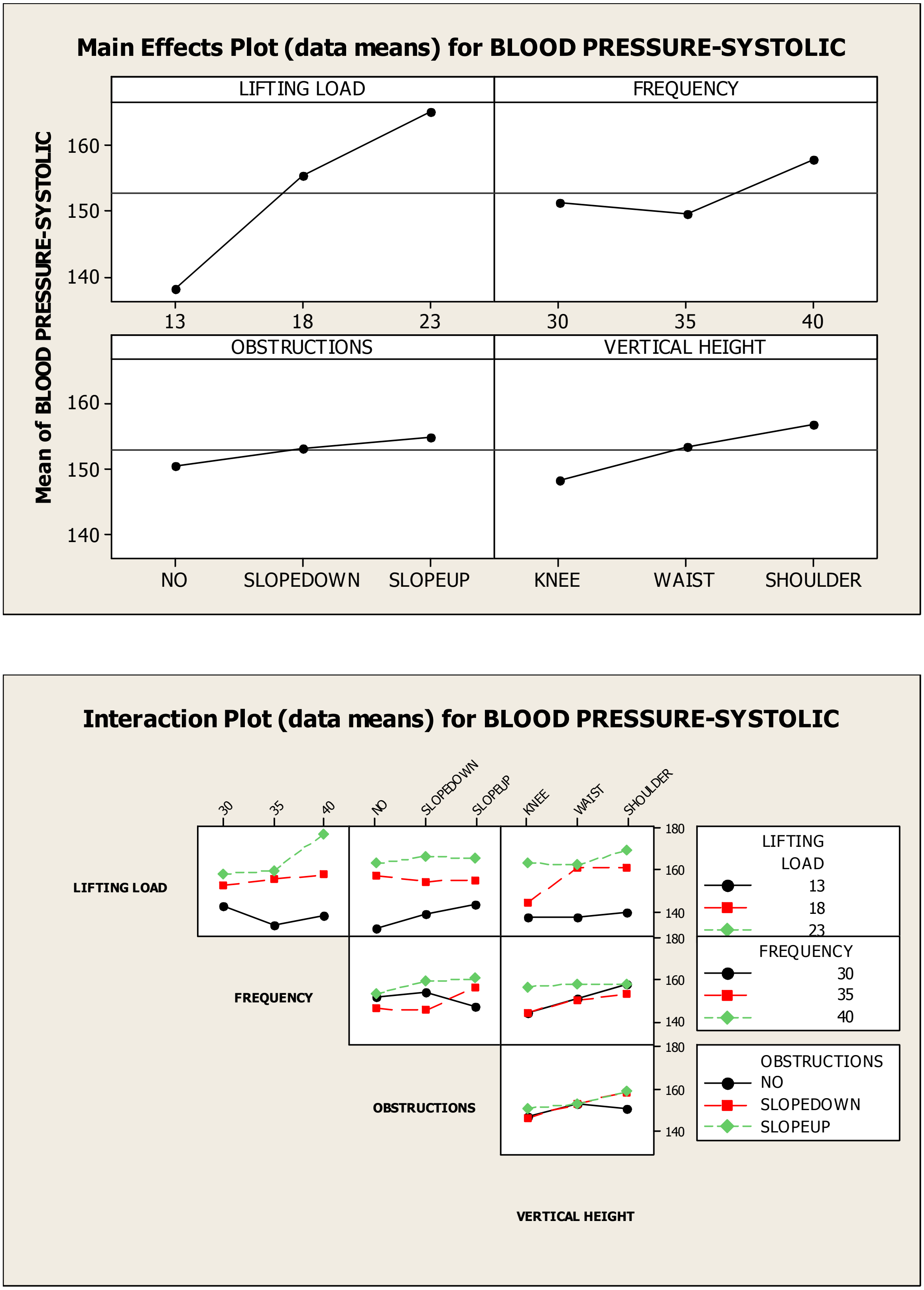
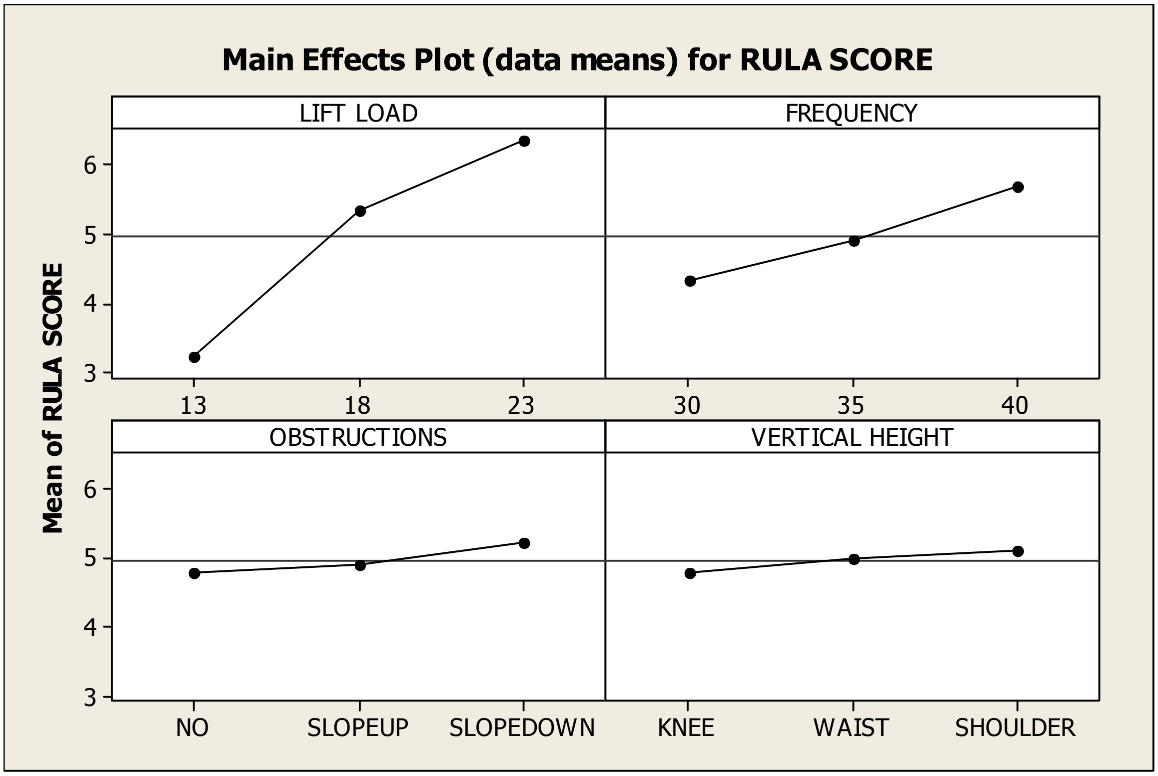


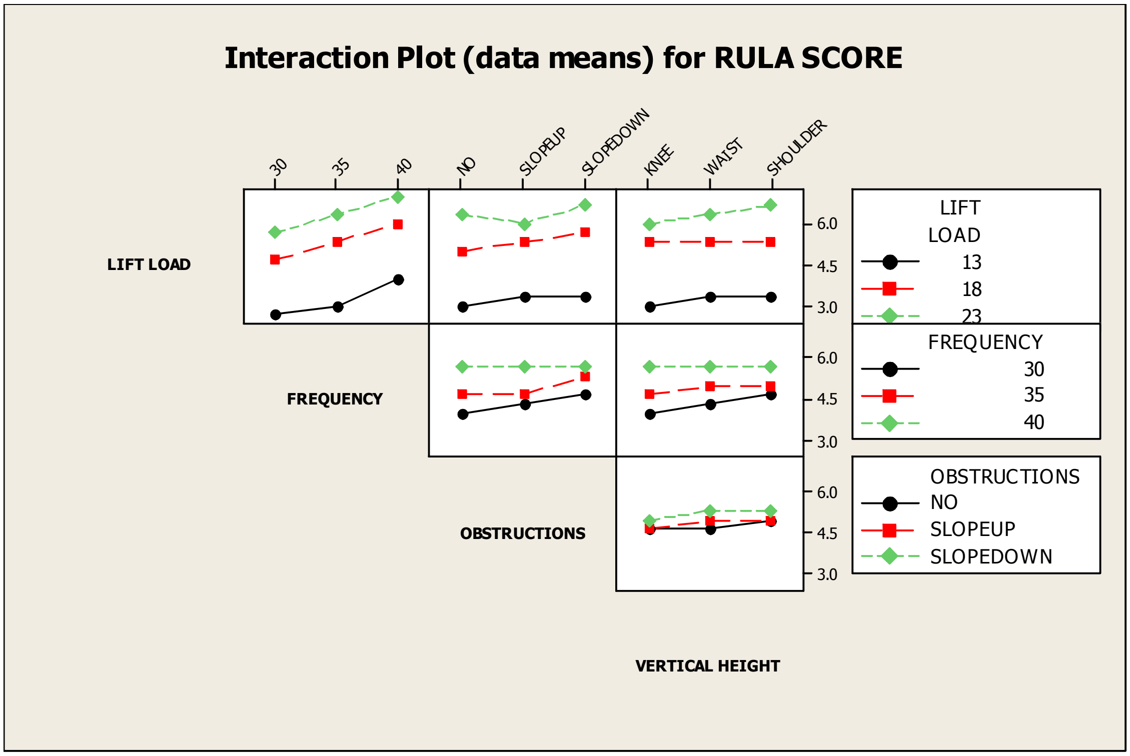
Table 4.28: ANOVA for RULA Score (Subject 4)

RULA SCORE												
			A1			**A2**			**A3**			
			29			48			57			
			LL1=13			LL2=18			LL3 = 23			**LL1**
		2					**5**		**5**		knee	43
B1	Fre1=30		**3**		**4**					**6**	waist	
39				**3**		**5**		**6**			shoulder	
				3		**5**		**6**			knee	**LL2**
B2	Fre2=35	**3**					**6**		**6**		waist	45
44			**3**		**5**					**7**	shoulder	
			4		**6**					**7**	knee	
B3	Fre3=40			**4**		**6**		**7**			waist	**LL3**
51		**4**					**6**		**7**		shoulder	46
		No	Sd	Su	No	Sd	Su	No	Sd	Su		
		43				44				47	**T=**	134
		D1				**D2**				**D3**		

Source	**SS**	**dof**	**Variance**	**F test**	**F critical**	**SS'**	**C (%)**	**Significance**
Lifting load(A)	45.4074	2	22.707	204.333	10.93	45.0158	79.026	Yes
Frequency (B)	8.07407	2	4.0370	36.3333	10.93	7.6825	13.486	Yes
Obstructions(C)	0.51851	2	0.2592	2.33333	10.93			
VH(D)	0.96296	2	0.4814	4.33333	10.93			
A XB	0.14814	4	0.0370	0.33333	9.15			
B X D	0.59259	4	0.1481	1.33333	9.15			
A X D	0.59259	4	0.1481	1.33333	9.15			
error	0.66666	6	0.1111					
Total	56.9629	26				56.9629	100	
e-pooled	2.74074	22	0.1245			4.26455	7.486	

Figure 4.12: Plots for main factors and Interactions – RULA Score (Subject 4)





The results of the 27 trials for Subject 4 are presented below:

The significant factors and their interactions for Subject 1 are listed below in Table 4.29

Table 4.29: Results for Subject 4

Response Type	Significant Factors and Interactions
Heart Rate	• Load Weight • Lift frequency • Interaction of Load weight vs. Vertical Height • Interaction of Load Weight and Frequency
Blood Pressure	• Load Weight • Lift frequency • Vertical Height • Interaction of Load Weight and Frequency
RULA Score	• Load Weight • Lift frequency

a) Estimated value for Heart Rate

The table 4.30 shows mean values for each signficant factor at its each level for heart rate.

Table 4.30: Mean values for Heart Rate

Level	$\overline{A}$	$\overline{B}$
1	133.4	141.3
2	147.5	147.4
3	164.8	157.0

A1B1	129.0	A1D1	127.7
A1B2	133.3	A1D2	134.3
A1B3	138.0	A1D3	138.3
A2B1	142.0	A2D1	145.0
A2B2	142.7	A2D2	148.7
A2B3	158.0	A2D3	149.0
A3B1	153.0	A3D1	169.7
A3B2	166.3	A3D2	161.0
A3B3	175.0	A3D3	163.7

Since Factor C has no significance, hence ignored.

Mean Heart Rate for easy conditions of work (low stress levels)

$$\overline{\mu}_{A_1B_1(AB)_1(AD)_1} = \overline{A}_1 + \overline{B}_1 + \left(\overline{A}_1\overline{D}_1\right) + (\overline{A}_1\overline{B}_1) - 3\overline{T} = 85.6$$

Confidence Interval around the estimated heart rate

The F ratio is determined from the F-Tables used in ANOVA.

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2}V_e}{n_{eff}}} = \sqrt{\frac{2.93 \times 13.87}{2.07}} = 4.43$$

$$n_{eff} = \frac{N}{1 + dof_{A,B,AD\&AB}} = \frac{27}{1+2+2+4+4} = 2.07$$

So the confidence interval around the estimated heart rate is 85.6 ± 4.43

b) Estimated value for Blood Pressure

The table 4.31 shows mean values for each signficant factor at its each level for Blood Pressure.

Table 4.31: Mean values for Blood Pressure

Level	$\overline{A}$	$\overline{B}$	$\overline{D}$
1	147.3	154.8	153.2
2	159.1	156.1	157.9
3	167.1	162.7	162.4

A1B1	142.7
A1B2	146.3
A1B3	153.0
A2B1	157.3
A2B2	162.3
A2B3	157.7
A3B1	164.3
A3B2	159.7
A3B3	177.3

Since Factor C has no significance, hence ignored.

Mean Blood Pressure for easy conditions of work (low stress levels)

$$\overline{\mu}_{A_1B_1D_1\,(AB)_1} = \overline{A}_1 + \overline{B}_1 + \overline{D}_1 + (\overline{A}_1\overline{B}_1) - 3\overline{T} = 124.4$$

Confidence Interval around the estimated Blood Pressure

The F ratio is determined from the F-Tables used in ANOVA.

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2}V_e}{n_{eff}}} = \sqrt{\frac{2.93\times 18.1}{2.45}} = 4.6$$

$$n_{eff} = \frac{N}{1+dof_{A,B,D\&AB}} = \frac{27}{1+2+2+2+4} = 2.45$$

So the confidence interval around the estimated Blood Pressure is 124.4 ± 4.6

c) Estimated value for Posture (RULA) score

The Table 4.24 shows mean values for each signficant factor at its each level for RULA Score.

Table 4.24: Mean values for RULA Score

Level	$\overline{A}$	$\overline{B}$
1	3.2	4.3
2	5.3	4.9
3	6.3	5.7

Mean RULA score for easy conditions of work (low stress levels)

$$\overline{\mu}_{A_1B_1} = 3.2 + 4.3 - 5.0 = 2.5$$

Some other observations from the plots could also be made:

- Load Weight and frequency are the two foremost important factors affecting the workmen during Lifting and Carrying Tasks
- The obstructions en route has little impact on the stress levels of this subject during the experimental trial conditions.
- The lift vertical height also does not have a large impact at least for this subject.
- The stress level varies from individual to individual as vertical height had impact for the other three subjects.

- Interactions between Load Weight and Frequency were found to be significant and needs further elaboration.
- Similarly interaction between Load Weight and Vertical Height of load at destination needs further analysis.

Load Weight and Frequency makes the most significant on the stress levels on this subject where stress level is measured through the combined effect of heart rate, blood pressure and RULA score.

CHAPTER 5: EXPERIMENTAL DESIGN

5.1 Further Analysis of Results

All previous analysis discussed in Chapter 4 addressed factors which might affect the average response, but there is an interest on effect of variation as well. Taguchi has created a transformation of repetition data to another value which is a measure of variation present. The transformation is the signal to noise (S/N) ratio. The S/N ratio consolidates several repetitions into one value which reflects the amount of variation present. The values of all the results according to Taguchi array parameter design layout are presented in this chapter.

Signal-to-noise ratio. The Taguchi method uses the signal-to-noise ratio (S/N) to express the scatter around a target value. A high value of S/N implies that the signal is much higher than the random effects of the noise factors. The noise is usually due to the uncontrollable factors, which exist in the environment, often cannot be eliminated and cause variations in the output. Hence, in the context of this study, the noise is attributed to different subjects used for experimental analysis.

5.2 Different S/N Ratios

The S/N ratio, which condenses the multiple data points within a trial, depends on the type of characteristic being evaluated. Since all the stress or fatigue measurement responses like Heart Rate, Blood Pressure and Posture (RULA) scores are Lower the best situations, only this process of calculating Signal to Noise (S/N) is explained here.

Lower-the-better response

The S/N_s for lower the better is used for situations where the target value is zero. The equation is

$$S/N_{LB} = -10\log(MSD) = -10\log[(\frac{1}{r}\sum_{i=1}^{r} y^2{}_i)$$

Where r is the number of tests in a trial (noise of repetitions regardless of noise levels)

$\sum_{i=1}^{r} y^2{}_i$ = summation of all response values under each trial

Computation of average performance: Average performance of a factor at certain level is the influence of the factor at this level on the mean response of the experiments. To compute the average performance of the factor A at level 1 (denoted as A1), results for trials including factor A1 were added and then divided by the number of such trials:

5.3 Calculation of S/N ratios to consolidate responses of 4 subjects

The S/N ratios for the three response factors have been calculated separately to identify the major contributing factors and interactions to variation observed in results for the four subjects. Tables below show the results separately for Heart rate, Blood Pressure and Posture (RULA) Score.

5.3.1 S/N Analysis for Heart Rate

Table 5.1 below represents data gathered for increase in heart rate each experimental run.

Table 5.1: S/N ratio calculation for Heart Rate

Lift Load	Frequency	Obstructions	Vertical Height	Subject 1 Y1	Subject 2 Y2	Subject 1 Y3	Subject 1 Y4	Mean response $\overline{T} = T / N$	S/N (Lower the best)
13	30	No	Knee	92	125	127	123	116.75	-41.4103
13	30	Slope down	Waist	99	132	135	129	123.75	-41.9097
13	30	Slope up	Shoulder	115	145	140	135	133.75	-42.5572
13	35	No	Waist	96	138	137	127	124.5	-41.9837
13	35	Slope down	Shoulder	116	142	139	135	133	-42.5021
13	35	Slope up	Knee	124	142	142	138	136.5	-42.7154
13	40	No	Shoulder	120	145	144	133	135.5	-42.6629
13	40	Slope down	Knee	126	143	147	139	138.75	-42.8587
13	40	Slope up	Waist	129	152	149	142	143	-43.1234
18	30	Slope up	Knee	135	157	162	138	148	-43.4322
18	30	No	Waist	140	153	157	143	148.25	-43.4295
18	30	Slope down	Shoulder	142	161	159	145	151.75	-43.6357
18	35	Slope up	Waist	133	167	163	147	152.5	-43.6994
18	35	No	Shoulder	156	161	154	139	152.5	-43.6779
18	35	Slope down	Knee	151	154	160	142	151.75	-43.6305
18	40	Slope up	Shoulder	143	163	169	162	159.25	-44.0579
18	40	No	Knee	157	154	153	153	154.25	-43.765
18	40	Slope down	Waist	159	157	161	159	159	-44.0283
23	30	Slope down	Knee	145	159	163	147	153.5	-43.733
23	30	Slope up	Waist	157	167	169	153	161.5	-44.1709
23	30	No	Shoulder	154	162	159	159	158.5	-44.002
23	35	Slope down	Waist	169	171	179	163	170.5	-44.6394
23	35	Slope up	Shoulder	163	164	183	169	169.75	-44.6058
23	35	No	Knee	175	179	172	167	173.25	-44.7384
23	40	Slope down	Shoulder	167	171	176	173	171.75	-44.7374
23	40	Slope up	Knee	169	166	180	169	171	-44.6642
23	40	No	Waist	159	165	169	183	169	-44.5696

Where T = Y1+Y2+Y3+Y4

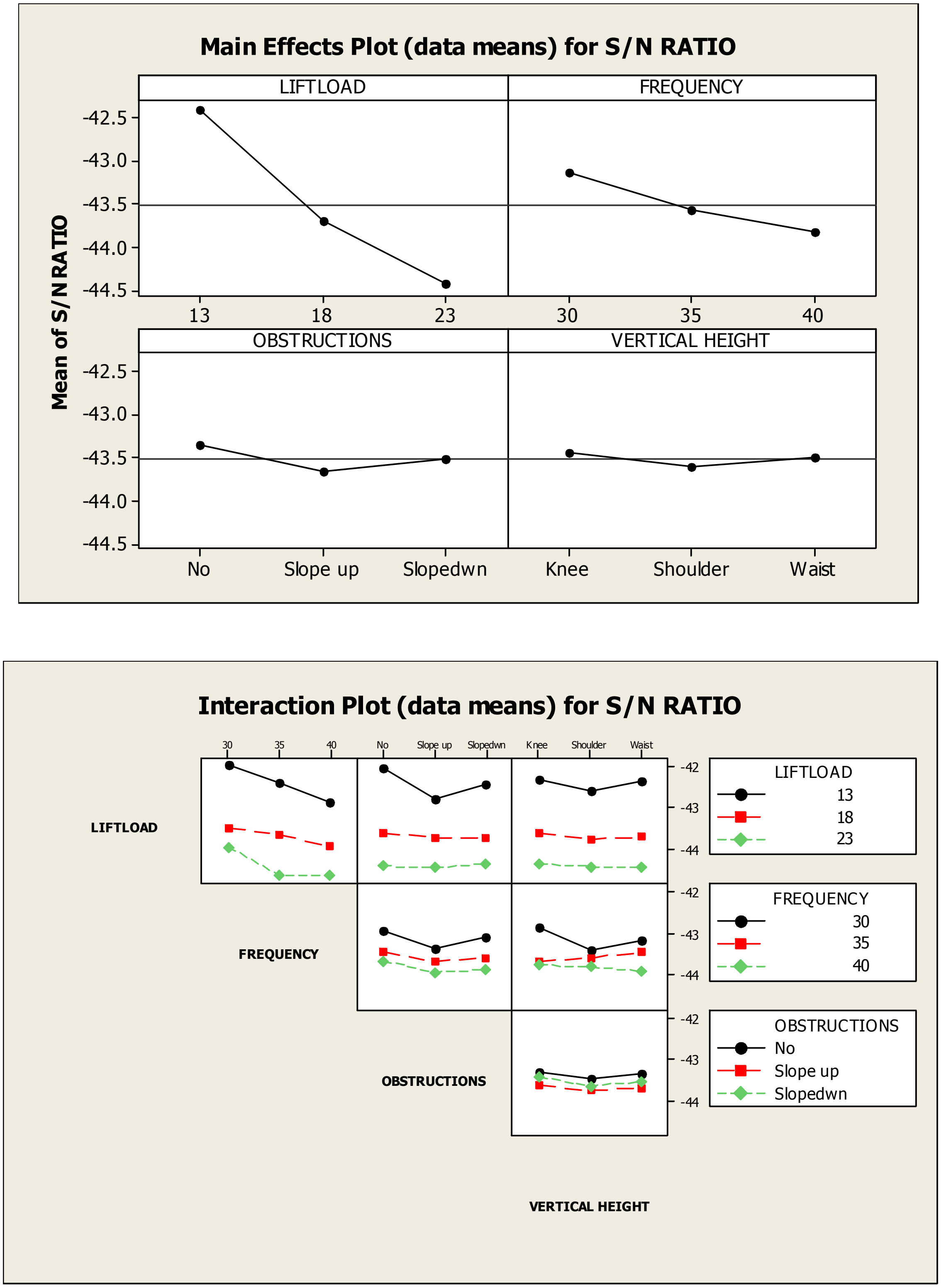
By conducting ANOVA on the S/N we obtain the following ANOVA table (Table 5.2)

Table 5.2: ANOVA table for signal to noise ratio

Source	SS	dof	Variance	F test	F critical	SS'	C (%)
Lifting load(A)	18.76275	2	9.381375	541.7844	10.93	18.61097	82.49323
Frequency (B)	2.176184	2	1.088092	62.83848	10.93	2.024406	8.973192
Obstructions(C)	0.124977	2	0.062489	3.60878	10.93		
VH(D)	0.431682	2	0.215841	12.46504	10.93	0.227824	1.009831
A XB	0.366628	4	0.091657	5.293294	9.15		
B X D	0.063111	4	0.015778	0.911177	9.15		
A X D	0.531379	4	0.132845	7.671933	9.15		
Error	0.103894	6	0.017316				
Total	22.56061	26				22.56061	100
e-pooled	1.517777	20	0.075889			1.925227	7.523748

The plots of main and interacting factors are shown in figure 5.1

Figure 5.1: Plots of Main and Interacting Factors – Heart Rate



The ANOVA analysis clearly depicts the major effect of Load weight and Frequency on the variation seen between subject to subject. The interactions though have minor affect in causing variations in the output response. The plots show that as the load weight and the frequency of lift increases, the variation between the subjects increase further thereby indicating the individual differences that creep in because of factors like muscle strength, physical fitness of each individual. Similar analysis for S/N ratios has been done for the other two responses i.e. Blood Pressure and RULA score.

5.3.2 S/N Analysis for Blood Pressure

Table 5.3 below represents data gathered for increase in blood pressure in each experimental run.

Table 5.3: S/N ratio calculation for Blood Pressure

Lift Load	Frequency	Obstructions	Vertical Height	Subject 1 Y1	Subject 2 Y2	Subject 3 Y3	Subject 4 Y4	Mean response $\overline{T} = T / N$ Where T = Y1+Y2+Y3+Y4	S/N (Lower the best)
13	30	No	Knee	162	147	155	135	149.75	-43.527
13	30	Slope down	Waist	169	153	158	142	155.5	-43.852
13	30	Slope up	Shoulder	175	160	162	151	162	-44.202
13	35	No	Waist	163	158	159	159	159.75	-44.069
13	35	Slope down	Shoulder	170	167	167	151	163.75	-44.293
13	35	Slope up	Knee	169	160	173	149	162.75	-44.244
13	40	No	Shoulder	169	165	157	147	159.5	-44.067
13	40	Slope down	Knee	166	160	169	145	160	-44.097
13	40	Slope up	Waist	169	171	173	167	170	-44.61
18	30	Slope up	Knee	169	163	165	159	164	-44.299
18	30	No	Waist	170	160	153	159	160.5	-44.116
18	30	Slope down	Shoulder	175	170	159	162	166.5	-44.435
18	35	Slope up	Waist	171	165	165	165	166.5	-44.429
18	35	No	Shoulder	174	167	159	159	164.75	-44.343
18	35	Slope down	Knee	164	159	162	163	162	-44.191
18	40	Slope up	Shoulder	183	152	168	163	166.5	-44.448
18	40	No	Knee	170	152	159	151	158	-43.983

18	40	Slope down	Waist	173	160	163	151	161.75	-44.187
23	30	Slope down	Knee	168	156	163	159	161.5	-44.167
23	30	Slope up	Waist	175	162	165	172	168.5	-44.536
23	30	No	Shoulder	174	163	183	162	170.5	-44.673
23	35	Slope down	Waist	174	162	177	160	168.25	-44.527
23	35	Slope up	Shoulder	184	170	183	166	175.75	-44.907
23	35	No	Knee	169	162	185	153	167.25	-44.489
23	40	Slope down	Shoulder	186	169	179	180	178.5	-45.038
23	40	Slope up	Knee	183	165	181	178	176.75	-44.954
23	40	No	Waist	177	160	172	174	170.75	-44.653

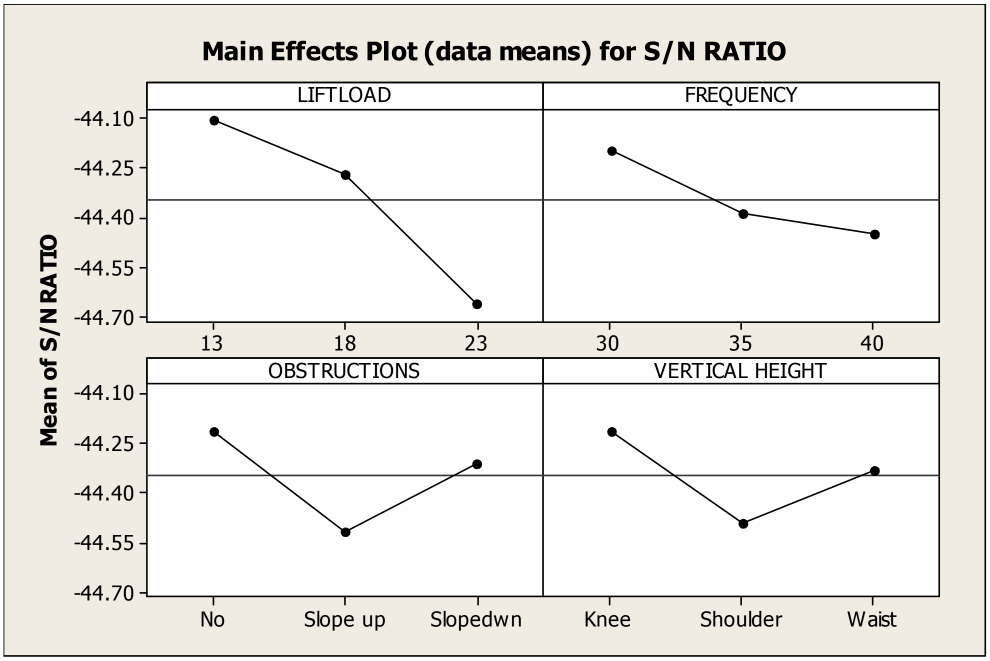
By conducting ANOVA on the S/N we obtain the following ANOVA table (Table 5.4)

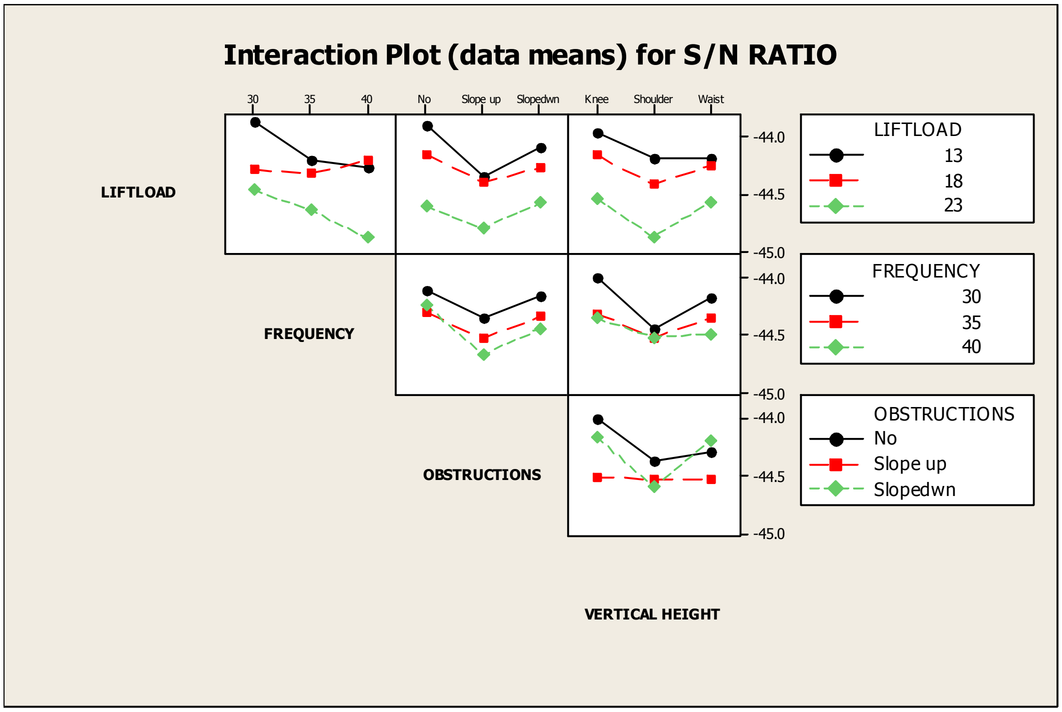
Table 5.4: ANOVA table for signal to noise ratio

Source	SS	dof	Variance	F test	F critical	SS'	C (%)
Lifting load(A)	1.456754	2	0.728377	63.90954	10.93	1.328229	44.53862
Frequency (B)	0.300339	2	0.150169	13.17623	10.93	0.171814	5.761332
Obstructions(C)	0.337783	2	0.168891	14.81894	10.93	0.209258	7.016916
VH(D)	0.425309	2	0.212654	18.6588	10.93	0.425309	28.69533
A XB	0.268391	4	0.067098	5.887319	9.15		
B X D	0.046738	4	0.011684	1.025221	9.15		
A X D	0.078501	4	0.019625	1.721974	9.15		
Error	0.068382	6	0.011397				
Total	2.982197	26				2.982197	100
e-pooled	1.156722	18	0.064262			1.482153	13.9878

The plots of main and interacting factors are shown in figure 5.2

Figure 5.2: Plots of Main and Interacting Factors – Blood Pressure





Results:

- Load Weight and Vertical Height have been found to be the most significant contributing factors to variation in subject's response values for with small contributions from Lift frequency and Obstructions en route.
- None of the interactions affect the response output significantly in this case which shows that interactions between main factors do not cause excessive variations in the results although these affect the mean response output as shown in plots for individual subjects.
- The best results for low stress would be obtained by setting the factors A and B at their respective level 1.
- As would have been obvious, slope-up condition is causes increase in Blood Pressure significantly and should be avoided all together.
- Similarly, the loads to be placed at shoulder height are most stressful and should be avoided as far as possible.

5.3.3 S/N Analysis for Posture (RULA) Score

Table 5.5 below represents data gathered for increase in RULA posture scores each experimental run.

Table 5.5: S/N ratio calculation for RULA score

Lift Load	Frequency	Obstructions	Vertical Height	Subject 1 Y1	Subject 2 Y2	Subject 3 Y3	Subject 4 Y4	Mean response $\overline{T} = T / N$ Where T = Y1+Y2+Y3+Y4	S/N (Lower the best)
13	30	No	Knee	3	2	2	2	2.25	-7.2016
13	30	Slope down	Waist	2	3	3	3	2.75	-8.893
13	30	Slope up	Shoulder	4	4	3	3	3.5	-10.969
13	35	No	Waist	3	3	3	3	3	-9.5424
13	35	Slope down	Shoulder	4	4	4	3	3.75	-11.538
13	35	Slope up	Knee	4	3	4	3	3.5	-10.969
13	40	No	Shoulder	3	4	4	4	3.75	-10.969
13	40	Slope down	Knee	4	3	4	4	3.75	-11.538
13	40	Slope up	Waist	5	5	5	4	4.75	-9.5424

18	30	Slope up	Knee	5	4	4	5	4.5	-12.613
18	30	No	Waist	4	5	4	4	4.25	-13.57
18	30	Slope down	Shoulder	5	4	5	5	4.75	-13.118
18	35	Slope up	Waist	5	6	6	6	5.75	-14.433
18	35	No	Shoulder	4	5	5	5	4.75	-13.664
18	35	Slope down	Knee	5	5	4	5	4.75	-13.57
18	40	Slope up	Shoulder	6	5	6	6	5.75	-14.843
18	40	No	Knee	5	4	5	6	5	-13.57
18	40	Slope down	Waist	5	6	6	6	5.75	-14.843
23	30	Slope down	Knee	5	5	6	5	5.25	-15.218
23	30	Slope up	Waist	7	6	7	6	6.5	-16.284
23	30	No	Shoulder	6	5	5	6	5.5	-14.433
23	35	Slope down	Waist	6	5	6	6	5.75	-15.218
23	35	Slope up	Shoulder	7	6	6	7	6.5	-15.938
23	35	No	Knee	6	5	5	6	5.5	-14.843
23	40	Slope down	Shoulder	7	7	7	7	7	-16.902
23	40	Slope up	Knee	7	7	7	7	7	-16.902
23	40	No	Waist	6	7	6	7	6.5	-15.938

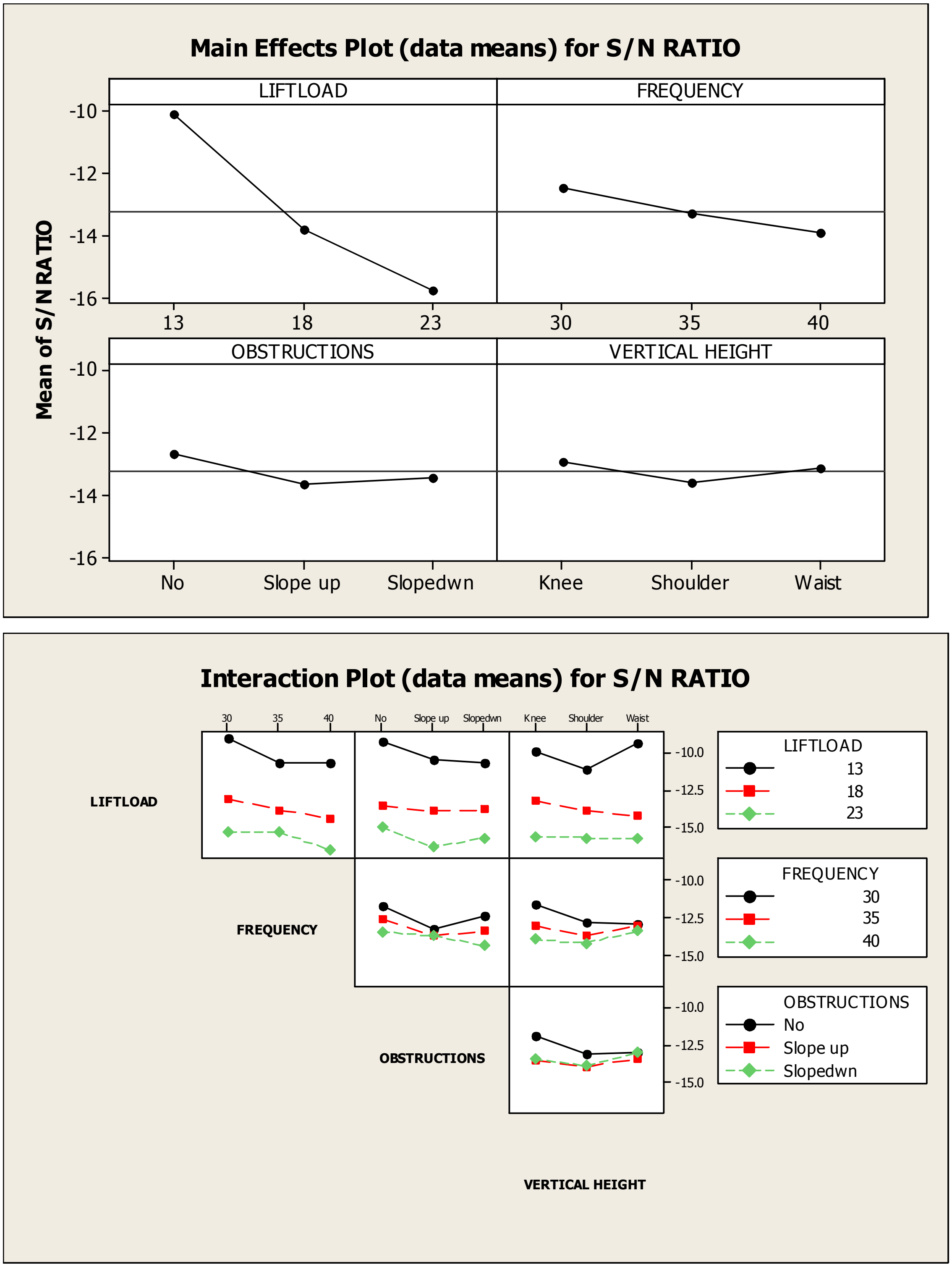
By conducting ANOVA on the S/N we obtain the following ANOVA table (Table 5.6)

Table 5.6: ANOVA table for signal to noise ratio

Source	SS	dof	Variance	F test	F critical	SS'	C (%)
Lifting load(A)	146.2691	2	73.13455	76.2489	10.93	145.205	83.49802
Frequency (B)	9.108545	2	4.554273	4.748211	10.93		
Obstructions(C)	2.061917	2	1.030959	1.074861	10.93		
VH(D)	4.815906	2	2.407953	2.510493	10.93		
A XB	2.223533	4	0.555883	0.579555	9.15		
B X D	2.109935	4	0.527484	0.549946	9.15		
A X D	1.558401	4	0.3896	0.406191	9.15		
error	5.754932	6	0.959155				
Total	173.9023	26				173.9023	100
e-pooled	12.76969	24	0.53207			28.69731	16.50198

The plots of main and interacting factors are shown in figure 5.3

Figure 5.3: Plots of Main and Interacting Factors – RULA Score



Results

- Since S/N ratio is larger the better response, for reducing the impact of poor posture, the most significant factors, Load weight and Lift frequency should be set at the lowest level.
- The results for posture scores show that lifting load from the floor level with high frequency of lift is the most stressful task.
- Lifting Load and frequency of lift are the two most significant factors which could cause lower back pain due to high postural score (RULA).
- None of the interactions between the major factors seems to be important and as such can be concluded that interaction between factors do not cause excessive variation in the results but affect the mean response by a large magnitude.
- Obstructions en route and vertical height do not contribute anything to the RULA score.

CHAPTER 6: RESULTS, CONCLUSIONS AND RECOMMENDATIONS

6.1 Results

The effects of the four independent variables (namely lifting frequency, load weight, obstructions en route and the vertical lifting heights) and their interactions were evaluated using ANOVA and factorial design analysis. In addition, plots of the significant factors and interactions were developed to show significance in the statistical procedure and helped to calculate the percentage contribution of different parameters based on the individual sum of square values.

The purpose of the ANOVA and significant factors plot was to identify the important parameters in prediction heart rate, blood pressure and RULA score calculations. This analysis helped to identify the best set of predictors one after the other based on their percent contribution for estimating the dependent response variables. In this statistical procedure, standardized by coefficient indicates the relative predictive power of individual parameters. The data were analysed using ***MINITAB*** Statistical Analysis Software. The percentage contribution from individual factors was calculated as the percentage of ratio of sum of square obtained from individual factor and total sum of square.

6.2 Significant Factors and their Interactions for dependent response variables

Table 6.1 consolidates the significant factors and interactions after the completion of ANOVA for each subject.

Table 6.1: Significant Factors and Interactions

Subject	**Dependent Response Variable**		
	Heart Rate	**Blood Pressure**	**Posture (RULA)**
Subject 1	• Load Weight • Interaction between Load Weight and Vertical Lift Height	Vertical Height	Frequency
Subject 2	• Load Weight (Major Impact) • Minor Significance: Frequency, obstructions and height	All the four factors + Interactions between A x B and B x D	• Load • Frequency • Vertical Height • Interaction between A x B
Subject 3	• Load Weight • Lift frequency • Vertical Height • Interaction of Load Weight and Frequency	• Load Weight • Lift frequency • Vertical Height • Interaction of Load Weight and Frequency	• Load Weight • Lift frequency • Interaction of Load Weight and Frequency
Subject 4	• Load Weight • Lift frequency • Interaction of Load weight vs. Vertical Height • Interaction of Load Weight and Frequency	• Load Weight • Lift frequency • Vertical Height • Interaction of Load Weight and Frequency	• Load Weight • Lift frequency

6.3 Some results consolidated from ANOVA and Plots

- The obstructions en route has no or little impact on the heart rate condition during this experiment.

- For placing the load weight at knee, waist, or shoulder height level, it was observed that the best heart rate condition exists for waist height while there is no appreciable difference when placing the load at knee level or shoulder level.
- Load Weight and Frequency makes the most significant on the worker stress levels on this subject where stress level is measured through the combined effect of heart rate, blood pressure and RULA score.
- Interaction between Load weight and Vertical Height has been found to be significant while no other factor makes any significant impact on stress levels.
- Load Weight and frequency are the two foremost important factors affecting the workmen during Lifting and Carrying Tasks
- Interactions between Load Weight and Frequency were found to be significant and needs further elaboration.
- Similarly interaction between Load Weight and Vertical Height of load at destination needs further analysis.
- The Lifting equation developed by NIOSH which does not consider such interactions may need modifications to include some of the important interactions.
- Interaction between Load Weight and Vertical Height of load at destination needs further analysis.
- The worker stress level varies from individual to individual when looked at separately for four different subjects.
- The ANOVA analysis clearly depicts the major effect of Load weight and Frequency on the variation seen between subject to subject. The interactions though have minor affect in causing variations in the output response. The plots show that as the load weight and the frequency of lift increases, the variation between the subjects increase further thereby indicating the individual differences that creep in because of factors like muscle strength, physical fitness of each individual. Similar analysis for S/N ratios has been done for the other two responses i.e. Blood Pressure and RULA score.
- Load Weight and Vertical Height have been found to be the most significant contributing factors to variation in subject's response values for with small contributions from Lift frequency and Obstructions en route.

- None of the interactions affect the response output significantly in this case which shows that interactions between main factors do not cause excessive variations in the results although these affect the mean response output as shown in plots for individual subjects.
- The best results for low stress would be obtained by setting the factors A and B at their respective level 1.
- As observed, slope-up condition causes increase in Blood Pressure significantly and should be avoided all together.
- Similarly, the loads to be placed at shoulder height are most stressful and should be avoided as far as possible.
- Since S/N ratio is larger the better response, for reducing the impact of poor posture, the most significant factors, Load weight and Lift frequency should be set at the lowest level.
- The results for posture scores show that lifting load from the floor level with high frequency of lift is the most stressful task.
- Lifting Load and frequency of lift are the two most significant factors which could cause lower back pain due to high postural score (RULA).
- None of the interactions between the major factors seems to be important and as such can be concluded that interaction between factors do not cause excessive variation in the results but affect the mean response by a large magnitude.

6.4 Identification of interaction effects of these four different lifting parameters

Factorial designs are widely used in experiments involving several factors to identify the interaction effects of different factors on the response pattern. In factorial design, the main effect averages the impact of the treatments of one factor across the treatment levels of other factors. The interaction effects are defined as the average effects of the simultaneous variation of different factors. The magnitude and the direction of these factors effects help to determine the relative importance of the factors. In the present study, analysis of variance (ANOVA) was used to confirm these interpretations. From the slope of the plots, it was interpreted that main effects were prominent in determining the average worker stress response variables. As these plots were having different slope values, indicated the interaction effects on dependent variable.

The ANOVA result also showed that Load Weight and Lift Frequency are two independent lifting parameters and their interactions were having significant effect on worker stress response variables. Among these four independent factors studies in this experiment, two were the interaction effects. ANOVA result indicated that the total percentage contribution of main effect was more than contribution of interaction effects.

6.5 Conclusions and Recommendations

- The results from the significant factors plot and their interactions indicate that Load Weight, Lift Frequency, and Vertical Height are the most significant factors affecting various measures of stress on workmen engaged in Manual Material Handling Activities.
- Also, interaction between Lift Load and Lift Frequency was found to be significant for almost all response variables.
- Obstructions en route has no significant effect on the stress response variables and can be ignored for further studies where the carry distance is less than 30 feet.
- Interactions between significant factors cause change in mean response values and do not contribute excessive variation to the response variable.

6.6 Comparison to NIOSH Lifting Equation

The most frequently used lifting task analysis is the NIOSH 91 Guide. This has a maximum weight of 51 lbs (23 Kgs). The maximum recommended weight limit is calculated by the following equation;

RWL = LC x HM x VM x DM x AM x FM x CM

Where,

LC = Load Constant or Maximum Weight Limit and is equal to 51 lbs

HM = Horizontal Distance Multiplier

VM = Vertical Distance Multiplier
DM = Distance of Lift Multiplier
AM = Asymmetric Angle Multiplier
FM = Frequency and Duration of Lift Multiplier
CM = Coupling Multiplier

The maximum weight limit is corrected using a manipulative model that provides a weighting for six task variables namely:

- i) Horizontal Distance, H
- ii) Vertical Distance, V
- iii) Vertical Travel Distance, D
- iv) Asymmetry Angle, A
- v) Frequency/Duration of Lift, F
- vi) Type of Coupling, C

The weightings are expressed as coefficients that serve to decrease the maximum weight limit, also referred to as load constant, which represents the maximum Recommended Weight Limit, hereafter written as, RWL, to be lifted under ideal conditions.

While Lifting equation is widely recognized as a common measure of stress it would cause if one exceeded the Recommended Weight Limit (RWL). However, it could be noticed that while RWL calculations considers a number of factors to arrive at the maximum load limit admissible in a particular situation, it does not consider any interactions between the main factors.

This study concludes that:

1. NIOSH Lifting equation provide for lifting parameters which could cause Musculoskeletal Disorders (MSD). However the equation will need to be modified to describe a lifting and carrying task simultaneously.

2. Other parameters like obstructions en route and the distance travelled with load in hand could be significant factors in this modified equation to describe the lifting and carrying task.
3. The Lifting equation in its current form is a multiplicative equation of main factors only and may not hold true for every situation. The interaction (combined affect of two or more parameters) of the main factors has not been described in its current form.
4. The consideration of interaction effects of different lifting parameters is required to quantify the effect of work-stress factors more precisely as different lifting parameters do not always work in isolation and their could be combined effects.
5. The study of individual lifting parameter effects alone would not interpret the physiological responses on worker stress factors properly.
6. This study shows some encouraging findings when analysed for individual subjects to indicate that the contributions of interaction effects would vary with different work conditions and different kinds of work environment, and these may not just be a mere multiplication factors as considered in NIOSH equations.
7. In this particular experimental study, interaction of Load Weight and Lift Frequency was found to have a significant effect on the work stress factors such as Heart Rate, Blood Pressure and Posture (RULA) score.

6.7 Scope for further Work

A more interesting and rigorous study of the interaction effects can open a new era in the better understanding of physiological processes and responses during lifting weights manually in the actual work environment.

More contributing factors and their possible interactions need to be identified to carry out a comprehensive study to revise the lifting equation from its current multiplicative form to include the interaction effects in some way.

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APPENDIX

Software used:

MINITAB 14: The main statistical software package used by the Six Sigma Blackbelts. Minitab is often used in conjunction with the implementation of Six Sigma, CMMI and other statistics-based process improvement methods.

ERGOMASTER 4: ErgoMaster is a suite of ergonomic analysis software modules containing a broad range of features and capabilities. The system is easy to use and produces easy to understand reports incorporating pictures or images of the job task being analysed or redesigned. The system's applications include ergonomic analysis, risk factor identification, training, as well as job and workstation redesign. Its suite of modules and tools assists in the analysis of lifting tasks, repetitive tasks, awkward postures, office ergonomics and many other areas. Modules can be purchased individually