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Determination of the range of safe-comfortable lifting postures using the aesthetic ergonomics theory

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**DETERMINATION OF THE RANGE OF SAFE-COMFORTABLE LIFTING
POSTURES USING THE AESTHETIC ERGONOMICS
THEORY**

Nicolas F. Salazar

**Dissertation submitted to the
College of Engineering and Mineral Resources
at West Virginia University
in partial fulfillment of the requirements for
the degree of**

**Doctor of Philosophy
in
Industrial Engineering**

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Workstation Design**

ABSTRACT

DETERMINATION OF THE RANGE OF SAFE-COMFORTABLE LIFTING POSTURES USING THE AESTHETIC ERGONOMICS THEORY

Nicolas F. Salazar

Past research indicates that, in general, individuals performing material handling tasks tend to underestimate lower back stress, i.e. L5/S1 disk compression, adopting free style lifting postures that often results a greater biomechanical stress in the lower back, increasing their potential risk of developing low back injuries in the short, mid and long terms.

The main objective of this research was to identify within theoretically safe workstation layouts, the subgroup of layouts that would lead workers to adopt cognitively comfortable and at the same time physically safe lifting postures. This research objective was achieved through the use of the Aesthetic Ergonomics Dual process discipline deployed in 2 interlinked stages: 1) the development, implementation and analysis of a survey where 121 experienced workers identified important cognitive factors and attributes which lead them to adopt perceived comfortable starting lifting postures in the sagittal plane, and 2) the design, implementation and analysis of a laboratory experiment where 20 workers experienced in material handling performed 12 different lifting, using a magnitude estimation scale to rate their perceived comfort at each lifting task. All lifting tasks were designed based on a lifting index, LI, which was set equal to one (1) according to the 1981 NIOSH Lifting guide.

Results of this study indicated that independent of horizontal reaches and container weights, workstations should be designed with a vertical height of approximately 30 inches. When compression and shear forces on the L5/S1 disc and subjects' average heart rate were considered in the analysis, the results support the recommendation that 30 inches should be the preferred vertical height in the design of workstations where lifting is frequently performed. The highest vertical height evaluated, 45", was associated with lifting tasks that posed a significantly higher physical demand on subjects' shoulders, depicted as an inconsistency between subjects' perceived comfort for 45" and this height's corresponding average shear and compressive forces estimates for subjects' L5/S1 disc. It was also found that average subject's perceived comfort decreased as the weight of the object lifted increased, is independent of the horizontal distance of the lift. However, the weight of the object lifted resulted in a significant increase in the subjects' estimated L5/S1 compression force with an increase in the height, which indicates that the counterpart nested factor in Zn, the horizontal distance, had a decreasing contribution as the vertical distance increased. In that matter, the vertical height found to have a greater potential impact on reducing the estimated L5/S1 was 30 inches.

DEDICATION

This dissertation is dedicated to the memory of my father, Dr. Juan Nicolás Salazar Vergaray and to my mother Lilia Ruth Medina de Salazar for their unconditional love and support throughout my whole life.

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LIST OF ACRONYMS

AL:	NIOSH 1981 Lifting Equation Action Limit
ANOVA:	Analysis of Variance
D:	Vertical travel distance between origin and destination of lift
df:	Degrees of freedom
EMG:	Electromyography
F:	Average frequency lift (lifts/minute)
FA:	Factor Analysis
F max:	Maximum frequency which can be sustained in the lifting task
H:	Horizontal Distance
HR:	Heart Rate
KMO:	Kaiser Meyer Olkin Indicator
LI:	Lifting Index in NIOSH 1981 Lifting Equation Action Limit
L4/L5:	Disk between lumbar vertebrae L4 and L5
L5/S1:	Disk between lumbar vertebra L5 and sacral vertebra S1
MAWL:	Maximum Acceptable Weight of Lift
MVC:	Maximum Voluntary Contraction
NIOSH:	National Institute of Occupational safety and Health
N/R:	Not Relevant
SMC:	Squared Multiple Correlations
SPSS:	Statistical Package for the Social Science software
V:	Vertical location at origin of lift
VO ₂ Max:	Maximum aerobic capacity

W: Weight of the object lifted

WMSDs: Work Musculoskeletal disorders

WPLG: Work Practice Lifting Guide

WVU: West Virginia University

Z: Factor Z nested under Factor V

Zn: Z nested

3DSSPP: 3 Dimensions Static Strength Prediction Program
(Biomechanical Software of the University of Michigan)

CHAPTER 1

INTRODUCTION

1.1 Background

One of the most common Work Musculoskeletal Disorders (WMSDs) is low back pain. Besides representing a health problem for the population, low back injuries, have an economic impact on the industry due to wage loss, workers' compensation, medical expenses, reduced productivity and lowered quality of life (Ayoub, 1992; Ayoub & Mital, 1989; Chaffin & Andersson, 1991). For instance in the year 1994, these injuries compromised 52% of the job related injuries in the United States. Low back injuries disable 5 million workers each year, costing about \$100 billion annually (Chaffin et al., 1994). In Canada, for instance, in the year 1987, a total of 602,531 work related injuries were compensated, the greatest number (27%) being back injuries (Statistics Canada, 1988). Some associations related to the groceries handling business, such as the National Association of Wholesale Grocers of America (NAWGA) and the International Foodservice Distribution Association (IFDA) stated that approximately 30% of the injuries in their industry are back trauma disorders (Waters et al., 1993). Furthermore, the NIOSH Interim Report (HETA 91-405) of March 1992 showed that back injuries were the cause of 60% of lost work days in a period of five years (Allread et al., 1996).

Injuries caused by overexertion when material handling tasks are performed represent an important problem for the industry. The percentage of people who

have experienced a lower back pain problem at some moment during their life is about 50% (Valkenburg and Haanen, 1982).

In 1979, it was estimated that between 19% and 25% of all workers' compensation claims in 26 states were due to back pain and from that percentage range, 48% were due to lifting objects (Klein et al., 1984). The National Council on Compensations Insurance estimates that for each dollar spent on workers' compensation, 33 cents are for back injuries (Rowe et al., 1983).

WMSDs are caused by the effect of one or more of the following risk factors: working postures, repetitive activities, forceful exertions, and static muscle load (Bernard 1997; Hagberg et al., 1995; Kroemer, 1989; Kumar, 2001). From all the above mentioned factors, an association between body postures with strains or symptoms of musculoskeletal disorders has been established in several studies (Armstrong, 1986, Armstrong et al., 1993; Grandjean & Hunting, 1977; Putz-Anderson, 1988; Van Wely, 1970, Westgaard & Aaras, 1984).

One activity that a worker often performs during a normal workday is the lifting of loads. NIOSH (National Institute for Occupational Safety and Health) has created guidelines (NIOSH Work Practices Guides for Manual Lifting) based on biomechanical, physiological, epidemiological and psychophysical criteria, that reference permissible loading weights, and adjusting horizontal, vertical distance and frequency discounting factors. Furthermore, some recommended postures and lifting techniques have been established based on the reduction of biomechanical stressors to avoid low back injuries.

It has been noticed that individuals with and without training adopt postures that are biomechanically stressful due the comfort perception of a free style lifting and the discomfort associated with the recommended postures in the literature (Wiker and Stultz ,1992).

The prior mentioned authors pointed out that although the NIOSH's Work Practices Guide for Manual Lifting assigns a similar degree of risk for several design alternatives of a lifting task, the predominant criterion for assigning risk is the biomechanical load, which supersedes the physiological (aerobic demands) and psychophysical criteria. This bias in the risk assignment, moreover, could lead the worker to avoid recommended biomechanically sound postures in order to adopt a more physiologically comfortable posture not necessarily in accordance with the NIOSH's Work Practices Guide for Manual Lifting, therefore developing a potential risk of injury to the low-back.

The above mentioned researchers also pointed out an important fact previously observed (Freivalds et al., 1984; Karwowski, 1991; Waikar et al., 1991) which is that workers' sensitivity to high levels of mechanical stress on the low back when they perform the lifting of loads is very low. This fact could indicate that workers have other criteria when selecting between a squat and a free style lifting posture. These criteria could be: lifting strategies, aerobic demands and other production demands. Workers, therefore, as a result of the predominance of biomechanical factors over physiological and psychophysical factors, could prefer using recommended postures only when they are going to perform a few

lifting tasks and could prefer adopting more comfortable postures when the rate of lifting is higher.

Garg et al., 1978 found in their study that individuals who adopted the recommended ergonomic lifting posture expended more energy than when they adopted the free style posture. Kumar (1984) stated that individuals become more fatigued when they adopted an ergonomics recommended posture than when they used stooped postures. In an interesting study; Barker and Atha (1994) pointed out that trained individuals reported being more fatigued than those who received little training or none at all on safe lifting techniques.

Resnick (1996); in his study of postural changes due to fatigue pointed out that even after having been trained, fatigued workers may use non-optimal biomechanical postures which reduces the effectiveness of the training effort significantly. Resnick also found that there were two groups of workers: those who kept the recommended squat lifting position for all the lifting, and others who after a period of time changed their posture to the stoop posture. One of Resnick's hypotheses is that those who changed to a more biomechanically stressful posture did so because they were in a better physical shape (lower base heart rate) and felt more confident in their capabilities and decided to use the stoop posture, which is dangerous because the fitness of a person is not a safety guarantee in the prevention of low back injury.

A new trend in low back prevention is the prediction of what posture the person is going to adopt in order to avoid or mitigate its health effects. Later in this document, some of the methods used in posture prediction are presented.

One of the posture prediction methods is the one based on psychophysical discomfort developed by Jung and Choe (1997), which is used to predict human reach posture. The authors claimed that “a man model is a useful design tool for the evaluation of man-machine systems and products with less time delay and cost, specifically at the early stage of design”. They carried out their study developing a regression model to predict discomfort with respect to the joint movement. The model was developed using a central composite design based on the response surface method.

Another branch among the posture prediction techniques is the Inverse Kinematics Model, which is performed to determine a posture based on the hand location (relative to the feet) and anthropometry (usually height and weight).

A hybrid method was proposed by Beck and Chaffin (1992), in which after prediction of an approximated posture given by the inverse kinematic method, such prediction is refined manually by the analyst having a fixed point of reference (i.e. the hands).

The present research has as its main goal the reduction of low back injuries. The fundamental basis for this research is the Aesthetic Engineering Theory and the proposed methodology, i.e. the Dual Process Model (Liu, 2003). Even though sometimes objects, workstations and job tasks are ergonomically designed, customers or workers don't like to use them because they don't like them aesthetically or they don't feel attracted to them. The goal of the Aesthetic Ergonomics theory is to ensure that objects, work stations and tasks that are well designed from the ergonomic point of view, also become more attractive or

appealing to the user at the same time. One of the dimensions of the aesthetic theory is pleasure, and within it is comfort. The Dual Process Methodology that was used in this study as an overall framework proposed the use of the statistical technique such as factor analysis to determine which factors and attributes determine that an individual adopts a comfortable posture for lifting an object in the sagittal plane, which is an imaginary plane that goes from the top to the bottom of the body dividing it into the left and right portions. Furthermore this methodology proposes the use of psychophysical techniques that were used to obtain limits of detection and degrees of perception of the subjects for those obtained factors and attributes. Afterward, through the use of Experiment Factorial Analysis technique (which actually is part of the set of conjoint analysis techniques) these factors were combined towards building a model of likely adopted comfortable lifting position, and determining the importance of other factors on the adoption of those positions.

Finally a second but important part of the research was carried out to compare the obtained comfortable adopted lifting posture and compare them with the NIOSH 1981 Lifting Equation and The University of Michigan's 3DSSPP 4.3 Biomechanical Software, in order to obtain a range of Lifting Postures which were comfortable and safe for the individual.

1.2 Problem Statement

Individuals adopt the most comfortable posture at the moment of lifting an object in the sagittal plane, some of them improper postures from the biomechanical point of view, even after they have received training. These improper biomechanical postures cause stressful forces on the low back spine which could lead to potential injuries in the short, middle or long term. In this research we studied the factors and attributes perceived as important by the individuals at the moment of adopting a comfortable posture while lifting a load in the sagittal plane.

1.3 Objectives

The main objectives of this research were: 1) to determine the cognitive factors and attributes which lead a person to adopt perceived comfortable starting lifting postures in the sagittal plane. 2) To determine a range of postures resulting from the intersection between the group of postures that were perceived as comfortable by the individuals and the group of postures that were recommended safe lifting postures with a low degree of biomechanical stress (see Figure 1-1). If that range of comfortable and safe lifting postures was found, it could be used as new guidelines for safe-lift training.

Figure 1-.1: Area of Safe and Comfortable lifting Postures in the Sagittal plane

1.4 Hypotheses

This study's main hypothesis is:

H_0 : There is a range of postures which are comfortable lifting postures in the sagittal plane and at the same time are within a range of permissible limits recommended by the NIOSH 1981 WPLG.

1.5 Benefits of the Research

Successful completion of this research will have the following benefits:

- Establishment of the Aesthetics Ergonomics' Dual Model as a new tool to determine likely postures, obtained from information received straight from the individuals and then processed and analyzed through statistical and psychophysical techniques.
- Determination of the range of safe-comfortable lifting postures (defined by the NIOSH 1981 WPLG) as new guidelines for safe training.
- Improved training techniques based on those factors, attributes, elements and characteristics found to be important in order to avoid the adoption of comfortable but biomechanically stressful postures.
- Highlighting of other criteria that are acknowledged by the workers as being important at the moment of adopting a lifting posture. This effort leads to the development of more sustainable lifting guidelines, with the potential of reducing risks of low back injuries caused by unsafe lifting postures.
- Development of additional criteria for designing work stations and material handling devices.
- Integration of cognitive elements and factors used for a lifting task with the criteria used in the development of the NIOSH 1981 WLPG (epidemiological, biomechanical, physiological and psychophysical approaches).
- Development of the basis for the design of new lifting techniques taking into consideration elements of the Planning –Control Model, (Glover, 2004).

- Better understanding of the role of elements belonging to the Planning and Control of Human Motor Behavior, on the onset and development stages of low back injury traumas.
- Development of new training guidelines taking into consideration the object's characteristics, environmental factors, and some subject's characteristics such as gender and age.
- Finally, the potential reduction of the number of low back injuries among workers, through the implementation of the obtained safe-comfortable postures.

CHAPTER 2

REVIEW OF LITERATURE

The goal of this research was the comparison of the obtained probable lifting postures in the sagittal plane, from the individual's cognitive factors for a comfortable posture at the moment of start lifting an object and the NIOSH 1981 WLPG recommended posture.

This chapter reviews the state of the art in the following areas: The Aesthetics Ergonomics Theory, the Dual Process Methodology, the NIOSH 1981 WLPG, a short reference to the Psychophysics discipline, the Planning-Control Model, the Perception-Control model and a new trend in the effort to prevent low back injuries.

2.1 Aesthetic Ergonomics Theory

Fierce global competition has forced manufacturers to take into consideration factors beyond product reliability and quality. Physical aspects such as aesthetics and subjective quality are becoming more important than ever before. Moreover nowadays metrics such as usability and aesthetics characteristics can make the difference between success and failure of a product (Yili Liu, 2003).

Designers mainly use their experience or their knowledge of fashion trends to design a product. In that sense, they don't use a systematic methodology for the

aesthetics' decision making nor evaluate a product from the aesthetic point of view (Noblet, 1993).

Human Factors and Ergonomics are disciplines devoted to improving safety, comfort, productivity, and user friendliness of human-machine–environment systems (Wieckens et al., 1998). Before, some scholars (Nagamachi, 1995, Jordan, 1998) had attempted to incorporate the emotional aspect to the human factors design stage, aesthetic factors had not been considered important.

Conversely, a discipline which has been more focused on the preference of consumers is marketing, which through its component of consumer behavior studies has attempted to evaluate how aesthetics influence the preference of customers at the moment of buying a product. Although marketing research is very useful for product design and publicity campaigns, it is mainly focused on selling and is not a comprehensive approach to the human-machine-environment system, which entails other product aspects such as social, productivity, and educational. Therefore, some researchers believe that it is necessary to incorporate aesthetics as an important part of human factors research (Liu, 2000).

Liu, (2003), in: “Engineering aesthetics and aesthetics ergonomics: Theoretical foundations and a dual-process research methodology” supports the incorporation of aesthetics into the human factors and ergonomics research and its applications, through some philosophical considerations, which are explained below. He supports his theory in some philosophical concepts which state that humans are searching for: the truth, the beauty, the good, and right. This search

derived respectively in three types of judgments: cognitive (scientific), aesthetic (beauty) and moral belonging to their respective branches of the philosophy: metaphysics, aesthetics, and ethics.

In his study Liu claims that traditional Human Factors (discipline concerned with the application of people characteristics, abilities, and limitations to the design of equipment, work environment, and jobs) are only involved in the branch of metaphysics and the pursuit of truth, which is composed of three dimensions: quality, information processing demands, and psychosomatic soundness. The ethics always must be part of the decision making process for a new design pursuing the well being of the customers and society. Therefore, Liu argues that both the ethics and the aesthetics dimensions should be added giving rise to a new discipline called “aesthetics ergonomics” or “aesthetics human factors”. This new discipline incorporates those previously mentioned five dimensions (quality, information processing demands, psychosomatic soundness, ethics and the aesthetics dimensions) providing, therefore, for an organized, comprehensive and overall understanding of human- machine- environment systems and products. This new discipline would help researchers to study some neglected areas, work systems, and products. Moreover, it would lead to the development of new products, which cannot be only physical or tangible products to be used, else intangible systems such as: work systems, jobs and environments. Aesthetics Ergonomics is not only focused on the study of pleasurable conditions, but on unpleasant conditions too, because through the development

of its different stages some design conditions that must be avoided can be detected.

2.1.1 Dual Process Model Methodology

The current research took advantage of the Dual Process Model Methodology developed by Yili Liu (2003). This researcher states that industrial designers should give more importance to the aesthetics factor, which will require that the Human Factors and Ergonomics disciplines go deeper in applying scientific, engineering and mathematical methods in order to understand aesthetics preferences and aesthetic design.

This methodology takes in account two main dimensions: 1) the external, and environmental object (healthful-harmful) and 2) the psychological response of the individual (attractive pleasing-unattractive unpleasing) which takes in consideration subjective factors that could affect the perception of the individual on the external stimuli or object depending of the subjects' characteristic could be for instance: age, education level, socioeconomic level, gender, physical characteristics, cultural background. A set of statistical and mathematical techniques such as unidimensional and multidimensional scaling, factor analysis, and cluster analysis can be applied to determine how a subject's characteristics interact with the environmental object inputs and construct a framework or structure of factors which are then analyzed through conjoint analysis techniques

or factorial analysis to determine how that set of factors combine to create an overall impression of the stimuli or object.

The above mentioned set of mathematical and statistical techniques are part of the Top-Down branch of the methodology (also called the Multidimensional Construct Analysis or Multivariate Psychometric Analysis, see Figure 3-1 in section 3.1.1), which helps to answer questions like: What is the conceptual and mathematical structure of the aesthetics constructs in question? What are the main psychological and physical dimensions involved? How will those dimensions be measured and scaled? How are those dimensions related to each other? and what is the relative importance of each dimension?.

The second branch of the methodology is the so called Bottom-Up branch, which is made up of psychophysical techniques in order to answer questions such as: How sensitive are the subjects in perceiving a small variation in these aesthetic variables? In the case of the current research these variables are those perceived as important by the subject in order to lead them to adopt comfortable postures and will be determined in the previous stage through the use of multivariate statistic techniques. Other questions are: What are the absolute and relative thresholds to detect such a change? How capable are the subjects to perceive and judge values, changes and variations in the design parameters? What are the preferred levels in the aesthetics design variables? The techniques used to answer questions such as those stated above could be for instance all those related to the Steven's Law (psychophysics technique), as Magnitude Estimations, Limen Method of limits and Borg scale method. Then, the Factorial

design is used to combine significant factors at their different levels and obtain the preferred product or system design.

2.2 NIOSH 1981 WLPG

The second important part of this research was the determination of the comfortable adopted lifting postures obtained through the methodology proposed by the Aesthetics Ergonomics Theory and the NIOSH 1981 Lifting Equation safe lifting parameters. This section summarizes the four approaches (epidemiological, biomechanical, physiological, and psychological) used by the NIOSH 1981 Work Lifting Guide to develop the NIOSH 1981 Lifting Equation, which is shown below:

$$AL(lb) = 90 \left(\frac{6}{H} \right) (1 - 0.01|V - 30|) \left(0.7 + \frac{3}{D} \right) \left(1 - \frac{F}{F_{\max}} \right) \quad 2-1$$

Where:

H= horizontal location (inches) forward of midpoint between ankles at origin of lift

V= vertical location (inches) at origin of lift

D= vertical travel distance (inches) between origin and destination of lift

F= average frequency of lift (lifts/minute)

F max = maximum frequency which can be sustained (see Table 2-1)

Table 2-1: Maximum frequency which can be sustained

Period (hrs)	Average Vertical Location (in)	
	V>30 in	V<30 in
	Standing (Fmax)	Stooped (Fmax)
1	18	15
8	15	12

2.2.1 Epidemiological Approach

Epidemiological studies are divided into job risk factors and personal risk factors.

The research carried out by Chaffin (1973, 1977) is among the studies in which the epidemiological job risk factors were based on. In the 1973 study after monitoring 400 workers for more than one year, it was concluded that “lifting loads greater than about 35 pounds (16 kg) when held close to the body, or equivalent conditions such as 20 pounds (9 kg) between 25 and 35 inches (64 and 89 cm) in front of the body, would be hazardous for some people.”

Another important study was developed by Ayoub et al., (1978), who studied 63 lifting jobs monitoring 220 males and 24 females. He determined job severity indices for the job demands based on the weight handled, box size and frequency of lifting.

Besides the above mentioned researches, the following authors determined the lifting capacity of an individual using four models: McDaniel (1972) studied lifting from the floor to the knuckle height, Dryden (1973) considered lifting from knuckle height to shoulder height, Knipfer (1974) examined lifting from shoulder height to reach height and Aghazadeh (1974) which added frequency and box size as additional factors.

The personal risk factors accounted in the development of this criterion were:

a) Gender: from several studies it was concluded that women's lifting strength was about 60% of men's strength, which means that for lifting the same weight an average woman was more stressed than an average man. However, given the large ranges of strength in women and men, the gender factor became secondary in the development of the NIOSH 1981 WPLG.

b) Age: due to its effect on reducing the physical capabilities of a worker, age was considered as a risk factor. In some cases, however, skill and experience on how to lift an object became advantages that a younger worker may not always have.

c) Anthropometry: it has been determined that body weight and stature were anthropometric characteristics which had a potential effect on the risk of developing an injury at the moment of lifting an object. The weight of the person had a direct effect on the metabolic expenditure, increasing fatigue the heavier the individual was. On the other hand, researchers also found that in general the heavier a person is the stronger he/she is.

- Ayoub (1978) studied the relationship between body size and the ability to lift an object; however no direct relationship between body weight and back pain was determined.
- In regards to stature, Tauber (1970) suggests that taller people have more low back pain incidents than shorter people. On the other hand, other studies such as Hult (1954), Rowe (1971) and Chaffin and Park (1973)

d) Strength: it was one of the most important factors to determine the capability of a person for a specific lifting task. From the previously mentioned study of Chaffin and Park (1973) where 400 newly hired workers were monitored, it was found that the mean low back pain incidence increases by a factor of 3 for those jobs performed by these new workers, where the personnel didn't demonstrate to have strength equal to or greater than the required strength necessary to perform the job. This result was also confirmed in the Chaffin's 1977 study.

Snook (1978) studied 191 low back injury worker compensation claims and found that 25% of the implicated jobs were acceptable for less than the 75% of the workers. Therefore, it was concluded that a worker is 3 times more in risk of developing a low back injury if he/she performs a task that is acceptable to less than the 75% of the population.

2.2.2 Biomechanical Approach

The biomechanics criterion is focused on determining with some degree of accuracy if a person is physically capable of lifting the object. This capability is obtained through the study of the compression and shear forces on the joints, exerted by the weight of the lifted object, parts of the body involved in the lifting and the mechanical torque (moment) caused by those forces and distances on the involved joints associated with the adopted body posture.

Biomechanical studies use average anthropometric measurements to determine if the moments or forces exceed the capability of a specific percentage of the industrial population.

Given all the clinical and biomechanical study results, it is suggested that the main focus of biomechanical studies for the low back stress should be on the L5/S1 disc.

Biomechanical studies such as: Morris, Lucas and Bressler (1961), Tichauer (1966) and Chaffin (1969), have shown that when a weight is lifted, the bending moment at the lumbar sacral joint can be as large as 2000 kg-cm when a 50 kg weight is lifted from the floor. Evans and Lissner (1959) obtained data from cadavers which showed micro fractures starting at 9310, 6370 and 2450 N of compressive force in the L5/S1 disc for males under 40 years, over 40 years and over 60 years, respectively. Sonoda (1962) in another research, also using cadavers, estimated that the female spinal compression tolerance was 17% lower than the tolerance of males.

From Chaffin (1973) Evans and Lissner (1959), and Sonoda (1962) a biomechanical design criterion was determined which dictates that those jobs that result in more than 6370 N of compressive force on the low back spine are hazardous for all workers except those who are in exceptional health conditions. To avoid risk, the compressive force in the lower spine originated by the lifting task must be less than 3430 N.

2.2.3 Physiological Approach

The physiological approach is focused on how repetitive the lifting task is and how it can cause physical fatigue. The physiological indicators which determine the maximum work intensity that can be performed without causing excessive physical fatigue are: oxygen consumption, metabolic energy expenditure rate, and heart rate.

There is evidence that when an isometric lifting (a lift where the limbs are placed symmetrically with respect to the sagittal plane) is performed, muscles with a work (contraction) time-rest ratio of 2:1 will develop fatigue at high exertion levels (60% Maximum Voluntary contraction, MVC). On the other hand when the force exertion is lower (25% MVC) a work time rest-time ratio of up to 3:1 will be necessary to cause fatigue.

Some laboratory studies suggested that lifting activities in the heavy industry seldom exceeds the average male workers 50% VO_2 Max (Aerobic Capacity, physiological limit for muscular fatigue), being generally associated with levels around 35% of the VO_2 Max. Ekblom, et. al (1968) and Snook and Irvine (1969) found that a 33% of aerobic capacity is more appropriate (rather than the 50%) for repeated lifting for eight hours.

For the case of the work capacity limits based on the energy expenditure criteria, Chaffin (1972) claims; "Probably 80% or more of American men are not physically fit as judged by their aerobic capacities, being their capacities below a reasonable value of 16 Kcal/min", while the recommendations of the NIOSH

1981 WPLG are made in the assumptions of 15 kcal/min for men and 10.5 kcal/min for women (75% of men). Lehman (1953), Bink (1962) and Bink (1964) determined that a workload of 5.2 kcal/min is the maximum energy expenditure rate for an eight hour/work day (assuming an average man of 35 years of age with an energy expenditure of 2500 kcal during the 8 hours day workshift). For occasional or short lifting tasks (one hour or less) the metabolic energy expenditure rates shouldn't exceed 9 kcal/min (for fit males) and 6.5 kcal/min (for fit females).

2.2.4 Psychophysical Approach

An important statement associated with the psychophysical criterion in the NIOSH 1981 WPLG, is: "A minimal requirement for performing any normal material handling is to have sufficient strength to exert the required force."

According to the above psychophysical criterion, the fact that the person can exert enough force to lift a specific object, reduces or eliminates the risk of developing a low back injury associated with the lifting task at hand.

The definition of strength that the NIOSH 1981 WPLG uses was taken from the American Industrial Hygiene Association (Chaffin, 1975), which defines strength as: "... the maximal force muscles can exert isometrically in a single voluntary effort (Roebuck, Kroemer, and Thompson, 1975)."

Regarding strength it is necessary to point out some important facts:

- Several studies have demonstrated that women have only about 64% of the strength that men have.
- Chaffin et al., (1977) showed that anthropologic measurements (height, body weight, age, gender) are not good predictors of isometric strength, when they are used alone. However, female workers are weaker than male workers, taller and heavier workers are stronger than shorter and lighter workers, and body weight is a drawback for older workers.

A couple of static strength models that were available when the NIOSH 1981 WPLG was being developed were:

- Garg and Chaffin (1975): 3 dimensional model
- Chaffin (1974): 2 dimensional model.

The above static models limit the performance analysis of the task to static conditions and also predict the percentage of male and female populations that could be expected to perform the task. The body weights and anthropometry lengths are based on the 50th percentile anthropometry for males and females.

A method to measure the dynamic strength is through the psychophysical strength, which is a method for measuring the capacity of an individual to lift. Several studies to determine different load capacities have been developed, such as: Snook (1976), Snook (1978), Snook and Ciriello (1974), Ayoub (1973). Ayoub determined that lifting capacity is a function of the isometric back strength.

In order to account for the psychophysical criterion, the NIOSH 1981 WPLG combined the Snook (1978) and the Ayoub (1978) studies, to predict the average

lifting capacity of the 75% of the female industrial population and 25% of the male industrial population.

Some important conclusions about this psychophysical criterion are:

- Low frequency lifting capacities are limited by strength rather than endurance.
- For occasional high frequency lifting, the psychophysical limits are more appropriate.
- For eight hours of continuous lifting, metabolic or physiological criteria are the determining factors to avoid fatigue, imposing a limit on the lifting capacity.
- It is important to mention that in the industry, when motion and time studies are performed, some other factors that affect fatigue are taken into account in order to obtain the allowances necessary for personal needs of the worker. Some of these factors are contained in the physiological factors used in the NIOSH 1981 WPLG, and others are mainly related to the work environment, the nature of the work and the general health of the worker. These factors are: 1) Work environment conditions (i.e. light, temperature, humidity, air freshness, color of room and environmental noise), 2) Nature of the work (i.e. concentration to perform the task, monotony of the movements, position of the worker, muscular tiredness), 3) General health of the worker, physical and mental (i.e. physical stature, diet, rest, emotional stability, home conditions) (Niebel, 1993).

2.3 Psychophysics

In this research, after using the multidimensional statistic techniques to determine those cognitive factors perceived as important by the individuals to adopt a comfortable starting posture for lifting objects in the sagittal plane, a psychophysical experiment was carried out to determine the detection limits of those factors. Therefore, a short review of the psychophysics discipline is given below.

Psychophysics is the branch of psychology dealing with the perceptual study of quantitative relations between people's perceptual experiences and corresponding physical properties.

In the nineteenth century, Weber (1834) and Fechner (1860) began the development of Psychophysics through the study of the perception of lifted weights. Weber developed the measurement of the smallest detectable change in a stimulus, Just Noticeable Difference (JND), which is $JND = \text{Standard Value}(S) * \text{Constant}(K)$. Later Weber's disciple Fechner, improved Weber's Law developing the original set of psychophysical methods, allowing a quantitative evaluation of sensory thresholds. Weber studies determined that the sensation of weight was slightly different if the weight lies in a large rather than on a smaller skin area. This was a first indicator that the perception of heaviness depends on the weight and the size of the object.

A milestone in the psychophysics discipline occurred when the Stevens' Law was developed (Stevens, 1960), which states that strength of sensation (S) is directly

related to the intensity of its physical stimulus (I) through the power function: $S=k*I^n$, where the constant (k) is a function of the specific units of measurement that are being used. Usually Stevens' Law is plotted on log-log coordinates, in order that the power function could be represented as a straight line, in which the exponent (n) become the slope of the line. As a manner of example, it has been experimentally determined that the exponents of stimuli such as salt taste, electric shock, loudness, muscular effort and force are: 1.3, 3.5, 0.6, 1.6 and 1.6 respectively.

Since the objective of this research study was related to the perception of different factors which lead to adopt a comfortable posture, the Stevens' Law is an important topic related to the goal of this study.

2.4 Planning and Control of Human Motor Behavior

An important issue about the adoption of a posture is whether the person plans the posture or it is adopted without previous planning. This matter is important given the nature of our hypothesis, which assumes that there are some cognitive factors and attributes, which lead the person to adopt a specific comfortable posture.

Currently there are some models that attempt to explain the process of adoption of a posture and the subsequent movement of a limb or part of it at the moment of grasping or lifting an object. The two most accepted models are the Planning-Control Model and the Perception-Control Model.

2.4.1 Planning-Control Model

An important factor to understand the inner process of adopting a posture was the study developed by Scott Glover (2004), who pointed out the existence of evidence that planning and on-line controls have different purposes and use different visual representations. Behavioral studies indicate that planning is influenced by a large number of visual and cognitive information (including spatial and non-spatial characteristics). Conversely control is influenced by the spatial characteristics of the target or object to be lifted (size, shape, orientation etc).

Studies from brain imaging and neuropsychology indicate that planning and control use different visual centers in the posterior parietal lobes of the brain. It seems that planning is carried out in newer developed regions of the brain which are the inferior parietal lobe along with the frontal lobe and basal ganglia, whereas control is carried out in older areas which are the superior parietal lobe and the cerebellum.

In the above mentioned study, the author states that in his planning-control model, body movements are chosen and performed through two temporally overlapping systems. Before the movement of an action starts, a motor program is chosen based on a large spectrum of cognitive factors along with a visual planning representation in the Inferior Parietal Lobe (IPL). At the moment of performing the movement it becomes more under the control of the “control system”, using visual and proprioceptive feedback and an efference copy (a sort

of blueprint of the movements obtained from the planning process before the starting of the movement) of the movement plan.

2.4.1.1 Planning

Planning requires choosing an adaptive motor program depending on the surrounding environment characteristics and the objective of the individual's movement. Conversely, the goal of the control system is the minimization of the spatial error of the movement, which requires a fast analysis of the spatial characteristics of the target and the physical position of the individual.

Planning is responsible for selecting a target and choosing how to grasp it. Planning has to determine the kinematic parameters of the movement (although the initial determination of the movements related to the spatial characteristic targets can be modified on line by the control system) as well as their timing: reaction time, movement times and the acceleration and velocity of the movements. An important fact is that planning is in charge of choosing the macroscopic aspect of the movement which includes the posture, which is the primary focus of this study.

In order to achieve the above mentioned goals, planning has to gather visual and cognitive information. Information is used along with memories of past experience, especially for the non spatial characteristics. This information can be summarized as:

- 1) Spatial characteristics of the individual and the target: size, shape, orientation of the target and spatial relation of the target and the individual.
- 2) Non spatial characteristics of the target: function of the object, weight, fragility, coefficient of friction of its surface.
- 3) Establishing what is the goal of the action.
- 4) Visual context surrounding the target.

Planning is related to cognitive processes; hence the planning process is influenced by processes such as language and memory. However, when the situation is unfamiliar to the individual, planning will not be as precise as when a familiar situation stored in the individual's memory exists. Between planning and cognitive processes, the planning process is affected by conscious influence.

2.4.1.2 Control

As mentioned above, planning selects a motor program depending on the surrounding environment, and target. The control system in turn can monitor and perform changes during the execution of the movement. These adjustments are only related to the spatial characteristics of the target and are mainly because of errors in the planning process (maybe due to interference of cognitive influences) or unanticipated spatial changes. Conversely, the non-spatial characteristics (e.g. weight) are very unlikely to change after the movement is planned. Therefore, a mistake of the planning process can still be corrected given the time frame, while a mistake in the control process will result in a failed act.

The control process requires a visual feedback, proprioception and an efference copy (when a motor command is sent through the nervous system, this internal copy is used to predict the expected sensation that will occur). It is necessary to emphasize the fact that control process only influences the spatial parameters of the movements. However, given that both processes (planning and control) are temporally overlapped in the time, the influence of control on the spatial parameters increases while the movement is carried out. It is also important to mention that the control process is not affected by cognitive processes as goal formation and conscious perception and therefore it works outside the conscious information effect and its influence. In other words, the control process manages the movements on the spatial parameters and it is not affected by the cognitive acquired information.

2.4.1.3 Time Sequence of Planning and Control

As mentioned before, several studies (Desmurget and Grafton, 2000; Wolpert and Ghahramani, 2000; Wolpert et al., 1995; Meyer et al., 1988) have documented a period of time when both planning and control are carried out together. Before the start of the movement, planning is in charge of determining all the movement parameters, and it maintains its importance during the early stage of the movement, and then control gradually takes the responsibility of the movement mainly on the spatial parameters (Wolpert and Ghahramani, 2000).

Glover (2004) points out that long duration movements will be under the authority of control (due to the visual and proprioceptive feedback loops), while short movements will be almost totally under the responsibility of planning.

Although some scholars criticize the Planning-Control model saying that control involves some advance planning, Glover claims that this is not a drawback for his model; conversely what the model does is to emphasize the existence of two different inputs in the planning and control stages which are the visual and the cognitive inputs. It doesn't mean that the outputs of the two mentioned stages must be implemented in different ways. In conclusion, the author of this model states that both stages are pre-planned, although the planning system uses a much richer and detailed visual representation than the control system.

2.4.2 Perception – Action Model

This model was developed by Goodale and Milner (1992). Analyzed from the visual neuroscience point of view, this model proposes that the information associated with object recognition and form representation (ventral stream) transmitted from the brain's primary visual cortex to the brain's inferotemporal cortex, plays the main role in the perceptual identification of the objects. However, the information associated to the guidance of actions and recognition of where the objects are in space (dorsal stream) projecting from the primary visual cortex to the posterior parietal regions mediates the required sensorimotor transformations for visually guided actions directed at such objects.

From the functional point of view, the authors of this model emphasize more on the output requirements (control of action) than on the input (object and spatial characteristics). In other words, they emphasize more “What vs. How” rather than “What vs. Where” (object vision versus spatial vision).

Goodale and Milner refer to DeYoe and Van Essen (1988), who claimed that for identification purposes, it is almost always necessary that the object's characteristics (shape, light, color) be kept constant during the time the object is observed. On the other hand, when an action is performed on an object, it is necessary that the location of this object and its specific position and movement with respect to the observer be performed by the neural visual system of the person.

Goodale and Milner state that the spatial factor is the main factor involved in the selection process carried out when attention needs to be focused on specific places and objects are the target either for an intended action or for identification purposes.

The conclusion of Goodale and Milner (1992) from the visual-neuro system point of view, about the spatial attention is that it is physiologically non-unitary (it has two streams) and it is more related with the ventral system (related to the non spatial object properties and context) more than with the dorsal system (related to the spatial object properties, control and monitoring).

On the other hand, Glover (2004) claims that the main difference between the planning-control model and the perception-action model is that in the first one the cognitive and perceptual influences are thought to potentially impact the planning

of movement kinematics (but never the on line control of the movements). In contrast, in the perception action model the planning and the control of movement kinematics are not both affected by the cognitive and perceptual influences.

2.5 Studies of Posture Prediction

Since one of the objectives of this study was to determine the factors which lead to the adoption of a comfortable posture, the most important attempts that have been carried out through the construction and use of different techniques and models to predict posture are mentioned below.

An important research which gives us a better understanding about the prediction of lifting postures was the study performed by Wiker and Stultz (1992): “NIOSH Work Practices Guide or Manual Lifting: Significance of Posturally – Based Differences in Perceived Stress in Lifting Tasks of Equivalent Design Merit”. The objective of these researchers was to determine if workers would rather use postures that minimized perceived strain rather than those postures recommended by the NIOSH WPLG even though the former were in contradiction with the NIOSH WPLG. If this premise is overlooked, it could lead to the design of unsustainable lifting practices.

Wiker and Stultz concluded from their findings, that workers would prefer to limit extensor activity about their knee and flexor activity at the shoulder, and to rely more upon the strong extensors of the back to initiate and complete a lift or lower

operation. It was observed that the before mentioned practice significantly reduced the perceived strain although it increased the magnitude of mechanical stress action on the lumbar spine.

The above mentioned researchers also found that high lifting frequencies reinforced the use of the stoop lifting position instead of the biomechanical recommended squat lifting position (See Figure 2-1). Therefore, when designing a fast pace lifting task it should be expected that the worker will choose to perform a stoop lifting.

Figure 2-1: The stoop and squat lifting postures

Another research on posture prediction is: “Human reach posture prediction based on psychophysical discomfort”, developed by Jung and Choe. (1997). Jung and Choe described a method used to predict the human reach posture. The authors stated that “a man model is a useful design tool for the evaluation of man-machine systems and products with less time delay and cost, specifically at the early stage of design”.

Jung and Choe also pointed out that in order to be truly useful a “man model” must be integrated with a proper posture prediction model, specially an arm reach prediction model. They carried out their study by developing a regression model to predict discomfort with respect to the joint movement. The model was developed using a central composite design based on the response surface method.

The authors treated the joint angles of the upper body with seven degrees of freedom and the weight of the load as independent variables, while the perceived discomfort measured using a magnitude estimation technique was used for the response variable. They also collected the perceived discomfort in the category scale and the normalized EMG (electromyography) of six muscles.

An important achievement of the above mentioned research was to obtain a three dimensional reach posture prediction model using an inverse kinematics technique based on the prediction of perceived discomfort. Their model predicted the posture by selecting the minimum discomfort configuration among feasible body postures to reach a target point.

Another branch of research among the posture prediction techniques is the inverse kinematics models, which consists of determining a posture based on the hand location (relative to the feet) and anthropometry (usually height and weight). There are two basic approaches in this technique; the first is to optimize variables such as strength or energy and the other approach is to base the model on the observed human behavior algorithms which are regression equations developed from a large number of measured postures (Beck and Chaffin, 1992).

A drawback of this technique is that some of the feasible solution postures are not likely to be assumed by the workers due to their preferences.

The way that the inverse kinematic models are evaluated is basically by their accuracy (the error of the joint less than 10 degrees) in predicting postures.

Some of the drawbacks of this method are: a) it can not predict asymmetric postures since the individuals' joints do not achieve the 10 degrees of accuracy recommended by Chaffin and b) because the predicted postures are not natural, given that the constraints of the inverse kinematic models are related to the geometric distances. Therefore, the inverse kinematic models can only be used as approximations.

A hybrid method was proposed by Beck and Chaffin (1992), where after obtaining the approximated posture given by the inverse kinematic method, the posture was refined manually by the analyst having a fix point of reference (i.e. the hands).

A study to predict preferred postures through the use of the NIOSH WPG was the one made by Bloswick and Weiler (1990): "Empirical evaluation of posture during manual material handling activities: Applications of NIOSH Work Practices Guide parameters to biomechanical model analysis." The primary goal of this study was to use the data required by the NIOSH WPG as input to determine the feasibility of generating the posture data required by the biomechanical models used to predict the back compressive forces and articulation moments. The researchers defined the posture by the angles between the horizontal and the upper arm, lower arm, torso upper leg and lower leg at the beginning of the lift.

They used the Hotelling–Lawley multivariate test on the factors of the NIOSH WPG in order to test which of them were capable of predicting these joint angles at the $\alpha=0.05$ level of significance. The following factors were found significant: the vertical distance from floor to hand, horizontal distance from ankles to hands, anthropometric measurements of the subject (stature and weight) and vertical distance x horizontal distance. It is important to mention that the weight of the load used (15-30 lbs) was not significant in the posture prediction. Some studies about factors that affect the posture in a lifting task are summarized below.

An important research was the study carried out by Resnick (1996) who published a paper entitled “Postural Changes due to Fatigue” where he studied the fact that workers very often change the posture taught in trainings to another posture. He attributes this fact to a combination of fatigue and loss of concentration. In his study he analyzed the effect of fatigue in subjects given the lifting conditions of: 120% of the Maximum Acceptable Weight of Lift (MAWL) and a frequency of 3 lifts per minute for two hours. The change in the posture was quantified by measuring their maximum torso angle and the maximum hand-L4/L5 distance. Resnick’s conclusion was that even after training, fatigued workers may use biomechanically non-optimum postures.

Among the literature reviewed to determine the relevance of the age factor on the lifting posture is the study performed by Chaffin, D, et al. (1994): “Age effects in biomechanical modeling of static lifting strengths”. In that study the researchers stated that although muscle strengths declines with age in a non proportional manner for different groups of muscles; it is not clear which types of exertions are

most sensitive to postural compensations. In their biomechanical study, the authors found higher spinal disc compression forces associated with younger workers who have greater lifting strength than older workers. This finding may explain the higher incidence rate of low back pain for young men in heavy manual labor. In the case of older populations the lack of strength in the back and hip muscles are protective of the spinal column.

The above mentioned topics that made up this chapter were applied in the development of this research in the following manner:

- The Aesthetics ergonomics theory gave the theoretical support, overall structure and frame methodology for the development of the research.
- The NIOSH 1981 WLPG was the guide that let designing the lifting exertions within safe parameters.
- The psychophysics technique was applied in the measurement of the comfort of the adopted posture at the starting of the lifting.
- The planning and control human motor behavior theory was used to understand better the nature of the posture adoption and to determine the items included in the survey related to the importance of some specific factors at the moment of adopting a comfortable lifting posture.
- The different studies of posture predictions were addressed in order to know previous related works that had been developed and then compare their results with those obtained from this research.

CHAPTER 3

METHODOLOGY

3.1 General Description

As mentioned before, the objective of this research was to determine a range of safe and comfortable lifting postures in the sagittal plane. In order to achieve this objective this research used the Aesthetic Ergonomics Dual Process discipline as a framework. This approach was used to determine what attributes, characteristics or elements were recognized by the subjects as factors which could drive them to adopt a comfortable posture at the moment of lifting an object in the sagittal plane. The overall methodology is shown in Figure 3-1, and the steps taken to perform this research are show in Figure 3-2.

3.1.1 Experimental Conditions

Each one of the experimental stages of the research were performed using the recommended methodology of design of experiments. That means looking for similar conditions for each one of the participant subjects at the moment of performing the lifting task where the elements of each experimental stage were randomly administered to subjects.

Engineering Aesthetic Dual-Process

Figure 3-1: Aesthetic Engineering Dual Process Model, Liu (2003)

Figure 3-2: Stages for the research methodology

3.1.2 Collection of Data

As mentioned, data collection stages were carried out in the subject's workplace and then in a prepared room. The data was obtained through the arrangement of the elements, factors, and their combinations in a random order.

3.1.3 Statistical Model

Factors used in the construction of the postures were obtained from a multivariate statistical technique, which was be used later during the development of this research study, with which a statistical model was built explaining the effects of each factor deemed significant to determine the individual's posture.

3.1.4 Subjects

Since the objective of this research was to determine a range of safe and comfortable lifting postures in the sagittal plane, and given the fact that it has been observed that individuals adopt the most comfortable posture at the moment of lifting an object, sometimes even after they received training, all subjects recruited to participate in this research have received training as part of their current occupation about lifting techniques. Furthermore, all of them affirmed to be in healthy conditions at the moment of their participation and were

recruited from the WVU housing staff, WVU maintenance staff, WVU dining service department, WVU Hospital nursing staff and some manufacturing companies close to Morgantown, WV (all of them had a volunteer participation, and were contacted through their managers or by personal references).

3.2 Methodology

As described in Figure 3-1 the methodology used in this research was applied in two phases. 1) The Top-Down branch, also called the Multidimensional Construct Analysis or Multivariate Psychometric Analysis (Liu, Y., 2004), and 2) The Bottom-Up branch or Psychophysical Analysis.

3.2.1 Top-Down Branch

3.2.1.1 Determination of the Elements or Items

A literature review was performed in order to determine and understand all those elements, factors or attributes which could be considered as important from a cognitive perspective for an individual at the moment of adopting a comfortable lifting posture.

Some of the elements or items that were included in the analysis are:

- Stability
- Symmetry of the posture

- Size of the object
- Horizontal distance of the object
- Vertical distance of the object
- Frequency
- Fatigue
- Time standing the posture
- Clothing
- Spacing
- Floor surface
- Weight of the object
- Handles
- Symmetry of the object
- Availability of time
- How easy it is to adopt the posture?
- How much it is necessary to stretch
- Stretching of the legs
- Stretching of the arms
- Bending of the trunk
- Bending of the neck

A complete list of the items evaluated in this study is located in Appendix A.

3.2.1.2 Scaling the Items (Analysis of the Items)

After completion of the literature review, a survey (see Appendix A) was conducted where the group of items or elements considered as important were selected and gathered in order of being rated using a unidimensional scaling technique. These kind of techniques are quantitative metric units that measure concepts that are one dimensional in nature, the items are rated in a 1 to 5 Disagree-Agree response scale

The above mentioned items were included in the survey using statements, which appeared in random order for each subject. The statements were constructed based on the following criteria:

- Avoiding statements that could be interpreted in more than one way
- Avoiding statements that could likely be endorsed by almost everyone or no one
- Selecting statements that were thought to cover the whole range of the effective scale of interest
- Keeping the statements simple, clear, and direct
- Statements shouldn't exceed 20 words
- Each statement should only have one complete thought
- Avoiding generalizing terms such as all, always, none and never
- Avoiding complex and compound sentences
- Avoiding double negatives, and
- Avoiding difficult words (Dunn-Rankin, 1981)

After determining the elements or items considered important by subjects in order to have a comfortable lifting posture through unidimensional scaling, the degree of importance of each element or item according to the subject's perception or cognition was determined. The methodology used for such determination was the Likert's Summated Ratings Method, which has the following steps described by Dunn-Rankin (1981):

- Elements or items were chosen and unit values were assigned to each ordered category (e.g. integers from 1 through 5).
- Then, the subjects responded by checking or marking one of the categories for each item and a matrix of information $N \times K$ (# subjects $\times$ # items) was generated.
- In the information matrix, the rows were the categorization or rating (1=strongly disagree, 2=disagree, 3=undecided, 4=agree, 5=strongly agree) that the subject gave to each of the items.
- Item analysis was performed on the data, such as: mean (item importance) and standard deviation.
- Total score for each subject was obtained from the answers of the subject regarding every item.
- The Pearson Correlation Coefficient [r] was calculated for each item, with a discriminator index threshold of 0.6. In case the Pearson correlation coefficient calculated was greater than 0.6 the item was deemed strongly correlated with the total score. These correlation coefficients were

obtained directly from the SPSS Factor Analysis output matrix (technique that is explained below)

However, the researcher's personal judgment regarding each factor interpretability and usability was also applied in the determination process, in conjunction with the above described selection criteria. This combined determination process was done in order to retain the items with a higher practical application.

The goal was to obtain a relatively small number of items which should have high item-total correlations and low variability.

3.2.1.3 Determination of the Factors

The attributes, elements and characteristics grouped in factors and their importance was determined using the multivariate statistic technique of Factor Analysis due the configuration obtained from the survey's result.

3.2.2 Bottom-Up Branch

In this second part of the process, through the use of the psychophysical technique of magnitude estimation, the degree of perception of the subject for a specific change in each of the factors under study was determined. Moreover this technique also measured the subject's perception of exertion.

3.2.3 Factor Analysis

Factorial Analysis was used to determine the importance of each factor evaluated (Lifting Geometry, Object Characteristics, Allowance Work, Body Adjustment, and Work Experience) in subjects' cognitive perception to determine a preferred comfortable lifting posture for the lifting task.

3.2.4 Finding a Comfortable Safe Posture

Once the comfortable lifting postures and its limits were determined, the next step was to determine which of them would fulfill the required criterion of being safe for a lifting task in the sagittal plane. This analysis was carried out by comparing those postures with the NIOSH 1981 Lifting Equation (the only NIOSH Lifting Equation that has been validated to date) and the biomechanical criteria.

3.2.4.1 Use of the NIOSH 1981 Lifting Equation

The NIOSH 1981 Work Practices Guide for Manual Lifting was chosen as the lifting risk index calculation tool for this study because it has been validated by converging medical, scientific, and engineering studies that proposed manual lifting recommendations. This independent study validation process has established the 1981 NIOSH Work Practices Guide for manual lifting as the preeminent ergonomic authority for the determination of acceptable weights of

manual lift (Wickes and Nelson, 1993). Another lifting risk calculation tool available in the literature is the 1991 revised lifting equation. This revised tool, however, has not been fully validated and more research is needed to validate it (Waters et al., 1994).

The objective of applying the NIOSH 1981 Lifting Equation was to determine if a lifting task was, according to such lifting guidelines, hazardous or not for the individual. As mentioned before, that equation was developed using four criteria: epidemiological, biomechanical, physiological and psychophysical. The goal in the design of this psychophysical experiment was to have a lifting task with an object weight below or within the range permitted by the NIOSH 1981 action limit. This action limit denotes the weight limit that nearly all healthy employees (90% of the adult population, 99 % of the male and 75% of the female workforce) can lift over a substantial period of time (i.e., up to 8 hrs) without placing excessive load on the back. In a real life scenario according to the NIOSH 1981 Lifting Guide if the ratio of the load handled and the Action limit is ≥ 1 and < 3 , administrative control are necessary to prevent injury.

The use of the 1981 NIOSH Lifting Equation to evaluate a lifting task requires the measurement of the following factors: Weight of the load, Horizontal Origin Distance (H), Vertical Origin Height (V), and Travel Vertical Distance (D), which is the vertical distance measured from the origin of the lift to the its destination. (See Glossary in Appendix B, and see Figure 3-3).

The 1981 NIOSH Lifting Equation was primarily used to design the work lifting station and the parameters of the lifting task in the psychophysical experiment,

where all the above mentioned measurements were controlled as to ensure that all the lifting tasks or experimental conditions had a Job Safety Index (JSI) equal to 1. The Job Safety Index is a ratio between the weight of the load lifted and the recommended weight given by the NIOSH 1981 Lifting Equation, a Job Safety Index up to 1 means that the lifting exertion is completely safe. When the JSI is between 1 and 3 imply that some administrative or engineering controls must be taken in order to avoid harmful consequences for the person lifting the weight. In any circumstance a JSI higher than 3 must not be allowed, because it can lead to potential injuries.

Figure 3-3: Schematics of how horizontal and vertical distances are measured

3.2.4.2 Biomechanical Analysis

Biomechanical analysis of the different postures was carried out using the University of Michigan 3DSSPP Biomechanical software. This software is able to predict static strength requirements for tasks such as lifts, presses, pushes, and pulls. The results obtained from the use of such analysis tool include the percentage of men and women who has the strength to perform the described job, the spinal compression forces involved, and data comparisons to NIOSH guidelines. These results are obtained through a job simulation from data input, which include: posture data, force parameters and male/female anthropometry. Biomechanical analysis was assisted using the software automatic posture generation feature and it is enhanced through the use of illustrative three dimensional human graphic pictures.

Through the use of the option “Task Input” of the software, a mock posture (see Figure 3-4) can be built so that through the “Report” option of the software one can obtain the estimated percentage of workers with adequate strength capabilities to perform the task at certain level, as well as the compression and shear forces (both in Newtons) on the L5/S1 disc on the spine.

Figure 3-4: Example of the University of Michigan's 3DSSPP 4.3 Biomechanical software mock posture.

The Biomechanical analysis was performed using the 3D software for subjects' anthropometry measurements and their specific adopted lifting posture. The capabilities from lifting loads at the mocked comfortable posture were obtained from the "Report Summary Analysis" and the estimated compression and shear forces (N) for the L5/S1 disc were compared to values associated with the Action Limit (3450N), and the Maximum Permissible Limit (6400 N).

A summary of the steps of the experimental stage is described in the following:

Once the survey was carried out through the use of the multivariate statistic technique of Factor Analysis it was determined the factors perceived by the subjects as important to adopt a comfortable lifting posture. Then, the experiment was designed taking into account those physical factors to be included in a physical experiment (physical distances and object weight). After the physical experiment was carried out, the subjects' adopted lifting postures were noted and

entered in the 3DSSPP University of Michigan Software and compression and shear forces were determined. Once these data was obtained, statistical analyses (ANOVA tests) were performed and was found the significance of the factors in the adoption of a comfortable lifting posture.

As an important step of this study, some recommended lifting postures with compression and shear forces below the Action limits (3400N) were determined; they were obtained using the recorded angles of the subjects' adopted lifting postures and the 95% confidence intervals of the means, which were entered into the 3DSSPP University of Michigan Software.

CHAPTER 4

EXPERIMENTAL STAGE

The first part of the experimental stage consisted of conducting a survey. The Dual Aesthetic Ergonomics Theory was used in this research study to carry out this survey to rate subject's perceived importance of items or variables found in the literature to be potentially relevant in determining subject's posture in a symmetric lifting task. The items tested in this survey were described in section 3.2.1.1 of this document, and Appendix A. Once the survey was completed, Factor Analysis was used to cluster these items in components that were sorted by perceived importance and tested for significance; the most significant components were then used as experimental factors in the second part of this research study; i.e. the psychophysical experiment.

4.1 First Part of the Experimental Stage

4.1.1 Steps

- Steps carried out in the first stage were: a) collection of items or variables considered to be important in the literature, b) determination of the ranking scale used in the survey, c) development of a set of instructions and explanations that were used in the survey (See final survey in Appendix A), and finally d) to conduct the survey.

4.2 Survey Procedure

4.2.1 Process of implementing the survey

The survey was conducted from 09/08/06 to 11/16/06. Participating subjects were workers with experience in lifting objects, who also had received training about the proper and safe way of lifting an object. Data collection was carried out in the subjects' work place, and it was conducted during their break time and with the permission of their managers or supervisors.

One hundred and twenty eight subjects (128) answered the survey. Surveys were checked for consistency and outlier pattern, as a result of which seven surveys were discarded. Answers were considered inconsistent when: a) subjects answered all the items with the same ranking, or b) subjects' answers were mostly the opposite of the overall group response. A final criterion used to decide if a survey had to be discarded, was given by a "control item" that was placed for that purpose. A positive answer to this item on the survey ("The color of the room and environment is an important factor towards adopting a comfortable lifting posture") implied that the subject either didn't understand the instructions, or wasn't paying attention to what he/she was doing, or wasn't answering the survey seriously.

Once the set of valid surveys were determined, a test for outlier detection was carried out. A leverage value using linear regression was compared with a cut point value of 0.5454 ($2p/N = 0.5454$), where p : # of variables (33) and N : # of

cases (121). Two possible outliers were detected. However, making use of the researcher's prerogative, it was decided to keep them given that in the Factor Analysis the results with the complete set of 121 surveys had a better interpretability.

Workers belonged to: the West Virginia University's Facilities Management department, West Virginia University's maintenance shops, some Morgantown nearby manufacturer companies, department stores, and supermarkets. Subjects' age ranged from 18 to 65 years old. After discarding subjects for inconsistent answers and/or outlier responses, there were 19 female subjects and 102 male subjects participating in this part of the study, most of whom, 92 subjects, were over 40 years of age (See Descriptive Statistic Table in Appendix C). The order of the survey's statements was randomized for each subject.

4.2.2 Factor Analysis Process

After completion of the survey, the next stage was to carry out the multivariate statistical technique of Factor Analysis (FA). This technique has the goal of determining what factors affect the different items or variables at the same time; this technique clusters the variables in different groups based on their common correlations; once these groups are interpreted, they are called "factors". The factor analysis determined the factors that were used in the following stage, which was the psychophysical experiment with the simulation of the sagittal lifting posture.

Factor Analysis is based on the maximization of the common variance in the variables that means that the practical purpose of this technique is to associate those variables (items) that have a common variability which in theory was determined by belonging to a common factor. The purpose of this analysis is to associate items with common qualities.

In FA only the shared variance between factors is analyzed (the idea is to eliminate variance due to error and variance that is unique to each factor). In a good FA, high percentage of the total variance is associated with the first few factors, and because factors are displayed in descending order of explained total variance, the first factors accounts for the most of variance, with later factors accounting for less and less of the total variance (Tabachnick and Fidell, 2001). For instance, that means that if in the Total Explained Variance output, the first component has a total variance of 30% that means that the 30% of the variance of items is explained by the first factor.

At this point, it is important to clarify some concepts: The items of the survey are the variables and these variables will be clustered in factors by the technique of Factor Analysis. It is important to point out that those factors are named depending on their practical meaning given by the similarities of the variables included in the factor (i.e. variables temperature, wind, humidity could be clustered in a factor that could be named Environmental Factor). However, it is necessary to mention that in some of the analysis of this technique, such as in the Total Explained Variance, the items (variables) are named components, being each component a potential factor. Nevertheless, only those components

with a significant value of total explained variance are considered, given the potential number of factors in which the items can be grouped.

Several tests were required on the set of items and data in order to determine if it was feasible and suitable to apply the multivariate statistic technique of Factor Analysis. The following analyses were performed on the data, subjects and items (variables):

- Normality Analysis: It was performed by analyzing skewness and kurtosis. In the analysis used by the descriptive statistics (see Appendix C) in SPSS, it was observed that only a few variables were associated with positive skewness (fear of failing in the task, using gloves, level of noise, air freshness, color of the room and diet). Therefore, there was not compelling evidence associated with lack of normality in the data.
- Multicollinearity: In FA, such a pattern is found when determinant and eigenvalues (an eigenvalue is an index that indicates the portion of total variance of a correlation matrix that is explained by the eigenvector, which is a linear function of the variables that maximize the amount of the total variance explained in a correlation matrix) approach to "0". If the SMCs (Squared multiple correlations) approach to 1, that implies the presence of singularity. Variables with multicollinearity or singularity should be deleted from the analysis.

Using the table given by SPSS for the analysis of communalities shown in Appendix D, it was determined that the variables evaluated were not associated with multicollinearity or with singularity patterns.

- Another test to determine how appropriate FA was for the obtained data was the anti-image test, which provides similar but more didactic information than the covariance matrix (how two variables co-vary when considered simultaneously). The anti-image test was also used to determine if the Correlation Matrix [R] was factorable, if that were the case, numerous pairs would be significant. Also, if R were factorable, then the values among the off diagonal elements of the anti-image matrix would be mostly small. For the data obtained, the anti-image matrix contained small values, which was desirable.
- A test to evaluate Factor Analysis on the data was the Residual Correlation Matrix. In this analysis it was observed whether the numbers in the Residual Correlation Matrix were small, because in that case, there would be a little difference between the original Correlation Matrix and the Reproduced Correlation Matrix, which indicates that the difference between the observed correlations and the correlations containing the determined factors was small. In this study the numbers obtained in all the analyzed Residual Correlation matrices were small, indicating the data adequacy and that the Factor Analysis developed was properly performed.
- Other indicators about the sampling adequacy obtained through the SPSS software were the Kaiser-Meyer-Olkin (KMO) and Bartlett's Test of Sphericity. The KMO test measures of whether the partial correlations among variables were small and the Bartlett's Sphericity tests whether the correlation matrix was an identity matrix (which would indicate that the factor model was inappropriate). A sampling is considered adequate if the KMO is greater than

- In FA, the variance in the correlation Matrix is condensed into eigenvalues. Mathematically the correlation matrix can be considered as the product of two matrices, each one a combination of eigenvectors and the square root of eigenvalues. The factor (mathematically called eigenvector and named as component in the SPSS's Total Explained Variance table) with the largest eigenvalues had the most total explained variance (factors with small or negative eigenvalues were omitted as possible solutions). Only solutions with eigenvalues greater than one were considered, given that if a eigenvalue is smaller than 1, it implies that less than the 10% of the Total Variance of the correlation matrix has been explained .
- Communalities analysis was another important tool that was used to test the appropriateness of the application of Factor Analysis to the data. This analysis for a variable is the variance accounted for by the factors. It is the squared multiple correlations "predicted by the factors". Communalities were used instead of "ones" to remove the unique and error variance of each observed variable, "only the variance that a variable shared with the factors was used in the solution". Final communalities (those were given by the SPSS software) represent the proportion of variance in a variable that was predictable from the factors underlying it. Communalities estimates did not change with rotation. If communality values were greater than one, problems were identified; given the existence of one or more of the following situations: few data, starting

communalities values were wrong, number of extracted factors were wrong (that could be improved by adding or deleting factors).

If communality values were “too low”, the variables were unrelated to each other. In this study all the item’s communalities were from 0.5 to 0.75, which indicated a potential relationship among some of them.

- Another important matrix obtained in the process of carrying out a Factor Analysis was the Factor Loading Matrix, which contained correlations between factors and variables. As mentioned previously a factor was built (interpreted) from the variables that were highly correlated (loaded) on it. An important tool for the interpretation of the loadings was the rotation, which was used after extraction to maximize high correlations and minimize low ones.

4.2.2.1 Some considerations about the number of factors extracted

A large number of factors extracted yield a better fit between observed versus reproduced correlation matrices. Furthermore, a bigger number of factors extracted yield a better fit and higher percentage of explained variance in the data. On the other hand, a drawback was that a bigger number of factors extracted cause a less efficient use of the resources in the solution. In that sense, a first estimate of the number of factors was given by the sizes of eigenvalues (represent variance), obtained from initial run with principal components extraction. Only components with eigenvalues >1 were accounted as possible factors.

Another important criterion to determine a feasible number of factors was given by the Scree test of the eigenvalues, which plots them against the factors. A Scree test is useful when the sample size is large, communalities factors are high and each factor has several variables with high loadings. A good solution is determined when the SMCs (Squared Multiple Correlations) are in the range between 0 and 1. A SMC close to 1, means that the factor is more stable. High SMCs (i.e values > 0.7) mean that the observed variables account for substantial variance in the factor scores. A low SMC means that the factors are poorly defined by the observed variables. If a SMC is less than "0", too many factors had been erroneously kept as possible factors in the solution set. If a SMC is >1 , the entire solution needed to be reevaluated. "A variable with a low SMC (Squared Multiple Correlation) with all the other variables and with a low correlation respect all important factors, it is an outlier among the variables, and it should be ignored in FA" (Tabachnick and Fidell, 2001).

By means of the SPSS software's option of Varimax Rotation an orthogonal rotation was applied to the loading matrix (where correlations between variables and factors were found). The purpose of a rotation was to obtain a clear pattern of loadings, that was, factors that were somehow clearly marked by high loadings for some variables and low loadings for others. This general pattern was also sometimes referred to as simple structure. For statistical significance purposes, in this study any correlation greater than 0.60 was considered meaningful. Therefore, this was the final criterion that let this technique to group the variables within factors.

4.3. Results of the Factors Survey

Survey results are provided in Appendix A. In order to process the 170 N/R (Not Relevant) answers obtained in the survey, different scenarios were analyzed using SPSS while conducting Factor Analysis (170 N/R answers out a total of 4224, 4.02%). Data was analyzed using the following scenarios:

- 1.- Not taking into account of the N/R answers (these items where the answers of the subjects were N/R, were considered as blanks). For this scenario SPSS's Factor Analysis couldn't give the Rotated Component Matrix, which is an essential tool to interpret the factors given by the variables. Therefore, this scenario was discarded.
- 2.- Considering the N/R answers as "zeros" (which would be a sort of a "neutral" rating). For this scenario, Factor Analysis yielded a Rotated Component Matrix where 11 component factors appeared, some of them could be clearly interpreted, however, for others their interpretation were not so clear.
- 3.- The N/R (Not Relevant) answers were assumed as the rating option of "I disagree" which had a numerical rating of 2. It was observed that some subjects used either one of the two alternatives throughout the survey to rate items that they considered as not important for the adoption of a comfortable posture. That was explained because each statement in the survey was an affirmation of the importance of the item to adopt a comfortable lifting posture and to say that the item "it is not relevant" was understood also as the item that wouldn't be important to adopt a comfortable posture.

This last scenario was analyzed with (See Appendix E) and without (See Appendix F) the two subjects determined as possible outliers. Both scenarios yielded two Rotated Component Matrices with good interpretability. However, the results obtained from the data keeping the two subjects yielded a solution with a slightly better interpretability.

After obtaining the Component Rotated Matrix, the two possible criteria to determine if a variable was useful or not were its interpretability (given by how well it contributed to the interpretation of a factor) and its importance (given by the average of the subject's answers for that item).

A first purging of the items that were included in factors but didn't give interpretability to the factors was carried out. Then a Factor Analysis without those items was performed where a new Rotated Component Matrix was obtained. In this new Rotated Component Matrix the factor structure had basically the same degree of interpretability.

Using the criterion of the importance of the item it was determined that only items interpreted as components of the Factors Work Study Allowances or Environmental Characteristics (items from 25 to 32) had a rating mean lower than 3.1. Therefore, that means that these items weren't important in the subjects' cognitive perception about what factors or variables lead them toward adopting a comfortable lifting posture. Therefore, the variables and factors made up of those variables with proper interpretability and importance greater than 3.1 and with a low dispersion were candidates to be used in the next stage of this research.

A summary of the results for the different analyses follows:

- Positive skewness was detected in few variables (items 27 to 32), which means that there was not compelling evidence for lack of normality in the data. See Appendix G.
- By the analysis of communalities and the covariance table it was determined that none of the variables was either close to 1 or was a low value (close to zero), they were from 0.5 to 0.75, which means that the amount of collected data (number of subjects) was appropriate and some variables are indeed related to each other. All the communalities for the different items were in the range between 0.55 and 0.74, which means no heterogeneity among the variables.
- In all the analyzed anti-image matrices, small correlation values were found, meaning that correlations were significant such that factors can be obtained from the correlation matrix after the application of the Factor Analysis.
- The numbers obtained in all the Residual Correlation matrices that were analyzed were also very small, which means a slight difference between the Correlation Matrix (Observed) and the Reproduced Correlation Matrix (matrix after the items adopted a grouped structure as factors); indicating the adequacy of the data and its analysis.
- In all the runs performed using the SPSS software for the different analyzed situations, the Kaiser-Meyer-Olkin (KMO) was greater than 0.75

(it is a good indicator if that measure is greater than 0.6), which means that the partial correlation of the variables is small.

- The Bartlett's Test of Sphericity showed to be close to zero (very significant), indicating that the Correlation Matrix was not an Identity Matrix. Therefore, the obtained factor model was appropriate.
- The analysis performed for the answers of 121 subjects on the 33 items using Factors Analysis and where the N/R option was treated as a rating of 2, was the one which yielded a better interpretability.
- For the above mentioned scenario, the Component Matrix yielded 10 factors, which after being rotated using the SPSS Varimax Rotation in order to improve the interpretability of the factors, yielded the following summary result shown in Table 4-1.

Table 4-1: Summary of Factors and Variables after Rotated Component Matrix for the first solution

Factor	Item	Loading	Avg. Rate	3(Std. Dev)
Lifting Geometry	Vertical Height	0.6512	4.181	3(0.795)=2.39
	Free Space	0.63545	4.444	3(0.561)=1.69
	Body Stability	0.61141	4.404	3(0.585)=1.76
Environmental Conditions	Air Freshness	0.7394	2.950	3(1.071)=3.21
	Relative Humidity	0.7389	3.099	3(0.995)=2.99
	Ambient temperature	0.6423	3.264	3(1.046)=3.14
Object Characteristics	Weight of the Object	0.7657	4.561	3(0.825)=2.48
	Size of the object	0.6173	4.586	3(0.628)=1.88
Body Adjustment	Legs stretching	0.4017	3.752	3(0.915)=2.75
	Neck bending	0.7909	3.64	3(0.911)=2.73
Work Factor Allowances I	Color of the room	0.7131	1.867	3(0.805)=2.42
	Diet	0.6626	3.082	3(1.069)=3.21
	Noise Level	0.5575	2.289	3(0.879)=2.64
Work Experience	Experience lifting	0.7908	4.347	3(0.760)=2.28
	Experience in Job	0.6632	3.917	3(0.962)=2.89
Symmetry of Object	Handles or not	0.7532	4.314	3(0.885)=2.66
	Object symmetric or not	0.4454	4.090	3(0.957)=2.87
Work Factor Allowances II	Site illumination	0.6984	3.264	3(0.983)=2.95
	Gloves	0.6335	3.066	3(1.152)=3.46
	Amount time available	0.4656	3.677	3(1.127)=3.38
Body Comfort	Stretching of arms	0.7123	4.148	3(0.881)=2.65
	Clothes fitting	0.6737	3.950	3(0.772)=2.32
	Symmetric posture	0.4909	4.140	3(0.809)=2.43
Tiredness	Fatigue	0.7569	4.250	3(0.736)=2.21
	Time of the Day	0.5073	3.074	3(1.163)=3.49

- The Total Variance Explained output given by SPSS (See Appendix H) shows 10 components with eigenvalues greater than 1. However, only 4 were above 1.5. It would suggest the presence of 4 possible factors. The same conclusion was obtained from the Scree Plot (see Appendix I) where the curve showed an inflection point (a point in the curve where it changed its slope) after the 4th component (factor), suggesting the potential presence of that number of factors.
- Another analysis of the data was carried out, where some items that apparently had a moderate contribution to the interpretability of the factors weren't considered. The SPSS's Factor Analysis option was performed and a new alternative structure for the factors was obtained, as shown in Table 4-2. However, it was observed that the structure obtained in Table 4-1, had a better general interpretability given that items (variables) with similar characteristics were clustered in a total of ten meaningful factors compared with only eight obtained when were not considered those items that apparently weren't contributing to the factors' interpretability. Given the purpose of this Factor Analysis which was to obtain more meaningful factors, the results from Table 4-1 were considered better.

Table 4-2: Summary of Factors and variables given by the Rotated Component Matrix

Factor	Item	Loading	Avg. Rate	3(Std. Dev)
Work Allowances I	Diet	0.6417	3.082	3(1.069)=3.21
	Color of the room	0.6313	1.867	3(0.805)=2.42
	Noise Level	0.6280	2.289	3(0.879)=2.64
Work Experience	Experience in Job	0.7497	3.917	3(0.962)=2.89
	Experience lifting	0.7171	4.347	3(0.760)=2.28
Object Characteristics	Size of the object	0.7982	4.586	3(0.628)=1.88
	Handles or not	0.6715	4.314	3(0.885)=2.66
	Weight of the Object	0.6279	4.561	3(0.825)=2.48
Environmental Conditions	Relative Humidity	0.8060	3.099	3(0.995)=2.99
	Air Freshness	0.7073	2.950	3(1.071)=3.21
	Ambient temperature	0.6908	3.264	3(1.046)=3.14
Lifting Geometry	Vertical Height	0.7475	4.181	3(0.795)=2.39
	Free Space	0.5846	4.444	3(0.561)=1.69
	Body Stability	0.5590	4.404	3(0.585)=1.76
Body Comfort	Clothes fitting	0.7320	3.950	3(0.772)=2.32
	Stretching of arms	0.6733	4.148	3(0.881)=2.65
Work Allowances II	Site illumination	0.7054	3.264	3(0.983)=2.95
	Gloves	0.6011	3.264	3(0.983)=2.95
Body Adjustment	Neck bending	0.8320	3.64	3(0.911)=2.73
	Legs Stretching	0.6166	3.752	3(0.915)=2.75

4.4 Usability of the results of the 1st stage.

The factors obtained from the first part of the experimental stage of this research study were evaluated to determine their feasibility, importance, and contribution

to this research objective and ergonomics point of view, in order to be used in the experimental design conducted during the second stage of this research.

4.5 Evaluation for the use or non use of some specific factors and items

The selection of a factor was based on the items that were included in it, and how feasible, practical, and important they were perceived by the subjects to adopt a comfortable posture for lifting an object in the sagittal plane. Also, another important criterion was the dispersion measure of the items (variables).

Table 4-1 included 5 columns: Factors, Items, Loadings, Average Rate of the item given by the subjects and 3 times the standard deviation of those ratings given by the subjects.

- Factors were determined by the interpretability obtained from the variables clustered within them by the Factor Analysis technique. However, some of them were not practical or feasible to be manipulated in a kind of experiment such as this research study.
- Items or variables were clustered together by the FA technique that could be related one to each other in a meaningful manner and have a loading value above 0.5 in the matrix.
- The average rate gave the perceived importance given by the subjects to the item (variable) as a factor toward the adoption of a comfortable lifting posture.
- The parameter: three times the standard deviation gave the comparison of how disperse were the responses among the subjects. They were also compared to

the average rate as another manner of evaluating the importance given by the subjects to the items.

The analysis of the factors selected from Table 4-1 is described below:

- Factor Lifting Geometry: This factor grouped variables such as vertical height, free space, and body stability. It was one of the most important from the ergonomics point of view, and also showed a very low dispersion:
 - Vertical Height: It is an essential factor that has been considered in the 1981 NIOSH Lifting Equation. It was also perceived as very important by the subjects in their perception of comfort for lifting an object.
 - Free Space: in order to evaluate its effect, a physical obstacle to hinder subjects' free manipulation of the object would have to be placed between the origin and the final destination. Given the range of horizontal and vertical distances that were used in the proposed experiment, this item was not considered for evaluation in the current research study.
 - Body stability: Important from the ergonomics and safety point of view, this item was also considered important by the subjects on the comfort perception for lifting an object.
- Environmental conditions: The items that made up this factor were associated with a relative low subjects' perception of importance in adopting a comfortable lifting posture in the sagittal plane (air freshness 2.95, relative humidity 3.09, ambient temperature 3.26), and with a high dispersion around their average. Given their relatively low rating, high dispersion and the difficulty associated

with their control, these items were not considered for the design of the experiment in the second phase of this research.

- Object Characteristics: The weight and size of the object were perceived as very important by the subjects, with average ratings of; 4.56 and 4.58, respectively, and presented a very low measure of dispersion. Therefore, these items were included in the experiment.
- Body adjustment. - This factor contained leg stretching, neck bending, which are related to some anthropometric characteristics of the subject (stature and length of legs). These two items showed moderate importance and dispersion. Therefore, stature and legs length were measured together with other anthropometric data and considered as covariates in the experiment.
- Work Factor Allowances I: This factor grouped some items used to determine the allowances to set the effect of fatigue and then the cycle time for a work activity. The items “color of the room” and “level of noise” were perceived very low in their importance by the subjects (1.867 and 2.289 respectively) and the “diet”, 3.08, which is relatively low and unfeasible to manipulate for our experiment. Moreover, given the fact that these items showed a high dispersion among the subjects’ importance perception, they were not considered in this second phase of the research.
- Work Experience: The items included in this factor (experience lifting objects and experience lifting in the job position), were rated high (4.34 and 3.91 respectively) and they showed a low dispersion measurement. Experience in

the job position was deemed feasible to be used as a covariate (number of years working that in that job or similar jobs).

- Object Symmetry: Although the items that grouped under this factor: (presence of handles and symmetry of the object) were considered as important and showed a low dispersion among the subjects, the handles characteristics have been studied and considered already in the NIOSH 1991 lifting equation, and the symmetry of the object would be difficult to consider in the next experiment. Therefore, the evaluation of these two variables (they are named items in a survey, variables in an experiment) was left for future research.
- Work Factor Allowances II: This factor was composed of the items: use of gloves, site illumination, and time available to perform the lifting task. The use of gloves was perceived to have a slightly low importance (3.06), and a high dispersion measurement ($3\sigma=3.64$). Illumination, on the other hand had a perceived average importance rating of 3.45 by the subjects and a little lower dispersion measurement ($3\sigma=2.94$), both variables would be considered for future research. However, the amount of time available is associated with the lifting frequency which was taken into account in the experiment.
- Body Comfort: This factor included the following items: stretching of arms, clothes fitting, and symmetric posture. The stretching of arms (rated high, 4.14), was related to the horizontal distance and an anthropometric measure (length of the arms), this item was considered through the horizontal distance in the experiment. Although the clothes fitting item (rated high in average and can in fact affect the comfort with which an individual lifts an object) it is unlikely that a

person would repeatedly wear clothes that do not fit well if he or she were performing a lifting task. However, some clothing characteristic such as heaviness of the clothes was not included as a variable in the experimental design of the second phase (winter clothing could be evaluated in future research for its effect on individuals adopted posture). The third item grouped in this factor, symmetric posture was included in the experiments through the specific design of the lifting task and through the instructions given to subjects to adopt a comfortable and stable posture.

- Tiredness: This factor was made up of the items: “fatigue” and “time of the day” (rated by 4.25 and 3.07 by the subjects). Since fatigue was associated with a poorly designed lifting frequency, it was taken into account as a factor in the experiment for the second phase of this study (Heart Rate Analysis). Time of the day, however, was not considered.

4.6 Summary of results obtained from the usability discussion

As explained above, the following factors through some of their variables were considered in the experimental stage of this research:

- Lifting Geometry
- Object Characteristics
- Body adjustment (studied through the anthropometric covariates)
- Work experience (studied through the covariate number of years in job activity)

Moreover, the above mentioned factors were studied through the following variables:

- Vertical Height
- Object Size
- Object weight
- Horizontal distance (related to factor Lifting Geometry and associated with items belonging to the factor Body Adjustment)
- Frequency (fixed level)
- Anthropometric measurements (covariates)
- Number of years in his/her job activity (covariate)

The variables indicated above as “covariates” (anthropometric measurements and years in the job) were associated with items related to stretching of the limbs and other parts of the body and work experience. Covariates were variables which through an ANOVA helped to adjust (eliminate) the difference in the comfort rating due to preexisting participant characteristics. These covariates were included in the Linear Statistical Model that was used, which is displayed later in this document.

4.7 Psychophysical Experiment

This experiment was designed to determine the difference between subjects' perceived comfort levels when starting the lifting of an object in the sagittal plane

among 12 established conditions, all of which considered safe by the 1981 NIOSH Lifting Equation.

In this experiment, the objective was to determine the magnitude of variation in the level of a studied variable from where a change in the subjects' perceived comfort would be detected. Achieving this objective would be associated with fulfilling a requirement of the Aesthetics Ergonomics Theory Dual Process mentioned earlier in this document. Basically, the main goal was to find the vertical distance where the subject perceived a higher level of comfort at the moment of lifting a weight in the sagittal plane, in a safe condition and adopting a free, stable posture (as shown previously in Figure 1-1).

The main factor evaluated in this experiment was the vertical height (V), since results from the first stage of this study indicated that the main factor considered as important to adopt a comfortable lifting posture was the geometry of the lifting. Furthermore, because vertical distance was an essential factor in the 1981 NIOSH Lifting Equation, it was of great interest to determine the importance of its effect on the subjects' perception of comfort at the moment of lifting an object in the sagittal plane.

The effect of Vertical Height (V) on the comfort perception of the subjects was evaluated through 12 different experimental conditions consisting of 4 different vertical heights of the origin of the lift, combined with 3 different object weights at a constant lifting frequency of 5 lifts / min, constant duration of the lifting task (4 minutes), and constant lifting vertical travel distance of 15 in.

There were two essential facts considered for this experiment: a) the first one was that all these 12 lifting conditions were designed within very consistent safe parameters. These lifting conditions, moreover, were set in such a way that all of them yielded a Nominal Lifting Index (Weight Lifted / NIOSH 1981 Action Limit) equal to 1. A Lifting Index of 1, according to the 1981 NIOSH lifting equation, represents the highest demand a lifting task can pose to the individual and still be accepted as safe for the majority of the population; and b) the second important fact was that all lifting conditions needed in fact to be equal from a safety point of view, in order to control unwanted potential sources of variability to the subjects' response at the moment they determined their comfort perception on the lifting condition. The objective in the design was therefore to keep every experimental condition at the same nominal level of safety stated by the NIOSH 1981 Lifting Index (LI) of 1.

Due to the above mentioned reasons, the vertical height (V) was used as a factor over which another factor denominated in this research study as "Z" (e.g. a combination of the factors: horizontal distance and one specific weight of the object, W) was used. The determining parameter for the safety level of each experimental condition was the LI, and this parameter depended on the vertical height "V", the weight of the object "W", and the horizontal distance "H". In order to assure that all experimental conditions were equally rated through LI at the same time they had 4 different vertical heights and 3 different weights, the horizontal distance for each experimental condition was set dependent upon the combination of vertical height and weight of the object. Therefore each of the 12

experimental conditions had one different horizontal distance, that combined with object weight was called as stated above variable “Z”.

As mentioned above, this study had subjects lifting objects with three different weights (e.g. small, medium, and large) at each level of V. Since H was applied in combination with (depending on) W, each experimental condition had a different value of H. Since this study evaluated 4 levels of V and three different object weights, Z had 3 levels nested in each level of V, as it is graphically explained in Figures 4-1 and 4-2 of this document.

Although the horizontal distance was not directly evaluated in this experiment (because findings of the NIOSH Lifting Equation show that a safe lifting is more affected by V than by H), some interesting conclusions about the combination of H and W were derived, and are later described in this document.

The 12 experimental lifting conditions evaluated in this experiment are shown in Table 4-3.

Table 4-3: The twelve used Experimental Lifting Conditions

F= 5 lift/min D=15 in Resting: 5 min	Condition	H(in)	V(in)	AL*	LI**	W (lb)
	V1H1W1	22.125	0	8.97	1.003	9.0
	V2H4W1	26.75	15	9.01	0.999	9.0
	V3H7W1	31.5	30	9.00	1.000	9.0
	V4H10W1	30.75	45	8.96	1.005	9.0
F= 5 lift/min D=15 in Resting: 5 min						
	V1H2W2	12.5	0	15.88	1.008	16.0
	V2H5W2	15.125	15	15.93	1.004	16.0
	V3H8W2	17.75	30	15.97	1.002	16.0
	V4H11W2	17.25	45	15.97	1.002	16.0
F= 5 lift/min D=15 in Resting: 5 min						
	V1H3W3	8.25	0	24.05	0.998	24.0
	V2H6W3	11.25	15	23.80	1.008	24.0
	V3H9W3	13	30	24.23	0.990	24.0
	V4H12W3	12.75	45	24.00	1.000	24.0

*AL: Action Limit (NIOSH 1981 Work Practices Guide for Manual Lifting

** LI=W/AL

This table shows the four levels of vertical height and the three levels of weight as well as the other two factors used in the NIOSH 1981 Lifting Equation, vertical travel distance and lifting frequency. The parameter that indicates a low (safe) lifting risk was the Lifting Index (Job safety index) equal to 1 obtained through dividing the object weight (W) by the Action Limit (AL, NIOSH 1981 WPLG) for each task (See calculations in Appendix J). It is important to mention that this safe condition is "nominally safe" given that there is always the probability that some special characteristic or unnoticed condition of the subject could represent some level of danger. Vertical distance and weight to be lifted were perceived as very important by subjects in the survey. The four levels of V are equidistant (travel distance = 15 in). It was desired that the factor weight would have been completely equidistant for its three levels (large, medium and small). However, since for consistency reasons, it was paramount in this experiment to make sure that $LI=1$, the smallest weight had to be slightly increased (9 lbs instead of 8 lbs). The horizontal distances were determined based on the other factors (V and W).

4.8 Experimental Design

4.8.1 Factors

This experiment was a two-stage nested design; where factor Z (which is a lifting condition given by a combination of H and W) was nested under Factor V (Vertical Height), due to the fact that the Z conditions for each Vertical Height (V)

were unique for that particular Vertical Height. Both factors V and Z were treated as “fixed effects”.

The experiment was carried out at the fixed conditions of: Frequency (F) = 5 lift/min, Vertical Travel Distance (D) = 15 in, Duration of each lifting condition = 4 minutes and resting period between lifting condition = 5 minutes. All the lifting conditions yielded a nominal Safe Lifting Index of 1. See Figure 4-1, Figure 4-2, and, Figure 4-3.

Figure 4-1, shows the nested structure of Z under V and the two alternative notations for Z, the notation which is in shadows that Z levels are numbered 1, 2 and 3 given that are similar but not identical, and the other notation is showing that the levels of factor Z can be renumbered, each of them with different numbers given that they have slight differences, which is an indication of factor Z being a nested factor (Montgomery, 2001).

Figure 4-1: Factor Z (condition given by a combination of H and W) nested on the Factor Vertical Height (V).

Figure 4-2: Horizontal Distances (using three different object's weight) applied on the four levels Vertical Height (V).

Figure 4-3: The proposed two-stage nested design.

4.8.2 Statistical Model

The statistical model was a linear model made up of factors V, Z nested along with some covariates as shown in equation 4-1.

The linear model included the effect of factor V, nested factor Z and some covariates (variables that cannot be controlled by the experimenter). This model is shown below:

$$y_{ijk} = \mu + \tau_i + \beta_{j(i)} + \phi_{1(ij)k}^c + \varepsilon_{(ij)k} \quad \begin{cases} i = 1, 2, 3, 4 \\ j = 1, 2, 3 \\ k = 1, 2, \dots, n \end{cases} \quad 4-1$$

Where:

y_{ijk} : Average response for the i^{th} , j^{th} , k^{th} level

μ : Overall mean

τ_i : Effect of the i^{th} level of factor V

$\beta_{j(i)}$: Effect of j^{th} level of factor Z nested within the i^{th} level of factor V

$\phi_{1(ij)k}^c$: Effects of each Covariate

$\varepsilon_{(ij)k}$: Random error component

There were 4 levels of Factor V, 3 levels of Factor Z nested within each level of V and n replicates (number of subjects, in this case it was 20). The covariates included were: heart rate, gender, age, right handed (dexterity), subject's height, subject's weight, years working, compression force, shear force, and center of gravity coordinates.

4.8.3 Hypothesis

Null hypothesis:

H_0 = There is not a significant difference among the average perception of comfort given by the four levels of V at the moment of lifting an object in the sagittal plane for equal safe lifting task (LI=1). See Figure 4-4.

Test of Hypothesis

$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$

H_1 : At least one average is different.

Where the four levels of the Vertical Height (V) are:

- 1.- V = 0 inches
- 2.- V = 15 inches
- 3.- V = 30 inches
- 4.- V = 45 inches

Figure 4-4: Graphic showing if there would have not been a difference among the average perception of comfort given by the various experimental conditions

4.8.4 Protocol of the Experiment

- The subjects read the IRB consent form. See Appendix K
- Before starting their participation (on the same day), all subjects received training about the proper way of lifting an object by watching a 15-minute training video (Lifting, Ergonomics Success. J.J. Keller & Associates Inc.)

- Subjects had a rehearsal lifting task (using a condition different from the 12 that were tested, using the average of each variable, which was not recorded). Subjects were urged to ask any questions they may had during this training period.
- Subjects received the following instructions:
 - The activity performed during the study should be considered as the primary activity that they did during the whole workday. (Note that only workers experienced in handling objects participated in this study).
 - Considering the training that subjects had received and their experience in this type of work, they were asked to adopt a posture that minimized the work injuries associated with lifting objects for each task condition they perform the lifting. Subjects were instructed to lift the object adopting a safe, comfortable and stable posture. Besides controlling the vertical and horizontal distances of the lifting tasks, the way subjects grabbed the box was not controlled in order to create as much as a realistic scenario as possible.
- Subjects lifted the object in each condition for 4 minutes at a frequency of 5 lifts / minute. In the first 3 minutes they were instructed to try as many different postures as they felt necessary in order to find the most comfortable posture for that condition. At the beginning of the 4th minute the experimenter let the subjects know that only one minute was remaining, and they were using the fourth minute to lift the object with the posture that they had determined as the best.

- At the end of the fourth minute, subjects were requested to rate their comfort perception of each experimental condition with a psychophysical rating scale, as explained below.
- Each of the twelve conditions was performed in random order.
- Before the beginning of the experiment (right after subjects signed the Consent Form) the researcher took their anthropometric measurements.
- After explaining to the subjects the purpose of using a Polar Heart Rate monitor and how to place it on their own chest, subjects placed the heart rate monitor by themselves. This was a heart rate monitor that was made up of two pieces: one that was placed on the chest and the other on the wrist (to display the heart rate). The purpose of using this heart rate monitor was to obtain the average heart rate while the subject was performing lifting objects in each one of the lifting conditions, then; this value was analyzed as a covariate in the statistical model.
- Then the experimenter read the instructions to the subjects (they were encouraged to ask about any questions they may have). See instructions in Appendix L.
- All subjects were photographed at the starting of the assumed final lifting posture (beginning of the fourth minute). It was the fourth minute of each experimental condition that was used to determine the biomechanical forces using the University of Michigan 3DSSPP Software.

- The photography station was placed at one of the lateral sides of the lifting station, recording the upper and bottom limbs on reference to the sagittal plane (side view).
- The psychophysical technique of magnitude estimation was used, where for each of the lifting conditions, subjects made a mark on a 10 cm line depending on the level of discomfort that they felt while carrying out the lifting task. There was an explanatory wording along the right hand side of this 10 cm line to help subjects rate their perceived discomfort (See Appendix M). The length from the beginning of the line to where the subject's mark was located was used as the subjective response variable obtained in a quantifiable continual scale approach (See Appendix M).
- Subjects' perceived comfort reported in this study for each condition was obtained by subtracting subjects' actual perceived discomfort response on the discomfort scale (a dimensionless number from 1 to 10) from 10. Subjects' perceived comfort values, calculated according to the description provided above, are shown for each experimental condition and for each subject in Appendix N along with the correspondent average heart rate.
- The biomechanical software by the University of Michigan 3DSPSS was used without using the built-in percentiles (anthropometric measurements of each subject were entered).
- The average heart rate of each subject was registered at the end of each lifting condition (right after the subject marked their perception on the 10 cm scale) for

- The subject did not see the rearrangement of the lifting station between conditions. This was a blind study.
- Although from previous research it was determined that there was no significant difference between male and female subjects. This experiment was expected to confirm this result.

4.8.5 Anthropometric Measurements

The following anthropometric measurements were taken as part of this study:

- Weight
- Static anthropometric heights of a standing person (stature, acromial height, tenth rib height, wrist height, knee height)
- Static anthropometric depths of a sitting person (buttock knee length, popliteal length).

Figure 4-5a shows a compendium of anthropometric measurements, including the measurements taken in this study.

Figure 4-5a: Compendium of Anthropometric measurements. (Panero, J. and Zelnik, M., 1979, p. 30).

- The place where the anthropometric measurements were taken is shown in Figure 4-5b

Figure 4-5b: Anthropometric measurement station

4.8.6 Apparatus

The following laboratory apparatus was used during the psychophysical experiment in this study

- A metal structure with four wooden platforms, one at each of the indicated vertical heights (15", 30", 45", and 60" only for the highest destiny) was used as the main laboratory apparatus for this experiment. The lowest level (0") was the floor. See Figure 4-6.

Figure 4-6: Metal structure and wood platforms

- Three boxes without handles, same color, and size but with three different weights (9 lb, 16 lb, 24 lb) were used to perform the lifting conditions. The weight of the boxes was concentrated at their center of gravity. The inside of one of the boxes containing sand bags spread evenly in the box is shown in Figure 4-7.

Figure 4- 7: Inside of one of the boxes

- A Digital Photo Camera with its tripod
- A TV and a VCR to give the lifting training. This media training station is shown in Figure 4-8

Figure 4-8: Training Station for the lifting tasks

- A Polar Heart Rate Monitor, is shown in Figure 4-9.

Figure 4-9: Polar Heart Rate Monitor

- A resting station. Since this was a blind experiment, in order to keep subjects from anticipating the next experimental condition, they had to leave the room while the experimenter changed the setup from one experimental condition to the next. The resting station is shown in Figure 4-10.

Figure 4-10: Resting station

- A measuring tape.
- 12 wood sticks with color markings to control the horizontal distance of each condition, by means of indicating a reference point where subjects located their ankles middle point. One of the sticks used in one of the conditions is shown in Figure 4-11.

Figure 4-11: Stick to point out the horizontal distance

- Reflecting tapes that were placed on each of the subject's right side joints: ankle, knee, hip, wrists, elbow, and shoulder in order to facilitate the measurements of the angles. These are shown in Figures 4-12 and 4-13.

Figure 4-12: Reflecting tapes markings

Figure 4-13: Reflecting tape markings placed on the joints

4.8.7 Average Time Structure of the Experiment Session

Table 4-4 describes the average time structure for the entire experimental session for each subject.

Table 4-4: Average time structure per subject for the Experiment Session

Activity	Approximated Time
Reading Consent Form	10 min
Watch training Video	20 min
Taking Measurements & Placing Polar HR	15 min
Performing 12 lifting Conditions	12 x 4min = 48 minute
Resting Times	11 x 5 min= 55 min
Total/ Subject	2 hours 30 min aprox.

The first three activities of this structure were carried out at the beginning of each experimental session and the last two were performed for each lifting condition. Each one of these activities was previously explained in detail in section 4.8.4. entitled “Protocol of the Experiment”.

CHAPTER 5

ANALYSIS OF RESULTS

5.1 Determination of the Adequacy of the Sample Size

The determination of the sample size was based on the psychophysical scale used in this experiment. This scale was used to measure the level of discomfort of the subjects for the 12 different lifting conditions. In this scale there were 5 discomfort levels arranged in ascending order from the bottom up. These five levels divided the scale in four sections each one 2.5 cm long on the scale.

This sample size for the psychophysical experiment was determined using a procedure described by Montgomery (2001), based on a full factorial design with 2 factors (A and B) with “n replicates” (in this experiment, n represented the number of subjects). Equation (5-1) from Montgomery (2001) was used as part of the sample size determination procedure.

$$\phi^2 = \frac{nbD^2}{2a\sigma^2} \quad 5-1$$

The psychophysical experiment had two factors V and Zn (V) (Z nested in V). Since V had more levels than Zn, the sample size determination was conservatively based on the experimenter’s wish to detect statistical differences between the psychophysical responses provided by subjects to different levels of V. In that sense in Equation (5-1) “b” in the numerator represented the number

of levels of Z nested, 3, that were evaluated, “a” in the denominator represented the number of levels of V, 4, (vertical height) evaluated in this study; and “D” represented the minimum distance in the 10 cm long response scale that the experimenter wished to detect with statistical significance between subjects’ responses for the different levels of the vertical height evaluated.

The minimum distance between the subjects’ discomfort responses that the experimenter wished to detect for different V levels was set to 1.3 cm, approximately half the length of each of the 4 sections in the 10 cm scale ($2.5 / 2 = 1.25$ cm).

Based on the values of “a”, “b”, and “D” stated above, the sample size of this experiment was determined based on a desired statistical power ($1 - \beta$) of at least 90%. Furthermore, the confidence level (α) used was 0.05 and the variance estimate (σ^2), obtained from the first 10 subjects participating in the experiment was 3.467 (Table 5-1). The sample size calculation, based on the above mentioned procedure, output 20 subjects as being the sample size associated with the desired test power of 90%. Therefore, the experiment was carried out for 20 subjects in order to fulfill the desired power (90%). Calculations are shown in Table 5-2

Table 5-1: SPSS ANOVA table showing the MSE used in sample size determinations

Tests of Between-Subjects Effects

Dependent Variable: Comfort

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	155.981 ^a	11	14.180	4.090	.000
Intercept	4757.761	1	4757.761	1.372E3	.000
V	38.991	3	12.997	3.749	.013
Zn	101.543	2	50.772	14.644	.000
V * Zn	15.447	6	2.574	.743	.617
Error	374.438	108	3.467		
Total	5288.180	120			
Corrected Total	530.419	119			

a. R Squared = .294 (Adjusted R Squared = .222)

Table 5-2: Tables shows the power calculations for a sample size of 10 and 20 subjects

$\alpha=0.05$ $D=1.3$ $n=10$

Factor	Φ^2	Φ	df Numerator	df Denominator	β	Power%
V	1.827949	1.352017	3	108	0.5	50
Zn(V)	5.849438	2.418561	8	228	<0.01	> 99

$\alpha=0.05$ $D=1.3$ $n=20$

Factor	Φ^2	Φ	df Numerator	df Denominator	β	Power%
V	3.655898	1.91204	3	228	0.1	90
Zn(V)	6.499375	2.549387	8	228	<0.01	> 99

As it can be observed from Table 5-2, sample size determination was conservatively based on factor “V”, which results in the greater number of subjects required to achieve the target statistical power.

5.2 Evaluating the Statistical Fitness of the Data

The fitness analysis of the data was carried out taking account the used statistical model with all its factors and covariates

5.2.1 Normality Test for the ANOVA

- In the ANOVA were considered the V and Z nested factors, Zn factor yielded a p-value less than 0.000, showing to be a significant factor. The Vertical Height Factor yielded a p-value of 0.00268 which is also significant. The interaction V* Zn had a p-value outcome of 0.532943 which is not significant.

The equal-variance and normality assumptions were tested using a normal probability plot, showed in Figure 5-1. This plot showed that plotted points fell approximately along a straight line. Therefore, there is no variability in the factors' normality at their different levels.

5.2.2 Analysis of Residuals

Examination of residuals was carried out as a part of the analysis of variance in order to check if errors were normally and independently distributed with mean zero and constant but unknown variance. The checking of the model was done by graphical analysis of the residuals. See Figure 5-1.

- The normal probability plot with the residuals showed that the underlying error distribution was normal due that the plot looked like a straight line.
- The histogram of the residuals showed a moderate departure from the normal shape (sometimes it is caused by the size of the sample), which doesn't imply a serious violation of the assumptions.
- The plot of residuals in time order of data collection was performed in order to detect correlation between the residuals. If there was a positive and negative tendency of the plot it would mean a violation of the independence assumption of the errors. Figure 5-1 shows that there is not a tendency, which means that a proper randomization of the experiment was carried out.
- Another way to determine if the model is correct and if the assumptions are satisfied is to plot the residuals versus the fitted values. In Figure 5-1 it is observed that this plot is structureless, which was desirable.

Figure 5-1: Data Residual Plots

5.3 Analysis of Results of the Lifting Experimental Stage

5.3.1 Using the Statistical Model

- The Statistical Model used was a Two Stage Nested Design. Although, the analysis of the two stage nested design recognizes the levels of the nested factor as different, this kind of statistical model handles the nested factor including all its levels (which have a common characteristic) within one same level, in this case, the same weight. In the current two stage

- nested model, Factor V (vertical height) has 4 levels and the nested factor is the Factor Z. This factor has 12 different combinations (3 weights: W1, W2 and W3; combined with 4 different horizontal distances) grouped in 3 levels: Zn₁, Zn₂ and Zn₃.
- The statistical Model for the two nested stage was described in equation 4-1.
 - The statistical analysis was performed to test the hypothesis that the average response comfort is the same at all levels of the factor vertical height.
 - SPSS software was used to perform data analysis. The analysis was performed with and without using covariates.
 - The Results are showed in Table 5-3 and Table 5-4.

Table 5-3: SPSS ANOVA Output of factors V and Zn (without covariates)

Tests of Between-Subjects Effects

Dependent Variable: Comfort

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected					
Model	248.949	11	22.63173	7.04579	2.93E-10
Intercept	9480.294	1	9480.294	2951.439	1.90E-132
Znested	180.652	2	90.326	28.12061	1.21E-11
V	52.7823333	3	17.59411	5.477462	0.001188
Znested * V	15.5146667	6	2.585778	0.805014	0.566921
Error	732.357	228	3.212092		
Total	10461.6	240			
Corrected Total	981.306	239			
a	Computed using alpha = .05				
b	R Squared = .254 (Adjusted R Squared = .218)				

- As shown in the above table, the significance of factor V is obtained less than 0.05. Therefore, there is evidence to support that at least one level of factor V is associated with an average comfort response that is significantly different than the others.
- The SPSS software doesn't have an option to determine nested factors. Therefore, it was necessary to use the procedure described in Montgomery (2001), where the interaction V x Zn obtained from SPSS is used to determine the sum of squares for the nested factor: Zn(V).

Table 5-4: SS Zn(V), without covariates

Finding SS Z(v)

$$SS\ Zn + SS\ VxZn = SS\ Zn(V)$$

SS Zn=	180.652
SS VxZn=	15.5146667
SS Zn(V)=	196.166667

Finding df

$$df\ Zn + df\ VxZn = df\ Zn(V)$$

$$2+6 = 8$$

MS Zn(V)=	24.5208333
F Zn(V)=	7.63391351
P-VALUE	4.8151E-09

- Table 5-4 shows that factor Z nested in V is also statistically significant. Other variables related to the subject characteristics or the effects of the lifting task on the subject were analyzed as covariates. These variables

were: Heart rate, gender, age of the subject, right hand (dexterity), height and weight of the subject, years working in manual activities, compression and shear on the L5/S1 disc. The results obtained from analyzing the data with covariates are shown in Table 5-5

Table 5-5: Finding Factor (V) with Covariates

FINDING FACTOR (V) WITH COVARIATES

Tests of Between-Subjects Effects

Dependent Variable: Comfort

Source	Type III Squares	Sum of df	Mean Square	F	Sig.
Corrected Model	334.0459562	20	16.7023	5.651211	1.10E-11
Intercept	14.68260777	1	14.68261	4.96785	0.026839
HR	0.144118283	1	0.144118	0.048762	0.825437
Gender	1.232345666	1	1.232346	0.416963	0.519132
Age	16.96404404	1	16.96404	5.739773	0.017426
RightHand	0.097006325	1	0.097006	0.032822	0.856403
Height	0.300888	1	0.300888	0.101805	0.749978
Weight	0.536683183	1	0.536683	0.181586	0.670432
YearsWorking	0.541547032	1	0.541547	0.183232	0.669031
Compression	18.28067988	1	18.28068	6.185256	0.013628
Shear	28.98497266	1	28.98497	9.807046	0.001976
CenterGravity	2.697	1	2.697	0.912	0.341
V	43.15575703	3	14.38525	4.86724	0.002686
Znested	196.1946053	2	98.0973	33.19116	2.57E-13
V * Znested	15.06644983	6	2.511075	0.849621	0.532947
Error	647.2600438	219	2.955525		
Total	10461.6	240			
Corrected Total	981.306	239			
a	Computed using alpha = .05				
b	R Squared = .340 (Adjusted R Squared = .280)				

- Factor V was again found to be significant. Sum of squares for Factor Z nested in V was also found as described previously. This is shown in Table 5-6:

Table 5-6: Finding SS Zn(V) with Covariates

Finding SS Z(v)

$$SS\ Zn + SS\ VxZn = SS\ Zn(V)$$

$$\begin{aligned} SS\ Zn &= 196.1946053 \\ SS\ VxZn &= 15.06644983 \\ SS\ Zn(V) &= 211.2610551 \end{aligned}$$

Finding df

$$\begin{aligned} df\ Zn + df\ VxZn &= df\ Zn(V) \\ 2+6 &= 8 \end{aligned}$$

$$MS\ Zn(V) = 26.40763189$$

$$F\ Zn(V) = 8.935004468$$

$$P\ Value = 1.38299E-10$$

- As seen in Table 5-6, the nested factor Z is also statistically significant.
- Of all the covariates included in the model the only ones that appear to be significant are Age of the subject and the compression and shear forces exerted on the subjects' L5/S1 spine disc.

5.3.2 Post-ANOVA analysis of independent factors V and Zn:

A post ANOVA analysis was carried out for the independent factors V and Zn. Table 5-7 shows the geometric lifting conditions and their quantitative measurements.

Table 5-7: Quantitative measurements of the Geometric Lifting Conditions

Condition	V (in)	H (in)	W (lbs)
V1H1W1	0	22.125	9
V1H2W2	0	12.5	16
V1H3W3	0	8.25	24
V2H4W1	15	26.75	9
V2H5W2	15	15.125	16
V2H6W3	15	11.25	24
V3H7W1	30	31.50	9
V3H8W2	30	17.75	16
V3H9W3	30	13.00	24
V4H10W1	45	30.75	9
V4H11W2	45	17.25	16
V4H12W3	45	12.75	24

5.3.2.1 Analysis of Factor V:

- Factor V was the vertical height used at 4 levels in the experiment (0", 15", 30" and 45"). The effect of V on subjects' response was found to be significant at 0.05 level. The average comfort level for each one of these 4 levels and the lower and upper bound of their 95% confidence intervals are shown in Table 5-8. Figure 5-2 shows a 95% confidence interval plot for the 4 levels of factor V.

Table 5-8: Average comfort of the 4 vertical levels and their 95% C.I

Dependent Variable: Comfort			95% Confidence Interval	
V	Mean	Std. Error	Lower Bound	Upper Bound
1	5.70	0.28	5.15	6.25
2	6.83	0.28	6.28	7.40
3	6.54	0.24	6.07	7.00
4	6.07	0.35	5.38	6.75

Figure 5-2: 95% Confidence Interval of the V level means

From Table 5-8 and figure 5-2 the following observations can be obtained:

- The vertical height level 2 was perceived by the subjects as the most comfortable for the different specific geometric characteristics (total average= 6.83) followed by vertical height level 3 (total average = 6.54), then vertical height level 4 (total average =6.07) and finally vertical height level 1 (total average = 5.70).
- Vertical height 3 would have been expected as the one with a higher level of comfort, it does not present statistically significant differences when compared to vertical height 2.

- If the 95% intervals are analyzed, it is clear that all of them except V1 with V2 and V3 with V4 overlap (this fact makes the vertical height factor to be significant).
- The two most similar intervals are V2 and V3, while some similarity is also observed between V1 and V4 (the two vertical heights with lower levels of comfort).
- The overlapping of the intervals is explained by the fact that the vertical height levels were evaluated at different conditions of horizontal distance and object weight (in order for the combination of these three parameters to result in a safety lifting index of 1), causing that some of the geometric characteristics be perceived with a similar level of comfort.
- It is important to mention that the above results are for the total subject population of the experiment, which is the one with the statistical significance.

5.3.2.2 Analysis of Factor Z

Factor Z was nested in Factor V. It was made up of three levels of weight: W1 (9 lbs), W2 (16 lbs) and W3 (24 lbs). Each weight was associated with four different horizontal distances which yielded 12 different levels of factor Z. However, from Montgomery (2001) these 12 levels of Z can be seen as three-two staged nested levels, each level affected by four specific characteristics; this was the way in which the Z nested factor was evaluated in the statistical analysis.

From the “One way ANOVA” analysis it was found that the Z nested factor had a significant effect with regards to the level of comfort pointed out by the subjects. The average comfort response for each one of these three Z nested factor and the lower and upper bound of their 95% confidence intervals are shown in Table 5-9:

Table 5-9: Average comfort level for the three Z nested levels and their 95% CI

Dependent Variable: Comfort			95% Confidence Interval	
Znested	Mean	Std. Error		
			Lower Bound	Upper Bound
1	7.39	0.20	6.99	7.79
2	6.50	0.19	6.11	6.88
3	4.97	0.20	4.57	5.37

The chart showing the 95% upper and lower Intervals is shown in Figure 5-3:

Figure 5-3: 95% Confidence Interval of the Zn level means

From the above table and chart of the nested factor Z, it can be observed that:

- All these factor levels were associated with specific geometric conditions (where the safety lifting index for all the conditions was 1). As an interesting outcome, the Z nested level which subjects perceived as the most comfortable (for the different geometric characteristics involving these weights and horizontal distances) was the Z nested level 1 (for which total average was 7.39) followed by the Z nested level 2 (for which total average was 6.50) and finally Z nested level 3 (for which total average was 4.50). It is important to note that the Z nested levels were associated with the object weights.
- The results associated with the effects of the Z nested factors showed the predominance of the object weight over the other geometric characteristic.
- None of the three confidence intervals for the Z nested factor overlapped.
- The three levels of the object's weight were almost equidistant among them (7 lbs from the lower weight to the middle one and 8 lbs from the middle weight to the upper weight). The small difference between weight levels was associated with the need to keep lifting index nominally equal to 1. Moreover, this difference could be the reason that the gap between the upper and middle level effects of factor Z on subject's response was slightly larger than the gap observed between the middle and the lower levels of Z.

5.3.2.3 Analysis of Covariates

The following covariates were analyzed in the ANOVA using SPSS: HR (Heart Rate), Gender, Age, Right Handed (If the subjects were right handed or left handed), Height (subject's height), Weight (subject's weight), Years_Working (years subject had been working in manual activities), Compression (compression on the L5/S1 spinal disc), Shear (shear on the L5/S1 spinal disc) and Center of Gravity on the axis resulting from the intersection between the sagittal plane and the floor where subjects were standing (axis forward backward).

From all the previous covariates the only ones that showed to be significant at $\alpha=0.05$ level were: Age, Compression and Shear. Age was significant at 0.017426 level, while Compression was significant at a 0.013628 level and Shear at a 0.001976 (see Table 5-5).

Descriptive statistics for the covariate Age along with statistics for other subjects' characteristics are shown in Table 5-10.

Table 5-10: Statistics for the covariate Age, and for other subjects' characteristics

	N	Mean	Std. Deviation	Min	Max
SubAge (years)	20	28.00	7.455	19.00	48.00
SubHeight (in)	20	68.30	3.568	62.20	76.38
SubWeight (lbs)	20	165.29	27.208	119.99	207.02
YearsWork	20	3.66	3.235	0.25	12.00
Male Subjects	12				
Female Subjects	8				
Right Handed	17				
Left Handed	3				

Next, the effects observed on subjects' perceived comfort, from Compression and Shear Forces, and their interrelationship with nested factor (Zn) components (weight of the object and horizontal distance), when data is categorized by the vertical distance of the lifting task were analyzed.

The analysis shown below had the objective of finding the level of vertical height that was associated with the adoption of postures that minimized the biomechanical load as well maximized subjects' comfort, while allowing an increased flexibility in future workstation design in regards to object weight and horizontal distance of the lift.

These analyses were carried out by the use of different charts, which were interpreted individually and as a whole and provided some strong evidence that vertical height level V3 (30 inches) should be the vertical height recommended for workstation design. The analyses performed were the following:

Analysis of Subjects' Comfort vs. Horizontal distances: Figure 5-4 shows, the scatter plot for Comfort data as a function of the horizontal distance utilized in the lifting task, categorized by the vertical distance utilized (V1, V2, V3 and V4), and with an indication for the weights (W1, W2, and W3) of the object lifted. From Figure 5-4, it is observed that V3 was associated with high and more consistent scatter data ranges for subjects' perceived comfort levels throughout the 3 object weights that were evaluated. Moreover, as can be seen in Figure 5-4, the horizontal distances used in the lifting tasks evaluated for V3 were always larger when compared to the other evaluated vertical distances.

Figure 5-4: Scatter Plot for Subjects' Perceived Comfort vs. the horizontal distances.

The Analysis of Means for the effects of vertical distance (V) and the nested factor Zn on subjects' perceived comfort can be observed in Figure 5-5. The upper chart in Figure 5-5 shows the interaction effects between factors V and Zn, in which though without statistical significance at a 5% level, it can be observed that V3 (30 in) was the only vertical height associated with ascending perceived comfort levels proportionally with ascending Zn levels.

The lower left chart shows the effect of V on subjects' perceived comfort, where it can be observed that the Vertical height V1 was associated with a significantly ($\alpha=5\%$) lower average Comfort level when compared to the other vertical heights.

On the other hand, the lower right chart in Figure 5-5, shows that Zn had significant effects over the average level of Comfort. This effect was positive for the first level of Zn and negative for the third level of Zn. This result indicates that in average, the object weight (W1) associated with the first level of Zn and with the longer horizontal distances of the experiment (see Figure 5-4), generated a high level of perceived comfort among the participants of the study. The expectation, nonetheless, was that long horizontal distances would be associated with low levels of perceived comfort due to higher levels of extension of arms and/or flexion of the back. In this case, another reason indicating that the vertical distance V3 is the most appropriate design height is the fact that this height was the only one associated with a low level of comfort for W1, which proves that in V3 the participants responded in a more proportionate way to the biomechanical loads generated on their bodies.

Also, from Figure 5-5, it can be observed that V3 was associated with the highest average perceived comfort for the third level of Zn (W3), which indicates that designs made with this height would allow individuals to lift higher loads without feeling too much discomfort.

Figure 5-5: Analysis of Means of the response Comfort for factors vertical Distance (V) and Factor nested Zn

Figure 5-6 shows the 95% confidence intervals for the average perceived Comfort in each experimental condition. It can be observed from this chart that the vertical height with highest consistency in regards to perceived Comfort was V3. In addition, it may also be observed that the highest average level of Comfort associated with W3 was the one reported for height V3 (V3H9W3).

Figure 5-6: 95% Confidence Intervals for the average perceived comfort reported for each experimental condition.

Figure 5-7 shows how V3 was associated with a longer average horizontal distance. It is important to remember that the differences between horizontal distances associated with each vertical distance and with each experimental condition was due to the need of keeping the lifting index, LI, nominally equal to 1. Therefore, for that matter, V3 is a height that imposes a smaller risk to the individual due to the fact that by reducing the horizontal distances associated with V3, the levels of risk for this height would be further reduced considerably.

Figure 5-7: 95% Confidence Intervals for the average horizontal distance associated with each level of V.

Another analysis performed was to compare for each vertical lifting height, the contribution that the weight of the object lifted had on the total estimated Shear Force (3DSSPP) at the L5/S1 disc of subjects, based on subjects' adopted postures in each experimental condition. For this analysis, 3DSSPP was used to estimate participants' shear forces at L5/S1 with and without contemplating the weight of the lifted object in the calculation for each experimental condition. Once both estimates for the shear force at L5/S1 were found, their difference was calculated and then divided by the shear force at L5/S1 estimated with the weight of the object lifted. The result of this division was then multiplied by 100 and represented the contribution that the weight of the object lifted had on the total estimated Shear Force (3DSSPP) at L5/S1. Figures 5-8 and 5-9 show, for

each of the 4 vertical heights studied, the 95% confidence intervals for the average shear forces at L5/S1 estimated with and without the weight of the object lifted, respectively. Moreover, Figure 5-10 shows the average percent contribution that the weight of the object lifted had on the estimated shear force at subjects' L5/S1disc. This shows that weight had the lowest contribution to the total shear force at V3, which is another point favorable to the recommendation of V3 as a potential vertical height for starting a lifting in a workstation. Moreover, because V3 was associated with longer horizontal distances, (compared to the other vertical heights) in case it would be necessary, some manipulation of the horizontal distance still could be done in order to reduce even more the shear force.

Figure 5-8: 95% Confidence Intervals for the average shear force at L5/S1 estimated with the weight of the object lifted, for each level of V.

Figure 5-9: 95% Confidence Intervals for the average shear force at L5/S1 estimated without the weight of the object lifted, for each level of V.

Figure 5-10: 95% Confidence Intervals for the average percent contribution that the weight of the object lifted had in the shear force estimated at L5/S1, for each level of V.

As it can be observed in Figure 5-10, the height in which the weight of the object lifted has the smallest contribution towards the shear force at L5/S1 is 30 inches (V3). Furthermore, from observing Figures 5-7 and 5-10, it can be inferred that a significant contribution towards the estimated shear force at subjects' L5/S1 disc, when the vertical height of the lifting task is 30 inches (V3), was associated to the long horizontal distances used in the experiment for that vertical height level. Moreover, as mentioned before, the real possibility of reducing the horizontal distances in a workstation with a designed V of 30 inches decreases even more the estimated level of risk associated with lifting task with this vertical height.

Similar to the analysis performed in Figures 5-8, 5-9 and 5-10, the contribution of the weight of the object lifted towards the estimated compression force at subjects' L5/S1 disc is described in Figures 5-11, 5-12 and 5-13. Figures 5-11 and 5-12 show, for each of the 4 vertical heights studied, the 95% confidence intervals for the average compression forces at L5/S1 estimated with and without the weight of the object lifted respectively. In addition, Figure 5-13 shows the average percent contribution that the weight of the object lifted had on the estimated compression force at subjects' L5/S1 disc.

Figure 5-11: 95% Confidence Intervals for the average compression force at L5/S1 estimated with the weight of the object lifted, for each level of V.

Figure 5-12: 95% Confidence Intervals for the average compression force at L5/S1 estimated without the weight of the object lifted, for each level of V.

Figure 5-13: 95% Confidence Intervals for the average percent contribution that the weight of the object lifted had in the compression force estimated at L5/S1, for each level of V.

Figure 5-13 shows how vertical height V4 is associated with the higher average percent contribution of the weight of the object lifted towards the estimated compression force at subjects' L5/S1 disc. This result indicates that little can be done to reduce compression forces in the individual's back when the lifting height is close to V4 (45 inches). On the other hand, from Figure 5-13, the lifting heights V1 and V2 were associated with the two smaller percent contributions of the weight of the object lifted towards the estimated compression force at subjects' L5/S1 disc. This result indicates that in order to reduce the estimated compression force for these two heights, the horizontal distance of the lifting would need to be reduced. This reduction in horizontal distance for V1 and V2, however, as can be observed in Figure 5-7, would be minimal given the fact that these two vertical heights were associated with the smaller horizontal distances

studied. Hence, little could be done to reduce the estimated compression force at subjects' L5/S1 disc while operating workstations designed with these two vertical heights. The height of 30 inches, however, was associated to a low object weight percent contribution, and as indicated in Figure 5-7, was associated with the longer horizontal distances studied. From this analysis, V3 is identified, among the other studied vertical heights, as the design vertical height with better potential for the reduction of the risk for back injury associated with lifting tasks.

From all the analyses conducted and described above, for subjects' perceived comfort as well as for the estimated shear and compression forces at subjects' L5/S1 disc, it is concluded that the distance V3 is the vertical height to be recommended for the design of lifting stations. This height was associated with a greater consistency in the reported perceived comfort levels, and with a greater potential for the reduction of back injury risk through the control of the horizontal distance parameter of the lifting task.

5.3.2.4 Analysis of the Heart Rate

An analysis of the effects of vertical distance V and nested factor Zn observed on subjects' average heart rate was also conducted (average heart rate of subjects for each condition shown in Appendix N). Figure 5-14 shows the 95% confidence intervals for subjects' average heart rate for each studied vertical lifting distance. As it can be observed, average heart rate tended to decrease with the increase

of vertical distance V. The higher average heart rates observed in lower vertical heights is most likely due to the fact that at these heights subjects used bigger and longer muscles to perform the lifting task, i.e. leg and back muscles. The use of bigger muscles is associated with greater energy consumption and, therefore, a greater oxygen consumption, which is directly related to a greater heart rate. On the other hand, higher vertical lifting heights were, through visual observation of subjects' postures, associated with the use of smaller muscles, i.e. shoulder and arm muscles, which tend to require a lesser amount of energy to operate, and therefore, less oxygen at a smaller average heart rate. Figure 5-14 also indicates that the average heart rate associated with V3 was the second smallest, which corroborates previous indications that V3 (30 inches) presents a bigger advantage to be recommended as a design parameter for intense lifting and lowering workstations.

Figure 5-14: 95% confidence interval for average heart rate versus vertical heights (V)

Figure 5-15 shows the analysis of means conducted at a significance level of 0.05 for the main effects of V over subjects' average heart rate. The graphical analysis depicted in Figure 5-15 shows that V3 was associated with the second smallest average heart rate, which reinforces previous indications that V3 = 30 inches is a better design value for the vertical height than V1 and V2. It is important to notice that V4, as depicted in Figure 5-15, was associated with the smallest average heart rate reported in the experiment, but as depicted in Figure 5-13, was also associated with the largest percent contribution of the object weight in subject's estimated compressive force at the L5/S1 disc. Therefore, V3 represents a more appropriate vertical height because it was associated with the second smallest average heart rate in the experiment, and with a greater flexibility towards reducing the risk of lifting tasks through further reduction of the horizontal distances of the lifting tasks.

Figure 5-15: Analysis of Means at 5% significance for the effects of vertical height on subjects' average heart rate.

Figures 5-16 shows the analyses of means for the main and interaction effects of factor V and nested factor Zn on subjects' average heart rate with two levels of significance, 5% and 20% respectively. As observed there was not interaction effect observed between V and Zn on heart rate. Zn by itself, however, had a positive effect on subjects' average heart rate at a 20% level, where average heart rate seemed to increase as the weight of the object (W within Zn) is increased.

Figure 5-16: Analysis of Means at 5% for the effects of V and Zn on subjects' average Heart rate.

In conclusion, from the graphical analysis conducted on subjects' average heart rate, there is supporting evidence indicating that V3 was associated with the second smallest average subjects' heart rate, with the advantage of presenting a great potential to further reduce lifting risk by allowing even smaller horizontal distances that the ones used in this experiment.

5.3.3 Postures Analysis

As mentioned in the methodology section, subjects were asked to lift an object in 12 different conditions where the weight of the object, the vertical height and the horizontal distance (from where subjects had to lift the object) were varied in a

controlled manner. For each of these 12 experimental conditions, subjects were instructed to lift the object with a posture they felt was the most appropriate and comfortable for them. In that sense, subjects adopted postures for each experimental condition were photographed. Once their posture was photographed (side view), their body segment angles were calculated and then input in 3DSSP (Appendix O) to estimate their L5/S1 compression and shear forces, as well as to simulate their posture in a three-dimensional view. At the end of the experiment, data was collected as to obtain one 3D view of each subject with his/her posture at each experimental condition.

Figure 5-17 shows the 95% confidence intervals for the average trunk flexion (measured as the angle between the horizontal plane and subjects' spine) adopted by subjects while lifting the object at each of the vertical heights evaluated (V1, V2, V3 y V4). In addition, Figure 5-17 also shows a 3D view of the average simulated posture for each vertical height.

Figure 5-17: 95% Confidence intervals for the average trunk flexion at each vertical height evaluated

As can be seen in Figure 5-17, the angle between the horizontal plane and subjects' trunk increased as the vertical height of the object increased (from V1 to V4). Trunk flexion is, as a matter of fact, a very important parameter for the estimation of the compression force on the L5/S1 disk. Another important parameter in the L5/S1 compression force estimation is the horizontal distance between the L5/S1 disk and the center of gravity of the object being lifted, also called the resistant arm. This information, along with the weight of the object is used to calculate the torque imposed by the object and the individual's posture on the L5/S1 disk, which is counteracted by the individual's back muscles to allow for stability during lifting. The compression force at L5/S1 is then calculated based on the forces (aligned with the individual's spine) acting on the upper body

of the individual. Making reference to Figure 5-11 where the 95% confidence intervals for the average estimated subjects' compression force are shown, it can be observed that as average trunk flexion got close to 90 degrees according to Figure 5-17, average compression force at L5/S1 got smaller. This reduction in the average estimated L5/S1 compression force, as shown in Figure 5-18, was due to the fact that with increasing vertical height, subjects got closer to an upright posture and, therefore, back muscles also got better aligned with the downward force exerted by the object's mass. This better alignment meant back muscles had to exert a lesser amount of force to counteract the torque generated by the object weight, and, therefore, the total compression force estimated at L5/S1 was reduced. Furthermore, as it can be observed in Figure 5-18, there was a clearly decreasing participation of subjects' flexed torso in the total resistant arm from V1 to V4, depicted by an increasingly shorter horizontal projection of subject's flexed torso.

Figure 5-18: 95% Confidence intervals for the average trunk flexion at each vertical height evaluated, along with total estimated resistant arm and the horizontal projection of the flexed torso

It is important to notice, however, that the average total resistant arm did not seem to decrease in length for any vertical height evaluated, which indicates that subjects' shoulders were subjected to an increasing torque from V1 to V4. In Figure 5-19, it can be observed how the resistant arm for shoulder torque increased with increasing vertical distance.

Figure 5-19: 95% Confidence intervals for the average right hand upper arm angle (with respect to 0 degrees in a circumference) at each vertical height evaluated.

Furthermore, Figure 5-19 shows subjects' average right upper arm angle with respect to the horizontal plane (counter-clockwise is positive, clockwise negative). Increasing vertical height was associated with an increasing horizontal projection of subjects' arm extension (surrogate for the resistant arm for shoulder torque, when force is vertical), which indicates that as the vertical height increased, subject's shoulders were subjected to increasing torque. The increasing torque in subjects' shoulders was most likely the cause of subjects' discomfort when lifting at the highest vertical distance of 45 inches.

Through the evaluation of subjects' perceived comfort and adopted postures, it seems that discomfort was better associated with L5/S1 estimated compression

in lower vertical heights, while at higher vertical heights subjects' discomfort was better associated with generated torque and forces exerted in their shoulders and arms.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions can be drawn from the results of this research:

- The Aesthetic Ergonomics Theory showed to be useful and versatile throughout the implementation of the present research, representing a structured and systematic tool that can be used towards solving Ergonomics and Human Factors problems.
- Factor Analysis Technique within Multivariate Statistics is a useful and reliable tool, which can help to determine relevant cognitive factors and their elements in Ergonomics research, when applied on statistically sound data and followed by a careful interpretation of the results.
- In the physical experiment, both independent factors (V and Z nested) were found to be significant at a 5% level. The only covariates that showed statistical significance were the Compression and Shear forces on the L5/S1 spine disc.
- The ranking of the four levels of vertical height used with respect to subjects' perceived comfort was in descending order 15", 30", 45", and 0.
- Vertical heights of 15", 30", and 45" did not differ from each other with respect to their effect on subjects' perceived comfort. Lifting from the floor (vertical

height of 0") however, was associated with a significantly lower perceived subjects' comfort.

- The ranking of the three levels of the two stage nested factor, Z_n , with respect to subjects' perceived comfort was in descending order, Z_1 , Z_2 , Z_3 , indicating that average subjects' perceived comfort decreased as the weight of the object lifted increased, quite independently from the horizontal distance of the lift.
- When compression and shear forces on the L5/S1 disc and subjects' average heart rate are considered, this study supports the recommendation that 30 inches (above the floor) should be the recommended approximate vertical height in the design of workstations (shelves, work tables, scissor tables) where lifting is frequently performed.
- The performed experiment showed that although the lifting conditions were nominally safe (all of them with a safety lifting index of 1 according to NIOSH 1981 Lifting Guide) some of them showed to be more comfortable than others, and some of the experimental conditions led subjects to adopt postures that were biomechanically stressful (compression force over 770 lbs).
- Vertical height had an effect on the appropriateness of subjects' adopted postures. The lower the vertical height, the higher the average back flexion and consequently the higher the average compression force on the L5/S1 disc.

- The highest vertical height evaluated, 45", was associated with lifting tasks that posed a significantly higher physical demand on subjects' shoulders, exhibited as an inconsistency between subjects' perceived comfort for 45" and this height's correspondent average shear and compressive forces estimates for subjects' L5/S1 disc. At subject's shoulders, resistance arm increased as the vertical height evaluated increased, while at subjects' backs, resistance arm decreased with increasing vertical height.
- Subjects' perceived comfort for 45" was not significantly different (5%) from their responses for 15" and 30", it was even a little lower in average than the response for 30", indicating subjects' discomfort with physical demand imposed upon their shoulders.
- When comparing the effects of vertical height and nested factor Zn on subjects' perceived comfort and on their L5/S1 estimated compression force, the only vertical height showing consistency between observed and expected patterns for these two outcomes was 30" (the higher the estimated compression force on L5/S1, the lower the perceived comfort). This observation reinforces that 30" represents a vertical height where subjects' perception seem to be better tuned to their lower back stress, and therefore can potentially reduce the risk of subjects adopting unsafe and dangerous postures during lifting tasks.
- Subjects' estimated L5/S1 shear force reduced with increasing vertical height, which is consistent with what was observed for subjects' back flexion. As the

vertical height of the lift increased, average subjects' back flexion decreased which is biomechanically associated with a reduced shear force estimate.

- The weight of the object lifted had a significant increasing contribution towards subjects' estimated L5/S1 compression force with increasing vertical height, which indicates that the counterpart nested factor in Z_n , the horizontal distance, had a decreasing contribution as the vertical distance increased. In that matter, the vertical height found to have a greater potential impact on reducing the estimated L5/S1 compression force due to a reduction in horizontal distance was 30 inches.
- Subjects' average heart rate decreased with increasing vertical height. The higher average heart rates observed in lower vertical heights was associated with the fact that at these heights, subjects used bigger and longer muscles (bigger oxygen consumption) to perform the lifting task than at higher vertical heights.
- Subjects' average heart rate increased with increasing weight of the object lifted indicating a greater physical load with increasing weight of the object lifted. In that sense, the weight of the object lifted was found to be more important in explaining subjects' perceived comfort than the horizontal distance (H).
- Through different experimental conditions with the same safety risk evaluated by the lifting index of the NIOSH Lifting Equation, it was demonstrated from a subjects' perceived comfort perspective, as well as from an estimated L5/S1

compression and shear forces perspective, that a lifting work station must not have low or elevated heights, even for trained workers.

- Finally, health and safety professionals should not entirely trust workers' ability to adopt a safe posture, based on training, or on any workstation design, but emphasize on designs where vertical height from the origination point of the lift is approximately 30 inches.

6.2 Recommendations

- A vertical height of approximately 30 inches above the floor should be used because it was found to be the most appropriate height when subjects' perceived comfort and estimated L5/S1 shear and compressive forces are considered.
- The vertical height of 0 inches is not recommended for workstation design based on the results obtained in this study.
- Workstations should be designed with as short horizontal distance as possible to reduce risk associated with back injury in lifting tasks.
- Object weight should be kept as low as possible to further reduce risk associated with back injury in lifting tasks.
- Engineering and worker training initiatives should try to use 30 inches being the recommended height for new designs as well as for modification designs. Furthermore, workers and design engineers should be advised on workers'

potential inappropriate and unsafe adopted postures for low vertical heights of the workstation, even after appropriate training is provided.

6.3 Future Research

The motivation for this research was based on the fact that individuals adopt their most comfortable posture at the moment of lifting an object in the sagittal plane, sometimes even after receiving training, which could cause potential injuries in the mid and long terms. This study was performed under the framework structure of the Aesthetics Ergonomics Theory that uses some Multivariate Statistics Techniques such as the Factor Analysis Technique.

The psychophysical experiment was designed and analyzed using Factor Analysis through the interpretability and the usability of the factors obtained. However, it would be interesting to perform further research using some of the factors and their elements that were not studied in the current research, such as:

- Symmetry of the Object: this would include: object with handles or without handles, and a symmetric or an asymmetric object.
- Work Allowances: these would include: different site illumination levels, use or not use of gloves, and setting a time constraint to perform the lifting task.
- Environmental Conditions: this is associated with air freshness, relative humidity and ambient temperature. In the current experiment, these conditions were controlled. However, a new experiment could be designed

where those environmental conditions would be manipulated within safe parameters.

- Body Comfort: it would be interesting to have an experiment where subjects would be wearing different winter clothing.

Regarding the factors used in this study some future research that could be carried out in order to maximize performance, maximize comfort and minimize the biomechanical and physiological efforts are:

- To expand the experiment toward a more diverse population (subjects with different characteristics, background, and experience).
- To re-design the psychophysical experiment, controlling the horizontal distance this time, and varying the vertical height and including the effect of the weight such that the NIOSH 1981 lifting index remains equal to 1.
- Another variation of the experiment would be to use larger containers that could simulate large objects (such as a TV set).

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APPENDIX A

Final Survey

Subject's Information:

Please fill the blank or check with an “X” the correspondent answer that works for you.

- Gender : Male ____
Female ____
- Age: _____
- Height: _____
- Weight: _____

- Have you received some kind of training about lifting objects?
Yes _____

No _____
- Was this training given:
 - By your supervisor in the workplace _____
 - In a special course _____
 - By a lecturer, in a conference or a seminar _____
 - Other circumstances, Please specify it,

- How long ago this training was received (approx)? _____
- For how long have you been working in this activity, or similar ones?

Some Definitions and Considerations

- Symmetric Object: an object is symmetric respect to an axis (an imaginary line crossing throughout the center of the object), so that every point in one side coincides exactly with a point on the other side. Some examples are

A can

A weight

A ball

A box

- Symmetric Lifting Posture: a lifting posture is symmetric respect to the sagittal plane (an imaginary plane which divide the human body in two sides, right and left) so that every part of the limbs, and trunk in one side coincides exactly with a point on the other side. For example

Symmetric Lifting Posture

Asymmetric Lifting Posture

- Free Space: It is the available space surrounding the person, free of any obstacle which could avoid the free movement of the subject. In the proposed scenario the subjects will have a free space within an area given by circle with a radio of two times the length of their arms
- Body Stability: It is how equilibrated or balanced, is the body of the subject during a specific lifting posture at the moment of grabbing the object
- Ambient Temperature: Temperature in the environment at the moment of lifting the object
- Ambient Humidity: Humidity in the environment at the moment of lifting the object
- Daily Diet: It is the composition of the kind of food that you eat (number of calories, carbohydrates, proteins, etc) every day.

- Air Purity: Fresh uncontaminated air (no polluted air, dusty, smoky or smelly air)
- Industrial Comfort: It is the sensation experienced as a result of the summation of all the individual sensations via the various sense channels (sensory stimuli experienced via all sense organs) judged as a totality. This would include a contribution from the environment as well as sensations experienced as a direct result of the man-workstation relationship.

Scenario proposed

- The scenario proposed is that you are standing up in front of the object ready to start the lifting. The object is resting on the floor in front of you, you have a free space of twice the length of your arm around you. You are supposed to lift the object from the floor and place it in front of you giving no more than one step forward.

Instructions:

- Please read carefully each of the following statements about the importance of a particular element towards obtaining a comfortable lifting posture to start lifting an object. You have to rate each statement circling the correspondent number or marking it with an "X".
- The above mentioned rating numbers are associated with the degree of agreement or disagreement you feel with respect the statement. Categories vary from 1 through 5, as follows

1= Strongly disagree

2= Disagree

3= Undecided

4= Agree

5= Strongly agree

N/R= If you think it is not relevant

- Important: You have to consider the elements or items mentioned in the statements as attributes, which means that they don't have a specific value. However, you have to consider those elements within two opposite states (i.e. good or bad, high or low, there is or there is not) and how important is that item or element to have a comfortable lifting posture

Some examples of how items and their attributes related should be considered are:

-Temperature: high or low

-Handles: If there are or there are not

-Symmetry: If it is or it is not

1 1= Strongly disagree 2= Disagree 3= Undecided 4=Agree 5= Strongly agree N/R= Not Relevant

- To use gloves is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- The number of times per /hour that I have to lift the object is an important factor to adopt a comfortable lifting posture	1	2	3	4	5	N/R
- Ambient temperature is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- The vertical distance (floor to my hands grabbing the object) is an important factor to adopt a comfortable lifting posture	1	2	3	4	5	N/R
- The time of the day (time into the work shift) is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- Fatigue is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- How the clothes I'm wearing fits is an important factor in adopting a comfortable lifting posture	1	2	3	4	5	N/R
- Whether the object is symmetric or not is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- Body stability is an important factor towards adopting a comfortable lifting position	1	2	3	4	5	N/R
- The amount of time available to perform the lifting task is an important factor to adopt a comfortable lifting posture	1	2	3	4	5	N/R
- The size of the object is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- The level of noise is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- Site illumination is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- How rough is the floor surface is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- Experience in the job position is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R

- The weight of the object is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- My experience lifting objects is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- Whether the object has handles or not is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- The color of the room and environment is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- My age is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- How much I stretch my arms in order to grasp the object is an important factor to adopt a comfortable lifting posture	1	2	3	4	5	N/R
- The fear of failing to complete the task successfully is an important factor to adopt a comfortable lifting posture	1	2	3	4	5	N/R
- How much I need to bend my neck is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- Free space to maneuver is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- Relative humidity is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- My weight is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- The air purity is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- My height is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- How much I need to stretch my legs is an important towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- My daily diet is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- How much I need to bend my trunk is an important factor towards adopting a comfortable lifting posture	1	2	3	4	5	N/R
- A symmetric posture is important to adopt a comfortable lifting posture	1	2	3	4	5	N/R

Survey Results

Subjects	Items																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	
S1	4	4	4	2	4	5	2	4	2	2	4	4	2	5	4	2	2	2	3	4	4	5	2	2	3	1	2	2	2	2	1	2	5	
S3	5	3	5	5	4	4	2	4	5	3	1	5	4	5	1	4	3	4	2	2	2	3	3	1	2	2	1	2	1	2	2	3	5	
S4	4	5	5	4	4	5	4	5	5	5	5	5	4	5	5	5	4	4	4	4	4	4	5	4	4	3	5	4	3	3	3	3	5	
S5	5	4	5	4	4	5	5	5	4	4	2	5	4	5	5	5	4	5	5	5	4	5	2	5	4	4	1	3	2	4	1	3	5	
S6	5	4	5	5	5	4	4	5	5	5	5	5	5	5	4	5	4	4	4	5	4	4	5	4	4	3	5	5	3	4	4	4	5	
S7	4	4	5	4	5	5	4	5	5	4	5	5	4	5	4	5	4	5	5	5	5	4	3	5	4	4	4	3	4	3	4	2	4	4
S8	5	5	5	5	5	5	5	5	5	5	5	5	4	5	5	4	4	5	5	5	2	5	4	4	2	4	4	2	2	3	2	4	5	
S9	5	4	5	4	4	5	4	4	5	4	4	5	4	5	5	4	4	4	4	4	4	4	4	3	3	3	4	4	4	3	4	3	4	4
S11	5	4	5	4	3	5	5	4	4	4	5	4	3	5	5	4	3	4	5	4	NR	4	5	3	4	5	2	4	4	4	1	NR	5	
S12	4	5	4	5	5	4	3	4	4	4	3	3	3	3	3	5	5	4	NR	3	4	4	5	3	NR	4	3	NR	NR	2	1	2	5	
S13	4	4	5	5	5	5	5	5	5	4	4	4	3	5	5	4	5	4	4	4	4	5	4	4	3	4	3	5	2	3	2	4	5	
S14	4	4	5	4	5	4	4	4	2	4	4	4	5	4	5	4	4	5	4	5	2	5	4	4	2	4	5	4	2	2	5	2	5	
S15	4	4	4	3	4	3	NR	4	3	4	4	3	NR	4	5	3	3	4	4	4	3	4	4	4	4	4	4	4	1	4	4	1	4	4
S16	4	4	5	3	3	3	3	4	4	4	4	4	4	4	5	4	4	2	2	2	4	4	3	2	2	2	1	1	1	1	2	1	2	4
S17	5	5	5	4	4	4	4	4	5	5	4	5	4	5	5	4	4	4	5	4	4	5	5	4	4	4	3	3	2	NR	2	3	5	
S18	3	4	4	4	4	5	NR	4	4	2	4	4	3	5	4	4	4	3	NR	3	NR	4	4	3	3	NR	4	3	2	NR	NR	NR	5	
S19	5	3	5	4	5	4	2	4	4	2	1	3	3	5	5	3	4	3	3	4	5	4	2	3	2	3	3	2	2	2	1	2	5	
S20	5	5	5	3	4	4	4	5	3	4	5	4	4	5	5	5	5	4	4	4	5	5	3	4	5	4	5	4	4	5	NR	5	5	
S21	4	4	5	5	4	5	4	5	NR	4	4	4	NR	5	NR	5	NR	4	5	5	NR	5	NR	NR	3	4	4	NR	NR	2	NR	5	5	
S22	5	5	5	5	5	5	4	5	2	2	2	3	2	5	5	5	4	2	NR	4	1	4	4	5	4	2	1	2	2	5	1	4	5	
S23	4	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	4	4	4	4	5	5	4	4	4	4	4	4	4	3	3	4	5	
S24	5	5	5	3	4	4	5	4	4	5	5	5	3	5	5	4	4	3	4	3	4	4	4	3	3	3	3	4	2	3	2	4	4	
S25	5	4	5	4	4	NR	NR	5	4	4	5	5	4	4	5	4	4	4	4	5	4	4	4	4	4	NR	4	4	4	NR	4	NR	4	4
S26	4	5	5	5	5	5	5	5	5	5	4	4	4	4	5	5	5	4	4	5	5	4	4	4	4	4	4	5	2	2	5	2	2	5
S27	4	4	5	4	5	3	4	4	3	3	5	4	2	5	5	4	3	3	4	5	4	4	4	4	4	3	2	2	3	2	3	1	3	4
S28	4	4	4	2	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	4	2	4	4	4	3	2	NR	NR	2	2	NR	2	4
S29	5	5	NR	5	NR	5	5	4	NR	NR	5	5	3	1	2	4	2	2	2	NR	2	2	4	NR	NR	NR	NR	2	NR	NR	NR	1	NR	
S30	5	5	5	5	5	5	5	3	5	5	5	5	4	5	5	1	5	5	3	5	3	5	3	5	1	3	1	3	3	1	1	1	3	5
S31	4	4	5	4	3	5	3	5	4	4	4	4	4	5	5	4	5	4	4	4	5	5	4	4	4	3	3	4	5	4	2	3	5	
S32	4	5	4	5	5	5	4	4	2	2	5	3	4	5	4	3	2	2	3	3	2	5	3	4	2	4	4	2	2	2	1	4	2	
S33	4	5	4	4	4	5	4	5	4	3	4	2	2	5	5	5	5	4	4	5	4	5	4	4	1	NR	3	2	4	4	2	5	5	
S34	4	4	4	4	4	4	4	4	4	5	4	5	4	4	5	5	3	4	4	4	3	4	4	4	2	2	4	2	4	3	4	2	3	5
S35	4	4	5	5	3	5	2	5	4	4	4	4	4	4	5	5	4	3	5	5	5	5	4	3	5	4	1	1	1	2	3	1	2	5
S36	4	4	5	4	5	5	5	5	2	5	5	4	4	5	5	5	2	4	4	4	5	5	4	4	NR	2	2	NR	NR	NR	5	4	5	
S37	5	4	5	4	4	5	4	5	1	4	5	4	4	4	4	2	1	4	1	4	4	5	4	4	5	1	1	NR	1	5	1	1	5	
S38	3	5	4	3	4	3	5	3	5	3	3	3	4	4	4	3	4	2	2	4	1	4	3	2	3	1	4	3	1	4	2	1	2	1
S39	5	4	4	5	4	5	4	5	4	4	5	5	4	5	5	5	4	4	5	5	2	4	4	3	1	4	4	4	2	2	NR	3	4	
S40	5	4	4	4	4	4	4	4	4	4	4	4	4	4	5	4	4	4	3	3	4	3	3	4	NR	NR	NR	3	3	3	3	3	4	4
S41	4	4	4	4	4	5	4	4	4	4	4	4	4	4	5	4	4	3	2	2	5	2	5	1	1	2	2	NR	NR	1	NR	NR	2	2
S42	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	2	4	4	4	4	4	2	4	4	2	1	1	1	2	4
S43	5	3	5	5	5	5	5	5	4	5	5	5	5	1	5	5	5	5	5	5	4	3	4	NR	NR	2	3	3	NR	1	NR	1	4	5
S44	5	4	5	4	4	4	4	4	4	4	5	4	4	5	5	4	5	4	4	4	4	4	4	3	4	3	4	5	3	NR	4	1	3	4
S45	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	3	4	4	3	4	4	5
S46	4	4	5	4	4	4	4	4	3	4	4	5	4	4	5	4	4	4	4	2	5	5	4	3	3	4	3	4	3	3	4	2	4	4
S47	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	2	4	3	4	3	2	3	2	4	2	2	2	2	2	4	4
S48	5	5	5	5	5	5	4	5	4	4	5	5	4	5	5	5	5	5	5	4	3	5	3	3	3	3	2	3	3	3	3	1	3	4
S49	5	5	4	4	4	3	4	5	5	5	5	4	5	5	5	4	2	4	4	4	4	2	2	3	3	2	2	2	2	2	4	2	4	4
S50	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	5	3	5	4	5	2	3	1	3	5
S51	5	5	5	5	5	5	5	5	5	4	5	5	4	5	5	5	4	4	5	5	5	5	5	4	4	4	5	2	5	2	4	2	4	
S52	5																																	

Survey Results (Continued)

Subjects	Items																																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33		
S70	4	4	5	5	5	5	4	4	5	4	4	5	3	5	5	4	5	5	4	5	4	5	4	5	4	5	4	3	3	3	2	5	5		
S71	4	4	5	4	4	4	4	4	4	4	1	4	2	5	4	4	2	4	2	4	4	4	4	4	4	2	2	NR	NR	NR	NR	4	4		
S72	4	4	4	4	2	5	4	4	4	4	4	4	3	5	4	4	4	1	1	5	2	4	4	4	2	2	2	1	2	2	2	1	2	4	
S73	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	3	4	4	2	2	3	3	2	3	4	
S74	5	4	5	5	5	5	4	5	5	5	5	5	5	5	5	5	4	5	5	5	5	4	4	4	4	4	4	4	4	4	4	3	4	5	
S75	3	5	5	5	5	4	3	5	3	3	4	4	3	5	5	4	4	4	3	5	5	5	5	5	4	3	4	3	5	3	3	4	3	4	
S76	4	4	4	4	4	4	4	4	1	4	4	2	4	4	4	4	4	4	2	2	2	4	NR	NR	NR	NR	4	NR	NR	4	NR	2	4		
S77	5	5	5	4	5	5	4	4	4	4	5	1	2	5	4	4	1	5	2	4	4	4	4	4	4	4	4	1	4	2	4	2	4	5	
S78	4	2	5	5	5	3	3	5	2	2	3	3	3	5	4	4	3	4	3	2	4	3	3	3	3	4	3	1	4	1	1	1	2	5	
S79	4	2	4	4	4	4	3	4	2	3	4	4	4	4	4	4	3	2	4	3	3	3	4	3	4	2	2	3	2	2	2	1	4		
S80	4	2	5	4	4	4	4	5	4	4	4	5	NR	4	4	5	2	5	3	4	4	5	2	NR	NR	4	NR	4	NR	NR	NR	4	4		
S81	5	5	5	5	5	5	5	4	4	5	5	5	4	5	5	5	4	5	5	5	4	4	2	2	2	4	4	4	2	3	2	3	4		
S82	4	4	4	2	4	4	4	4	4	4	4	4	4	4	4	4	2	4	2	2	5	4	2	2	3	4	3	2	2	3	2	3	5		
S83	5	4	4	4	2	4	4	4	5	2	4	5	3	4	3	4	NR	4	4	2	4	5	5	4	3	3	NR	4	2	3	NR	2	4		
S84	4	4	5	5	4	5	4	5	5	4	5	5	3	5	5	4	5	4	5	4	4	3	4	4	3	4	3	4	3	3	3	3	4		
S85	5	5	5	5	5	5	4	5	5	4	5	5	4	5	5	5	NR	4	5	5	5	4	3	3	5	5	5	NR	3	NR	4	5			
S86	4	5	5	4	5	5	4	4	5	4	4	4	4	4	5	5	4	4	5	5	4	NR	2	4	4	4	5	3	2	4	NR	3	4		
S87	4	4	5	4	3	4	4	4	4	4	4	5	4	3	5	4	4	4	5	4	4	4	4	3	NR	NR	3	NR	NR	NR	NR	NR	4		
S88	4	4	4	4	3	4	4	3	4	4	4	4	4	4	5	4	3	4	2	3	4	2	4	4	3	2	2	3	4	2	3	2	2	4	
S89	4	4	4	4	4	3	5	4	3	2	4	4	4	4	4	5	4	4	4	4	4	2	1	4	2	1	2	2	3	1	1	1	2	4	
S91	4	3	4	5	NR	5	4	5	2	4	4	4	4	4	4	3	5	4	NR	4	NR	5	3	2	2	2	2	2	1	1	1	2	NR		
S92	5	5	5	5	5	5	4	5	2	4	4	5	1	5	5	5	5	5	5	5	2	3	2	3	3	5	1	1	1	2	2	3	5		
S93	5	3	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	2	2	2	4	4	4	4	2	4	2	2	4	1	1	4		
S94	4	4	4	4	4	4	4	4	4	3	4	4	3	4	4	4	4	4	NR	4	4	4	4	3	3	3	3	NR	NR	NR	NR	NR	4		
S95	5	4	4	4	5	4	4	5	3	4	4	4	4	3	4	5	3	5	4	4	4	2	4	3	3	4	4	3	3	4	2	5	5		
S97	5	2	5	4	4	4	4	4	4	4	4	4	4	5	5	4	4	3	4	4	4	4	3	4	4	2	5	3	2	3	2	2	4		
S99	4	5	5	3	4	4	4	5	4	4	5	5	4	5	5	4	2	2	4	4	2	4	NR	4	3	NR	4	NR	NR	2	NR	NR	4		
S100	5	4	5	4	5	5	4	5	4	3	4	5	4	5	5	4	4	4	5	5	4	5	3	4	4	4	3	4	2	4	1	3	4		
S101	5	5	5	5	4	4	4	5	4	4	5	5	4	4	5	4	4	4	2	4	3	4	3	2	2	1	2	4	1	3	1	2	5		
S102	5	4	5	5	4	4	4	4	5	4	4	4	4	4	5	4	4	5	4	4	4	3	3	NR	2	2	3	NR	2	NR	NR	NR	4		
S103	4	4	4	5	4	4	3	4	3	2	4	4	3	5	4	4	4	4	3	5	4	4	2	4	3	4	3	2	3	4	2	3	4		
S104	5	4	4	4	4	5	4	4	5	2	4	4	4	5	5	5	2	4	2	5	5	4	2	4	4	2	4	2	2	4	2	4	5		
S105	5	4	5	5	5	5	4	5	4	4	5	5	5	5	5	5	5	4	5	5	5	5	4	4	4	5	5	5	3	2	2	4	5		
S106	4	5	2	4	4	4	3	5	3	3	2	4	4	2	4	4	3	4	2	3	3	2	3	2	3	2	2	2	2	1	3	3			
S107	5	4	5	5	5	5	4	5	5	3	3	5	4	5	5	5	5	5	3	5	5	4	4	3	4	2	2	2	4	2	3	2	3	5	
S108	4	4	5	4	4	4	2	5	3	4	4	5	3	5	5	5	4	2	2	5	5	4	4	2	4	3	3	NR	2	4	2	4	5		
S109	5	4	5	5	4	4	4	5	5	4	4	5	4	5	4	4	5	5	5	5	4	5	5	2	2	4	5	1	2	2	1	4	5		
S110	4	5	5	2	5	4	5	5	4	4	5	5	2	5	5	4	4	4	2	5	5	5	3	2	3	4	2	2	5	4	1	3	4		
S111	5	4	5	5	5	4	5	4	3	5	5	5	5	5	2	3	5	4	3	4	4	4	4	5	5	3	5	1	1	5	1	1	5		
S113	5	5	5	5	5	5	4	5	4	4	5	5	5	5	5	5	5	5	4	5	4	5	5	4	3	5	4	5	3	3	3	5	5		
S114	4	4	4	4	4	5	5	5	3	4	3	5	2	5	5	5	5	3	5	5	3	3	5	3	1	1	1	5	1	1	1	1	4		
S115	5	5	5	5	5	5	5	5	5	4	4	4	4	5	5	5	4	5	4	5	4	4	4	4	4	4	4	4	4	3	3	3	4	5	
S116	4	4	5	4	4	5	4	4	4	4	4	4	5	4	5	4	5	4	2	3	2	3	4	4	2	2	2	2	3	2	4	1	4	3	
S117	4	4	NR	4	4	3	4	4	1	NR	4	4	4	4	1	1	4	2	NR	4	3	4	4	4	4	4	NR	2	NR	NR	NR	NR	NR	4	
S118	4	5	4	5	5	4	4	4	3	2	4	5	NR	5	5	4	1	4	NR	5	4	4	3	2	NR	5	NR	4	3	NR	NR	NR	3		
S119	4	2	4	4	2	4	4	4	4	4	3	4	2	4	4	2	2	4	2	4	4	2	4	2	4	2	3	4	2	2	2	4	4		
S120	5	5	5	3	5	2	2	4	2	4	4	5	4	5	4	5	1	4	2	5	2	2	2	2	2	4	2	2	2	2	1	3	4		
S121	5	4	5	5	4	4	4	4	4	4	4	4	4	5	5	4	4	4	NR	4	4	4	4	4	4	NR	5	4	4	5	NR	5	5		
S122	4	5	5	3	4	5	5	NR	4	4	4	3	4	1	1	4	3	3	4	3	3	3	NR	4	3	3	3	3	3	3	NR	3	4		
S123	4	5	5	4	5	5	NR	5	5	4	5	4	4	5	5	NR	4	5	NR	NR	4	4	NR	NR	NR	2	2	NR	2	NR	2	NR	NR	4	
S124	4	4	4	4	4	5	4	4	4	4	4	4	4	5	4	5	4	4	5	4	4	4	3	3	3	4	4	4	3	4	3	3	4		
S125	4	4	5	4	5	4	4	4	4	4	5	4	5	4	5	2	4	4	5	4	4	4	4	3	2	4	4	4	2	3	1	5	5		
S126	5	5	5	5	5	5	5	5	5	5	3	4	4	4	5	5	5	4	3	4	4	5	4	5	4	5	3	3	4	4	3	4	5		
S128	5	5	5																																

APPENDIX B

Glossary NIOSH 1981

GLOSSARY

Action Limit (AL): In the NIOSH Work Practice Guide 81. This term denotes the weight limit that nearly all healthy employees (90% of the adult population, 99 % of the male and 75% of the female work force) can lift over a substantial period of time (i.e., up to 8 hours) with out placing excessive load on the back. If the ratio of the load handles and the Action limit is ≥ 1 and < 3 , administrative control are necessary.

Distance Multiplier (DM): A reduction coefficient defined as $(0.7 + (7.5/D))$, for D measured in inches, and $(0.7 + (3/D))$, for d measured in centimeters

Horizontal location of the hands, Ho and Hf: The horizontal location of the hands at both the star (origin, Ho) hand end (destination, Hf) of the lift are measured. The horizontal location is measured as the distance from the mid point between the employee's ankles to a point projected on the floor directly below the mid-point of the hands grasping the object. The horizontal distance should be measured when the object leaves the surface).

Incidence Rate (IR): This is a ratio used to show the effect that injuries or accidents have on the total work hours of determined work station or facility and is given by the ratio: $(\# \text{ Cases} \times 200,000)/(\text{Total_Work, Hrs})$.

Job Severity Index (JSI): This is defined as a relative estimate of the level of physical stress associated with a particular lifting task, the estimate of the level of physical stress is defined by the relationship of the weight of the load lifted divided by the Action Limit

Lifting Frequency (F): The lifting frequency is determined by the average number of lifts per minute. The frequency is assumed between 0.2 (one lift every 5 min) and the F max Index, which varies between 18 ($V > 75$ cm and 1 Hr of duration) and 12 ($V \leq 75$ cm and 8 Hr of duration). For lifting less frequently than the minimum, set $F=0$.

Load Handled (L): A term defining the weight of the object to be lifted, in Kg or pound, including the container.

Maximum Permissible Limit (MPL): This term indicates if the level of the Job Severity index is greater than three, that lifted weight exceeds the capacity to safely lift for most of the population, it is likely to cause injury, and should be modified by implementation of engineering controls.

Travel Distance of the load (D): The total vertical travel distance of the load during the lift is determined by subtracting the vertical location of the hand at the start of the lift (V_0) from the vertical location of the hands at the end of the lift

(Vf). For lowering, the total vertical travel distance of the load is determined by subtracting the vertical location of the hands at the end of the lower (Vf0 from the vertical location of the hands at the start of the lower (Vo). For travel distance less than 25 cm (10 in), set D= 25 Cm (10 in).

Vertical location of the hands (V): The vertical location is measured from the mid-point between hands at the origin of the lift measured from the floor level (the middle knuckle can be used to define the mid-point).

Sagittal Plane: The sagittal plane is a vertical plane through the longitudinal axis dividing the body into left and right portions.

APPENDIX C

Descriptive Statistics of Survey

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Gender	121	1	2	1.15702479	0.36533693
AgeGroup	121	1	2	1.76033058	0.42865669
BMIGroup	121	1	2	1.76859504	0.42348417
TimesTrainedGrpoup	121	1	2	1.87603306	0.33091409
ExperGroup	121	1	2	1.68595041	0.46606612
Item1	121	2	5	4.40495868	0.58564085
Item2	121	1	5	4.14049587	0.80938027
Item3	121	2	5	4.58677686	0.62808467
Item4	121	1	5	4.18181818	0.79582243
Item5	121	2	5	4.25619835	0.73630752
Item6	121	1	5	4.34710744	0.76060002
Item7	121	2	5	3.95041322	0.77299461
Item8	121	3	5	4.44628099	0.56199664
Item9	121	1	5	3.80165289	1.05372225
Item10	121	1	5	3.75206612	0.91543243
Item11	121	1	5	4.14876033	0.88186504
Item12	121	1	5	4.25619835	0.75860536
Item13	121	1	5	3.6446281	0.91158748
Item14	121	1	5	4.56198347	0.82555599
Item15	121	1	5	4.31404959	0.88537241
Item16	121	1	5	4.09090909	0.95742711
Item17	121	1	5	3.67768595	1.12705276
Item18	121	1	5	3.80165289	0.97142365
Item19	121	1	5	3.4214876	1.15290984
Item20	121	1	5	4.10743802	0.97298212
Item21	121	1	5	3.56198347	1.11723291
Item22	121	1	5	3.91735537	0.9625208
Item23	121	1	5	3.45454545	0.98319208
Item24	121	1	5	3.26446281	1.0469686
Item25	121	1	5	3.09917355	0.99502897
Item26	121	1	5	3.07438017	1.16307989
Item27	121	1	5	2.95867769	1.21378673
Item28	121	1	5	3.0661157	1.15279036
Item29	121	1	5	2.2892562	0.87975391
Item30	121	1	5	2.95041322	1.07122391
Item31	121	1	5	1.8677686	0.80562759
Item32	121	1	5	3.08264463	1.0691646
Item33	121	1	5	4.36363636	0.79582243
Valid N (listwise)	121				

APPENDIX D

Communalities

Communalities

	Initial	Extraction
Item1	1	0.62541666
Item2	1	0.56160601
Item3	1	0.70734747
Item4	1	0.63057164
Item5	1	0.70718994
Item6	1	0.74453905
Item7	1	0.57942267
Item8	1	0.58526454
Item9	1	0.66818395
Item10	1	0.69592943
Item11	1	0.62999419
Item12	1	0.55023998
Item13	1	0.67189296
Item14	1	0.71627778
Item15	1	0.7363354
Item16	1	0.5751415
Item17	1	0.58784411
Item18	1	0.54997585
Item19	1	0.57067545
Item20	1	0.58529807
Item21	1	0.54483225
Item22	1	0.62139922
Item23	1	0.64870481
Item24	1	0.64540442
Item25	1	0.64088597
Item26	1	0.64867766
Item27	1	0.68983729
Item28	1	0.674716
Item29	1	0.67862024
Item30	1	0.73810256
Item31	1	0.55431064
Item32	1	0.59811955
Item33	1	0.66268287

Extraction Method: Principal Component Analysis.

APPENDIX E

Rotated Component Matrix

Rotated Component Matrix(a)

Item4	The vertical distance (floor to my hands grabbing the object) is an important factor to adopt a comfortable lifting posture
Item8	Free space to maneuver is an important factor towards adopting a comfortable lifting posture
Item1	Body stability is an important factor towards adopting a comfortable lifting position
Item18	My weight is an important factor towards adopting a comfortable lifting posture
Item33	My general physical health is an important factor towards adopting a comfortable lifting posture
Item12	How much I need to bend my trunk is an important factor towards adopting a comfortable lifting posture
Item19	My height is an important factor towards adopting a comfortable lifting posture
Item30	Air freshness is an important factor towards adopting a comfortable lifting posture
Item25	Relative humidity is an important factor towards adopting a comfortable lifting posture
Item24	Ambient temperature is an important factor towards adopting a comfortable lifting posture
Item21	My age is an important factor towards adopting a comfortable lifting posture
Item14	The weight of the object is an important factor towards adopting a comfortable lifting posture
Item3	The size of the object is an important factor towards adopting a comfortable lifting posture
Item20	The number of times per /hour that I have to lift the object is an important factor to adopt a comfortable lifting posture
Item10	How much I need to stretch my legs is an important factor towards adopting a comfortable lifting posture
Item13	How much I need to bend my neck is an important factor towards adopting a comfortable lifting posture
Item27	The fear of failing to complete the task successfully is an important factor to adopt a comfortable lifting posture
Item31	The color of the room and environment is an important factor towards adopting a comfortable lifting posture
Item32	Diet is an important factor towards adopting a comfortable lifting posture
Item29	The level of noise is an important factor towards adopting a comfortable lifting posture
Item6	My experience lifting objects is an important factor towards adopting a comfortable lifting posture
Item22	Experience in the job position is an important factor towards adopting a comfortable lifting posture
Item15	Whether the object has handles or not is an important factor towards adopting a comfortable lifting posture
Item9	The roughness of the floor surface where my feet are is an important factor towards adopting a comfortable lifting posture
Item16	Whether the object is symmetric or not is an important factor towards adopting a comfortable lifting posture
Item23	Site illumination is an important factor towards adopting a comfortable lifting posture
Item28	Using gloves is an important factor towards adopting a comfortable lifting posture
Item17	The amount of time available to perform the lifting task is an important factor towards adopting a comfortable lifting posture
Item11	How much I stretch my arms in order to grasp the object is an important factor to adopt a comfortable lifting posture
Item7	How the clothes I'm wearing fits is an important factor in adopting a comfortable lifting posture
Item2	A symmetric posture is important to adopt a comfortable lifting posture
Item5	Fatigue is an important factor towards adopting a comfortable lifting posture
Item26	The time of the day (time into the work shift) is an important factor towards adopting a comfortable lifting posture

Extraction Method: Principal Component Analysis. □ Rotation Method: Varimax with Kaiser Normalization.

a

GeoLif/Subject Component	Environm	ObjChara	Bending	Allowa-I	WorkExpe	Sime-Obj	Allow-II	BodyCo
1	2	3	4	5	6	7	8	
0.651241397	-0.113153	-0.033129	-0.028819	0.000659	0.108497	-0.041918	0.357687	-0.02921
0.635454953	0.048535	0.205312	-0.158227	-0.023502	0.08461	0.209798	0.098146	0.2001
0.611417163	0.322354	-0.068525	0.260299	-0.087407	0.061162	0.094882	-0.163606	0.16701
0.553297097	0.085668	0.160045	0.189401	0.357392	0.072147	0.057524	0.042232	-0.05901
0.475588813	0.424314	0.453951	-0.036937	0.116877	-0.123365	-0.009043	0.069667	-0.07991
0.472180489	-0.193192	0.109273	0.295503	-0.027163	-0.151337	0.276436	0.063985	0.26341
0.353632142	0.000309	0.269919	0.327273	0.226086	0.214329	0.309896	0.206292	0.10321
-0.022030475	0.73948	-0.120303	0.022799	0.163825	0.049769	0.187998	-0.18972	0.25201
0.068658743	0.738971	0.148034	0.113325	0.031576	0.038001	-0.121973	0.189941	0.01111
0.070355399	0.642382	0.067879	0.098605	0.0862	0.307734	0.090072	0.244879	-0.03991
0.064783884	0.473888	0.416298	0.138268	0.281007	0.034226	0.096704	0.14256	-0.11131
-0.057465635	0.076673	0.76569	0.022642	0.089093	0.277122	0.108002	0.12269	-0.09401
0.357767669	0.253032	0.617348	0.004697	-0.01511	0.006815	0.309073	-0.126312	0.10331
0.137518991	-0.115163	0.595395	0.071478	0.145354	0.13735	0.064166	0.248005	0.17411
0.277059859	0.053387	0.432132	0.40176	0.272858	0.144931	0.0191	0.04114	0.38861
0.084030357	0.084539	-0.011432	0.790944	-0.047295	0.116369	0.049872	0.016284	0.1061
-0.067117979	0.143818	0.094095	0.674971	0.284151	0.023654	-0.021312	0.165582	0.11371
-0.021242113	0.037923	0.000143	0.073808	0.713766	0.118558	-0.037787	0.107099	0.08271
0.187779834	0.138022	0.244608	-0.030979	0.662695	-0.017096	0.139093	-0.014721	0.01301
-0.314388858	0.355403	0.038574	0.05056	0.557527	0.134768	0.211763	0.232251	0.1221
0.244032807	0.028123	0.066803	0.01361	0.10384	0.790877	0.047952	0.130531	0.1251
-0.131276758	0.238982	0.237457	0.1572	0.113984	0.663286	-0.018089	-0.064972	0.00211
0.095664984	0.000468	0.264916	-0.146649	-0.013113	0.01186	0.753232	0.049448	0.13871
0.130753025	0.183764	-0.016751	0.417477	0.150585	0.037338	0.622642	0.098742	-0.00991
0.276036122	0.004566	0.109398	0.172238	0.299628	0.366054	0.445494	-0.009089	-0.01371
0.115934714	0.23437	0.080409	0.060667	0.143569	0.110958	-0.095383	0.698451	0.15021
0.079850401	0.040268	0.212249	0.085378	0.254115	-0.114682	0.329208	0.633535	0.15371
0.095485542	0.096639	0.088169	0.357229	-0.133112	0.35697	0.155027	0.465604	-0.02091
0.033019259	0.095128	0.150653	0.262536	0.046445	-0.050437	0.077632	0.002382	0.71231
0.198535909	0.00349	-0.197238	-0.042489	0.071375	0.089784	0.036563	0.172219	0.67371
-0.080926921	0.062537	0.180313	0.060768	0.039928	0.389826	0.050743	0.115884	0.4901
0.262220185	0.130281	0.108511	0.001324	0.028726	-0.016481	0.133668	-0.094248	0.09421
0.143889086	0.13366	0.122134	0.306014	0.409933	0.169992	0.025048	0.210517	0.04741

Rotation converged in 11 iterations.

APPENDIX F

Rotated Component Matrix without 2 subjects

Rotated Component Matrix(a)
WO-Outliers

Item4	The vertical distance (floor to my hands grabbing the object) is an important factor to adopt a comfortable lifting posture
Item18	My weight is an important factor towards adopting a comfortable lifting posture
Item8	Free space to maneuver is an important factor towards adopting a comfortable lifting posture
Item1	Body stability is an important factor towards adopting a comfortable lifting position
Item12	How much I need to bend my trunk is an important factor towards adopting a comfortable lifting posture
Item25	Relative humidity is an important factor towards adopting a comfortable lifting posture
Item30	Air freshness is an important factor towards adopting a comfortable lifting posture
Item24	Ambient temperature is an important factor towards adopting a comfortable lifting posture
Item21	My age is an important factor towards adopting a comfortable lifting posture
Item33	My general physical health is an important factor towards adopting a comfortable lifting posture
Item14	The weight of the object is an important factor towards adopting a comfortable lifting posture
Item3	The size of the object is an important factor towards adopting a comfortable lifting posture
Item15	Whether the object has handles or not is an important factor towards adopting a comfortable lifting posture
Item20	The number of times per /hour that I have to lift the object is an important factor to adopt a comfortable lifting posture
Item13	How much I need to bend my neck is an important factor towards adopting a comfortable lifting posture
Item27	The fear of failing to complete the task successfully is an important factor to adopt a comfortable lifting posture
Item19	My height is an important factor towards adopting a comfortable lifting posture
Item7	How the clothes I'm wearing fits is an important factor in adopting a comfortable lifting posture
Item11	How much I stretch my arms in order to grasp the object is an important factor to adopt a comfortable lifting posture
Item2	A symmetric posture is important to adopt a comfortable lifting posture
Item10	How much I need to stretch my legs is an important factor towards adopting a comfortable lifting posture
Item16	Whether the object is symmetric or not is an important factor towards adopting a comfortable lifting posture
Item9	The roughness of the floor surface where my feet are is an important factor towards adopting a comfortable lifting posture
Item31	The color of the room and environment is an important factor towards adopting a comfortable lifting posture
Item32	Diet is an important factor towards adopting a comfortable lifting posture
Item29	The level of noise is an important factor towards adopting a comfortable lifting posture
Item5	Fatigue is an important factor towards adopting a comfortable lifting posture
Item26	The time of the day (time into the work shift) is an important factor towards adopting a comfortable lifting posture
Item23	Site illumination is an important factor towards adopting a comfortable lifting posture
Item28	Using gloves is an important factor towards adopting a comfortable lifting posture
Item17	The amount of time available to perform the lifting task is an important factor towards adopting a comfortable lifting posture
Item22	Experience in the job position is an important factor towards adopting a comfortable lifting posture
Item6	My experience lifting objects is an important factor towards adopting a comfortable lifting posture

Extraction Method: Principal Component Analysis. □ Rotation Method: Varimax with Kaiser Normalization.

a

GeoLiftin	Env/Age	ObjChara	SubHeigh	Stretching	?	Allow-I	Tireness	Allow-II
Component	1	2	3	4	5	6	7	8
	0.667078	-0.142568	-0.081166	0.013902	-0.053526	-0.035283	-0.026313	0.24847
	0.622344	0.144355	0.098828	0.148584	0.024969	0.080567	0.327098	0.227086
	0.61285	0.084627	0.258578	-0.126434	0.239089	0.207045	-0.07368	0.10937
	0.566359	0.299745	-0.056656	0.303024	0.138455	0.199342	-0.171554	-0.023216
	0.402355	-0.194768	0.231874	0.356541	0.258626	0.110212	-0.040599	-0.04971
	0.075261	0.79061	0.078167	0.069905	0.093639	-0.19422	-0.009115	0.034832
	-0.047212	0.691101	-0.062391	0.086967	0.174025	0.288495	0.120824	0.027508
	0.081084	0.652897	0.090241	0.065312	0.003651	0.06556	0.011151	0.255706
	0.073433	0.563675	0.274836	0.128874	-0.104534	0.140324	0.227335	0.060039
	0.47516	0.485557	0.374281	0.023067	-0.097305	-0.064786	0.154266	0.041672
	-0.083507	0.143374	0.76704	0.006978	-0.079055	0.027314	0.039496	0.027656
	0.340427	0.254841	0.707878	0.096209	0.082319	0.111262	0.047246	0.043812
	0.105582	-0.053677	0.556444	-0.048052	0.095201	0.446483	0.010994	0.139632
	0.116037	-0.028526	0.530745	0.03947	0.285981	-0.034589	0.068548	0.424391
	0.099297	0.094127	-0.050135	0.784148	0.161041	0.019375	-0.093195	0.007257
	-0.093478	0.155165	-0.022363	0.675321	0.081597	-0.007892	0.27424	0.341584
	0.349514	0.010689	0.278254	0.351187	0.117678	0.298081	0.167808	0.177716
	0.153631	-0.040662	-0.079837	0.019963	0.698306	-0.079096	0.127433	0.009116
	-0.00981	0.100539	0.143059	0.307859	0.637635	0.073035	0.05914	0.111176
	-0.098169	0.152016	0.005769	-0.042668	0.530648	0.442419	-0.193424	0.350008
	0.281329	0.137628	0.239802	0.427071	0.4948	0.127076	0.230944	-0.124763
	0.334907	0.030887	0.127772	0.117016	0.025478	0.66451	0.13775	0.167406
	0.096428	0.123975	0.195681	0.489509	-0.044863	0.508463	0.125079	-0.147096
	-0.032835	0.043954	0.011685	0.081339	0.110529	-0.041861	0.746031	0.01263
	0.204523	0.207803	0.167674	-0.055421	0.045858	0.268715	0.590977	0.184179
	-0.335312	0.385074	-0.028765	0.0273	0.100871	0.407603	0.443778	0.118277
	0.278529	0.143236	0.218394	0.004041	0.069479	0.090078	0.025981	0.691259
	0.124613	0.189543	0.009511	0.26157	0.04053	0.194261	0.30417	0.60043
	0.106959	0.285793	-0.10947	0.030481	0.150774	0.041452	0.072831	-0.121243
	0.066241	0.052971	0.28005	0.11587	0.151465	0.110066	0.251331	0.11931
	0.114143	0.07015	0.106274	0.341432	-0.013717	0.122908	-0.145603	0.239902
	-0.123935	0.208252	0.205561	0.132813	0.014137	0.034905	0.120325	0.109842
	0.315284	-0.000174	0.077508	-0.072336	0.284975	0.109704	0.055409	-0.039485

Rotation converged in 10 iterations.

APPENDIX G

Skewness

Descriptive Statistics

	N	Min	Max	Mean	Std. Devia	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Item1	121	2	5	4.403361	0.586852	-0.639106	0.221782	0.933447	0.440097
Item2	121	1	5	4.168067	0.78459	-1.270475	0.221782	2.650753	0.440097
Item3	121	2	5	4.588235	0.629928	-1.891438	0.221782	4.940973	0.440097
Item4	121	2	5	4.201681	0.743102	-0.848635	0.221782	0.855049	0.440097
Item5	121	2	5	4.243697	0.736073	-1.069049	0.221782	1.661185	0.440097
Item6	121	2	5	4.369748	0.699462	-0.958471	0.221782	0.822472	0.440097
Item7	121	2	5	3.941176	0.773437	-1.015668	0.221782	1.325213	0.440097
Item8	121	3	5	4.445378	0.562944	-0.361293	0.221782	-0.846352	0.440097
Item9	121	1	5	3.789916	1.056649	-0.79536	0.221782	-0.085063	0.440097
Item10	121	2	5	3.798319	0.849525	-0.780249	0.221782	0.213436	0.440097
Item11	121	1	5	4.142857	0.885722	-1.476414	0.221782	2.94385	0.440097
Item12	121	1	5	4.252101	0.76156	-1.281458	0.221782	2.850544	0.440097
Item13	121	1	5	3.655462	0.877564	-0.716827	0.221782	0.12665	0.440097
Item14	121	1	5	4.613445	0.726137	-2.768446	0.221782	9.988902	0.440097
Item15	121	1	5	4.310924	0.890133	-1.830581	0.221782	4.022964	0.440097
Item16	121	1	5	4.117647	0.922198	-1.556354	0.221782	3.040579	0.440097
Item17	121	1	5	3.697479	1.108936	-0.81542	0.221782	-0.157927	0.440097
Item18	121	1	5	3.823529	0.944629	-0.865121	0.221782	0.20884	0.440097
Item19	121	1	5	3.462185	1.118337	-0.254984	0.221782	-1.123038	0.440097
Item20	121	2	5	4.159664	0.892371	-1.049124	0.221782	0.547014	0.440097
Item21	121	1	5	3.605042	1.075289	-0.568537	0.221782	-0.57771	0.440097
Item22	121	1	5	3.941176	0.932412	-0.902444	0.221782	0.424706	0.440097
Item23	121	1	5	3.495798	0.937667	-0.332656	0.221782	-0.587552	0.440097
Item24	121	1	5	3.277311	1.032722	-0.205313	0.221782	-0.935133	0.440097
Item25	121	1	5	3.109244	0.981092	-0.167752	0.221782	-0.932757	0.440097
Item26	121	1	5	3.109244	1.140844	-0.182787	0.221782	-1.047327	0.440097
Item27	121	1	5	2.991597	1.196717	0.046573	0.221782	-0.933465	0.440097
Item28	121	1	5	3.10084	1.130434	0.049291	0.221782	-1.071366	0.440097
Item29	121	1	5	2.310924	0.870884	0.756145	0.221782	0.641077	0.440097
Item30	121	1	5	2.932773	1.063502	0.049823	0.221782	-0.817708	0.440097
Item31	121	1	5	1.87395	0.808374	1.213946	0.221782	2.708978	0.440097
Item32	121	1	5	3.109244	1.055975	-0.089876	0.221782	-0.862455	0.440097
Item33	121	1	5	4.378151	0.770116	-1.67633	0.221782	3.991887	0.440097

APPENDIX H

Total Variance Explained

Total Variance Explained

Component Initial Eigenvalues

			Extraction Sums of Squared Load Rotation Sums of Squared Loadings					
	Total	% of Variar	Cumulative Total	% of Variar	Cumulative Total	% of Variar	Cumulative Total	% of Variar
1	7.62821	23.11579	23.11579	7.62821	23.11579	23.11579	2.814204	8.527891
2	2.468679	7.480844	30.59663	2.468679	7.480844	30.59663	2.53995	7.696817
3	1.919215	5.815804	36.41243	1.919215	5.815804	36.41243	2.481037	7.518294
4	1.682209	5.097604	41.51004	1.682209	5.097604	41.51004	2.181697	6.611202
5	1.42462	4.31703	45.82707	1.42462	4.31703	45.82707	2.178874	6.602648
6	1.351377	4.095082	49.92215	1.351377	4.095082	49.92215	1.920646	5.82014
7	1.285314	3.89489	53.81704	1.285314	3.89489	53.81704	1.80461	5.468517
8	1.19749	3.628757	57.4458	1.19749	3.628757	57.4458	1.793322	5.434309
9	1.061844	3.21771	60.66351	1.061844	3.21771	60.66351	1.779347	5.391961
10	1.006483	3.049948	63.71346	1.006483	3.049948	63.71346	1.531753	4.641676
11	0.978982	2.966612	66.68007					
12	0.945819	2.866117	69.54618					
13	0.90743	2.749788	72.29597					
14	0.872402	2.643641	74.93961					
15	0.812497	2.462113	77.40173					
16	0.697567	2.113839	79.51557					
17	0.644214	1.952163	81.46773					
18	0.614549	1.862269	83.33					
19	0.582666	1.765655	85.09565					
20	0.551332	1.670702	86.76636					
21	0.529293	1.603918	88.37027					
22	0.519311	1.573669	89.94394					
23	0.466365	1.413229	91.35717					
24	0.420592	1.274522	92.63169					
25	0.374809	1.135784	93.76748					
26	0.365907	1.10881	94.87629					
27	0.313184	0.949043	95.82533					
28	0.298561	0.90473	96.73006					
29	0.288916	0.875504	97.60556					
30	0.259217	0.785507	98.39107					
31	0.200778	0.608417	98.99949					
32	0.186829	0.566148	99.56564					
33	0.14334	0.434364	100					

Extraction Method: Principal Component Analysis.

APPENDIX I

Scree Plot

Scree Plot

APPENDIX J

Calculation AL & LI

Condition	AL and LI Calculation
V1H1W1	$AL_{V1H1W1} = 90 \times (6/22.125) \times (1 - 0.01 \times 0 - 30) \times (0.7 + 3/15) \times (1 - 5/12) = 8.97$ $LI_{V1H1W1} = \frac{9.0}{8.97} = 1.003$
V2H4W1	$AL_{V2H4W1} = 90 \times (6/26.75) \times (1 - 0.01 \times 15 - 30) \times (0.7 + 3/15) \times (1 - 5/12) = 9.01$ $LI_{V2H4W1} = \frac{9.0}{9.01} = 0.999$
V3H7W1	$AL_{V3H7W1} = 90 \times (6/31.5) \times (1 - 0.01 \times 30 - 30) \times (0.7 + 3/15) \times (1 - 5/12) = 9.00$ $LI_{V3H7W1} = \frac{9.0}{9.00} = 1.000$
V4H10W1	$AL_{V4H10W1} = 90 \times (6/30.75) \times (1 - 0.01 \times 45 - 30) \times (0.7 + 3/15) \times (1 - 5/15) = 8.96$ $LI_{V4H10W1} = \frac{9.0}{8.96} = 1.005$
V1H2W2	$AL_{V1H2W2} = 90 \times (6/12.5) \times (1 - 0.01 \times 0 - 30) \times (0.7 + 3/15) \times (1 - 5/12) = 15.98$ $LI_{V1H2W2} = \frac{16.0}{15.98} = 1.008$
V2H5W2	$AL_{V2H5W2} = 90 \times (6/15.125) \times (1 - 0.01 \times 15 - 30) \times (0.7 + 3/15) \times (1 - 5/12) = 15.93$ $LI_{V2H5W2} = \frac{16.0}{15.93} = 1.004$
V3H8W2	$AL_{V3H8W2} = 90 \times (6/17.75) \times (1 - 0.01 \times 30 - 30) \times (0.7 + 3/15) \times (1 - 5/12) = 15.97$ $LI_{V3H8W2} = \frac{16.0}{15.97} = 1.002$
V4H11W2	$AL_{V4H11W2} = 90 \times (6/17.25) \times (1 - 0.01 \times 45 - 30) \times (0.7 + 3/15) \times (1 - 5/15) = 15.97$ $LI_{V4H11W2} = \frac{16.0}{15.97} = 1.002$
V1H3W3	$AL_{V1H3W3} = 90 \times (6/8.25) \times (1 - 0.01 \times 0 - 30) \times (0.7 + 3/15) \times (1 - 5/12) = 24.85$ $LI_{V1H3W3} = \frac{24.0}{24.85} = 0.998$
V2H6W3	$AL_{V2H6W3} = 90 \times (6/11.25) \times (1 - 0.01 \times 15 - 30) \times (0.7 + 3/15) \times (1 - 5/12) = 23.8$ $LI_{V2H6W3} = \frac{24.0}{23.8} = 1.008$
V3H9W3	$AL_{V3H9W3} = 90 \times (6/13) \times (1 - 0.01 \times 30 - 30) \times (0.7 + 3/15) \times (1 - 5/12) = 24.23$ $LI_{V3H9W3} = \frac{24.0}{24.23} = 0.990$
V4H12W3	$AL_{V4H12W3} = 90 \times (6/12.75) \times (1 - 0.01 \times 45 - 30) \times (0.7 + 3/15) \times (1 - 5/15) = 24.0$ $LI_{V4H12W3} = \frac{24.0}{24.0} = 1.000$

APPENDIX K

IRB Consent Form

CONSENT AND INFORMATION FORM

Experiments for the Second Stage of the Research : Determination of the Range of Safe-Comfortable Lifting Postures Using the Aesthetic Ergonomics Theory

Introduction. I, _____, have been invited to participate in this research study that has been explained to me by Nicolas F. Salazar. This research is being conducted to fulfill the requirements for a doctoral dissertation in Ergonomics in the Department of Industrial and Management Systems Engineering at West Virginia University.

Purposes of the Study. The purpose of this study research is to determine which elements (related to people, environment, objects, etc) are perceived by a person as important to adopt a comfortable posture at the moment of lifting an object. Then it will be determined a range of postures which are comfortable and at the same time safe for the persons. This experiment is being conducted with healthy subjects aged 18-65.

Description of Procedures. If I participate in the first experiment of this second stage of the study I will rate the perceived discomfort at the moment of lifting an object for 15 established lifting conditions. Each lifting condition evaluated during 4 minutes at a frequency of 5 lift/min. All lifting conditions are considered as safe by the 1981 NIOSH Lifting Equation.

If I participate in the second experiment of this second stage I will rate the perceived discomfort at the moment of lifting an object at 27 set up lifting conditions. Each lifting condition evaluated during 2 minutes at a frequency of 5 lift /min. All lifting conditions are considered as safe by the 1981 NIOSH Lifting Equation

All the lifts will be photo recorded in order to determine the exact posture used in the lifting which later will be analyzed using a Biomechanical Software.

Risks and Discomforts. There are not known or expected risks from participating in this study. The physical activities performed by the subjects are similar to those performed daily by everybody such as lifting an supermarket bag, a box with some books.

Alternative. I understand that I do not have to participate in this study.

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Benefits. I understand that this study is not expected to be of direct benefit to me, but the knowledge gained may be of benefit to others.

Financial Considerations. I understand that I will receive \$ 30.00 for my complete participation in any of the two experiments of this second stage of the project.

Contact Persons. For more information about this research, I can contact Nicolas F. Salazar at 304-599 4283 or his supervisor, Dr. Majid Jaraiedi at 304-293-4607 ext. 3708. For information regarding my rights as a research subject, I may contact the Executive Secretary of the Institutional Review Board at 304-293-7073.

Confidentiality. I understand that any information about me obtained as a result of my participation in this research will be kept confidential. I understand that all data will be assigned a random code and that it will not be able to be linked to me. I understand also that my research records, just like hospital records, may be subpoenaed by court order or may be inspected by federal regulatory authorities. In any publications that result from this research, neither my name nor any information from which I might be identified will be published.

Voluntary Participation. Participation in this study is voluntary. I understand that I am free to withdraw my consent to participate in this study at any time. Refusal to participate or withdrawal will involve no penalty or loss of benefits. I have been given the opportunity to ask questions about the research, and I have received answers concerning areas I did not understand.

Upon signing this form, I will receive a copy.

I willingly consent to participate in this research.

_____ Signature of Subject	_____ Date	_____ Time
_____ Signature of Investigator	_____ Date	_____ Time

APPENDIX L

Instructions for the Subject

Subject's Instructions for the Experiment

- 1) After the subject will read and sign up the Consent Form he/she will fill some information in the Subjects' information
- 2) The reflective markers will be placed in the some of his/her joints (shoulder, elbow, wrist, hip, knee, ankle).
- 3) Some of his/her anthropometric measurements will be taken
- 4) He/She will watch the training video (10 minutes approx.)
- 5) The Heart Rate measurement device will be placed on him/ her.
- 6) - The subject will have a rehearsal lifting task. This a training period and he/she can ask any question that may have.
 - The subject will perform the lifting task of the object (from the origin shelf to the destiny shelf) by 4 min, lifting it at intervals of seconds (5 lifts/min). (In the actual experiment the subject will have a resting period time of 5 min between each condition)
 - He/she will place his/her feet such that the circle in the stick beside them become a middle point between their ankles
 - As soon as the subject hears the BEEP he/she will press the front button of the Heart Rate device and will start performing the lifting condition.

-The subject should perform the lifting applying their experience, the lifting techniques watched in the video, trying to minimize work injuries. The subject should adopt a comfortable, safe and stable posture at the moment of lifting the object.

Important: He/she should lift the box grabbing it at the bottom and can perform one step to place it on the Destiny Shelf.

-In the first 3 minutes the subject will try for the different lifts as many different postures as he/she feels necessary to find the most comfortable lifting posture (trying to remember the most comfortable one until that point for that condition)

-At the beginning of the 4th minute the experimenter will let the subject to know that only one minute is remaining (5 more lifts). The subject will use the 4th minute to lift the object with the posture that he/she has determined as the best

-At the end of the 4th min. After he/she heard the word STOP he/she will press the front bottom of the HR device. Then he/she will rate the degree of discomfort he/she felt exerting that lifting of the object at the ORIGIN SHELF, making a mark on a 10 cm line at any point of this line (no necessarily just beside of any of the phrases placed beside the line).

7) Then the subject will start performing the actual experiment for the actual 12 lifting conditions. The procedure is exactly the same one used in the training condition, with the only exception that after performing the last lift (at the end of the 4th minute and marking his/her rating on the 10 cm line) the subject will be asked to adopt again his/her final posture at the ORIGIN SHELF in order to take a picture. This picture later will let to measure the angles in the joints.

APPENDIX M

Psychophysical Scale

HR

Subject:

Lifting: V1H1W1

APPENDIX N

**Calculated Subjects' Perceived Comfort
& Heart Rate**

Subject	V1H1W1		V1H2W2		V1H3W3		V2H4W1		V2H5W2		V2H6W3		V3H7W1		V3H8W2		V3H9W3		V4H10W1		V4H11W2		V4H12W3	
	Comfort	HR	Comfort	HR	Comfort	HR	Comfort	HR	Comfort	HR	Comfort	HR	Comfort	HR	Comfort	HR	Comfort	HR	Comfort	HR	Comfort	HR	Comfort	HR
1	7.9	90	6.2	95	5	94	7.5	86	7.4	91	6.3	92	7.5	86	6.1	86	6.5	88	7.8	85	6.5	83	3.7	87
2	3.1	79	1.8	83	4.2	80	6.8	73	5.3	76	5.5	79	6.3	69	4.6	77	4.4	77	4.3	68	5.4	72	5.5	80
3	6.5	94	4.5	99	1.8	106	7.9	99	5	102	8.2	94	5.4	93	5	105	4.8	93	7.5	92	2.9	95	3.3	95
4	5	85	4.3	86	4.1	88	7.6	80	5	78	5.1	80	3.4	76	7.5	78	4.4	76	5.6	78	6.3	73	4.2	73
5	8.8	118	7.2	120	4.4	130	9	113	9.7	116	5.2	118	9.8	110	9.6	109	2.1	107	9.6	109	7.3	106	1.3	109
6	6.7	115	5	112	4.7	115	9.2	108	5.7	111	4.1	112	4.1	105	5.1	105	2.4	111	7.7	107	7.3	108	0.4	112
7	8.3	102	6.8	99	6.7	106	7.7	100	7.3	97	6.2	99	7.8	96	8.6	95	7.9	99	8.2	90	8.5	92	6.3	98
8	7.1	94	5.6	92	4.4	88	7.2	91	6.6	87	4.4	89	8.8	86	6.2	86	4.4	86	5.3	87	6.9	86	4	88
9	8.1	92	6.6	89	5.3	90	9.3	87	9.4	86	9.9	93	9.9	86	9.7	86	7.8	90	9.7	89	9.8	88	9.7	88
10	7.2	101	3.7	103	5.2	111	7.9	101	9.9	91	7.5	100	8.2	100	6.5	96	7	101	5.9	98	8.3	97	4.6	96
11	6.8	88	6.5	91	5.2	93	6.8	88	6.6	91	4.9	91	7.3	86	6.4	89	5.4	92	7.1	86	6	84	5.4	86
12	4.9	88	6.2	90	3.6	88	7.5	86	4.9	90	2.4	92	6.3	78	7.5	83	6.3	84	8.6	80	6.2	78	3.6	79
13	7	97	5.7	100	4.7	107	9.4	94	6.4	91	6.4	103	8.3	98	7	96	6.9	101	6.6	96	5.7	95	5.1	103
14	4.6	97	5.8	94	6.2	94	5.5	90	4.9	87	3.7	97	6.7	88	8.7	76	5.3	82	9.5	75	7.5	76	7.7	82
15	3.2	115	3.2	114	3.3	115	3.4	114	4.8	112	2.8	116	4.9	100	4.1	106	5.2	112	4.8	104	4.2	103	5	107
16	8.6	86	6.6	86	7.6	83	8.7	77	8.8	79	6.9	77	9.1	77	9.7	70	7.5	74	9.9	70	8.2	74	6.1	83
17	5.5	90	4.9	95	4.4	96	5.8	92	5.2	90	6.4	92	7.2	87	7.2	90	7.7	86	7.5	88	7.4	91	4.7	95
18	6.5	92	4.5	98	0.8	100	4.2	98	9	90	4.2	96	3.2	94	4.1	96	4.2	98	8.8	88	6	92	5.3	95
19	7.1	94	6.1	91	5.7	94	8.1	83	7.2	84	7	85	9.1	77	8.2	82	7.3	87	8.2	82	8.1	84	7.4	87
20	9.9	110	6.2	101	1.3	113	9.5	107	9.9	108	2.5	106	7.9	98	8	101	6.2	108	9.6	100	9.3	98	4	99

HR in beats per minute

APPENDIX O

3DSSPP Posture Input Angles

V1H1W1	Subject																			
Angle (Degrees)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Left Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Forearm	-33	-65	-60	-66	-45	-65	-50	-46	-61	-53	-89	-55	-72	-57	-45	-76	-53	-85	-63	-74
Left Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Upper Arm	-75	-84	-70	-72	-72	-70	-68	-62	-90	-73	-88	-62	-84	-90	-80	-70	-71	-85	-80	-81
Left Upper Leg	103	120	180	180	180	135	180	180	113	180	135	198	157	164	165	179	178	180	136	132
Left Lower Leg	48	58	30	40	67	68	28	47	83	48	0	74	80	23	35	38	39	34	68	85
Right Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Forearm	-33	-68	-60	-66	-49	-65	-46	-40	-65	-53	-65	-52	-72	-57	-45	-76	-53	-65	-63	-77
Right Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Upper Arm	-75	-90	-70	-74	-90	-70	-90	-51	-71	-73	-65	-89	-84	-66	-57	-70	-71	-65	-80	-90
Right Upper Leg	150	130	180	170	147	135	180	180	113	180	175	132	143	164	175	179	178	180	136	103
Right Lower Leg	72	68	30	43	0	68	28	47	83	48	65	0	51	23	57	38	39	34	68	39
Trunk Flexion	0	-9	47	38	23	8	40	36	-20	33	18	38	5	48	27	47	46	48	-7	-13

V1H2W2	Subject																			
Angle (Degrees)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Left Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Forearm	-58	-52	-90	-65	-56	-70	-69	-64	-90	-45	-90	-43	-78	-87	-80	-78	-90	-73	-90	-90
Left Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Upper Arm	-68	-80	-90	-81	-66	-80	-90	-72	-90	-90	-90	-67	-90	-90	-90	-90	-90	-78	-90	-90
Left Upper Leg	180	168	124	176	180	146	148	177	97	150	148	203	144	155	180	166	178	177	132	138
Left Lower Leg	30	30	70	37	79	69	62	52	90	25	66	54	68	54	52	56	42	35	68	66
Right Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Forearm	-58	-52	-90	-83	-58	-85	-74	-50	-75	-45	-65	-43	-78	-87	-70	-78	-62	-86	-75	-80
Right Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Upper Arm	-68	-80	-90	-74	-90	-90	-90	-71	-79	-90	-86	-67	-90	-90	-70	-90	-90	-90	-85	-80
Right Upper Leg	180	193	124	168	163	146	148	177	97	182	148	203	144	155	177	166	178	177	132	138
Right Lower Leg	30	80	70	46	10	69	62	52	90	90	66	54	68	54	87	56	42	35	68	66
Trunk Flexion	55	40	-25	45	40	12	3	30	-20	30	0	51	0	34	41	38	42	53	-9	-4

VIH3W3	Subject																			
Angle (Degrees)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Left Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Forearm	-49	-90	-90	-64	-70	-68	-72	-90	-90	-90	-90	-62	-90	-90	-90	-90	-90	-70	-90	-80
Left Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Upper Arm	-81	-90	-90	-80	-70	-90	-90	-90	-90	-90	-90	-78	-90	-90	-90	-90	-90	-70	-90	-80
Left Upper Leg	186	110	131	180	168	149	153	180	105	157	155	211	150	168	154	161	166	145	128	122
Left Lower Leg	48	50	67	48	38	75	155	66	88	67	72	60	72	61	45	64	63	10	75	74
Right Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Forearm	-49	-90	-90	-64	-90	-82	-67	-53	-74	-90	-75	-62	-90	-75	-70	28	-67	-90	-90	-90
Right Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Upper Arm	-81	-90	-90	-80	-90	-90	-90	-90	-87	-90	-84	-78	-90	-83	-70	-90	-87	-90	-90	-90
Right Upper Leg	195	135	131	180	168	149	153	180	105	157	155	211	150	168	177	-90	166	198	-80	122
Right Lower Leg	96	75	67	69	38	75	55	66	88	67	72	60	72	61	86	161	63	90	128	58
Trunk Flexion	47	-6	-20	45	25	15	4	30	-21	8	6	60	7	42	35	64	30	53	75	-9

V2H4W1	Subject																			
Angle (Degrees)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Left Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Forearm	-43	-63	0	-44	-18	-45	-22	-27	-54	-64	-48	-18	-56	-31	-18	-14	-18	-15	-63	-40
Left Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Upper Arm	-79	-80	-72	-72	-76	-62	-51	-24	-84	-90	-70	-46	-88	-64	-70	-71	-74	-60	-73	-90
Left Upper Leg	80	87	186	95	146	105	177	172	95	94	92	177	121	147	161	164	157	193	80	128
Left Lower Leg	80	80	24	86	42	85	30	49	95	44	60	66	97	53	24	34	35	66	80	74
Right Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Forearm	-43	-63	0	-56	-28	-45	-2	-21	-40	-45	-44	-6	-56	-31	-21	-14	-25	0	-53	-40
Right Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Upper Arm	-79	-80	-72	-90	-90	-62	-89	-58	-60	-90	-54	-67	-88	-64	-50	-71	-55	-90	-73	-60
Right Upper Leg	123	100	186	112	146	105	177	117	95	116	120	137	114	147	176	164	157	110	112	128
Right Lower Leg	88	90	24	80	42	85	30	0	95	79	94	0	50	53	49	34	35	-33	78	74
Trunk Flexion	27	15	50	14	38	18	59	51	0	16	18	46	27	44	61	68	49	60	20	16

V2H5W2	Subject																			
Angle (Degrees)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Left Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Forearm	-60	-78	-58	-66	-24	-35	-60	-68	-72	-59	-72	-7	-64	-30	-15	-65	-45	-60	-79	-56
Left Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Upper Arm	-78	-90	-81	-72	-90	-90	-75	-90	-90	-90	-90	-52	-82	-90	-90	-86	-90	-90	-90	-90
Left Upper Leg	124	104	135	104	145	135	135	135	101	127	124	191	128	148	170	137	139	117	95	124
Left Lower Leg	60	90	70	90	66	74	60	62	90	73	82	57	84	62	38	70	63	111	76	85
Right Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Forearm	-60	-78	-58	-48	-29	-45	-60	-57	-63	-49	-65	10	-64	-24	-24	-65	-33	-32	-65	-55
Right Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Upper Arm	-78	-90	-81	-84	-90	-90	-90	-70	-69	-85	-74	-80	-82	-85	50	-86	-85	-90	-90	-78
Right Upper Leg	124	104	135	116	145	135	135	135	101	127	124	191	128	148	176	137	139	107	109	124
Right Lower Leg	60	90	70	80	66	74	60	62	90	73	82	57	84	62	70	70	63	58	91	85
Trunk Flexion	53	10	30	19	25	25	30	35	13	24	18	53	27	51	60	47	38	10	25	11

V2H6W3	Subject																			
Angle (Degrees)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Left Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Forearm	-64	-90	-83	-76	-24	-48	-45	-76	-90	-86	-60	-5	-71	-50	-30	-30	-60	-10	-80	-90
Left Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Upper Arm	-90	-90	-83	-79	-90	-84	-90	-76	-90	-90	-90	-63	-86	-90	-90	-90	-90	-90	-90	-90
Left Upper Leg	128	120	107	111	136	128	126	138	102	125	125	185	134	150	172	144	127	150	85	135
Left Lower Leg	66	95	90	90	60	80	75	63	93	72	76	64	75	54	35	98	78	25	85	74
Right Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Forearm	-64	-70	-83	-49	-34	-48	-55	-42	-74	-78	-51	0	-71	-40	-28	-38	-44	-10	-65	-60
Right Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Upper Arm	-90	-90	-83	-86	-90	-84	-90	-90	-76	-90	-76	-89	-86	-85	-62	-90	-90	-70	-85	-90
Right Upper Leg	128	98	107	118	136	128	126	138	102	125	125	185	134	150	178	144	127	175	100	135
Right Lower Leg	66	95	90	104	60	80	75	63	93	72	76	64	75	54	78	61	78	75	100	74
Trunk Flexion	52	21	10	36	23	38	30	36	23	35	23	44	40	40	57	42	28	65	30	22

V3H7W1	Subject																			
Angle (Degrees)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Left Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Forearm	-22	-38	-33	-32	-35	-20	-22	-12	-47	-33	-23	-55	-38	-13	-13	-26	5	0	-35	-30
Left Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Upper Arm	-48	-58	-50	-68	-50	-42	-48	-85	-67	-60	-59	-42	-77	-41	-48	-46	-50	-70	-70	-55
Left Upper Leg	76	90	128	82	96	110	128	106	88	78	72	102	103	135	80	124	137	156	87	72
Left Lower Leg	76	90	60	68	90	95	49	74	77	57	72	81	92	59	80	54	56	56	82	69
Right Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Forearm	-22	-38	-33	-33	-37	-20	-21	-22	-26	-33	-29	-42	-38	-13	-16	-26	0	5	-35	-25
Right Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Upper Arm	-48	-58	-50	-88	-72	-42	-66	-37	-58	-60	-41	-74	-77	-41	-49	-46	-40	-90	-55	-47
Right Upper Leg	122	78	128	96	96	110	128	78	108	102	118	82	79	135	100	124	137	90	101	113
Right Lower Leg	78	78	60	75	90	95	48	53	105	89	88	66	63	59	100	54	56	5	86	99
Trunk Flexion	50	55	46	46	54	43	53	56	40	64	40	52	73	58	49	73	41	60	50	34

V3H8W2	Subject																			
Angle (Degrees)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Left Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Forearm	-35	-67	-53	-53	-25	-42	-19	-16	-52	-34	-30	-8	-44	-47	-19	-11	-10	0	-40	-51
Left Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Upper Arm	-50	-76	-82	-68	-89	-80	-90	-83	-78	-90	-90	-53	-72	-69	-90	-90	-90	-90	-90	-90
Left Upper Leg	83	75	96	102	120	99	133	120	90	76	116	142	96	90	112	122	126	158	90	111
Left Lower Leg	83	75	80	93	57	86	48	66	90	70	81	91	84	90	60	54	66	24	90	73
Right Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Forearm	-35	-53	-53	-48	-32	-40	-22	-12	-43	-34	-33	4	-44	-47	-20	-11	-8	0	-50	-43
Right Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Upper Arm	-50	-77	-82	-78	-90	-65	-90	-68	-65	-90	-67	-90	-72	-69	-67	-90	-76	-70	-65	-68
Right Upper Leg	112	90	96	94	120	99	133	120	90	122	116	114	96	90	121	122	126	158	90	111
Right Lower Leg	99	90	80	80	57	86	48	66	90	90	81	52	84	90	84	54	66	24	90	73
Trunk Flexion	74	60	78	72	71	62	60	63	54	64	52	54	76	90	60	85	60	80	80	65

V3H9W3	Subject																			
Angle (Degrees)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Left Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Forearm	-39	-52	-55	-50	-48	-25	-32	-21	-57	-30	-47	-5	-45	-30	-15	-44	-40	0	-54	0
Left Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Upper Arm	-58	-90	-76	-90	-73	-90	-78	-90	-82	-90	-85	-71	-76	-90	-90	-51	-90	-90	-80	-90
Left Upper Leg	87	80	118	92	90	122	122	124	90	77	112	140	108	116	113	122	90	154	83	130
Left Lower Leg	87	80	78	83	90	95	42	70	90	77	67	52	66	67	67	81	90	26	83	75
Right Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Forearm	-39	-52	-52	-38	-46	-17	-24	-21	-44	-30	-53	0	-45	-29	-9	-40	-42	0	-41	0
Right Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Upper Arm	-58	-90	-90	-76	-90	-90	-90	-76	-67	-90	-57	-90	-76	-72	-78	-90	-67	-70	-70	-78
Right Upper Leg	110	90	118	103	90	122	122	124	90	114	112	140	108	116	121	111	90	154	95	130
Right Lower Leg	90	90	78	85	90	95	42	70	90	98	67	52	66	67	79	48	90	26	95	75
Trunk Flexion	78	73	64	64	82	56	70	64	54	67	83	62	90	68	61	87	90	80	80	60

V4H10W1	Subject																			
Angle (Degrees)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Left Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Forearm	0	4	0	-4	-7	0	3	2	-10	6	8	-7	15	12	10	0	0	10	5	15
Left Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Upper Arm	-25	-48	-72	-42	-90	-19	-28	-21	-33	-31	-35	-54	-40	-65	-90	-14	-65	-90	-35	-52
Left Upper Leg	80	96	102	74	88	90	116	104	90	77	86	76	92	87	83	117	85	68	80	74
Left Lower Leg	80	96	80	72	88	90	47	88	90	71	57	66	97	75	82	53	85	58	80	74
Right Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Forearm	0	4	0	0	-7	0	14	24	-12	6	-11	-1	5	-8	7	17	-3	0	-10	0
Right Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Upper Arm	-25	-53	-72	-32	-90	-19	-51	-52	-27	-31	-27	-31	-40	-45	-90	-54	-50	-70	-23	-30
Right Upper Leg	115	80	102	95	88	90	116	78	90	105	98	108	76	101	92	117	85	130	94	111
Right Lower Leg	98	80	80	87	88	90	47	56	90	92	80	74	64	101	92	53	85	68	94	90
Trunk Flexion	67	70	65	70	82	90	77	75	71	78	77	71	90	84	68	90	70	72	75	65

V4H11W2	Subject																			
Angle (Degrees)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Left Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Forearm	0	12	0	-3	11	5	-3	6	-17	15	-7	-4	3	11	33	7	20	0	8	10
Left Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Upper Arm	-30	-74	-68	-47	-54	-25	-65	-40	-36	-53	-54	-34	-55	-57	-90	-35	-85	-90	-65	-75
Left Upper Leg	90	90	104	94	90	90	100	106	92	90	78	94	90	94	85	82	90	108	90	90
Left Lower Leg	90	90	81	83	90	90	60	68	76	90	70	94	90	78	77	82	90	53	90	90
Right Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Forearm	0	12	0	13	21	35	0	19	-15	15	-11	10	3	-8	0	7	0	0	0	0
Right Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Upper Arm	-30	-74	-68	-62	-87	-66	-90	-69	-32	-53	-14	-81	-55	-34	-30	-35	-40	-75	-47	-45
Right Upper Leg	110	86	104	103	90	90	100	106	102	90	105	89	90	100	95	112	90	129	90	90
Right Lower Leg	110	82	81	88	90	90	60	68	102	90	76	86	90	95	95	92	90	78	90	90
Trunk Flexion	90	72	82	85	90	90	90	83	86	90	90	90	90	80	72	86	90	80	90	90

V4H12W3	Subject																			
Angle (Degrees)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Left Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Forearm	21	-3	0	6	9	0	2	10	6	17	10	0	27	6	16	-30	20	0	4	20
Left Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Left Vertical Upper Arm	-52	-74	-70	-64	-52	-30	-51	-90	-90	-74	-90	-49	-75	-82	-90	-40	-85	-90	-90	-60
Left Upper Leg	81	90	90	85	90	90	114	105	90	88	88	96	90	90	85	90	90	126	80	123
Left Lower Leg	81	82	90	84	90	90	45	73	90	88	73	94	90	90	85	90	90	57	80	86
Right Horizontal Forearm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Forearm	21	-3	0	15	17	40	23	6	-4	17	-22	10	27	6	-4	-5	0	5	0	0
Right Horizontal Upper Arm	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Right Vertical Upper Arm	-52	-74	-70	-85	-90	-74	-90	-53	-58	-74	-32	-90	-75	-82	-34	-90	-40	-90	-42	-28
Right Upper Leg	114	90	90	103	90	90	114	105	90	88	99	84	90	90	94	90	90	126	100	101
Right Lower Leg	100	90	90	85	90	90	45	73	90	88	80	82	90	90	94	90	90	57	100	51
Trunk Flexion	90	90	90	90	90	90	90	90	90	85	90	90	90	90	80	90	90	74	90	90