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The Development Of A Methodology For Assessing Industrial Workstations Using Computer-Aided Ergonomics And Digital Human Models

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THE DEVELOPMENT OF A METHODOLOGY FOR ASSESSING INDUSTRIAL WORKSTATIONS USING COMPUTER-AIDED ERGONOMICS AND DIGITAL HUMAN MODELS

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This study examined an existing industrial workstation at an automobile assembly plant using computer aided ergonomics and digital human models. The purpose of this evaluation was the development of a motion capture based methodology for evaluating workstations to identify potential design issues that could result in musculoskeletal injury in a real work environment. An ergonomic risk assessment was conducted on a lifting task while being performed both manually and using an assist device. JACK digital human modeling and ergonomics software were used to conduct a computer-based ergonomic analysis. Four analysis tools in JACK (static strength analysis, rapid upper limb assessment, metabolic energy expenditure analysis and NIOSH lift analysis) were used to evaluate the potential injury risk of the current method of task performance and any difference between using and not using the assist device. Muscle activity was measured by electromyography (EMG) to identify physiological indicators of stress and strain. Also, Borg's Rating of Perceived Exertion (RPE) scale was administered to obtain psychophysical data. Results of this study revealed that there were relative stresses on the trunk and arm areas when the task was performed manually. The results also suggest although using the assist device decreased

injury risk potentially, use of the assist device had an adverse impact on the productivity of the assembly line. Based on the findings of this study, the methodology used appears to be an appropriate ergonomic analysis tool for assessing and predicting potential risks associated with the design of industrial workstations. Furthermore this methodology can be extended to designing and redesigning industrial workstations.

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CHAPTER I

GENERAL INTRODUCTION

Purpose

In order to lower the stresses imposed on the musculoskeletal system during Manual Material Handling (MMH) tasks, assist devices were introduced into assembly workplaces for short distance transfer tasks. These devices require operators to exert forces horizontally instead of vertically (Resnick, 1992). The basic function of these manipulator devices is to: eliminate the magnitude of the static (gravitational) load that the worker must handle, with an expected reduction in musculoskeletal stresses (Nussbaum, 2000). However, the potential risks and benefits of various assist devices have not been fully investigated.

Industrial reports suggested and laboratory studies confirmed that many material handling assist devices do not always decrease the workload, at least the workload as perceived by the operator. Informal interviews with workers who operate assist devices revealed that in many cases the operators find using the devices equally fatiguing as lifting or carrying the load manually. In situations where the load is not extremely heavy (i.e., 30 to 50 lbs), it is not unusual to see assist devices discarded in favor of manual methods (Waldstad, 1994; Nassbaum, Chaffin et.al, 1999, 2000).

A few previous studies have investigated physical loads associated with the use of common manipulators using traditional ergonomics job analysis methods to evaluate the relationship between task parameters and the type of manipulator. These studies were conducted in laboratory environments and concentrated on the potential adverse effects of forces, postures and repetitions, which are recognized as traditional risk factors in the workplace. Recent investigations indicate that these pragmatic methods may be overly simplistic and fail to predict risk factors associated with certain motions (Chaffin, 2002). Thus previous studies may not adequately address whether the specific assist device used at the assembly line is beneficial to the operator or determine if the current design is optimal.

Industrial reports also indicate that productivity is often significantly impacted when manual material handling assist devices are used. The additional motion time required to use the assist devices is one of the major disadvantages of using this type of ergonomic intervention (Nussbaum et al., 2000). Therefore, it is the objective of this study to develop a methodology to assess the industrial workstations using computer-aided ergonomics and digital human modeling which would indicate the differences associated with the potential risk of musculoskeletal injury and the productivity between the task performing by a material handling assist device and performing manually in a real working environment.

Project Description

An ergonomic assessment was conducted on an existing industrial workstation at an automobile assembly plant. The study aimed to develop a methodology useful for the assessment of industrial workstations during the design phase. This project was undertaken in response to concerns expressed by the industrial sponsor primarily due to non-usage of an assist device. An ergonomic risk assessment was conducted on the task while being performed both manually and using assist device. The overall objective of the project was to evaluate if: 1.) the task should be performed with or without the lift assist device; and 2.) the design of the assist device was sufficient for the required task.

Relevance or Benefit of Study to Industry

More and more companies are embracing ergonomics since they have learned that designing a safe work environment can result in greater efficiency and productivity. Yet, the new ergonomic designs are not always significant improvements over the existing design. In fact, many designs may result in new problems for both safety and productivity when job task elements are not considered and incorporated into the design phase (Spielholz, 2001). Thus the application of some ergonomic interventions can sometimes lead to higher costs with no gain, and can result in ergonomics being viewed negatively. Therefore, companies need a practical method for investigating and analyzing both existing and new designs and equipment in order to make sound purchasing decisions. Furthermore this methodology can be extended to designing and redesigning industrial workstations.

Although there are different approaches available for conducting ergonomics decision analysis in the workplace, the quality of the analysis is highly dependent on the completeness and validity of the information assessed. If the descriptions of the task and/or task elements do not accurately represent the true job characteristics (physically or temporally), the results of the analysis will not be valid (Johnson, 1999). Thus, determining the ergonomics assessment and analysis methods and considering different characteristics of the workstation are critical issues to achieve accurate and persuasive results.

CHAPTER II

LITERATURE REVIEW

Musculoskeletal Injuries and Manual Material Handling (MMH) Tasks

Work-related musculoskeletal disorders (MSDs) can be defined as any disease, injury or trauma that affects the body's soft tissues, including damages to the tendons, tendon sheaths, muscles, and nerves of the hands, wrists, elbows, shoulders, neck and back (Saldaña, 1996). MMH tasks, which include lifting, carrying, pushing, pulling, and holding external loads of various weights and sizes, are the major source of worker absence and high compensation for MSDs claims in the U.S.(National Institute for Occupational Safety and Health [NIOSH], 1981), costing 170 to 240 million work days and $4.6 billion dollars per year (Khalil, 1991). According to the survey of occupational injuries and illnesses by the bureau of labor statistics of U.S. Department of Labor, a total of 6.1 million nonfatal injuries and illnesses were reported in private industry workplaces during 1997, resulting in a rate of 7.1 cases per 100 equivalent full-time workers. The manufacturing sector has the highest incidence rate (10.3 cases per 100 equivalent full-time workers) and 4 out of 10 injuries and illnesses resulting in time away from work were sprains or strains.

Back pain is the most prevalent and costly MSD among industries today (NIOSH, 1997). It has been estimated that MMH tasks account for 50-75% of all back injuries (Snook, 1989). Within the worker's compensation system the total cost (direct and indirect costs) for low back pain could be as high as $35 billion each year (Frymoyer, 1997). Traditional studies on the relationship between occupational factors and musculoskeletal disorders recognized seven occupational risk factors most frequently associated with the development of injuries in the low back: heavy physical work, static work postures, frequent bending and twisting, lifting, pushing and pulling, repetitive work, vibrations and psychological and psychosocial (Andersson, 1999). Shoulder disorders are another common occupational disease associated with manual handling tasks. According to previous epidemiological studies, shipyard welders, orchard harvesters, packers, garment workers, workers in light assembly tasks and office workers with intensive use of a mouse have shown a high risk for shoulder disorders (Viikari, 1999). Ten work-related risk factors were recognized by these studies: heavy physical work, manual handling, elevated postures of the arm, nonneutral trunk postures, static posture, repetitive work, lack of pauses, vibration, draft and work organizational factors.

Assembly tasks in many workplaces frequently have the typical risk factors for both low back pain and shoulder disorders: static work postures, frequent bending and twisting (nonneutral trunk postures), lifting, pushing and pulling, repetitive work. Keyserling et al. (1988) found low back pain to be related to asymmetric postures in an automobile assembly plant. Further analysis of the data from the automobile assembly plant (Punnett et al., 1991) revealed the odds ratios and confidence intervals for mild trunk flexion were 4.9 and 1.4-17.4, severe trunk flexion was 5.7 and 1.6-20.4, and trunk twist or lateral bend were 5.9 and 1.6-21.4. The risk increased with exposure to multiple postures and with increasing duration of exposure.

Shoulder disorders of 152 female assembly-line packers and 133 female shop assistants were investigated by Luopajärvi in 1979. He found that prevalence of humeral tendonitis was 9.2% among the packers and 3.8% among the shop assistants. Christensen investigated the myoelectrical activity of shoulder muscles (Anterior deltoid, upper trapezius and infraspinatus) on 25 assembly workers in 1986. It was shown that there was a high static activity levels of about 7-14% of maximal activity in all body muscles and median activity levels (about 16-20%) in infraspinatus and trapezius. Previous cross-sectional studies of assembly tasks have shown that patients with trapezius myalgia use their muscles at a higher static level than healthy subjects (Philipson, 1990). Relative time with elevated shoulders and a flexed neck are risk factors for shoulder disorder. These studies suggest that assembly tasks with maintained postures and repetitive work tasks show a high prevalence of low back and shoulder disorders. Recent research (Chaffin, 1997) shows that low back pain (LBP) and upper extremity cumulative trauma disorders (UECTDs) are the two most prevalent musculoskeletal problems especially in the automotive industry.

Material Handling Devices (MHDs)

Previous laboratory studies have investigated physical loads associated with the use of common manipulators. Woldstad, Langolf and Chaffin (1988) studied the kinematic performance of subjects, including both dynamic postures and inertial effects by simulating a real factory task using an industrial hoist. The study found that peak pushing forces exerted ranged from 200N to 500N, and peak pulling forces ranged from 150 N to 300N. Peak accelerations ranged from 0.30g to 0.10g and peak decelerations ranged from 0.25g to 0.07g. Resnick, Chaffin and Erig (1991) had subjects push a laden cart to simulate the low friction and high inertia found in material handling device (MHD) jobs. Resnick and Chaffin (1996) found high peak hand forces during horizontal pushing and pulling of work piece supported on hoist at elbow height when moved in self-paced conditions.

Chaffin et.al. (1999) investigated the potential effect on low back stresses during lifting and transfer by the material handling devices (MHDs) in the form of an articulated balance arms and a pneumatic hoists compared to manual work. Low back dynamic moments, EMG measured torso muscle antagonism and EMG predicted L4/L5 disc compression forces were examined to discover the motor learning issue of MHDs. This study indicated that the effects of the MHDs had a particularly beneficial effect on reducing L4/L5 compression forces during load lowering activities. Furthermore, the study found that the level of torso muscle co-contraction increased significantly when MHDs were involved compared to manual task performance. The investigations and biomechanical modeling of material handling tasks focused on the static component and static loads were employed as the basis for manual handling limits.

Woldstad and Chaffin (1994) indicated that a manipulator may be unsuccessful because its use requires significant additional accelerative and decelerative forces, which can be compounded if increased time to perform a task is not provided. Acceleration force, velocity and movement time were measured as a function of time corresponding to different loads, distance, target width, and friction conditions in the experiment. Their results suggested that the fatigue experienced by workers using a manipulator is related to dynamic forces resulting from large system inertias and forced pace production.

Nussbaum, Chaffin, et.al (2000) studied motion times, required hand forces, and trunk kinematics, when using a manipulator compared with performing tasks manually. They reported that use of MHDs increased elemental motion times for symmetric sagittal plane and asymmetric transfers compared to similar transfers performed manually. The results suggested that for self-paced job tasks, moderate mass work pieces will be transferred slower over short distances and with lower levels of hand forces when using mechanical aids.

Task Evaluation Methods

Based on the moderate motion required for this assembly task, only static analysis techniques will be considered. There are various task evaluation methods available for assessing MMH activities based on static biomechanical evaluations. These methods can be classified into four basic categories: biomechanical methods, postural evaluations, physiological methods and psychophysical methods.

The following sections are a review of previous research that applied these methods in occupational ergonomic assessments.

Biomechanical Methods

Biomechanical methods are commonly used to estimate forces acting on the body parts during normal daily activities. The NIOSH lifting equation (NLE) is one of the approaches based on biomechanical studies used for manual lifting analysis advocated by the National Institute for Occupational Safety and Health (NIOSH, 1994). Several job characteristics in manual lifting tasks are documented when conducting this type of evaluation, including the weight of the object lifted, position of the load with respect to the body, frequency of lift, period (or duration), and grip capability. The evaluation provides a value known as the recommended weight of lift (RWL) and a lifting index (LI) to determine the relative stress of each task analyzed.

The NIOSH Work Practices Guide for Manual Lifting applies only to lifting of loads with both hands. Various one-handed lifts, pushes and pulls are evaluated by a more comprehensive physical stress analysis approach. These approaches rely on the static strength prediction model which compares the load moments produced at various body joints during the execution of a large variety of manual exertions with the static strength moments obtained from tests of over 3,000 workers in the United States. One commercial program of the use of this method is the 3D Static Strength Prediction Program™ (3DSSPP) developed at the University of Michigan. The method is based on a biomechanics-based human model. A human body is assumed as a geometric linkage with specified dimension and weight of each segment and the equilibrium of moment and force are calculated (Chaffin, D.B., Andersson G.B., Martin, B.J., 1999). The major issue of using 3DSSPP is how to provide input data on three-dimensional posture. Studies show that the biomechanical static strength prediction logic is extremely sensitive to errors in postures and the model is capable of predicting a population's mean static strengths reasonably well with good postural data (Chaffin, 1991). A study by Paul and Douwes (1993) showed that two-dimensional video images of people can be successfully used to provide the information to build the target posture.

The static strength prediction in JACK occupational task analysis toolkits is similar to 3DSSPP. It requires the input of the postural angles of the body relative to a horizontal reference axis system, the magnitude and direction of the load and the general anthropometric data. The torque on human joints is calculated by solving the equilibrium of self-weight of each segment and the loaded weight on both hands. The output will also include a prediction of the percentage of the male and female populations expected to have sufficient static strength at each major joint.

Postural Evaluation Methods

Another approach to evaluating potentially stressful postures is referred to as postural evaluation methods. One of the early postural observation systems applied in ergonomic assessment for identifying and evaluating unsuitable working postures is the Ovako Working Posture Analysis System (OWAS). The method consists of two parts. The first is an observation technique for the evaluation of working postures. The gross postures of the lower body, trunk, neck, and shoulders are coded into several categories. The second part of the method uses a set of criteria for redesigning work method and workplaces based on the time workers are observed in certain postures. Four "action" categories (acceptable, slightly harmful, distinctly harmful and extremely harmful) are used to guide corrective measures. OWAS has been used for ergonomic evaluation in various industrial jobs, such as the analysis of working postures in garages (Kant et al. 1990), in a perchery system (Scott and lambe, 1996), in nursing professions (Engels et al. 1994) and in building constructions (Mattila, Karwowski and Vilkki, 1993, Li and Lee 1999). It is relatively easy to use; however, the posture categories are too broad to provide an accurate posture description (Keyserling 1996).

Rapid Upper Limb Assessment (RULA) is another posture targeting method useful for ergonomic investigations of workplaces where work related upper limb disorders are reported. RULA is used as a screening tool that assesses biomechanical and postural loading on the whole body with particular attention to the neck, trunk and upper limbs. A coding system is used to generate an action list which indicates the level of intervention required to reduce the risks of injury due to physical loading on the operator. A scoring system is used to indicate the risk level of individual body parts. The grand score is compared to an action level list. Action level 1 (a score of 1 or 2) indicates that posture is acceptable if it is not maintained or repeated for long periods. Action level 2 (a score of 3 or 4) indicates that further investigation is needed and changes may be required. Action level 3 (a score of 5 or 6) indicates that investigation and changes are required soon. Action level 4 (a score of 7) indicates that investigation and changes are required immediately.

RULA has been used to conduct assessment on groups of visual display unit (VDU) users and sewing machine operators. It has shown good correlation with self reported musculoskeletal discomfort (Freivalds, 2004). RULA assessment requires little time to complete and the scoring generates an action list which indicates the level of intervention required to reduce the risks of injury due to physical loading on the operator. RULA is intended to be used as part of a broader ergonomic study. Moreover, it should be noted that the RULA system provides a guide, and was developed to draw boundaries around the more extreme situations (McAtamney, et.al 1993).

Physiological Methods

Biomechanical assessment methods are based on biomechanical criteria, which limit what a worker can do on an intermittent or infrequent basis while physiological criteria are more important for repetitive activities that occur for extended periods of time (Waters, et al, 1998). The goal of a physiological limit is to prevent local muscle or whole body fatigue.

Physiological measurements include surface electromyography (EMG), oxygen consumption, heart rate, and prediction of energy expenditure. A brief discussion of the electromyography (EMG) and prediction of energy expenditure (PEE) assessment techniques follows.

Electromyography

EMG can pick up the distinct electrical signal produced by a muscle as it becomes fatigued. The EMG signal is measured by place electrical transducers on the skin surface over the muscles. It has been used to measure muscle activity for job evaluation purposes (De Luca, 1997; Chaffin et al, 1999; Marras, 1990). The relative activity level interpreted by EMG signal amplitude can indicate the difference of the muscle effort resulting from repetitive activity, heavy workload or maintenance of awkward postures. It has been widely used to discover the relationship between work demands and workers capacity. Muscles on trunk, shoulders and hands area are commonly used to examine the potential low back, upper limb disorder in many workplace tasks. Three applications dominate the use of the surface EMG signal in occupational biomechanics: its use as an indicator of the initiation of muscle activation, its relationship to the force produced by a muscle, and its use as an index of fatigue processes occurring within a muscle (De Luca, 1997).

Veiersted (1990) examined the upper trapezius muscle activity patterns among workers who did packing tasks on a chocolate packing machine to discover the relationship of muscle activity pattern and the muscle pain from the neck and shoulder region. Mientjes and Norman (2003) examined effects of lumber curvature on low back pain risk factors for the reporting of low back pain during an apparently "light" but repetitive and prolonged, low peak loading industrial assembly task. Lowe et al. (2001) examined muscle fatigue and discomfort in a confined-space welding operation at a shipyard. Surface EMG was recorded from seven upper extremity and torso muscles of welders in a mock-up of the work environment.

Several EMG signal processing approaches have been applied to characterize MSDs in occupational biomechanics. Root mean square (RMS) value of EMG is recommended by the literatures (Bao, 2000; De Luca, 1997; Hansson, 2001; Oddsson, 2003) to quantify muscle activity. The activity is usually normalized to maximum voluntary contraction level due to the large inter-individual differences in the amplitude of the EMG, caused by the differences in thickness of the subcutaneous tissue.

Amplitude probability distribution function (APDF) of the muscular activity is commonly used to describe a profile of the muscular load in terms of “static”(10th), median(50th) and peak load (90th percentile of the APDF) during a period of work(Jonsson, 1982; Sjøgaard and Jensen, 1999). Jonsson conducted a study using EMG APDF value to analyze the muscular strain during constrained work. Limit muscle activity values were suggested in his research: the static load level (10th) should not exceed 2% of MVC and must not exceed 5% of MVC; the median load level should not exceed 10% of MVC and must not exceed 14% of MVC; and the peak loads should not exceed 50% of MVC and must not exceed 70% of MVC.

Low levels of muscle activation might induce muscle damage if sustained or repeated over prolonged periods of time (Mientjes, 2002; Sjøgaard, 1999). Low level static exertion has been identified as a risk factor for the development of cumulative trauma disorders or repetitive strain injuries from epidemiological studies (Sjøgaard and Jensen, 1999). Increased EMG activity and intramuscular pressures have been noted during static work tasks adopted to stabilize hand tools near shoulder height during assembly. According to the standardized Nordic questionnaire for an assembly plant, when 8% MVC, 16% MVC, and 27%MVC for static, median and peak load, the one-year prevalence of MSD symptoms showed 64% in the neck area and 56% in the shoulder area (Kuorinaka et al. 1987).

Another well-known quantification of muscle fatigue to detect MSDs is investigating the spectral modification property of the EMG signal during a sustained contraction. Kumar and Narayan (1999) looked at the relationship between median frequency and muscle fatigue in a small sample during axial rotation of spinal muscles. The slope of the decline of the median frequencies introduces the notion of fatigue. A negative slope of median frequency determined if muscles were becoming fatigued. The median frequency is preferred by researches to represent muscle fatigue index because it is less sensitive to noise, less sensitive to signal aliasing, and sensitive to the biomechanical and physiological processes that occur within the muscles during sustained contractions (De Luca, 1997; Kumar et al.2001).

Energy Expenditure

Garg (1978) developed a metabolic prediction model used to indicate fatigue during work which is based on the assumption that a job can be divided into tasks or activity elements. The energy expenditures of the tasks are calculated using prediction equations derived from empirical data:

$$E_{job} = E_{basal} + \Sigma(E_{taskj} / T_{taskj})$$

where:

E_{job} = average energy expenditure rate of the job (Kcal/min)

Ebasal = metabolic energy expenditure rate necessary to maintain basal metabolism and posture (Kcal/min)

E_{taskj} = net metabolic energy expenditure of the j_{th} task in steady state (Kcal)

T_{taskj} = time duration of the j_{th} task (min.)

As the equation shows, the energy expenditure prediction model has two basic components: energy expenditure necessary to maintain non-work related body energy requirements and energy requirements of the various work tasks. Information for each task such as: force exerted, distance moved, frequency, task posture, lifting technique for lifting tasks, the time needed to perform the tasks, gender and body weight are needed to compute these energy expenditures. The average metabolic energy expenditure rate for the job is predicted as the average (over time) of the sum of the energy requirements. The methods have been used to conduct physical work analysis in packaging tasks and welding work in shipyards (Okumoto, 2004). Prior findings suggest, measurements such as oxygen consumption and heart rate are suitable for the activity and frequently exceed the energy-producing capacity of a worker (Waters, 1998).

Psychophysical Methods

Psychophysical methods are one of the first approaches used to control MMH injuries by specifying task limits. Psychophysical methods assess the level of subjective physical strain based on the assumption that people perceive relative physical stress levels (Borg, 1982). Psychophysical ratings result from an integration of various information by the central nervous system, including many signals elicited from the peripheral working muscles and joints, and from the cardiovascular and respiratory systems. It allows for the simultaneous evaluation of the combined effects of different physical stressors.

Borg's CR–10 scale ranging from 0-10 (Borg, 1990) and Borg's Rating of Perceived Exertion (RPE) scale ranging from 6 to 20 are two practical subjective measures used to assess a participants' level of intensity for physical exertion during the performance of manual work. The RPE-scale is more suitable for assessments of overall physical exertion, while the CR-10 scale is used for different kinds of local sensations (Kjellberg, 1998).

Summary of Task Evaluation Methods

Although a variety of ergonomic measurement systems have been applied to identify potential or existing ergonomic problems in the workplace, it is not possible to specify an "optimal" analysis method for all jobs. Previous studies have been conducted to identify and evaluate differences between those assessment methods. Waters and his colleagues (1998) reviewed eight currently available assessment methods, including NIOSH lifting equation (NLE), 3DSSPP, the Oxylog portable oxygen consumption meter (VO2), the Polar portable heart rate monitor (HR), Energy Expenditure Prediction Program (EEPP), dynamic lumbar motion and the logistic regression models developed by the researchers at The Ohio State University. Their findings identified the weaknesses of these methods. For example, the NLE only applies to lifting and requires many assumptions, while SNOOK may over- or underestimate demands for infrequent or highly repetitive activities and is based on what worker will accept not what is safe. Differences between these methods related to job type and appropriate task frequency are presented in Table 1.

Another study conducted by Lavender and his coworkers (1999) compared five methods for quantifying work-related low back disorder risk by assess 178 autoworkers from 93 randomly selected production jobs. These five methods include NIH, 3DSSPP, LMM and two variations on the United Auto Workers (UAW) – General Motors (UAW-GM) Ergonomics Risk Factor Checklist (RFC). The results of this study showed that the 3DSSPP is the most conservative method in that most jobs were considered low risk. While the NIH is at the other extreme which classified the most jobs as high risk. Similar to the findings of the Walters study (1998), Lavender found that the NIH and the LMM are most sensitive to the lift frequency and conversely the 3DSSPP is insensitive to the lift frequency.

These previous research studies illustrate that the outcome of an ergonomic job evaluation for risks depends on the method used for that evaluation. This may be because of their differential focus and limitations of the methods. It is suggested that greater consideration needs to be given before selecting an ergonomic evaluation method and a complete evaluation of a task should incorporate more than one method.

Table 1 Differences between task evaluation methods (3DSSPP, LMM, VO2, SNOOK, NEL)

	Tool				
Task Activity	3DSSPP	LMM/OSU	VO2/EEPP	SNOOK	NEL
Lift/lower					
Frequent		√	√		√
Moderate		√		√	√
Infrequency	√				√
Push/pull					
Frequent			√		
Moderate				√	
Infrequency	√				
Carrying					
Frequent			√		
Moderate				√	
Infrequency	√				
Mixed					
Frequent			√		
Moderate				√	
Infrequency	√				

Computer Aided Ergonomics and Digital Human Models

Since the design of workstations and products migrated from paper to the computer, ergonomists, who used the physical prototypes to perform human factors analyses, have been challenged to move the analysis into the digital domain using new tools and methods (Raschke, Schutte, Chaffin, 2001). During the past decades, computer aided ergonomic analysis based on human modeling tools have been proposed to assess and design workplace and products. Schaub, et al. (1997) described a computer-aided tool for ergonomic workplace design called ERGOMan. Feyen, et al. (2000) developed a software program that allows a designer to quantify a worker's biomechanical risk for injury based on a proposed workplace design. The program coupled an established software tool, the Three-Dimensional Static Strength Prediction Program (3DSSPP) for biomechanical analysis, with the widely used computer-aided design software package, AutoCAD. Virtual environment for ergonomic studies were developed and used by Caputo et al.(2001). Chang, Wang (2004) proposed a method to integrate dynamic simulation and ergonomic evaluation. Motion capture systems were used in their study for conducting ergonomic evaluation including RULA (Rapid Upper Limb Assessment) and biomechanics analysis. The method was applied directly to evaluate automobile assembly tasks. Barone et al. (2004) developed a computer-aided design-based system for posture analyses of motorcycles.

Many powerful computer-aided ergonomic tools are available commercially. For example, "Boeman" developed by Boeing Aircraft company in the late 1960s and other more general models for assessing reach, accommodation and human performance analysis integrating in modern CAD, 3D visualization and automation products were developed such as SAMMIE, Deneb Ergo, TecMath Ramsis, Tecnomatix RobCAD Man and JACK. JACK is a human modeling and ergonomic analysis software package developed at the Center for Human Modeling and Simulation at the University of Pennsylvania. It features a detailed human digital model with anthropometric scaling, task animation and evaluation systems. One of the advantages of JACK is that it can drive its digital manikin with the motion data collected in real time in its three-dimensional interactive environment. Thus, it is possible to conduct a realistic ergonomic task analysis in the laboratory using the real motion data collected on-site in a field experiment.

Conclusion from Literature Review

Findings of previous research indicated:

1) Manual material handling tasks may have potential ergonomic injury risk relevant to the load, symmetry or asymmetry posture, and static postures involved repeated and prolonged low force contraction of skeletal muscles.

2) Material Handling Devices (MHD) may decrease work efficiency and impart potential stress to the back and shoulder, primarily due to the inertia of the device, weight of the load and frictional resistance when being dynamically moved. Therefore, it is necessary to evaluate the assist devices with regard to the type of manipulator and the specific task being performed.

3) Previous research on both MMH and MHD are primarily laboratory studies that involved inexperienced subjects. These methods typically do not consider the circumstance of the real workplace as well as the high frequency of the lifting events over an entire work shift.

4) Most ergonomic evaluations involving manual material handling typically falls into two categories, static biomechanical analysis and dynamic biomechanical analysis. Although most manual tasks in industry involve significant body motion, static biomechanical analysis is often used to evaluate specific exertions within a manual task (Chaffin, 1999). However, the extent to which an entirely static model is acceptable depends upon the size of the inertial forces in a dynamic lift compared with the static load and body segment weights that create forces and moments (McGill, 1999). For example, heavy loads may be analyzed statically since the lifters are incapable of appreciably accelerating the load. Considering that the physical exertion of the task in this study is not performed frequently (it is performed less than three time per minute), the task does not require unusually fast movements and the load is light (less than 10 pounds), a static biomechanical evaluation is sufficient for this study.

CHAPTER III

HYPOTHESIS AND METHODOLOGY

Hypotheses

Both objective and subjective measures were utilized in this experimental study to examine the difference between performance of the lifting task with and without the assist device. The study addressed the following hypotheses:

- Hypothesis 1: There is no significant difference associated with potential ergonomic injury risk between the task when performed with the current lift assist device and the task when performed manually.
- Hypothesis 2: There is a potential ergonomic injury risk during the fixture subtask.
- Hypothesis 3: The use of the lift assist device (LAD) increases motion time.

Workstation and the Multiple Components of the MMH task

The work task evaluated in this study involved the installation of a panoramic glass window in an automobile. The task is a common combination MMH task that requires a technician to lift an eight pound piece of glass, carry it for a short distance (2 m), lower the glass and press the glass onto the roof of a moving vehicle. This task can be performed either manually using a suction hand cup for coupling the panoramic glass or using a lift assist device to acquire and hold the glass. The assist device, composed of two suction cups installed on a frame with two handles to manipulate the device, is a pneumatic powered gantry rolling on rails (see figure 1).

Suction hand cup

Assist device

Figure 1 Workstation in assembly line

When the task performed manually, workers use a suction hand cup to acquire and hold the panoramic glass, walk and carry it to a vehicle on a slowly moving conveying, place it accurately into the rectangular sunroof space and push it to make sure the seal is tight. Thus, the task includes components of asymmetric lift, transfer, lowering and a vertical push. The assist device is located on the overhead rail. While use of the assist device requires the worker to push a button to turn on the servo-motor to drag the assist device along the overhead rail to the top of panoramic glasses, pull down the suction cups into the surface of the glass, lift the glass to the bracket of the assist device, drive the device by using the servo-motor to the target vehicle, pull down the glass and install it accurately into the rectangular sunroof space, relieve the suction cups from the glass, and push the glass to the vehicle to make sure the seal is tight. The task using assist device includes the components of acquisition the glass by the assist device, push/pull of the loaded assist device for short transfer, alignment of the glass above the vehicle, and a vertical push on the glass for fixture.

This manual material handling assist device was introduced into the assembly line as an ergonomic intervention for the installation of the roof window task. However, recent report indicated the assist devices were being discarded by the operators.

Experimental Design

Participants

This study utilized 8 employees (6 males, 2 females) who were solicited on a voluntary basis. The participants in this research study were selected on the basis of their experience at the workstation being evaluated. This selection criterion was chosen to ensure that the participants were familiar with both the glass installation task and the proper use of the assist device. The primary work tasks of the participants in this study involved the lift, transfer, placement and fixture of an eight pound piece of glass onto the roof of a moving vehicle. The participants worked two fixed shifts, day shift (7:00am – 4:00pm) and evening shift (20:00pm – 6:00am) and the effective working time (40 hours per week) varied between 350 and 400 min per day. Anthropometric data of the participants in this study is presented in Table 2.

Table 2 Demographic data of experiment participants

Statistics	Age (yr)	Height (cm)	Weight (lbs)	Shoulder height (cm)	Upper arm (cm)	Lower arm (cm)
Mean	34.4	174.9	182	144.8	36.0	47.4
S.D.	6.8	8.6	27.2	8.2	2.6	4.0
Minimum	26	160.0	148.0	130.0	32.0	43.0
Maximum	43	184.0	220.0	153.0	40.0	54.0

Dependent and Independent Variables

Four traditional ergonomic assessment tools in JACK including static strength prediction (SSP), rapid upper limb assessment (RULA), metabolic energy expenditure (MME) and NIOSH lift equation were used in this study. Both the intensity and the duration of the performed task were considered by these analysis tools.

Table 3 Dependent variables, corresponding measurements and analysis tools

Measurement	Analysis tools	Variables	Subtask	Body part
Motion capture	Static strength prediction	Joint Strength Capabilities	Lift, transfer, placement, fixture	Shoulders and trunk
	RULA	RULA grand score	Lift, transfer, placement, fixture	Whole body
	NIOSH	NIOSH lift index	Lift, lowering	Low back
	Metabolic energy expenditure	Energy expenditure rate	Lift, transfer, placement , fixture	Whole body
	Statistical analysis	Task manipulation time	Lift, transfer, placement, fixture	
EMG	Amplitude probability distribution function	Static, media and peak muscle activity	Lift, transfer, placement, fixture	Multifidus, upper trapzius and flexor carpi radialis
	frequency slope	Muscle fatigue index	Whole task	Multifidus, upper trapzius and flexor carpi radialis
Borg's RPE Scale	Statistical analysis	Ratings of perceived exertion	Lift, transfer, placement, fixture	Whole body

Table 3 lists the dependent variables, corresponding measurements and analysis tools. SSP was used to evaluate the static biomechanical strength of the joints on the human body for each subtask. RULA was primarily considered to evaluate the task when performed using the assist device and held at chin height for about 1 minute. MME assessed both the intensity and the duration of the entire task and NIOSH evaluated the risk of low back associated with the lifting and lowering components of the task. EMG data and Borg's RPE scale were assessed to provide physiological and psychophysical information on the participants. The independent variable in this study was the methods of task performance, (i.e., using the assist device or using a suction hand cup coupling tools). Nine categories of dependent variables were identified based on the analysis methods applied in the study.

Apparatus and Materials

The on-site data collection workstation is shown in Figure 2. The equipment used in this study for data collection included a motion capture system, electromyographic equipment, force gauge, and four video cameras.

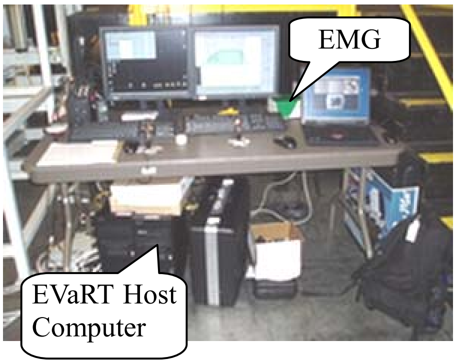


Figure 2 Data collection workstation

Figure 3 A participant wearing the motion capture suit

Motion data was collected by motion capture camera system (Eagle Digital System, MotionAnalysis Corp., Santa Rosa, CA). Thirty-four reflective markers were attached to the motion capture suit representing a typical marker set consistent with JACK Motion Capture (Mocap) Toolkit (see figure 3). A seven-camera system was calibrated to obtain 3D coordinates of these markers at 60 frames per second. Cameras were clamped on the girder above the assembly workstation (see figure 4).

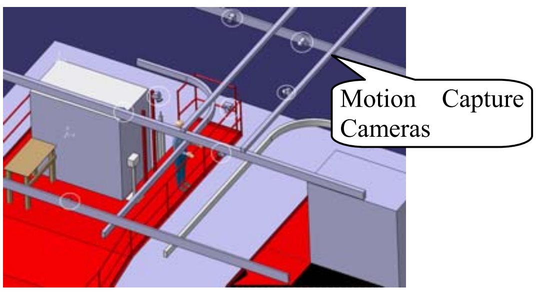


Figure 4 Setup of motion capture cameras on the workstation

Setup of the motion capture system in industrial facilities in order to capture the real motion of the task is one of the challenges for this study. Preliminary works were performed at laboratory considering possible variations in some conditions that make it difficult to acquire good motion data in the industrial environment. The considerations includes: 1) Environment variables: a. the extra noise reflected by ambient light source except the reflective markers. b. the positions that the camera can be mounted in the workplace. 2) Software variables: parameters for cameras: threshold, brightness for markers. 3) Hardware variables: a. the number of cameras b. the motion capture volume. Setups and results of those tests are illustrated in appendix D.

The EMG signals were recorded by an eight-channel wireless SEMG-recording system (Noraxon U.S.A. Inc, Arizona), which includes a receiver unit (Telemyo 2400R) and a transmitter unit (Telemyo 2400T). A sampling frequency of 3000 Hz was used in this study to transfer the analog signal to digital units for computer processing. National Instruments data acquisition system (Austin, TX) was used for conversion and synchronization of all EMG and motion data captured in this study. The system includes an A-D card that resides within the EVaRT host computer and an analog terminal box to support the connection with the EMG equipment. The connection diagram is shown in Figure 5.

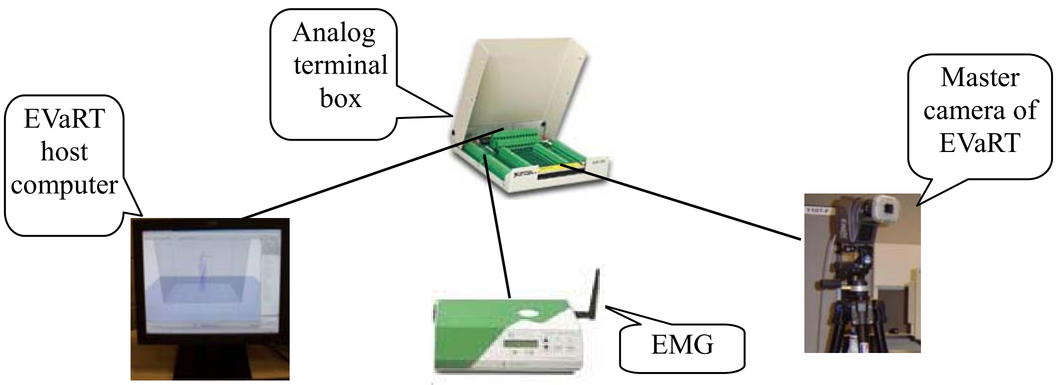


Figure 5 Synchronization connection diagram

Experimental Procedure

The experiment was conducted at a workstation in an automobile manufacturing facility. Two assembly lines were in operations and the participants were performing their daily task during the study that was conducted over a three day period. Two subjects participated on the first day, four participated on the second day and two participated the third day. A short video about the experimental procedure was shown to participants prior to beginning data collection and all participants completed an informed consent form (see appendix A) approved by the Mississippi State University Internal Review Board and the corporate sponsor. The time required for participation in this study was approximately 1 hour.

Anthropometric data (see appendix B, form A) including weight, standing height, shoulder height, upper and lower arm length was then obtained by the experimenter. The skin was sanitized and EMG electrodes were attached to the target muscle areas bilaterally, including paraspinal multifidus (support moments about L4/L5), upper trapizus (support moments about shoulder) and flexor carpi radialis (support motion of hand and wrist). After the EMG electrodes were attached and the subjects dressed in the motion capture suit (see figure 6), maximum voluntary exertions were performed twice to estimate the maximum electromyographic activity levels for each muscle group for a five-seconds duration. MVC for each muscle group were computed by averaging the peak EMG values. Figures 6 and 7 show the positions of the electrodes and the postures assumed during MVC measurement.

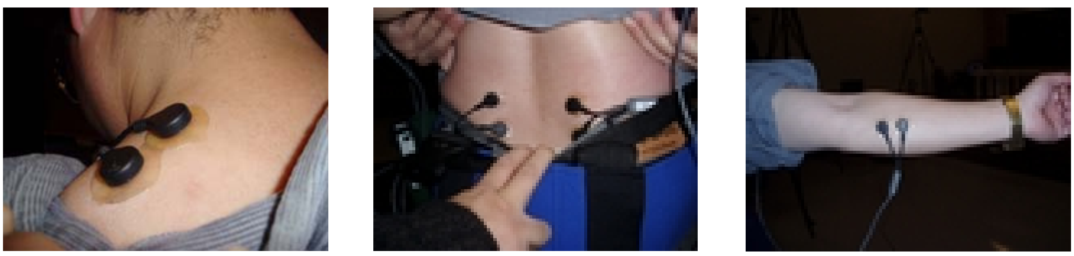


Figure 6 Electrode positions



Arm Flexion Trunk Extension Hand Grip

Figure 7 Postures used to measure MVC

Demographics and musculoskeletal data (see appendix B, form B) were collected verbally. For example, Borg's RPE was obtained after each experimental trial (see appendix B, forms C). Also, participants were asked their perceived hand force exerted during the fixture subtask in order to estimate the hand force of each participant (see appendix B, form D). Each subject was asked to perform the installation task twice manually and twice using the lift assist device. The order of the two methods of task performance was randomized. After the four trials, force match for the press exertion was conducted using a force gauge.

Data Analysis

All collected data were further analyzed after the field experiments in the laboratory. The analysis was based on the assumption that any additional dynamic contributions (e.g. body segment accelerations) were minimal.

Motion Capture Data

The captured motion data was imported into JACK and drive the JACK manikin as shown in the figure 8. Each participant's anthropometric data is used to determine the size of each manikin.

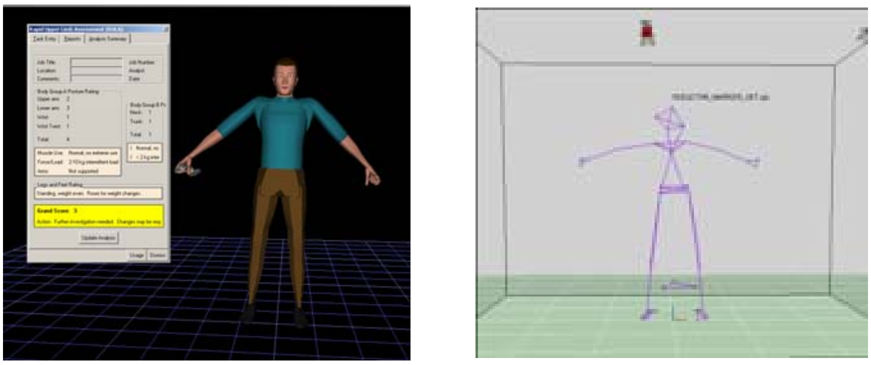


Figure 8 Jack manikin and skeleton model in motion

Both methods of task performance (with and without the assist device) were evaluated using the different analysis tools embedded in JACK to identify the potential injury risk. A review of the literature suggested all of the subtasks should be evaluated when the task has multiple components (Dempsey, 1999), therefore the four subtasks (lift, transfer, placement /lowering and fixture of the glass) of this multiple component task were all evaluated. SSP, RULA, MME evaluated each subtask and provided a result for each component respectively, while NIOSH conducted a multiple task analysis evaluating only the lifting and lowering components and providing a multiple task lifting index. MEE also provided an energy expenditure rate for the multiple subtasks. Table 4 shows the strategy of the JACK analysis tools.

Table 4 JACK analysis tools

Analysis tools	Lift	Transfer (pull/carry)	Placement (lowering)	Fixture (pressing)	Total task
Static Strength Prediction	√	√	√	√	
RULA	√	√	√	√	
NIOSH	√		√		√
Metabolic energy expenditure	√	√	√	√	√

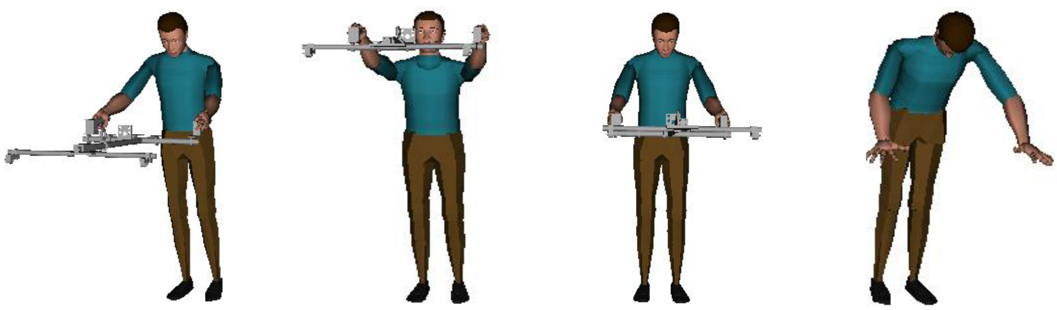
The following sections describe the procedure for each JACK task analysis tool.

Static Strength Prediction

Posture for each subtask, anthropometric data and load or hand force are required for SSP analysis. The anthropometric data obtained from the manikin represents each participant. Four postures representing the lift, transfer, placement and fixture subtasks were modeled using the motion data. The task entry and result summary screens for SSP analysis are shown in figure 9. Figure10 depicts the postures required to perform the installation task using the assist device, while Figure 11 depicts the postures required when performing the task manually with a suction hand cup.

Task posture　　Task entry　　Analysis summary

Figure 9 SSP analysis in JACK



(a) Lifting　　(b) Transferring　　(c) Placing　　(d) Pressing

Figure 10 Postures for SSP analysis when using the lift assist device

(a) Lifting (b) Transferring (c) Placing (d) Pressing

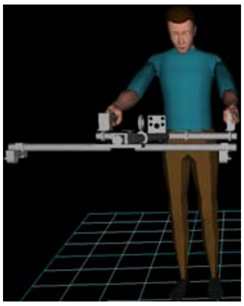
Figure 11 Postures for SSP analysis when performing the task manually

Since only one hand was used to lift, carry and place the glass, the hand force for manual task performance was estimated to be equal to the weight of the glass, (8 lbs). However, due to the continuous operation of the assembly line, it was difficult to obtain the hand force exertion data when using the lift assist device. Therefore, the hand force needed for lifting, pulling and affixing the glass were estimated to be approximately 3 lbs based on the design of the lift assist device (primarily due to the inertia of the device and load and frictional resistance when being moved (Waldstad et.al 1994)). The total force was also estimated to be evenly distributed over both hands.

The downward push force for the fixture subtask was obtained using a force match approach. After each participant finished the four experimental trials, they were asked to conduct a force match three times, and the average of the values obtained from the force gauge was used to determine the hand exertion force for the fixture subtask. Again, equal force was assumed for both hands. Similar postures and hand forces were used for all analysis tools for each participant.

Rapid Upper Limb Assessment (RULA)

The task entry for RULA assessment requires the specification of input parameters for the tasks to be analyzed. Categories include human attributes, body group loading and legs and feet status. A target human figure is selected to provide anthropometric information and to identify the posture adopted by the participant. Figure 12 indicates the human figure of a participant conducting the task with assist device, task entry and analysis summary tab for the RULA analysis. The body group loadings solicit information about muscle use, forces and loads for the arm/wrist and neck/trunk area respectively. The legs and feet category includes seated, standing with even weight distribution and legs and feet unsupported with uneven weight distribution options. The analysis summary provides the RULA grand score and the recommended action level for the task.



Task posture

Task entry

Analysis summary

Figure 12 RULA analysis tool in JACK

In this study, information about muscle use and force loading for arm and trunk area was obtained from the EMG muscle activity collected synchronously with the motion capture system. Figure 13 shows the synchronized muscle activity signal displayed with the motion capture data.

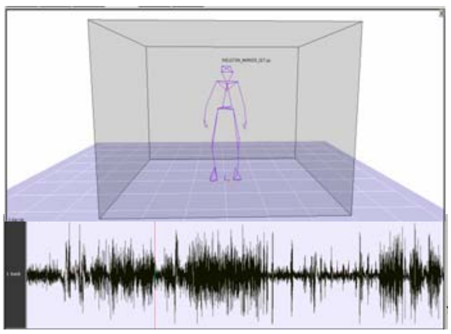
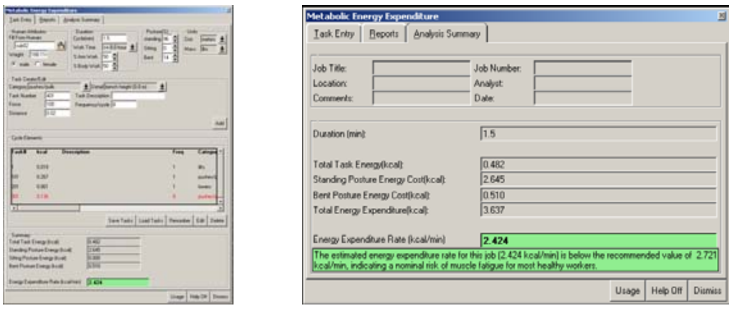


Figure 13 Synchronized EMG data from motion capture analysis

The EMG analysis helps to decide whether the exerted muscle force is static, intermittent or dynamic. Peak EMG MVC% was evaluated to determine if the muscle has been extremely exerted during the task (higher than the limit value recommended by the Veiersted, 1990). For the lifting, transferring and placing subtask, a category of less than 2 kg intermittent load was selected when using the assist device, while a 2-10 kg intermittent load was selected for tasks performed without the assist device. For the fixture subtask, "action repeated more than 4 times per minute" was chosen for arm muscle as several press actions were exerted to secure the glass. Standing, weight even posture for Legs/feet was selected for the status of the legs and feet.

Metabolic Energy Expenditure (MEE)

MEE analysis requires the entry of information about human attributes, duration of the task, percentage of the standing, sitting and bent posture, unit specification used for distance and mass, task categories with required parameters and the lists of the cycle elements. The analysis summary displays the energy expenditure results including the total task energy, standing posture energy, sitting posture energy, bent posture energy and the energy expenditure rate for the total cycle energy. Figure 14 shows the task entry and analysis summary tab for MEE analysis.



Task entry Analysis summary

Figure 14 MEE analysis tool in JACK

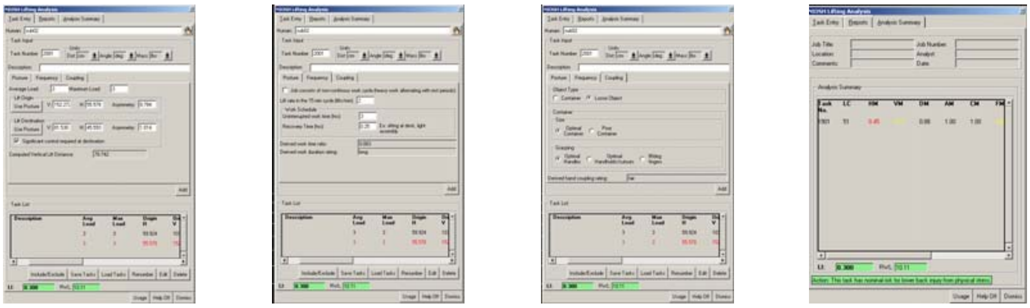
In this study, the weight and gender of each participant were entered in the human attribute options. Cycle time was calculated and entered according to the task manipulation time from the motion data for each experimental trial. Fifty percent arm and fifty percent whole body work were estimated for this assembly task. The percentage of standing, sitting and bent postures was also calculated from the manipulation time of the motion capture data. Different task categories were associated with the performance of the task using the assist device and performing the task manually. Descriptions for each task component are listed in table 5. The lowest and highest positions for lift and lowering task category were obtained from the motion capture data for each participant. The load was 3 lbs for the task when performed using the assist device and 8 lbs when performed manually. Parameters of height, distance, and time were also obtained from the task motion data. For the fixture subtask, the number of press actions was used to determine the frequency parameter for the specific task.

Table 5 Task description of MME analysis tool

Task category		Parameters for each category					
Assist device	Lifts	Lowest position	Highest position	Load	Frequency		
	Pushes	Force	Height	Distance	Frequency		
	lowers	Lowest position	Highest position	Load	Frequency		
Manual	Lifts	Lowest position	Highest position	Load	Frequency		
	Carries	Height	Time	Slope	Distance	Load	Frequency
	Lowers	Lowest position	Highest position	Load	Frequency		
Fixture	Pushes	Force	Height	Distance	Frequency		

NIOSH Lifting Equation

Task entry and analysis summary for NIOSH lifting analysis are shown in figure 15. Multiple task analysis techniques were applied in this study. Human attributes, specific task posture, frequency of lift and coupling type were required to be input in the analysis. The analysis summary lists the multiplier for the lift equation and the composite lifting index (CLI) for the overall task.



(a) Posture (b) Frequency (d) Coupling (d) Analysis summary

Figure 15 NIOSH lifting analysis in JACK

In this study, vertical distance, horizontal distance and asymmetry angular values were obtained directly from the origin posture and destination posture by the software. A load of 3 lbs for the lifting, transferring and placing subtask was used when the task was performed using the assist device task and 8 lbs for subtasks when performed without the assist device. The frequency of lift is described by the time endurance of the lift. For this assembly task, lift rate in the 15 minute cycle was assumed as 2; the task was uninterrupted for three hours (endurance for one shift) and the recovery time was around 0.25hrs (time for break). Loose object was selected as the coupling type. All parameters for frequency and coupling information were the same for both methods of task performance.

EMG Muscle Activity

Raw EMG muscle data were further processed by full-wave-rectifier, 15-300 low and high pass cut-off. Root mean square (RMS) was calculated by converting over 50 ms and normalized to MVC. The normalized data for each subtask was transformed into the amplitude probability distribution function (APDF). 5th, 50th and 90th percentiles of APDF were calculated to represent measures of low level muscle activity, median level and peak muscle activity, respectively. The slope of mean median frequency of muscle activity throughout each experiment trial was used to determine if muscle fatigue occurred during the task. Mean median frequency of muscle activities at shoulder, trunk and arm area were calculated at 1000 ms intervals using the MyoResearch software of the EMG system.

CHAPTER IV

RESULTS

The results of this study are presented in three division based on the three hypotheses evaluated in this study. The results for hypothesis 1 & 2 were divided into three subcategories: JACK task analysis results, EMG muscle activity and Ratings of perceived exertion (RPE). The results were compared with the threshold limit value or the safe handling limits to indicate whether potential injury risk existed for the current work task. Both mean and extreme (minimum/maximum) values were used for statistical description of the recordings. When comparing the method of task performance (with and without the assist device), the Wilcoxon two-sample one-tail test was used with a significance limit of $P<0.05$. The MANOVA (Multiple Analysis of Variance) test was also applied to see the effects on overall body parts.

Hypothesis 1

Hypothesis 1: There is no significant difference associated with potential ergonomic injury risk between the task when performed with the current lift assist device and the task when performed manually.

Static Strength Prediction

Results of the static strength analysis provided an indication of the percent capable for torque moments on shoulder abduction/adduction and trunk flexion/extensions for the lifting, transferring and placing subtasks, see table 6. According to the design guidelines of the static strength prediction, the strength design limit (SDL) is 99% for men and 75% for women. Findings of this study indicated that the percent capable for shoulder and trunk torque were negligible when performing the task using assist device. The mean values were greater than 98% for all three subtasks and the minimum percent capable for the trunk joint (95%) occurred during the fixture subtask. However when the task was performed manually, the mean values of percent capable were below 97%. The minimum percent capabilities were 85% for the shoulder area during the lifting and transferring subtasks and 83% for the trunk area during the fixture subtask.

The MANOVA results revealed statistically significant differences between the two methods of performance (p-value < 0.0001) for the three subtasks. Also, the capability percentage is lower when the task is performed manually than when using the lift assist device. The lowest percent capability occurred during the placing subtask when the task was being performed without the assist device.

Table 6 Percent capable for torques on shoulder abduction/adduction and trunk flexion/extension

Body part	Method	Lifting			Transferring			Placing		
		N	Min-Max	Mean	N	Min-Max	Mean	N	Min-Max	Mean
Shoulder	LAD	15	100-100	100	15	100-100	100	14	100-100	100
	W/O LAD	11	85-100	95	10	85-100	95	8	92-100	97
Trunk	LAD	15	99-100	99	15	98-100	99	14	95-100	98
	W/O LAD	11	96-100	98	10	98-100	99	8	83-99	93
MANOVA p-value		0.0001			0.0001			0.0001		

Rapid Upper Limb Assessment

Table 7 presents the RULA summary and the output of the ANOVA test for each subtask. The mean RULA grand score for the task when performed with the assist device was 3 for both the lift and placement subtasks. This score indicates an action level 2 (grand score is 3-4) which requires further investigations and changes are suggested. The mean RULA grand score for the task when performed with the assist device was 5 for the transfer subtask. This score indicates an action level 3 (grand score is 5-6) which implies further investigation and changes should be implemented soon.

The mean RULA grand score for the task when performed without the assist device was 3 for both the lift and transfer subtasks and 4 for the placement subtask. Again, these scores indicate an action level 2 (grand score is 3-4) which implies further investigations and changes are necessary.

The ANOVA result revealed statistically significant differences between the two methods of task performance in both the transfer (p-value < 0.0001) and placement subtasks (p-value < 0.0035). Thus, the mean grand score indicated that using the assist device is worse than performing the task without the lift assist device during the transfer subtask and a little bit better during the placement subtask.

Table 7 RULA grand scores for each subtask

	Lift			Transfer			Place		
	N	Mean	Min-Max	N	Mean	Min-Max	N	Mean	Min-Max
LAD	15	3	3-5	15	5	3-6	14	3	3-6
W/O LAD	11	3	3-4	10	3	3-4	8	4	3-4
P-value		0.4			<0.0001			0.0035	

Energy Expenditure Analysis

The statistical results of the energy expenditure rate for the installation task are presented in table 8.

Table 8 P-value and mean for energy expenditure rate (Kcal/min)

	N	Mean	Min-Max	P-Value
LAD	9	1.166	0.954-1.408	0.0004
W/O LAD	7	2.575	1.935-3.216	

Figure 16 indicates the energy expended for each task component, which combined the total energy consumption, including the bent posture energy and standing posture energy required to perform the task components. The allowable energy expenditure rate is calculated by JACK with respect to different work cycles (see figure 17). The limit for 8 hours of continuous work is

2.72kcal/min and for 4 hours of work is 3.11kcal/min. The red dashed line in figure 16 represents the energy expenditure limit for 8 hours of continuous work.

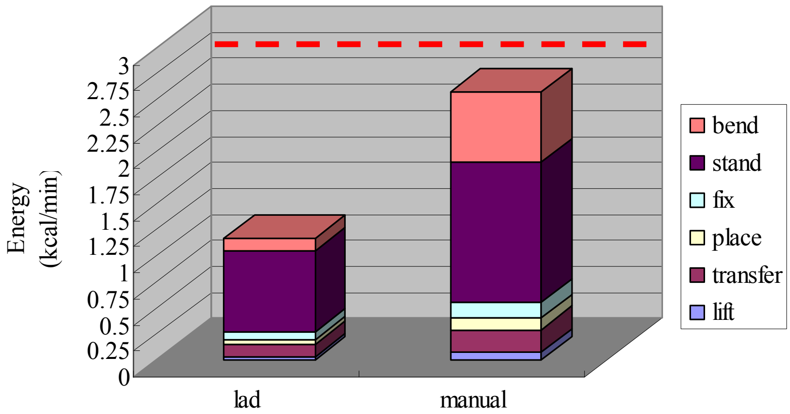


Figure 16 Mean energy expenditure rate

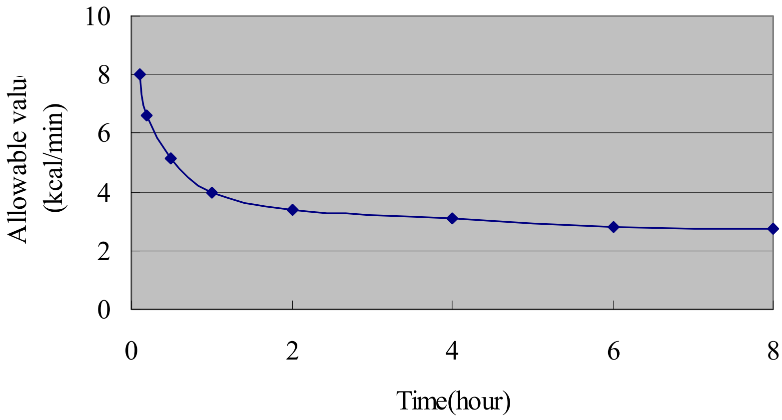


Figure 17 Allowable energy expenditure

Findings of the energy expenditure analysis indicate that the energy expenditures of both conditions are sufficiently under the allowable values. Therefore, accumulation of physical fatigue does not seem to occur for either method of task performance. However, the results do not consider boundary conditions such as temperature, humidity, and noise. Hence, the energy consumption in actual work will slightly increase. The maximum expenditure rate throughout the seven participants was 3.216 Kcal/min, over the safe handling limit, occurred when the task was conducted without the assist device. This suggests that this task may cause physical fatigue for certain populations if a greater sample size had been used. In addition, the ANOVA results revealed statistically significant differences between the two methods of task performance (p-value = 0.0004), the mean energy expenditure rate for the task using lift assist device was 55% less than the energy consumed when performing the task manually.

NIOSH Lifting Analysis

Figure 18 shows the lift index values of the eight participants. Three participants had a lift index value greater than 1.0 although the mean index value was 0.92 when the task was performed without the assist device. All lift index values were less than 0.6 and the mean value was 0.43 when the task was performed with the assist device. The results revealed statistically significant differences between the two methods of installation (p-value < 0.0001) and suggest potential injury risk exists when the task is performed manually.

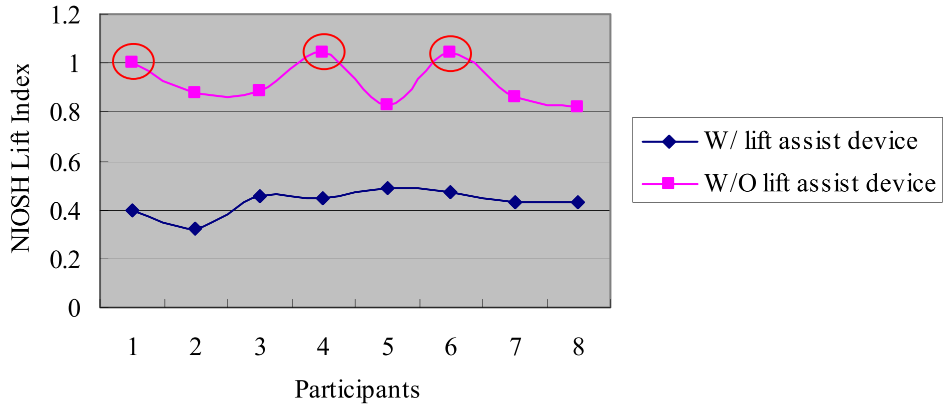


Figure 18 NIOSH lift index for eight participants

Muscle Activity Levels

Analysis of the recording data was performed in two ways:

1. Static, median and peak levels were determined using the APDF throughout each subtask.
2. Fatigue report throughout the cycle time was investigated by the spectral modification property of the EMG signal.

Maximum percent MVC between left and right side of muscle activity was used to represent the results of shoulder, trunk and arm muscle activity respectively. Grayed numbers in the following table are p-values less than 0.05.

Amplitude probability distribution function

Tables 9-11 represent mean MVC% at static, median and peak level and p-value for non-parametric test between the two methods of task performance for each subtask (lifting, transfer and placement of the glass).

Table 9 Statistical results of the EMG APDF analysis for the lift subtask (LAD: N=16, W/O LAD: N=14)

Body part	Mean Static LAD	Mean Static w/o LAD	P-value (Wilcoxon testing)	Mean Median LAD	Mean Median w/o LAD	P-value (Wilcoxon testing)	Mean Peak LAD	Mean Peak w/o LAD	P-value (Wilcoxon testing)
Shoulder	7.84	6.00	0.36	14.07	17.09	0.17	23.05	34.99	0.01
Trunk	10.66	12.69	0.10	21.44	29.44	0.11	49.96	56.09	0.11
Arm	11.59	21.09	0.30	20.50	34.02	0.38	45.93	68.18	0.27

Table 10 Statistical results of the EMG APDF analysis for the transfer subtask (LAD: N=16, W/O LAD: N=15)

Body part	Mean Static LAD	Mean Static w/o LAD	P-value (Wilcoxon testing)	Mean Median LAD	Mean Median w/o LAD	P-value (Wilcoxon testing)	Mean Peak LAD	Mean Peak w/o LAD	P-value (Wilcoxon testing)
Shoulder	7.55	9.92	0.03	14.83	17.70	0.01	25.98	28.33	0.07
Trunk	9.56	11.05	0.15	16.75	21.48	0.03	43.25	40.74	0.25
Arm	11.26	19.01	0.41	19.91	26.72	0.33	45.72	47.09	0.09

Table 11 Statistical results of the EMG APDF analysis for the placement subtask (LAD: N=16, W/O LAD: N=15)

Body part	Mean Static LAD	Mean Static w/o LAD	P-value (Wilcoxon testing)	Mean Median LAD	Mean Median w/o LAD	P-value (Wilcoxon testing)	Mean Peak LAD	Mean Peak w/o LAD	P-value (Wilcoxon testing)
Shoulder	3.55	7.93	0.02	8.28	22.59	0.002	18.07	36.84	0.009
Trunk	10.79	12.86	0.21	18.37	27.72	0.02	43.04	51.21	0.07
Arm	13.14	23.37	0.37	26.81	38.99	0.08	54.45	120.04	0.11

Figure 19-21 indicate the MVC% at static, median and peak level, respectively. The solid lines represent the muscle activity level experienced when using the assist device while the dashed lines represent the muscle activity level experience without the assist device. Yellow and red dashed lines represent the limit values for each muscular load based on previous studies (Jonsson, 1978), the yellow line means the muscular load should not pass this value and the read line means that the muscle load must not pass this value.

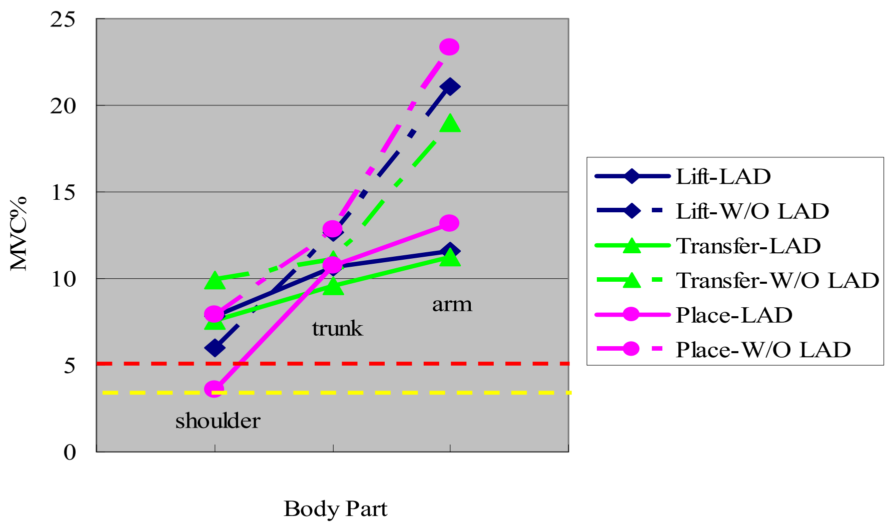


Figure 19 Static muscle load for two methods of task performance

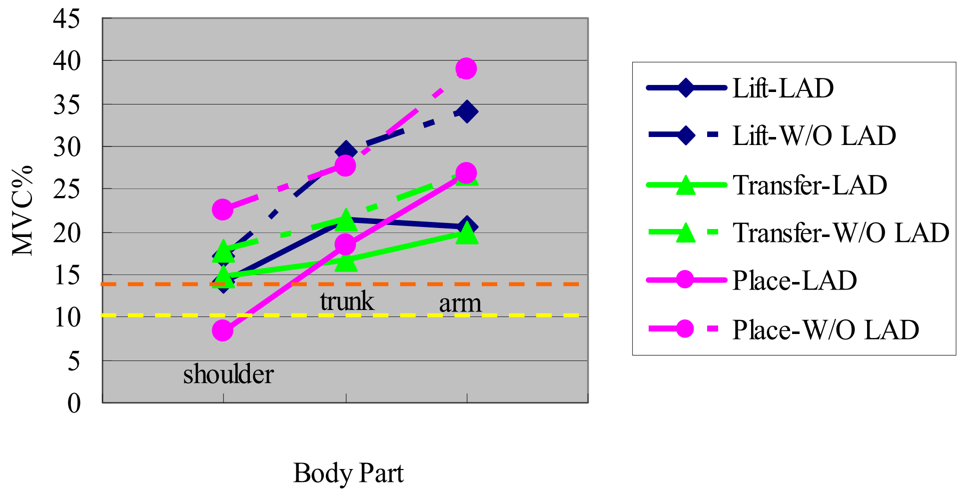


Figure 20 Median muscle load for two methods of task performance

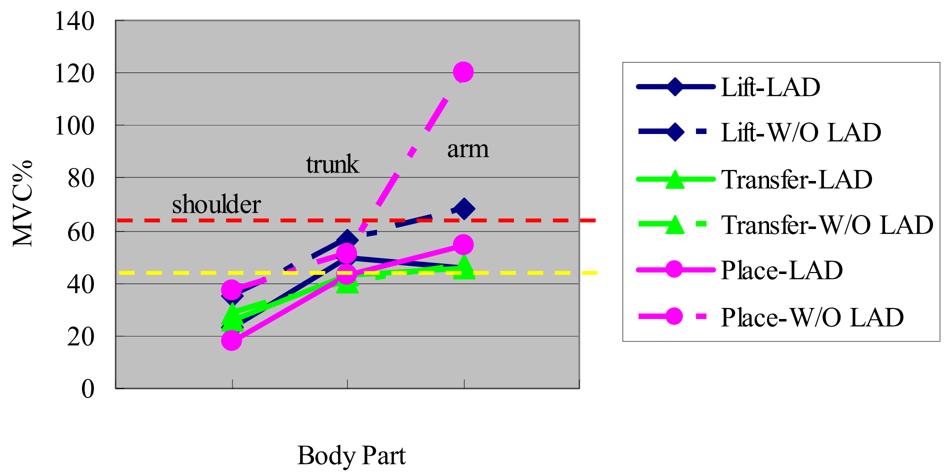


Figure 21 Peak muscle load for two methods of task performance

Compared with the limit values for muscular load, the average static load levels of the shoulder, trunk and arm muscle all exceeded 2% of MVC, and most of them were greater than 5% of MVC for both methods of task performance. Also, the average median load levels exceeded 10% and most of them exceeded 14% of MVC for both methods. However, the average peak load values did not exceed the safe limit which is about 70% MVC with the exception of the arm muscle load level during the placement subtask, which was high as 120.04. The high arm muscle load level experienced during the placement subtask resulted from the extreme dynamic press motion that the technician exerted with a suction hand cup to secure the glass at the end of the placement subtask.

The ANOVA tests indicated statistical significant differences between the two method of task performance occurred on the shoulder and trunk muscles during all three subtasks, with higher values occurring without the lift assist device. More significant differences occurred during the placement subtask. Figure 22 shows the difference between the two methods of task performances on the shoulder area when placing the glass at static, median and peak load levels. The percent of MVC decreased 55%, 63%, 51% respectively. Findings of the muscle load level analysis indicate this assembly task has an extremely high static and median load level requirement in the shoulder, trunk and arm musculatures and introducing the assist device decreased those levels to some extent.

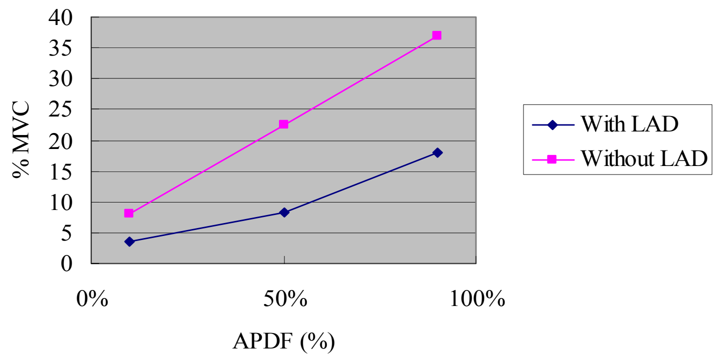


Figure 22 Differences between two task performances on shoulder area when placing the glass in static, median and peak load levels

EMG Fatigue analysis

Table 4.7 presents the mean median_frequency_slope for the task when performed with and without the assist device. The median_frequency_slope was calculated during the entire task using the fatigue report function of the EMG Myoresearch software. Table 12 shows a significant decline in median_frequency_slope when the task was performed without the lift assist device for the arm (p-value = 0.0009), trunk (p-value=0.0089) and shoulder musculatures (p-value=0.0009). Significance in the MANOVA test for the median frequency slope also indicates the difference between the two methods of task performance. Findings of this analysis approach demonstrate muscle fatigue is incurred during the assembly task, and using the lift assist device does minimize the fatigue.

Table 12 Median_frequency_slope and the p-value for the two methods of task performance

	Muscles	Method	N	Mean	P-value
Non-parametric Wilcoxon Testing	Arm	LAD	16	-0.4	0.0009
		W/O LAD	15	-1.6	
	Trunk	LAD	16	-0.68	0.0089
		W/O LAD	15	-0.81	
	Shoulder	LAD	16	-0.32	0.0009
		W/O LAD	14	-0.81	
MANOVA					0.0152

Borg’s RPE 15-Point Scale

Results of Borg’s RPE assessment of the three subtasks (lift, transfer and placement of the glass) revealed the mean values of the subtasks when performed using the assist devices were 11 points, 10 points, and 11 points respectively. The mean value was 7 points for all subtasks when performed without the assist device. Results of the t-test indicated statistically significant differences in the perceived level of exertion between the two methods of task performance (with and without the assist device) for all subtasks. The mean values and p-values of the t-test are shown in Table 13.

Table 13 Results of the Borg's RPE rating analysis (N= 15)

	Lift	Transfer	Place
Mean Value for W/lift device	11 points	10 points	11 points
Mean Value for W/O lift device	7 points	7 points	7 points
P-value	0.0005	0.0004	0.0012

Conclusion from Hypothesis 1

1. Task without LAD is unacceptable.
2. For most analysis tools, task with LAD is acceptable, and using LAD can decrease the injury risk obviously.
3. Results of some analysis tools indicate current LAD design is not sufficient.

Hypothesis 2

Hypothesis 2: There is a potential ergonomic injury risk for the fixture subtask.

JACK Analysis Results

Table 14 Results of the MME Percent Capable and RULA Grand Score (N= 18) for the fixture subtask

Body part	MME (Percent Capable) %			RULA (Grand Score)		
	Min	Max	Mean	Min	Max	Mean
Shoulder	67	100	97	3	7	6
Trunk	53	99	94			

Results of the MME and RULA analyses for the fixture subtask are presented in Table 4.9. The percent capable for torque moments on shoulder abduction/adduction and trunk flexion/extensions during the fixture subtask was 97% and 94%. The minimum value for trunk was 53%. The mean grand score of the RULA analysis was 6, which implies immediate investigation and changes are necessary for this subtask. Both analyses results indicate potential injury risk exists for the particular component.

EMG APDF Results

Table 15 shows the static, median and peak load level during the fixture subtask. High values of trunk and arm musculatures at static, median and peak load level indicate potential risk exists. Specifically, the high peak value of arm muscle activity, 196% MVC, indicates potential CTD risk exists for technicians working at this workstation.

Table 15 Statistical results of the EMG APDF analysis for the fixture subtask (N=29)

Body part	Mean Static	Mean Median	Mean Peak
Shoulder	3.83	8.88	23.37
Trunk	10.29	24.01	67.05
Arm	17.76	61.02	196.93

Borg's RPE Rating

The mean Borg's RPE rating point for the fixture subtask was 7.2. This rating indicates the participants perceived level of exertion was minimal for this component of the installation task.

Hypothesis 3 (Motion time)

Table 16 shows the average task manipulation times for three subtasks.

Table 16 Mean motion times recorded for each subtask (N = 15)

	Lifting the glass	Transferring the glass	Placing the glass
P-value	< 0.0001	< 0.0001	< 0.0001
W Assist device	20.6 seconds	19.4 seconds	21.9 seconds
W/O Assist device	4.6 seconds	6.28 seconds	6.3 seconds
Percent increase	77.7%	67.6%	71.2%

The results indicate that performing the task with the assist device increases task manipulation time by an average of 44.7 seconds. The mean manipulation times for Lifting, transferring, and placing subtask were increased 77.7%, 67.6% and 71.2%, respectively. In addition, significant differences ($P < 0.05$) in motion time occurred within all three subtasks.

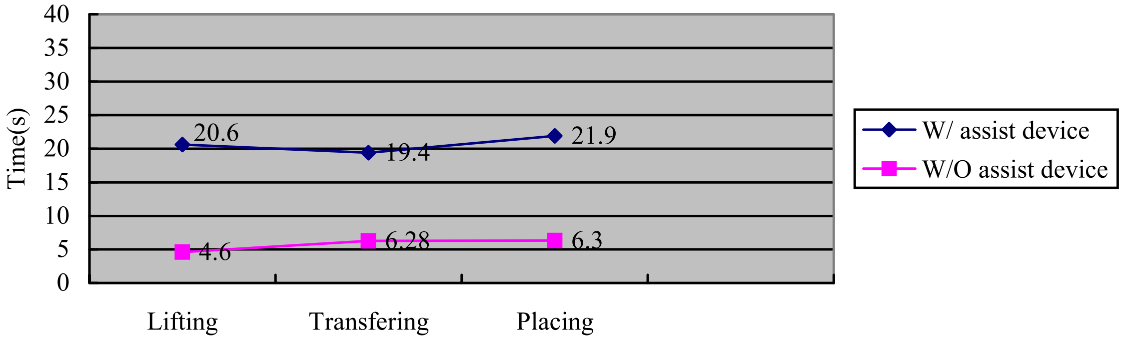


Figure 23 Motion times of the three different subtasks

CHAPTER V

DISCUSSION

The general goal of ergonomics and human factors engineering is to achieve an optimal fit between work requirements and operator capabilities. Companies that embrace ergonomics expect a safe work environment as well as an increase in efficiency and productivity. Unfortunately, new ergonomically designed tools are not always necessarily improvements based on direct physical measurement, user's perceptions as well as productivity. In this study, the ergonomic intervention was considered a failure after being introduced into the workplace. But, the major question is, can the lift assist device be considered an ergonomic intervention which provides benefits in both safety and productivity?

All three hypotheses were supported by the experimental results. It was indicated that performance of the lifting task using the assist device reduced the potential musculoskeletal injury risk, yet adversely impacted the productivity of the assembly line. However, the increased motion time appeared to be associated with the higher demands for control and stability required when using the lift assist device (as indicated in the Borg's RPE assessment). Potential occupational risks, low back and CTD risks exist during the fixture task. It is also noted that although the task manipulation time may be reduced by providing additional training and mandating use of the assist device, redesign is suggested to improve the usability of the assist device. The following discussion includes the interpretation of the statistically significant depend variables and the possible limitations of the study affecting the results.

Lift Assist Device vs. Manual Task

Four task analysis tools in JACK ergonomic software package, Static Strength Prediction, Rapid Upper Limb Assessment, Metabolic Energy Expenditure and NIOSH Lift Equation were used to investigate the differences associated with potential ergonomic injury risk between conducting the assembly task with the lift assist device and without the lift assist device.

Table 17 Outcome risk levels for the four analysis tools used in JACK

Analysis tool	Dependent Variable	Acceptable	Unacceptable
Static Strength Analysis	Percent Capable	≥ 99%	< 99%
Rapid Upper Limb Analysis	Grand Score	≤ 4	> 4
Metabolic Energy Expenditure	Energy Expenditure Rate	≤2.72 (8 hrs)	> 2.72
NIOSH	Lift Index	≤ 1	> 1

Table 18 Acceptability of the different task methods (Y/N)

Analysis tool	Lifting		Transferring		Placing	
	LAD	W/O LAD	LAD	W/O LAD	LAD	W/O LAD
Static Strength Analysis	Y	N	Y	N	Y	N
Rapid Upper Limb Assessment	N	Y	N	Y	N	Y
		LAD			W/O LAD	
Metabolic Energy Expenditure		Y			N	
NIOSH		Y			N	

To assist in comparing how the different methods of task performance affected the potential job risk, the outcome of each task analysis tool was categorized as acceptable and unacceptable based on the criteria listed in table 17. The acceptability of the two task approaches based on the criteria is shown in table 18. Peak risk index values across all the participants and the investigated body were used to determine the acceptability. Table 18 indicates that performing the task without using the lift assist device is not acceptable based on the criteria outlined by SSA, MEE and NIOSH and is acceptable when performing the task with lift assist device. No significant upper limb disorder was found for subtasks performed without assist device, while it was noted that using assist device has potential risk. It indicated that the assist device does bring new risk factors regarding the upper limb activity since the holding posture at the chin level lasted for more than 1 minute. Furthermore, statistical analysis indicates significant differences exist between using and not using the lift assist device. Also, based on the results of the static strength analysis, metabolic energy expenditure, and NIOSH analysis, using assist device reduced the potential musculoskeletal injury risk. These results show that the introduction of the assist device is beneficial in reducing the risk of occupational injury associated with the performance of this work task.

The 5^{th} percentile of the APDF reflects low level muscle activity during the full work cycle, including work and recovery. The musculature was unable to reduce its activity due to noise level (2% of MVC) during a full work cycle. This indicates that a low level static exertion problem exists for the current workstation design. The median levels of muscle activation found in this study, which exceeded 20% MVC, resulted in the onset of muscle fatigue. This was also supported by the negative median-frequency-slope indicated in the muscle fatigue analysis. The EMG results support the positive effect of the assist device as well.

The negative effect in ergonomic aspect is illustrated by the Borg's RPE result as well as the higher grand score indicated in RULA when using lift assist device, especially during transferring the glass as shown before. This appeared to be associated with the higher demands for control and stability required when using the lift assist device which resulted in the performance of awkward postures.

The difficulty required to control and stabilizes the device also increased the motion times significantly when using the lift assist device in comparison to manual task performance. Overall, increases in motion times were on the order of 77.7%, 67.6% and 71.2% for the lifting, transferring and placing subtasks, respectively. Previous study of the manual material assist devices suggest the overall increase in motion time when using a hoist is 75% which is close to the present study. From these results, it is expected that time delay in using the assist device will primarily occur during the acquisition and placement events (for tasks without precision placements) which is true for this study. The additional time for object placement was a result of the need to position the object over a moving object. Moreover, the low lever static exertion problem became even worse because of the increased sustained time when acquiring, moving and placing of the glass when performing the task using assist device.

Another issue that should be considered in the redesign is the fixture event of this assembly task. Investigation of the fixture task indicates high risk of musculoskeletal injury occurred in the low back and upper extremities. Unfortunately, the current design of the lift assist device is inadequate. Figure 24 illustrates some issues that should be considered in the redesign phase of the current lift assist device.

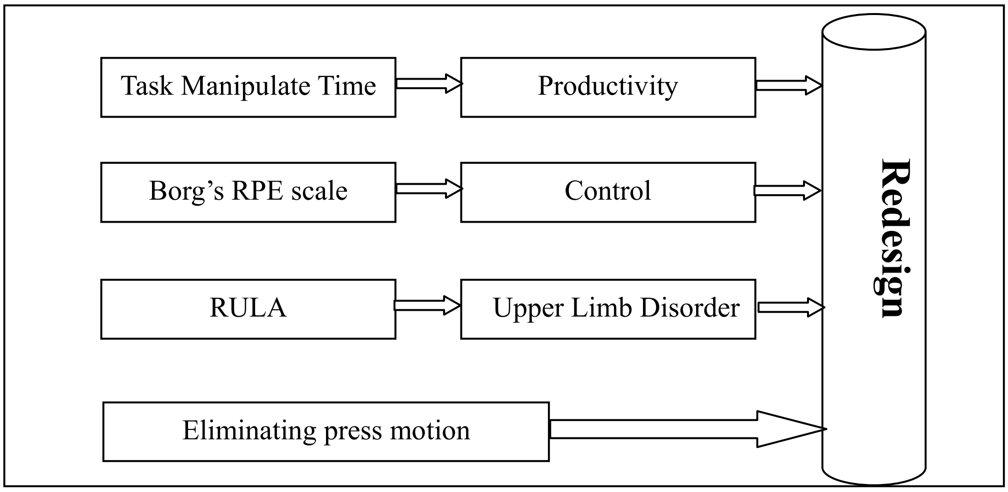


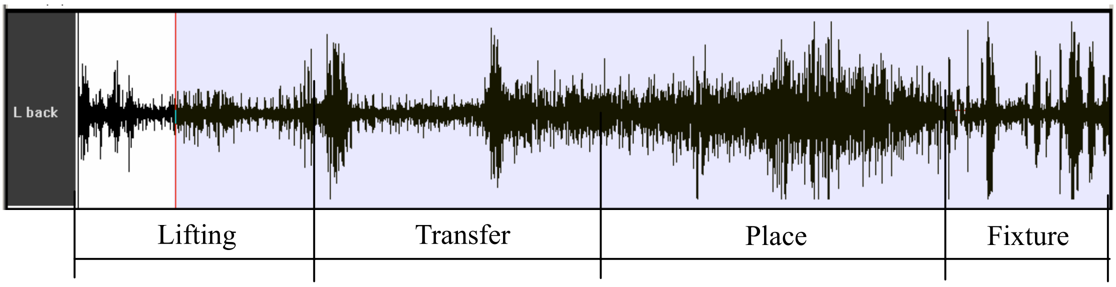
Figure 24 Issues for redesign of the current lift assist device

Methodology

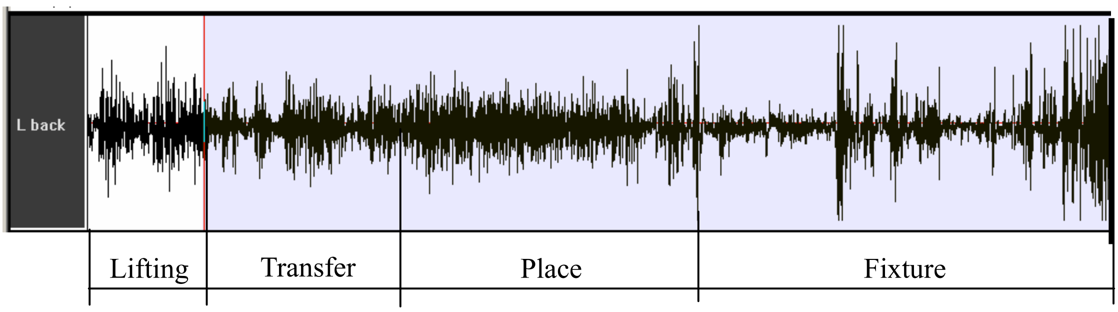
As the literature illustrated, the results of this study also indicate that the outcome of an ergonomic task evaluation depends on the method used for that evaluation. Each method, depending on the respective set of risk factor measurements, results in different underlying causes of occupational risks. As a posture assessment tool, RULA targets the upper limb musculoskeletal injury risk. Although the assist device alleviates the musculoskeletal stress on the trunk by eliminating the magnitude of the static load that the worker must handle, it causes discomfort and fatigue on the upper limbs. The chin level height of the upper limbs and the inertia mass of the system appear to be risk factors when pushing the lift assist device during the transfer subtask. However, the static strength analysis fails to consider the frequency factors while at the other extreme is the metabolic energy expenditure, which is the most sensitive to task frequency. While the NIOSH analysis targets only the lifting and lowering task, it should be recognized that the study has gone beyond one of the stated limitations in the NIOSH model by including one-handed lifting tasks in the analysis of the task performance without the lift assist device.

The study investigated a multiple components assembly task which focuses on several transitional events involved in acquisition, short distance transferring, placement and fixture of an object. These transitions associate with components tasks as lifting, pushing, carrying and lowering during which peak biomechanical stresses are imposed. Each components task has different risk factors, thus none of the above ergonomic assessment techniques can be used solely to conduct a sufficient investigation based on the limited risk factors described above. The present study illustrates a method that can be used to conduct ergonomic assessment which can apply these commonly used methods to quantifying risks in occupational settings efficiently and sufficiently. The overlap and differences shown in the results justified the success of applying the methodology to identify the potential injury risk and differences in real industrial environments.

The electromyography assessment used in this study acted as two fold: 1.) It provided muscle load information to JACK analysis tools and 2.) It supported the application of the method developed by this study with respect to physiology. Examples of simultaneous recording of muscle activity in the left back muscles for both task performances indicate the agreement between the EMG muscle activity results and the JACK analysis results (See figure 25).



(a) Task performed with assist device



(b) Task performed without assist device

Figure 25 EMG recording from left back muscle during two typical experiment trials

In lift and transfer subtasks, an intermittent load pattern is seen for both task performances. Peaks due to lifting and holding of the glass are separated by periods with little muscle activations for the task performed manually. When transfer of the glass with the assist device, peak muscle activities were produced during turning and bending motions. The level of activity during the task conducted with the assist device is lower than the level of activity when the task conducted without the assist device. Nearly continuous use of back muscle activity pattern is seen during place of the glass. Few time intervals with a contraction level near zero are seen. Dynamic muscle pattern is seen obviously during fixture subtasks with high frequency of the peak level separated by periods of little muscle activation. Thus, the consistent results from different assessments illustrate the applicability of this method in occupational ergonomic analysis.

Limitation

There are certain factors that affected the results of this study. For example, the installation task was assumed static, thus the significance of the dynamic component of the material handling task has not been investigated. The analysis tools used for this study were based on the static biomechanical model. It neglected the increasing inertial forces on the body due to acceleration of the motion. Punnet et al. (1991) showed that the majority of low back disorders in automobile assembly plants are not simply due to the weight of the object lifted or the instantaneous posture in many high-risk jobs that are dynamic. Freivalds et al. (1984) has shown that the rise in the vertical ground reaction forces corresponds to the effect of accelerating the load at values as much as 40% greater than the static load. Although, the roof window installation task investigated in this study is relatively slow and it is relatively accurate to perform a static analysis since the task motion is almost controlled. The 'jerky' EMG muscle activity signal of the trunk and arm area recognized during the installation task and the margin level of the torque moments also indicate that static analysis is not sufficient. Thus, dynamic biomechanical risk factors could influence the results of the study.

To some extent, the sophisticated condition of the industrial environment affected the data collection of the motion capture camera system and EMG equipment. The assembly line workstation limited the setup of the motion capture cameras at ideal locations unlike the laboratory environment. The extra noises reflected by the ambient light source affected the accurate positions of the reflective markers. Also there are some obstructions in the motion capture volume which can not be controlled at the workstation. To prevent interruption of the workflow, the experimenter had no time to replace the EMG electrodes during testing when perspiration affected the EMG data. As a result, some data were lost. A great degree of cleaning was required before the data could be further processed and some postures were estimated on the basis of the joint angles driven from the motion data. In addition, the sample size decreased which possibly affected the statistical results. Also, the fact that the experiment was conducted on an actual assembly line made it difficult to obtain hand force data directly. Therefore, estimation and force match approach used to obtain this data and may have affected the analysis results.

Recommendations and Future Work

The computerized method presented in this study is an efficient approach to conduct ergonomic evaluations of workstations industrial environments. As a recommendation for future study, dynamic biomechanical analysis should be conducted with the motion data collected at the workstation. Dynamic biomechanical assessment tools have been studied and developed for several years, however, there are few ergonomic tools currently available to evaluate the dynamic aspects of tasks and are known to have been applied in real industry environments. Two major issues need to be considered for developing a dynamic analysis assessment tool: 1. an approach that can acquire the sufficient motion data that can present human body kinematics in three-dimensional space along with the characteristics of the workplace parameters; 2. A dynamic biomechanical model using actual motion data to determine the relative stresses of the various types of industrial tasks. The method presented in this study provided a practical way to obtain motion data and integrate them with a digital human model technique. Thus, if a dynamic biomechanical model can be embedded into the digital human in the future, a dynamic ergonomic assessment tool can be developed using this strategy.

It should be noted that this method can be used not only for work station assessment in terms of human machine interaction but to build virtual workplaces and conduct ergonomic evaluations at the design phase. With advances in the computer aided ergonomics and the digital human modeling techniques, it is now possible to predict the risks of the potential injuries for industrial workstations during design phase. It can lessen or eliminate the need for physical prototypes, thus decreasing the time for workstation development and validation of the design and reduced the cost of design alterations in the early design phases. The introduction of digital human modeling technique into product and workstation design can significantly decrease the design time and enhance the number and quality of design options that could be rapidly evaluated by the design team (Chaffin, 2002). Findings of this study concluded some design factors associated with both the productivity and the safety of the assist device should be considered in redesigning of the current assist device. These variables include the device's settling time, the height and weight of the vertical-moveable suction cups part, distance and orientation of the panoramic glass bracket and the anthropometry of technicians. Furthermore, the development of an interactive virtual workstation design targeting the optimization of both ergonomics and productivity would be proposed to determine the values of the design variables to maximize the overall performance the assist device. The methodology using optimization and virtual build methods would be extended to designing other human-machine systems in the future.

CHAPTER VI

CONCLUSION

The results of this study indicated that the assembly task performed with assist device can reduce the potential injury risk and muscle fatigue comparing with the task performed without the assist device. However, the using of this assist device at current workstation will bring new risks on upper limb, increase task manipulator time. Thus far, the design of the assist device ignored the risk of fixture task.

The methodology developed and applied in this study which integrated the motion capture system and JACK digital human modeling technology conducted an ergonomic assessment using the real task motion data. The limitations for each individual analysis tools were avoided by using multiple ergonomic analysis tools in this study. However, the complexities of the industrial workstation need some negative influences on the experiment data collection.

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APPENDIX A

INFORMED CONSENT FORM FOR PARTICIPANTS

INFORMED CONSENT for Participants in Ergonomic Evaluation of the Panoramic Glass Installation

Principle Investigator: Dr. Vince Duffy, Associate Professor, IE& CAVS at Mississippi State University

THE PURPOSE OF THIS STUDY: You are invited to participate in a study to assist in an ergonomics decision analysis for a lift assist device in short distance transfers during assembly task. The experiment is designed to determine the influence of the assist device on ergonomics, quality, and productivity. All identity information will be kept confidential.

PROCEDURE: In experiment phase one, you will conduct your daily assembly line installation task without any interaction from researchers. A set of small video cameras will be used to view the installation with and without the lift assist device. In phase two, you will be asked to wear motion analysis suit, and researchers will put some reflective markers on the suit. The suit with markers is used to track your motion of performing the installation task. You will also have electrodes place on several muscles on your shoulder, arm and back. These electrodes are used to collect information from the muscles, which can indicate the muscle strain. The procedure of each electrode involved cleansing a small patch of skin of the muscle area, and then the electrodes are placed on the skin and remain in place with an adhesive. You will also wear a small wireless transmitter for SEMG and we will measure your MVC value. Then you can perform your panoramic glass installation normally while in production at least twice using the lift assist device, as well as twice without using the lift assist device. The estimated time of participation of setup and data collection is about 1 hour. We would also ask participants a few simple things re: demographics such as 'age, how long you have worked here', then current health status re: any musculoskeletal problems, as well as take some anthropometric measures before putting on the suit. For example we'd want to measure arm length, height (we'd ask weight). After the task we would likely ask you to tell your perceived exertion for the task.

RISK AND BENEFIT OF THIS RESEARCH: Your participation in this study will provide information that will be used to develop guideline for your daily installation work. It is the objective of this study to contribute design information for improving worker safety, comfort, satisfaction, productivity and quality. It is expected that a benefit of the research is that an analysis of ergonomic risk for this and other lift assist devices can provide a better working environment in the future. There is no known risk for this experiment. However, if you feel as if you become uncomfortable or begin overheating, please notify your supervisor immediately.

EXTENT OF ANONYMITY AND CONFIDENTIALITY: It is the intent of the researchers to report the methodologies and findings regarding justification of modified lift assist designs to the scientific community after NISSAN review and authorization. However, the individual identities and company identity will be protected and will not in any way be shown to be connected with any written summary of or presentation of results.

COMPENSATION: The NISSAN Company will be responsible for the compensation for this project. It is our understanding that the overseeing the experimental setup may require some paid overtime independent of the participation.

FREEDOM TO WITHDRAW: You are free to withdraw from this study at any time for any reason without penalty.

APPROVAL OF THIS RESEARCH: The research project has been approved by the Institutional Review Board at Mississippi State University for projects involving human participants and also by NISSAN-USA safety management and production management representatives in Canton, MS.

PARTICPANT RESPONSIBILITIES: To notify the researchers at any time about a desire to discontinue participation and to notify the researchers of any medical conditions which may interfere with results or increase the risk of injury or illness.

PARTICIPANT'S PERMISSION: If you have any questions, please ask the researchers at this time.

I have read a description of this study and understand the nature of the research hereby consent to participate with the understanding that I may discontinue participation without penalty at any time if I choose to do so.

Signature, Printed name & Date:___________________________

For further information please contact: Zach Rowland, CAVS Mississippi State University, Mississippi State, MS, 39762, (662) 325-1607. Dr. Vincent G. Duffy, CAVS & Department of Industrial Engineering, Mississippi State University, Mississippi State, MS 39762, (662) 325-1677, duffy@ie.msstate.edu. They will answer any questions you have regarding the purpose or outcome of the study. However, answers which may influence the study's outcome will be deferred until the end of the experiment.

In addition, if you have detailed questions regarding your rights as a participant in this research, you may contact: the Mississippi State Regulatory Compliance Office at (662) 325-0994.

APPENDIX B

DEMOGRAPHIC AND ANTHROPOMETRIC FORMS

B1 Subject Data

Participant Number ________________ Date __________________

Starting Time ______________________ Age ___________________

Gender: Male Female

Participant name ____

First *Middle* *Last*

Address ____

City *State*

B2 Anthropometric and Workstation Data

Anthropometrics

Weight ____________________kg ____________________lbs

Stature ____________________cm

Shoulder (Acromion) Height ________________________cm

Upper Arm (Shoulder – Elbow) Length _______________________cm

Lower Arm (Elbow – Fingertip) length ________________________cm

Workstation Data

	Original location	Destination location
Horizontal Distance	_______________________cm	___________________cm
Height	________________________cm	___________________cm

Lifting Load

Weight ________lbs Width _____________cm Length __________cm

B3 Demographics and Musculoskeletal Data

Demographics

Present Occupation (Part/Full time) ________________________________

How many hours per week? ________________________________

Previous Occupation (Part/Full time) ________________________________

How long have you done Manual Work Occupation? ________________________

Have you had a significant injury during the past? (Yes/No)________________

If yes, which body parts were affected by the injury? _____________________

How would you describe your general fitness level? _____________________

a) Poor b) Moderate c) Average d) Above average e) Excellent

Musculoskeletal Trouble

Have you had pain, ache, discomfort, injuries in	In the past 12 months			In the last 7 days		
	When did it occur	Rate (1-10) *1: lowest 10: highest*	Duration it lasted	When did it occur	Rate (1-10) *1: lowest 10: highest*	Duration it lasted
Neck						
Shoulders						
Elbows/Wrist/Hands						
Upper /Lower Back						
Knees/Legs						
Hips/Thighs						
Knees/Ankles/Feet						

B4 Borg's RPE Scale

Borg's RPE scale (Rating of Perceived Exertion) is a simple rating of perceived exertion used to assess the level of intensity for overall physical exertion during sports training or manual work. This is the original scale developed by Borg which is more suitable for assessments of overall physical exertion. The Borg Scale is a 15-point scale (6 – 20):

Point 6: would be the equivalent of sitting down doing nothing

Point 9: would be walking gently

Point13: would be a steady exercising pace

Point 19/20: would be the hardest exercise you have ever done.

6 -------- No exertion at all
7 -------- Extremely light
8
9 -------- Very light
10
11 ------- Light
12
13 ------- Somewhat hard
14
15 ------- Hard (heavy)
16
17 ------- Very hard
18
19 ------- Extremely hard
20 ------- Maximal exertion

Borg RPE Scale -- © Gunnar Borg, 1998, *Borg's Perceived Exertion and Pain Scales, Human Kinetics, Champaign, IL.*

Please write down the appropriate level of your evaluation of this task

Trial No.	Borg Scale				
Sub-task	Get the glass	Transfer the glass	Placement of the glass	Place the device back	Press the glass
1 (using suction cup)					
2 (using lift device)					
3 (using suction cup)					
4 (using lift device)					

B5 Estimation Exertion Using Force Gauge

After the task is complete, before taking the suit off – be sure to get EMG data while you collect the force gauge data – that will allow you to map the three different types of data; EMG, force gauge & subjective rating of exertion(ask after the first measure)

Press force estimation:

Time	1	2	3	Average
Force(pound)				

APPENDIX C

CONFIDENTIALITY/NON-DISCLOSURE AGREEMENT

CONFIDENTIALITY/NON-DISCLOSURE AGREEMENT
Between
NISSAN NORTH AMERICA, INC.,
NISSAN TECHNICAL CENTER NORTH AMERICA and Mississippi State University
Individual Researchers

This Confidentiality/Non-Disclosure Agreement (hereinafter referred to as "Agreement") is made and entered into by and between ______________________, an employee in the Department of ________________________________ of MISSISSIPPI STATE UNIVERSITY ("MSU"), Mississippi State, Mississippi 39762, (hereinafter referred to as "MSU EMPLOYEE") and NISSAN NORTH AMERICA, INC., 983 Nissan Drive, Smyrna, Tennessee, 37167, and NISSAN TECHNICAL CENTER NORTH AMERICA, 39001 Sunrise Drive, Farmington Hills, MI 48331 (hereinafter collectively referred to as "NISSAN").

WHEREAS, NISSAN is in the business of manufacturing automotive vehicles, and

WHEREAS, MSU EMPLOYEE conducts research relevant to the automotive industry, and

WHEREAS, NISSAN may find it beneficial to disclose to MSU EMPLOYEE

Trade secrets and confidential or proprietary information (hereinafter defined and referred to as "Confidential Information"), which Confidential Information NISSAN would not otherwise disclose to a third party.

NOW, THEREFORE, for valuable consideration, the receipt of which is hereby acknowledged, NISSAN and MSU EMPLOYEE agree as follows:

1. MSU EMPLOYEE shall not at any time, directly or indirectly, reproduce, disclose, divulge, disseminate, publish, reveal, or otherwise make known to any third party, the terms and conditions of this Agreement without the prior written consent of NISSAN.
2. Confidential Information shall include, but is not limited to, trade secrets, designs, discussions, specifications, drawings, samples, prototype, hardware, production hardware, data, computer programs, business plans, ideas, concepts, quality plans, manufacturing

processes, minutes of meetings, business organization, electronic media or other which NISSAN may consider Confidential Information and so declare to MSU EMPLOYEE.

3. MSU EMPLOYEE shall hold confidential Information received under this Agreement
   a) in confidence and protect it in accordance with security regulations by which MSU protects its proprietary information, provided MSU EMPLOYEE uses at least reasonable care to protect this information and
   b) restrict disclosure of the information solely to MSU employees or to employees of its parent or affiliates with a need-to-know, who have signed a Confidentiality/Non-Disclosure Agreement with NISSAN, and not to disclose it to any other parties.
4. MSU EMPLOYEE shall have no obligation to keep Confidential Information confidential with respect to any information which
   a) was previously known to MSU EMPLOYEE, free of any obligation to keep it confidential, or
   b) is disclosed to third parties, other than affiliates, by NISSAN without restriction, or
   c) is or becomes publicly available by other than unauthorized disclosure, or
   d) is independently developed by MSU EMPLOYEE, or
   e) at the time of disclosure, the information is in the public domain, or becomes a part of the public domain by publication or otherwise through no action or omission of MSU EMPLOYEE, or
   f) if, at the time of disclosure or subsequently, the information becomes otherwise lawfully within MSU EMPLOYEE's possession without binder of secrecy, or
   g) is approved for release by written authorization of the NISSAN, or
   h) is disclosed pursuant to a governmental or court order or subpoena. In the case of such

actions,

i. MSU EMPLOYEE shall give NISSAN prompt notice of the order or subpoena and cooperate with NISSAN in obtaining a protective order or other appropriate remedy.

ii. Within the scope of the subpoena or order, only the necessary Confidential Information shall be provided.

5. MSU EMPLOYEE shall not use any Confidential Information disclosed to it or in its possession for any other purpose whatsoever except for the purpose of discussing collaborative activities.
6. The Confidential Information disclosed hereunder shall be deemed to be and remain at all times the property of the NISSAN. MSU EMPLOYEE shall, upon request, return all Confidential Information to NISSAN or destroy this Confidential Information upon NISSAN's request.
7. MSU EMPLOYEE agrees to mark all Confidential Information, and MSU EMPLOYEE will maintain such information in a consolidated file, in accordance with MSU's records management policies for specific instances requested by NISSAN.
8. Nothing contained in this Agreement shall be construed as granting or conferring any rights by license or otherwise expressly implied or otherwise for any invention, discovery, or improvement made, conceived or acquired prior to, on or after the date of this Agreement.
9. MSU EMPLOYEE acknowledges that NISSAN could be seriously damaged by breach of this Agreement. Therefore, NISSAN shall be entitled to seek injunctive relief to prevent breach of this Agreement and disclosure of NISSAN's Confidential Information in addition to any other remedies that may be available.
10. MSU EMPLOYEE agrees that it shall not use NISSAN's Confidential Information to develop

or manufacture products that are competitive with the products manufactured and sold by NISSAN.

11. This Agreement sets out the entire understanding and agreement between the parties hereto as to the subject matter of this Agreement and supersedes all previous communication, negotiations, warranties, representations and agreements, either oral or written, with respect to obligations of confidentiality of the subject matter hereof, and no addition to or modification of this Agreement shall be binding on any party hereto unless reduced to writing and duly executed by each of the parties hereto.
12. This Agreement
    a) shall be effective for 5 years from last date of execution or until terminated in writing by either party; however, the obligation to protect confidentiality of specific Confidential Information shall be for a period of three (3) years from receipt of said information, independent of the termination of this Agreement,
    b) is exclusive as to its subject matter, and
    c) shall be construed under the law of the State of Mississippi.

IN WITNESS WHEREOF, the parties hereto have caused this Agreement to be duly executed by their authorized representatives.

WITNESS: MISSISSIPPI STATE UNIVERSITY EMPLOYEE

____

Date: ____

WITNESS: NISSAN NORTH AMERICA, INC.

____

Date: ____

WITNESS: NISSAN TECHNICAL CENTER NORTH AMERICA

____

Date: ____

APPENDIX D

DATA COLLECTION EFFORTS FOR MOTION CAPTURE SETUP

Preliminary Work for the Motion Capture Setup in Industrial Facility

This report is based on the practices we have made for the purpose to use the Eagle motion capture system in non-laboratory environment, a workstation in automobile assembly line. Several issues associated with the environment compared with the optimum laboratory conditions are listed below:

1. Ambient lights that offend the reflection of the markers

Ambient Light	Optimum Laboratory Conditions	Workstation in assembly line
Light	Fluorescent lights are the best ambient light when red filters are used on the motion capture camera	Multiple light types are used in assembly line
Floor or surface	Carpeting or non-shiny floor surface	No carpeting, shiny surface reflection from the painted vehicle body

2. Constrained range of motion

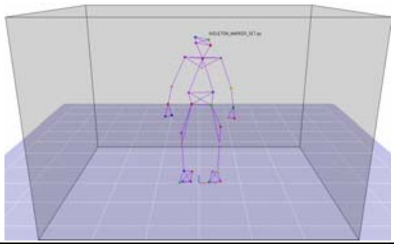
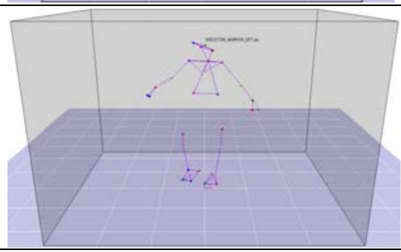
Environment	Optimum Laboratory Conditions	Workstation in assembly line
Capture volume size and shape	Good coverage is obtained depends on the match of the number of cameras and the capture volume	Irregular size and shape in addition with occlusion object in the capture volume

3. Limited camera mounted place

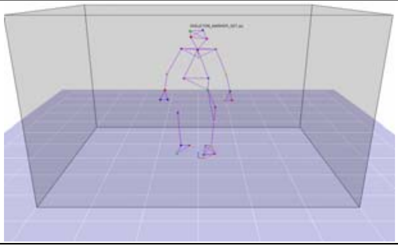
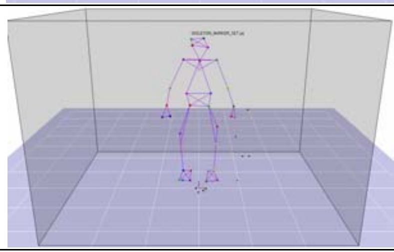
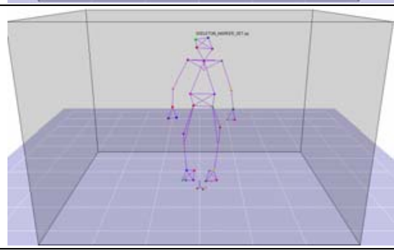
Position of the camera	Optimum Laboratory Conditions	Workstation in assembly line
Height of the camera	Controlled by tripods and adding cameras low to get good result	Difficult to find optimum places for mount the camera
Distance between cameras	Equally spaced, prevent cameras from seeing an apposing camera’s ring light	Can not position the cameras evenly around the capture area

Experiments at laboratory showed that threshold and brightness values of the motion capture system affect the quality of data collection. Some preliminary results from laboratory setup by adjusting threshold and brightness values to reduce the offend reflection from ambient light are illustrated:

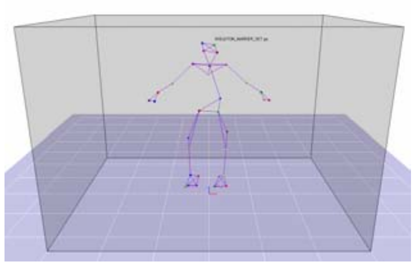
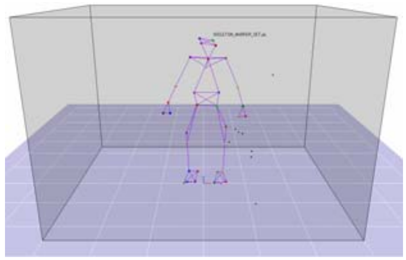
1. 6 camera, volume size: 2.5*3*2, distance between the cameras to volume: 1-2.4 m, brightness: 50, threshold: 500

Minimum camera used to recognize one marker	Environment under control (No mask)	Non-control Environment (use mask)	Picture
2 (The marker is recognized until 2 cameras see that marker)	Good (using mask)	good	
3 (The marker is recognized until 3 cameras see that marker)	Lost data (using mask)	Lost data	

2. 6 cameras, volume size: 2.5*3*2, distance between the cameras to volume: 1-2.4 m, environment does not under control but use mask, minimum. camera used to recognize one marker is 2

Brightness (The brightness of the ring lights for all cameras)	Threshold		Screen print
	250	500	
15	N/A	Lost markers	
50	Appear flicker markers	N/A	
85	N/A	Appear more markers	

3. 6 cameras, volume size: 2.5*3*2, distance between the cameras to volume: 1-2.4 m, environment under control (no mask), minimum camera used to recognize one marker is 2

Factors	Threshold		Screen print
	250	500	
15	N/A	Lost markers	
50	Appear flicker markers		
85	N/A	good