ABSTRACT

EFFECT OF GLOVE PORT HEIGHT ON UPPER BODY STRESS FOR PERFORMING LABORATORY WORK

by
Jason Mark Williams

Glove boxes are used in many industries to constrain environmental contamination and protect the worker from harmful or hazardous exposures. This research specifically evaluates the effect of height of the glove box arm ports on the efficiency of task performance and physiological costs of work for the glove box users.

Seven male and two female participants performed liquid mixing and vial filling tasks within a portable glove box. The tasks were designed to simulate common glove box tasks performed in pharmaceutical and laboratory settings. Each participant repeated the designed tasks while the glove port height was set at two different levels, at 122cm and 132cm.

Electromyography techniques along with discomfort surveys performed before and after the experimental sessions were used to analyze the data. The electromyography data was analyzed for localized muscle fatigue in the targeted muscles, (trapezius, anterior deltoid, bicep, and erector spinae muscle groups). The surveys were used to gather information on the performed task while using glove boxes and to measure perceived stress and discomfort at the varying glove port heights.

Results from this study reinforce the ergonomic guidelines for work height and demonstrates the importance of adjusting the correct glove port height according to the anthropometry of the user. The research also provides, for the first time, a set of qualitative data on upper body stresses in such situations with a glove box.

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by
Jason Mark Williams

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EFFECT OF GLOVE PORT HEIGHT ON UPPER BODY STRESS FOR PERFORMING LABORATORY WORK

Jason Mark Williams

Dr. Arijit Sengupta, Thesis Advisor Associate Professor of Industrial Engineering, NJIT	Date
Dr. George Olsen, Committee Member Adjunct Professor of Industrial and Manufacturing Engineering, NJIT	Date
Dr. Anthanassios K. Bladikas, Committee Member Associate Professor of Industrial and Manufacturing Engineering, NJIT	Date

BIOGRAPHICAL SKETCH

Author: Jason Mark Williams

Degree: Masters of Science

Date: August 2006

Undergraduate and Graduate Education:

- Master of Science in Occupational Safety and Health Engineering, New Jersey Institute of Technology, Newark, NJ US, 2006

- Bachelor of Science in Industrial and Manufacturing Engineering, Indiana Institute of Technology, Fort Wayne, IN US, 2004

Major: Occupational Safety and Health Engineering

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CHAPTER 1

INTRODUCTION

Glove box use began in early 1940's to contain radioactive materials and to protect the workers that were working with them. The Department of Energy, NASA, and many military research facilities used glove boxes for potentially dangerous objects from handling rocks from the moon to plutonium. Today, electronics, pharmaceutical, health care, food processing and other industries use glove boxes in some form or another to do variety of tasks. A glove box is an enclosure used to handle potentially hazardous and hard to contain objects. The glove boxes are used to protect a worker from direct contact with a harmful or hazardous material or to protect a product from environmental contamination.

The performance of tasks in a glove box is subject to the constraints on arm movement and body leaning imposed on the operator by the fixed position of arm ports (glove ports). There are also visual restrictions that may interact with the postural limitations to make an otherwise easy task very awkward to perform. In addition to these, the operator wears gloves, which further reduces his or her dexterity. The American Glovebox Society has developed a detailed standard and guidelines that specify ventilation, seals, glove attachments and necessary services within the glove box, but according to Eastman Kodak (1983), ergonomic considerations of glove box design are not well studied. The majority of the glove boxes used today are purchased from outside vendors as mainly off the shelf glove boxes or custom made for the industry. Glove boxes are used either placed on table tops for seated configurations or attached on top of instrumentation cabinets for standing configurations. Standing configurations are more common because in majority of the cases the plumbing lines and instrument connections are contained under the cabinet below.

For light manipulative type of work, the compatibility of the worker anthropometry and working height is an important determinant of worker productivity and comfort. Too low of a work height necessitates leaning forward of the torso and consequent increased static muscle stress in the lower back and neck. Too high of work height necessitates constant elevation of ones arm and shoulder imposing static stress in the upper arm and shoulder region. Both types of postures need static muscle contractions in lower back or the shoulder, respectively, which is known to be fatiguing. In determining the appropriate work height, the height of the objects handled over the work surface, manual force requirements to perform the job and visual requirement should also be considered. The optimum work heights for several types of manual industrial tasks have been studies in detail, but no such studies have been performed for the glove port height.

Based on 95th percentile adult male anthropometry, Eastman Kodak Co. (1983) recommends that the center of the glove ports for standing glove box configurations should be 132 cm from the floor. For shorter workers they recommend raising the worker by providing platforms of appropriate thicknesses. In reality such platforms are never used in industry, possibly due to tripping hazards and storage difficulties. Furthermore, the suggested height of the glove ports are purely based on anthropometry, and never been validated by experimental trials. The American Glove Box Society is in the process of setting standards and acquiring more research on the ergonomic impacts of glove boxes. This is a pro-active approach to problems that may develop from long-term glove box use and to help in the future design of glove boxes that will better protect the worker's physical health and comfort.

1.1 Problem Statement and Research Objective

In a review of the literature, no experimental data were found regarding the effect of glove port height on the muscular work, fatigue and work efficiency of glove box users. Based on the performance reports from the users, the American Glove Box Society is considering revising this existing guideline for the glove port height of 132 cm (Eastman Kodak Company, 1983) which they think to be too high for the general user population. The objective of this research is to evaluate the effect of glove port height on the muscular work, fatigue and work efficiency of glove box users through a laboratory experiment. The specific research objectives are the following:

(1) Select a group of subjects with no previous upper body injuries who will participate in this experiment.

(2) Design and conduct an experiment to determine the upper body stress in these workers while performing a of set simple laboratory tasks using glove boxes at varying heights.

(3) Measure muscle strains through surface Electromyography and to conduct a written survey as to comforts and discomforts while using differing glove box designs.

(4) Record all prevalent data and analyze it to determine the effect of glove port height in terms of muscle fatigue and strain while comparing this data to the perceived discomfort and fatigue acquired through written survey by the subjects.

1.2 Research Significance

The results of this experiment will provide for the first time physiological effects of varying glove port height which will help in recommending a better standard for the glove port heights. The findings will provide a reference for designing glove boxes and setting standards for glove box requirements. Better designed glove boxes will reduce muscular strains and possibly will lead to reduced users fatigue and in the long run risk of work related upper body musculoskeletal disorders. Reduced fatigue should improve worker performance.

CHAPTER 2

BACKGROUND AND LITERARY REVIEW

Working with glove boxes (also known as containment cabinets, clean boxes, dry boxes and anaerobic chambers) requires extended static muscle loading on the shoulders. Extending the arms for more than a couple of minutes can be very tiring and put additional stress on the shoulder muscles. Furthermore, repeated and sustained forceful exertions have been associated with the development of musculoskeletal disorders in the hands, wrists, fingers, and shoulders. There are several general ergonomics design recommendations which are applicable to glove box work. These include using anti-fatigue matting for laboratory personnel who must stand for long periods of time, taking frequent micro-breaks to perform stretching exercises, move all needed materials for the experiment from the side chamber to the main chamber at one time to reduce the amount of side reaching, and if necessary use a sit-stand seat to alleviate stress on the lower back.

The performance of tasks in a glove box or chemical hood is very constrained due to the limitations on arm movements by the armholes and front shields. Higher or lower glove port height with respect to the relaxed elbow level of the operator may require constant shoulder elevation or excessive leaning forward at lower back, respectively, to maintain the forearm position within the glove ports. These problems coupled with the awkward postures imposed on workers due to the visual restrictions of the glove boxes and chemical hoods make working in them quite difficult for extended periods of time. Glove boxes having a strictly vertical frontal shield pose a greater constraint to the upper body and neck postures, while a glove box with a more slanted front allows the worker to assume a more neutral posture. And in most chemical handling operations workers will be wearing gloves, further reducing their dexterity and strength in most tasks.

2.1 Glove Box Ergonomics

Several guidelines have been provided by the American Glovebox Society (AGS) for the design of glove boxes and hoods that specify certain seals, glove attachments, ventilation, necessary services inside the contained areas, decontamination and cleaning facilities (http://www.gloveboxsociety.org, 2006). However the human factors considerations are less well studied.

In the Eastman Kodak book (1983), the authors recommended the following: glove port height for seated and for standing workstations, glove port diameter, separation width between the glove ports, reach limitations, biomechanical aspects (task-dependent), visual constraints, seat height and adjustability (for seated operations), location of controls and switches, location of pass-through compartments into and out of the box, access for cleaning, decontamination, or product changes, design of tools, trays, and containers to be used inside the box, and task durations.

Ideally, the determination of a sitting or standing workplace for hoods and glove boxes should be determined by the nature of the task to be done and the general work environment and placement of the hood or glove box. Reaches should be kept within 15 to 41 cm of the front of the work surface for seated operations and 51 cm for standing operations. For glove box operations, seated workplaces are preferred, since workers can easily adjust their workplace height using a chair, e.g. a pneumatic chair. Leg clearances should be at least 66cm in length or depth. Some tasks are easier to do with a chair adjusted to its lowest level, while others are best done with the chair adjusted to its highest level. An example would be in which the force is exerted downward; or conversely if the task involves extending reaches of the arms. Work can be done more efficiently if some means are provided to enable an operator to adjust the chair to a comfortable height for the arms and shoulders without having to remove his or her hands from the gloves. Providing height adjustment by foot pedal, forearm switch, or a similar method allows the operator to move the chair to suit the task. Time is not lost in manual adjustments then, and muscle fatigue from awkward working postures is less probable. Chair adjustability should be around the range of 15cm, and adequate clearance must be provided so that the workers legs are not wedged underneath the workstation.

According to Eastman Kodak research (1983) if a standing glove box is needed, the center of the arm ports should be 132cm (52 inches) from the floor. This height should be comfortable for taller people; shorter operators should get a retractable step stool or platform with standing levels at 8 and 15cm above the floor. Since there is less flexibility in adjusting these platforms, every effort should be made to adapt the work to a seated operation, especially if the glove box is used regularly and the worker uses the glove box for a majority of the time that the worker is at the workstation. As has been stated earlier, standing glove boxes are quite common in industry, and availability of variable height platforms are practically non existent, without adjustable platforms this standard glove port height of 132cm may pose serious strain on medium or short height operators. The Eastman Kodak (1983) recommended height of 132cm is based on using platforms to elevate shorter workers to the glove box openings.

A study by Whitemore and Bergen (1996) conducted with six subjects, (three male and three female), evaluating ergonomic aspects of workstations in microgravity found that flexible arm holes were better than rigid ports for repetitive fine manipulation tasks to allow maximum range of arm movement. The study showed, through video posture analysis, that very similar postures were assumed by both the smallest and tallest subjects. Also, EMG profiles revealed that consistent muscle performance was found in glove box operations, whereas in the general purpose workstation variability was found in the EMG data which was attributed to the subjects' attempts to provide more stabilization for themselves in microgravity.

Another study was done by Whitemore et al. (1994) evaluating ergonomics of Spacelab Glove Boxes for NASA (National Aeronautics & Space Administration). The study consisted of a video analysis of posture and a compilation of crew comments on the design and interface and their perceived discomfort levels. This study was done on the Columbus Space Shuttle using four astronauts as subjects. The objectives of the study were to evaluate the design of the glove box interface and to evaluate the astronauts' working posture in microgravity at the glove box. Science experiments were conducted in the Spacelab for extended periods of time (approximately 6 to 8 hours a day). Results from the study showed that the crewmembers rated the overall glove box design marginally acceptable if there were some design modifications. The posture analysis of the crewmembers revealed that they had a hunched shoulder posture approximately 40% of the total time at the glove box. It was observed that the crewmembers needed to be very close to the viewing window while working at the glove box.

These studies discussed in this section provide some important insights into glove box design but do not address the height issue of glove ports, which is the primary objective of investigation of this research. The objective of this research is to investigate the effect of glove port height on muscle stress and fatigue. The following two sections provide details on (1) working height for standing workstations, and (2) the application of EMG on the measurement of muscle stress and muscle fatigue.

2.2 Standing Workstations and Work Height

Standing for long periods of time to perform a job should be avoided whenever possible. Long periods of standing work can cause back pain, leg swelling, problems with blood circulation, sore feet and tired muscles, lowered productivity, and usually more mistakes made on the job, equating to a greater risk of injury to themselves and others (Konz, 1995). Because standing workstations provide more freedom of movement and greater reach (Sengupta and Das, 2000) capability over the work surface, standing workstations are not uncommon in industry. Here are some guidelines taken from Eastman Kodak (1983) to follow when standing work cannot be avoided:

- If a job must be done in a standing position, a chair or stool should be provided for the worker and he or she should be able to sit down at regular intervals.

- Workers should be able to work with their upper arms at their sides and without excessive bending or twisting of the back.

- The work surface should be adjustable for workers of different heights and for different job tasks.

- If the work surface is not adjustable, then provide a pedestal to raise the work surface for taller workers. For shorter workers, provide a platform to raise their working height.

- A footrest should be there to help reduce the strain on the back and to allow the worker to change positions. Shifting weight from time to time reduces the strain on the legs and back.

- There should be a mat on the floor so the worker does not have to stand on a hard surface. A concrete or metal floor can be covered to absorb shock. The floor should be clean, level and not slippery.

- There should be adequate space and knee room to allow the worker to change body position while working.

Working height is of critical importance in the design of a standing work station. If work is raised to high the shoulders must be frequently lifted up to compensate, which may lead to discomfort, fatigue, or even painful cramps in the neck and shoulders. If the work surface happens to be too low, then the back must be kept at a flexed position, which may lead to backache. In general, the ideal work surface height should correspond to the relaxed elbow height of the operator. According to Konz (1995), the optimum work height for manipulative hand-arm work should be 50mm below the elbow, or slightly below heart level. Konz stated that work height should be defined in terms of elbow height rather than a fixed height from the floor, since peoples heights will always differ. Optimum height from the elbow is the same for both sitting and standing. This means work height from the floor will differ for sitting and standing, unless the chair height is adjusted. It was also mentioned that work height is not table height. Most items (table tops, keyboards, tools and other objects handled) have a thickness. Thus, if the thickness of the object being handles is 50mm thick, the table surface height should be about 100mm below the elbow.

The height of the workstation also depends on the nature work being performed. If a worker is performing fine dexterous work, which requires visual acuity then the work station should be higher to keep him/her from bending over. If the worker is performing a strength intensive task, such as cutting meat or material, a lower work station is needed so the worker can use his/her weight to their advantage. The American Glove Box Society recommends that the arm ports of glove boxes should be placed at 132 cm from the ground, which corresponds to 95th percentile male elbow height. This guideline has been adopted from Eastman Kodak Co. (1983). Unless the average or shorter operators are provided with platforms to stand upon, this height can be excessive. Furthermore, according to Das and Sengupta (1996), the maximum height of standing workstation height for women should be no more than 120cm.

2.3 EMG and Measurement of Muscle Activity and Muscle Fatigue

2.3.1 Physiological Basis of EMG

The specific sequence of muscle activation and movement initiation requires complex interactions between the muscles and nervous system. Skeletal muscle cells are arranged in parallel to produce force, through the muscles tendon, at a common point in the bone. For all of these cells, (muscle fibers collectively), to contract, they must be activated by signals from motor neurons; these fibers and a neuron combinations form motor units (MU). MUs, are the 'final common pathway' for motor control of movement. Each unit will contain an anterior motor neuron and all of the muscle fibers innervated by its motor axon. The entire motor unit follows the all-or-none rule by which if the anterior motor unit is activated; all fibers supplied in it are contracted.

The technique of EMG, or electromyography, is based upon the theory of electromechanical coupling in muscles. In a resting state, the cell membrane of a muscle fiber is in equilibrium, meaning on the inside it is negatively charged and on the outside it is positively charged. This polarized state is due to the presence of positive and negative ions inside and outside of the cell membrane in specific concentrations. When a nerve impulse, in the form of a neurotransmitter chemical, reaches a motor end plate, it changes the permeability of the muscle cell membrane at the neuromuscular junction, causing a flow of charged ions across the cell membrane at this junction. This flow of ions causes a local depolarization of the cell membrane. This local depolarization, in turn, sets up a potential difference between the polarized and the adjacent depolarized region of the cell membrane. This potential difference again changes cell membrane permeability in the adjacent regions, causing more flow of ions and consequently depolarizing the adjacent regions. As the adjacent regions are being depolarized, the previously depolarized regions are repolarized by active ion transport. This process of depolarization-repolarization wave, called action potential, propagates from the neuromuscular junction in two directions until it cover the entire length of the muscle fiber and which mediates the muscle contraction.

As a single or a train of action potentials sweep the sarcolemma (muscle membrane), the electrical potential differences travel deep into the muscle cells through t-tubules. This unique organization allows the electrical potential to travel to the deepest parts of the muscle almost instantly as it sweeps the surface of the muscle. These action potentials trigger the release of Calcium ions ($Ca2+$) from the sarcoplasmic reticulum into the muscle cytoplasm. The calcium ions are responsible for starting muscle contraction which in turn manifests into motion of the muscle and the generation of force. Hence, there is an electromechanical coupling of the muscle that is mediated through biochemical means.

The basis of surface electromyography is the direct relationship between the action potentials of fibers in the muscle and the extracellular recording of the action potentials at the skin surface where the electrodes are placed. This simple model shows the recording of the action potentials with extracellular electrodes.

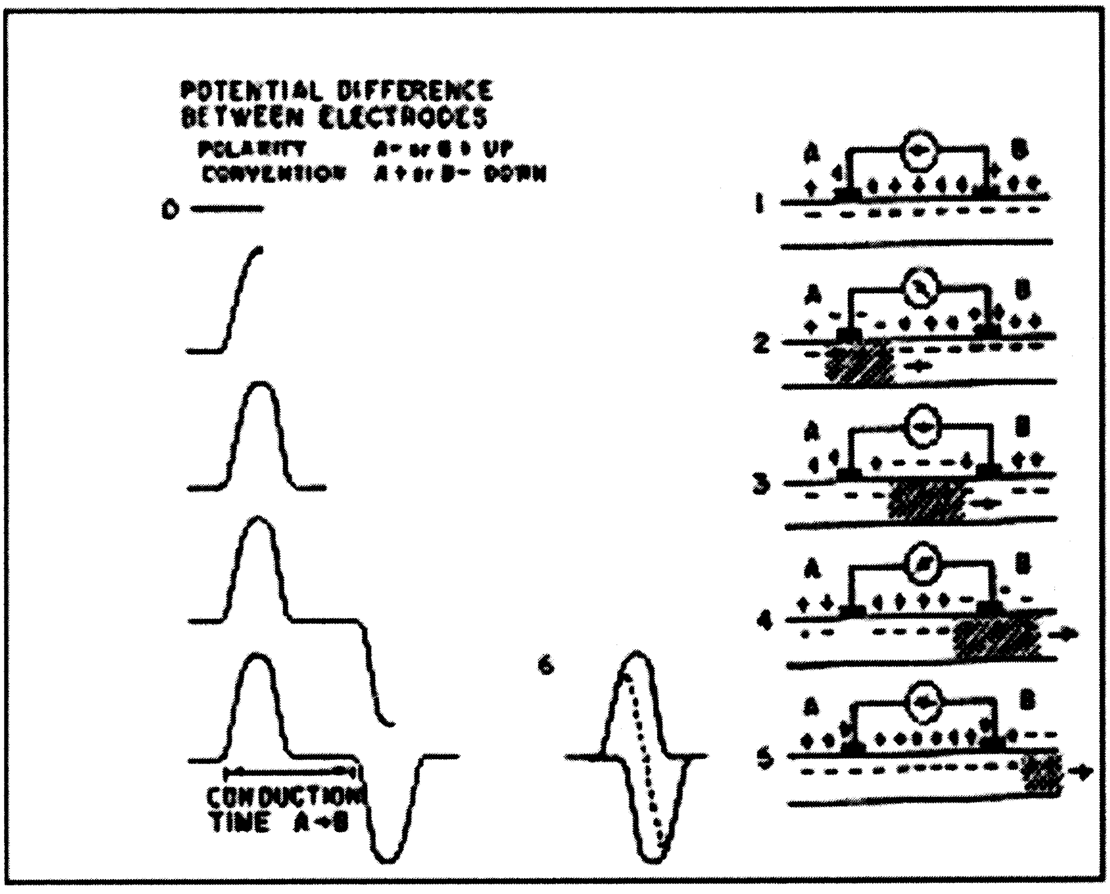


Figure 2.1 Measurement of action potentials, with electrodes placed on the surface of isolated tissue.

Two electrodes (A and B respectively) that are connected to an oscilloscope are placed on a muscle a certain distance apart. In a resting state, entire length of the muscle fiber is in equilibrium and thus there is no potential difference between the two electrodes showing no changes in reading from the oscilloscope baseline. If the muscle fiber is excited to the left of electrode A, it becomes negative with respect to electrode B, and the oscilloscope deflects upward. As the action potential continues toward electrode B, the area under electrode A repolarizes, and the oscilloscope returns to the baseline. When the action potential is between electrodes A and B, the area under electrode A has recovered and the area under electrode B has not depolarized, making the difference between the electrodes zero again, returning the oscilloscope to baseline, staying there, until the area under the electrode B is depolarized. Now, as the action moves from under electrode B, the area becomes negative with respect to A, and the oscilloscope dips downward, and as the repolarization occurs under electrode B, the difference in potential returns to baseline. The graph resulting from this is a set of monophasic waves separated by a short period of time when no potential difference is measured. The time between the waves depends on distance between the electrodes and the conduction velocity of the muscle fiber. Now, if the electrodes are placed close together, the waves temporarily summate forming a biphasic wave with smaller peak to peak amplitude then the monophasic wave. The biphasic wave is similar in appearance to a muscle fiber action potential.

The above model shows the EMG generated by the action potential from one muscle fiber. In reality, the CNS regulates the force production from a whole muscle by employing two mechanisms; rate coding and recruitment. Rate coding is employed by changing the frequency of the release of neurotransmitter at the neuromuscular junction.

By increasing this firing frequency, force production by the motor unit can be increased to a certain extend. The other mechanism, recruitment, employs increasing number of motor units firing simultaneously to increase the force production from the whole muscle. In general for any muscular work, both the mechanism may be applied simultaneously by CNS to match the internal muscular force production to the outside demand. The EMG signal is based on changes in amplitude and frequency, but can be quantified and used to classify the electrical activity level that produces a certain muscular tension. The change in the myoelectric signal is based on the recruitment and firing rate of motor units within the muscle. As a rule of thumb, as more force is needed, more motor units are recruited, and the motor units already firing increase their frequency in firing, but, this reaction is not the same for every muscle. This interpretation of the changes in recruitment and changes in firing rate can provide information concerning the muscle's level of force or more importantly, its level of fatigue. The electromyographic amplitude signal is used as an indirect measure of contraction-force, but because there is no one-to-one relationship, a standard of reference, or normalization, must be determined, to force calibrate the process. This calibration must occur every time an experiment is done because the signal may change from one time to another for the same task for various reasons such as skin temperature, electrode location, or change in tissue properties. The most common method of this normalization process is to perform one reference contraction, usually an isometric maximal voluntary contraction, or MVC. The myoelectric values are then subsequently obtained are expressed as a percentage of the MVC.

2.3.2 Interpretation of Muscle Activity Levels from EMG Recording

The electrical signals picked up by the bipolar skin electrodes reflect the summation of action potentials from different motor units firing at a different frequency within the muscle. The bipolar electrodes are usually two silver-silver chloride surface electrodes that are placed on the skin overlying the muscle or muscles of interest to line up with the predominant fiber direction close to the motor point. The subject is grounded by placing an electrode at an inactive place on the body and the electrodes are connected to the pre-amplifier. The electrodes at the pick up site pick up small EMG signals in the magnitude of micro-volts. These signals can be taken over by outside artifact or outside electrical noise. Therefore, these signals are pre-amplified close to the source of generation before noise has a chance to contaminate the signals beyond recognition. Between the pre-amplifier and amplifier the signal can be amplified by a factor of several thousands. Most amplifiers do signal conditioning and may be able to filter undesirable frequency components. The plot of the amplified signals over the time axis constitutes the electromyogram and its recording is electromyographic recording.

A sample EMG plot collected during this investigation is shown in Figure 3.3. The EMG plot constitutes a series of positive and negative amplitudes. The magnitudes of the amplitudes are roughly proportional to the intensity of muscle activation at a given point of time. To determine the average activity level of a muscle over a period of time, the raw EMG signals cannot be averaged because it contains both positive and negative amplitudes, and activity levels are proportional to the absolute value of the amplitudes. Either root mean square (RMS) or rectification must be performed before the average of the signals can be taken over time (USDHH, 1992).

2.3.3 Physiology of Muscle Fatigue

Fatigue is a loss of efficiency and a disinclination for effort but it is not a single, defined state (Kroemer & Grandjean, 1997). There are many different types of fatigue such as eye, mental, general, nervous, chronic, and circadian, but for this study, concentration will be placed on localized muscular fatigue and its effects. This form of fatigue reduces performance of a muscle after prolonged stress at low muscle intensity through decreased strength and force.

Studies have shown that during muscle contraction chemical processes occur which provide energy necessary for physical exertion. After the contraction, energy supplies are replenished, both of these processes are going on in any particular healthy muscle while work is being performed. Fatigue occurs when the demand of energy exceeds the replenishment capabilities of the resting period, lowering muscular performance overall. Under heavy amounts of stress, the muscles use up its energy supply while the muscles waste products build up turning the muscle slightly acidic and accounting for the burning sensation in over used muscles. In ergonomics the problems associated with sustained muscular effort evoke pain and discomfort, that the biomechanical loading on body structures may cause tissue damage in the long run, and that muscular fatigue may impair the possibility to carry out the working task. Muscle fatigue can also help contribute to tremors and reduces fine motor control.

Fatigue does not occur on its own. It is an effect of what happens after one exerts his or her self through work. Work is traditionally defined as force multiplied by the distance that the force is applied over. For the purpose of this study though, work will be related to muscle contractions. There are two different types of muscular work, dynamic and static. Dynamic work is characterized by muscle contraction alternating with relaxation, and resulting in the movement of a body part. Static work is work without alternating between relaxation and contraction, but usually involves simply the constant contraction of a muscle or muscle group. Work can be translated into muscular efforts, static and dynamic. In a dynamic situation, the muscles effort is sometimes expressed as the product of the force developed and the shortening of the muscle (work=force x distance). During static effort of the muscle, the muscles length does not change but remains at a constant length under increased tension, with force exerted over a certain length of time. When this is occurring, no useful work is externally visible nor can it be defined as simply in terms of force and distance as in dynamic work.

There is a major difference between static and dynamic muscular effort, and that is blood flow occurring through the muscle. During a static effort, the blood vessels in the muscles are compressed by the pressure of the muscle tissue around it from being used, relatively halting the blood flow through the muscle. Therefore, if a muscle is undergoing heavy static work, it is receiving no fresh blood that carries with it energy and oxygen that it needs to perform, and must rely on its reserves. More importantly no waste products are being removed from the muscle, so waste products are accumulating in the muscle, causing discomfort and fatigue. In dynamic work, the opposite is happening. As a person moves, the muscles contraction and relaxation act as a pump, compressing and squeezing blood out of the muscle, and relaxation bringing fresh blood back in. With dynamic work of the muscle, the muscle can get up to 20 times more blood than it can while resting. According to Kroemer and Grandjean, (1997) static effort can be said to be considerable if a high level of effort is maintained for more than 10 seconds, if moderate effort persists for more than 1 minute, or if slight effort lasts for more than 5 minutes. Constrained postures are the most frequent of static muscular work because of carrying our trunk, arms, and head in unnatural positions.

The effects of static muscular effort are proportional to the level of effort exerted. If the effort is 70 percent of the maximum, the blood flow to the muscle will mostly probably be completely stopped, but a certain amount of blood flow is available at lower exertion levels, normally around 15-20 percents of maximums. Therefore, the oncoming of muscular fatigue from static effort will be more rapid the greater the force exerted. Now this can be expressed in terms of the relationship between the maximal duration of a contraction and the force expended.

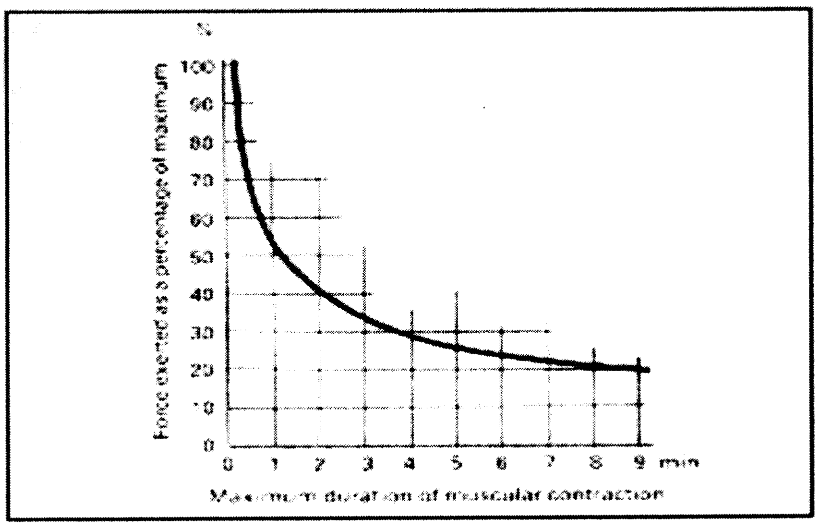


Figure 2.2 Maximum duration of static muscular effort in relation to the force exerted.

The graph in Figure 2.2 adapted from Eastman Kodak (1986) shows the results on four different muscles. It appears from his work that a static effort which requires 50 percent of maximum force can last no more than one minute where if the force expended is less than 20 percent of maximum, the muscular contraction can last for quite a long time.

2.3.4 Interpretation Localized Muscle Fatigue from EMG

Usually when discussing fatigue effects on the EMG signal, power spectrum properties are addressed. The surface electromyography power spectrum contains a large amount of data. Hence, studies of spectral alterations needs reduction of spectral data to a single index like the median frequency or the mean power frequency. In this study, the median frequency was used because of the superior high-frequency noise immunity. The median frequency is defined as the frequency which divides the power spectrum in tow parts with equal areas. Conventionally, the power spectrum is calculated and thereafter the median frequency.

It is well documented that any spectrum index decreases at a sustained strong contraction. Chaffin (1973) was the first to suggest surface electromyographic power spectrums alterations as indicators of local muscle fatigue. The physiological background for these alterations has been a matter of controversy and a complete explanation of this phenomenon is still lacking. However, three major events are pointed out to occur in muscle fatigue studied through electromyographical means, (Kumar and Mital, 1996). Action Potential Conduction Velocity (APCV) decrease is one of them. The second is synchronization of motor unit firings which imply increased peaks in the low frequency band of the surface electromyographical power spectrum. Third, additional recruitment of new motor units most likely also influence the alteration during a sustained contraction. Motor units with higher initial action potential conduction velocity are recruited, increasing index readings. However, when more fatiguable type II motor units are recruited the action potential conduction velocity decrease is accelerated. The APCV decrease is a genuine local muscular event while the others are related to CNS factors.

During localized muscle fatigue changes occur in the surface recording EMG. Figure 2.3 shows the effect during sustained, isometric contraction with a frequency spectral shift resulting from local muscle fatigue during a sustained, isometric contraction of the first dorsal interosseous muscle (USDHH, 1992).

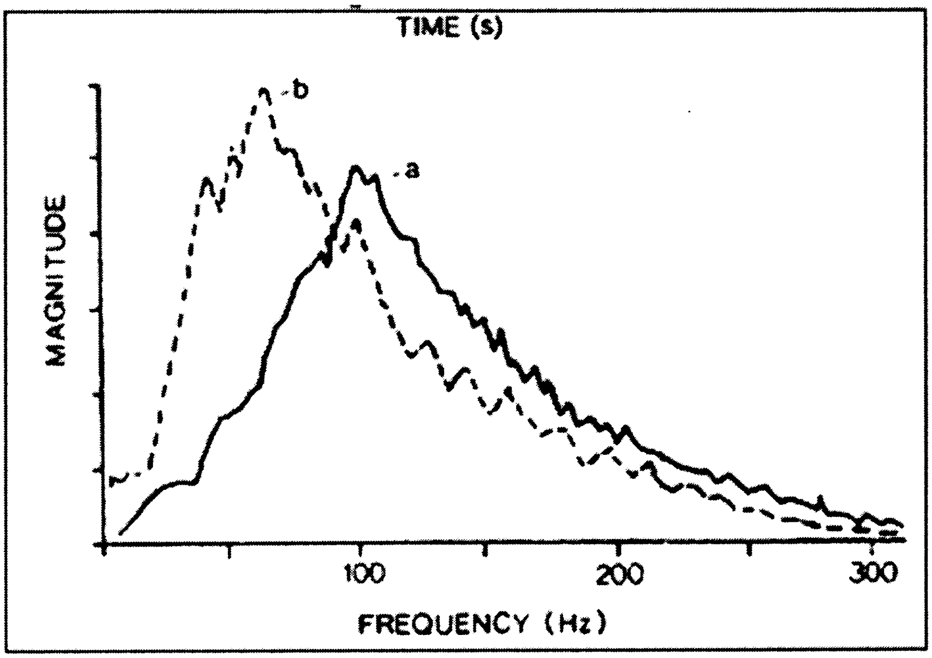


Figure 2.3 Power spectrum shift to the left indicates localized muscle fatigue.

The median frequency is calculated for a block of samples whose length is defined by the filter constant, (64, 128, 256,512, 1024, 2048, 4096, 8192). This calculation is repeated as many times as necessary across the trace and the resulting frequencies plotted as a series of lines connecting the median frequencies. The following steps are performed:

- A block of samples defined by the filter constant is taken and zero padded to the nearest power of 2.

- A Windowing Function applied to the data as specified by the selection at the bottom left of the Settings Window.

- A Fast Fourier Transform (FFT) is performed and, if selected, FFT High Pass Filters are used to Remove DC and to Remove Very Low Frequencies from the calculations. Note that a large DC component can seriously degrade the accuracy of the median frequency calculation.

- The amplitude magnitude of each FFT output frequency is squared.

- The median frequency is determined such that the area of the amplitude-squared frequency graph below the median frequency is the same as above the median frequency i.e. there is equal power either side of the median frequency.

- The process is repeated for the next block of examples.

Chapter 3

EXPERIMENTAL METHOD

The experiment was conducted in NJIT Safety Laboratory over the course of six weeks with the use of nine participants. There were seven males and two females who were tested. Flyers placed around the NJIT Newark campus were used to recruit participants in this study, and each participant was paid 10 dollars an hour for their work. The participants were able bodied and were free of illness or injury contraindicated for manual work. The ages ranged from 19 to 26, with an average age of 22 years. Participant height ranged from 160cm (63 inches) to 190cm (75 inches), with an average height of 177cm (69.8 inches). Masses ranged from 52.7kg (116 lbs) to 111.4 kg (245 lbs). The demographics of the participants are provided in Table 3.1.

Table 3.1 Anthropometric and demographic data of participants

Participants	Age (year)	Height (cm)	Weight (kg)
1	21	180	86
2.	21	190	111
3	19	170	64
4	26	185	95
5	25	185	71
6	20	182	84
7	23	183	65
8	25	160	52
9	18	160	68
Average	22	177	77
Standard deviation	3	11	18

Each participant was asked to perform the set of experimental tasks twice with an approximately 48 hour's interval between the two sessions. The glove port height was set either at 132 cm or at 122 cm from the floor for these sessions. The participants were not told which heights they were working at to avoid subjective bias.

3.1 Experimental Setup

A Captar Field Pyramid Model 2200A portable glove box constructed with transparent plastic was used (Figure 3.1) to simulate the restrictive nature of the glove box, extra muscle strength required for fine motor work, and sometimes awkward positioning required for utilization of the glove box while performing the required tasks. It was placed on an adjustable height table which was used to change the working height of the glove ports to 122cm (48 inches) and 132cm (52 inches). This glove box is designed for industrial use and had integrated gloves in the glove ports. The participant stood in front of the glove box with their forearms inserted in the gloves. The participants were instructed to stand as close as possible to the glove box that allows them to perform the experimental tasks conveniently. This position was selected by trial and error method. Once the position was selected by a participant, that position was maintained through out the experimental session.

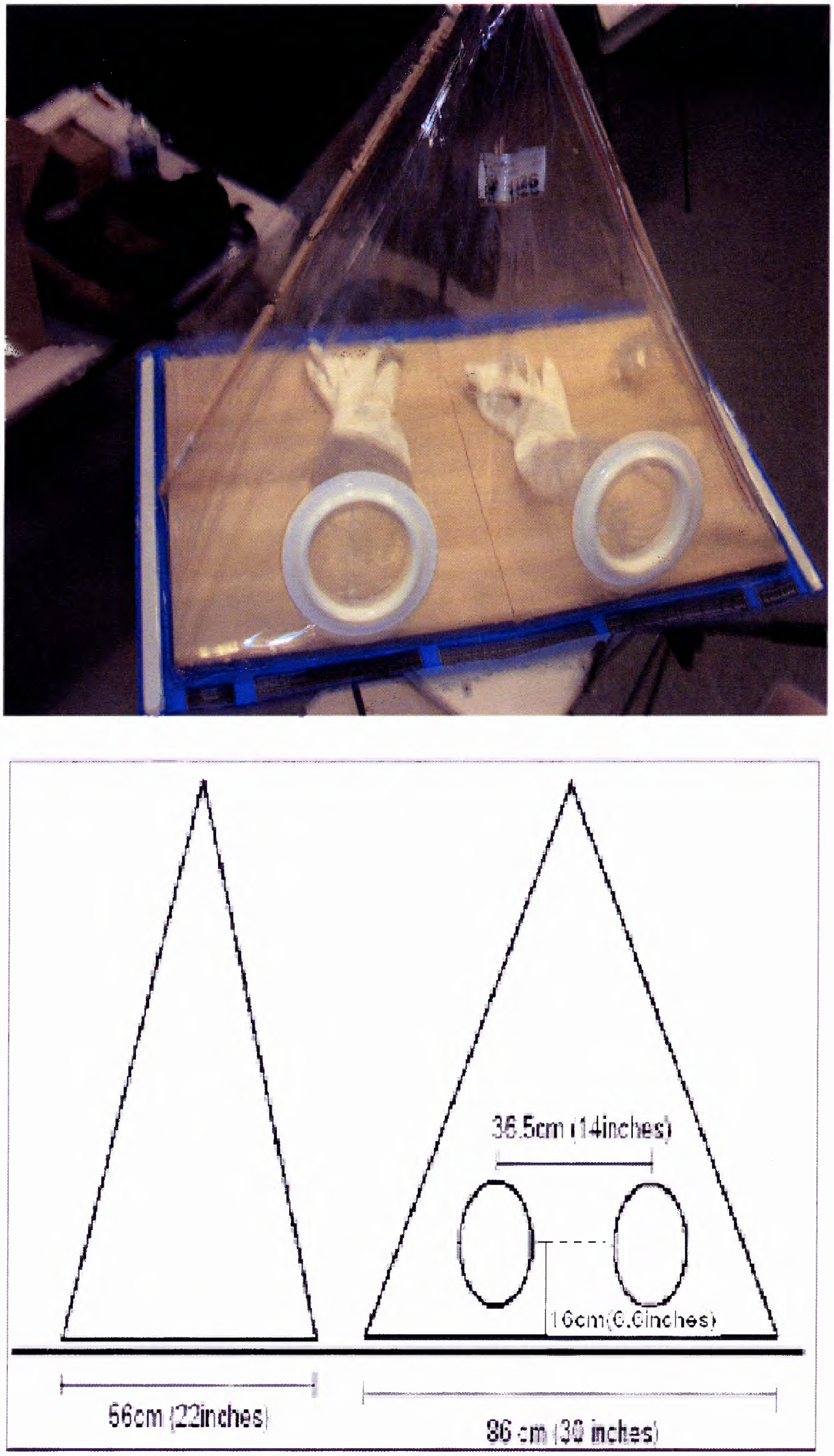


Figure 3.1 Captar Field Pyramid Model 2200A portable glove box along with relevant dimensions.

Six 250 mL graduated cylinders with screw tops, three plastic spoons, two porcelain bowls, one pipette, 12 microfuge tubes, one microfuge tube rack, one half gallon container of water, and sugar and colored lemonade mix was used as 'replacement' chemicals, within the portable glove box. The tasks that were performed by the participants were a series of simple measurement, pouring, and stirring tasks that were predetermined and repeated in every test. The series of steps that were taken by every participant were told to them verbally by the investigator identically before every test, to limit the potential stress on the neck and eyes from trying to read and comprehend a list of instructions while using a glove box. The tasks that were given to the participants were as follows in this order:

1. Place your arms through the glove ports and situate your arms comfortably in the gloves

2. Take the caps off the 250mL bottles (in any order)

3. Place one scoop of the lemonade mix (the pink powder) in each of the six 250mL bottles with the plastic spoon labeled 'mix' (in any order)

4. Place three scoops of sugar (white powder) into each of the six 250mL bottles with the plastic spoon labeled 'sugar' (in any order)

5. Using the half gallon jug of water, pour approximately 150mL of water into each of the 250mL bottles (in any order)

6. Using the unmarked spoon, stir until mixed all six 250mL containers

7. Place cap back on half gallon jug of water

8. Using the plastic pipette, take a large sample from the 250mL bottle marked '1' and use that sample to fill up the two microfuge capsules that correspond with the number 1. Repeat for bottles 2-6 and microfuge capsules 2-6.

9. Screw the caps back on all six 250mL containers

10. Place the lids on the tops of the 12 microfuge containers.

11. Take hands out of gloves and place arms by your side

These exact steps were repeated for the working height of 132cm, (52 inches) or 122cm, (48 inches) in two different days in a random order. Each participant took approximately 15 minutes to complete each of the sessions.

3.2 Experimental Procedure and Data Collection

Before the experiment was started, the participant had to fill out a series of forms. These included: (1) participation consent form approved by the NJIT Institutional Review Board that gave the participants their rights as being a willing subject in the experiment and potential dangers of being in the study, (2) a photo-release form stating that their picture may be taken using the digital video camera, and a (3) pre-survey questionnaire which included contact information along with various questions on how the participant was feeling before the experiment started (Appendix A to D). Once these forms were filled out and completed, the experiment could begin.

A digital video recorder was set up next to the work station to record all the events and upper body posture of the experimental subject. All containers were cleaned and refilled and placed back in there proper order within the glove box. Once the participants information was filled out, the video recorder set up, and the experimental set up was arranged in the pre-determined places, the participant could be connected to the EMG electrodes for the duration of the experiment.

3.3 Recording EMG

An eight channel Biometrics Data Link Base Unit, a Biometrics amplifier with a ground and four bipolar skin electrodes with pre-amplifiers was used in this study to collect the EMG data signals. The electronic equipment was connected to a desktop computer and the Bio-analysis Software facilitated the data collection and analysis of the EMG signals. The EMG data collection system was set up in this order:

1. The computer with Bio-Analysis Software was turned on the program was stared.

2. Once the program is running, the four skin electrodes were connected to the participant on the right lower back, the right bicep, the right middle trapezius, and the anterior deltoid muscle using the sticky double-sided adhesive tape provided by the manufacturer. The electrode positions for muscle groups are shown in Figure 3.2. Once the electrodes are in place, the participant stands in front of the work station in a neutral and relaxed position (hands to the side, standing straight up). At this position, all four channels were initialized to zero and Sampling Rates were set to 1000 Hz.

3. After the EMG channels were initialized, the subject was asked to perform a standard task of holding a 5 lb weight in the right hand for approximately 15 seconds while the arm and the forearm were kept horizontal at the shoulder level. During this standard task, EMG signals were collected at a rate of 1000 Hz for the duration of the task and saved in the computer hard disk. A DC channel and a hand switch was used for marking the precise start and finish of the standard task. This EMG recording was used later for normalization of task EMG signals.

4. After a brief rest period of approximately 2 minutes, the experimental task began. The camera was turned on and while the subject performed the predefined experimental task, EMG signals were collected at a rate of 1000 Hz. The data collection was continued for the entire period of the experimental task.

5. After the experimental tasks are completed, the camera was turned off, and EMG data was saved on a separate file for further analysis.

6. This procedure was repeated for the next height setting of the experiment.

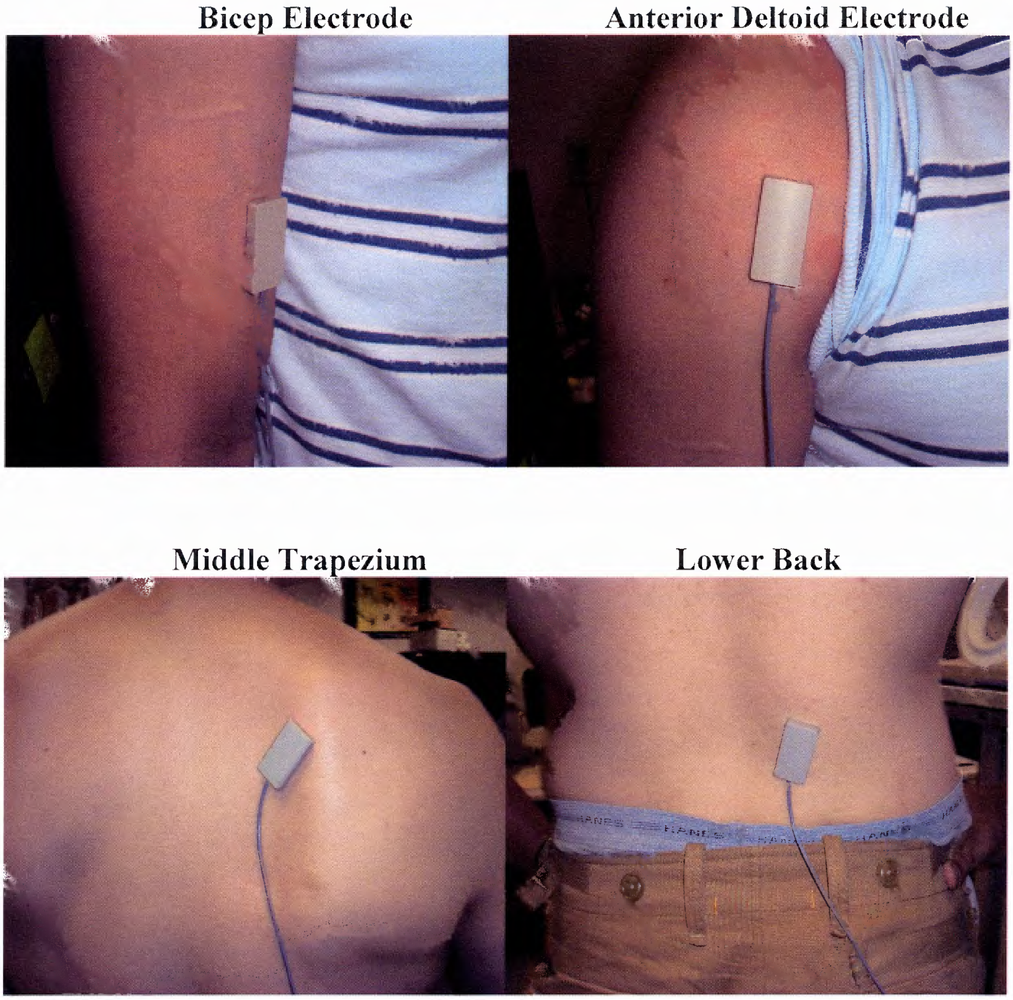


Figure 3.2 EMG surface electrode positions for biceps, middle deltoid, middle trapezium and lower back.

The Bio-analysis software provides real-time display of the plot of the acquired EMG signals which were constantly monitored to ensure data integrity. In the event any of the skin electrodes becomes loose, the signals show erratic pattern. During the data collection phase, no such event occurred. Figure 3.3 shows a sample screen of the real time plot of the EMG data from four channels from the Bio-analysis software. The abscissa represents the time in seconds and the ordinate represents signal strength in milli-volts.

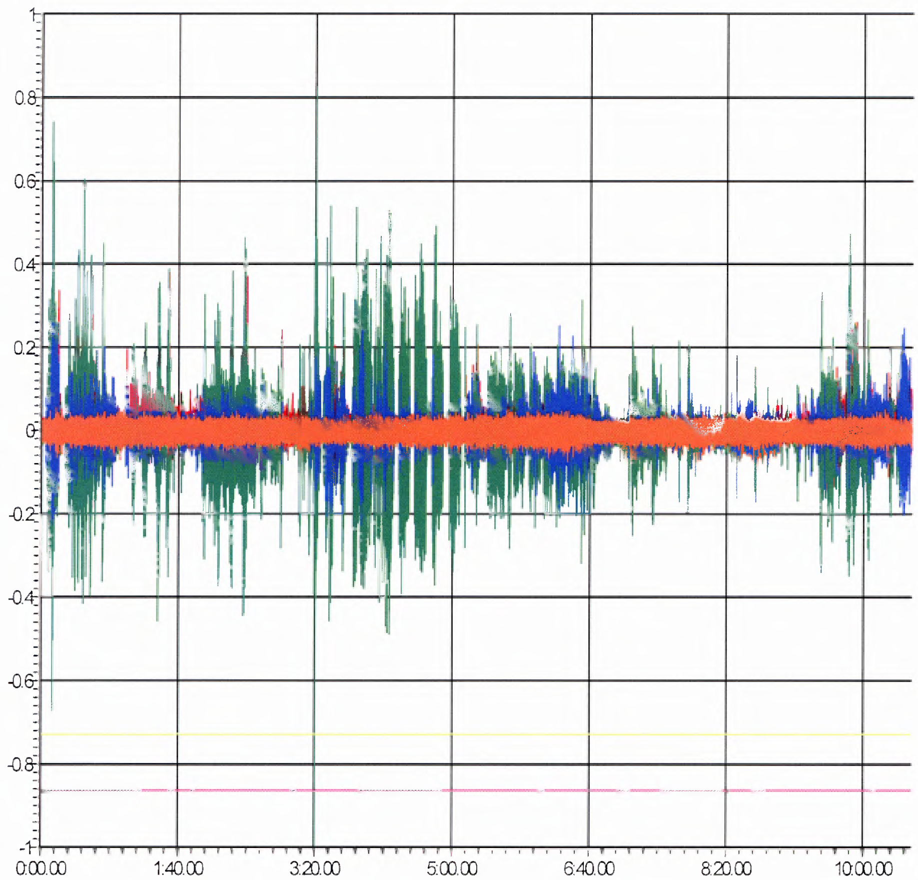


Figure 3.3 Real time EMG signal display by Bio-analysis software during the experimental task execution.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Body Discomfort Ratings and Questionnaire Survey

The questionnaires were created to assess a participants overall feeling of fatigue after the performance of the experimental tasks. Before the start of the experimental session, participants were well rested with no perceivable body discomfort. Thus, the discomfort ratings perceived at the end of the experimental session can be attributed to the performance of the experimental tasks. Body discomfort rating was assessed in a scale of 0 to 10 with 10 being discomfort, 5 being some (moderate) discomfort and 0 being no discomfort. Appendix E contains the raw discomfort scores by the participants. Figure 4.1 summarizes the average body discomfort ratings by the subjects for 122 cm and 132 cm glove port height sessions.

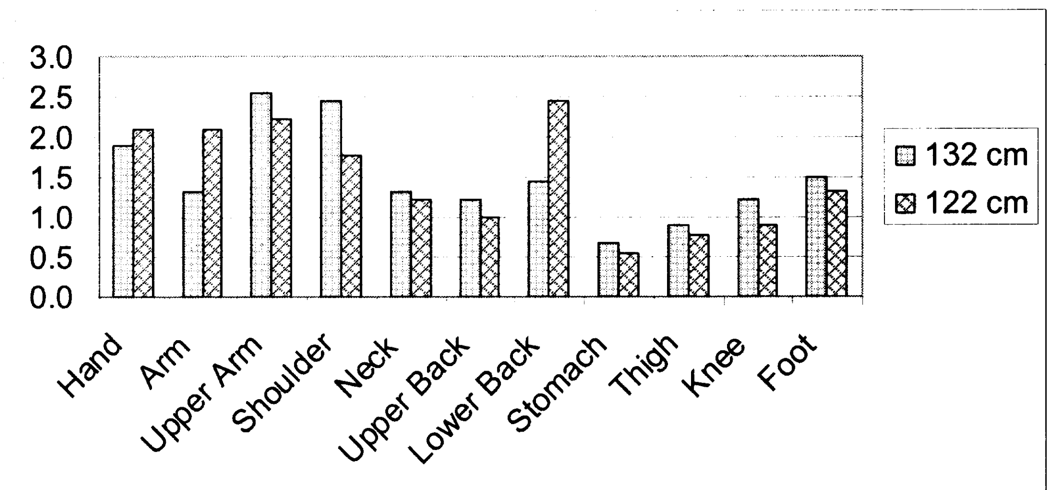


Figure 4.1 Average body discomfort ratings in 0 to 10 scale after completing the experimental task.

The average ratings were all below 3, which indicate that most of the participants perceived discomfort between no discomfort and moderate discomfort. Highest three ratings were given to upper arm (2.6), shoulder (2.4) and lower back (2.4). This is consistent with the expected muscle group strains that will mostly be stressed by the experimental task, which has been discussed earlier in this thesis. The other body regions that obtained average ratings higher than 2 were hand (2.1) and arm (2.1). The rest of the body regions scored less than 2. The low scores in each body region indicate minor or no discomfort, which was expected because the experimental task was quite light and the duration was approximately 15 minutes.

When the average discomfort ratings were compared for two glove port heights, the shoulder and upper arm scored 0.33 and 0.67 points less for 122cm, respectively, but for the lower back the score was higher by 1.0 points. Such scoring patterns are again consistent with the fact that at lower glove port height requirement of shoulder and arm elevation will be less and thus a less stressful muscle activity; a lower glove port height will necessitate more bending of the back and hence more stress level of the back.

Table 4.1 shows the subject-wise scores of these three body regions for 122cm and 132cm glove port heights. To verify the statistical significance of this difference in scores, a paired one tailed *t*-test of the difference has been conducted with test hypothesis:

$H_0 : \mu_1 - \mu_2 = 0;$

$H_1 : \quad |\mu_1 - \mu_2| > 0,$

where, $|\mu_1 - \mu_2|$ is the absolute difference in the average scores with 122cm and 132cm glove port heights, respectively.

Test statistic: $t' = \dfrac{\bar{d}}{s_d / \sqrt{n}}$, where $\bar{d}$ and s_d are the mean and standard deviation of the n differences. Probability p = P[$t > t'$] for a t-distribution with d.f of n-1 = 8, gives the p value of the test. Table 4.2 provides the details of the t-test.

P-value of the t-test for the upper arm, shoulder and lower back were 0.38, 0.19 and 0.05, respectively. Thus at the 95% confidence level, a significant increase in body discomfort ratings of the lower back was found for 122cm glove port height for lower back versus the 132cm glove port height with an average increase of 1.0 points.

Table 4.1 Subject-wise Body Discomfort Ratings and t-test of Difference Between Glove Port Heights

Subject	Upper arm			Shoulder			Lower back		
	122 cm	132 cm	Diff	122 cm	132 cm	Diff	122 cm	132 cm	Diff
1	3	0	3	2	0	2	5	2	3
2	3	2	1	2	3	-1	3	2	1
3	4	8	-4	5	8	-3	0	1	-1
4	0	2	-2	2	1	1	3	1	2
5	5	6	-1	5	10	-5	5	5	0
6	0	0	0	0	0	0	6	2	4
7	0	5	-5	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	5	0	5	0	0	0	0	0	0
Average difference			-0.33			-0.67			1.0
Standard deviation			3.162			2.121			1.658
Test statistics t'			-0.316			-0.943			1.809
P value of the test			0.38			0.19			0.05

Based on the post experiment surveys, practically all participants perceived that the experimental task was not too long or not too hard. Only the subject # 6 though the experimental task was too long when the glove port height was set at 122cm. All participants found the lighting level adequate for the experimental task. Average scores of general survey questions about the task difficulty levels are summarized in Table 4.2. Task difficulty ratings were assessed in a scale of 0 to 10 with 10 being stressful, 5 being some (moderate) stress and 0 being no stress. Highest average score for stressfulness score of 5.8 was given to the "pouring water to the beaker or bottle" task. It appeared within the compact enclosure of the glove box, handling liquid filled bottle was perceived to be most stressful. This was probably the precise muscular control required for the task, as well as trying to avoid spilling liquid. The average scores were not appreciably different for the two glove port level for any specific tasks. Appendix F contains the raw stressfulness scores by the participants. A subject-wise matched paired *t*-test revealed no effect (α=0.05) of glove port height on any of the individual tasks.

Table 4.2 Average Rating Scores of Task Difficulty Levels in a Scale of 0 to 10

Task #	Specific task	Score	
		122 cm	132 cm
1	Holding your arms through the arm ports and into the gloves	3.0	2.3
2	Using the plastic spoon to scoop either drink mix or sugar into the container	2.3	2.2
3	Pouring water into either the beaker or the 250mL bottles	5.8	4.8
4	Using the plastic pipette	1.6	1.6
5	Screwing the caps onto the plastic bottles	1.3	1.6
Average score		2.8	2.5

4.2 Rectified Average EMG Levels

EMG raw data in milli-volts was collected from four muscle groups at a rate of 1000 Hz for approximately 15 seconds for the normalization task and on an average 13 minutes for the experimental task. Thus total number of data points per subject for each experimental session was 15*1000*4 =60,000 for normalization and 13*60*4*1000 = 3,120,000 for each experimental session. Raw EMG data contains both positive and negative voltage values, depending on the direction of the action potentials with respect to the bipolar skin electrodes. At any instant, a positive or a negative voltage is collected at the bipolar electrode. The positive or negative sign represents only a direction in current, but the amplitude of the signals represents the strength of the action potentials generated within the muscle, which is an indicator of the internal muscle contraction force generated at that moment. Figure 3.2 shows a sample plot of the raw EMG data from four muscle groups for one session of the experimental task.

Each set of raw EMG signals in milli-volts was first rectified, and then the average score was taken. The mean amplitude of the rectified EMG signals for each of the four muscle groups both for the normalization and experimental task were determined using the Bio-analysis software. For the normalization process, markers were used to indicate the starting and completion when the normalization task was being done. The time interval between these markers was used for averaging the normalization of EMG data. This time interval was approximately 15 seconds. For the task EMG, the time interval selected was over the entire task duration over which the average amplitude was determined.

The strength of EMG signals sensed at the bipolar electrode is highly sensitive to the electrical conductivity of the skin layer which separates the muscle and the electrode. This conductivity is affected by the condition of the skin where the electrodes are applied and also on the location of the electrodes with respect to the muscle. As a result of this the task EMG amplitudes for 122 cm and 132 cm glove port heights cannot be compared directly, because the EMG data was collected on two different days with new surface electrodes placement on the second day, which may change the conductivity drastically.

4.2.1 Normalization of the Average Rectified EMG Signals

To compare the average EMG amplitude between the two task conditions, the rectified average amplitude was normalized by dividing it by the rectified average amplitude of the normalization task. Because in each of the experimental session, both normalization and experimental tasks were performed without disturbing electrode placements, so no changes in conduction properties are expected. Thus the normalized task EMG amplitudes measured on two different days, now expressed in terms of the percent of the normalization EMG, can be compared.

4.2.2 Comparison of the Normalized EMG

Table 4.3 provides the rectified average EMG values from trapezius muscle for normalization and experimental task in volts and normalized task EMG in percent both for 122cm and 132cm glove port heights. The last column of the table provides increase in normalized EMG level which is calculated by subtracting the normalized EMG score of 132cm from that of the 122cm. Similar computations for other three muscle groups – anterior deltoid, biceps and erector spinae are provided in Appendices H – J.

For the trapezius muscle, normalized EMG (NEMG) increased for all subjects for the 132cm height, with an average increase of 33.1/41.7 = 79% of trapezius muscle activity when compared to that of 122cm height.

Table 4.3 Average EMG Activity of the Trapezius Muscles in Participants at 122 cm and 132 cm Glove Port Heights

Participant	122 cm			132 cm			Increase in normalized EMG
	Rectified average EMG (volt)		Normalized EMG (%)	Rectified average EMG (volt)		Normalized EMG (%)	
	Norm	Task		Norm	Task		
1	0.033	0.010	29.8	0.024	0.021	87.6	57.9
2	0.045	0.012	27.4	0.051	0.015	30.2	2.8
3	0.072	0.038	52.2	0.069	0.052	74.4	22.1
4	0.038	0.008	21.9	0.020	0.008	41.8	19.9
5	0.035	0.008	22.1	0.047	0.025	51.9	29.7
6	0.034	0.011	33.1	0.018	0.013	71.2	38.1
7	0.038	0.023	60.3	0.041	0.058	142.1	81.8
8	0.031	0.020	64.5	0.022	0.017	76.7	12.2
9	0.028	0.018	64.2	0.026	0.025	98.0	33.8
		Average	41.7			74.9	33.1

For the anterior deltoid, (Appendix H), seven participants out of nine showed and increase in normalized EMG. The overall average increase of NEMG was 2.9, which constitutes 2.9/20.9 = 13.9% increase over NEMG for the 122cm height, (Appendix H).

For the bicep muscles, (Appendix I), an increase and decrease in NEMG is equally distributed among the participants, except for participant #3. Participant #3 hand an abnormally high increase of 77.5. Upon scrutiny of the raw data, no explanation could be found for such an unusually high value. Since the data point could not be discarded, the average NEMG for the biceps increased by 10.3 for the 132cm height which constitutes 10.3/24.0 = 42.9% increase over the 122cm value.

During processing of the normalization, data for erector spinae muscle for the 132cm heigh was lost for participant #1. As a result, participants NEMG values could be compared, (Appendix J). The rest of the participants NEMG varied widely in both directions. Overall, there was a (14.2/103.8 = 13.7%) decrease in the NEMG for the 132cm height.

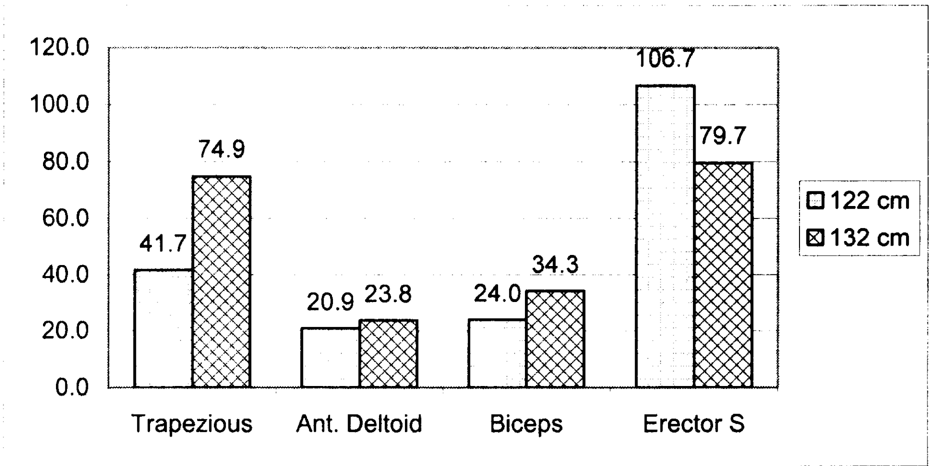


Figure 4.2 Normalized EMG scores averaged over all participants for 122 cm and 132 cm glove port height.

Figure 4.2 summarizes the average NEMG's over all participants for the four muscle groups. Clearly, the first three muscle groups, i.e., trapezius, anterior deltoid and biceps, show a decline for a glove port height of 122cm. As opposed to that of erector spinae experienced an increase. This is exactly the effect that was anticipated.

Here it should be stressed that average NEMG values from the individual muscles should not be compared to each other. For example, average NEMG for a trapezius muscle is 74.9 as opposed to that of biceps is 24.0 for 122cm height. Even though it shows that the bicep was comparatively carrying a lesser load, but the ultimate fatigue characteristics depends on the maximum voluntary contraction capacity, (MVC), of the individual muscles. MVC's for the individual muscle groups were not determined in this research.

A one tailed t-test of difference of NEMG has been performed (Table 4.4). At $\alpha = 0.05$, the increase in trapezius NEMG was proved to be significant, where other differences were not.

Table 4.4 Statistical Analysis of difference in the average activity in the muscle groups

	Trapezius	Ant. Deltoid	Biceps	Erector Spinae
Mean difference	33.1	2.9	10.3	-14.2
Stdev of diff	24.2	6.9	26.7	42.2
T-statistics	4.114	1.267	1.156	-0.948
P-value	0.002	0.120	0.141	0.185

4.3 Analysis of Muscle Fatigue

The Median Frequency was used as a filter for all four muscles to analyze the raw EMG signal. When using the Median Frequency Filter, options are given to choose the amount of data points to be lumped together for analysis. The number of data points that were chosen for this analysis was 4096. This was selected after given trials with other selections. This option provided a smoother plot. The program was set up before hand to record 1000 readings per second, so for each point in the median frequency plot, there is approximately four seconds of data analyzed. What was expected to be found, if there was indeed any fatigue, would be a general decrease (negative slope) of the median frequency over time. But, upon examination, no discernable trends were evident while using the median frequency filter on any of the participants muscle groups for either test condition. Figure 4.3 shows the median frequency plot for participant #1.

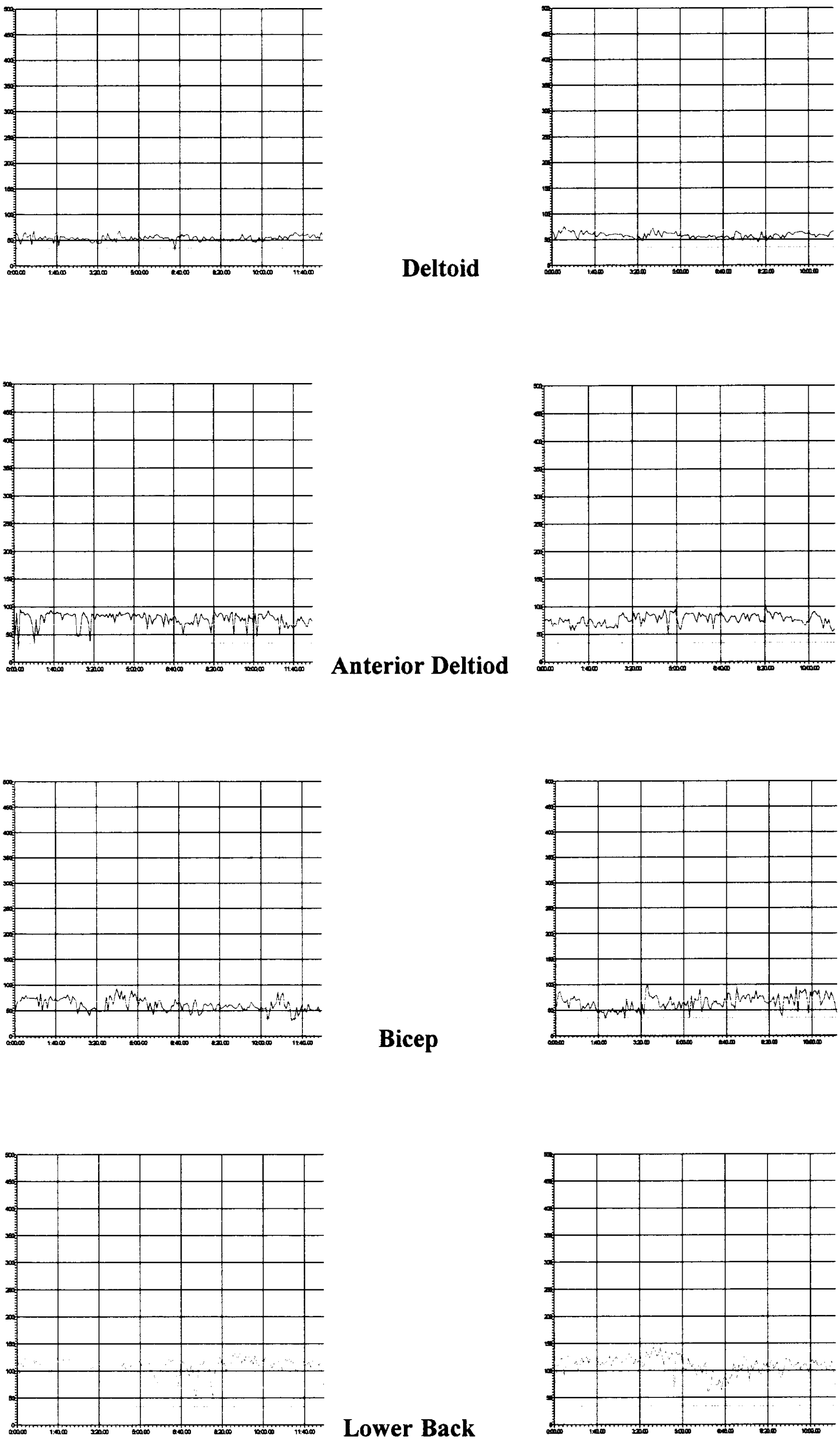


Figure 4.3 Median frequency plot over time for participant #1.

The power spectrums for all four muscles at both 122cm and 132cm were analyzed for a downward shift that would indicate that fatigue took place. Three of the first four participants had a shift in their power spectrums (mean frequency) for the trapezius muscle, while the other muscle groups were found to have weak or no discernable shifts. The other participants had little or no shifts in all other muscle groups from 122cm to 132cm. Appendix K shows Participant #1 Power Spectrum 'shift' from 122cm to 132cm. Both median frequency plot and power spectrum analysis could not establish any change in fatigue level in any of the muscle groups for the glove port heights. This is possibly due to the fact that the total experimental tasks were of small duration and light in nature. Longer experimental tasks would probably bring out any difference in the fatigue levels when working at different heights.

CHAPTER 5

CONCLUSION

This research investigated the effect of glove port height on upper body muscle stress in a simulated laboratory experiment. The experiment allowed for a wide range of muscle groups to be used along with varying degrees of dexterity while being constrained in an effective simulation of a real glove box work station. The adjustable table used to raise and lower the workstation and glove port heights allowed for physiological effects different from previous studies with glove boxes.

Previous studies (Whitemore et al. 1994; Whitemore and Berman, 1996) found similar survey results to this study when comparing two work stations, whether it was height of the workstation or positioning at the workstation. This study found results that reinforce posture sensitivity in workstation design. On average, the lower work station found a higher perceived stress on the lower back, which was found to be statistically significant ($p = 0.05$) attributed to bending forward. Also, it was anticipated that higher workstations put more stress on the shoulders and upper arms. Findings of this study were not statistically significant for trapezius, anterior deltoid and biceps. However, average perceived discomforts were lower for those muscles, when working with lower heights.

Results of this study in terms of Normalized EMG scores found that on average, the trapezius, anterior deltoid, and bicep muscles had higher Mean Activities at 132cm than were found with the 122cm glove port height, suggesting that more muscle activation was used at 132cm than at 122cm. Increase in NEMG of trapezius was statistically significant when glove port height was set to 132 cm.

Results of this study in terms of power spectrum analysis, where as the mean frequency is analyzed for a shift in the average frequency, indicating fatigue, found that several participants showed a small shift their power spectrums for the trapezius muscle groups, but little or no shifts were found in any other muscle groups. No definite conclusion could be drawn from the data that was given from the program. Therefore, no muscle fatigue was found anywhere except for in several participants in the trapezius muscle groups. This may be attributed to the short duration of the experimental tasks.

In conclusion, results from this study reinforced the ergonomic guidelines for work height and demonstrates the importance of adjusting the correct glove port height according to the anthropometry of the users. The research also provides, for the first time, a set of quantitative data on upper body stresses in such situations. Further research with larger numbers of participants would be necessary to find an optimum glove port height when no height adjustment facility is available. Future studies can experiment with larger populations of participants while performing longer durations than the 15 minute task used in this study to better determine the fatiguing aspects of glove boxes. Also, if a larger group of participants is studied, finding the relationship between worker height and upper body muscle fatigue would be useful upon breaking the participants into subgroups that are separated by height.

APPENDIX A

INFORMED CONSENT FORM

OCCUPATIONAL SAFETY AND HEALTH ENGINEERING PROGRAM
DEPARTMENT OF INDUSTRIAL AND MANUFACTURING ENGINEERING
NEW JERSEY INSTITUTE OF TECHNOLOGY
323 MARTIN LUTHER KING BLVD.
NEWARK, NJ 07102

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

TITLE OF STUDY: Effect of Glove Port Heights in Glove boxes on Work Performance and Comfort of the workers for Performing Laboratory Work.

RESEARCH STUDY:

I, ____, have been asked to participate in a research study under the direction of Dr. Arijit Sengupta. Other professional persons who work with him as study staff may assist to act for them.

PURPOSE:

The objective of this study is to find body comfort levels and performance efficiency at differing arm port heights while performing laboratory tasks using a glove box. This information is being sought after by the American Glove Box Society to provide guidelines for better design of glove boxes in industry.

PROCEDURES:

I have been told that, during the course of this study, the following will occur:

1. I will be asked to fill out a pre-survey and contact information questionnaire pertaining to my current physical well being and fatigue and stress levels prior to testing.
2. Electromyography electrodes will be placed on my lower back, shoulders and arm muscles after lightly abrading the skin with an emery paper and cleaning the site with alcohol. These electrodes will be connected to the EMG preamplifier by means of electrical leads.
3. After I am connected for EMG, I will be asked to lift a 10 lb load and hold it for 2 minutes at three different upper arm positions: outstretched horizontally, 45 degrees from horizontal and vertically downward. In each of these position, EMG signals will be recorded and will be used for normalization of EMG signals.
4. After normalization, I will perform a series of simple laboratory tasks in a glove box (see attached Experimental Procedures), which will take approximately 15 to 20 minutes. During this time I will be video taped for finding out later my postural load and task completion times.

5. Immediately after the completion of the experimental task, I will be asked to fill out a post-survey to obtain my body discomfort levels due the performance of the experimental tasks.
6. EMG electrodes will be removed and I will be asked to come back 2 days later to perform similar tasks and repeat the steps previously stated with a different height of the workstation.

PARTICIPANTS:

I will be one of about 20 participants to participate in this trial.

EXCLUSIONS:

I will inform the researcher if any of the following apply to me:

If I am not between the ages of 18 and 65.

If I have had any previous major reconstructive surgery on either shoulder in the past.

If I have a weak heart, shortness of breath, dizziness, or am diagnosed by a doctor that I should not be working for extended periods of time.

If I have had any muscular-skeletal disorders or any other conditions/diseases which may impact on the ability to perform the experimental tasks.

RISKS/DISCOMFORTS:

I have been told that the study described above may involve the following risks and/or discomforts.

Soreness of shoulder, neck, back, arm muscles. Minor itch at the electrode sites.

There also may be risks and discomforts that are not yet known.

I fully recognize that there are risks that I may be exposed to by volunteering in this study which are inherent in participating in any study; I understand that I am not covered by NJIT's insurance policy for any injury or loss I might sustain in the course of participating in the study.

In case of an emergency, the principal investigator is trained and instructed to call 911.

If I am not at least 62 inches of height, I will be provided with a platform of at least 3 inches and no greater than 6 inches to perform the experiment.

If I am taller than 78 inches of height, I will be provided with a stool or chair to perform the experiment.

If you experience soreness or other adverse effects please contact your physician immediately and contact the principal investigator.

CONFIDENTIALITY:

I understand confidential is not the same as anonymous. Confidential means that my name will not be disclosed if there exists a documented linkage between my identity and my responses as recorded in the research records. Every effort will be made to maintain the confidentiality of my study records. If the findings from the study are published, I will not be identified by name. My identity will remain confidential unless disclosure is required by law.

PAYMENT FOR PARTICIPATION:

I have been told that I will receive $10 dollars per hour compensation for my participation in this study. If I withdraw without finishing the experiment to its completion, or I am unable to finish the experiment due to excessive pain, discomfort, or unforeseen medical condition, I will be paid $5 dollars minimum for my effort.

RIGHT TO REFUSE OR WITHDRAW:

I understand that my participation is voluntary and I may refuse to participate, or may discontinue my participation at any time with no adverse consequence. I also understand that the investigator has the right to withdraw me from the study at any time.

INDIVIDUAL TO CONTACT:

If I have any questions about my treatment or research procedures, I understand that I should contact the principal investigator at:

Assocaite Professor Arijit Sengupta
New Jersey Institute of Technology
2517, Guttenburg Information Technologies Center (GITC)
973-642-7073

If I have any additional questions about my rights as a research subject, I may contact:

Dawn Hall Apgar, PhD, IRB Chair

New Jersey Institute of Technology
323 Martin Luther King Boulevard
Newark, NJ 07102
(973) 642-7616
dawn.apgar@njit.edu

SIGNATURE OF PARTICIPANT:

I have read this entire form, or it has been to me, and I understand it completely. All of my questions regarding this form or this study have been answered to my complete satisfaction. I agree to participate in this research study.

SubjectName:____

Signature:____

Date:_____________

SIGNATURE OF READER/TRANSLATOR IF THE PARTICIPANT DOES NOT READ ENGLISH WELL:

The person who has signed above, ______________________________, does not read English well or at all, I can read English well and am fluent in ____________________, a language the subject understands well. I have translated for the subject the entire content of this form. To the best of my knowledge, the participant understands the content of this form and has had an opportunity to ask questions regarding the consent form and the study, and these questions have been answered to the complete satisfaction of the participant.

Reader/Translator Name:_____________________________________

Signature:____

Date:_______________

SIGNATURE OF INVESTIGATOR OR REPSONSIBLE INDIVIDUAL:

To the best of my knowledge, the participant, __________________________, Has understood the entire content of the above consent form, and comprehends the study. The participants and those of his/his parent/legal guardian have been accurately answered to his/their complete satisfaction.

Investigator's Name:____
Signature:____
Date:_______________

APPENDIX B

PHOTO RELEASE FORM

New Jersey Institute of Technology
University Heights
Newark, NJ 07102-1982
Tel: (973) 596-3433

I hereby irrevocably grant to New Jersey Institute of Technology the absolute right and permission to copyright and/or publish or take or use my name, voice or photographic portraits or pictures, or in which I may be included in whole or in part, or in composite form in conjunction with my name and other identifying information, or reproductions thereof in color or otherwise, made through any media for art, print, web, advertising, film, telecast or any other lawful purpose whatsoever. I also grant New Jersey Institute of Technology the same right and permission to us written or verbal statements or testimonials made by me.

Date___________________________

Print Name ____

Signature ____

Address ____

City _________________________________ State ______________ Zip Code ________

Parent (if under 18 years old) or Guardian

____

APPENDIX C

CONTACT INFORMATION

Name: ______________________________

Address: ______________________________

____

Phone Number: ______________________________

E-Mail Address: ________________@__________

Particpant Number #:__________________________
Date: (1)______________Time____________
Date: (2)______________Time____________

APPENDIX D

PRE-SURVEY QUESTIONNAIRE

Height: ______________________________
Weight: ______________________________
Age: ______________________________

Sex: Male Female

I have never had any serious shoulder injuries?
Yes No

I do **not** have a weak heart, shortness of breath, or diagnosed by a Physician that I cannot perform physical work for extended periods of time:
Yes No

I did not any do any fatiguing upper body exercises in the past 2-3 days
Yes No

I do not feel tired or fatigued for the performance of the experimental task?
Yes No

I understand that my personal information will only be used for the purposes of this study and that all of my information is correct.

Signature: ____

APPENDIX E

POST-SURVEY QUESTIONNAIRE

Participant Number #:______________________________

Date:______________________________

Body Part Stress/Discomfort Scale

10 ---------------------------------5---0

Stress/Discomfort   Some(moderate) Stress/Discomfort   No stress/Discomfort

Using the above scale, rate the stress/discomfort at the following body parts in the table below:

Hand –	Upper back –
Arm –	Lower back –
Upper arm –	Stomach -
Shoulder –	Thigh –
Neck –	Knee –
	Foot -

Using the above rating scale, what level of stress did you perceive while performing these specific tasks? :

Holding your arms through the arm ports and into the gloves: ____________

Using the plastic spoon to scoop either drink mix or sugar into the

Containers: ____________

Pouring water into either the beaker or the 250mL bottles: ____________

Using the plastic pipette: ____________

Screwing the caps onto the plastic bottles: ____________

General Survey

Did the task seem too hard? Yes No

If yes, what was hard about it? ____________________

Did the task seem to be long in duration? Yes No

Was the lighting adequate? Yes No

Anywhere on your person that was in pain besides those indicated by earlier questions?

____

Any other remarks you may have to the experimental task:

____

____

If you experience soreness or other adverse effects please contact your physician immediately and contact the principal investigator

Associate Professor Arijit Sengupta
New Jersey Institute of Technology
2517, Guttenburg Information Technologies Center (GITC)
973-642-7073
Department of Engineering Technology

APPENDIX F

BODY DISCORMFORT RATINGS

Table F.1 Body Discomfort Ratings in 0-10 Scale After Completion of the Laboratory Tasks.

POST SURVEY 122 CM (48 INCHES)

Participant	Hand	Arm	Upper Arm	Shoulder	Neck	Upper Back	Lower Back	Stomach	Thigh	Knee	Foot
1	2	2	3	2	2	1	5	0	0	0	0
2	1	2	3	2	2	1	3	1	2	1	1
3	4	5	4	5	3	1	0	1	0	2	3
4	7	1	0	2	0	1	3	0	0	0	2
5	5	5	5	5	4	5	5	3	5	5	6
6	0	0	0	0	0	0	6	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	4	5	0	0	0	0	0	0	0	0
Average	2.1	2.1	2.2	1.8	1.2	1.0	2.4	0.6	0.8	0.9	1.3

POST SURVEY 132 CM (52 INCHES)

Participant	Hand	Arm	Upper Arm	Shoulder	Neck	Upper Back	Lower Back	Stomach	Thigh	Knee	Foot
1	0	0	0	0	0	1	2	0	1	0	0
2	1	3	2	3	2	1	2	1	2	2	1
3	4	5	8	8	3	2	1	2	0	3	5
4	0	0	2	1	0	2	1	0	0	0	0
5	3	4	6	10	7	5	5	3	5	6	6
6	4	0	0	0	0	0	2	0	0	0	0
7	0	0	5	0	0	0	0	0	0	0	0
8	5	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	
Average	1.9	1.3	2.6	2.4	1.3	1.2	1.4	0.7	0.9	1.2	1.5
Overall average	2.0	1.7	2.4	2.1	1.3	1.1	1.9	0.6	0.8	1.1	1.4

APPENDIX G

GENERAL SURVEY RESULTS

Table G.1 General Survey Questions Asked After the Laboratory Activities.

POST SURVEY 122 CM (48 INCHES)

Participant	Holding your arms	Plastic Spoon	Pouring Water	Pipette	Caps	Too Hard	Too Long	Lighting
1	0	0	3	0	0	No	No	Yes
2	3	3	5	1	1	No	No	Yes
3	6	5	7	3	3	No	No	Yes
4	0	1	7	2	0	No	No	Yes
5	4	3	6	4	3	No	No	Yes
6	4	5	8	3	4	No	Yes	Yes
7	0	0	5	0	0	No	No	Yes
8	5	0	5	0	0	No	No	Yes
9	5	4	6	1	1	No	No	Yes
Average	3.00	2.33	5.77	1.55	0.77	100%	89%	100%

POST SURVEY 132 CM (52 INCHES)

Participant	Holding your arms	Plastic Spoon	Pouring Water	Pipette	Caps	Too Hard	Too Long	Lighting
1	0	1	3	1	1	No	No	Yes
2	1	1	3	1	1	No	No	Yes
3	3	6	7	3	2	No	No	Yes
4	0	1	2	1	1	No	No	Yes
5	8	7	10	6	4	No	No	Yes
6	2	3	6	2	3	No	No	Yes
7	0	0	5	0	0	No	No	Yes
8	5	0	5	0	0	No	No	Yes
9	2	1	2	0	2	No	No	Yes
Average	2.33	2.22	4.77	1.55	1.55	100%	100%	100%

APPENDIX H

ANTERIOR DELTIOD MUSCLE DATA

Table H.1 Average EMG Activity of the Anterior Deltoid Muscle in Participants at 122 cm and 132 cm Glove Port Heights

Participant	122 cm			132 cm			Increase in normalized EMG (%)
	Rectified average EMG (volt)		Normalized EMG (%)	Rectified average EMG (volt)		Normalized EMG (%)	
	Norm	Task		Norm	Task		
1	0.128	0.020	15.8	0.141	0.033	23.2	7.4
2	0.202	0.028	14.0	0.279	0.023	8.1	-6.0
3	0.116	0.040	34.2	0.103	0.026	24.8	-9.4
4	0.076	0.015	20.0	0.100	0.021	21.0	1.0
5	0.129	0.010	7.6	0.110	0.016	14.6	7.1
6	0.188	0.016	8.4	0.068	0.013	19.4	11.0
7	0.092	0.036	38.8	0.093	0.041	43.8	5.1
8	0.176	0.027	15.2	0.087	0.021	24.0	8.8
9	0.064	0.022	33.9	0.061	0.022	35.1	1.2
		Average	20.9			23.8	2.9

APPENDIX I

BICEPS MUSCLE DATA

Table I.1 Average EMG Activity of the Biceps Muscle in Participants at 122 cm and 132 cm Glove Port Heights

Participant	122 cm			132 cm			Increase in normalized EMG (%)
	Rectified average EMG (volt)		Normalized EMG (%)	Rectified average EMG (volt)		Normalized EMG (%)	
	Norm	Task		Norm	Task		
1	0.098	0.010	10.2	0.064	0.012	18.0	7.8
2	0.039	0.012	31.6	0.039	0.011	26.8	-4.9
3	0.109	0.025	22.4	0.318	0.318	99.9	77.5
4	0.039	0.012	29.3	0.034	0.008	24.1	-5.2
5	0.101	0.021	20.6	0.130	0.020	15.4	-5.3
6	0.119	0.017	13.9	0.063	0.010	16.3	2.4
7	0.079	0.025	31.7	0.068	0.029	42.9	11.1
8	0.074	0.018	24.1	0.043	0.018	41.5	17.4
9	0.059	0.019	31.8	0.071	0.017	23.5	-8.3
		Average	24.0			34.3	10.3

APPENDIX J

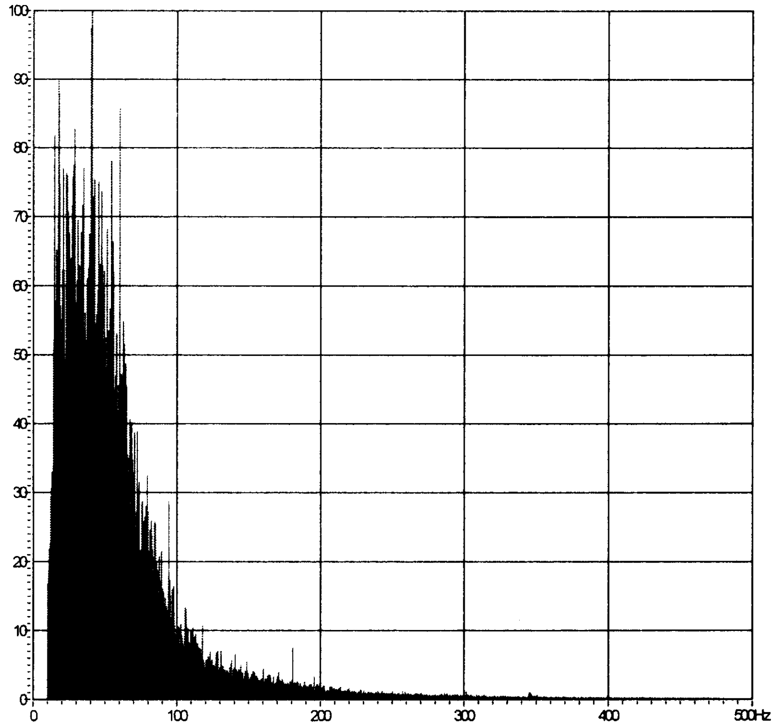
ERECTOR SPINAE MUSCLE DATA

Table J.1 Average EMG Activity of the Erector Spinae Muscle in Participants at 122 cm and 132 cm Glove Port Heights

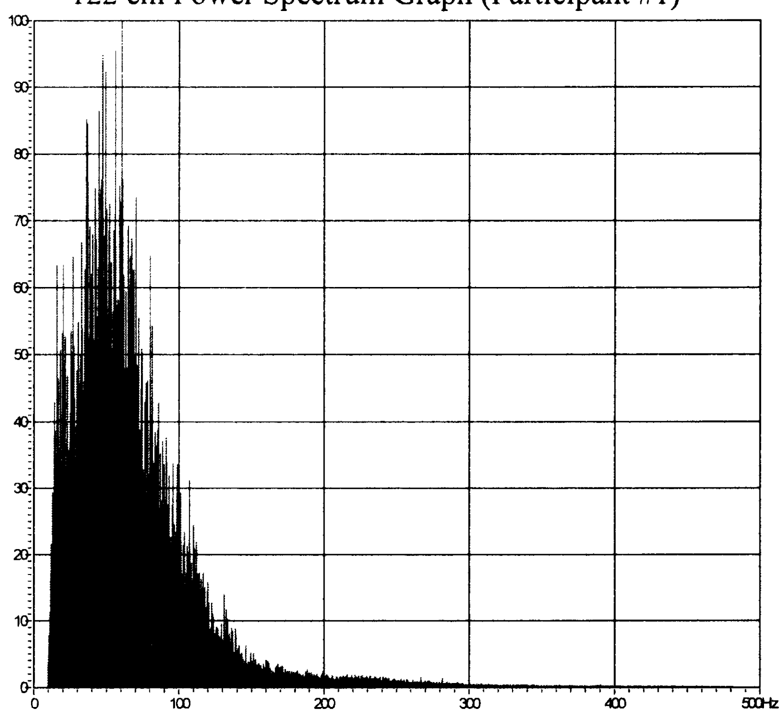
Participant	122 cm			132 cm			Increase in normalized EMG (%)
	Rectified average EMG (volt)		Normalized EMG (%)	Rectified average EMG (volt)		Normalized EMG (%)	
	Norm	Task		Norm	Task		
1	0.005	0.007	130.0	0.000	0.005	0.0	n/a
2	0.006	0.012	192.0	0.008	0.008	90.9	-101.1
3	0.022	0.024	109.2	0.068	0.068	100.0	-9.2
4	0.004	0.007	152.9	0.080	0.079	99.7	-53.3
5	0.010	0.007	76.3	0.014	0.011	80.0	3.7
6	0.017	0.013	75.8	0.011	0.008	76.2	0.4
7	0.019	0.011	58.4	0.061	0.047	77.0	18.5
8	0.011	0.007	60.0	0.008	0.005	64.5	4.5
9	0.004	0.005	105.9	0.006	0.008	129.2	23.3
		Average	106.7			79.7	-14.2

APPENDIX K

POWER SPECTRUM GRAPH



122 cm Power Spectrum Graph (Participant #1)



132 cm Power Spectrum Graph (Participant #1)

Figure K.1 Example power spectrum graphs of participant #1 that were analyzed.

REFERENCES

1. Chaffin, D B. (1973), Surface electromyography frequency analysis as a Diagnostic Tool, Journal of Occupational Medicine 11 : 109-115.

2. Das, B. Sengupta, A: (1996), Industrial Workstation Design: A Systematic ergonomics Approach, Applied Ergonomics, Volume 27, No. 3, 157-163.

3. Eastman Kodak, (1983), Ergonomic Design for People at Work Volume 1 Human Factors Section Health Safety and Human Factors Laboratory 1983 30-50.

4. Eastman Kodak, (1986), Ergonomic Design for People at Work, Volume 2, 20-30, 217-230.

5. Kroemer,K.H.E. Grandjean, E. (1997), Fitting the Task to the Human, (Fifth Edition) 35, 53, 147-150.

6. Konz, S. (1995), Work Design Industrial Ergonomics (Fourth Edition)Part 4, Chapter15, 200-211.

7. Kumar, S. Mital, A. (1996), Electromyography in Ergonomics, 1-48, 163-182.

8. Schudlt, K, Ekholm J, Harms-Ringdahl K, et al. (1986), Effects of Changes in Sitting Work Posture on Static Neck and Shoulder Muscle Activity, Ergonomics, 1525-1537.

9. Sengupta, A.K Das, B. (2000), Maximum Reach Envelope for the Seated and Standing Males and Females for Industrial Workstation Design, Ergonomics 44(g): 1390-1404.

10. USDHH (U.S. Department of Health and Human Services), (1992), Selected Topics in Surface Electromyography for use in the Occupational Setting: Expert Perspective, publication number 91-100, March 1992.

11. Whitemore, Mihriban, McKay, Timothy D., Mount, Frances E. (1994), Ergonomic Evaluation of a Spacelab Glove box, International Journal of Industrial Ergonomics 16, 155-164.

12. Whitemore, Mihriban and Berman, Andrea H. (1996), Ergonomic Evaluation of Microgravity Workstations NASA CR – 1996 – 201378. 1-20.

13. Website: Internet Explorer, http://www.gloveboxsociety.org, 2006.