ABSTRACT

AN EROGONOMIC JOB ANALYSIS OF A WORK PROCESS WITHIN A GLOVEBOX

by
Tamara McNair

Gloveboxes have been used in various industries to protect the user and environment from hazardous materials and/or isolate the materials from environmental contamination. As the use of gloveboxes continues to grow in an effort to reduce contamination and the dependency of personal protective equipment as well as increase the level of safety through containment, technical design specifications have been studied and investigated to great lengths. Unfortunately, ergonomic design criteria for this enclosed and restricting workstation have not been extensively investigated or documented.

This research evaluated ergonomic risk factors associated with the use of a glovebox in a pharmaceutical production facility. Using direct observation and detailed job analysis, design shortcomings were identified. Four ergonomic assessment tools were used to evaluate the combinatorial effect of the upper limb extremity postures, applied force, recovery time, and repetition to quantify postural stresses during the vial filling task and vial capping task that were performed within the glovebox. These two tasks were found to be hazardous in terms of risk of musculosketal disorders. The scores from all of these assessments tools were indicative that these tasks could be a possible cause of work-related musculoskeletal disorders, unless administrative or engineering controls were initiated in the near future. Recommendations to improve the glovebox design have been discussed.

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APPROVAL PAGE

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Proverbs 3:13-18

Blessed is the man who finds wisdom,
the man who gains understanding,
for she is more profitable than silver and yields better returns than gold.
She is more precious than rubies;
nothing you desire can compare with her.
Long life is in her right hand;
in her left hand are riches and honor.
Her ways are pleasant ways,
and all her paths are peace.
She is a tree of life to those who embrace her;
those who lay hold of her will be blessed.

I extend my deepest love and appreciation to my family and friends for their support.

I owe all my blessings to GOD because with him anything is possible.

Thank You.

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To All of You...Thank You.

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Access Panel - A removable and resealable panel used for interior access

AGS – American Glovebox Society

Airlock – A transition enclosure for material movement into and out of the glovebox that maintains the primary containment. The term is interchangeable with transfer lock.

Anthropometry – The study or use of comparative human body measurements.

Barrier – A boundary that provides physical separation.

Cervical Nerve Root Syndrome – caused by changes in the cervical spine from muscular tension such as neck tension syndrome.

Containment Glovebox – A specific type of glovebox that protects the operator and ambient environment from the material being processed.

CTD – Cumulative Trauma Disorder. A family of musculoskeletal or neurological illnesses or symptoms that appear to be associated with repetitive tasks in which forceful exertions of the fingers, or deviations or rotations of the hand, wrist, elbow, or shoulder are required. Also called Repetitive-Motion Disorder or Musculoskeletal Disorder (MSD).

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CTS – Carpal Tunnel Syndrome. The entrapment of the median nerve of the hand and wrist in the passageway (tunnel) through the carpal bones of the wrist.

Cubital Tunnel Syndrome - entrapment compression of the ulnar nerve at the elbow.

De Quervain's Disease – most common type of stenosing tenosynovitis that affects the tendons on the radial side of the wrist at the base of the thumb.

Epicondylitis – irritation and/or inflammation of the tendons attaching to the epicondyles.

Ganglionic Cyst – an affected tendon sheath that swells with fluid, causing a lump beneath the skin.

Glove – An interface between the worker and the glovebox interior that maintains the barrier while allowing the worker to perform work with his hands.

Glovebag – A glovebox that is made from flexible plastic film.

Gloveport – The aperture attached to the glvebox that secures the glove.

GMP – Good Manufacturing Practices

Guyon's Tunnel Syndrome – entrapment compression of the ulnar nerve at the wrist.

HEPA – High Efficiency Particulate Air filter. HEPA is a registered trademark of HEPA Corporation.

HFEL – Human Factors and Ergonomics Laboratory

Isolation Glovebox – A specific type of glovebox that protects the material being processed from the operator and/or environment.

Isolator – An industry-specific type of glovebox combining features of both the containment glovebox and isolation glovebox.

Radial Tunnel Syndrome - entrapment compression of the radial nerve at the wrist.

Rotator Cuff Tendinitis – inflammation of the muscle tendons that form the cuff over the shoulder joint.

SI – Strain Index

Tendinitis (Tendonitis) – inflammation of the tendon.

Tenosynovitis – any form of inflammation involving the tendon, synovial sheath, or both.

Thoracic Outlet Syndrome – Compression of both nerves and blood vessels in the neck and shoulder

CHAPTER 1

INTRODUCTION

Ergonomics is an interdisciplinary field concerned with the performance of humans at work, and how these workers cope with the working environment as well as interact with machines (Weimer, 1995). Similarly, human factors focuses on human beings and their interaction with products, equipment, facilities, procedures, and environments used in work and everyday living. Therefore, both terms are usually used synonymously when explaining the effectiveness and efficiency of fitting the job task to the worker by understanding the capabilities, limitations, and needs of the people (Sanders and McCormick, 1993). Overall, ergonomics aims to boost certain desirable human values such as greater user acceptance and effectiveness in the workplace, improved quality of life, and increased comfort and job satisfaction by:

- Eliminating or minimizing injuries, strains, and sprains
- Reducing fatigue and overexertion
- Reducing absenteeism and labor turnover
- Improving the quality and quantity of output
- Minimizing lost time and cost associated with injuries
- Maximizing safety, efficiency, and productivity (Sanders and McCormick, 1993; Weimer, 1995).

This research originated from an ergonomic assessment at a pharmaceutical facility that involved the evaluation of a variety of production and distribution processes that introduced employees to the potential risk of musculoskeletal disorders (MSDs). After having an overall idea of the injury and illness records at the facility, records specific to ergonomic related injuries and illnesses became the key focus. The incidents being identified from the OSHA 200 logs included suspect musculoskeletal disorders or symptoms such as sprain, strain, inflammation, or discomfort to the upper extremities and the back. Since the manufacturing and distribution departments became operational, it was observed that the facility had 14 MSD cases out of 47 reported incidents.

Although it was not listed in the OSHA 200 logs as a cause of injury, one particular piece of equipment that was of concern was an isolation glovebox. The chemically inert Teflon structure known for its excellent anti-static and insulating properties was used to maintain a humidity-controlled environment while employees placed pharmaceutical material, in the form of microbeads, into vials, and capped the vials for further processing. The glovebox and capped vials were used to maintain the chemical stability of the microbead within it until it was used for its intended purpose. The filled vials were used by healthcare and diagnostic facilities to conduct blood tests.

Observations and analysis of employees working with this glovebox displayed potential risk for workers developing a variety of musculoskeletal disorders of the upper extremities as a result of its design and the operations being performed. Furthermore, these observations were corroborated by the employees' concern with restricted movement and lighting when working within the glovebox. Therefore, the evaluation of this glovebox was attempted to shed light on the ergonomic hazards in an effort to prevent, reduce, or eliminate the hazards.

CHAPTER 2

LITERATURE REVIEW

As the use of gloveboxes increases in a variety of industries to protect the operators from contamination or to isolate the materials from environmental contamination, a myriad of designs have been developed to meet process specifications. Although several companies and organizations have developed design guidelines and technical specifications for gloveboxes, many of them failed to consider and extensively investigate the human factors aspect. Documentation on ergonomic requirements is scant. The Human Factors and Ergonomic Laboratory (HFEL) at Johnson Space Center conducted several studies to evaluate gloveboxes for ergonomic compliance in an effort to establish findings that will prove beneficial to the design elements of spacelab and ground gloveboxes.

The ergonomic studies were conducted in space shuttles or in simulated microgravity atmospheres to evaluate gloveboxes while performing biological experiments that are typically conducted while in flight. Although the assessments were geared towards microgravity environments, most of the ergonomic concerns discovered can be applicable to ground gloveboxes as well. The main difference between a spacelab glovebox and ground glovebox is the size of the glovebox, which influences the work volume. As shown in Figure 2.1, the spacelab glovebox is a lot smaller than the ground glovebox of interest due to the allotted space given within the space shuttle. In addition, as a result of the microgravity environment, the spacelab glovebox requires the operators' feet to be restrained, as illustrated in Figure 2.2, in order to execute their experiments successfully.

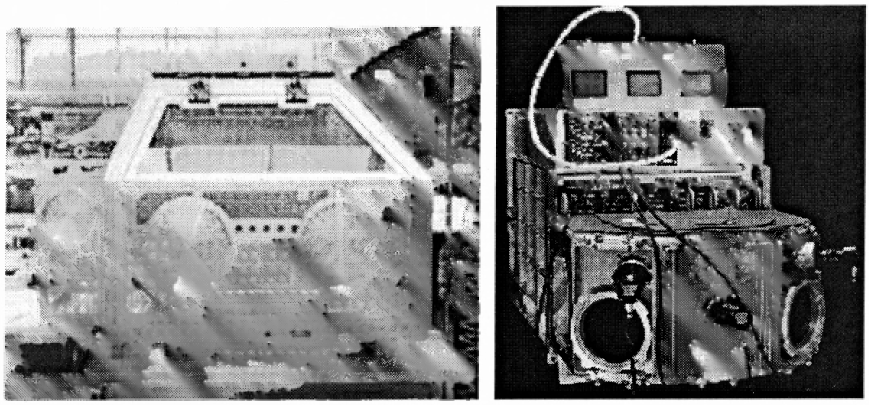

Figure 2.1 Pictures of two spacelab glovebox designs.
(Source: Whitmore et al. 1995)

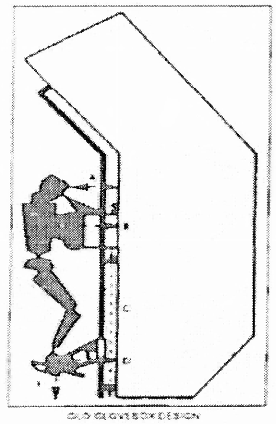

Figure 2.2 Image of operator posture while using spacelab glovebox.
(Source: Whitmore et al. 1995)

The ergonomic studies conducted by HFEL used video analysis, computer modeling, questionnaires, and a compilation of operators' remarks to assess and investigate ergonomic design concerns with gloveboxes. The studies included non-experienced subjects to experienced crew members; a job task time of 20 – 30 seconds for 40 time intervals to 4 – 6 hours per day; subject's height ranged from 5 feet (5th percentile Japanese female) to 6 feet and 4 inches (95th percentile American male); and the number of subjects ranged from 2 to 5 per experiment. In addition, the studies typically examined and required feedback on the same aspects of the glovebox operation.

For instance, pre-, in-, and post-flight questionnaires and comments were commonly geared towards overall configuration or general design of the glovebox, physical discomfort with task performance, glovebox accessories, and foot restraints. Based on the in-flight subjects' feedback, human computer modeling using anthropometric models and video analysis were used to examine these issues further, and develop possible solutions to unacceptable and borderline design aspects. The results from these studies were generally similar in nature. They particularly raised concerns over unacceptable and borderline gloveport design and cuff size, distance between gloveports, work volume and area accessibility, viewing window size, and reach capabilities that led to a "hunched" posture and upper extremity discomfort (Mihriban and Mount, 1995a; Mihriban and Mount, 1995b; Mihriban et al. 1995). However, many ergonomic concerns that plagued the spacelab glovebox such as work volume, foot restraints, cuff size, and the distance between gloveports does not typically affect ground gloveboxes because ground gloveboxes are not spatially restricted like spacelab gloveboxes.

2.1 Gloveboxes

Gloveboxes are sealed and environmentally controlled work enclosures that provide the primary physical barrier between the operator and the work area. The purpose of the glovebox is protection and/or isolation, depending on the type of glovebox. The physical barrier may isolate a sensitive material inside the glovebox from contamination by the environment and operator. This type of glovebox is known as an isolation glovebox. Whereas, a containment glovebox protects the ambient environment and operator from hazardous materials being manipulated within the work enclosure. Lastly, an isolator, which is an industry-specific type of glovebox, combines features of both of the containment and isolation gloveboxes (AGS, 1998). Although there are three basic types of gloveboxes, their structural characteristics allows them to come in a multitude of shapes and sizes depending on the features needed to safely perform the specified task.

For example, one stainless steel glovebox was designed to accommodate the repackaging and treatment of alpha-beta contaminated and transuranic radioactive waste stored in 3,500 drums that varied from 30 to 85 gallon drums. In order to properly protect the workers from the radioactive material, and accommodate the amount of material being handled including the size of the containers and the equipment being used, this glovebox was designed to be as long as 45 feet, as wide as 50 inches, and as high as 55 inches (Tobias, 2003). Whereas, in other areas such as pharmaceutical research, gloveboxes that are typically built with plastic material can be as small as 42 inches long, 18 inches wide, and 24 inches high for use in labs when handling potent compounds ("Critical Environmental", 2004). As a result of the use of gloveboxes in various industries, they can be altered or designed to meet the necessary specifications that depend on the material being handled, and the environment in which it should be handled as well as the job location, which can vary from a research lab to a space shuttle to a warehouse.

2.1.1 Structural Characteristics

The American Glovebox Society (AGS) has developed guidelines for the application of gloveboxes from design to fabrication to decommissioning. The document provides information for each component with its specific requirements for gloveboxes (AGS, 1998). However, this thesis looks at design aspects that can impact the ergonomics of gloveboxes in relation to the issues encountered in the case study.

2.1.1.1 Shell. The design of gloveboxes should be compatible with the process and the accessibility of equipment and material to be installed, transported, and removed as well as human limitations. The basic frame of the glovebox is referred to as the shell, and numerous items like safety, human factors, appurtenances, and other interfaces should be considered before designing it. The shell takes into account corners, tolerances, materials, and basic dimensions that are based primarily on human limitations (AGS, 1998).

There are two basic types of glovebox frames that are dependent upon the placement of the gloveports within the window. The low-profile glovebox has vertical gloveport panels below the viewing window. Unlike the low-profile glovebox, the high-profile design has the gloveports set into the sloping window, which offers an optical advantage when performing visually demanding job tasks (Eastman Kodak, 1986a). These glovebox profiles can be altered to meet the needs of the designer with respect to the dimensions, tolerances, and appurtenances such as the number and position of the gloveports and transfer devices.

Mainly from a safety perspective, another significant aspect of the shell is the material used for glovebox construction. The durability and compatibility concerns with regards to the process that will take place within the glovebox, determine the type of the material to be selected. Stainless steel is typically used because of its availability and ease of fabrication into most product forms (i.e. plate, sheets, pipe, and other shapes) along with its favorable chemical and physical properties. Stainless steel has long-term durability, low maintenance requirements, and exceptional qualities of corrosion resistance and weldability. In addition, it provides a clean, hermetically controlled environment for a broad range of manufacturing operations, such as parts degassing, temperature and humidity testing, and chemical mixing in the semiconductor, pharmaceutical, chemical, and other industries ("Critical Environmental", 2004). Other alternatives are mild steel, aluminum, and fiberglass reinforced plastic. Mild steel and aluminum are very malleable and ductile. In addition, aluminum has the property of being lightweight. However, mild steel and aluminum lack in the qualities of weldability, corrosion resistance, and strength (AGS, 1998).

Plastic gloveboxes provide a clean, low-humidity environment for critical processing operations. They are a more economical solution to a controlled processing environment for a spectrum of manufacturing and testing operations in a variety of industries. As a result of their usage in various industries, they are available in an assortment of plastic material such as polycarbonate, acrylic, and variations of polyvinyl chloride (PVC) that are discussed in the next section. Therefore, it is important to understand the job process, and keeping in mind the properties of the materials in order to properly design structural integrity into the glovebox.

2.1.1.2 Window. The primary viewing mode to see inside a glovebox is through windows, which are supported by the glovebox shell. Windows that are maximized in size and slanted at an angle of 10 to 15 degrees help to reduce potential blind spots and glare. Slanted windows also improve overall visibility inside the glovebox, and working postures compared to vertical windows. Ideally, a larger angle would be more comfortable for the worker as the work performed on items on the interior bench top of the glovebox becomes more accessible.

Depending on the process that will occur within the glovebox, the appropriate type of window material should be selected based on resistance to fire, abrasion, corrosion, and puncturing. Sometimes shielding may be applicable due largely to radioactive protection, which is generally installed outside the containment safety glass and sustained by the shell (Figure 2.3). This containment safety glass is most often used in the construction of gloveboxes because of its noncombustible properties due to the

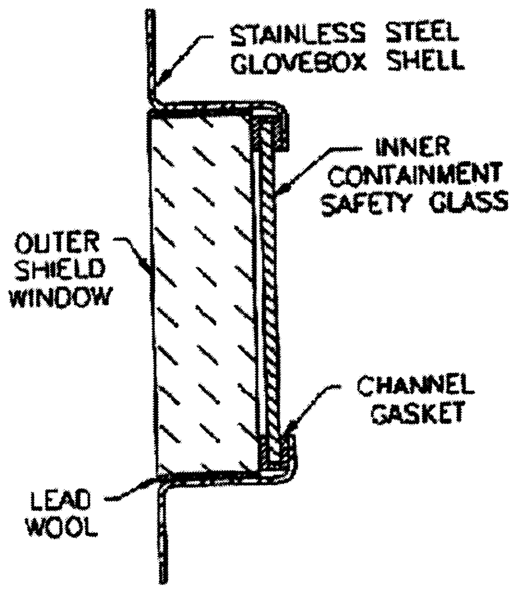

Figure 2.3 Diagram of an Inset Containment Window.
(Source: AGS, 1998)

safety plate glass being laminated by polyvinylbutyryl (PVB). Polycarbonate windows may be used to protect the window from hydrogen fluoride or other materials that are damaging to glass as long as there is an automatic fire suppression system established

(AGS, 1998). For chemical resistance, films with coatings and materials like polyvinylidene fluoride (PVDF) have been used while processes that require the use of corrosive chemicals tend to use non-dissipative PVC and polypropylene for even greater chemical resistance. Polycarbonates have been selected for operations involving thermal stress. For general-purpose operations and cost-effective reasons, acrylic has been selected as the ideal choice. Transparent static-dissipative PVC maintains a clean glovebox inside and outside because it helps eliminate static charges that attract particles (AGS, 1998; "Critical Environmental", 2004). Fiberglass reinforced plastic is extremely strong, and offers excellent thermal distribution and chemical resistance ("Durostone" Plastics, 2004). Although these are just a few of possible choices, there are a multitude of window materials available, and the selection process is based on a variety of chemical, physical, and mechanical properties such as durability, clarity, temperature and chemical compatibility (AGS, 1998).

2.1.1.3 Appurtenances. Appurtenances are vital attributes of gloveboxes because they permit work functions, seal penetrations, or provide for transfers while maintaining containment. Two features that allow access into gloveboxes without breaching containment are gloveports and transfer devices.

Gloveports are oval or round apertures that allow access inside of gloveboxes, and if necessary, they are used to secure gloves to the glovebox. From the floor, the centerline height of the gloveports is normally 48 inches, but can range from 48 to 52 inches. In addition, the spacing between horizontal centerlines of a working pair of gloveports ranges from 15 to 18 inches with a nominal spacing of 16.5 inches.

Gloveports are mounted into the glovebox shell or glovebox window by bolt rings, gasket assemblies, or welded directly into the shell. The gloveports should offer an absolute seal, and foster glove replacement without breaching containment. They are available in metal and non-metal versions with or without plugs, safety covers, and window inserts that are used to maintain containment when the gloveports are not in use.

There are a variety of transfer devices to select depending on what needs to be moved in and out of the glovebox without breaching containment. Bagports are a type of transfer device that requires a bag to be attached to the bagport by stretching the open end of the bag over the bagport ring. The seal is maintained and the bag is secured to the port ring by an elastomer ring residing in the open end of the bag. Items and/or materials are removed from the glovebox through the bagports by extracting them to the farthest end of the bag from the port ring. The bag is sealed on both ends by heat-sealing or tightly twisting the bag and wrapping it with tape in the section to be cut. This allows the material or items to be separated and removed from the glovebox without breaking containment within the glovebox.

Another type of transfer device is an airlock. Airlocks are transition zones between a clean and a contaminated environment or between specially ventilated gloveboxes, and with a fail-safe approach they can prevent contamination during transfer. Airlocks permit the transport of materials in and out of the glovebox through fairly small passageways between two sealable doors. The airlock size usually depends on the size of the items that will pass through it, and the allowable air input, which should have minimal effects on the glovebox and the transfer of contaminants. Although airlocks are designed based on the size of the items, it is more difficult to sustain the seal as the airlock increases in size. In addition, since airlocks typically do not have gloveports, items are transferred by reaching through doors that are to some extent aided by slide trays or long-handled devices (AGS, 1998).

Airlock doors are available in a variety of styles from a standard hinge, sliding (horizontal or vertical) to a pivoted door. With standard hinge door, an adequate hinge pin offset should be guaranteed to avoid binding. In addition, these doors tend to create air turbulence that may spread contamination if opened hastily. However, top-opening outer doors cause particles that are disturbed to fall back into the airlock when the door is opened, thereby improving the regulation of contamination.

A third type of transfer device is an input sphincter. It provides a means of transferring cylindrical objects such as round cartons and plastic jars that may be used to carry smaller items and powdered material into the glovebox. The sphincter is designed to fit the size of the cylinders to be used for transport. Items are introduced into the glovebox by a cylinder in the sphincter being displaced inward by pushing in a follow-up cylinder. With this type of transfer device, it is crucial to keep a cylinder in the sphincter at all times to maintain glovebox containment, and to refrain from using heavy transfer canisters and storing heavy items for long periods of time in a horizontally oriented sphincter because it can cause the gasket to set, breaking the containment seal. Finally, a double-door transfer system is available that permits canisters to be transferred rapidly and repetitively from one containment enclosure to another with minimal chances of contamination release (AGS, 1998).

2.1.2 Atmospheric Systems

The glovebox atmosphere is commonly described in terms of pressure (positive or negative), in relation to ambient, and by the physical make-up of the atmosphere.

2.1.2.1 Pressure. Positive pressure ventilation gloveboxes are generally used where air leakage into the glovebox poses more of a threat than air leakage out of the glovebox. This type of system circulates conditioned air or inert gas into the glovebox, often using recirculated air systems to avoid high consumption of the ventilating medium. It also requires a leak-tight environment to be maintained if toxic or other hazardous atmospheres are used in a positive pressure glovebox. In addition, to avoid excess air in bagout bags and to maintain containment, it is important to ensure proper glove change outs and bagging operations.

Unlike positive pressure gloveboxes, negative pressure systems extract air from the glovebox. Therefore, it is vital that the system provides sufficient exhaust flow rates to prevent the transport of contaminants out of the glovebox. This is achieved by minimizing leaks through the preservation of the appropriate negative operating static pressure.

2.1.2.2 Air. Under either negative or positive pressure environments, standard room air can be appropriately circulated, ducted, and filtered to offer safe working conditions. Gloveboxes with flow rates sufficient enough to maintain a negative pressure present a suitable environment for non-hazardous gases, vapors, and particles. However, high air exchange rates are often essential for the dilution of fumes and vapors of hazardous substances, while somewhat low flow rates are more often than not adequate for limited combustibles. The air for a ventilated glovebox is filtered through an inlet HEPA filter into the glovebox after being extracted from the room. This process assists with prolonging the life of the exhaust filter, and deterring the spread of contamination if the glovebox pressure unintentionally becomes positive (AGS, 1998).

2.1.2.3 Non-Reactive. Another type of atmosphere that can operate under negative and positive pressure systems without being reactive with processes or materials is an inert atmosphere, which contain inert gases such as nitrogen, helium, or argon. This type of atmosphere is obtained by purging the glovebox to a logical extent with these inert gases until the needed atmosphere is obtained. As a result of a gloveboxe being a completely enclosed system, and sometimes a recirculating system as in inert atmospheres, slight changes in volume and/or temperature can readily affect the pressure within the glovebox. Therefore, it is imperative to control leakage, atmosphere purity, and pressure within these inert atmospheres through heat removal processes, scrubber systems to maintain cleanliness, and other systems that help sustain the quality of the glovebox atmosphere.

2.1.2.4 Other Atmospheric Systems. A specific case of non-reactive atmospheres is a vacuum system. To obtain a vacuum system the air is removed from the glovebox, and is not replaced with anything. Since the maximum pressure differential across the glovebox wall is one atmosphere, each glovebox requires a thick-wall structure.

Some glovebox operations that are performed under positive or negative pressure require isolation from moisture, but do not require a reduced oxygen environment. This condition is referred to as a dry air atmosphere, which is a specific function of both the air and non-reactive atmosphere gloveboxes. However, if some materials and/or processes need to maintain a pure moisture and oxygen free ambiance, a purification system can be added to the glovebox to remove their residues (AGS, 1998). In addition to humidity, temperature, vacuum, and process gas control, other glovebox environments can be developed and designed based on the specific needs of the material and/or process such as a static, particle, and germ control atmospheres ("Critical Environmental", 2004).

2.1.3 Human Factors

According to AGS (1998), to improve operator performance and safety, and to reduce operator fatigue and potential injury, human dimensional statistics and performance capabilities should be used in glovebox design. From an anthropometric perspective, design parameters can be determined by identifying users in advance, or by designing to fit a user population from the 5th percentile female to the 95^{th} percentile male. AGS (1998) also asserts that the majority of the tasks should be conducted in a normal work envelope of 11 to 13 inches with a maximum of 18 to 20 inches. For precision work, an ideal working position is 2 inches below elbow height, which is 44 inches from the floor with 48-inch port centerlines from the floor. For maximum accessibility for a single-sided access glovebox, a nominal optimal dimension of 24 inches with a maximum of 26 inches (a range of 18 to 26 inches for a 5^{th} percentile female) should be considered. These optimal dimensions are doubled for a double-sided glovebox.

For gloveboxes with slanted windows that are normally located on the side faces of the glovebox shell, a top window is often provided to allow illumination within the glovebox from external lighting sources located directly above the glovebox. To prevent and minimize glare and other visibility challenges, gloveboxes should be designed with 100 foot-candles at the work surface along with a means to adjust the lighting levels both inside and outside the glovebox. Baffles can also be used to disperse light, such that the operator's eye is not directly exposed to concentrated levels of light. As long as it is consistent with decontamination requirements, flat, matte finishes on the inner surface of the glovebox can be used to help reduce glare (AGS, 1998).

2.2 Physiological Background

2.2.1 Anatomy of the Musculoskeletal System

Muscles are organs comprised of tissue arranged in bundles of fibers. The muscle's primary function is to produce the forces and movements used by multicellular organisms for the regulation of the body's internal environment such as the stomach and airways in the lungs. It is also necessary to generate movements of the entire organism in its external environment, which permits object manipulation such as carrying a box. These functions are performed as a result of muscle contraction that is innervated by chemical energy through the nerves within the body.

There are three types of muscle that can be identified on the basis of their structure, contractile properties, and control mechanisms. They are skeletal muscle, smooth muscle, and cardiac muscle. However, from a physiological perspective, the principal concern of ergonomists is the muscles that control movement of various bones within the body, which are skeletal muscles. These muscles are attached to bones, and their contractions are responsible for supporting and moving the skeleton. A skeletal muscle refers to the number of cylindrical muscle fibers bound together by connective tissue that are linked to bones by bundles of collagen fibers called tendons. Tendons are located at the end of each muscle, and provide the pathway for transmission of muscle force to the bone. Ligaments connect bone to bone while nerves supply the communication within the body. Together, these components control the movement of the body, which is typically voluntary (Vander et al. 1994).

The combinatorial unit of the ligaments, tendons, and three major joints of the arm, wrist, elbow, and shoulder, provides leverage and a wide range of motion for the arms and hands. Consisting of thirty-two bones, the working arm is composed of four main parts: the shoulder, upper arm, forearm, and the wrist and hand with fingers. This versatile structure is capable of performing the most delicate and precise manipulations.

Shoulder – The clavicle and the scapula form the framework of the shoulder, and serves as a pivot that allows the shoulder to be moved up, down, forward, and backward.

Upper Arm – The humerus is joined at the shoulder in a ball and socket joint arrangement, giving the arm ability to reach out in almost all directions.

Forearm – The elbow joins the ulna and radius, which are located in the forearm to the humerus. This controls the flexion and extension of the elbow as well as the supination and pronation of the forearm and hand at the proximal and distal radial-ulna joint, respectively.

Wrist and Hand with Fingers – The carpals in the wrist, the metacarpals in the palm of the hand, and the phalanges in the fingers make up the strong and flexible arm unit (Putz-Anderson, 1998). The wrist rotates the radius on the ulna, and flexes and extends the hand. The hand and fingers work together to open and close the hand by flexing and extending the phalanges.

As a result, these four components of the upper extremities form a remarkably complex system of pulleys and canals through which the tendons must smoothly slither to open and close the hand. This action is due to the muscles on the back of the forearm pulling the tendons to extend (open) the hand when the muscles are contracted. Contrary to this movement, the fingers are flexed closed when the flexor muscles located on the front of the forearm are contracted. This occurs as a result of the flexor muscles being connected to the fingers via the tendons that run through the wrist, and the pulley-like structures on the fingers, which cause the hand to close (Konz and Johnson, 2000).

2.2.2 Cumulative Trauma Disorders

The human body has great recuperative powers given the opportunity to repair itself. When the recovery between high usage is insufficient, and when high repetition is combined with forceful and awkward postures, the worker is at risk of developing a cumulative trauma disorder (CTD). Although many symptoms are associated with CTDs, the most notable are pain, restriction of joint movement, and soft tissue swelling. In early stages, there may be little or no visible signs of bruises or swollen joints. Manual dexterity and the sense of touch may be reduced if the nerves are affected. If left untreated, CTDs can produce a significant and lasting disability (Konz and Johnson, 2000).

CTDs are being recognized as a leading cause of significant human suffering, loss of productivity, and economic burden on compensation systems. A main reason for the evident increase in CTDs is the pace of work. Modern work is geared to production standards, which sometimes tend to make people compete with machine production speed. Although mechanization and automation have served to lighten the workload, the negative side effects are that it has increased the pace of work and concentrated forces on smaller elements of the upper extremities such as the hands and wrists. Most jobs involve performing a simple, repetitive task such as twisting, gripping, pushing, and reaching thousands of times in a workday despite fatigue.

Physical ailments or abnormal conditions that develop gradually over a period of weeks, months, or even years as a result of repeated aggravations or stresses to the muscles, tissues, and joints define Cumulative Trauma Disorder. When these repetitive activities are performed in a forceful and awkward fashion with insufficient rest or recovery time, these activities become hazardous, leading to a potential case of CTD (Putz-Anderson, 1998). Therefore, the combinatorial effect of the four major components of CTDs, force, repetition, posture, and no rest (Figure 2.4), can eventually lead to a serious injury or disorders such as the ones described below that characteristic of the upper body extremities.

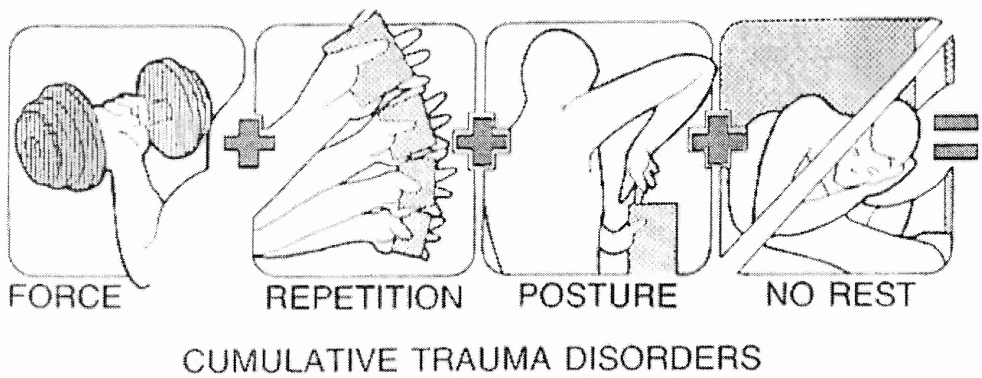

Figure 2.4 Illustration of Components that leads to CTDs.
(Source: Putz-Anderson, 1998)

2.2.2.1 Tendon Disorders. Tendon disorders usually develop at or near the joints where the tendons and their sheaths rub nearby ligaments and bones. Symptoms are usually marked by discomfort with particular motions, a dull aching feeling, and tenderness to touch, normally without any redness or local heat. This type of disorder can easily become chronic if the cause is not eliminated because of the slow recuperation process associated with the disorder (Putz-Anderson, 1998).

Tendinitis (Tendonitis) – Possible symptoms are partial tearing of the tendon fibers, inflammation, and thickened and rough tendons.

Tenosynovitis – Possible symptoms are inflammation and pain involving both the tendon and the synovial sheath.

De Quervain's Disease – Possible symptoms are swelling, pain, and crepitation localized to the thumb.

Ganglionic Cyst – Possible symptoms are tendon sheath swells into a firm, well-defined lump under the skin.

Epicondylitis – Possible symptoms are irritation and/or inflammation of the tendons at the elbow, pain radiating from the elbow down the forearm.

Rotator Cuff Tendinitis – Possible symptoms are pain and inflammation of the muscle tendons around the shoulder.

2.2.2.2 Nerve Disorders. Nerve disorders are a result of recurring or persistent work activities that expose the nerves to pressure from hard, sharp edges of tools, work surfaces, or nearby bones, ligaments, and tendons. Numbness, tingling, and pain over the affected area or in remote areas of the arm are the most common symptoms. The most common cause of nerve disorders is tasks that require a combination of high repetition and high force (Putz-Anderson, 1998).

Carpal Tunnel Syndrome (CTS) – Possible symptoms are numbness in the fingers, wrist pains on the palmar side of the thumb, index and middle finger, pain during gripping, and/or loss of grip strength.

Guyon's Tunnel Syndrome – Possible symptoms are muscle weakness, numbness or paresthesias of the ring and small finger.

Cubital Tunnel Syndrome - Possible symptoms are muscle weakness, numbness or paresthesias of the ring and small finger.

Radial Tunnel Syndrome – Possible symptoms are tenderness or pain without sensory loss.

Cervical Nerve Root Syndrome – Possible symptoms are soft tissue swelling and/or inflammation, symptoms can range from the upper back and shoulder to the fingers of the affected extremity (Eastman Kodak, 1986a).

2.2.2.3 Neurovascular Disorders. Another category of cumulative trauma disorders is neurovascular disorders, which involves the compression of both the nerves and blood vessels. Symptoms are similar to those of CTS consisting of numbness, tingling, and pain within the affected region. Slow muscle recovery and restricted muscle activity denotes the obstruction of blood circulation by activities and postures that put excessive pressure on the blood vessels by the adjacent tendons, ligaments, and muscles.

Thoracic Outlet Syndrome – Possible symptoms are pain, swelling, temperature changes, paresthesias, and weakness that affect the shoulder, arm, forearm, and hand (Putz-Anderson, 1998).

2.3 Ergonomic Assessment Tools

The ergonomic assessment tools described below are used to evaluate the combinatorial impacts of force, repetition, and posture on the upper body extremities for possible risk of Cumulative Trauma Disorders.

2.3.1 Rapid Upper Limb Assessment

Rapid Upper Limb Assessment (RULA) is an additive survey method that investigates work-related exposures of musculoskeletal loads on workers due to postures, forces, and repetitive activities that have been shown to contribute to musculoskeletal disorders of the upper body. This model was developed from information gathered from past findings on biomechanics, physiology, and epidemiological studies. This information allowed Corlett and McAtamney ("ErgoIntelligence", 2004) to develop a "Grand Score" that correspond to four action levels as follows:

Action Level 1 – A score of 1 or 2 indicates an acceptable posture if it is not maintained or repeated for extended periods of time.

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 the advantage of providing a quick method for assessing a working population for exposure to work-related upper limb disorders. It also permits the detection of combinatorial risk factors of force, repetition, and posture. The grand score and corresponding action levels help to communicate and prioritize the risk and/or hazards associated with the investigation. Although RULA maybe a good assessment tool for quick evaluations, it should be used in addition to at least two assessment tools due to the limited information on its validity, and its questionable capabilities to reproduce uniform results (“ErgoIntelligence”, 2004).

2.3.2 Strain Index

Strain Index (SI) analyzes jobs for risks of distal upper extremity disorders in the elbow, forearm, wrist, and hand. This semi-quantitative work analysis tool generates a numerical score (SI score) that is believed to correlate directly with the potential development of distal upper extremity disorders. Positively correlated jobs are associated with distal upper extremity morbidity such as epicondylitis, trigger finger, carpal tunnel syndrome, and DeQuervain’s tenosynovitis. Prior studies have found that an increase in SI score is paralleled by an increase in the mean incidence rate for distal upper extremity disorders. Therefore, it is recommended that a SI score of seven is the cut-off criterion for identifying high-risk jobs for distal upper extremity disorders.

Similar to RULA, the Strain Index provides a quick method of screening a working population for exposure to the possible risk of upper limb disorders through the identification of multi-factorial risk factors. These risk factors were drawn from physiological, biomechanical, and epidemiological principles to determine a value for the Severity Index (SI) score. The SI score is generated from a multiple of six variables: intensity of exertion, duration of exertion, efforts per minute, hand/wrist posture, speed of work, and duration of task. Similar to RULA, and the work evaluation tools discussed below, the validity of the information pertaining to this method is limited.

Unlike RULA, the Strain Index is limited to the assessment of the distal upper limbs only, and does not take into account the position of the legs, shoulder, shoulder girdle, neck, or back. Some disorders should not be predicted using this method such as hand-arm vibration syndrome (HAVS) and hypothenar hammer syndrome, or augmented risk disorders of the distal upper extremity disorders of uncertain etiology or relationship to work like ganglion cysts and ulnar nerve entrapment at the elbow. Lastly, when using this assessment tool, it is imperative to discriminate properly between "light" and "somewhat hard" exertion because this variable can generate significant differences in the SI score ("ErgoIntelligence", 2004).

2.3.3 Occupational Repetitive Actions Index

Occupational Repetitive Actions Index (OCRA) is a measurement tool that quantifies the relationship between the daily number of actions actually performed by the upper limbs in repetitive tasks, and the corresponding number of recommended actions. The recommended actions are calculated on the basis of a constant 30 actions per minute that can be lessened, case-by-case, as a function of the presence and characteristics of other risk factors like force, posture, additional elements, and recovery periods. OCRA was developed to evaluate jobs or tasks that exposed workers to the risk of musculoskeletal loads to the upper extremities of the shoulder, the upper and lower arm, and the hand as result of working posture, applied force, and repetition. The result of the OCRA evaluation is an OCRA risk index score that is comparable to three action levels of red-yellow-green.

Zone: Red
Risk Level: PRESENT, significant excess of Work-related Musculoskeletal Disorders predicted.
Consequences:
-Redesign of tasks at workstations according to priority.
-Health surveillance plus training/information of exposed subjects

Zone: Yellow
Risk Level: SLIGHT, slight excess of Work-related Musculoskeletal Disorders predicted (up to 3 times).
Consequences:
-Health surveillance recommended
-Recommended to seek ways to improve exposure conditions (especially for higher values)

Zone: Green
Risk Level: ABSENT
Consequences: None

Unlike RULA and the Strain Index, OCRA was derived and validated from data gathered from ceramics plant, auto assembly, packaging plant, supermarket checkouts, metal-working plant, tile sorting, pig slaughtering, and a mixture of small parts assembly plants. However, OCRA still offers the quick survey methodology to evaluate work-related risk of musculoskeletal disorders to the upper extremities, except for the shoulder, shoulder girdle, neck and back. Similar to the rest of the upper extremity assessment tools, OCRA should not be used to predict disorders like hand-arm vibration syndrome (Occhipinti, 1998).

2.3.4 Cumulative Trauma Disorders Risk Index

Cumulative Trauma Disorders Risk Index (CTD Risk Index) is another upper extremity assessment model that is capable of predicting injury incidence rates that are based on the data of 200,000 working hours for a cumulative trauma disorder ("ErgoIntelligence", 2004). The incident rate represents the number of new CTD cases in a population for a specific period of time. The 200,000 working hours is OSHA's standard of exposure time, which is representative of a hundred employees working 40 hours per week for 50 weeks out of the year (Putz-Anderson, 1998). Unlike other models, this work assessment tool utilizes quantitative data of hand motions frequencies and forces to produce a frequency factor score that is reflective of the of the strain inflicted on the muscles and tendons of the wrist. In addition, gross upper extremity positions are taken into consideration as a part of the posture factor score as well as a variety of minor job stressors that are included in a miscellaneous factor score.

In general, the CTD Risk Index is comparable to the other upper limb assessment tools because it takes into account the combinatorial effects of posture, force, and repetition. It is also a quick screening tool that lacks sufficient evidence to validate its ability to reproduce output data. Furthermore, similar to RULA and the Strain Index, the CTD Risk Index uses the principles of physiology, biomechanics, and epidemiology to develop its variables and scores. CTD Risk Index originated over a period of ten years through research conducted by the Center of Cumulative Trauma Disorders Research at Pennsylvania State University. The model is based on data gathered from forty or more member companies, representing industries from meat packing to poultry processing to garment manufacturing to metal fabricating, and more (Seth et al. 1999).

CHAPTER 3

EVALUATION OF THE GLOVEBOX

The glovebox under consideration is situated in the production department of a pharmaceutical company. The primary reason for the glovebox use is to control a specific humidity level, which is necessary for stability of intermediate drug formulation. Additionally, the glovebox provides protection for workers from exposure to potentially harmful chemicals. Since the glovebox operation is dependent upon the batch size, it was found to be characterized by burst in activity that can last for a steady week, but generally a couple days interspaced by a couple of weeks of inactivity between batches. During the activity period, the glovebox is used continuously through the seven hours shifts. During the inactive period, the glovebox is not used, but the employees rotate to another job that may still involve the same musculoskeletal group and repetitive motion. Two or more workers, depending on the size of the batch, work simultaneously in the glovebox under consideration (Figure 3.1). At the time of this assessment, three employees were working simultaneously, two females and one male. They are provided adjustable height lab chairs with footrest rings for working in a seated condition. A dimensional layout of the glovebox is provided in Appendix A.

The basic tasks involved filling vials in a tray with a microbead, capping the vials, and exchanging the filled trays for empty trays from the airlock within the glovebox. Each tray contains a hundred vials that are filled using a vacuum operated hand tool that picks up five microbeads at a time. The tasks involved arm and hand motions for holding, moving, positioning, twisting, and exerting pressure with precision. Overall, the task was highly repetitive. Based on direct observations and feedback from concerned workers and supervisors, the following ergonomic issues are identified as shortcomings for the glovebox workstation.

3.1 Ergonomic Criteria

3.1.1 Illumination and Visual Performance

As a result of the environmental factors such as lighting, white walls and ceilings, and the surface finish of the glovebox, glare is produced causing visual discomfort as illustrated in Figure 3.1. Glare is produced by brightness within the visual field that is significantly greater than the luminance to which the eyes are adapted to, initiating annoyance, discomfort, or loss of visual performance and visibility. As the eye tries to adapt to the different levels of luminance while looking from one point to the next, its visibility is momentarily reduced while transitioning to the new level of light.

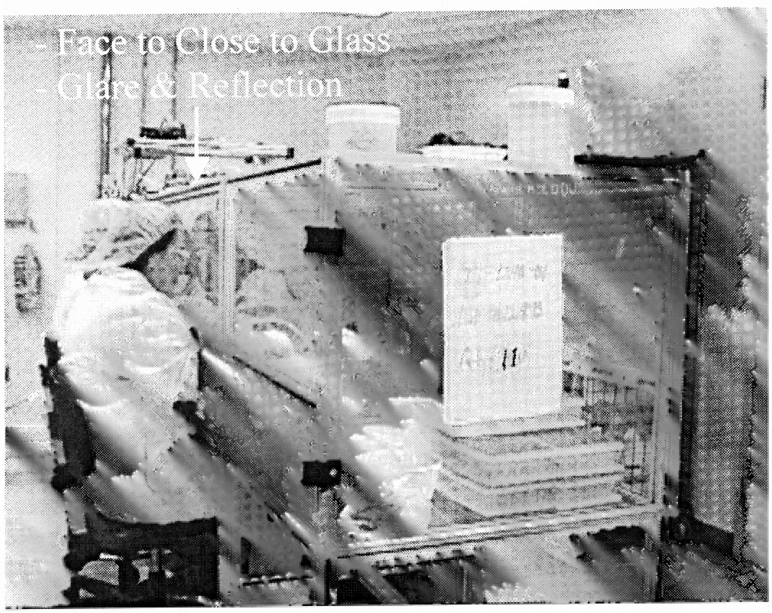

Figure 3.1 Picture of employees working at glovebox.

There are three classifications of glare: discomfort glare, disability glare, and blinding glare. Discomfort glare creates visual distress and irritation, but does not interfere with visual performance or visibility. Disability glare diminishes visual performance and visibility, and is usually accompanied by discomfort. Lastly, blinding glare is so overwhelming that nothing can be seen once the glare has been removed for a substantial period of time. Additionally, reflectance is light distribution within a room that is a function of the amount of light, and location of luminaries. It is also subject to the reflection from light bouncing off the walls, ceilings, and other room surfaces, such as the glovebox windows, generating reflected glare or reflections that are illustrated in Figure 3.1. The glare was classified as discomfort glare for this assessment since the workers were still able to perform their job task (Sanders and McCormick, 1993).

3.1.2 Window Structure and Eye / Neck Discomforts

Another problem with this glovebox is that the window is vertically flat (Figure 3.1), restricting head and neck movement, causing potential neck discomfort and eyestrain as the workers try to position themselves for better visibility.

3.1.3 Gloveports and Upper Extremity Constraints

As shown in Figure 3.2, the two gloveports are fixed at a distance of 15 inches from center to center, which is close to the anthropometrical shoulder width of the 50th percentile for United States' adult females (15.57 inches) (Eastman Kodak, 1986b). This is a concern because male workers also work with this equipment, and the 50th and 95th percentile male shoulder width is 17.72 and 18.83 inches, respectively. Therefore, this fixed position puts males at a greater risk for the development of MSDs because males have a greater joint angle deviation about the arm than females. As a result of the fixed gloveports, the workers tend to deviate their wrist (both ulnar and radial deviation) from its neutral position as much as 30° (Figures 3.2 and 3.3).

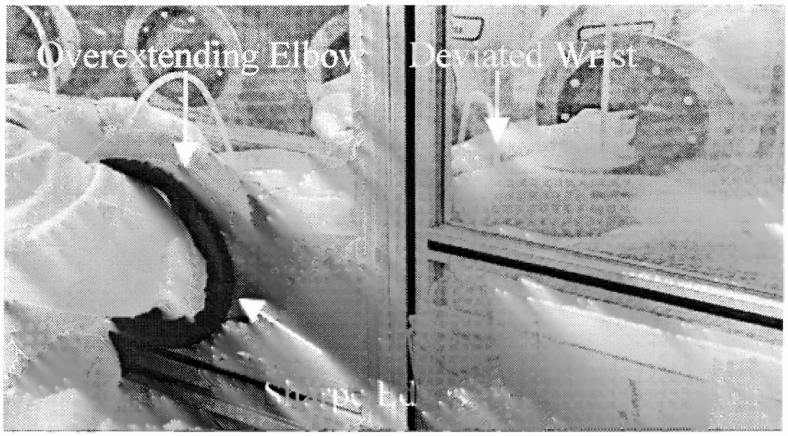

Figure 3.2 Picture displaying arm and hand postures while accessing airlock (Outside View).

The greatest potential risk of MSDs is illustrated in Figures 3.2 and 3.3 with the combination of the overextended elbow, deviated wrist, and force application. This task is a regular part of the workers' production process. The figures mentioned above show the worker attempting to retrieve more trays of vials from the airlock to continue with production. The airlock is used to maintain the humidity-controlled environment of the glovebox when materials are being transferred in and out of the work area. However, as a result of the fixed gloveports, the retrieval of the trays creates a high potential for tendonitis, tenosynovitis, carpal tunnel syndrome, epicondylitis, and other possible MSDs due to the combinatorial effect of the force, awkward postures, and the repetitive motion of the job in general. Although this specific task is not as frequent, the muscles still do not have ample time to recover because the process of filling the vials with the microbeads and capping them is a repetitive task, which utilizes the majority of the same muscles.

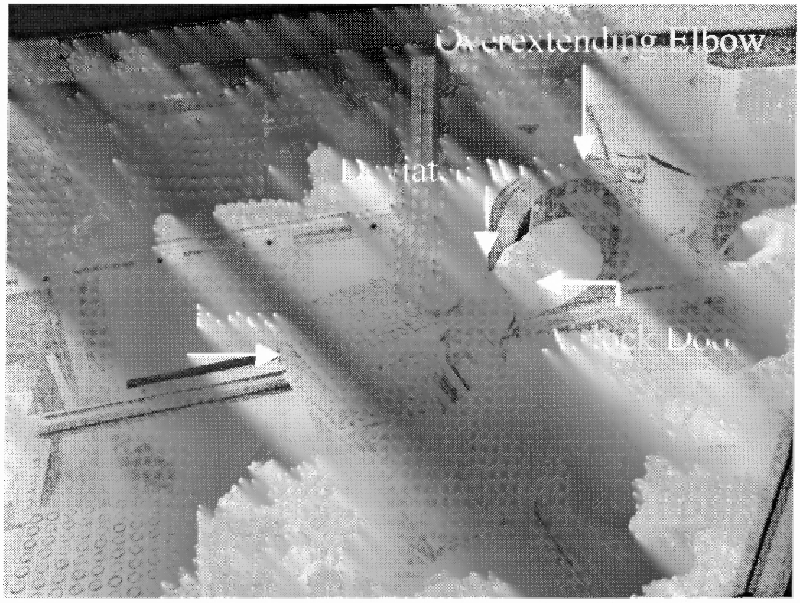

Figure 3.3 Picture displaying arm and hand postures while accessing airlock. (Inside View).

3.1.4 Gloveports and Contact Stress

The gloveports were covered with rubber barriers that resembled a camera aperture for work environment containment. However, several of these rubber barriers were torn or missing due to the workers' arm continually rubbing the barriers against the sharp edges of the gloveports' ring (Figure 3.2). Consequently, the ring of the gloveports caused contact stress to the workers' arm as they performed their job, especially since the barriers were damaged.

3.1.5 Awkward Posture and Repetitive Motion

The operation of the hand tool required constant deviation of the wrist as shown in Figure 3.4 with a frequency of 10 times per minute for the vial filling task. It was calculated from replay of the video that the workers spent 50% or more of their task cycle time bending their wrist 20° or more while performing the vial filling tasks. Figure 3.5 illustrates the use of force when continuously twisting the caps on the vials with a pinching posture at a frequency of 15 times per minute, which creates friction on the tendons in the thumbs, and irritates the flexor tendons in the wrist.

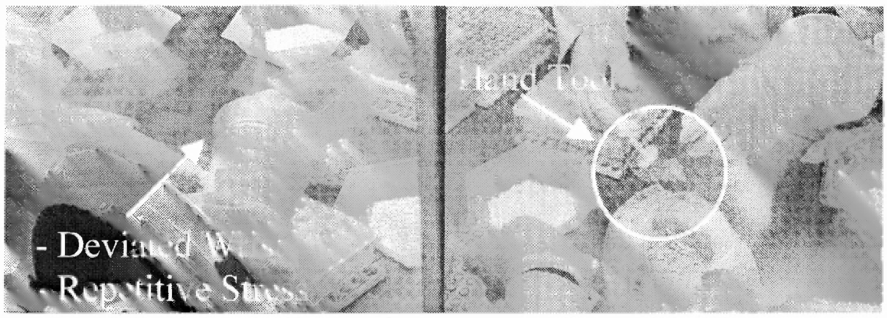

Figure 3.4 Illustration of hand tool and wrist/hand posture during vial filling process.

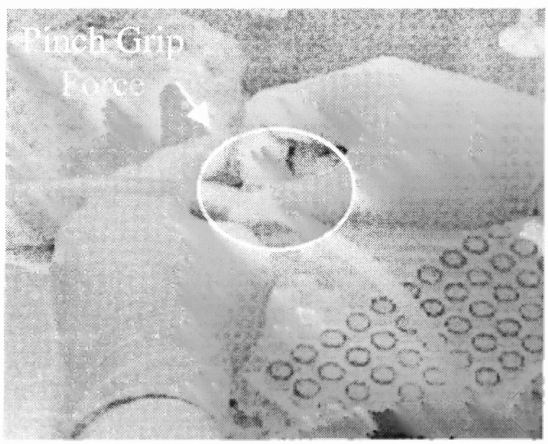

Figure 3.5 Illustration of hand posture during vial capping process.

3.2 Postural Analysis

Dimensions of the equipment and workspace were obtained using a tape measure. A Sony PD-100A digital camcorder (with the advantage of acquiring still images by taking snapshots from the replay of the video), and an Olympus C-3030 digital camera with 3.3 megapixels resolution were used to capture working postures of the workers. This video recording provided postural angles and time during different postures and was analyzed later in the laboratory.

Vial filling and vial capping tasks were identified as the two most critical tasks leading to cumulative trauma disorders. The acquisition of raw data used in the analysis of these tasks was obtained from the video and snapshots of the employees performing the tasks. The frequency and cycle time for these tasks were determined by counting the number of repetitions per minute for each task, using the clock displayed on the video. Additionally, the cycle time was considered to be the time it took for the employee to move their hand tool to pick up the microbeads, and place them in the vial as well as the time it took for the employee to pick up a filled vial from the tray, cap it, and replace it back in the tray for the vial filling and capping tasks, respectively. The postural angles were extrapolated by using a protractor to measure the position of the employees from pictorial snapshots as well as a few self-reenacted positions. Although the extrapolation of data offers more accuracy in data, the force applied by the employees was estimated from self-reenactment, and the qualitative descriptions given by the software assessment tools.

The following assumptions were made to evaluate the vial filling and capping processes. Since the daily work shift for the employees was 7.5 hours with a half-hour lunch break, it was assumed that the remaining 7.0 hours were equally divided between both processes, since they were conducted simultaneously. Given that the tasks were performed within a glovebox, it was assumed that the forearms were well supported by the gloveports although contact stress was of some concern. Table 3.1 enumerates the summary of the results obtained from this analysis.

Table 3.1 Summary of Posture Analysis

Parameters	Vial Filling	Vial Capping
Task Duration	210 minutes	210 minutes
Frequency	10 efforts per minute	15 efforts per minute
Cycle Time	6 seconds	4 seconds
Intensity of Exertion	Barely Noticeable – Relaxed Effort	Noticeable – Definite Effort
% Maximum Strength	10%	15%
Type of Grip	Tight Grip	Pinch Grip
Wrist Posture	>30 ° (Flexion)	<20 ° (Flexion)
Ulnar Deviation	<10 °	>25 °
Lower Arm Posture	>60 ° (Flexion)	>60 ° (Flexion)
Elbow Posture	>60 ° (Pronation)	>60 ° (Pronation)
Upper Arm Posture	<30 °	<30 °
Neck Posture	<15 ° (Flexion)	<15 ° (Flexion)
Back posture	<15 ° (Flexion)	<15 ° (Flexion)

3.3 Evaluation of Postural Stress

Four posture evaluation tools, RULA, Strain Index, OCRA Index, and CTD Risk Index, were used to analyze the posture data for the vial filling and vial capping tasks. As described earlier, these tools determine the level of ergonomic risk factors of a task. These levels are based on the degree of stressfulness and the duration of the postures involved in the task. Each tool has been implemented as computer software that enables the user to enter the posture category of each body segment and time spent in each posture, using graphic user interfaces (GUI). The postures and the GUI's have been included in Appendix B.

The results from the four upper limb evaluation tools for the vial filling and vial capping tasks are summarized in Table 3.2 and Table 3.3, respectively. The results show that there is a potential risk of developing a musculoskeletal disorder from performing this job function. The recommendations provided by the assessment tools suggest that an investigation should be conducted, and a redesign of the glovebox workstation and tasks should also be considered. This supports the initial observations that these tasks have high ergonomic risk.

Table 3.2 Results from Vial Filling Task

Assessment Tool	**Score**	**Action/Risk Level**	**Recommendation**
RULA	4	2	Further investigation is needed & changes maybe required
Strain Index	9.0	High	Criterion for high-risk upper distal extremity disorders: Score >= 7
OCRA Index	10.80	Red	Redesign of tasks at workstations according to priority
CTD Risk Index	77.65	N/A	N/A

Table 3.3 Results from Vial Capping Task

Assessment Tool	**Score**	**Action/Risk Level**	**Recommendation**
RULA	5	3	Investigation & changes required soon
Strain Index	18.0	High	Criterion for high-risk upper distal extremity disorders: Score >= 7
OCRA Index	24.69	Red	Redesign of tasks at workstations according to priority
CTD Risk Index	39.91	N/A	N/A

CHAPTER 4

DISCUSSION AND RECOMMENDATIONS

After researching and reviewing glovebox designs and guidelines, the following recommendations can assist with the prevention, elimination, or reduction of the ergonomic issues.

4.1 Discussion of Results

The entire operation of filling and capping the vials was characterized by a burst in activity that can last for a steady week, but generally a couple of days with lulls of 2 to 3 weeks between batches. The batches consist of filling and capping a tray of 2cc size vials with each tray containing 100 vials. Table 3.2 displays the assessment results for the vial filling process that is illustrated in Figure 3.4. These results are based on a frequency of 10 repetitions per minute, a wrist flexion of at least 30 degrees, and a task time of 3.5 hours. Table 3.3 represents the assessment results for the vial capping process portrayed in Figure 3.5. These results are based on a frequency of 15 repetitions per minute, ulnar deviation of at least 15 degrees, pinch grip posture, and a task time of 3.5 hours. The total task time of 7 hours per day was divided in half to allocate time to each of the two processes.

The RULA score for both processes were approximately the same due to its inability to take into account the length of time of the job task and the actual number of repetitions like the other assessment tools. The CTD Risk score is the predicted incidence rate for a year with 200,000 hours of exposure time, which is representative of

100 employees working 40 hours per week for 50 weeks out of the year. Therefore, there is a possibility, out of 100 employees, to incur nearly 78 new cases of MSDs for the vial filling operation alone, and approximately 40 new cases for the vial capping on an annual basis. The Strain Index and the OCRA Index both showed scores exceeding their criterion, thereby, advocating that the job task is in need of attention.

Table 4.1 Correlation from Assessment Tools

	RULA	Strain Index	OCRA Index	CTD Risk Index	Correlation
Score (Vial Filling)	4	9.0	10.80	77.65	0.87
Score (Vial Capping)	5	18.0	24.69	39.91	

A correlation coefficient was determined between the scores obtained for the two tasks. The correlation value measures the relationship between the scores of the two tasks. It can also tell how well the analysis tools relate to one another, and what factors contribute to musculoskeletal disorders. Table 4.1 summarizes the scores from the assessment tools for the two tasks, which resulted in a correlation coefficient of 0.87. The correlation's positive value confirms that the scores for the two tasks increase in a parallel fashion, and the proximity to one supports the initial observations that these are high-risk tasks. It is also evidence that there is a strong possibility to acquire some type of musculoskeletal disorder from this job task, and confirms previous studies that the chief factors predicting the onset of cumulative trauma disorders or musculosketal disorders are posture, repetition, force, and time. Although the correlation value of one was not obtained due to the vial filling score being greater than the vial capping score for the CTD Index. Overall, the scores generated by the evaluation tools predict there is a high potential for cumulative trauma disorders to the upper extremities, and the level of risk predicted by the tools suggests further investigation and prompt change is needed to the job task.

4.2 Recommendations

4.2.1 Illumination and Visual Performance

Most labs and manufacturing facilities have white walls for Good Manufacturing Practices (GMP), which tend to reflect light. It is best to provide baffles to diffuse the light and/or methods to adjust the lighting levels both inside and outside the glovebox to diminish glare. In addition, it is recommended that the light source be situated to permit 100 foot-candles at the work surface, and to not be directly positioned in the user's line of sight. Another way to decrease or eliminate the glare is to design a glovebox with flat, matte finishes on the surface.

4.2.2 Window Structure and Eye / Neck Discomforts

To relieve the user from neck discomforts and eyestrain due to the flat vertical window structure while performing the job task, the window should be slanted by 10° to 15°. The angled window will allow more head and neck movement, thereby permitting more maneuverability in the working posture, and enhancing visual performance by reducing glare and blind spots.

4.2.3 Gloveports and Upper Extremity Constraints

As mentioned earlier, the centerline distance from gloveport to gloveport was 15 inches, which is the minimum distance recommended by AGS. Therefore, this distance is an acceptable design specification, especially since the majority of the users of the glovebox were women. However, a better distance may be the nominal distance of 16.5 inches as stated by AGS (AGS, 1998) since it is the median distance between the 5th percentile female and the 95th percentile male shoulder breadth.

To eliminate the overextension of the elbow and wrist, the airlock door should be accommodated with a tray or a long-handle device to make reach accessibility for material transport from the airlock into the glovebox more efficient. Since this is a double-sided glovebox, a vertical-sliding airlock door would be more efficient for material accessibility by users on both sides of the glovebox.

4.2.4 Gloveports and Contact Stress

To eliminate or reduce contact stress, the gloveport rings should be rounded to eliminate sharp edges. The rubber barriers should be replaced when torn. Whitmore, McKay, and Mount (1995) suggested that oval-shaped gloveports allow better and more comfortable positioning of the user's arms than circular ports because the shape permits positioning without exerting any force on the edges of the gloveport rings.

4.2.5 Height of the Gloveport Centerline

The centerline height from the floor is normally 48 inches (AGS, 1998), which is 8 inches higher than the centerline of the case study glovebox (see Appendix A for dimensional sketch). Therefore, it is better to increase the height of the glovebox work surface to accommodate taller users, and provide adjustable platforms (standing workstation) or multi-adjustable lab-type chairs with foot rings (sitting workstation) to compensate for height differences.

CHAPTER 5

FUTURE WORK

This thesis evaluated an industrial glovebox from an ergonomic perspective. It discussed the dimensions of the glovebox compared to recommended guidelines, and the corresponding work postures as a result of this design. It also assessed the potential risk of musculoskeletal disorders as a result of the job task and tool design through the use of ergonomic assessment tools.

Further studies should particularly focus on gloveports, and determining the most advantageous design criteria for this feature. Since it is the most used and most restricting aspect of the glovebox, consideration should be given to standardizing and determining criteria for the diameter, shape (i.e. oval versus circular), and distance between the gloveport rings. Additionally, the study should explore possible gloveport designs that are not so rigid. Such a glovebox could allow the flexibility of arm movement without breaching containment.

In addition to the gloveports, an acceptable minimum work volume would also help in the design of gloveboxes, especially those used in the spacelab. Creating a more detailed ergonomic checklist and guidelines for gloveboxes would be beneficial for the prevention and reduction of musculoskeletal disorders.

APPENDIX A

SKETCH OF GLOVEBOX

This appendix shows a dimensional sketch of the glovebox discussed within the thesis.

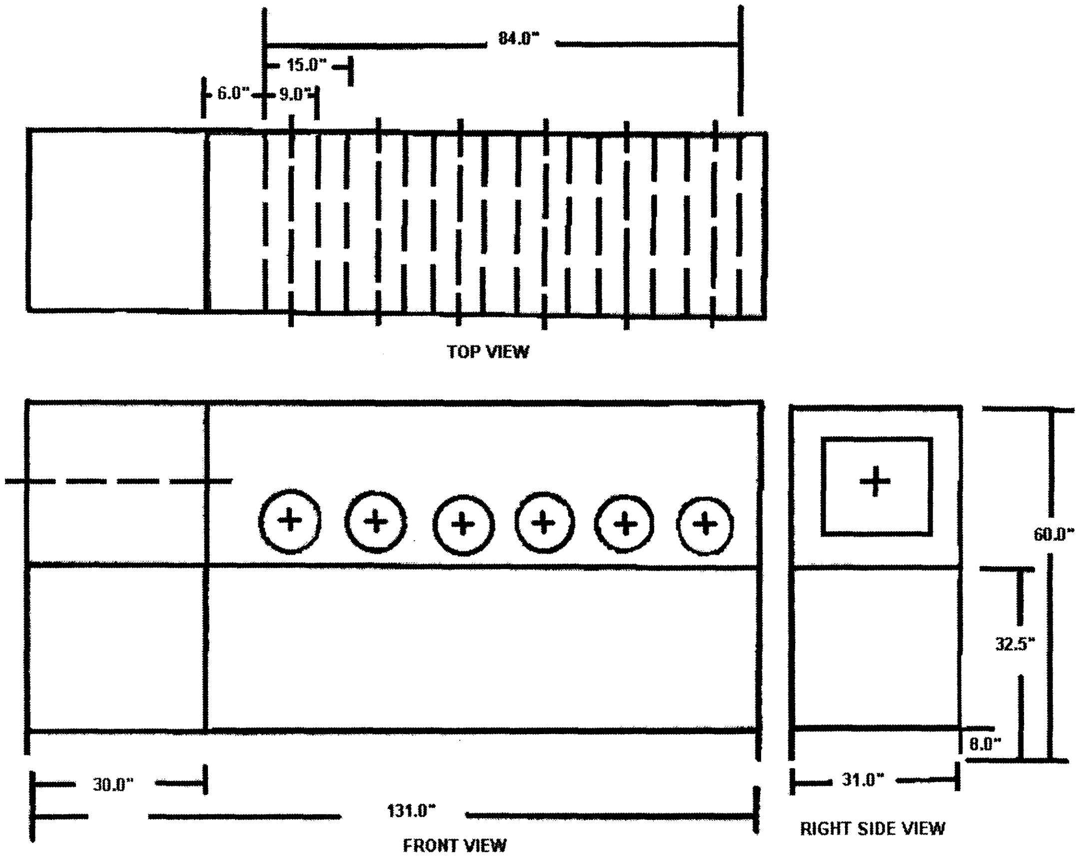

Figure A.1 Dimensional sketch of glovebox.

APPENDIX B

HAND AND WRIST POSTURES

This appendix shows illustrations of various finger, hand, and wrist postures. (Source: Putz-Anderson, 1998.)

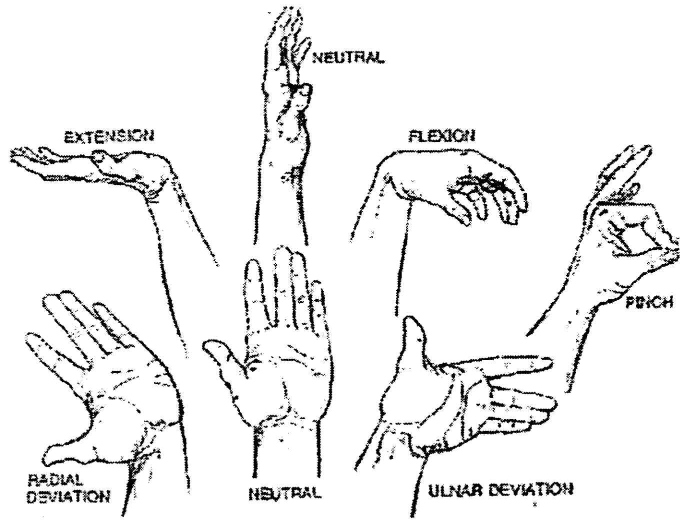

Figure B.1 Hand and wrist postures.

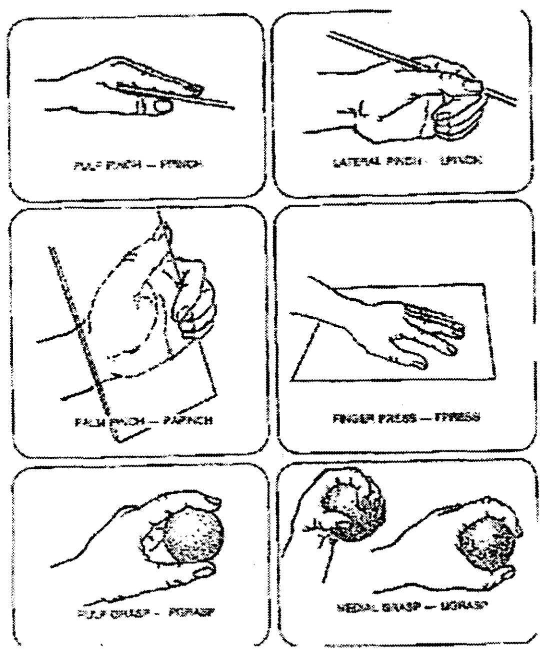

Figure B.2 Classification for various finger closing postures.

APPENDIX C

COMPUTER DISPLAY OF ASSESSMENT TOOLS

This appendix shows screen shot(s) of the computer software used for each assessment tool that was discussed in Chapter 2.
(Source: NexGen, 2005)

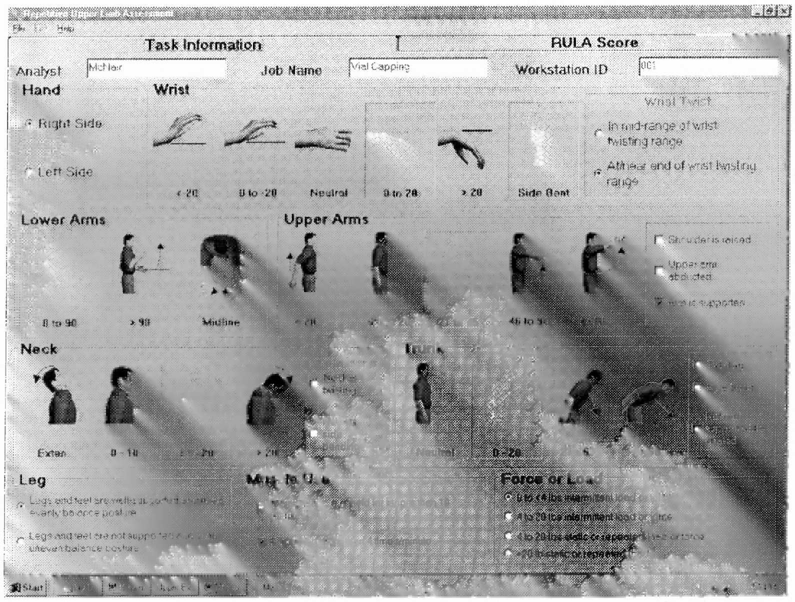

Figure C.1 Rapid Upper Limb Assessment.

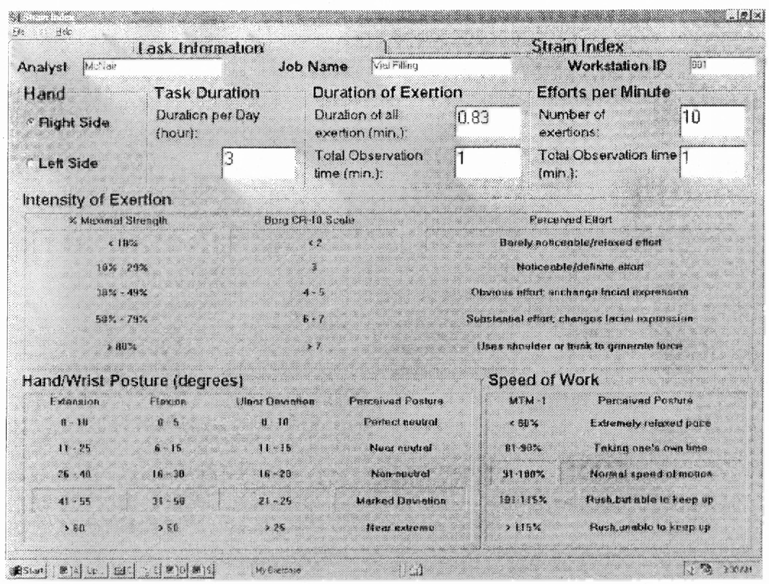

Figure C.2 Strain Index.

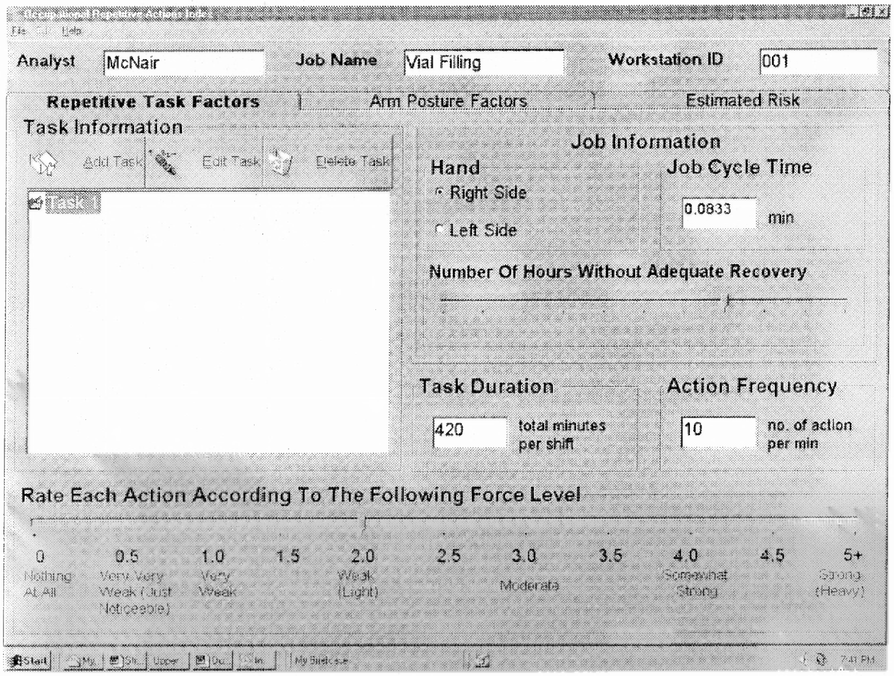

Figure C.3 Occupational Repetitive Action Index: Repetitive Risk Factors.

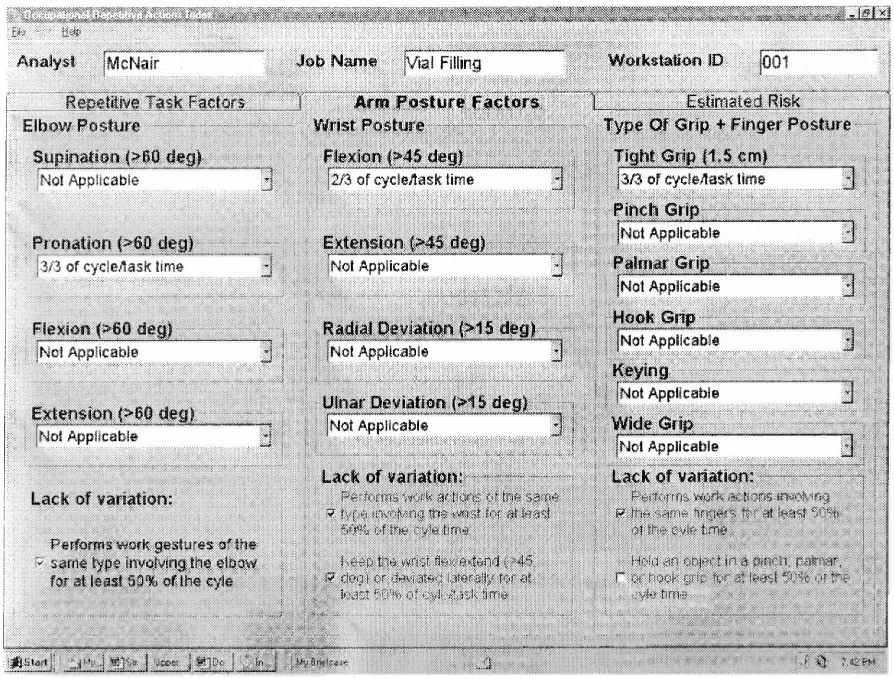

Figure C.4 Occupational Repetitive Action Index: Arm Posture Factors.

Figure C.5 Cumulative Trauma Disorder Risk Assessment Model: Force Frequency Factors.

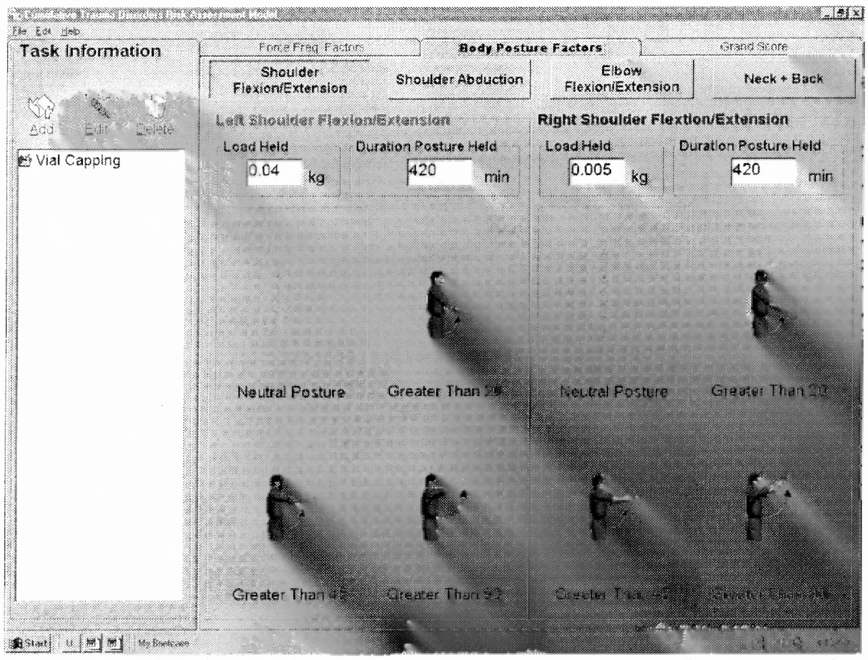

Figure C.6 Cumulative Trauma Disorder Risk Assessment Model: Body Posture Factors.

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