ERGONOMIC EVALUATION OF MANUAL ASSEMBLY OPERATIONS USING DIRECT AND INDIRECT OBSERVATION WORKSTATIONS IN SITTING AND STANDING POSITIONS

By

SEE SHYONG LIM

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

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Abstract

Pain in the upper extremity, particularly in the neck and shoulder region is a major source of work place injuries in industries. The occurrence of such occupational injuries is also on the rise. Shoulder and neck pain has been associated with awkward and static postures, repetitive arm movements and lack of rest. Awkward working postures at the trunk, neck and shoulders may be caused by a number of factors including workstation layout and work methods. This can lead to the development of fatigue, discomfort and disability. As a result, the elimination or reduction of awkward postures is a major objective of many workplace ergonomic programs.

This research evaluated the traditional or direct observation workstation and the newly developed indirect observation workstation in manual assembly operations. The direct observation workstation requires the bending of the head and trunk in order to perform the task. The indirect observation workstation uses a video camera to project the work area onto a television monitor directly in front of the worker. Muscle activities of the trapezius and anterior deltoid muscles were quantified using Electromyography (EMG). This research found that static load on the trapezius muscle was lower when using the indirect observation workstation particularly in the standing position. The interval between the activation of motor unit potential is measured in micropauses. Duration in micropauses or micro-breaks were longer when using the indirect observation workstation for both the trapezius and anterior deltoid muscles. This research also found that excessive bending of the head can be reduced by using the indirect observation workstation. Productivity, however, is slower when using the indirect observation workstation compared to the direct observation workstation due to the two dimensional image projected by the television monitor. Dynamic workstation which utilizes a combination of direct and indirect observations, in the sitting and standing positions, shows an improvement in productivity but is accompanied by an increase in static load and shorter duration in micropauses particularly in the trapezius muscle. Data from the laboratory experiment also supports the field study conducted at the Northern Telecom Plant in Calgary in terms of reduction in static loading of the trapezius muscle when using the indirect observation workstation.

The newly developed indirect observation workstation is capable of reducing muscle strain especially in the trapezius muscle as each subject is able to keep the head in an upright position while performing specific tasks. It also provides an option to the workers to continue with their work when neck and shoulder pain become intolerable due to excessive bending of the head when using the traditional workstation.

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Chapter 1
Introduction

1.1 Background

Musculoskeletal injuries are a major problem among workers in the industrial field particularly in assembly lines and manual material handling (MMH). In the U.S., the Occupational Safety and Health Administration (OSHA) has categorized musculoskeletal injuries among its ten highest priorities for reduction and equivalent interest in their control is evident world-wide (Millar, 1988). It has also been reported that musculoskeletal injuries have increased more than tenfold from 1982 to 1992, at an annual estimated cost of over 100 billion dollars in the United States alone (Gabor, 1990, US Dept. of Labor, 1992). In Canada, one out of every 15 workers suffers from some type of occupational injuries and in 1994, worker's compensation authorities paid out more than five billion to workers who suffered from these injuries (Human Resources Development Canada, 1995). In Sweden, Norway, Denmark and Finland, the total economy loss due to musculoskeletal injuries accounted from about 3 to 5 % of the Gross National Product annually (Hansen, 1993).

Musculoskeletal injuries occur when excessive stress is placed on a human's musculoskeletal system. In industry, musculoskeletal injuries often occur in the upper extremities, which includes the neck, shoulder, arms and upper back. This is because most work is performed above the elbow. Injuries in these parts of the body are a viewed as being a leading cause of human suffering, loss of productivity and economic burden on society (Andersson, 1984). It can also lead to long term injury compensation or disability insurance for workers which in turn will impose a financial burden to related government bodies.

There are two major causes of musculoskeletal injuries in industry (1) awkward working postures and (2) performing repetitive work. Awkward working postures such as bending the head and trunk, outstretched arms and twisting of the body creates a static load on the muscles of the upper extremity. Static muscle load is characterized by a prolonged state of muscle contraction, which results in oxygen depletion and contaminant build-up of toxic inflammatory substances in the muscle (Grandjean, 1988). In recent years research has found static muscle load to be a major factor in the development of musculoskeletal injuries (Jorgensen et. al., 1988, Aaras, 1990).

The second major cause of musculoskeletal injuries is from performing repetitive work, which leads to repetitive strain injuries (RSI). RSI occurs when the same muscle group is used repeatedly to perform a particular task, which depletes oxygen supply and results in contaminant build-up of toxic inflammatory products in the muscle (Bammer and Blignault, 1987). Electronic assembly line workers, keypunch operators, musicians and factory workers are particularly subjected to RSI.

Clinically RSI disorders fall into two broad groups (1) localized injuries and (2) neuro-musculo-tendinous injuries. Localized injuries are injuries which occur on a specific part of the body, such as carpal tunnel syndrome which affects the wrist. The second group of injuries may involve a single muscle, group of muscles or more extensive areas of the body. Strains in these muscles can vary from an intermittent ache to a severe, unremitting constant pain. It may be localized (found close to the site of the injury) or referred (located some distance away from the causative factor). Physical signs such as local tenderness, swelling or induration (hardening) may be apparent. The most common pattern is at first for symptoms to occur only occasionally during work. If the person continues doing the damaging work without taking any rest, the symptoms may become progressively more frequent and persistent, resulting in chronic disorders.

In industry, musculoskeletal injuries are primarily caused by awkward postures, combined with repetitive manual work and insufficient recovery time (Komoike, 1975, Nevaiser, 1983). Awkward posture results in a high prevalence of musculoskeletal complaints and injuries among industrial workers (Guangyan Li et. al., 1995). Silverstein et. al. (1986) found that highly repetitive jobs involving a cycle time of less than 30 seconds or more than 50% of the time doing the same type of fundamental cycle exhibit greater odds of injury compared to low repetitive jobs.

Many jobs in the industry require workers to conduct tasks in awkward fixed postures at a workstation. The most common type of workstation used in industry is the direct observation workstation, or traditional workstation. An example of the direct observation workstation is shown in Figure 1.1. At this workstation the operator often performs the required task by bending the head to closely view small-sized objects. For example, in an electronic assembly line, workers have to insert small-sized chips into printed circuit boards (PCBs) and in order to do this they have to bend their head and trunk to perform this detailed task. This position leads to musculoskeletal injuries particularly in the neck and shoulder regions.

Figure 1.1 Traditional or direct observation workstation at Northern Telecom assembly line, Calgary.

Studies conducted at the Northern Telecom assembly line in Calgary (Venda, 1995[a]) found that neck and shoulder injuries are the most widely spread traumas among the workers. The assembling operation at Northern Telecom Plant which incorporates the use of a direct observation workstation, is characterized by a sitting posture with the operator's head and trunk flexed forward. These workers have been found to experience considerable musculoskeletal problems due to the static posture that has to be maintained during their whole working period combined with performing highly repetitive manual tasks. The workers are required to perform a task which involves simultaneous but different motions with both hands. Awkward posture arises when the operator has to flip the PCB over with one hand and solder the electronic component (integrated circuits) with another hand while looking at the soldering point with the head flexed forward. Excess material of the electronic component is then cut off using a pair of scissors. Repetitive motion of the hands can be observed when the workers reach for different integrated circuits placed in different plastic bins to be inserted onto the PCB. This work activity is maintained throughout the whole work shift. Such poor postures have been found to be associated with decreased efficiency of performance, an important cause of which was recognized to be the body discomfort resulting from the restricted posture (Corlett, 1987).

The musculoskeletal injuries associated with the use of the direct observation workstation led to the development of a new, ergonomically designed workstation by Venda (1995[a]) known as the indirect observation workstation. Figure 1.2 shows a subject performing a task using the indirect observation workstation. This workstation uses a remote camera which is mounted directly above the work area to project its image onto a television monitor. This allows workers to "indirectly" view the work-area on the monitor without bending their head or trunk. The remote camera is also equipped with a zoom lens which can be used to magnify the image of the work-area.

This research evaluates the use of the new indirect observation workstation compared to the traditional direct observation workstation to determine if the static loading which is a major cause of musculoskeletal injuries in the upper extremities is reduced. In addition, postural angle measurement for the head, trunk and upper arm are assessed between the two workstations to determined the risk factors resulting from awkward postures.


Figure 1.2 Indirect observation workstation used in Northern Telecom assembly line, Calgary.

1.2 Purpose of the study

The purpose of this study is to evaluate the direct and indirect observation workstations in terms of (1) muscle activities of the upper extremities, (2) postural angles, (3) perceived level of comfort based on a subjective questionnaire and (4) task performance as measured by work quality and productivity. Two different working postures were examined for each workstation, namely, the sitting and standing postures. In addition, this research investigates the use of a combination workstation which incorporates sitting, standing, direct and indirect methods to perform a specific task. This is known as the dynamic workstation.

This research examines the muscles in the upper extremity, including the trapezius and the anterior deltoid muscles. The trapezius muscle plays an important role in arm and shoulder movements. It provides the main lift for the shoulder girdle and is important for the stabilization of the scapula during arm movements. Research has shown that the trapezius muscle is highly subjected to static load in industrial operations (Hagberg and Wegman, 1987, Ranney et. al., 1995). The anterior deltoid muscle is important because it provides flexion and abduction of the upper arm.

Muscle activities in the trapezius and anterior deltoid are measured using electromyography (EMG). EMG is the process of monitoring the low level electrical charges which are emitted during muscle contractions. It has been used for many years to evaluate muscle load, particularly in laboratory investigations. EMG techniques make it possible to measure work load and muscle fatigue on individual muscles. The electrical signal (myoelectric) is picked up by the surface electrodes which are placed on the muscles of interest and these signals can be used for analyzing muscle activities. Raw EMG data can be processed to examine the micropauses, peaks, median and low level muscle loading (Jonsson, 1982).

This research also considers the postural angle measurement of the upper extremities in comparing the two workstations. Goniometers or angle transducers, are used to measure the angle displacement of the head, upper arm and trunk during the experimental task. In addition, the angle displacements were also examined by video-taping the subjects' body movements and posture during the experiment. Postures from the experiment are compared to standard labor-management ergonomics intervention program issued by the U.S. Occupational Safety and Health Administration (OSHA) to assess risk factors resulting from awkward postures.

Thirdly, this research evaluates the subjects' perceived level of comfort of using both workstations based on a subjective questionnaire.

Finally, the research investigates the subjects' task performance when using the direct and indirect observation workstations in sitting and standing positions. Task performance is measured by the quality and productivity for performing that task.

1.3 Null Hypothesis

This research hypothesizes that there is no difference in the normalized activities of the upper extremity muscles when performing experimental tasks using the direct and indirect observation workstations. The upper extremities include the trapezius and anterior deltoid muscles. The muscular activities of these upper extremities are expected not to differ when comparing both the direct and indirect observation workstations, in the sitting and standing positions.

1.4 Rationale for the study

The traditional workstation requires the bending of the trunk and head which induces pain in the back, shoulder and neck region after a period of time. Many workers in the manual assembly operations can be seen trying to relieve the pain by bending their head backwards or tilting it from side to side. However, insufficient recovery time will not remove the pain and hence injuries to the neck or shoulder area will persist. The usage of the indirect observation workstation will provide many of these workers with an option when performing their tasks. They can maintain an upright posture by looking directly into the television monitor in front of them when bending of the neck is becoming bothersome. This option will enable them to continue working without having to cause grievous pain to an already sore neck and provide sufficient time for the affected muscles to recover. A more active workstation can be achieved by incorporating dynamic work posture involving a combination of sitting and standing positions. This will prevent the worker from being locked in a single position the whole time.

Determination of whether or not the indirect observation workstation provide less static load on the upper extremities in sitting or standing would be useful information to the workers in sedentary occupations. Recovery time of the muscles measured in micropauses from EMG analysis can be used to compare between the two workstations. Risk factors resulting from awkward postures can also be analyzed as it is a silent epidemic which cripple the upper body and costing companies millions aside from disabling workers so severely that they can't turn a doorknob. The results of such study could either change the work posture strategy or strengthen the theory that the indirect observation workstation is a new and effective method especially in preventing the incidence of musculoskeletal injuries particularly in the upper extremity. Another important reason to conduct the study is that this research will provide knowledge as well as to fill in the gap in understanding about the indirect observation workstation. Finally, the study may stimulate more questions and generate more research towards the prevention of musculoskeletal injuries of the upper extremities especially in the assembly line and manual material handling in the industries.

Chapter 2
Review of Literature

2.1 Introduction

This chapter reports on existing literature which are relevant to the study. The literature review contains (1) major causes and impact of musculoskeletal injuries, (2) the comparison between sitting and standing postures, (3) general structure of muscle, (4) dynamic and static muscular effort, (5) electromyography and (6) description of the muscles that are analyzed in the laboratory experiment.

2.2 Major causes and impact of musculoskeletal injuries

Neck and shoulder disorders of the upper extremities are common in many sedentary occupations whether in the sitting or standing position. Prolonged sitting or standing in occupations associated with repetitive jobs, awkward posture and insufficient recovery time will lead to an increase in static muscle loading to the back, neck and shoulder muscles (Andersson, 1984). Neck and shoulder disorders are more prevalent when the job tasks include high static load due to constrained work postures such as forward flexion of the neck and abduction in the upper arm (Hagberg, 1987, Kilbom and Persson, 1987). Several authors have shown that an increase in the magnitude of low level static activity causes an increase in neck and shoulder disorders (Westgaard et. al., 1986, Aaras and Westgaard, 1987).

Static load may be imposed on shoulder muscles in two ways. First, the work situation may demand elevation of the arms hence, the weight of the arms and the object held may induce static load onto respective shoulder muscles. Secondly, prolonged bending of the head and trunk will result in an increase in muscle activities of the neck and shoulder, thus inducing static load to these muscles (Kilbom, 1988).

In many work situations, operators must adopt a relatively fixed sitting or standing posture throughout the working period of several years or even a life time. Research has shown that individuals working in a prolonged sitting posture are at a higher risk of occupational injuries compared to the standing position (Mandal, 1991). Prolonged seated work itself leads to back and neck injuries (Andersson, 1984). This has become a major problem not only because larger numbers of people are now doing sedentary work in sitting position, but also because many work process, like machine sewing or assembly of electronic components, impose a need for workers to adopt a forward bending of the trunk and head in order to see the work. Forward bending of the trunk and head causes the backrests of seats to support the lumbar less effective than they are supposed to be (Guangyan Li et. al., 1995).

In the upright posture, man has the most economical anti-gravity mechanism of all animals (Basmajian, 1978). However, in order to maintain an upright posture with a minimum muscular effort, the line of the center of gravity must fall through the major weight bearing joints and be equidistant from each foot (Roaf, 1977). Typical working posture rarely meets this requirement. This is because the typical sitting or standing postures involves bending forward. The most common way of doing this is by arching the back in the thoracic region or bending from the lumbar region (Fox and Jones, 1976). This awkward and constrained posture will result in musculoskeletal stress on the neck and shoulder region in both the sitting and standing positions.

Overall, the U. S. Bureau of Labor Statistics (1995) reported that about 20 million people in the United States have musculoskeletal impairments. Musculoskeletal injuries rank second only to diseases of the circulatory system and are first among all disease groups in total economic cost attributed to loss of earnings and non-fatal illness. In the United States alone, at least 85,000 workers receive permanent disability allowances for musculoskeletal injuries each year. Musculoskeletal injuries also rank second in the number of visits to physicians, fifth in the number of visits to hospitals and third in number of operations in hospitals (Hagberg and Wegman, 1987). In short, there is ample evidence to indicate that musculoskeletal problems are quite prevalent and costly.

2.3 A comparison of sitting to standing postures

In order to determine the posture which provides the most comfortable position in a typical working environment, it is necessary to compare the sitting and standing positions in terms of (1) absorption of body weight (2) cardiovascular demand and (3) center of gravity.

Basmajian (1978) indicated that in the sitting position, most of the body weight is absorbed by the lower extremities as opposed to the standing position where the entire body weight is supported by the lower limbs. However, in the standing position, pain in the lower extremity is not due to muscle fatigue. Instead, it is due to the stress placed upon the ligaments and skeletal system.

Cardiovascular demands placed on the standing position are greater compared to the sitting position. Ward et. al. (1966) investigated several cardiovascular parameters of twenty healthy individuals from a supine (lying on the back) to standing posture and from a supine to sitting posture. Due to the influence of gravity, they found that standing resulted in an increase peripheral pooling of blood. Compared to the supine position, the stroke volume decreased 45% and the heart rate increased 36%. There was also a 27% decrease in the cardiac output. The postural change from the supine to sitting resulted in approximately half as much peripheral pooling of blood as the change from supine to standing. From supine to sitting, the stroke volume decreased 20% and there was only an 18% increase in the heart rate. As a result, cardiac output fell only about 10%. If the energy consumption when lying down is taken as 100%, standing will result in an 8 to 10% increase in energy consumption and stooping will result in another 50 to 60% increase in energy consumption. Sitting, however, will only result in a 3 to 5% increase in energy consumption (Grandjean, 1973).

Sitting and standing positions can also be compared in terms of their stability. In the standing position, the center of gravity of the trunk is higher than in the sitting position and the base of support involves only the feet. In sitting, not only is the center of gravity of the trunk is lowered, but the base of support is enlarged, extending from the feet to the buttocks. The increased stability of the body when sitting with proper support for the buttocks, feet and back will increase one's capacity for precision tasks or fine movements (Asatekin, 1975). However, there is a greater potential for pelvic instability in sitting compared to standing. In a relaxed standing posture, a passive locking mechanism is available at the hip joints from ligamentous support when the hip is at full extension. In the sitting posture, this passive locking mechanism is not available as the hip joints are in a mid-position. As a result, muscular stabilization or other external support is needed to stabilize the trunk over the hips (Coe, 1983).

Whether due to poorly designed chairs or workstations, musculoskeletal factors or improper movement patterns, a slouched anterior sitting posture pre-dominates among observed sitting postures. Anterior sitting posture is characterized by a forward leaning posture from the vertical position. This resulted in the bending of the spinal cord and has been frequently implicated as a major cause of low back pain (McKenzie, 1981). Overall, depending on how forward the anterior sitting posture, there will be an increased potential for pain and stress to the lower back, upper back and neck. This prolonged, slouched anterior sitting posture has also been implicated as impairing both respiratory and digestive functioning (Bunch and Keagy, 1976).

Another disadvantage of the sitting position is that the lumbar disc pressure is considerably higher compared to the standing position (Andersson et. al., 1975). Of all the sitting postures, the disc pressure is the lowest in the upright posture and the highest in the anterior sitting posture as shown in Figure 2.1.

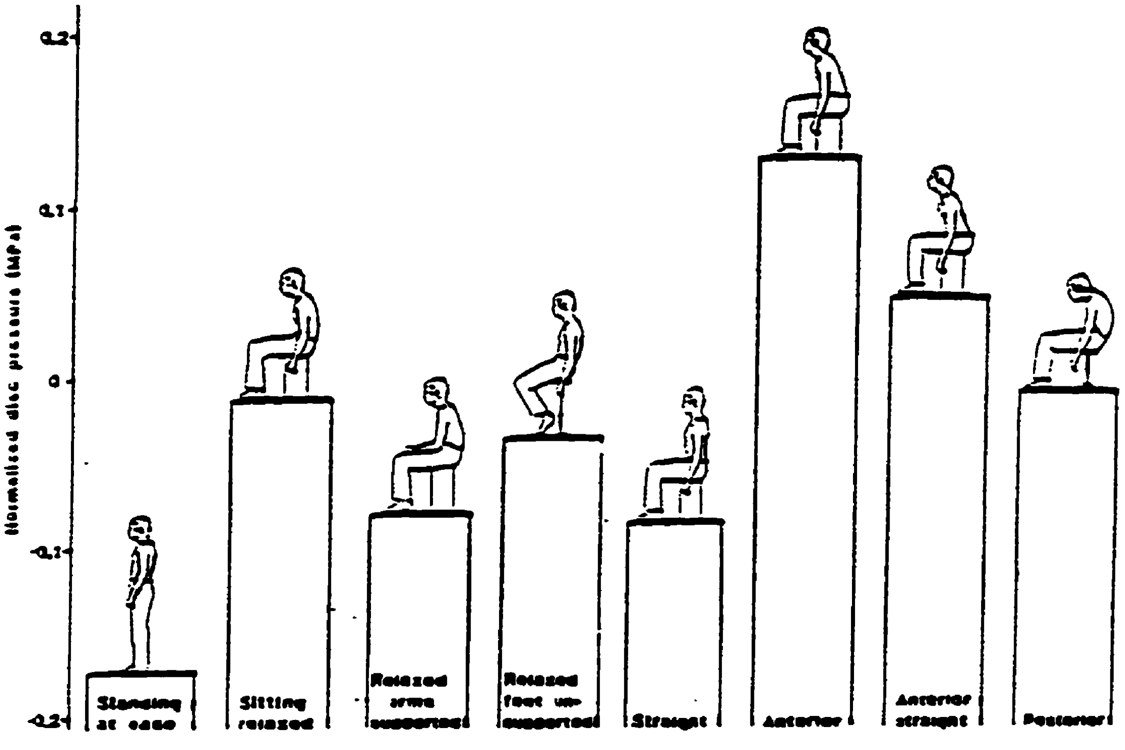


Figure 2.1 Mean values of normalized lumbar disc pressure (Zacharkow, 1988, pg. 58).

2.4 The general structure of a muscle

The following section describes the general structure of a muscle and explains how muscle contractions are controlled by electrical impulses.

Figure 2.2 shows the general structure of a muscle. Each muscle is covered by a fascia called the epimysium, from which connective tissue septa extend inward, subdividing the muscle into muscle fiber bundles called the fasciculi. These fasciculi are further subdivided into individual fibers that are again surrounded by connective tissue membranes. The connective tissue is important to the muscle as it provides a pathway for nerves and blood vessels and contributes to the mechanical properties of the muscle (Chaffin and Andersson, 1984, Basmajian and DeLuca, 1985).

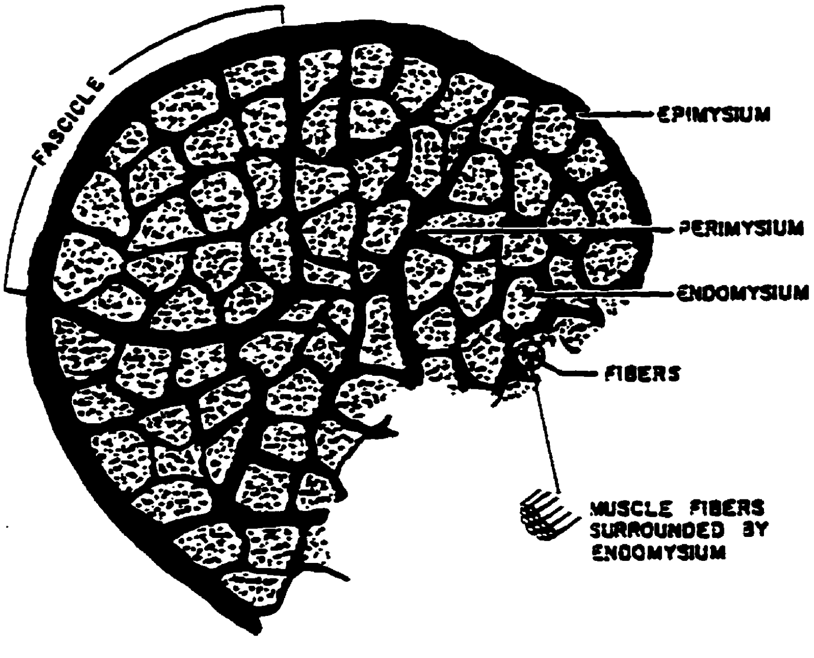


Figure 2.2 Portion of a muscle in transverse section (Chaffin and Andersson, 1984, pg. 28).

In the muscle, the individual muscle fibers are each connected by a terminal branch of an efferent nerve fiber or axon. An axon is used for conducting impulses from the nerve system to these muscle fibers. The group of muscle fibers connected by branches of the same efferent neuron axon are called a motor unit as shown in Figure 2.3.

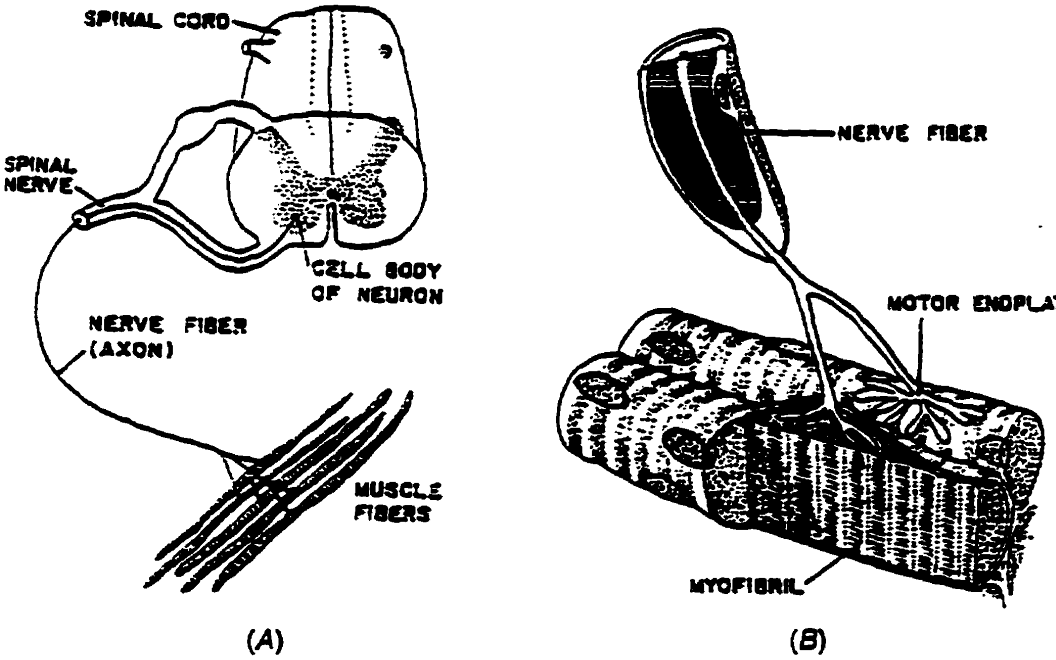


Figure 2.3 Scheme of (*A*) motor unit (*B*) neuromuscular junction of the muscle fibers (Chaffin and Andersson, 1984, pg. 29).

The motor unit is the functional unit of the muscle. It varies in size (number of fibers) depending upon the muscle. Motor units are small in muscles where precise control is important and larger in coarse-acting muscles. Muscle fibers contract upon receiving an electrical impulse (Chaffin and Andersson, 1984). When an individual muscle nerve is stimulated, a number of motor units will contract, depending on the size of the stimulus. Most of the fiber volume is taken up by the longitudinally arranged myofibrils, which are the contractile elements. The contractile unit in the myofibril is called the sarcomere (Chaffin and Andersson, 1984).

An electrical potential always exists because of the differences in ions on the inside and outside of a nerve or muscle cell membrane. The nerve impulse generated in the efferent or motoneurons of the central nervous system manifests itself as a change in the selective permeability of the membrane, called depolarization. The resulting nerve action potential is transmitted along the axon to the motor endplates. This causes a muscle unit action potential (MUAP) to develop along the muscle fiber membranes which can be picked up by surface electrodes or indwelling electrodes.

2.4.1 Recruitment of motor unit

Each muscle has a finite number of motor units, each of which is controlled by a separate nerve ending. The electrical indication mentioned earlier is a motor unit action potential (MUAP) and the mechanical result is a twitch of tension. An increase in tension can therefore be accomplished in two ways, either by an increase in the stimulation rate for that motor unit or by excitation of an additional motor unit. Figure 2.4 shows the EMG signal of a needle electrode in a muscle as the tension was gradually increased.

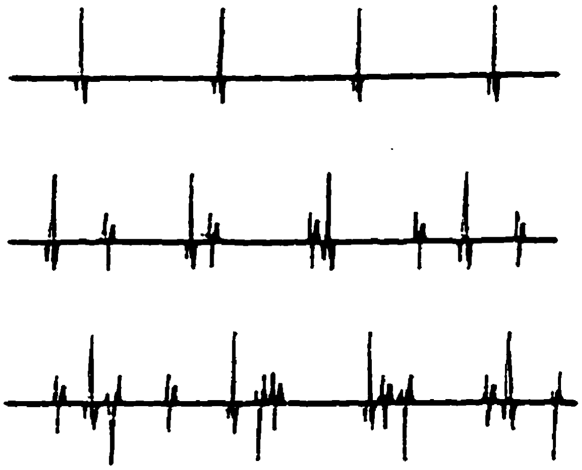


Figure 2.4 EMG from an indwelling electrode in a muscle as it begins to develop tension. The smallest motor unit is recruited first, and as its rate increases, a second, then a third motor unit are recruited (Winter, 1990, pg. 167).

The upper tracing shown in Figure 2.4 shows one motor unit firing, the middle tracing with two motor units and the lower tracing with three motor units. Initially muscle tension increases because the firing rate increases. At a certain tension, the second motor unit was recruited and further tension increases are then accomplished by increases in the rate of the second motor unit plus possible further increases in the rate of the first unit (Winter, 1990). As each unit has a maximum firing rate, it appears that this maximum rate is reached after the next unit is recruited. Winter (1990) also reported that when the tension is reduced, the reverse process occurs. The firing rate of the recruited units decreases until the minimum rate for the last recruited unit is reached, at which point the unit drops out. Each unit usually drops out in reverse order in which it was recruited.

2.5 Dynamic and static muscular effort

There are two kinds of muscular effort (1) dynamic effort and (2) static effort. These two muscular efforts can be described by the behavior of muscle contractions and the blood supply to these muscles. This section also discusses how static load can lead to localized muscle fatigue.

2.5.1 Muscle contractions

Dynamic effort is characterized by a rhythmic alternation of contraction and extension, tension and relaxation in the muscle. Static effort, in contrast, is characterized by a prolonged state of contraction of the muscle (Grandjean, 1988).

In a dynamic situation the muscle shortens when a force is applied to it (Grandjean, 1988). This type of muscular contraction is also called isotonic, meaning that the muscle contracts when it is activated. At least one quarter of the chemically available energy in the muscle is utilized to perform the work (Nag, 1985). Energy expenditure increases during the first few minutes of work and then levels off as the energy demand reaches a level sufficient to meet the requirements of the task.

The muscle contraction without any change in its length is called isometric. During static effort the muscle is not allowed to extend, but remains in a state of heightened tension, with force exerted over an extended period of time. Static effort resembles an electromagnet, which has a steady consumption of energy while it is supporting a given weight, but does not appear to be doing useful work (Grandjean, 1988). During static contraction, the force exerted on the muscle remains constant although the muscular motor units remain active throughout the contraction. Due to the accumulation of acidic metabolites, static work induces rapid muscular fatigue (Nag, 1985).

2.5.2 Blood supply

There are certain basic differences between static and dynamic muscular effort. During static effort the blood vessels are compressed by the internal pressure of the muscle tissue, so that the blood no longer flows through the muscle. During dynamic effort as when walking, the muscle acts as a pump in the blood system. Compression squeezes blood out of the muscle, and the subsequent relaxation releases a fresh flow of blood into it. By this means the blood supply becomes several times greater than normal, in fact the muscle may receive 10 to 20 times as much blood as when it is resting (Grandjean, 1988). A muscle performing dynamic work is therefore flushed out with blood and retains the energy rich sugar and oxygen contained in it, while at the same time waste products are removed. In contrast, a muscle that is performing heavy static work is receiving no sugar or oxygen from the blood and must depend upon its own reserves. Moreover, waste products are not being excreted into the blood stream. The accumulation of these waste products are associated with the acute pain of muscular fatigue. For this reason one cannot continue a static muscular effort for very long. On the other hand a dynamic effort can be carried on for a very long time without fatigue, provided that a suitable rhythm is chosen for it (Grandjean, 1988, Nag, 1985).

There is no defined or clear distinction between dynamic and static effort. Often tasks involve partly static and partly dynamic effort. Since static effort is much more exhausting than dynamic, the static component of mixed effort assumes the greater importance. Constrained and awkward posture are certainly the most frequent form of static muscular work. The main cause of constrained postures is carrying the trunk, hand, head or limbs in unnatural positions (Grandjean, 1988).

2.5.3 Localized muscle fatigue

Static work produces localized fatigue in muscles, which can build up to intolerable pain (Grandjean, 1988, Aaras 1987). If the static load is repeated daily over a long period, more or less permanent aches will appear in the limbs and may involve not only the muscle but also the joints, tendons and other tissues. Thus long lasting and daily repeated static efforts can thereby lead to a damage of joints, ligaments and tendons. All of these acute and chronic impairments are usually summarized under the term musculoskeletal injuries.

Symptoms of over-stress can be divided into two groups, reversible and persistent musculoskeletal injuries. The reversible symptoms are short lived. The pains are mostly localized to the muscle and tendons and disappear as soon as the static load is relieved. Persistent troubles are also localized to strained muscles and tendons but they affect the joints and adjacent tissues as well. The pains do not disappear when the work stops but continue to carry on. These persistent pains are attributable to inflammatory and degenerative processes in the overloaded tissues. According to Van Wely (1970), persistent musculoskeletal injuries are commonly observed among operators who work all the year round without sufficient breaks at the same machine. Elderly employees are more prone to such persistent disorders. Persistent musculoskeletal injuries, if unchecked over years, may get worse and lead to chronic inflammations of tendon sheaths or even deformation of joints.

2.6 Electromyography

Electromyography (EMG) is a technique which is used to measure muscle activitiy. It has been used for this purpose since the late 18th century (Basmajian and DeLuca, 1985). It is the study of muscle function through the inquiry of the electrical signal which the muscles emanate. In the field of biomechanics and ergonomics, EMG has contributed to the understanding of how the muscle of the body function in relation to one another, especially how they act together to produce movement. EMG examination is often particularly helpful when clinical evaluation is difficult. Over the years, the activity of individual muscles in the maintenance of posture during normal or abnormal movement has also been studied by electromyography. EMG has also provided scientists and researchers with a knowledge of muscle contractions, muscle force and muscle fatigue. The EMG data collection system has found its place in the laboratories of ergonomic, vocational medicine, rehabilitation, anatomy as well as physical and occupational therapy.

2.6.1 The electromyographic system

The electrical activity of muscle is studied for diagnostic purposes by placing surface electrodes on the skin or indwelling electrodes under where the muscle is to be examined. According to Grieve (1975), the electromyography is an index of the electrical activity occurring at the muscle cell during excitation. This excitation consists of depolarization and repolarization of the membrane resting potential (Rau and Reucher, 1984). The depolarization of the muscle fiber membrane establishes a small electrical potential (muscle unit action potential) across the membrane which is a result of the transfer of the charged ions potassium, calcium and sodium (Chaffin and Anderson, 1991). The recorded EMG voltage, called myoelectric activity, is the sum of several motor unit action potentials. The electrodes then pick up the myoelectric activity generated as the result of muscle fiber membrane depolarization. The electrical potentials that are picked up by the electrodes are amplified and displayed on a computer monitor screen for visual analysis. Graphical display of muscle amplitude on the screen can be saved on the hard drive for retrieval at a later date. The major components of the electromyographic system are the recording electrodes, amplifier, signal processing software for data acquisition and EMG calibration platform. Electromyographic signals can also be displayed using a cathode ray oscilloscope, magnetic tape or acoustically using a loud speaker.

2.6.2 Electrodes

The electrodes are the interface between the subject and the instrumentation. Proper application and use of electrodes is one of the most fundamental requirements for obtaining good signals. Electrodes are low impedance devices placed over the muscles of interest and record the algebraic sum of all motor unit action potential (MUAP) that is being transmitted along a muscle fiber during contraction (Winter, 1990). Motor unit action potentials are the principal electrical event recorded from muscles during muscle contraction. Motor units that are far away from the electrode site will result in a smaller MUAP than those of closer to the electrode. Electrodes made of silver-silver chloride are commonly used because this material is non polarizable which allows bi-directional flow of current between the electrode and electrolyte interface (Soderberg and Cook, 1984). In addition, these types of electrodes are low in impedance, stable, light and small in size.

Many types of EMG electrodes have been developed over the years, but generally they can be divided into two groups, surface and indwelling electrodes. Surface electrodes consist of disks of metal, usually silver-silver chloride, of about 6 mm in diameter. These electrodes detect the average activity of muscles and give more reproducible results than indwelling electrodes. Indwelling electrodes, such as the needle type, are required for the assessment of fine movements or to record from deep muscles (Winter , 1990). Both surface and indwelling electrodes come in monopolar and bipolar configuration. Monopolar and bipolar detection are shown in Figure 2.5.

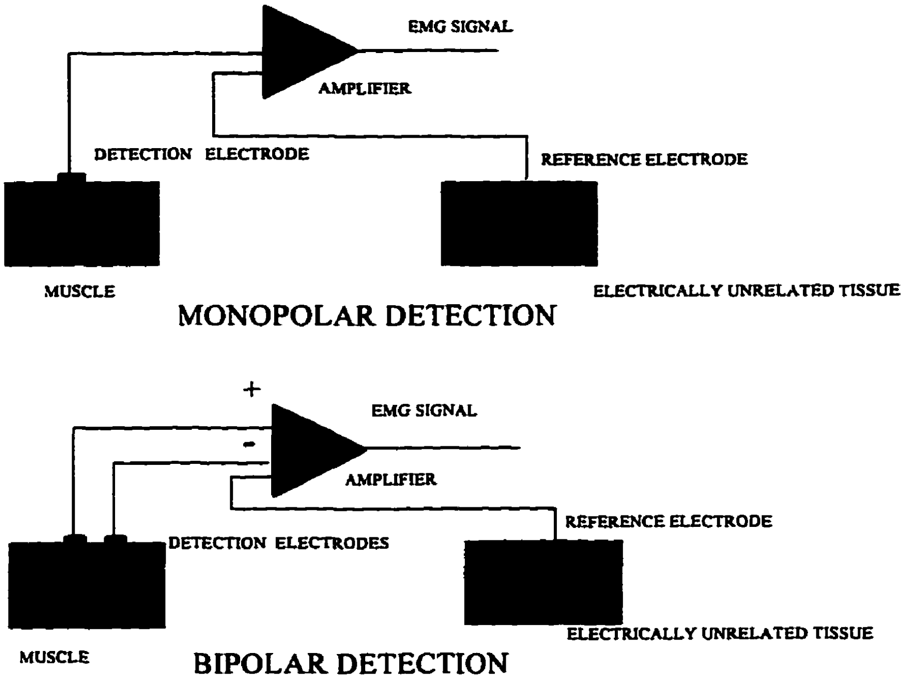


Figure 2.5 Monopolar and bipolar detection arrangement (Basmajian and DeLuca, 1985, pg. 38).

The monopolar configuration has only one detection electrode while the bipolar detection has two detection electrodes with each having one reference electrode. The reference electrode is either electrically quiet or contains electrical signals which are unrelated to those being detected. By unrelated, it is meant that the two signals have minimal physiological and anatomical association (Basmajian and DeLuca, 1985). The monopolar configuration has the drawback that it will detect all the electrical signals in the vicinity of the detection surface which includes unwanted electrical signals from sources other than the muscle being investigated. The bipolar detection configuration overcomes this limitation. This configuration is used to detect two potentials in the muscle of interest, each with respect to the reference electrode. The two signals are then fed to a differential amplifier which amplifies the difference of the two signals, thus eliminating any common mode components in the two signals.

2.6.3 EMG calibration platform

The EMG calibration platform also called the force platform is a device designed to measure the forces exerted by a body on an external surface. The most common type of transducers in force platforms are strain gauges or piezoelectric quartzes. According to Winter (1990), the platform must be designed to accommodate foot contact with a minimum necessity of targeting the platform. In addition, the force platform should also provide valid measurement of forces, adequate sensitivity and high linearity. Special care must also be taken to eliminate the interference associated with cable aberrations, electrical conductance, temperature and humidity variations. The structure of the platform must also be relatively light and designed in a way to provide high stiffness.

2.6.4 Recording of EMG signal

An amplifier is required for the recording of the EMG signal, whether from surface or indwelling electrodes. Along with the muscle activity, the electrodes pick up various unwanted signals (noise or artifacts) that can contaminate the EMG signal (Aminoff, 1992). Noise can be introduced from sources other than the muscle and can be biological in origin or man-made. Artifacts generally refer to false signals generated by the electrodes themselves or the cabling system. An amplifier is placed on or near the recording site to enhance and increase the amplitude of the desired response and reduce the noise or artifacts. According to Aminoff (1992), this can be achieved by a differential amplifier which also helps to reduce distortions of the signal by rejecting interference signals. The major considerations when specifying the EMG amplifier are the amplifier gain, input impedance, frequency response and common mode rejection.

2.6.5 Amplifier gain

The amplifier gain is defined by the ratio of its output voltage to its input voltage. Stern et. al. (1980), states that amplifier gain should be high to sufficiently output the recordings. The exact gain chosen for any given situation will depend on what is to be done with the output signal. In general, a good amplifier should have a range of gains selectable from 100 to 10,000. Independent of the amplifier gain, the amplitude of the signal should be reported as it appears at the electrodes, in millivolts (Winter, 1990).

2.6.6 Input impedance

An electrode exhibits some opposition or impedance to the flow of an electric current and is therefore important that the amplifier to which it is connected have a relatively high input impedance to prevent loss of signal. Each electrode-skin interface has a finite impedance which depends on many factors, thickness of the skin layer, cleaning of the skin prior to the attachment of the electrodes, area of the electrode surface and temperature of the electrodes. Figure 2.6 shows the amplifier for recording electrode potentials.

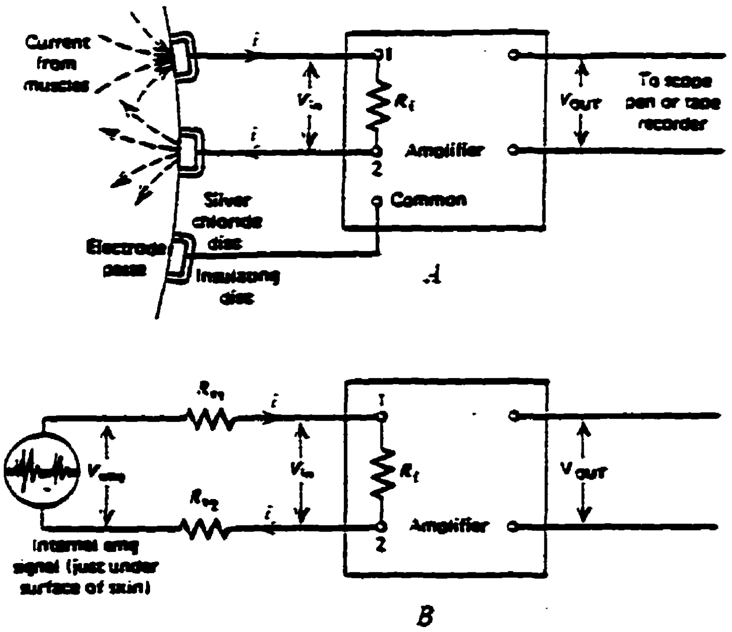


Figure 2.6 Amplifier for recording electrode potentials. (*A*) Current resulting from muscle action potentials flows across skin-electrode interface to develop a voltage V_{in} at the input terminals of the amplifier. A third, reference electrode is normally required because the amplifier is a differential amplifier. (*B*) Equivalent circuit showing electrodes replaced by resistors (Winter, 1990, pg. 198).

In Figure 2.6(*B*), the electrode-skin interface is replaced with an equivalent resistance of the actual situation. As soon as the amplifier is connected to the electrodes, the EMG signal will cause current to flow through the electrode resistances R_{s1} and R_{s2} to the input impedance of the amplifier R_t . The current flow through the electrode resistances will cause a voltage drop so that the voltage at the input terminal V_{in} will be less than the desired signal V_{EMG}. For example, if $R_{s1} = R_{s2} = 10{,}000\ \Omega$ and $R_t = 80{,}000\ \Omega$, a 2 mV EMG signal will be reduced to 1.6 mV at V_{in}. A voltage loss of 0.2 mV occurs across each of the electrodes. If R_{s1} and R_{s2} were decreased by better skin preparation to 1000 Ω and R_t were increased to 1 MΩ, the 2 mV EMG signal would be reduced only slightly, to 1.996 mV. Thus it is desirable to have input impedance of 1MΩ or higher and to prepare the skin to reduce the impedance to 1000 Ω or less (Winter, 1990).

2.6.7 Frequency response

Frequency response is defined as the range of frequencies between low and high cut off points (Winter, 1990). The difference between the two frequencies are known as the frequency bandwidth. All amplifiers have limits on the range of frequency over which they operate. A recommended frequency range for surface electrodes by Winter (1990) is 10 to 1000 Hz and 20 to 2000 Hz for indwelling electrodes.

2.6.8 Common mode rejection

Basmajian and DeLuca (1985) defined the common mode rejection as the ability to reject common mode signals of hum and artifact. The effectiveness of the differential amplifier at rejecting common mode signals is known as the common mode rejection ratio (CMRR). The human body is a good conductor and therefore act as an antenna to pick up any electromagnetic radiation that is present. The most common radiation comes from domestic power such as power cords or fluorescent lighting an appears as sinusoidal signal (Aminoff, 1992). Figure 2.7 shows unwanted common mode sinusoidal signal been truncated by the differential amplifier.

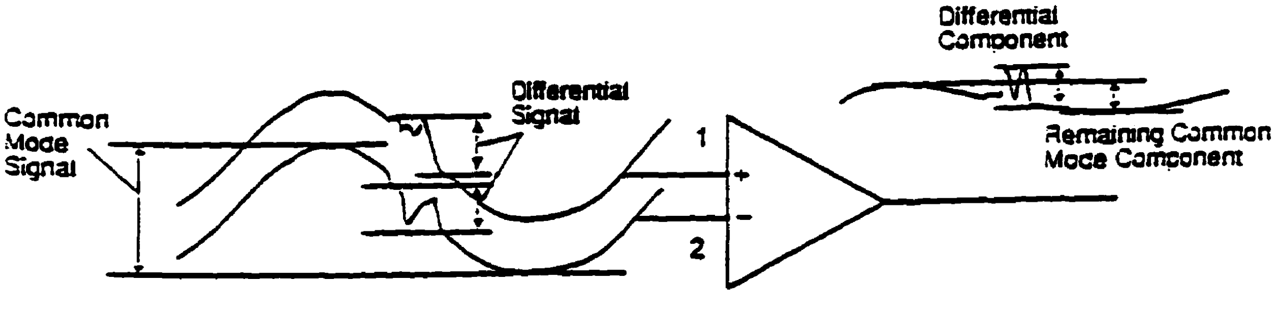


Figure 2.7 A differential amplifier will reduce the output signal by the same ratio, any difference between detection and reference signal is amplified (Aminoff, 1992, pg. 33).

Such an amplifier takes the difference between the signals on the detection terminals as shown in Figure 2.7. As can be seen, the hum or artifact interference appears as an equal amplitude on both detection terminals. Hence, by using a differential amplifier with a gain of *A* and net signal at terminal 1 as V_{hum} + emg_1 while at terminal 2 as V_{hum} + emg_2, the ideal output signal is:-

$$\begin{aligned} e_o &= A\,(e_1 - e_2) \\ &= A\,(V_{hum} + emg_1 - V_{hum} - emg_2) \\ &= A\,(emg_1 - emg_2) \qquad (2.1) \end{aligned}$$

The output e_o is an amplified version of the difference between the EMG signals on terminal 1 and 2. The above description is idealistic, realistically hum or artifact is always present to some extent unless amplifiers are powered by battery and operated far away from domestic power sources (Winter, 1990).

2.6.9 Processing of EMG signal

Once the EMG signal has been amplified, it can be processed for comparison. Winter (1990) and Basmajian and DeLuca (1985) listed the most common type of on-line processing of raw EMG signals which include half or full wave rectification, linear envelope detector, integration of the full wave rectified signal over the entire period of muscle contraction, integration of the full wave rectified signal for a fixed time and integration of the full wave rectified signal to a preset level. Figure 2.8 shows several common EMG processing systems.

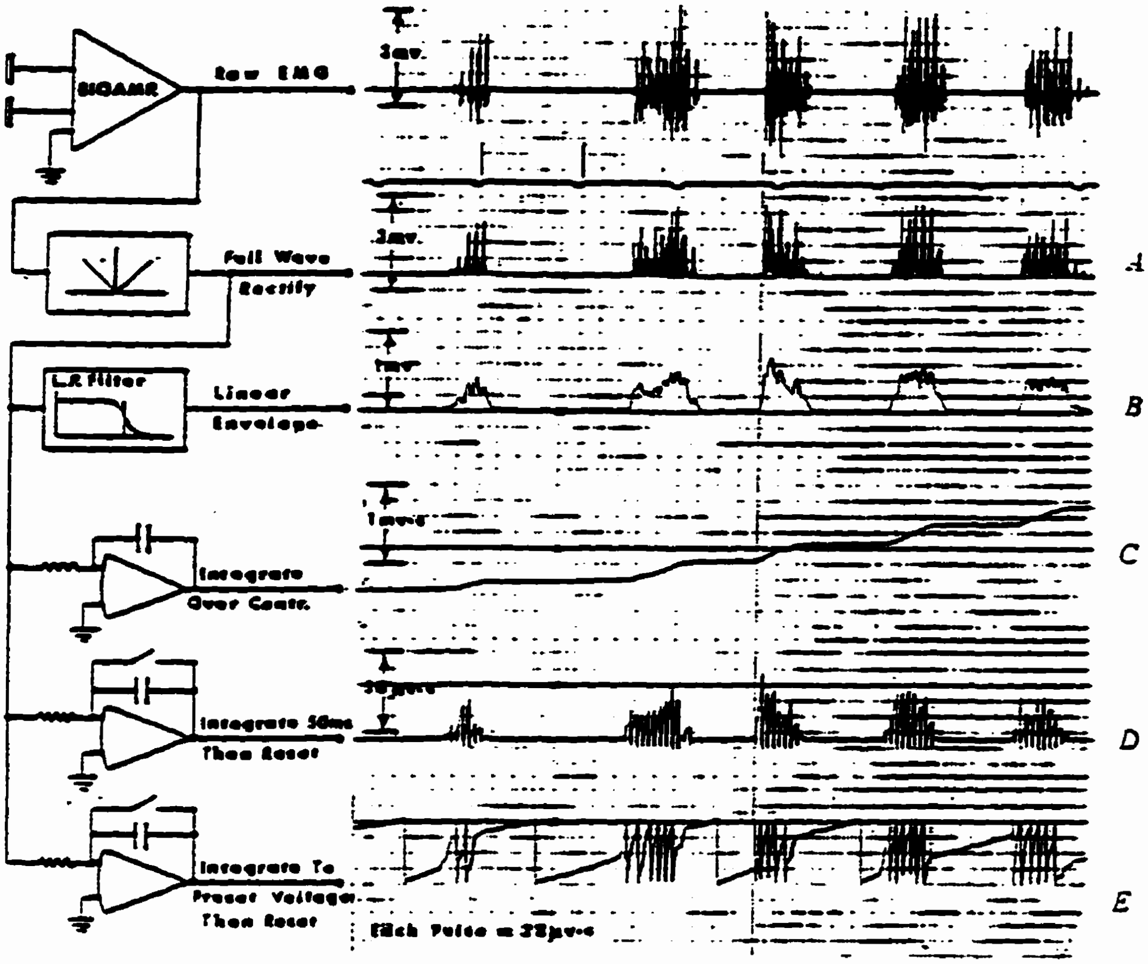


Figure 2.8 Schematic diagram of several common EMG processing systems and the results of simultaneous processing of EMG signals through these systems (Winter, 1990, pg. 205).

2.6.10 Rectification

The process of rectification involves the concept of rendering only positive deflections of the signal. This may be accomplished either by eliminating the negative values of the raw EMG signal (half-wave rectification) or by inverting the negative values (full-wave rectification) (Basmajian and DeLuca, 1985). The latter is the preferred procedure because it retains all the energy of the signal (Figure 2.8(*A*)). Winter (1990) stated that the quantitative use of the full wave rectified signal by itself is somewhat limited. It usually serves as an input to other types of processing.

2.6.11 Linear envelope

A linear envelope is the result of filtering the full-wave rectified signal with a low pass filter (Figure 2.8(*B*)). It can be described as a moving average because it follows the trend of the EMG signal (Winter, 1990, Basmajian and DeLuca, 1985). It is a valuable method in assessing how EMG activity changes with time over the period of contractions as well as providing a typical pattern of EMG activity for repetitive movements. There is also considerable confusion concerning the proper name for this signal. Many researchers call it an integrated EMG (IEMG) which is wrong because it can be confused with the mathematical term integrated, which is a different type of processing.

2.6.12 Integration

According to Basmajian and DeLuca (1985), the most commonly used data reduction procedure in electromyography is the concept of integration. The purpose of the integration of the full wave rectified signal is to measure the area under the curve. The simplest form starts its integration at a preset time and continues during the time of the muscle activity (Figure 2.8(*C*)). At the desired time, which could be a single contraction or a series of contractions, the integrated value can be recorded. The average EMG signal during a given contraction can be calculated by dividing the integrated value by the time of the contraction (Winter, 1990).

A second form of integration involves a resetting of the integrated signal to zero at regular intervals of time. Such a scheme yields a series of peaks which represent the trend of the EMG amplitude with time (Figure 2.8(*D*)). Each peak represents the average EMG over the previous time interval and the series of the peaks is a moving average. However, if the reset time is too high, it will not be able to follow rapid fluctuations of EMG activity. If the reset is too frequent, noise will be in the trendline (Winter, 1990).

The third common form of integration uses a voltage level reset (Figure 2.8(*E*)). This type of integration allows the measurement of the strength of muscle contractions by evaluating the frequency of resets (Winter, 1990). The integration begins before the muscle contraction. If the muscle activity is high, the integrator will rapidly charge up to the reset level. If the activity is low, it will take longer to reach the reset level. Hence, the frequency of reset pulses indicates the level of muscle activity.

2.6.13 Root mean square

Another type of processing used for EMG analysis is the root mean square method (RMS). The RMS method is very similar to the linear envelope processing and is a time domain analysis. The RMS method according to Soderberg and Cook (1984) can provide nearly instantaneous output of the characteristics of the EMG signal and is frequently used in studying muscular fatigue.

2.6.14 EMG relationship to muscle force

According to Soderberg (1986), many researchers have attempted to relate EMG activity to muscle force. There is a general acceptance that as muscle length becomes shorter, the EMG output increases. Although this may be due to an increased number of fibers below the recording electrodes, the relationship generally holds (Soderberg, 1986). According to Winter (1990) and Soderberg (1986), most evaluation of the EMG/force relationship has occurred during isometric contractions. The EMG signal processed through a linear envelope detector has been widely used to compare the EMG/force relationship, especially if the force is changing with time.

Winter (1990), Soderberg (1986), Basmajian and DeLuca (1985) indicated that both linear and nonlinear relationships between EMG amplitude and force have been discovered. Study conducted by Lippold (1967) found a linear relationship of muscle force and EMG on human calf muscles. Zuniga and Simons (1969) and Vredenbregt and Rau (1973), found quite nonlinear relationship between muscle force and EMG in elbow flexors over a wide range of joint angles. Both these studies were in static calibrations of the muscle under certain length conditions (Winter, 1990). Figure 2.9 shows the relationship of muscle force and EMG signal.

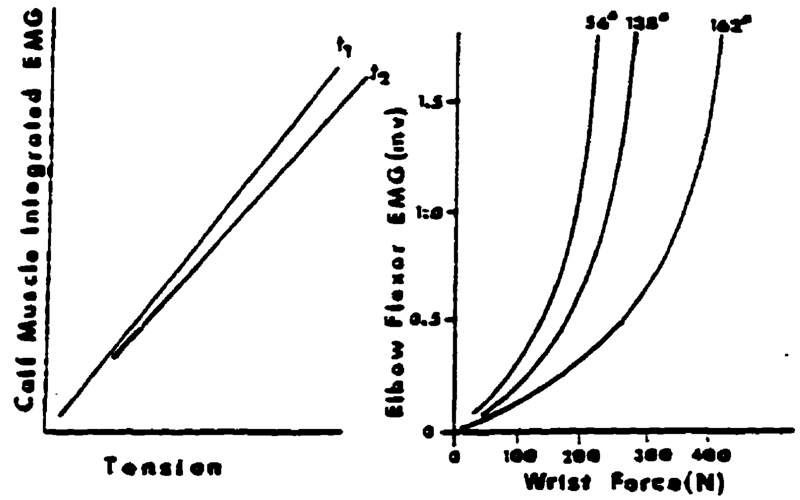


Figure 2.9 Relationship between the average amplitude of EMG and the muscle force in isometric contraction (Winter, 1990, pg. 207).

Other factors that could affect the ability to show a relationship between muscle force and EMG activity include specific muscle characteristic such as orientation of muscle fibers, muscle length, muscle fatigue and different firing rates. Electrode configuration, amount of subcutaneous tissue and other factors also imposed limitations on the relationship (Soderberg, 1986). Hence, comparisons between subjects are impossible unless care is taken in the technique and study methodology. However, a common method to allow for comparisons is the normalization process whereby the subject performs a maximum voluntary contraction (MVC) while EMG is recorded. Data collected during subsequent trials can then be related to this quantity (in terms of percentage of activity evoked during the maximum contraction).

2.6.15 Normalization of EMG signal

Normalization is a technique used to quantify an EMG signal so that a muscle's relative activity can be assessed. Normalized EMG, in conjunction with EMG/force relationship, allows researchers to estimate the amount of force exerted across the muscle of interest. The relative activity of a muscle can be found by comparing a given muscle EMG activity with a reference EMG value and expressing the task muscle activity as a percentage of this reference value. According to Mirka (1991), the point of reference can be associated with the muscle's maximum voluntary contraction (MVC) activity level. Sub-maximal reference voluntary contraction (RVC) activity level can also be used as a reference point (Mirka, 1991). Quite often, an EMG resting value is also collected in order to quantify the resting level activity that is required to hold a body segment (Soderberg, 1991, Serroussi and Pope , 1987). This value then becomes a low end reference for the normalization of the EMG signal. Regardless of the type of reference contractions used, the final output of normalization procedures is the conversion of data points into meaningful values.

Normalization techniques allow for comparisons of EMG values obtained across a variety of conditions. Comparisons between subjects can be made because the relative amount of activity for a given subject is compared with the reference activity for that subject and therefore is a subject dependent (Mirka, 1991). This provided the ability to compare the relative effort required to perform a task between all subjects. These techniques also allow for day to day comparisons of EMG signals within a subject because all the day to day effects due to slight changes in variables such as skin temperature, electrode position, muscle geometry and so on, can be controlled through normalization.

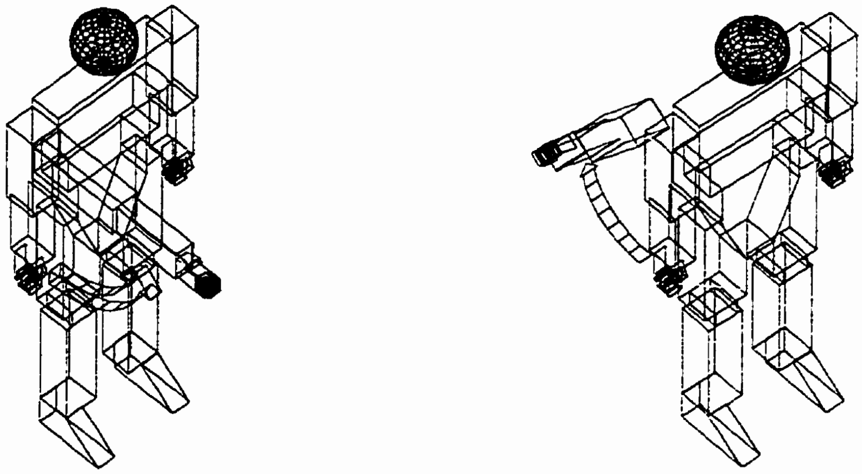
According to Mirka (1991), the normalization of the EMG signal has its limitations. Each muscle that is subjected for comparison has to be normalized for a resting and a maximum EMG value. This can be both time consuming and fatiguing to the subject. If this method is not employed, the ability to assess accurately the relative activity of a muscle cannot be determined.

2.7 Description of the shoulder muscles

The shoulder represents the first link in a mechanical chain of levers that extends from the shoulder to the fingertips. The main movements of the shoulder joint complex include abduction, adduction, flexion and extension. The major muscles involved in these movements are the deltoid, pectoralis major, latissimus dorsi, teres major, rhomboids, trapezius, subscapularis, supraspinatus, infraspinatus and teres minor. For purpose of this research, the trapezius and deltoid muscles are discussed as these were the two muscles that were tested in the laboratory experiment.

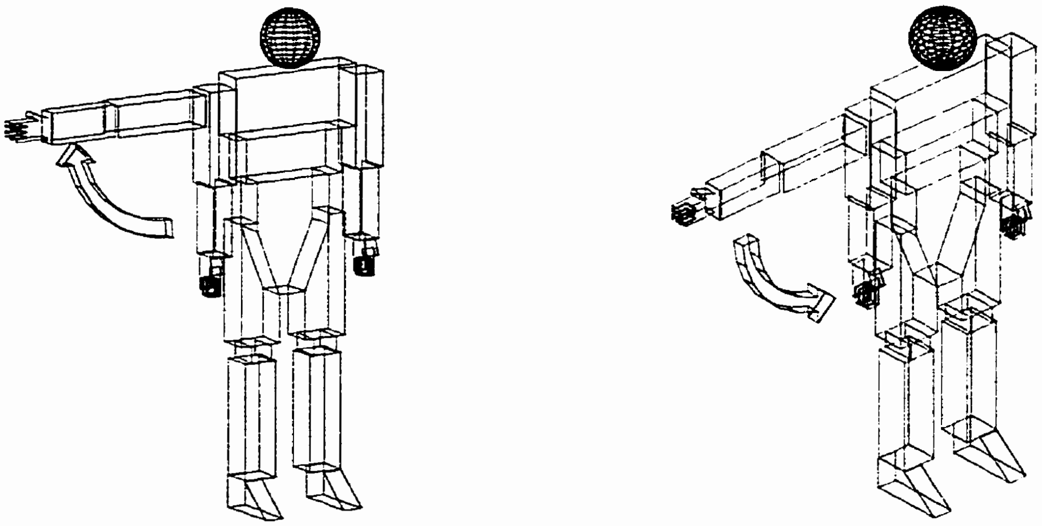
2.7.1 Range of motion of the shoulder complex

Shoulder elevation is defined as movement of the humerus away from the side of the thorax in any plane. It is measured in degrees from the vertical. However, different types of shoulder elevation are possible depending on the plane of motion chosen. Forward and backward flexion is shoulder elevation in the sagittal plane, while abduction and adduction is elevation in the frontal plane. This is shown in Figure 2.10 and Figure 2.11 respectively .



(*A*) (*B*)

Figure 2.10 (*A*)Forward Flexion and (*B*) backward extension of the arm in sagittal plane.



(*A*) (*B*)

Figure 2.11 (*A*) Abduction and (*B*) adduction of the arm in frontal plane.

The normal range of forward flexion is about 180 degrees (AAOS, 1965). This range decreases with age (Germain and Blair, 1983, Murray et. al., 1985), but the decrease has been shown to be significantly smaller in physically active persons (Germain and Blair, 1983). The range of adduction is also about 180 degrees (AAOS, 1965).

2.7.2 Deltoid Muscle

Crouch (1985) described the deltoid muscle as a large, thick, triangular muscle that helps form the roundness of the shoulder. This is shown in Figure 2.12. Superficially, the muscle appears to be one continuos mass of flesh, but in reality it has three portions. These portions are the anterior, posterior and middle fibers.

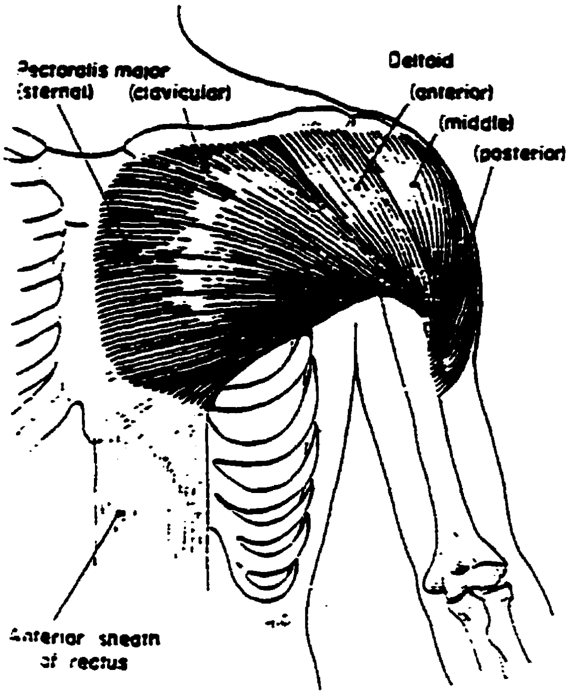


Figure 2.12 Anterior deltoid muscle (Luttgens and Wells, 1982, pg. 85).

The anterior fibers of the deltoid arise from the lateral third (anterior border) and upper surface of the clavicle. The middle fibers originate from the lateral border and upper surface of the acromion. The posterior fibers arise from the inferior lip of the crest of the spine (Crouch, 1985, Basmajian, 1982). All three portions converge into a thick tendon that inserts on the middle lateral surface of the humerus, on the deltoid tuberosity.

According to Basmajian (1982) and Crouch (1985), the deltoid as a whole is powerful flexor and abductor of the humerus. The anterior fibers are involved in flexion, horizontal adduction and medial rotation of the humerus. The middle fibers are the strongest of the three portions. This strength is attributed to its bipennate muscle fiber arrangement. The middle fibers are solely involved in abduction of the humerus. Finally, the posterior fibers, considered the weakest fibers of the deltoid, are involved in lateral rotation and extension of the humerus as well as adduction of the arm.

2.7.3 Trapezius muscle

The trapezius muscle contributes significantly to shoulder movements by stabilizing the scapula abduction, flexion and lateral rotation of the humerus (Basmajian, 1982).

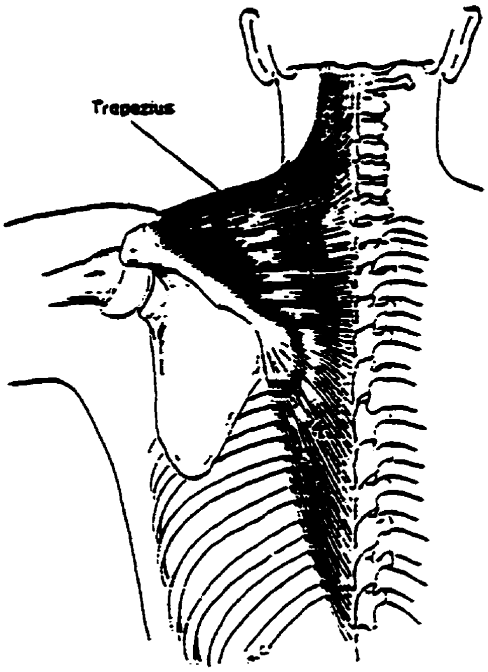


Figure 2.13 Trapezius muscle (Luttgens and Wells, 1982, pg. 96).

Basmajian (1982) and Crouch (1985) described the trapezius as a large, flat, triangular muscle that covers the back of the neck and upper half of the trunk, shown in Figure 2.13 above. Crouch (1985) stated that the trapezius originates on the occipital bone of the skull, the ligamentum nuchae and the vertebral spines of the seventh cervical and all of the thoracic vertebrae. The muscle can be divided into three portions of fibers that have separate insertions. Basmajian (1982) stated that the upper fibers descend and insert on the posterior lateral border of the clavicle, the middle fibers run horizontally and insert on the length of the spine of the scapula and the lower fibers rise and insert on the tubercle of the spine of the scapula.

Crouch (1985) also stated that the insertion of these three groups of fibers indicated the function of the trapezius. The upper fibers serve to elevate and rotate the scapula as well to elevate the tip of the shoulder. The middle fibers retract the scapula and they also stabilize the scapula during the initial movements of flexion and abduction of the humerus. The lower fibers pull the medial end of the scapula downward, cooperating with the upper fibers to rotate the glenoid fossa upward (Basmajian, 1982). The trapezius muscle and the upper serratus anterior muscle (located on medial border of the scapula) are antagonistic, the former adducting and the latter abducting the scapula. This action facilitates elevation of the arm.

Chapter 3
Method of Experiment

3.1 Introduction

This chapter describes how the experiment was conducted for the evaluation of the direct and indirect observation workstations. In both methods, subjects were required to perform the experimental task in the sitting and standing positions. In addition, this experiment was conducted for the dynamic workstation which involves a combination of direct and indirect observation workstations in the sitting and standing positions.

Electromyography (EMG) is used to measure muscle activities in the upper extremity. Goniometers are used to measure the postural angle measurement. The perceived level of comfort using the direct and indirect observation workstations in the sitting and standing positions is determined using subjective report based on questionnaire provided. In addition, productivity and quality measurements of the task will also be included as a comparison between different workstations. A null hypothesis of no difference in muscle activities of the trapezius and anterior deltoid muscles using the direct and indirect observation workstations in the sitting and standing positions was adopted.

3.2 Subjects

Twenty one healthy subjects participated in the laboratory experiment, 5 of the subjects were females and the remaining 16 were males. The ages of these subjects range from 19 to 30 years of age and the mean age was 23.7 years. Consent to perform the laboratory experiment using human subjects was granted by the Ethics Committee of the Faculty of Arts, University of Manitoba.

3.3 Apparatus

The equipment used for the indirect observation workstation consists of a JVC video camera (Model TK-1280U) with zoom lens which is mounted directly beneath the work-area, a 20 inch Panasonic color monitor (Model CT-20511CS), a Pelco zoom controller (Model MPTA 24DT) with features such as tele-zoom, focus, iris and lens speed options, a spring loaded monitor stand, an office chair with back and arm rest and an adjustable table with a 0.25hp motor mounted beneath the table. Apart from using the goniometers to measure the head, trunk and upper arm movement of each subject, other body postures were captured through video recording of the experiment. A similar JVC video camera (Model TK-1280U), a SHARP video cassette recorder (Model XA-405) and a 20 inch Panasonic color monitor (Model CT-20511CS) were used for recording the postural angles during the experiment.

The direct observation workstation uses only the adjustable table. The subjects were required to perform the task in the sitting and standing positions at this table. An office chair is used only when the experiment is done in the sitting position. A 486 desk top computer with math co-processor and 4MB RAM was used to run the software for measuring the EMG signals from muscle of interest and the postural angles of the head, trunk and upper arm. Figure 3.1 shows the layout of the laboratory experiment in which this study was conducted.

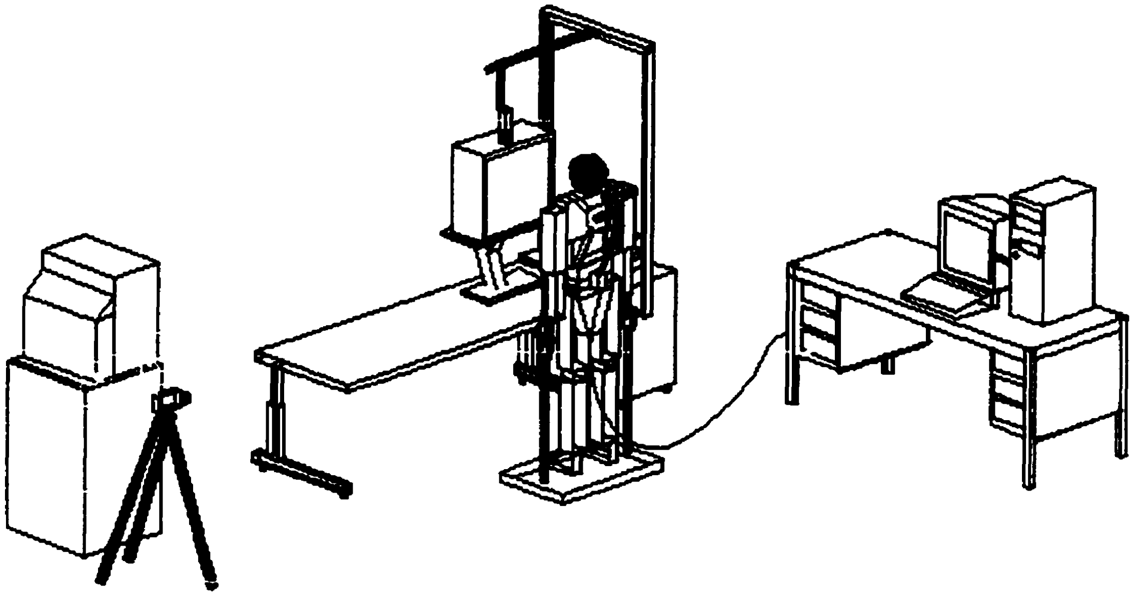


Figure 3.1 Layout of the laboratory experiment.

Analysis of the muscle activities and postural angle measurement were made possible with the Physiometer PHY-400 supplied from PREMED A/S from Norway. The Physiometer PHY-400 consists of postural angle sensors (goniometers) for the head, trunk and upper arm, surface electrodes, Data Acquisition Unit (DAU), EMG calibration platform and a MS-DOS version software for data acquisition. The battery operated Data Acquisition Unit (DAU), worn as a waist pack is capable of recording up to 4 channels of signals from the electrical activity of the muscle and up to 6 channels of signals for different angular sensors. This unit also houses the amplifier to amplify the myoelectric signal from the muscles through surface electrodes.

Each of the four channels for measuring the EMG signal has two different gain settings that are automatically selected during the measurement according to the magnitude of the input signal. The sampling rate for the EMG inputs is 1600Hz. The value of each EMG signal is calculated in real time in the DAU, full wave rectified, integrated and sent five times a second (0.2 seconds interval) on the serial interface port together with the six other channels which measures the postural angles. The DAU consists of a microcomputer with memory and an Analogue Front End (AFE) with interface to the sensors. The AFE consists of 4 EMG Band-Pass Filters (BPF) with cut off frequency of 25Hz and 800Hz and a 12 bit A/D converter. The microcomputer (HD63A03YF) operates at 4.9 MHz and have 128Kbyte of external RAM for data storage. The DAU communicates with the host computer on an isolated, asynchronous serial interface, operating at 4800 baud. The other 6 channels for angle measurements are sampled at 10 Hz and transmitted to the host computer together with the EMG signals (Physiometer manual, 1994). Figure 3.2 shows the equipment worn by subjects to measure the muscle activity and postural angles.

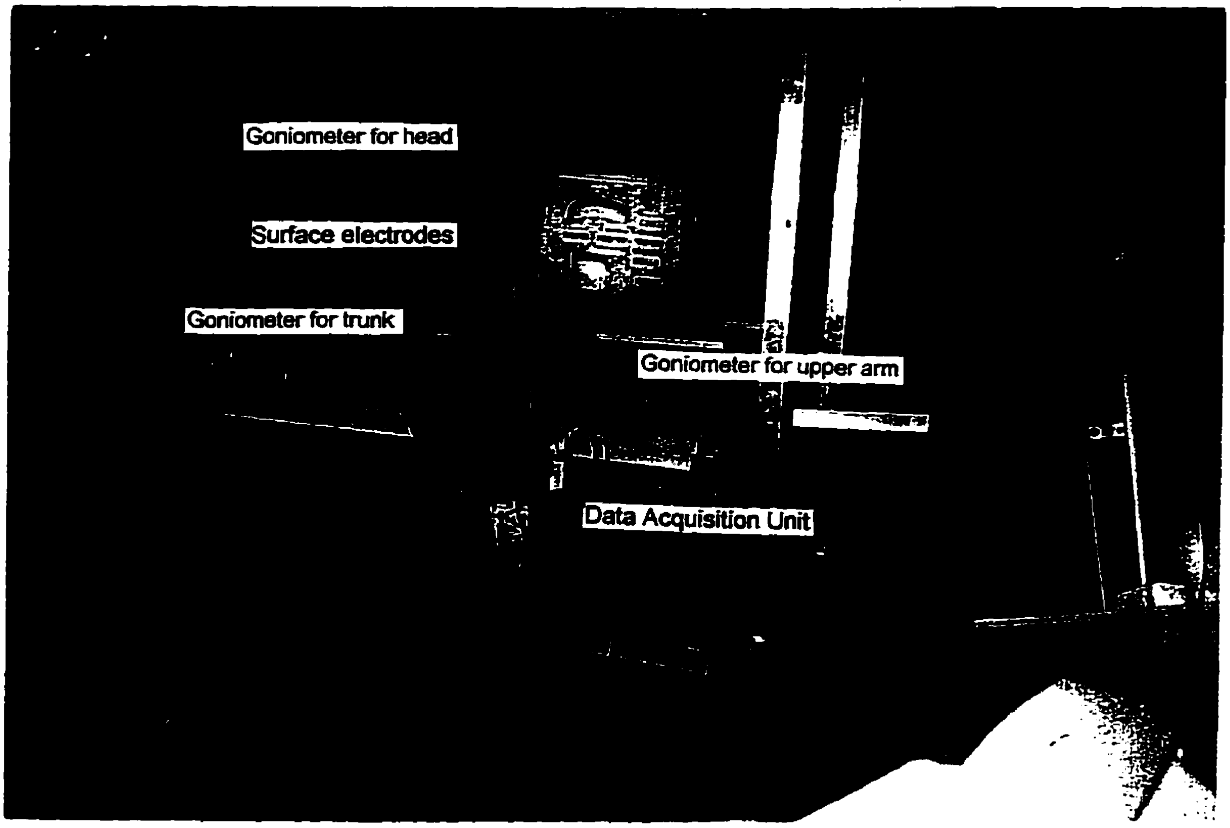


Figure 3.2 Surface electrodes, Data Acquisition Unit (DAU) and goniometers for head, trunk and upper arm.

The amplifier in the Data Acquisition Unit operates with a gain of 215, input impedance of 5 GΩ and a common mode rejection ratio (CMRR) of 100dB. These specifications meet the criteria recommended by Winter (1990). The EMG signals have two different amplification factors. If the signal is low, an increase of ten times (x10) the input signal is used and if the signal is large, an increase order of one (x1) is applied to the input signal. Since the EMG amplifier has a gain of 215, the total gain of the EMG signal is 215 or 2150, which ensures a satisfactory total dynamic range (Physiometer manual, 1994).

All experimental data are stored on the hard disk for future analysis. The software also allows for on-line analysis of the experiment in which any incorrect signals from the surface electrodes will be shown on the computer monitor screen while conducting the experiment. Incorrect signals could be due to loose connection between the electrodes cable and DAU or improperly attached surface electrodes onto the skin. On-line analysis provides a real time feedback and thus correction can immediately be done to rectify the problem in such an event. The off-line analysis allows the user to retrieve experimental data from the hard disk for statistical analysis. Cumulative amplitude distribution function graph as well as distribution graph of the EMG signal were plotted for the muscle activity. Number of contractions due to muscular activity are recorded in shifts/min. Full wave rectified, integrated and normalized EMG signal is found under the "*Direct display*" of the Physiometer software. Analysis of postural angle displacements for the head, trunk and upper arm are also obtained using the similar method by switching to the relevant channels using the Physiometer software.

3.4 Experimental procedure

All participating subjects in the laboratory experiment were required to perform the given task using the direct and indirect observation workstations in the sitting and standing positions. In order to simulate the actual work performed at an electronic assembly line, each subject was required to insert a total of 40 integrated circuits onto a printed circuit board (PCB). This procedure is repeated over a total of five times using different printed circuit boards.

The same procedure was used to evaluate the dynamic workstation. In this workstation, subjects were asked to use a combination of direct and indirect observations, in sitting and standing positions, while performing the task.

Each subject was first required to find the optimal table height for both the direct and indirect observation workstations in the sitting and standing positions. This was done to achieve the most comfortable position of the arm and shoulder while performing the given task. The height of the table was changed using a foot-pedal controlled motor mounted beneath the table. Once the optimal height was found, the table height was incremented by 5cm and the individual's comfort level at the new table height was re-determined. Each subject was asked to rate the level of comfort on a scale of one to seven. A rating of one indicates a very uncomfortable position while a rating of seven indicates a very comfortable position. This was repeated until the maximum achievable height of the table was reached. The same procedure was conducted by decreasing the height of the table from the optimal height in order to determine the level of comfort at a lower table height.

After the optimal table height was obtained for the indirect observation workstation, each subject was also required to find the optimal height of the monitor which produces the most comfortable position. The office chair was fixed at a pre-adjusted height for all the subjects.

Next, muscle activities were measured using EMG. Surface electrodes made of silver-silver chloride (Ag-AgCl) were then placed on the trapezius and anterior deltoid muscle for the measurement of myoelectric (electrical impulses). Calibration of the electromyography signals from the shoulder was performed with respect to a maximum voluntary contraction (MVC) by having the subjects to perform maximal shoulder elevation efforts against restraining straps mounted on the calibration platform. The trapezius muscle was selected as an indicator of the load on the shoulder and neck area since this muscle provides the main lift for the shoulder girdle and is important for stabilization of the scapula during arm movements (Aaras, 1990). The anterior deltoid muscle was also measured for myoelectric activity as this muscle is involved in flexion and abduction of the humerus.

Postural angles were measured by placing goniometers on the head, trunk and upper arm. The head, trunk and upper arm angle was measured in terms of deviation from a reference body position. This was defined as a standing position with balanced, neutral upright head and trunk posture, relaxed shoulders with both arms hanging down the body. Postural angles of other body parts were assessed by video taping the entire experiment.

Finally, each workstation was assessed in terms of the quality and productivity of the work performed. Work quality was measured by determining the number of incorrectly placed integrated circuits. Integrated circuits were considered incorrectly placed if they were placed on top of several dots that were pre-marked on each PCB. Each incorrectly placed integrated circuit was counted as an error. Any integrated circuits that were not fitted properly were also considered as an error. Productivity was measured by the time taken to insert the 40 integrated circuits into one PCB. Figure 3.3 shows the flow chart used for conducting the experiment in the laboratory.

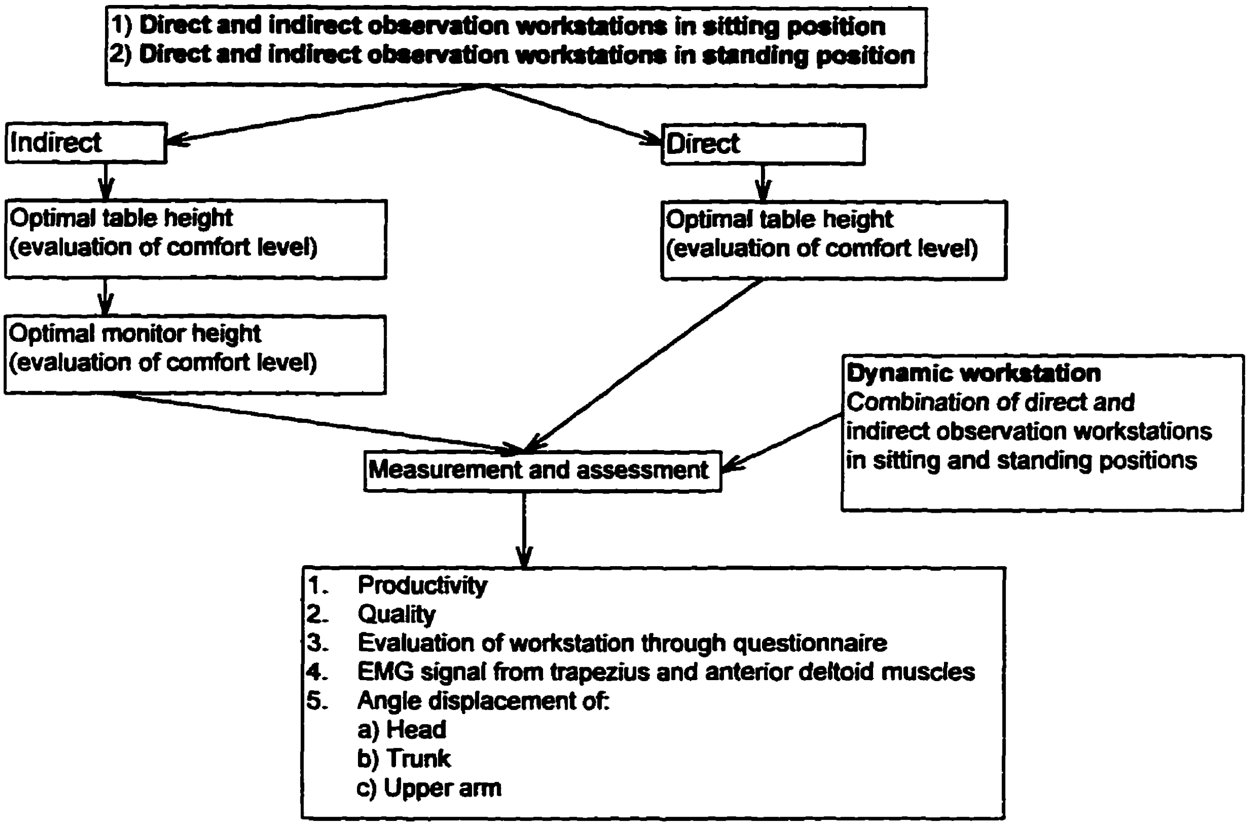


Figure 3.3 Flow chart used for conducting the laboratory experiment.

3.5 Electromyography measurements

Bipolar surface electrodes are used to measure the muscle activity. It consists of three electrodes in which two are detection electrodes (black and white) for measuring the EMG signal and the remaining as a reference electrode (green), each with a diameter of 6mm. The reference connection is an active output that cancels the common mode signal present at two detection electrodes, thereby increasing the CMRR (Common Mode Rejection Ratio) of the amplifier. The signal present at the two detection electrodes are measured, inverted and integrated with a time constant in the data acquisition before being sent to the host computer (Physiometer manual, 1994).

Before placing the electrodes on the shoulder, the skin was cleaned and to further reduce the resistance of the skin, a mixture of 1/4 ether and 3/4 alcohol was used on the area. In addition to improve decornification of the skin, a skin rasp was used. The location of the electrodes on the trapezius muscle varied within a 20mm distance upward from the center of the muscle longitudinally to the muscle fiber direction (Basmajian, 1989). As for the anterior deltoid muscle, the electrodes were centered vertically within an elongated oval below the lateral end of the clavicle (Basmajian, 1989). The distance between the two detection electrodes varied between 25 to 40mm for the two muscles measured. Figure 3.4 shows the location of the electrodes for the trapezius and anterior deltoid muscles.

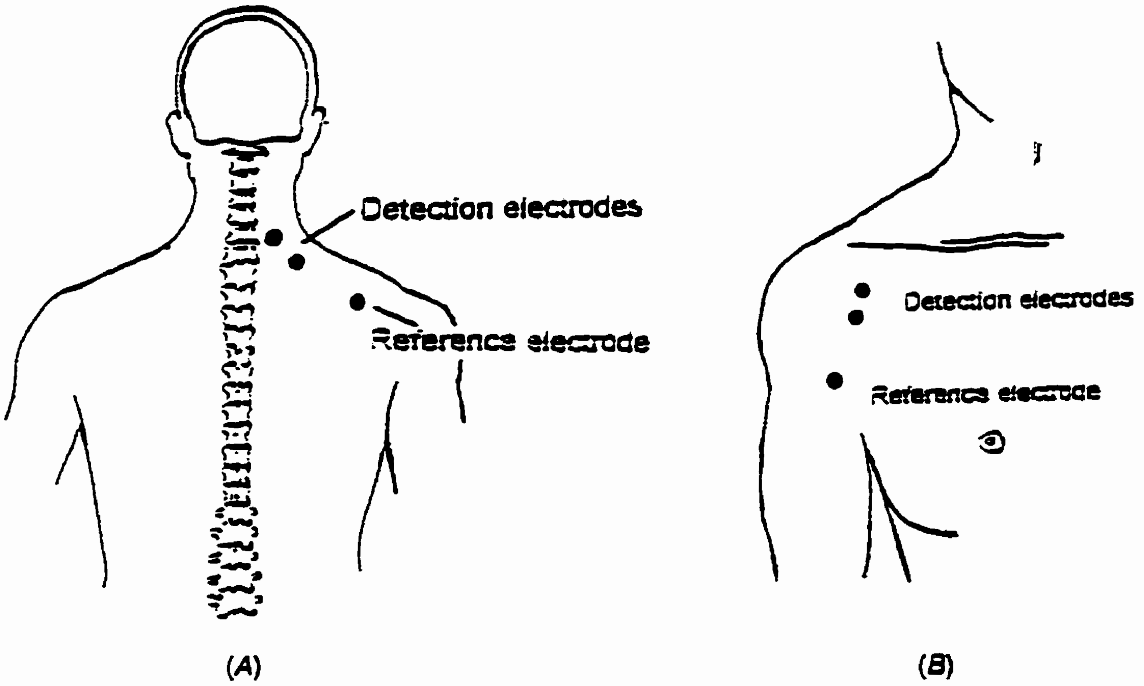


Figure 3.4 Location of detection electrodes for (*A*) trapezius muscle and (*B*) anterior deltoid muscle.

3.6 Electromyography calibration

Calibration must be carried out on all signals present before any recording can begin. It is used to establish the relationship between the input signal and the actual parameter measured. For postural angle calibration of the head, trunk and upper arm using goniometers, the reference position is established while the subject stands upright with the arms hanging relaxed down and looking at a point in eye height.

The normalization of the EMG signal is done by performing calibration of the EMG response to an applied force. This was carried out by using a calibration platform with a force transducer. The height of the handles was adjusted so that the shoulders were in a relaxed position when holding the handles of the restraining straps. The subject then hold the handles with straight arm, just lifting the shoulders. This procedure is shown in Figure 3.5.

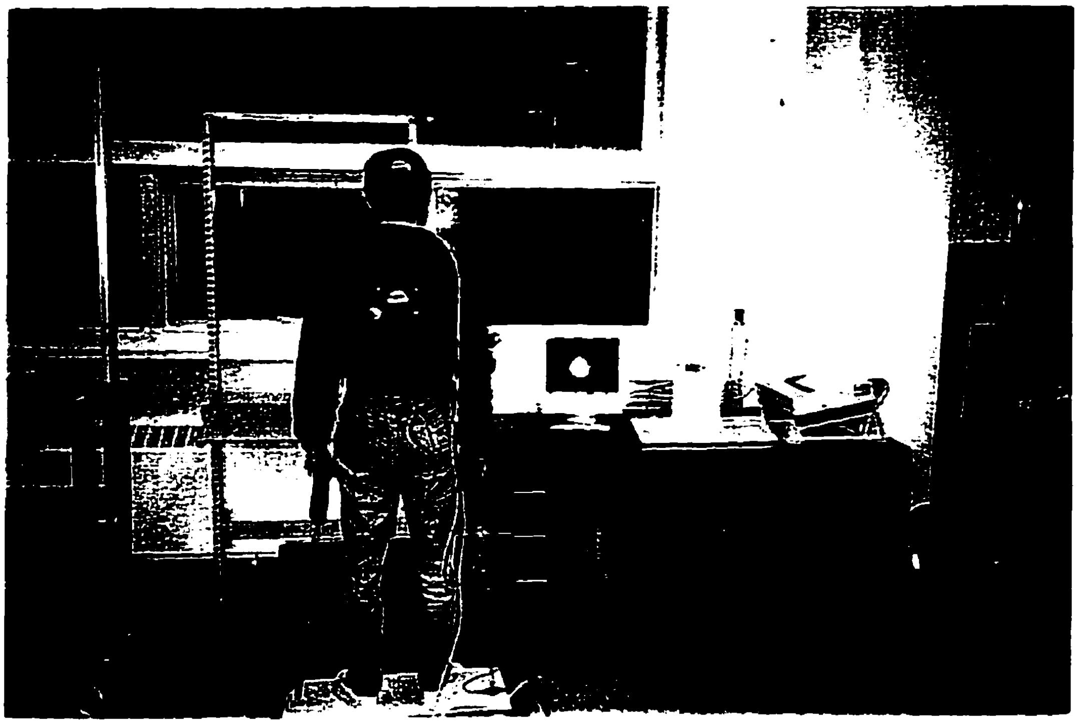


Figure 3.5 Subject holding the restraining straps for EMG signal calibration.

The direction of the isometric lifting contraction of trapezius muscle was straight upwards or upwards and slightly backwards. The same assumption is made for the anterior deltoid muscle. The force signal was presented simultaneously with the EMG signal. First, the maximum voluntary contraction (MVC) measurement was carried out and the maximum contraction was kept for no longer than two seconds to avoid fatigue in the shoulder region. Three trails were performed to ensure that a true maximal contraction was obtained. The highest of these values were used.

If a low maximum EMG was obtained, then the electrodes were removed and new electrodes placed slightly differently from the original position. A maximum EMG of less than 200 μV should not be accepted (Physiometer manual, 1994). A value of 400 μV or higher is preferred for the EMG readings (Physiometer manual, 1994). The normalization technique for the EMG signal is defined as follows (Nag, 1985):

$$Normalized\ EMG = \frac{EMG - EMG_{MIN}}{EMG_{MAX} - EMG_{MIN}} \tag{3.1}$$

where

EMG is the actual task EMG signal for a particular muscle

EMG_{MAX} is the maximum EMG values taken from the static MVC

EMG_{MIN} is the minimum EMG values taken from static MVC (obtained with arms in relaxed position)

An EMG/force relationship for the actual range of the work load is then established. By visual feedback from the computer, the subject was able to control the trapezius muscle by trying to track a straight inclined line on the computer screen during a ten seconds period, hence increasing the force linearly with respect to time. This method enables the subject to increase the force gradually as the cursor moves upward on the straight inclined line on the computer screen. The EMG/force relationship was calculated by linear regression. The tracking operation was repeated, if necessary, until a satisfactory result was obtained regarding the EMG/force relationship. The result was considered satisfactory if the correlation coefficient was 0.7 or higher. The same procedure is repeated for the anterior deltoid muscle. Figure 3.6 shows the EMG/force relationship output on the computer screen.

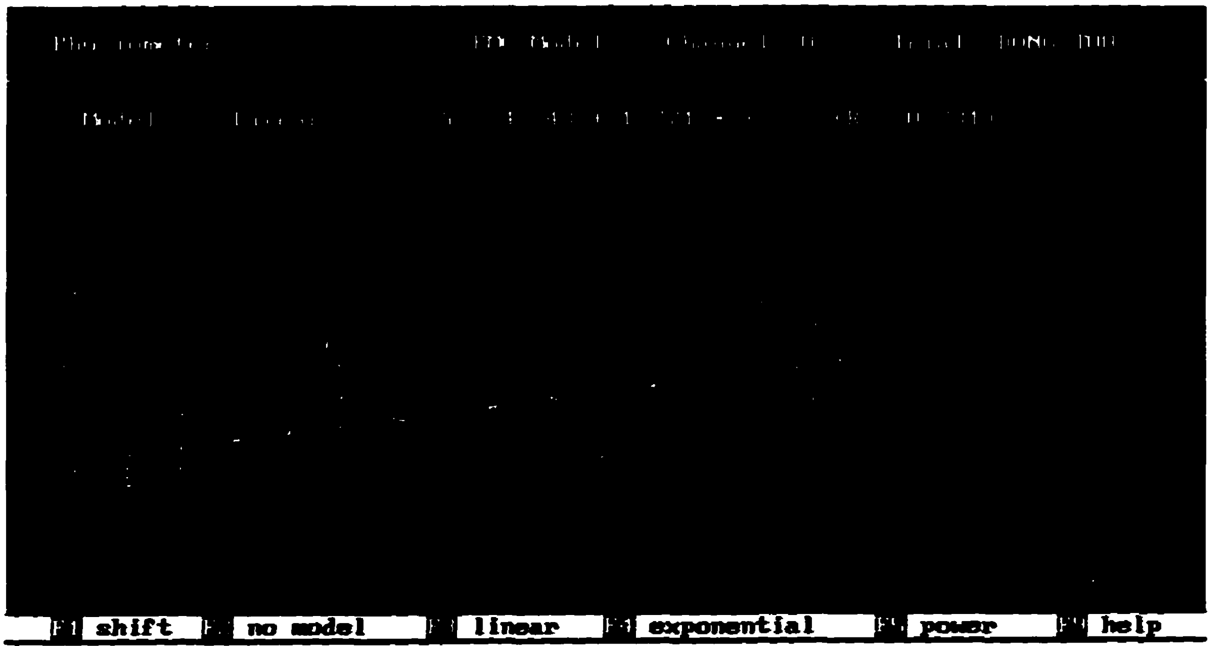


Figure 3.6 Establishment of EMG/force relationship.

The EMG/force relationship obtained during the calibration procedure was used to convert the EMG recorded to %MVC in the analysis which is shown below (Physiometer manual, 1994):-

$$\% MVC = \frac{(EMG - m)}{a \times F_{\max}} \times 100\% \qquad (3.2)$$

where:

EMG is the normalized EMG signal

F_{MAX} is the maximum force in N obtained during the MVC procedure

a is the slope of the linear regression line in μV/N

m is the minimum value of EMG signal in μV

Analysis of static, median and peak loads are measured in terms of %MVC. A low %MVC indicates that a muscle is subjected to less load compared to a higher %MVC. In addition, integrated and normalized EMG signal, muscle contractions in shifts/min, cumulative amplitude distribution function graphs and distribution graphs are also indicated in terms of %MVC.

Chapter 4
Analysis and Results of Experiment

4.1 Introduction

This chapter presents the analysis and results of the experiment in terms of muscle activities, task performance, postural angles and perceived level of comfort for the different workstations. Muscle activities are analyzed for micropauses and static, median and peak loads for the trapezius and anterior deltoid muscles. Postural angle measurement involves the head, trunk and upper arm. Task performance was measured in terms of quality and productivity and the perceived level of comfort was analyzed through a subjective questionnaire.

4.2 Muscle activities

The muscle activities of the trapezius and anterior deltoid muscles are analyzed based on micropauses and static, median and peak loads exhibited by the muscles during the experiment.

4.2.1 Analysis of micropauses using EMG signal

Integrated and normalized EMG signals indicate the activities in a muscle as work is being performed. An example of the EMG signal recorded for the trapezius muscle is shown in Figure 4.1. This signal was recorded for a duration of 170 seconds while the subject was performing the experiment in the sitting position, using the direct observation workstation. The x-axis shows the time interval and the y-axis indicates the force exerted on the muscle as a percentage of the maximum voluntary contraction (%MVC). A similar EMG signal for the anterior deltoid is also shown in Figure 4.2.

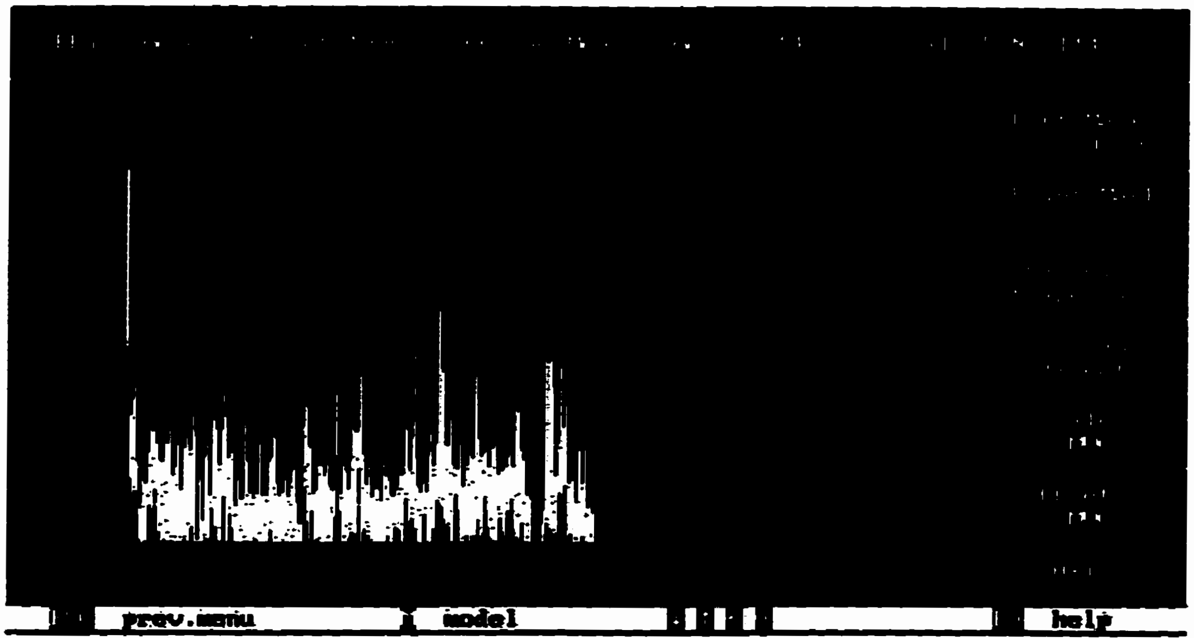


Figure 4.1 EMG signal for trapezius muscle using direct observation workstation in sitting position.

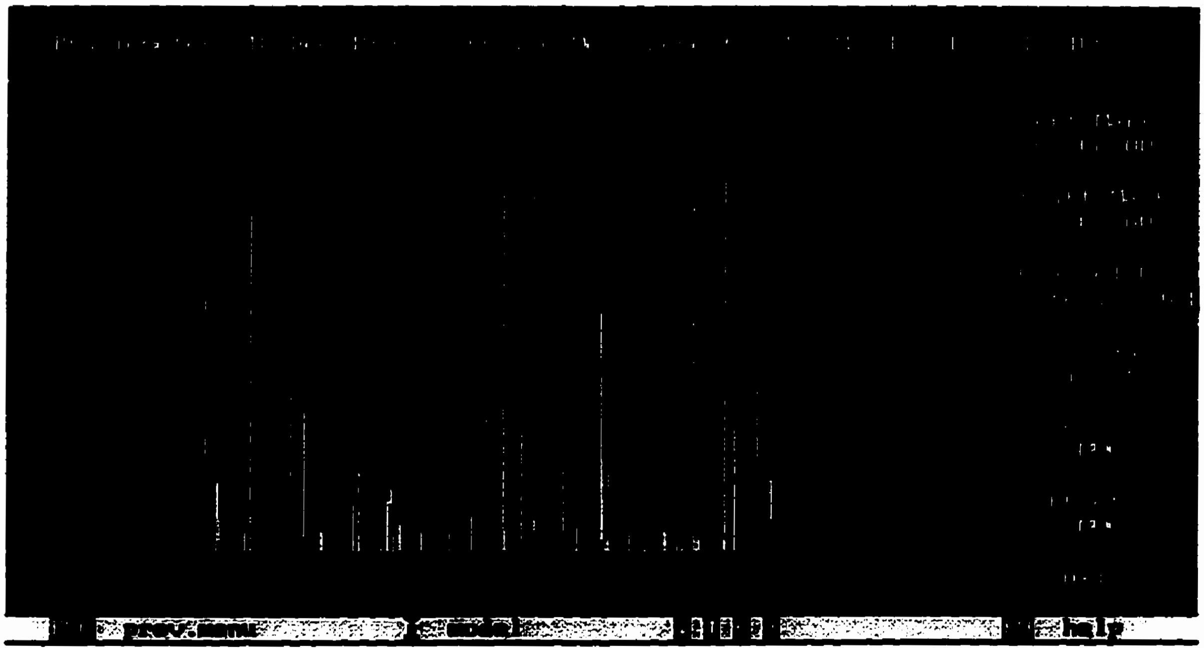


Figure 4.2 EMG signal for anterior deltoid using direct observation workstation in sitting position.

The EMG signal is based on full wave rectification and integration over 0.2 second intervals, resulting in discrete values which are a measure of average electrical muscle activity over this interval (Physiometer manual, 1994). These values were used to estimate the muscle load developed by the trapezius and anterior deltoid muscles as a percentage of the maximum voluntary contraction (%MVC) by using the established EMG/force relationship calibration curve. This is indicated by equation 3.2 in Chapter 3.

The PHY-400 software measures the number of muscle contractions in shifts/min. Figure 4.3 shows the number of muscle contractions (shifts/min) on the y-axis and the muscle load as a percentage of the maximum voluntary contraction (%MVC) on the x-axis for the trapezius muscle under the same operating condition mentioned earlier. This graph is used to determine the number of contractions per minute for a given muscle load. A similar graph for the anterior deltoid muscle is shown in Figure 4.3.

Figure 4.3 Shifts/min for trapezius muscle using direct observation workstation in sitting position.

Figure 4.4 Shifts/min for anterior deltoid muscle using direct observation workstation in sitting position.

The distribution analysis of the muscle load was also obtained by ranking the interval estimates at 0.2 seconds as mentioned earlier. This in turn produces the cumulative amplitude distribution function graph for the muscle load. An example of the cumulative amplitude distribution function graph for the trapezius muscle using the direct observation workstation in sitting position is shown in Figure 4.5. The percentage of the muscle load according to the cumulative amplitude distribution function curve is obtained by reading the y-axis of *% P Acc*. The muscle load (%MVC) given by this curve indicates the time fraction of the recording period with the load lower than or equal to a given value. The percentage of the muscle load can also be obtained according to the distribution curve using *Fractiles* located on the y-axis on left hand corner of the graph. Similarly, Figure 4.6 shows the cumulative amplitude distribution function graph of the muscle load for the anterior deltoid muscle.

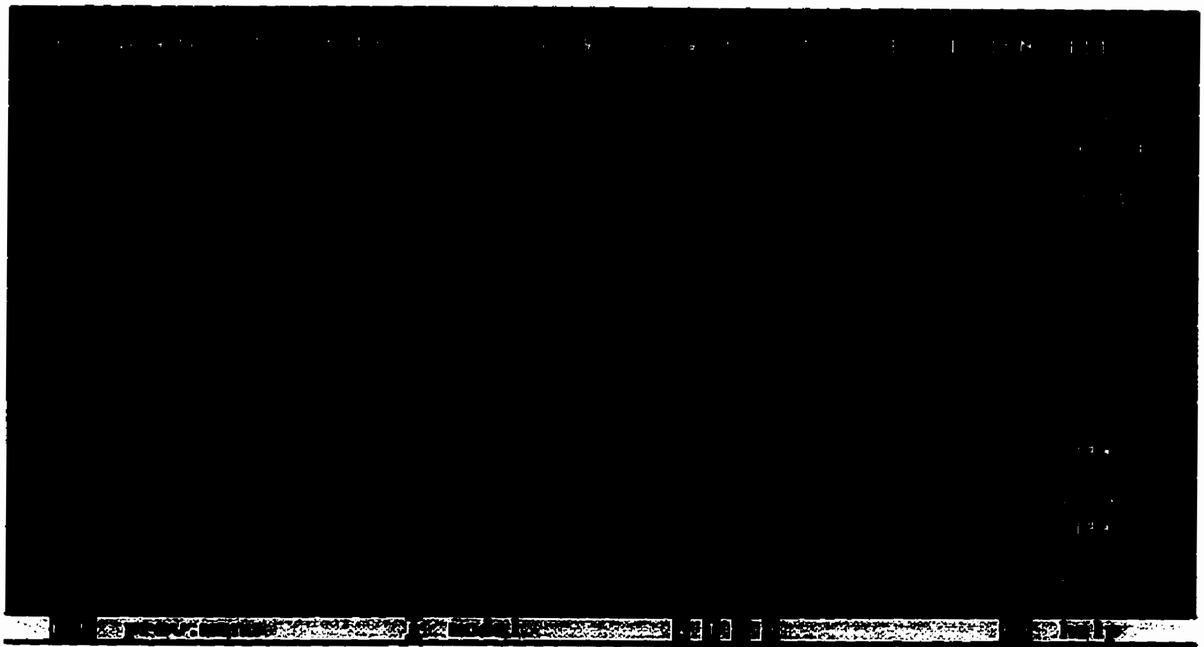


Figure 4.5 Cumulative amplitude distribution function graph for trapezius muscle using direct observation workstation in sitting position.

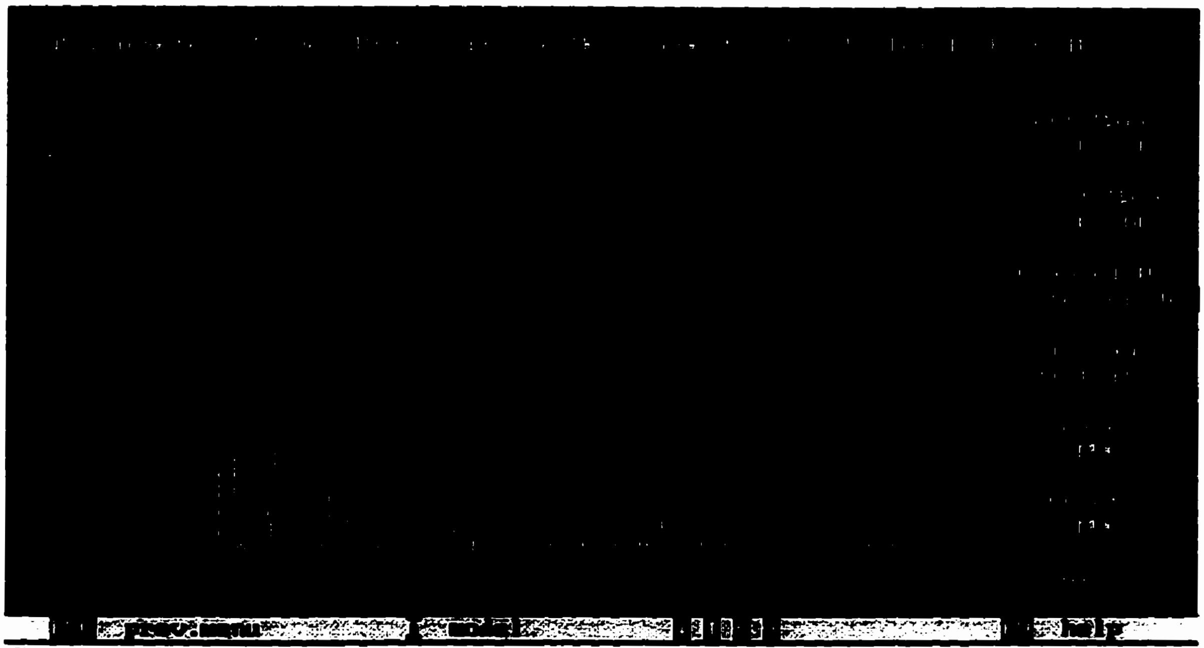


Figure 4.6 Cumulative amplitude distribution function graph for anterior deltoid muscle using direct observation workstation in sitting position.

The micropauses of the muscle activity is calculated by using the number of muscle contractions and the percentage of the cumulative amplitude distribution function graph according to a given load. This is also known as the average duration of each muscle contraction. The micropauses represent the time in which the muscle is in a dormant condition before receiving the next electrical impulse in order to perform work. In assessing work comfort, not only work intensity but duration of micropauses are considered important and has shown to influence the development of fatigue (Lehmann, 1962). Micropauses are therefore indispensable as a physiological requirement if performance and efficiency are to be maintained. The equation for finding the micropauses of the muscle activity is given below:-

$$micropauses = \frac{\%P.Acc \times Total\ recording\ time(s)}{(\frac{Shifts}{\min}) \times Total\ recording\ time(\min)} \qquad (4.1)$$

The unit of micropauses is measured in seconds/shift. Hence, from the "*Level display*" of the trapezius muscle shown in Figure 4.3, the number of muscle contractions at 8 %MVC is 110 shifts/min, which means that the signal has been below 8 %MVC at an average of 110 times per minute during the entire recording time. From the "*Distribution display*" of the trapezius muscle shown in Figure 4.5, the corresponding percentage of the cumulative amplitude distribution function curve at 8 % MVC is 47.5%. This means that the EMG signal has been below 8 %MVC for 47.5% of the recording time. Since the total recording time is 2.83 minutes, the micropauses is calculated to be 0.259 sec/shift. Other muscle loads as a percentage of MVC including the calculation of micropauses for the anterior deltoid muscle can be found using the similar procedure described above.

The average micropauses for the trapezius muscle using different workstations in the sitting and standing positions is presented below. The muscle loads are sampled at 2 %MVC, 4 %MVC, 5 %MVC, 8 %MVC, 10 %MVC, 12 %MVC and 15 %MVC respectively. Table 4.1 and 4.2 show the average micropauses for the trapezius muscle using the direct and indirect observation workstations in the standing position. The micropauses for the direct and indirect observation workstations in the sitting position are shown in Table 4.3 and Table 4.4.

Muscle load	No. of subjects	Average micropauses [sec/shift]	Standard deviation	min. micropauses [sec/shift]	max. micropauses [sec/shift]
2 %MVC	13	6.7	14.48	0.32	50.8
4 %MVC	13	13.8	33.38	0.78	117.4
5 %MVC	13	24.9	65.51	1.23	230.5
8 %MVC	13	31.6	54.52	3.25	190
10 %MVC	13	39.8	60.21	4.82	190
12 %MVC	13	45.0	65.14	5.42	190
15 %MVC	13	46.1	42.42	8.95	160

Table 4.1 Average micropauses for trapezius muscle using direct observation workstation in standing position.

Muscle load	No. of subjects	Average micropauses [sec/shift]	Standard deviation	min. micropauses [sec/shift]	max. micropauses [sec/shift]
2 %MVC	13	26.3	51.17	0.47	182.68
4 %MVC	13	40.4	60.51	1.46	204.13
5 %MVC	13	43.9	36.22	1.51	124.08
8 %MVC	13	47.1	50.7	3.11	163.74
10 %MVC	13	50.7	40.79	7.48	155.34
12 %MVC	13	58.5	36.45	10.41	134.55
15 %MVC	13	59.1	51.6	11.88	146.67

Table 4.2 Average micropauses for trapezius muscle using indirect observation workstation in standing position.

Muscle load	No. of subjects	Average micropauses [sec/shift]	Standard deviation	min. micropauses [sec/shift]	max. micropauses [sec/shift]
2 %MVC	14	0.8	0.643	0.17	2.51
4 %MVC	14	1.3	1.15	0.18	4.20
5 %MVC	14	1.8	2.23	0.18	8.58
8 %MVC	14	4.7	7.88	0.21	29.58
10 %MVC	14	6.4	9.88	0.26	29.7
12 %MVC	14	9.8	16.18	0.36	45.21
15 %MVC	14	15.4	18.25	0.55	53.46

Table 4.3 Average micropauses for trapezius muscle using direct observation workstation in sitting position.

Muscle load	No. of subjects	Average micropauses [sec/shift]	Standard deviation	min. micropauses [sec/shift]	max. micropauses [sec/shift]
2 %MVC	14	6.9	21.29	0.33	61.25
4 %MVC	14	9.0	24.88	0.37	71.49
5 %MVC	14	10.2	26.68	0.40	78.03
8 %MVC	14	14.6	32.26	0.48	91.57
10 %MVC	14	30.0	48.49	0.60	164.34
12 %MVC	14	24.6	30.76	0.76	105.33
15 %MVC	14	25.7	33.24	1.03	125.33

Table 4.4 Average micropauses for trapezius muscle using indirect observation workstation in sitting position.

The range of micropauses for the trapezius muscle is given by the minimum and the maximum values in the tables. The micropauses of the dynamic workstation is presented in Table 4.5.

Muscle load	No. of subjects	Average micropauses [sec/shift]	Standard deviation	min. micropauses [sec/shift]	max. micropauses [sec/shift]
2 %MVC	12	2.4	2.89	0.16	9.90
4 %MVC	12	3.4	4.24	0.19	14.72
5 %MVC	12	4.8	6.82	0.21	23.74
8 %MVC	12	5.4	4.95	0.28	17.35
10 %MVC	12	7.3	6.47	0.37	20.08
12 %MVC	12	11.6	10.26	0.51	31.69
15 %MVC	12	18.6	17.43	0.80	60

Table 4.5 Average micropauses for trapezius muscle using dynamic workstation.

A comparison of the average micropauses for the trapezius muscle using different workstations at different muscle loads is shown in Figure 4.7.

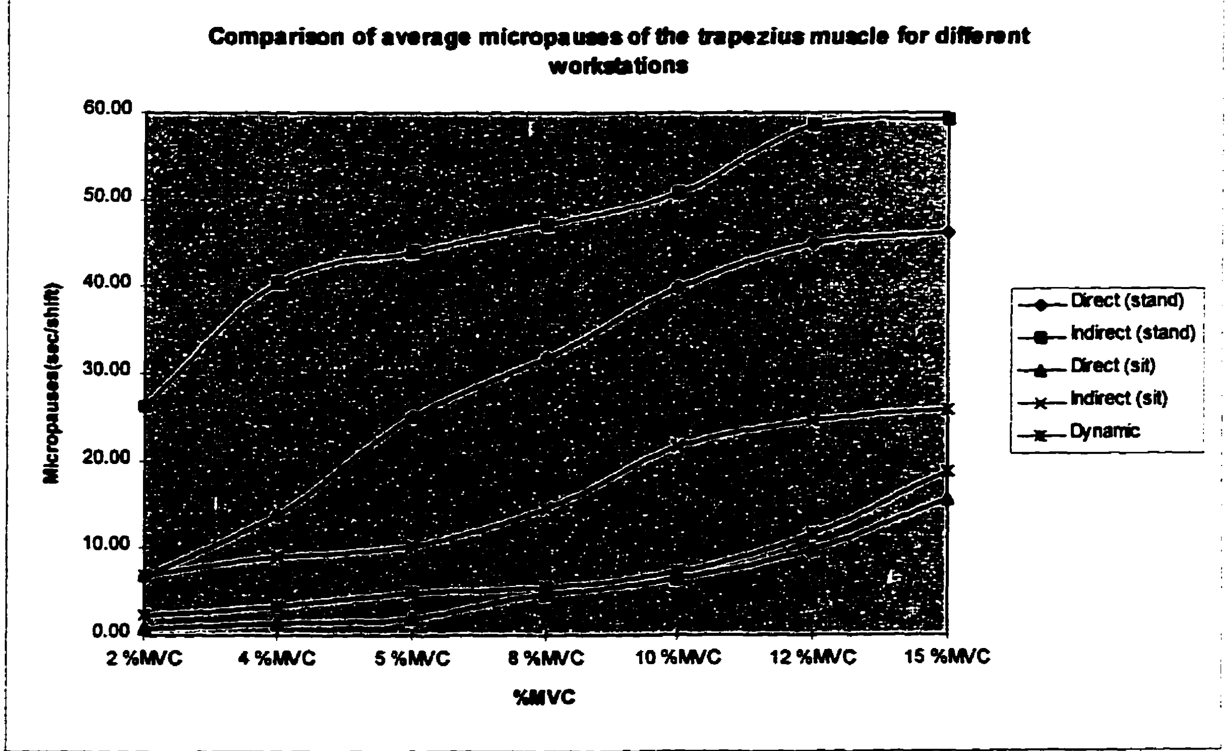


Figure 4.7 Comparison of average micropauses for trapezius muscle using different workstations.

From Figure 4.7, the average micropauses of the trapezius muscle using the indirect observation workstation in the standing position indicated a longer duration compared to other workstations at different muscle loads. The direct observation workstation in the sitting position, on the other hand, shows the shortest duration in micropauses. From analysis of variance (ANOVA), there is a significant difference in micropauses between the indirect observation workstation in the standing position compared to the direct observation workstation in the sitting position (p=0.0001). At 2 %MVC, the difference in micropauses between the indirect observation workstation in the standing position is about 96% from the direct observation workstation in the sitting position (26.3 sec/shifts vs. 0.8 sec/shifts).

In comparison of micropauses in the sitting position, the indirect observation workstation shows a longer duration compared to the direct observation workstation (p<0.02). The same result was also obtained for the standing position (p<0.05). The dynamic workstation, which encompasses the direct and indirect observation workstations in the sitting and standing positions, shows only a slight increase in the duration of micropauses compared to the direct observation workstation in the sitting position (p<0.6). Overall, the duration of micropauses is longer in the predominantly standing position compared to the sitting position.

A shorter duration in micropauses indicates that signals or impulses from the nerve system is being sent constantly at an intense rate in order for the muscles to perform work. This will then lead to shorter rest pauses for the muscles. Shorter rest pauses means that the muscles are not permitted to relax completely, hence leading to chronic muscle injuries.

Table 4.6 and 4.7 shows the average micropauses for the anterior deltoid muscle using the direct and indirect observation workstations in the standing position. The micropauses for the direct and indirect observation workstations in the sitting position are shown in Table 4.8 and Table 4.9.

Muscle load	No. of subjects	Average micropauses [sec/shift]	Standard deviation	min. micropauses [sec/shift]	max. micropauses [sec/shift]
2 %MVC	4	0.381	0.067	0.333	0.428
4 %MVC	4	0.410	0.040	0.381	0.439
5 %MVC	4	0.461	0.016	0.450	0.473
8 %MVC	4	0.510	0.082	0.452	0.568
10 %MVC	4	0.521	0.069	0.472	0.570
12 %MVC	4	0.558	0.094	0.491	0.625
15 %MVC	4	0.580	0.055	0.540	0.619

Table 4.6 Average micropauses for anterior deltoid muscle using direct observation workstation in standing position.

Muscle load	No. of subjects	Average micropauses [sec/shift]	Standard deviation	min. micropauses [sec/shift]	max. micropauses [sec/shift]
2 %MVC	4	0.881	0.215	0.728	1.033
4 %MVC	4	0.953	0.268	0.763	1.142
5 %MVC	4	1.016	0.291	0.822	1.222
8 %MVC	4	1.371	0.464	1.043	1.700
10 %MVC	4	1.543	0.566	1.142	1.944
12 %MVC	4	1.735	0.600	1.310	2.160
15 %MVC	4	2.079	0.755	1.545	2.614

Table 4.7 Average micropauses for anterior deltoid muscle using indirect observation workstation in standing position.

Muscle load	No. of subjects	Average micropauses [sec/shift]	Standard deviation	min. micropauses [sec/shift]	max. micropauses [sec/shift]
2 %MVC	4	1.627	0.130	1.535	1.720
4 %MVC	4	1.705	0.148	1.600	1.810
5 %MVC	4	1.863	0.031	1.841	1.885
8 %MVC	4	2.093	0.162	1.977	2.208
10 %MVC	4	2.148	0.101	2.076	2.220
12 %MVC	4	2.270	0.059	2.228	2.312
15 %MVC	4	2.369	0.08	2.312	2.426

Table 4.8 Average micropauses for anterior deltoid muscle using direct observation workstation in sitting position.

Muscle load	No. of subjects	Average micropauses [sec/shift]	Standard deviation	min. micropauses [sec/shift]	max. micropauses [sec/shift]
2 %MVC	4	7.778	9.364	1.156	14.40
4 %MVC	4	7.831	9.289	1.263	14.40
5 %MVC	4	8.928	10.768	1.313	16.54
8 %MVC	4	9.364	10.273	2.100	16.62
10 %MVC	4	10.891	12.174	2.282	19.50
12 %MVC	4	10.680	12.614	1.760	19.60
15 %MVC	4	11.527	13.698	1.841	21.21

Table 4.9 Average micropauses for anterior deltoid muscle using indirect observation workstation in sitting position.

Similarly, Table 4.10 shows the average micropauses for the anterior deltoid muscle using the dynamic workstation.

Muscle load	No. of subjects	Average micropauses [sec/shift]	Standard deviation	min. micropauses [sec/shift]	max. micropauses [sec/shift]
2 %MVC	4	6.375	1.166	5.550	7.20
4 %MVC	4	5.925	1.803	4.650	7.20
5 %MVC	4	6.976	1.051	6.233	7.72
8 %MVC	4	8.192	2.202	6.635	9.75
10 %MVC	4	8.946	1.136	8.142	9.75
12 %MVC	4	9.305	0.628	8.861	9.75
15 %MVC	4	10.765	1.576	9.650	11.88

Table 4.10 Average micropauses for anterior deltoid muscle using dynamic workstation.

A comparison of the average micropauses using the different types of workstations at different muscle loads for the anterior deltoid muscle is shown in Figure 4.8.

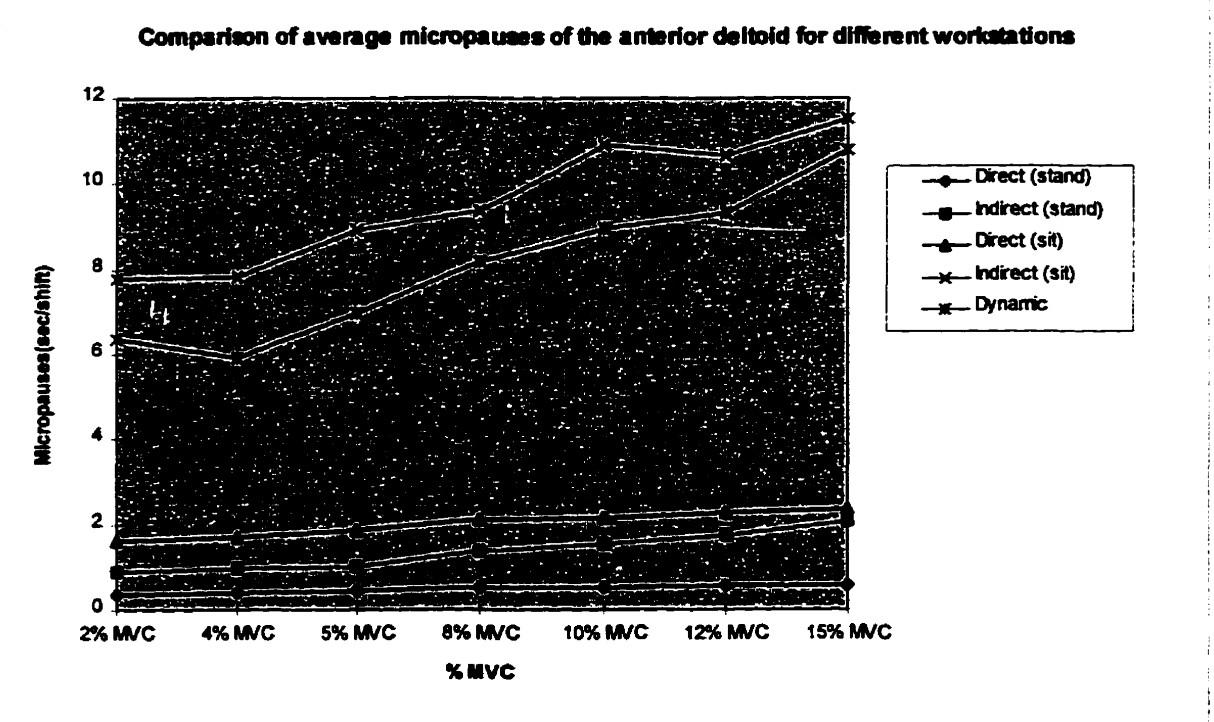


Figure 4.8 Comparison of average micropauses for anterior deltoid muscle using different workstations.

From Figure 4.8, the indirect observation workstation in the sitting position shows a longer duration in micropauses compared to other workstations at various muscle loads for the anterior deltoid muscle. This is followed by the dynamic workstation and the direct observation workstation in the sitting position. There is also a significant difference in the duration of micropauses between the direct and indirect observation workstations in the sitting position ($p=0.0001$).

Overall, the workstations in the standing position show a relatively shorter duration in micropauses compared to the workstations in the predominantly sitting position. These findings are in contrast to the micropauses found for the trapezius muscle. In the trapezius muscle, the workstations in the standing position indicated a longer duration in the micropauses compared to the workstations in the sitting position. This phenomena can be explained from the positioning of the arm between the sitting and the standing position. In the standing position, the whole arm is suspended loose without any support when performing the experimental task whereas in the sitting position, the elbow is leaned against the table as a support for the upper arm. This resulted in less muscular activity for the anterior deltoid muscle as most of the activity is accomplished using the lower arm. Less flexion and extension of the upper arm was also observed when using the elbow as a support. As a result, a longer duration in micropauses of the anterior deltoid muscle was obtained when using the workstation in the sitting position.

4.2.2 Analysis of static, median and peak loads using EMG signal

EMG signals were analyzed using the cumulative amplitude distribution function curve to determine the static, median and peak muscle loads. Static load is defined as the level of muscular contraction corresponding to 10% of the cumulative distribution function curve, i.e the muscle load is higher than this level for 90% of the recording time. Peak load is defined as the load corresponding to 90% of the cumulative distribution function curve, i.e the muscle load is higher than this level for 10% of the recording time. Distribution level according to 50%

of the recording time defines the median muscle load (Aaras, 1987). In prolonged low level static contractions, the static component itself is considered to be harmful (Kilbom, 1988). According to Bjelle et. al. (1979) and Jonsson et. al. (1988), there is strong epidemiological evidence that static workload is related to musculoskeletal injuries in the upper extremity. Hence, emphasis will be given to the determination of static load especially to the trapezius muscle at different workstations.

From Figure 4.5, the values in the vertical axis under *Fractiles* represent the muscle load as described earlier. Hence, by choosing the percentage of the cumulative amplitude distribution function curve corresponding to 10%, 50% and 90%, the static, median and peak loads for the trapezius muscle are 0, 8.9 and 28.6 %MVC respectively. Static, median and peak loads for the anterior deltoid muscle are also obtained in a similar manner.

Average static, median and peak loads for the trapezius muscle using different types of workstations are presented below. Table 4.11 and 4.12 show the muscle loads using the direct and indirect observation workstations in the standing position. Similarly, Table 4.13 and 4.14 represent the muscle load in the sitting position using the direct and indirect observation workstations.

	No. of subjects	Average(%MVC)	Std. dev.	Min. (%MVC)	Max. (%MVC)
Static	16	0.068	0.249	0	1
Median	16	0.621	1.397	0	5.4
Peak	16	3.045	3.30	0	11.6

Table 4.11 Muscle load for trapezius muscle using direct observation workstation in standing position.

	No. of subjects	Average(%MVC)	Std. dev.	Min. (%MVC)	Max. (%MVC)
Static	17	0	0	0	0
Median	17	0.114	0.284	0	0.98
Peak	17	1.084	1.627	0	5.6

Table 4.12 Muscle load for trapezius muscle using indirect observation workstation in standing position.

	No. of subjects	Average(%MVC)	Std. dev.	Min. (%MVC)	Max. (%MVC)
Static	17	1.327	3.991	0	16.4
Median	17	3.832	5.798	0	22.4
Peak	17	11.278	8.663	1	32.4

Table 4.13 Muscle load for trapezius muscle using direct observation workstation in sitting position.

	No. of subjects	Average(%MVC)	Std. dev.	Min. (%MVC)	Max. (%MVC)
Static	16	0.226	0.792	0	3.18
Median	16	1.739	3.231	0	12.2
Peak	16	7.313	8.422	0	26

Table 4.14 Muscle load for trapezius muscle using indirect observation workstation in sitting position.

The average static, median and peak loads using the dynamic workstation are given in Table 4.15. The ranges of static, median and peak loads are given by the minimum and maximum values as indicated in the tables.

	No. of subjects	Average(%MVC)	Std. dev.	Min. (%MVC)	Max. (%MVC)
Static	9	0.062	0.147	0	0.44
Median	9	1.131	1.394	0	4.04
Peak	9	4.215	3.241	0	10.22

Table 4.15 Muscle load for trapezius muscle using dynamic workstation.

The comparison of static, median and peak loads for the trapezius muscle using different workstations are shown in Figure 4.9. A more detailed description of the static load between all the different workstations is shown in Figure 4.10.

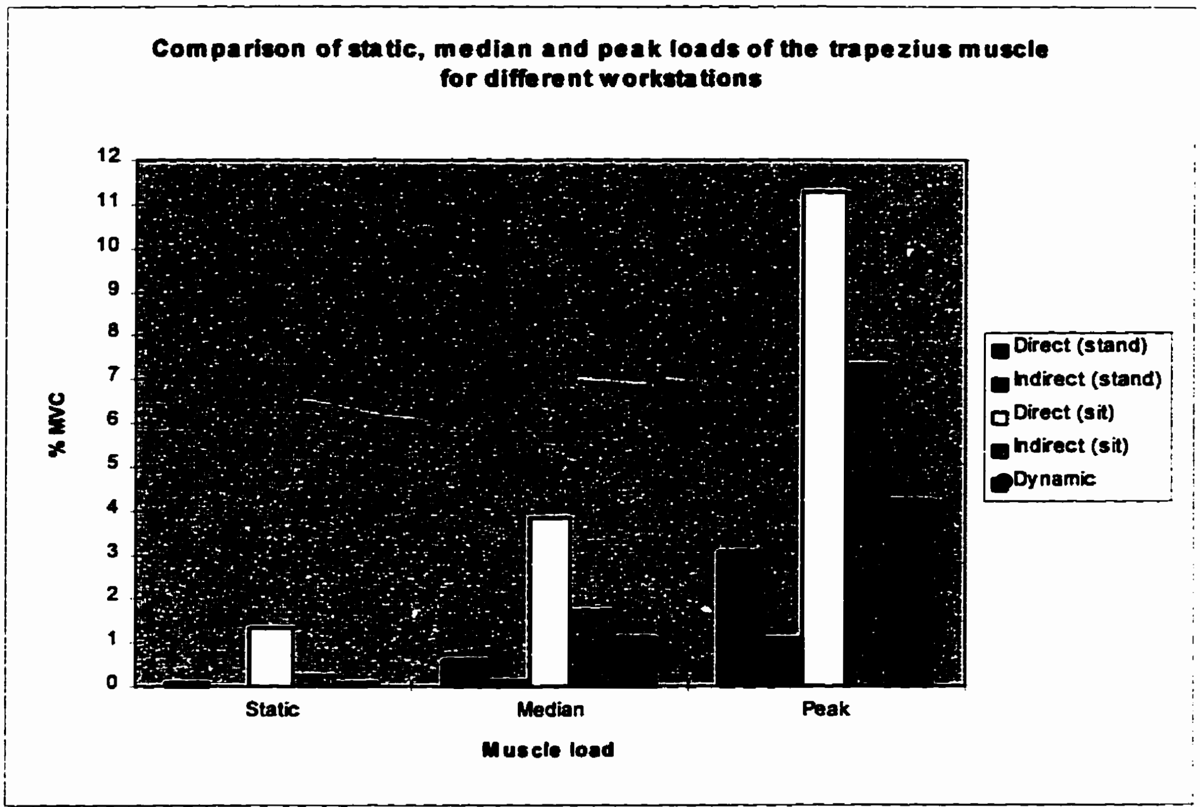


Figure 4.9 Static, median and peak loads of the trapezius muscle using different type of workstations.

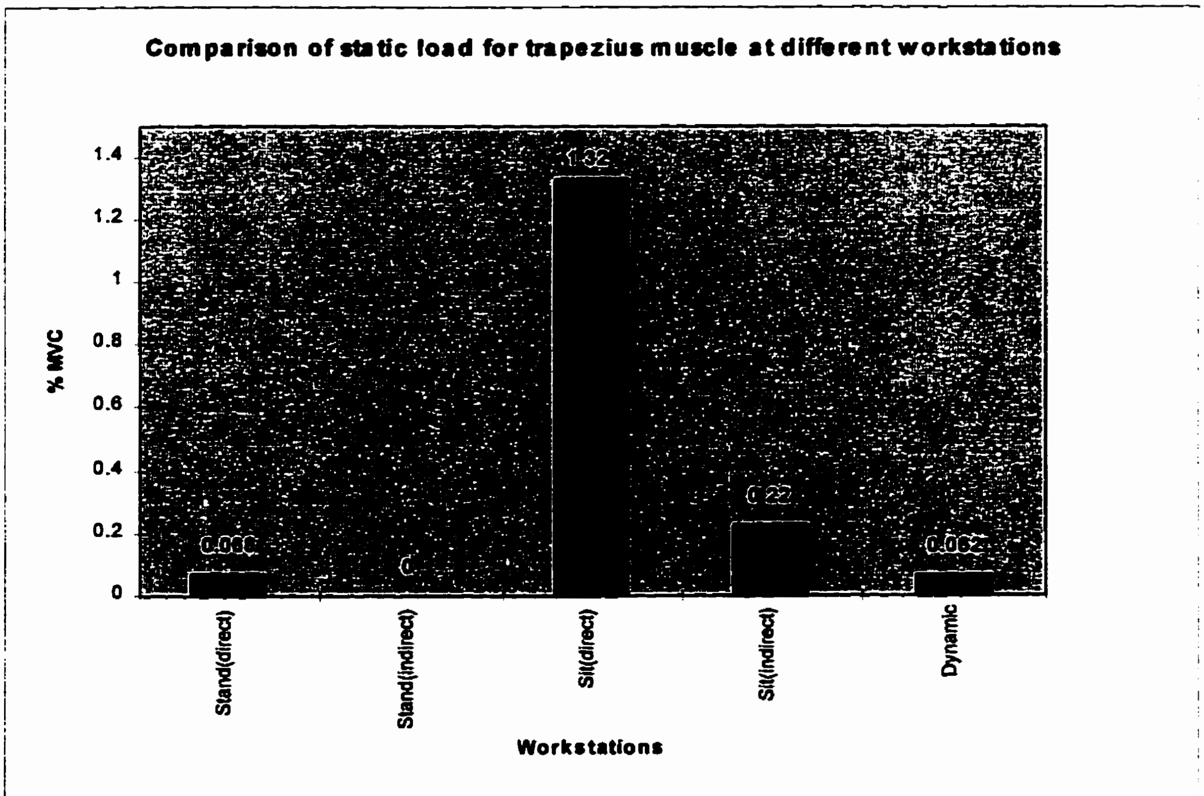


Figure 4.10 Average static load for trapezius muscle at different workstations.

From Figure 4.10, the static load for the indirect observation workstation in the standing position shows the lowest value with 0 %MVC while the direct observation workstation in the sitting position shows the highest static load with a value of 1.3 %MVC ($p<0.2$). The static load for the dynamic workstation is about the same as the direct observation workstation in the standing position. The indirect observation workstation in the sitting position shows a value of 0.22 %MVC. A zero static load indicates that the trapezius muscle is not subjected to any static muscular effort. During static muscular effort, the muscle is not allowed to extend but remains in a state of heightened tension, with force exerted over an extended period. Blood no longer flows through the muscle during static muscular effort as the blood vessels are being compressed by the internal pressure of the muscle tissue. Waste products such as blood lactate begin to form due to the anaerobic metabolism in the muscle. The accumulation of waste products lead to acute pain and muscular fatigue (Bjelle et. al., 1979).

Median and peak loads for the direct observation workstation in the sitting position shows the highest value compared to other workstations (3.83 %MVC and 11.28 %MVC respectively). This is followed by the indirect observation workstation in the sitting position. The dynamic workstation indicated a value of 1.13 %MVC for the median load and 4.21 %MVC for the peak load. Overall, the workstations in the standing position indicated a lower value in the static, median and peak loads compared to the workstations in the sitting position during the laboratory experiment.

The comparison of static, median and peak loads for the anterior deltoid muscle using the direct and indirect observation workstations in the standing position are shown in Table 4.16 and 4.17. Similarly, Table 4.18 and 4.19 represent the muscle load in the sitting position using the direct and indirect observation workstations.

	No. of subjects	Average(%MVC)	Std. dev.	Min. (%MVC)	Max. (%MVC)
Static	4	0	0	0	0
Median	4	10.05	3.606	7.5	12.6
Peak	4	41.05	5.727	37.3	45.4

Table 4.16 Muscle load for anterior deltoid using direct observation workstation in standing position.

	No. of subjects	Average(%MVC)	Std. dev.	Min. (%MVC)	Max. (%MVC)
Static	4	0	0	0	0
Median	4	0	0	0	0
Peak	4	15.46	3.959	12.6	18.2

Table 4.17 Muscle load for anterior deltoid using indirect observation workstation in standing position.

	No. of subjects	Average(%MVC)	Std. dev.	Min. (%MVC)	Max. (%MVC)
Static	4	0	0	0	0
Median	4	0	0	0	0
Peak	4	8.42	2.545	6.7	10.9

Table 4.18 Muscle load for anterior deltoid using direct observation workstation in sitting position.

	No. of subjects	Average(%MVC)	Std. dev.	Min. (%MVC)	Max. (%MVC)
Static	4	0	0	0	0
Median	4	0	0	0	0
Peak	4	0	0	0	0

Table 4.19 Muscle load for anterior deltoid using indirect observation workstation in sitting position.

The static, median and peak loads using the dynamic workstation are given in Table 4.20. The ranges of static, median and peak loads are given by the minimum and maximum values as indicated in the tables.

	No. of subjects	Average(%MVC)	Std. dev.	Min. (%MVC)	Max. (%MVC)
Static	4	0	0	0	0
Median	4	0	0	0	0
Peak	4	8.13	11.313	0	19

Table 4.20 Muscle load for anterior deltoid using dynamic workstation.

The comparison of static, median and peak loads for the anterior deltoid muscle using different workstations are shown in Figure 4.11.

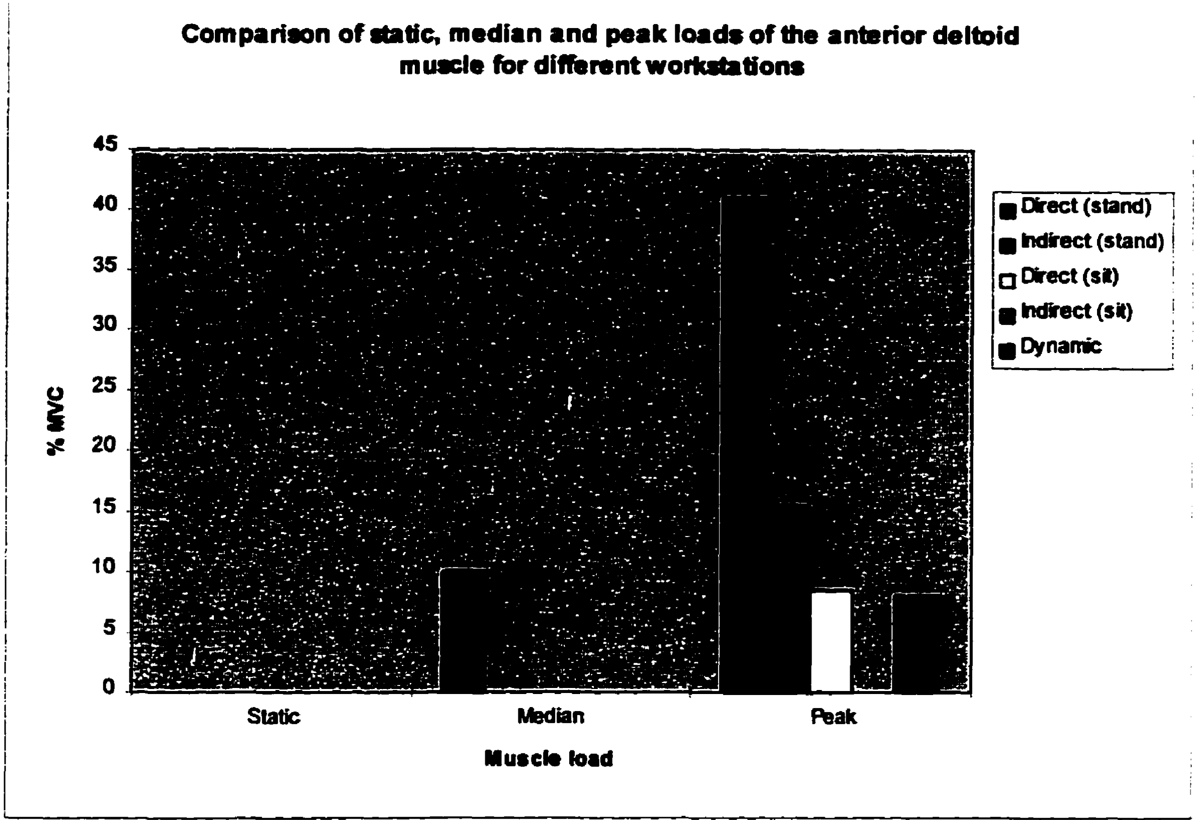


Figure 4.11 Static, median and peak loads of the anterior deltoid muscle using different type of workstations.

From Figure 4.11, there was no static load imposed on the anterior deltoid muscle for all the workstations. Hence, the anterior deltoid was not subjected to any static muscular effort during the laboratory experiment. The median load was also zero for the anterior deltoid muscle except when using the direct observation workstation in the standing position. Consequently, the peak load for this workstation is also higher compared to other workstations.

4.3 Task performance

The task performance of the laboratory experiment involves productivity and quality assessment.

4.3.1 Productivity assessment

Productivity is assessed by the time taken to complete a task. Each task involves inserting 40 integrated circuits into each PCB board. Each subject was required to perform five tasks for each type of workstation. The average time taken to complete the five boards was used to assess the productivity. The time of each task was measured using the PHY-400 software. Table 4.21 shows the time in seconds to complete each task for all the different workstations.

	No. of subjects	Average time[s]	Standard deviation	Min. time[s]	Max. time[s]
Direct(stand)	15	230.2	52.02	150.4	387
Indirect(stand)	15	261.5	49.20	195.4	356
Direct(sit)	15	188.2	32.47	143.4	281.4
Indirect(sit)	15	231.4	31.33	180.8	283.4
Dynamic	13	207.9	32.31	161.4	249

Table 4.21 Average time to complete each task for different workstations.

The range of time to complete each task is represented by the minimum and maximum value as indicated in the table. Figure 4.12 shows the comparison in productivity using different workstations.

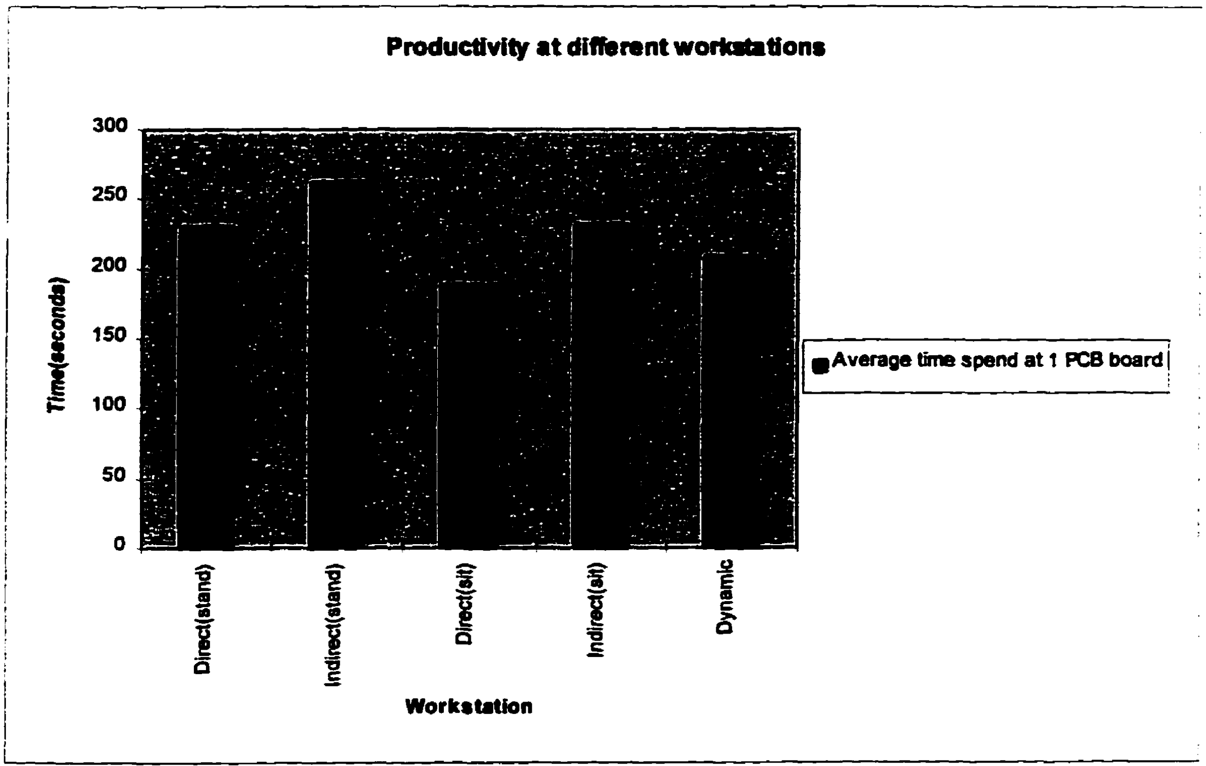


Figure 4.12 Comparison of productivity for different workstations.

From Figure 4.12, it can be seen that the direct observation workstation in the sitting position is capable of producing a better speed performance compared to the indirect observation workstation in the standing position (188s vs. 261s). This denotes a 28% difference in productivity between the two workstations. The productivity using dynamic workstation followed closely behind the productivity of the direct observation workstation in the sitting position with a difference of 9% (207s vs. 188s). Overall, the indirect observation workstation shows a lower productivity compared to the direct observation workstation, both in the sitting and standing positions.

The reason behind the lower productivity for the indirect observation workstation is that the image projected by the television monitor is in two dimension as opposed to the three dimensional perception when looking directly at the work area while performing the task. The depth perception between the integrated circuit and the printed circuit board is difficult to be determined when using the television monitor as the video camera is mounted directly above the printed circuit board. Hence, the projected image on the monitor screen is therefore viewed as a flat image and the depth can be over or under estimated, which makes the task of inserting circuits very difficult. This is considered to be the main reason for the slower productivity when using the indirect observation workstation.

The productivity according to successive trials is presented in Table 4.22. This is assessed to determine if the productivity increases as more of the task are being performed by the subjects using different workstations.

	Direct(stand)	Indirect(stand)	Direct(sit)	Indirect(sit)	Dynamic
	Ave. time[s]	Ave. time[s]	Ave. time[s]	Ave. time[s]	Ave. time[s]
Trial 1	286.1	284.2	214.8	247	212
Trial 2	231.2	271.3	177.6	231.8	201
Trial 3	225.5	260.5	184.6	217.5	215
Trial 4	211.1	260.4	174.2	239.1	197
Trial 5	194.5	231	188.9	216.1	215

Table 4.22 Average time for successive trials for different workstations.

Figure 4.13 shows the trend of the productivity according to successive trials for different workstations.

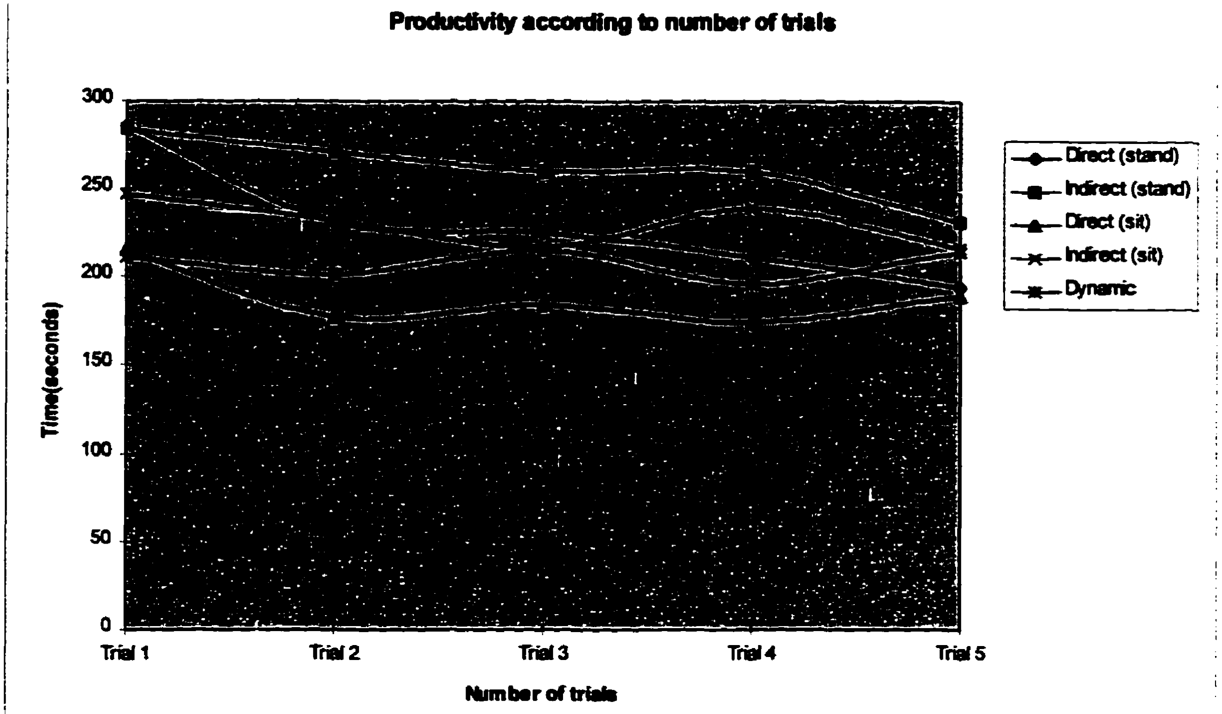


Figure 4.13 Average time for successive trials using different workstations.

From Figure 4.13, the indirect observation workstation in the standing position shows a downward trend towards a better productivity after five trials. This trend is similar for the indirect observation workstation in the sitting position except for the forth trial with a slight decrease in the productivity. The lower productivity using the indirect observation workstation, as mentioned earlier, is due to the two dimensional image projected onto the television monitor screen. However, with proper training, self adjustment and adequate time for getting accustomed to the new work environment, the same productivity as the direct observation workstation can be achieved.

4.3.2 Quality assessment

The quality assessment of the task is done by inspecting the number of errors produced by inserting the integrated circuits to a spot marked with a dot. Improperly inserted circuits are also taken into consideration. These are circuits that are not properly fitted onto the printed circuit board which are either loose or not touching the base of the printed circuit board. Figure 4.14 shows the accumulated errors against the productivity of each different workstation.

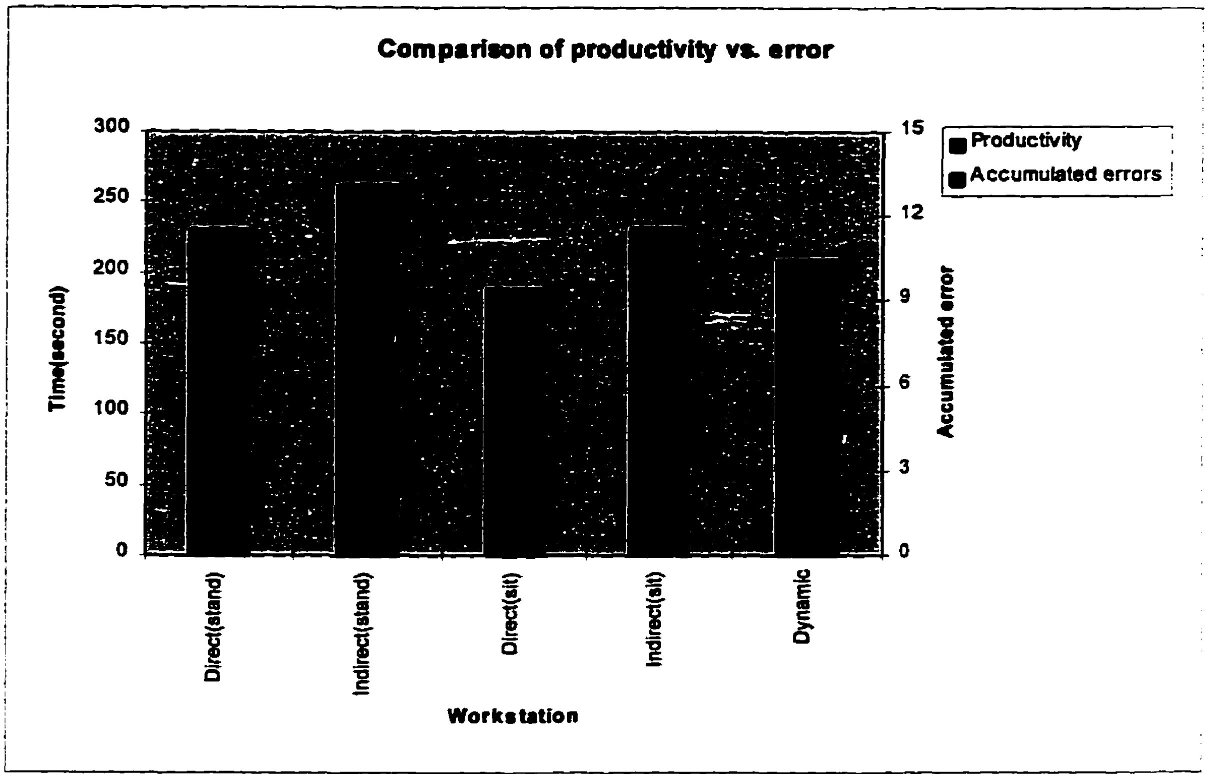


Figure 4.14 Accumulated errors against productivity at different workstations.

From Figure 4.14, the indirect observation workstation in the standing position indicated the highest number of accumulated error with the lowest productivity. This shows that the accumulated errors are inversely proportional to the productivity as can be seen throughout the different workstations. Again, the main reason behind the high number of errors especially for the indirect observation workstation is due to the two dimensional image projected by the television monitor. This phenomena is natural as all the subjects are not familiar with working using a television monitor that project images in two dimensions as opposed to their normal perception in three dimensions. The direct observation workstation in the sitting position indicated the least error as all the subjects are able to view their task in three dimensions and hence a better work quality was achieved due to greater familiarity. The dynamic workstation falls behind the direct observation workstation in the sitting position with an accumulation of five errors. Overall, the indirect observation workstation shows a higher number of errors produced during the laboratory experiment.

4.4 Postural angle measurement

The postural angle measurement of the head, upper arm and trunk were recorded using goniometers which continuously record the angular displacement during the experiment. Each goniometer occupies two channels in the Data Acquisition Unit and measures angles relative to the vertical in two directions at 90 degrees to each other. Therefore, as for the upper arm, angle measurement for flexion and extension in the sagittal plane as well as the abduction and adduction in the frontal plane can be measured simultaneously. Forward flexion and backward extension along with sideways bending of the head and trunk are also measured in a similar manner.

In addition to the goniometers, video recordings were performed to assess the angle displacement of the forearm. This is also done to analyze the overall body movements and posture when using different workstations in the sitting and standing positions. The postural angle analysis from the Physiometer software was performed in a similar manner as that of the EMG signal. Figure 4.15 shows an example of the postural angle measurement for the head flexion and extension in the sagittal plane using the direct observation workstation in the sitting position.

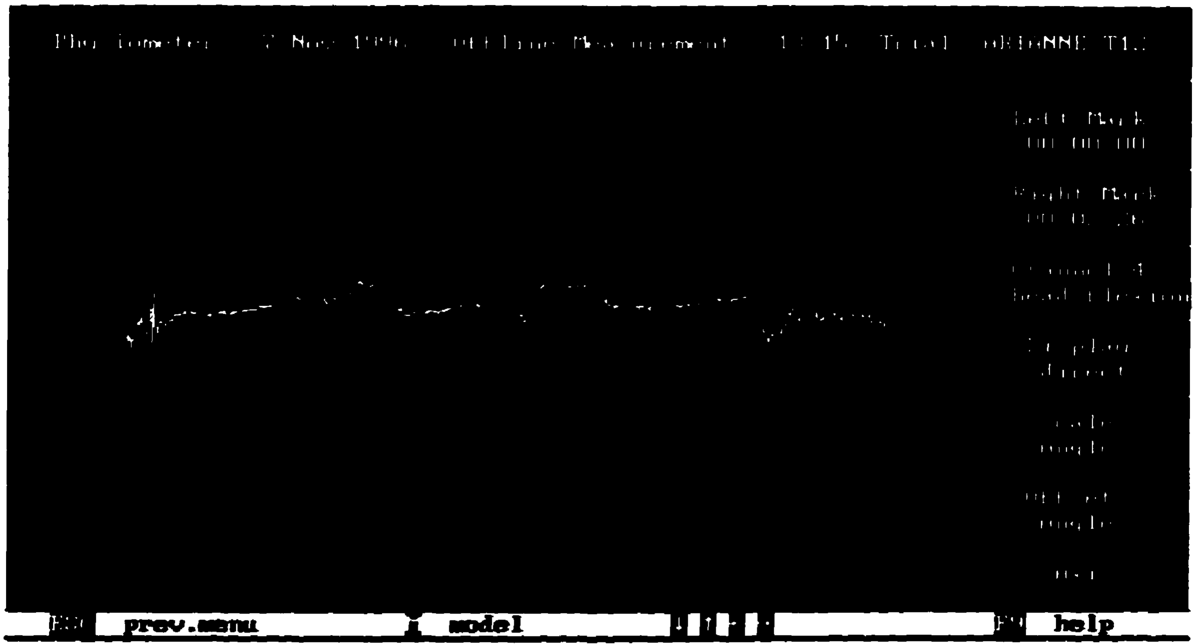


Figure 4.15 Forward flexion and backward extension of the head using the direct observation workstation in sitting position.

From the "*Distribution display*" of the postural angle plot shown in Figure 4.16, the angle measurement for head flexion and extension were taken according to 10%, 30%, 50%, 70% and 90% of the cumulative amplitude distribution function curve. The same measurement is also taken for the sideways bending of the head. Angle measurement for the trunk and upper arm in the sagittal and frontal plane is obtained in a similar manner for comparison between different workstations.

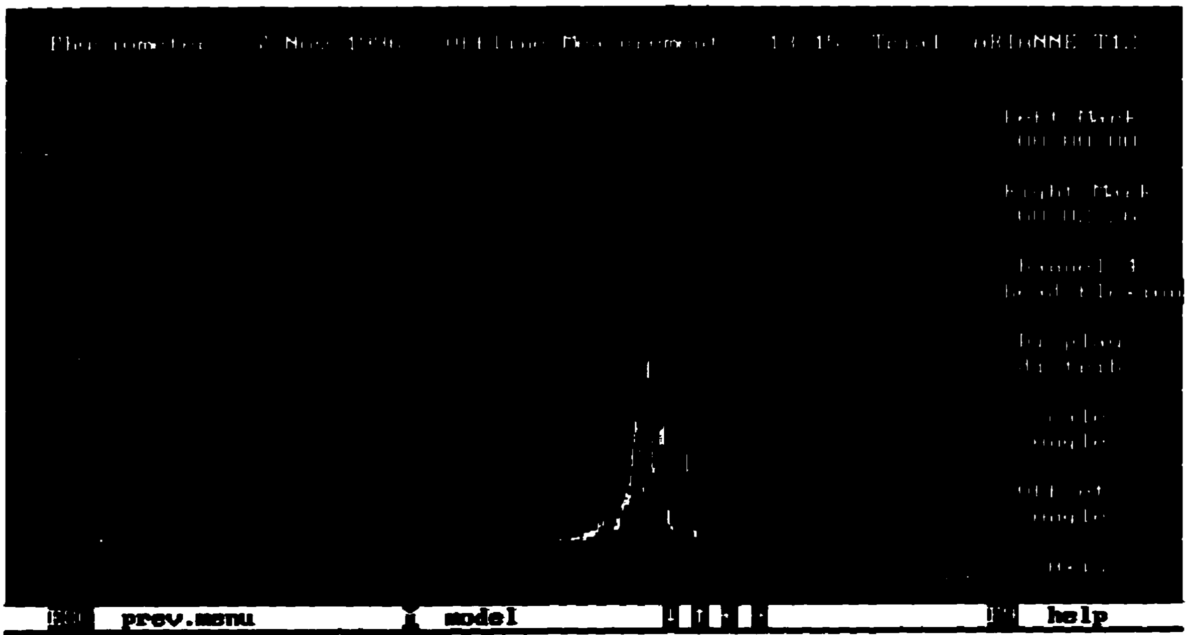


Figure 4.16 Distribution display for head angle displacement (flexion/extension) in sagittal plane using direct observation workstation in sitting position.

Table 4.23 shows the average angle displacement for flexion and extension of the head in the sagittal plane when using different workstations according to 10%, 30%, 50%, 70% and 90% of the cumulative amplitude distribution function curve. Similarly, the sideways bending of the head in the frontal plane is shown in Table 4.24.

	10%	30%	50%	70%	90%
Stand(direct)	38.5°	42.5°	45.75°	49.8°	54°
Stand(indirect)	3.8°	6°	7.45°	8.95°	12.15°
Sit(direct)	40.6°	46.55°	49.8°	52.4°	55.95°
Sit(indirect)	3.45°	7.6°	9.95°	12.25°	15.8°
Dynamic	8.25°	17.1°	40.15°	51.5°	62°

Table 4.23 Average angle displacement for head flexion/extension in sagittal plane for different workstations.

	10%	30%	50%	70%	90%
Stand(direct)	6.5°	10.85°	13.05°	16.2°	19.75°
Stand(indirect)	1.35°	3.6°	5.9°	7.65°	9.6°
Sit(direct)	4.8°	6.8°	9.35°	12.25°	11.75°
Sit(indirect)	3.15°	7.15°	9.45°	11.4°	14.8°
Dynamic	7.75°	12.05°	16.9°	21.15°	25.7°

Table 4.24 Average angle displacement for head sideways in frontal plane for different workstations.

The average angle displacement for the trunk flexion and extension as well as the sideways bending when using different workstations are shown in Table 4.25 and Table 4.26 respectively.

	10%	30%	50%	70%	90%
Stand(direct)	1.9°	3.2°	4.55°	5.75°	7.05°
Stand(indirect)	2.1°	3.05°	3.65°	4.2°	4.8°
Sit(direct)	3.55°	4.95°	6.3°	8°	10.7°
Sit(indirect)	2.15°	3.1°	3.75°	6.45°	7.6°
Dynamic	1.5°	2.7°	4.5°	5.65°	7.3°

Table 4.25 Average angle displacement for trunk flexion/extension in sagittal plane for different workstations.

	10%	30%	50%	70%	90%
Stand(direct)	1.8°	3.1°	3.85°	4.45°	5.55°
Stand(indirect)	2.6°	4.1°	5.05°	5.85°	7°
Sit(direct)	3.2°	4.55°	5.15°	5.8°	6.65°
Sit(indirect)	2°	3.45°	4.35°	5.35°	6.85°
Dynamic	5.35°	7.2°	8.05°	8.65°	9.55°

Table 4.26 Average angle displacement for trunk sideways bending in frontal plane for different workstations

The average angle displacement for the upper arm flexion and extension as well as the abduction and adduction when using different workstations are shown in Table 4.27 and Table 4.28 respectively.

	10%	30%	50%	70%	90%
Stand(direct)	18.85°	24.3°	27.8°	34.45°	50.8°
Stand(indirect)	13.8°	19.8 °	25.65°	32.75°	40.8°
Sit(direct)	11.45°	20.9°	24.7°	31.2°	43.25°
Sit(indirect)	4.95°	11.55°	22.15°	33.05°	41.3°
Dynamic	9.1°	14.9°	19.25°	25.3°	33°

Table 4.27 Average angle displacement for upper arm flexion/extension in sagittal plane for different workstations.

	10%	30%	50%	70%	90%
Stand(direct)	2.95°	3.9°	5.05°	6.15°	7.1°
Stand(indirect)	2°	2.85°	3.45°	4°	4.55°
Sit(direct)	2.25°	3.35°	4.6°	6.2°	8.75°
Sit(indirect)	2.1°	3°	3.6°	6.4°	14.9°
Dynamic	1.35°	2.5°	4.25°	5.5°	7°

Table 4.28 Average angle displacement for upper arm abduction/adduction in frontal plane for different workstations.

From Table 4.23, the head flexion and extension for 50% of the recording time using the indirect observation workstation in both the sitting and standing positions show only a small deviation from the neutral vertical body position. Conversely, the direct observation workstation in both the sitting and standing positions shows the most head deflection from the reference body position. This phenomena is natural as the subjects have to bend their neck in order to view the PCB as opposed to using the indirect observation workstation (p=0.0001). There is no significant difference in the sideways bending of the head for all the different workstations as the experimental task involves little or no sideways motion.

From Table 4.25, the angle displacement for the trunk flexion and extension did not differ much between all the workstations according to 50% of the recording time (p=0.439). This is because most of the flexion is done by the head as opposed to the trunk while doing the experiment. There is also no significant difference in the sideways bending of the trunk as the experimental task involves little or no bending motion.

The upper arm flexion and extension according to 50% of the recording time (Table 4.27) shows that the workstations in the sitting position have a slightly less angle displacement compared to the workstations in the standing position. Overall, there is little variation in the upper arm flexion and extension using the direct and indirect observation workstations in both the sitting and standing positions (p=0.711). As for the upper arm abduction and adduction, there is also little variation between all the workstations according to 50% of the total recording time (p=0.670).

4.5 Perceived level of comfort

The subjective measurements of comfort level for different workstations were analyzed using a questionnaire. Comfort levels were assessed for the upper and lower extremities. Assessment of comfort level in the upper extremities include strain in the eyes, upper back, neck, shoulder, upper arm, lower arm and the wrist. The comfort level in the lower extremities include the lower back, thighs, legs and feet. Figure 4.17 shows a schematic of a human body that has been divided into a set number of body areas. Subjects were required to rate the comfort level in each of these body parts using numerical values from least comfortable to most comfortable. The comfort level was based on a scale of one to seven. Level one indicates a very uncomfortable condition while level seven indicate a very comfortable condition. Questionnaires were handed out to all the subjects immediately after the experiment.

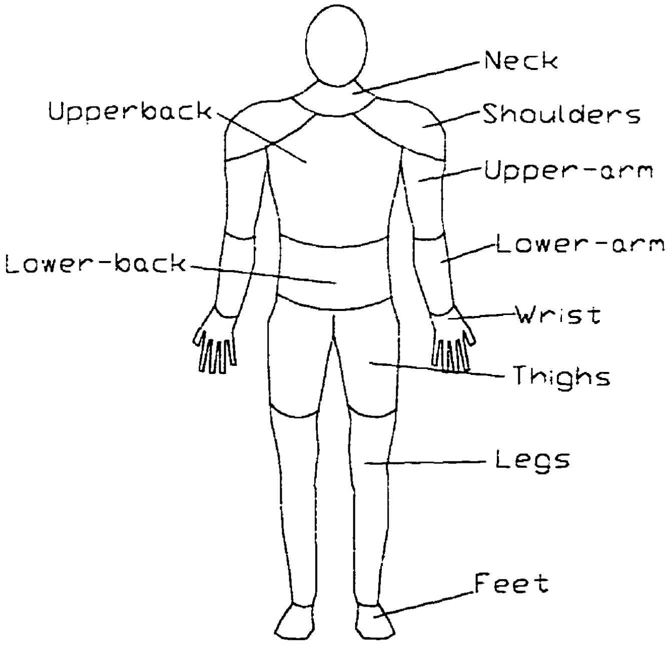


Figure 4.17 Rating of body part comfort levels.

In addition to comfort levels, subjects were also asked to rate each workstation in terms of the level of satisfaction with that workstation and ease of assembling and reaching for the integrated circuits. Table 4.29 shows the average comfort levels of all the workstations.

	Stand(direct)	Stand(indirect)	Sit(direct)	Sit(indirect)	Dynamic
Personal satisfaction	3.92	4.23	5.08	5.54	5.46
Ease of assembling	5.31	4.69	5.31	4.08	5.08
Ease of reaching	5.00	4.54	5.38	4.85	4.77
Strain in eyes	4.38	4.46	4.92	4.77	4.38
Strain in shoulder	4.77	5.08	4.69	5.00	4.77
Strain in neck	3.54	5.62	3.46	5.46	4.77
Strain in upper back	3.77	4.85	4.31	5.23	4.69
Strain in upper arm	4.83	5.61	3.69	4.01	5.32
Strain in lower arm	4.56	4.69	4.59	4.43	4.87
Strain in wrist	4.54	4.46	4.62	4.62	4.85
Strain in lower back	3.63	5.12	3.56	5.45	4.92
Strain in thighs	4.41	4.62	4.53	4.71	4.58
Strain in leg	4.39	4.84	5.52	5.83	4.98
Strain in feet	4.53	4.68	5.21	5.47	5.21
Total average	*4.39*	*4.82*	*4.63*	*4.96*	*4.90*

Table 4.29 Average comfort levels of different workstations.

From Table 4.29, it can be seen that the subjects in this experiment were personally more satisfied with the indirect observation workstation in the sitting position compared to other workstations. The average of all the criteria based in the questionnaire also indicated that the subjects prefer the indirect observation workstation in the sitting position. The direct observation workstation whether in the sitting or standing positions have the advantages in terms of ease in assembling and reaching for the integrated circuits. This is in line with the productivity assessment in which the direct observation workstation has a better speed performance compared to the indirect observation workstation in both the sitting and standing positions. Ease of assembling can also lead to good quality products and this is parallel with the better quality performance using the direct observation workstation. A two dimensional perception through the television monitor slowed down the speed performance and hence affected the quality accomplishment of the task when using the indirect observation workstation.

As for the strain in shoulder, upper back, lower back, upper arm and neck, the indirect observation workstation surpass the comfort level of the direct observation workstation in both the sitting and standing positions. Since all the subjects were able to work in an upright posture while performing the experimental task using the indirect observation workstation, the strain in shoulder, upper back, lower back, upper arm and neck was greatly reduced. Strain in leg and feet was less severe when using both the direct and indirect observation workstations in the sitting position. However, strain in wrist, thighs and lower arm shows little variation among all the different workstations.

Chapter 5
Reproducibility Test

5.1 Introduction

Reproducibility or reliability is the ability of an item to reliably perform a required function under stated conditions for a stated period of time. In this study, it is important to describe the reproducibility characteristics of the Physiometer PHY-400 which is used to produce the EMG readings and postural angle measurement. This is necessary to determine if the Physiometer is capable of producing consistent results.

Many investigators have tested the reproducibility of different EMG signals by using surface electrodes (Komi and Buskirk, 1970, Viitasalo and Komi, 1975, Yang and Winter, 1983, Veiersted, 1991). Most of the studies use the EMG signals of the muscles of the back recorded under strongly standardized condition with unchanged electrode position. Veiersted (1991) studied the reproducibility contractions of trapezius muscle for calibration of EMG measurements. The influence of arm position and electrode position was studied with regards to EMG signal both with and without normalized EMG response. According to Veiersted (1991), the EMG signal of the trapezius muscle varies significantly within subjects according to the position of the electrodes when performing shoulder lifting. However, this significant difference was reduced when the EMG signal was calibrated to the applied force and normalized.

5.2 Reproducibility of the experiment

The EMG method used in this laboratory experiment to assess the resulting work load of different workstations requires several recordings in sequence. Therefore the reproducibility of the EMG recordings is of crucial importance when measuring work load within or between individuals on separate trials. The reproducibility of the experiment is determined by using the analysis of variance (ANOVA) which is a technique by which the statistical relationship between the related variables are analyzed. The reproducibility test is based on the null hypothesis that (1) there is no difference in the mean of the normalized EMG signals within and between subjects and (2) there is no difference in the mean of postural angle measurement between subjects using the same workstation. The ANOVA result is obtained using the statistical analysis software, *Minitab*. The components of the EMG signal to be tested using ANOVA are the number of muscle contractions (shifts/minute) and the muscle load as a percentage of cumulative amplitude distribution function curve for the trapezius muscle. Reproducibility of the postural angle displacement is analyzed using data produced by the bending of the head, upper arm and trunk. The reproducibility of the experiment is achieved using the F-test from ANOVA.

Table 5.1 shows the reproducibility result for the number of muscle contractions within the subjects at different trials using the direct and indirect observation workstations in the sitting and standing positions. Six subjects' data were randomly chosen for the reproducibility test. The F-ratio value obtained through ANOVA is compared with the F-table value with a confidence level of 95%. Samples of ANOVA results for the reproducibility test can be found in the Appendix.

	Stand(direct) F-ratio	Stand(indirect) F-ratio	Sit(direct) F-ratio	Sit(indirect) F-ratio
Subject 1	0.41	10.57	0.57	1.55
Subject 2	2.61	1.25	0.65	2.60
Subject 3	0.81	0.76	1.01	0.61
Subject 4	0.43	0.22	0.77	5.59
Subject 5	0.06	0.85	1.56	2.12
Subject 6	2.16	0.75	1.41	1.65

Table 5.1 F-ratio value (shifts/min) for trapezius muscle within subjects obtained from ANOVA for different workstations.

The reproducibility test within the subjects for the muscle load as a percentage of the cumulative amplitude distribution function curve using different workstations is shown in Table 5.2.

	Stand(direct) F-ratio	Stand(indirect) F-ratio	Sit(direct) F-ratio	Sit(indirect) F-ratio
Subject 1	0.56	2.40	0.77	0.65
Subject 2	2.55	2.13	0.76	4.10
Subject 3	0.93	1.31	0.90	0.53
Subject 4	0.92	0.38	6.18	3.84
Subject 5	0.38	0.81	1.17	2.06
Subject 6	1.65	0.58	0.71	1.04

Table 5.2 F-ratio value (cumulative amplitude distribution function) for trapezius muscle within subjects obtained from ANOVA for different workstations.

From the F-table with 4 degrees of freedom in the numerator and 30 degrees of freedom in the denominator along with a 95% confidence level, the value obtained ($F_{0.95,4,30}$) is 2.68. Since the numerator and denominator are constant throughout the analysis for the number of muscle contractions and muscle load , the same F-table value can be compared to the F-ratio value obtained through ANOVA.

If the F-table value is greater than the F-ratio value, the null hypothesis of having the same mean should not be rejected. However, from Table 5.1, subject 1 in standing(indirect) and subject 4 in sitting(indirect) indicated a F-ratio value greater than 2.68. Hence, the null hypothesis of having the same mean between trials should be rejected for subject 1 in standing(indirect) and subject 4 in sitting(indirect). Overall, the F-test indicated that the F-ratio value for different trials within subjects for the number of muscle contractions has a smaller value compared to the F-table value.

As for the muscle load measured as a percentage of the cumulative amplitude distribution function curve (Table 5.2), subject 2 in sitting (indirect) and subject 4 in sitting(direct and indirect) shows a higher F-ratio value compared to the F-table value, hence the null hypothesis should be rejected in this particular case. Overall, the muscle load as a percentage of the cumulative amplitude distribution function curve shows a smaller F-ratio value compared to the F-table value.

Reproducibility test for normalized EMG signal between subjects is also analyzed. Five different data for the number of muscle contractions (shifts/min) from different subjects using the same type of workstation were randomly chosen for the analysis. Table 5.3 shows the results of normalized EMG signal between the subjects.

Stand(direct) F-ratio	Stand(indirect) F-ratio	Sit(direct) F-ratio	Sit(indirect) F-ratio	Dynamic F-ratio
1.01	0.63	0.55	0.83	1.48

Table 5.3 F-ratio value (shifts/min) for trapezius muscle between subjects using different workstations.

Since the numerator and denominator is the same in this test as for the within subject test, the same F-table value ($F_{0.95,4,30}$) will be used for comparison. From Table 5.3, the F-ratio value is indeed less than the F-table value of 2.68. Hence, the null hypothesis of having the same mean for the number of muscle contractions between subjects using the same workstation should not be rejected.

Table 5.4 shows the reproducibility test between subjects for the muscle load as a percentage of the cumulative amplitude distribution function curve. Five different data from different subjects using the same type of workstation were also randomly selected for the analysis .

Stand(direct) F-ratio	Stand(indirect) F-ratio	Sit(direct) F-ratio	Sit(indirect) F-ratio	Dynamic F-ratio
0.93	0.21	0.54	1.04	1.56

Table 5.4 F-ratio value (cumulative amplitude distribution function) for trapezius muscle between subjects using different workstations.

In Table 5.4, the F-ratio between subjects shows a smaller value compared to the F-table value of 2.68. Hence, the null hypothesis of having the same mean should not be rejected for the muscle load as a percentage of the cumulative amplitude distribution function curve.

The reproducibility test for the postural angle measurement within subjects for the head, trunk and upper arm in terms of flexion/extension and sideways bending (abduction/adduction for the upper arm) is shown in Table 5.5.

	F-ratio (Head)		F-ratio (Trunk)		F-ratio (Upper arm)	
	Flex./Ext.	Sideways	Flex./Ext.	Sideways	Flex./ext.	Abd./Add.
Stand(direct)	1.55	2.31	6.15	0.89	1.35	1.46
Stand(indirect)	1.07	2.59	1.73	1.22	3.26	2.54
Sit(direct)	2.13	1.64	2.45	2.35	2.15	1.68
Sit(indirect)	4.52	1.53	1.45	1.05	1.95	0.96

Table 5.5 F-ratio for postural angle measurement at different workstations.

The F-table value for the reproducibility test of the postural angle measurement with 95% confidence level is $F_{(0.95, 4, 20)}$ 2.86. Only three values of the F-ratio exceeded the value of the F-table of 2.86 and in this case, the null hypothesis should be rejected. Overall, the F-ratio value for the postural angle measurement is smaller compared to the F-table value. Hence, the null hypothesis of having the same mean in the postural angle displacement should not be rejected.

5.3 Discussion

The EMG recordings are measurements of very complex biological processes in the muscle. During contraction, electrical activity is generated according to the force of contraction. However, there are many different factors that influence the amount of electrical activity recorded from the muscle. Therefore during the laboratory experiment, it is important to reduce the influence of different sources which produces errors in the recorded EMG signal. Hence, the calibration procedure is important in this experiment. The maximum voluntary contraction (MVC) may show variability due to motivational factors and muscle fatigue (Komi and Buskirk, 1970). However, by using the on-line feedback during the calibration procedure, each subject was able to obtain a high correlation between the EMG amplitude and force by ensuring that the muscle activity increases continuously for the actual work load (Aaras and Westgaard, 1987). Goniometers, on the other hand, measures the angle displacement directly from postural joint of interest and is subjected to less variability in the measurement.

The EMG amplitude varies with the direction of the muscle contraction (Viitasalo and Komi, 1975). Therefore the direction of the isometric lifting contraction of the trapezius and anterior deltoid muscles may add to the variation of the EMG activity during the calibration procedure. It is important that the force direction of the shoulder during lifting is straight upwards and slightly backwards to obtain the maximum activation of the trapezius and anterior deltoid muscles.

Many factors influence the recorded EMG signal amplitude. These include the type of electrodes used to measure the muscle activity (Komi and Buskirk, 1970), electrode contact area (Geddes et. al., 1967), the placement of the electrodes (Lippold, 1967), source impedance and amplifier input impedance (DeVries, 1968), the muscle length (Hakansson, 1957), tissue distance between the electrodes and the muscle (Basmajian and DeLuca, 1985) and muscle temperature (Petrofsky, 1979). Some of the above factors depend on the experimental set up and can be controlled, while others vary from experiment to experiment. However, the variability within most of these factors can be removed by normalization, which is done by dividing a reference value determined during the calibration procedure shown in equation 3.1 in Chapter 3.

Taking into account the factors influencing the recorded EMG signal, the results from analysis of variance indicated an excellent reproducibility for the Physiometer PHY-400. The F-ratio value obtained from the number of muscle contractions was overall small for both the within and between subjects compared to the F-table value. Similar results were also obtained in the muscle load as a percentage of the cumulative amplitude distribution function curve. Excellent reproducibility was also obtained for the postural angle measurement using the goniometers. This supports the null hypothesis of no difference in the means of the measurements, which indicated that there is little variation between each trial for each subject. Hence the Physiometer is reliable in reproducing identical experimental results based on the EMG signal and postural angle measurement recorded.

Chapter 6
Discussion of Results

6.1 Introduction

This chapter discusses the results of the laboratory experiment to determine the best workstation and position (sitting or standing) for the subjects in terms of (1) muscle activities of the trapezius and anterior deltoid muscles, (2) postural angles of the head, trunk and upper arm, (3) task performance and (4) the perceived level of comfort of each workstation.

Muscle activities of the trapezius and anterior deltoid muscles are used to determine the development of muscle strain in the different workstations. Postural angle measurement of the head, trunk and upper arm are compared to the standard guidelines issued by the U.S. Occupational Safety and Health Administration (OSHA) to determine if the different workstations meet these standards. The effectiveness of different workstations in terms of productivity and quality of the experimental task were also discussed.

In addition, satisfaction in terms of comfort level to the upper and lower extremity as well as usability of each workstation were compared. Results from the laboratory experiment are compared to the field study conducted at Northern Telecom Plant in Calgary (Venda, 1995[a]). Reproducibility test was also carried out for the EMG signal and postural angle measurement. Results of the reproducibility test shows that the Physiometer PHY-400 is capable of reproducing identical experimental data.

6.2 Muscle activities

This section discusses the findings of the laboratory experiment for the muscle activities in terms of micropauses and static, median and peak loads for the trapezius and anterior deltoid muscles.

6.2.1 Micropauses

Analysis of EMG activity recorded from the trapezius muscle and the anterior deltoid muscles was undertaken to establish the duration of micropauses when using different workstations. On a physiological basis, micropauses or micro-breaks in the muscle load pattern is necessary and important for the recovery of muscle functions. This finding was based on research by Lehmann (1962) who showed that both the length of the pauses as well as the period of work activity, can influence the development of fatigue. Furthermore, Rohmert (1973) reported that sufficient micropauses will result in optimum work performance.

The trapezius muscle experienced longer micropauses when subjects used the standing position to perform the experimental task, in both the direct and indirect observation workstations (6.7 sec/shift and 26.3 sec/shift for the direct and indirect observation workstations in the standing position respectively vs. 0.8 sec/shift and 6.9 sec/shift for the direct and indirect observation workstations in the sitting position respectively at 2 %MVC). Another characteristic in micropauses of the trapezius muscle is that the indirect observation workstation shows a longer duration in the micropauses compared to the direct observation workstation. This holds for both the sitting and standing positions. The same can also be observed at a higher muscle load (Figure 4.7). The dynamic workstation shows only a slight increase in the duration of micropauses compared to the direct observation workstation in the sitting position at various muscle load ($p<0.6$). This is because most of the subjects, although being told to use an equal combination of direct and indirect observation while performing the experimental task, tended to spend a longer duration using the direct observation. As a result, a shorter duration in micropauses for the trapezius muscle using the dynamic workstation was obtained.

This shows that the standing position is able to provide longer micropauses for the trapezius muscle compared to the predominantly sitting position. The longer duration in the average micropauses of the trapezius muscle at respective muscle load for the standing position is a result of fewer muscle contractions (Table 6.1) as opposed to the sitting position (30.80 shifts/min and 23.0 shifts/min for the direct and indirect observation workstations in the standing position respectively vs. 59.33 shifts/min and 27.3 shifts/min for the direct and indirect observation workstations in the sitting position respectively at 2 %MVC).

The trends in micropauses for the trapezius muscle were similar for all the different workstations. An increase in the muscle load is accompanied by an increase in the micropauses (Figure 4.7). This phenomena is due to the experimental task which requires little strength to perform and hence less stimulation was required for the activation of muscles at a higher load. This can be observed from the decreasing number of muscle contractions (shifts/min) at a higher muscle load for different workstations as shown in Table 6.1. Therefore, longer duration in micropauses is associated with fewer muscle contractions in the trapezius muscle.

	Stand(direct) [shifts/min]	Stand(indirect) [shifts/min]	Sit(direct) [shifts/min]	Sit(indirect) [shifts/min]	Dynamic [shifts/min]
2% MVC	30.80	23.00	59.33	27.30	30.43
4% MVC	22.30	12.72	52.07	25.79	25.43
5% MVC	17.93	9.83	48.00	25.08	22.33
8% MVC	11.13	4.93	40.72	23.27	15.90
10% MVC	8.00	3.55	35.93	21.91	12.82
12% MVC	6.31	2.63	30.87	21.40	11.07
15% MVC	4.27	1.77	24.59	18.03	7.97

Table 6.1 Average muscle contractions in shifts/min for trapezius muscle using different workstations.

Contrary to the trapezius muscle, the anterior deltoid muscle shows a longer duration in micropauses when using the predominantly sitting position (0.381 sec/shift and 0.881 sec/shift for the direct and indirect observation workstations in the standing position respectively vs. 1.627 sec/shift and 7.778 sec/shift for the direct and indirect observation workstations in the sitting position respectively at 2 %MVC). Longer duration in micropauses was also obtained when using the indirect observation workstation compared to the direct observation workstation in both the sitting and standing positions (Figure 4.8), showing a similarity in muscle activities as the trapezius muscle.

Anterior deltoid muscle plays an important role in the flexion and extension of the upper arm. However, with the use of the lower arm or elbow as a support to the whole arm when performing the experimental task in the sitting position, the flexion of the upper arm is limited. Hence, less muscle activity was recorded in the anterior deltoid muscle in the predominantly sitting position compared to the standing position. The trends in micropauses for the anterior deltoid muscle is similar to the trapezius muscle, an increase in the muscle load is accompanied by an increase in the micropauses for all the different workstations (Figure 4.8).

The results of micropauses obtained from the laboratory experiment were compared to the field study conducted by Dr. Venda at the Northern Telecom Wireless plant in Calgary (1995). In the field study, electromyography analysis of the trapezius muscle was performed similar to the laboratory experiment described in this study. However, analysis of the anterior deltoid muscle was not conducted in the field study. Twelve workers participated in the field study that lasted for a period of one month. Their task included inserting integrated circuits into the printed circuit boards (PCBs) and soldering the integrated circuits. In addition, workers were required to remove any excess material due to the soldering process. The field study was conducted only in the sitting posture using the direct and indirect observation workstations. A cut out workstation was analyzed for muscle activities in addition to the conventional workstation utilizing both the direct and indirect observation method (Venda, 1995[a]). A cut out workstation is basically a table in which the center edge is cut off in a circular manner. This enables the workers to be seated closer to the equipment and provide extra work area spaces. The results of average micropauses obtained from the field study are presented in Table 6.2.

	Cut-out(direct) [sec/shift]	Cut-out(indirect) [sec/shift]	Conventional (direct) [sec/shift]	Conventional (indirect) [sec/shift]
2 %MVC	0.319	0.405	0.443	0.504
3 %MVC	0.383	0.403	0.369	0.526
8 %MVC	0.421	0.492	0.440	0.769

Table 6.2 Average micropauses of conventional and cut-out workstations in sitting position for trapezius muscle.

Micropauses from the field study were analyzed in a similar manner described in this study. Muscle contractions in shifts/min and the cumulative amplitude distribution function curve were analyzed at 2 %MVC, 3 %MVC and 8 %MVC respectively for micropauses. From Table 6.2, the conventional workstation using the indirect observation shows a longer duration in micropauses compared to other workstations. This result corresponds to the laboratory findings found in this study. However, the micropauses from the field study using the conventional indirect observation workstation indicated a much lower value compared to the laboratory findings (0.504 sec/shift vs. 6.9 sec/shift at 2 %MVC). This shows a difference of 93% between the two findings. Such difference is attributed to the task involved which is more strenuous at the field study compared to the laboratory experiment. This can be observed from the average static load which is 0.33 %MVC (Table 6.3) for the field study compared to 0.22 %MVC for the laboratory experiment for the trapezius muscle. A higher median muscle load of 3.56 %MVC can also be noticed for the field study (Table 6.3) compared to 1.74 %MVC for the laboratory experiment. The workers at the field study were not only required to insert integrated circuits but were also required to perform soldering by flipping over the PCB and removing excess material using pliers. In addition, data collected from the field study was based on an eight hour shift as opposed to a shorter duration in the laboratory. However, both the field study and the laboratory study indicated that the indirect observation workstation in the sitting position is able to provide a longer duration in micropauses compared to the direct observation workstation.

According to Thompson (1990), longer micropauses would assist the affected muscle group to stimulate blood circulation, reducing the lactic acid concentration in these muscle group caused by postural rigidity and repetitive work task. Longer micropauses would enable the oxygenation of lactic acid back to glycogen to fuel new muscular activity. In addition, Lindh (1980) reported that in an upright sitting posture as demonstrated in the indirect observation workstation, the disc pressure is reduced compared to a slouched anterior sitting posture. This is because as the backward pelvic rotation and lumbar flexion are reduced, the lever arm for the force exerted by the weight of the trunk will be shortened (Lindh, 1980).

6.2.2 Static, median and peak loads analyzed using EMG signal

It is not possible to use the arm or hand without stabilizing the shoulder girdle and the glenohumeral joint. Any arm movement requires continuous activation of the shoulder muscles such as trapezius, levator scapula, rhomboid, serratus anterior and rotator cuff muscles. Therefore, work tasks with a demand of continuous arm movements generate load patterns with a static load component (Aaras, 1987, Westgaard et. al., 1986, Winkel and Oxenburgh, 1990). The load on the glenohumeral joint is transmitted to the scapula and further to the trapezius muscle, which thereby acts as the principal antigravitational muscle for the arm. Hence, emphasis was given to the trapezius muscle in this study as this muscle is the main stabilizer to the shoulder girdle during arm movement and is highly subjected to static loading.

Recent findings have indicated that low level but prolonged static muscle load is a major risk factor in the development of load related injuries. If left unattended, static load imposed on muscles especially in the upper extremity could lead to the development of musculoskeletal injuries (Aaras, 1990). Much effort has been spent in the industry to prevent muscular disorders by reducing the static load level. The approach was based on laboratory studies which suggested a load level low enough to allow an unlimited duration of contraction without risking muscle injuries. Jonsson (1982), Aaras and Westgaard (1987) found that static muscle load level below 2 %MVC is important in order to reduce the development of musculoskeletal injuries. The importance of keeping the static muscle load below 2 %MVC is also supported by other laboratory studies (Hagberg, 1981, Kilbom et. al., 1983). Hence, determining the development of muscle load related injuries of the trapezius and anterior deltoid muscles at different workstations in this study will be based on a static load of 2 %MVC. Static muscle load at or below 2 %MVC is regarded as the threshold which could be maintained for a long time without much disturbance of homeostasis in the working muscles (Aaras and Westgaard, 1987).

Static muscle load in the trapezius muscle conducted in this laboratory is shown in Table 4.11 to Table 4.15. Subjects using the direct observation workstation in the sitting position indicated a higher static muscle load (1.32 %MVC) compared to other workstations. However, this finding is below the value of 2 %MVC suggested by researchers for the development musculoskeletal injuries. Nonetheless, as a comparison of static muscle load between all the different workstations, the direct observation workstation in the sitting position proved to induce a greater static load on the trapezius muscle. The indirect observation workstation in the standing position on the other hand, shows no static load imposed on the trapezius muscle in any of the subjects.

The duration of time in which the static load was below 2 %MVC for all the subjects using the indirect observation workstation in the standing position ranged from 53% to 100% of the total recording time, as measured from the cumulative amplitude distribution function curve. A 53% of the recording time would mean that the trapezius muscle is subjected to a static load greater than 2 %MVC for the remaining 47% of the recording time. Subsequently, 100% of the recording time would mean that the trapezius muscle is no longer subjected to any static load greater than 2 %MVC. Based on these findings, the indirect observation workstation in the standing position is able to elevate a substantial amount of static load imposed on the trapezius muscle.

The standing posture appears to be more favorable than the sitting posture in terms of static load on the trapezius muscle. When using the indirect observation workstation in the sitting position, there is a higher static load on the trapezius muscle compared to the indirect observation workstation in the standing position (0.22 %MVC vs. 0 %MVC). These results were also supported by the direct observation workstation between the sitting and standing postures which indicated a static muscle load of 1.32 %MVC and 0.068 %MVC respectively. Such findings correspond with studies conducted by Aaras (1990) which indicated that the standing position imposed less static load on the upper extremity compared to the sitting position.

The effect of muscle activities between the sitting and standing positions can be observed from the EMG activity of the dynamic workstation. The dynamic workstation, which utilizes both the direct and indirect observation workstations in the sitting and standing positions, shows a decrease in EMG activity from sitting to standing in the trapezius muscle. This is shown in Figure 6.1. A high EMG activity is associated with high number of muscle contractions. A higher number of muscle contractions generally leads to a shorter duration in micropauses and consequently a higher static load.

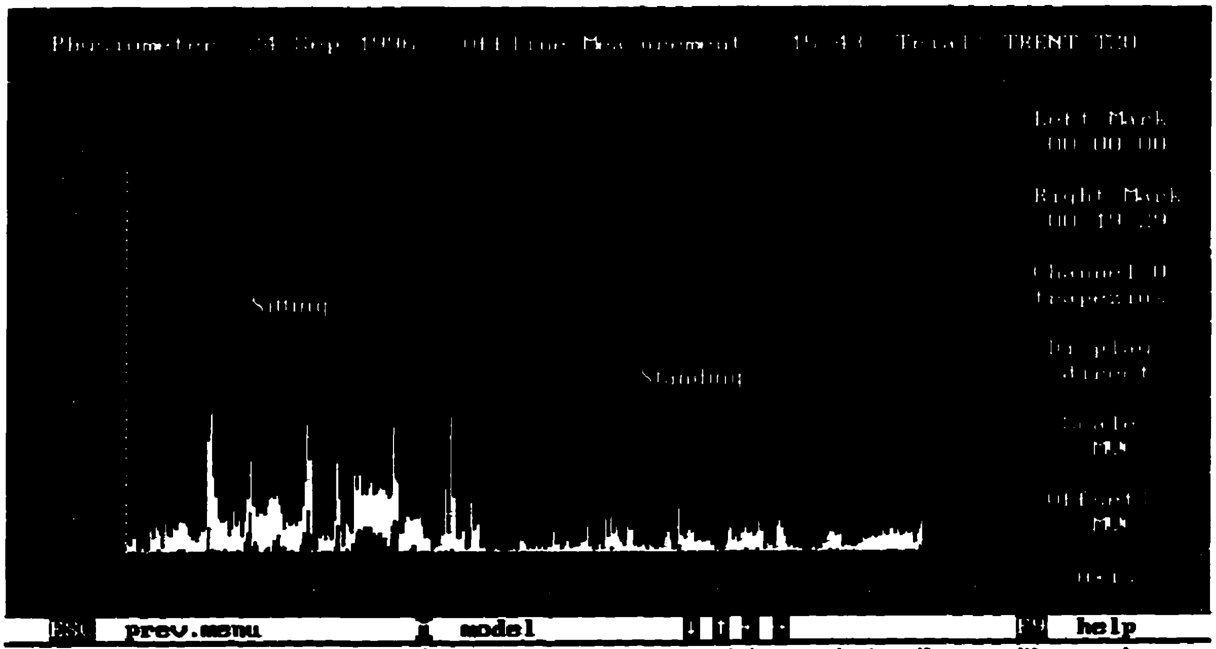


Figure 6.1 Muscle contractions for trapezius muscle in sitting and standing positions using dynamic workstation.

The static load in the trapezius muscle using the dynamic workstation is lower than the workstation in the sitting posture due to the combination of direct and indirect observations in the sitting and standing positions (Figure 4.10).

As for the anterior deltoid muscle, there was no static muscular effort induced in it during the laboratory experiment. All the workstations indicated a zero value in the muscle load according to 10% of the cumulative amplitude distribution function curve. This is consistent with most clinical studies of occupational shoulder-neck injuries where symptoms from the deltoid muscle are rare. According to Hagberg (1981) the anterior deltoid muscle may be oversized for its actions and thus resistant to exertion.

Static load of the trapezius muscle obtained in the laboratory experiment is also compared to the field study. Table 6.3 shows the static, median and peak loads of the trapezius muscle obtained from the field study using different workstations according to 10%, 50% and 90% of the cumulative amplitude distribution function curve.

	Cut-out(direct) [%MVC]	Cut-out(indirect) [%MVC]	Conventional (direct) [%MVC]	Conventional (indirect) [%MVC]
Static load	5.366	1.77	4.55	0.33
Median load	16.136	9.24	14	3.56
Peak load	34.964	20.15	30.65	15.43

Table 6.3 Muscle load of the trapezius muscle from field study.

From Table 6.3, the conventional workstation using the indirect observation shows the lowest static load on the trapezius muscle compared to other workstations. The conventional direct observation workstation on the other hand indicated a static load of 4.55 %MVC. This value exceeded the suggested value of 2 %MVC for the development of musculoskeletal injuries. Hence, the workers at the electronic assembly plant had a high static load imposed on the trapezius muscle when using the conventional direct observation workstation. This can also be observed from the cut-out direct observation workstation. If this problem is left unattended, these workers will be subjected to shoulder muscle pain in the long run.

The findings in the field study are in agreement with the laboratory studies in which the direct observation workstation in the sitting position indicated a higher static load imposed on the trapezius muscle. However, the value obtained in the laboratory is smaller compared to the field study (1.32 %MVC vs. 4.55 %MVC respectively). Again, this is attributed to the work task involved in the field study which is more strenuous and measurements were taken based on an eight hour shift as opposed to a shorter duration in the laboratory.

The high static load on the trapezius muscle from field study can also be explained from the short work cycle (3 minutes for each printed circuit board) and repetitive arm movement of the workers observed through video. The workers at the electronic assembly plant were required to insert several different integrated circuits into one printed circuit board in addition to soldering it together. Hence, repetitive arm movements can be observed as they reached for different integrated circuits contained in different plastic bins. This procedure is repeated with the arrival of another printed circuit board from an adjacent workstation. Repetitive arm movements have been suggested as factors in occupational shoulder and neck disorders (Luopajarvi et. al., 1979). During rapid muscle contractions, the intra muscular pressure rises, local circulation of the blood supply of oxygen in the muscle is lowered and the efficiency of the removal of metabolic by-products is decreased (Astrand and Rodahl, 1986).

6.3 Postural angle measurement and analysis

It has been widely accepted that awkward and constrained postures result in musculoskeletal stress on the neck and shoulder of sedentary workers and are a major factor in the development of musculoskeletal injuries (Chaffin, 1973, Hunting et. al., 1980). Hence, the U.S. Occupational Safety and Health Administration (OSHA) has recommended guidelines for an effective control program to identify and correct postural hazards. The standards defined by OSHA for joint postures conducted in this laboratory are shown in Table 6.4. These guidelines will be used to compare the postural angles measured in the field with those measured from laboratory studies.

	Neutral	Mild	Severe
Trunk flexion	0-20°	21-30°	>30°
Trunk twisting	-	-	>20°
Head/neck flexion	0-20°	21-45°	>45°
Head/neck twisting	-	-	>20°
Upper arm flexion	0-30°	31-60°	>60°
Upper arm abduction	0-30°	31-60°	>60°

Table 6.4 OSHA standards for joint postures in the upper extremity.

Based on the field study, the average angle displacements of the head, trunk and upper arm are shown in Table 6.5 according to 50% of the cumulative amplitude distribution function curve.

	Trunk flexion	Head flexion	Upper arm flexion	Upper arm abduction
Cut-out(direct)	13.6°	36.3°	19.2°	24.7°
Cut-out(indirect)	10.2°	18.3°	16.3°	19.2°
Conventional(direct)	12°	33°	19.7°	22.3°
Conventional(indirect)	9.5°	14.8°	17.3°	20.7°

Table 6.5 Average angle displacement for different workstations from field study.

In the field study, the cut-out and conventional direct observation workstations show a relatively high angle displacement especially for the head. Although this value falls in the mild category outlined by OSHA, such postures can consequently lead to a high static load in the neck and shoulder muscles if it is repeated over a long period of time. However, by using the indirect observation workstation, a lower head angle displacement is noticed. The angle displacement of the trunk and upper arm flexion and abduction from the field study shows little variation between all of the workstations and are categorized as neutral according to OSHA standards.

In the field study, point soldering and inserting of the integrated circuits is accompanied with the bending of the head and trunk in order to obtain an acute visual angle using the cut-out and conventional direct observation workstations. This leads to a better perception with improved magnification of the work-area. However, with a slumped anterior sitting posture, the gravity line of the head will pass anterior (forward) to the cervical spine and there will be an increase demand placed on the neck musculature (Jones et. al., 1961, Bunch and Keagy, 1976). An increase in shoulder and neck activity will be required to keep the head erect compared to an upright sitting posture. Hence, the greater the slump or bending of the head, the greater the forward thrust of the head, resulting in a marked increase in activity from the trapezius and other posterior neck muscles (Gray et. al., 1966). This in turn affects the static load on the trapezius muscle which was higher in the conventional direct observation workstation (4.55 %MVC) compared to the conventional indirect observation workstation (0.33 %MVC). Similar results can also be seen from the cut-out workstation.

Prolonged bending of the head and trunk in a sitting posture has been frequently implicated as a major cause of low back injuries (McKenzie, 1981, Walsh et. al., 1989, Burdoff et. al, 1991). In addition, forward bending of the head and trunk rendered the lumbar support of the chair useless. McKenzie (1981) also noted that bending of the head and trunk will cause stress to the posterior fibrous wall of the discs and posterior ligaments of the back as well as causing a greater pressure increase within the discs. Neck flexion has also been shown to be related to neck pain as a function of the angle of flexion (Hunting et. al., 1980). Overall, depending on the degree of flexion of the head and trunk, there will be an increase potential for pain and stress to the lower back, upper back and neck.

In the laboratory study, the head flexion using the direct observation workstation in both the sitting and standing positions falls into the severe category (Table 4.23). As in the field study, subjects in the laboratory experiment were required to lean forward to obtain a good view of the work area when using the direct observation workstation. This is denoted by the small abduction of the upper arm which indicated that the work-area is at the elbow height for most of the subjects (Table 4.28). Hence, excessive bending of the head and neck was required as a compensation for the acute abduction of the upper arm (Venda, 1995[b]). From video analysis, most of the subjects bend their head instead of hunching their back over the experimental task in both the sitting and standing positions. According to Schuldt et. al. (1986), excessive bending of the head results in an increase in the EMG activity of the trapezius muscle. This can be seen from the regression analysis shown in Figure 6.2. In this figure, an increase in the head flexion is followed by an increase in the muscle contractions of the trapezius muscle. The summary of the regression analysis can be found in the Appendix. An R^2 value of 22.1% is due to the wider spread of points beyond 20° of the head inclination. The linear regression equation is given as $S = 27.7 + 1.20\theta$ where S = number of muscle contractions in shifts/min and θ = head inclination.

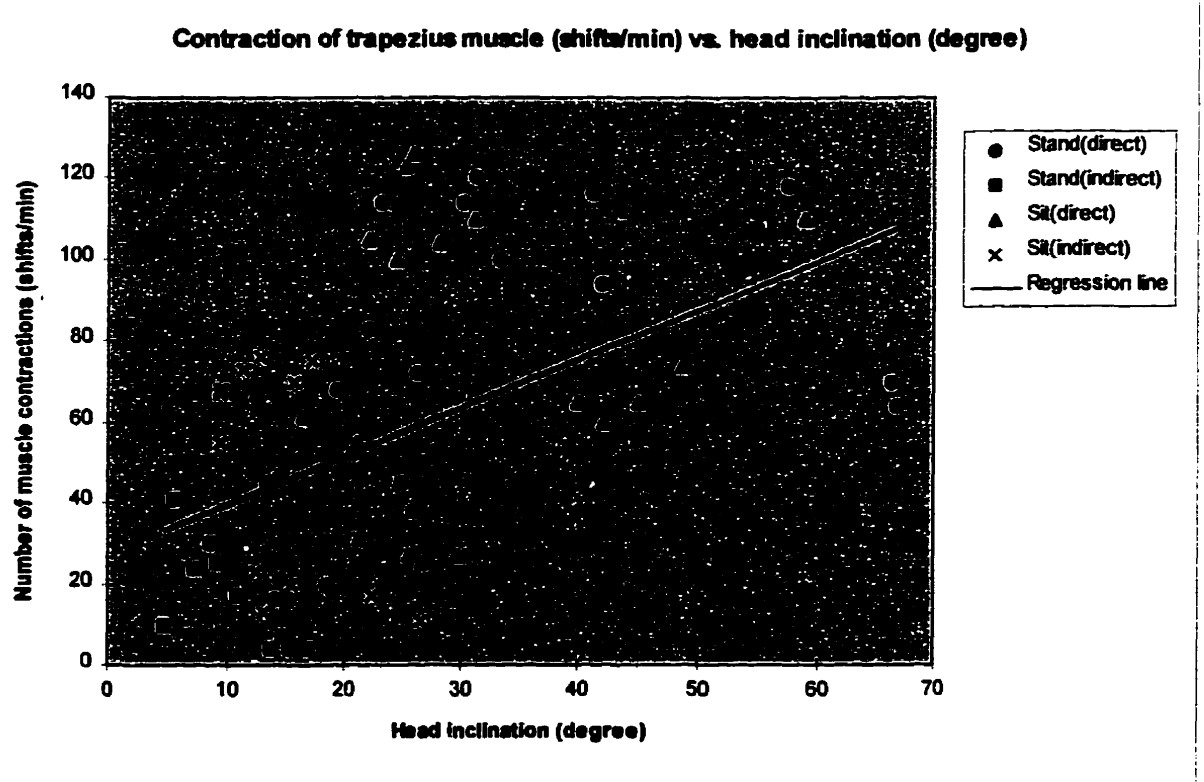


Figure 6.2 Linear regression for contraction of trapezius muscle vs. head inclination.

Higher number of muscle contractions will consequently lead to higher static load imposed on the trapezius muscle. These results are in agreement with studies by Harms-Ringdahl (1986) showing that the flexion in the head had substantial influence on the load imposed on the trapezius muscle. Furthermore, Kumar and Scaife (1979) also noted subjective reports of neck discomfort during the workday and found these to be related to neck inclination angle.

The upper arm flexion and abduction in the field study (50% recording time) fall within the neutral zone suggested by OSHA. However, Aaras et. al. (1990) suggested a lower value of upper arm flexion and abduction for the development of musculoskeletal injuries in the shoulder region. An upper arm flexion of 15° and abduction of 10° was suggested by Aaras et. al. (1990) as the maximal allowable joint postures according to 50% of the recording time. Hence, upper arm flexion and abduction in the field study using the conventional direct and indirect observation workstations exceeded these values. Greater arm flexion is due to the work task at the assembly plant which requires the hand reaching for different integrated circuits.

As for the upper arm flexion in the laboratory experiment using the direct and indirect observation workstations in the sitting and standing positions (Table 4.27), the results also exceeded the value suggested by Aaras et. al. (1990). However, a slightly less upper arm flexion was obtained from the workstation in the sitting position compared to the standing position. This is primarily due to the support provided by the elbow or the lower arm which restricted the upper arm movement. Using the elbow or the lower arm as a support also drew the subjects closer to the edge of the table and thus able to slightly minimize the arm flexion. In the standing position, the whole arm is suspended without any support and this causes a greater upper arm flexion when reaching for the integrated circuits. Angle displacement for the upper arm abduction in the laboratory study is less than the suggested 10° angle by Aaras et. al. (1990) for all the workstations.

Using the elbow or the lower arm as a support to the upper arm causes less muscle activity in the anterior deltoid muscle. This can be observed from the lower number of muscle contractions in the sitting position compared to the standing position. Hence, a longer duration in micropauses for the anterior deltoid muscle was obtained from the predominantly sitting position.

The trunk inclination for both the field study and laboratory experiment falls into the neutral category. The trunk flexion in the laboratory experiment shows little variation among all the workstations at 50% of the recording time (p=0.439). The small angle displacement of the trunk from the sagittal (vertical) plane is due to a greater flexion of the head. The twisting of the trunk in the laboratory experiment was not considered to be in the severe region as the experimental task requires little bending motion.

6.3.1 Two way analysis of variance for postural angle measurement

Two way analysis of variance is an extension to the one-way analysis of variance in which two independent variables are used to determine the effect of the dependent variable.

The two way ANOVA was performed for head flexion, trunk flexion, upper arm flexion and abduction for the laboratory experiment according to the posture and type of workstation. This is done to determine the effect of different postures and workstations on the inclination of head, trunk and upper arm. The posture refers to either the sitting or standing positions while the type of workstation refers to the direct or indirect observation workstations. The sideways bending of the head and trunk were not included as little bending motion was involved in the experimental task. In addition, the sideways bending of the head and trunk for all the workstations falls into the mild category as stated by the OSHA guidelines. Table 6.6 shows the results of the two way balanced ANOVA for head flexion. Similarly, Table 6.7, 6.8 and 6.9 shows the results for trunk flexion, upper arm flexion and abduction respectively.

Source	DF	SS	MS	F	P
posture	1	65.3	65.3	2.58	0.117
type	1	15081.6	15081.6	597.03	0.001
posture*type	1	1.7	1.7	0.07	0.795
Error	36	909.4	25.3		
Total	39	16058.0			

Table 6.6 ANOVA for head flexion.

Source	DF	SS	MS	F	P
posture	1	1.600	1.600	0.50	0.485
type	1	0.625	0.625	0.19	0.662
posture*type	1	8.464	8.464	2.64	0.113
Error	36	115.622	3.212		
Total	39	126.311			

Table 6.7 ANOVA for trunk flexion.

Source	DF	SS	MS	F	P
posture	1	225.6	225.6	1.17	0.287
type	1	45.4	45.4	0.23	0.631
posture*type	1	45.4	45.4	0.23	0.631
Error	36	6967.2	193.5		
Total	39	7283.6			

Table 6.8 ANOVA for upper arm flexion.

Source	DF	SS	MS	F	P
posture	1	17.29	17.29	1.03	0.316
type	1	1.19	1.19	0.07	0.791
posture*type	1	17.29	17.29	1.03	0.316
Error	36	602.64	16.74		
Total	39	638.42			

Table 6.9 ANOVA for upper arm abduction.

From Table 6.6, it can be seen that the type of workstation has a significant effect on head flexion (p=0.001). This is parallel with the results which indicated that the indirect observation workstation imposed less bending on the head compared to the direct observation workstation. The bending of the head was not significantly different in the sitting and standing postures (p=0.117). As for the trunk flexion (Table 6.7), the posture and type of workstations do not indicate a significant effect imposed on it (p=0.485 and p=0.662 respectively). This can also be observed from the small variation in the trunk flexion between all the workstations at 50% of the total recording time (p=0.439). From Table 6.8, the posture and the type of workstations do not have any significant influence on the upper arm flexion. Similarly, the upper arm abduction is also not significantly influenced by the posture and type of workstations used (Table 6.9). Hence, from the two way balanced ANOVA results, head flexion is greatly affected by the type of workstations used.

6.4 Productivity assessment

Productivity of workers at a particular workstation plays an important role from a managerial perspective. Hence, quantification of productivity is important in the evaluation of a new workstation such as the indirect observation workstation.

In this experiment, productivity was assessed by the time taken to insert 40 integrated circuits into one PCB. From Figure 4.12, the productivity using the direct observation workstation in the sitting position was shown to surpass the productivities of the other workstations, while the indirect observation workstation in the standing position was found to be the least productive (188.2s vs. 261.5s). The slower pace in productivity for this workstation is primarily due to the two dimensional image projected by the television monitor. Subjects have difficulty in judging the depth perception when inserting the integrated circuits into the PCB. This in turn causes a slower speed performance of the work task.

Overall productivity is also better in the predominantly sitting position as opposed to the standing position (Figure 4.12). This is attributed to the shorter sight distance between the surface of the work area and the subjects. A better view of the work-area enhances the speed of performance (Venda, 1995[b]). From video analysis, the sight distance is closer in the sitting position compared to the standing position. According to Asatekin (1975), sitting also provides better stability to the body especially to the feet and buttock and this increases one's capacity for precision tasks or fine movements. The combination of using the direct and indirect observation workstations enables the dynamic workstation to follow closely behind the direct observation workstation in the sitting position in terms of productivity (188s vs. 208s).

Performing tasks using a remote camera to project the work area onto a television monitor in two dimensions is certainly a new experience for all the subjects. This is another reason for the slower productivity using the indirect observation workstations. However, from the sequential trials analysis shown in Figure 4.13, the productivity using the indirect observation workstation indicated a downward trend. This shows that subjects become more familiar with the indirect observation workstation by performing more trials.

6.4.1 The learning curve

One method of analyzing the number of trials required to become familiar with a new workstation is to use a learning curve. A learning curve is a form of expressing the improvement in productivity as a function of the output (Monks, 1982). This is shown in equation 6.1.

$$T_n = T_1 n^x \tag{6.1}$$

where:

T_n = time to produce *n*th unit
T_1 = time to produce first unit
n = unit number
$x = \dfrac{\text{log of learning (\%)}}{\log 2}$

This equation shows that the time required to produce the *n*th unit of a PCB is exponentially related to the time to produce the first unit.

The learning curve is used to find the number of trials (*n*) required by the other workstations to match the average time of producing a single PCB using the direct observation workstation in the sitting position as this workstation produces the best speed performance (188s). Therefore, the direct observation workstation in the sitting position is taken as a benchmark for the improvement in productivity.

The first step is to determine the log of learning for each workstation. This is done by using equation 6.1 above in which the time for the fifth trial at each workstation was used to determine the log of learning. Table 6.10 shows the log of learning for the different workstations.

	Direct(stand)	Indirect(stand)	Indirect(sit)	Dynamic
Log of learning	85%	91.40%	94.40%	98%

Table 6.10 Log of learning for different workstations.

Using these values, the number of trials required at each workstation to achieve equal productivity as the direct observation workstation can be determined. For example, the time required to produce the first unit of PCB using the direct observation workstation in the standing position is 286.1s whereas the average time to produce one PCB is 188.2s using the direct observation workstation in the sitting position. Hence, from equation 6.1 with log of learning 85%, the number of trials required by the subjects using the direct observation workstation in the standing position to match the efficiency of the direct observation workstation in the sitting position is about 5 trials. Similarly, the learning curves for the other workstations can be analyzed by using the same procedure above. Figure 6.3 shows the learning curves for all the workstations to match the efficiency of the direct observation workstation in the sitting position.

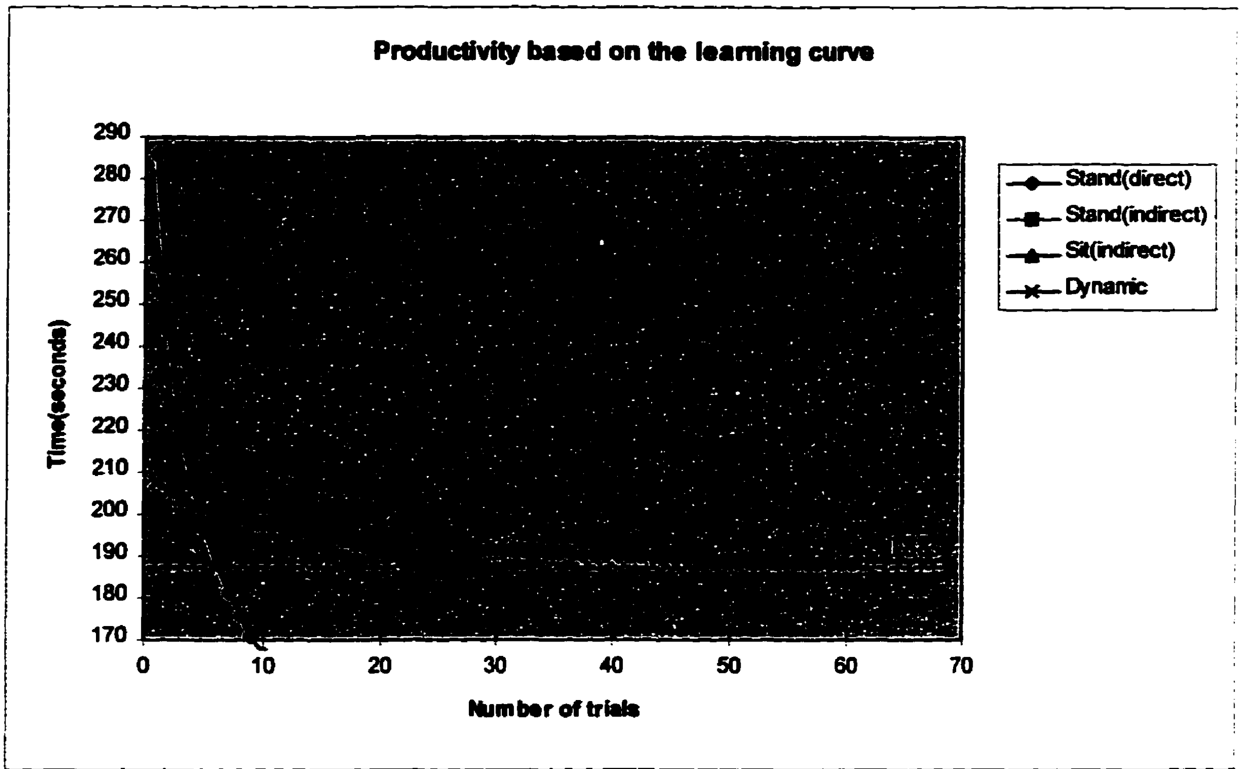


Figure 6.3 Learning curves for different workstations.

From Figure 6.3, approximately 25 trials are required by the subjects using the indirect observation workstation in the standing position to match the efficiency of the direct observation workstation in the sitting position. As for the indirect observation workstation in the sitting position, approximately 25 trials were also required. Using the dynamic workstation, a total of 60 trials were required to match the productivity of the direct observation workstation in the sitting position.

From the analysis of the learning curve, the productivity of the indirect observation workstation can be increased by performing more trials as the subjects will become more familiar with this workstation. Therefore, with proper training and self motivation towards the indirect observation workstations, a better speed performance and quality of work can be achieved.

6.5 Subjective measurement

In addition to the quantitative EMG signals and postural angle measurement, each subject in the laboratory experiment was also required to evaluate the comfort level and usability of each different workstation. Assessment of comfort levels in the upper and lower extremities were evaluated along with ease of assembling and reaching for the integrated circuits using different workstations. Comfort levels were rated on a scale of one to seven. Level one indicates a very uncomfortable condition while level seven indicate a very comfortable condition. Figure 6.4 and 6.5 shows the comfort rating according to body parts for the direct and indirect observation workstations in the standing position. Similarly, Figure 6.6 and 6.7 shows the comfort rating according to body parts for the direct and indirect observation workstations in the sitting position.

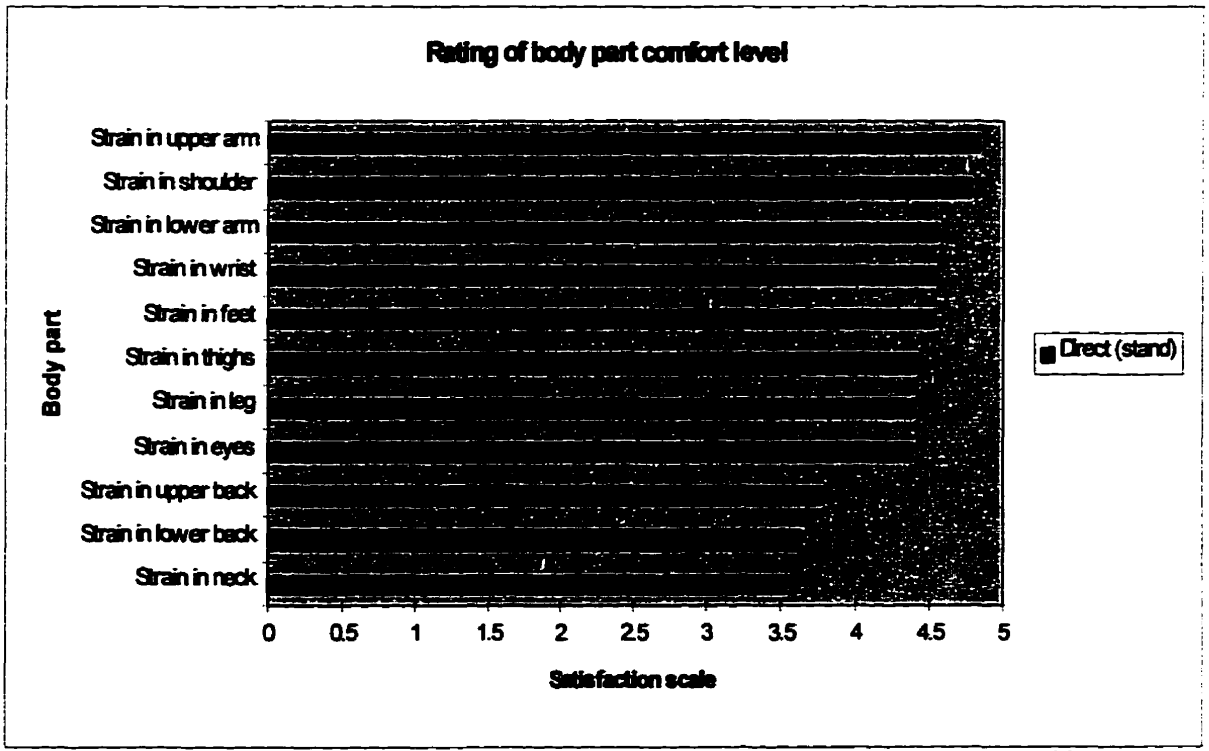


Figure 6.4 Rating of comfort level using direct observation workstation in standing position.

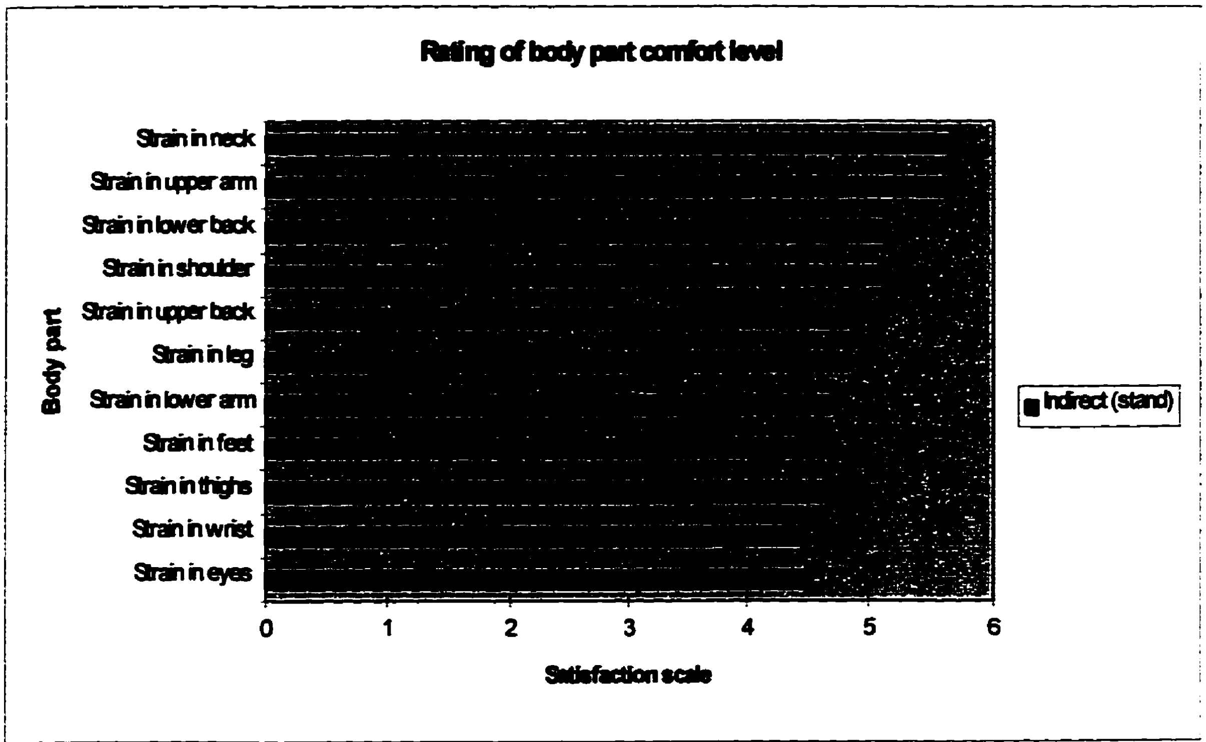


Figure 6.5 Rating of comfort level using indirect observation workstation in standing position.

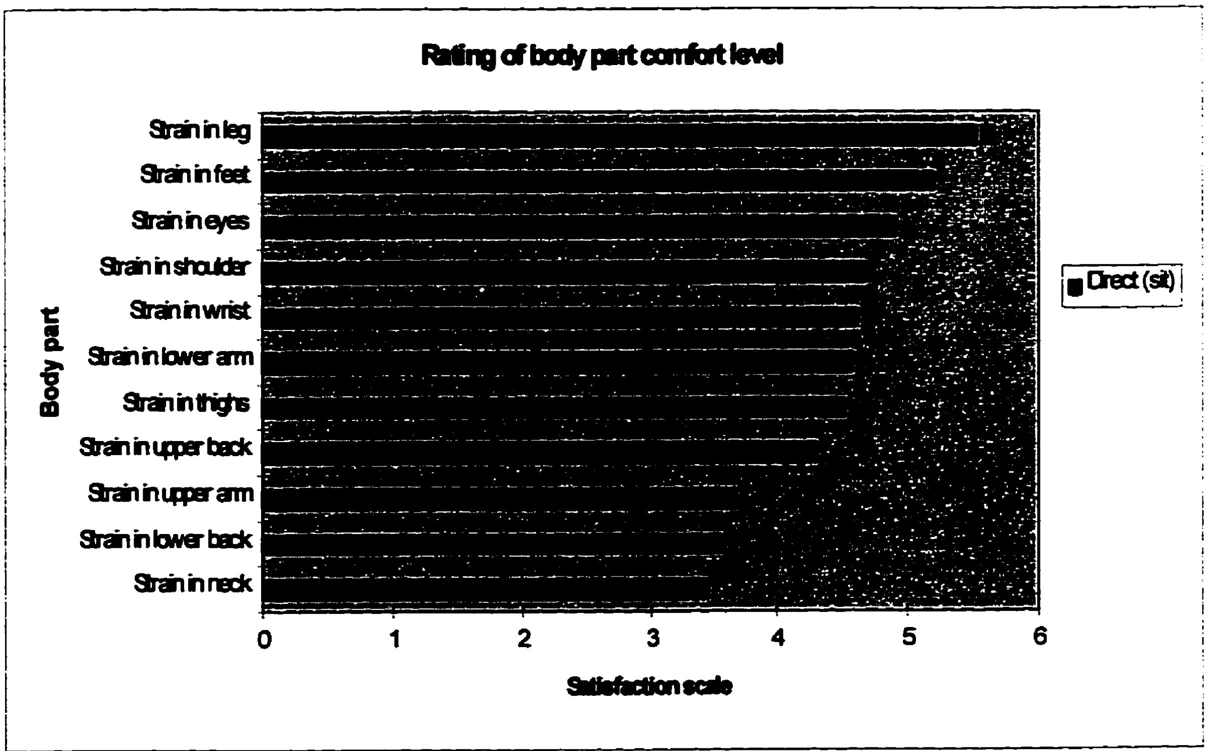


Figure 6.6 Rating of comfort level using direct observation workstation in sitting position.

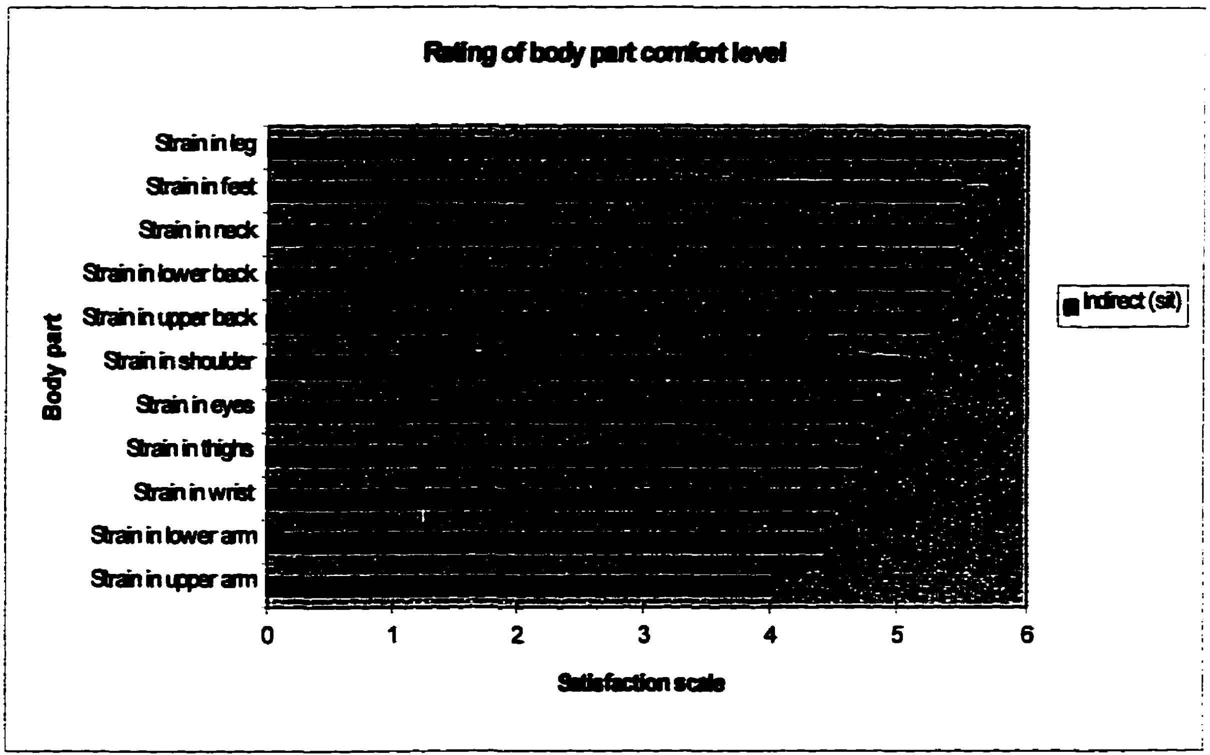


Figure 6.7 Rating of comfort level using indirect observation workstation in sitting position.

From Figure 6.4, the neck, lower back and upper back were rated as being the most uncomfortable body parts when using the direct observation workstation in the standing position. This is mainly due to the bending of the head when performing the experimental task. The most comfortable body part when using the direct observation workstation in the standing position is the upper arm.

On the other hand, the neck was rated as being the most comfortable body part when using the indirect observation workstation in the standing position as shown in Figure 6.5. However, strain in the wrist and eyes causes some discomfort to the subjects when using this workstation.

Similar to the direct observation workstation in the standing position, the neck and back were also evaluated to be the most uncomfortable when using this workstation in the sitting position (Figure 6.6). This is primarily due to the bending of the head which was required in order to have a better view of the work area while inserting the integrated circuits into the printed circuit boards. The body parts which were rated as being the most comfortable for the direct observation workstation are the strain in legs and feet. This is because in the sitting position, the feet carry only 25% of the total body weight whereas the rest of the weight was supported by the buttocks (Jurgens, 1969). Legs and feet were also rated to be most comfortable when using the indirect observation workstation in sitting position (Figure 6.7). However, upper and lower arm were evaluated to be least comfortable compared to other body parts.

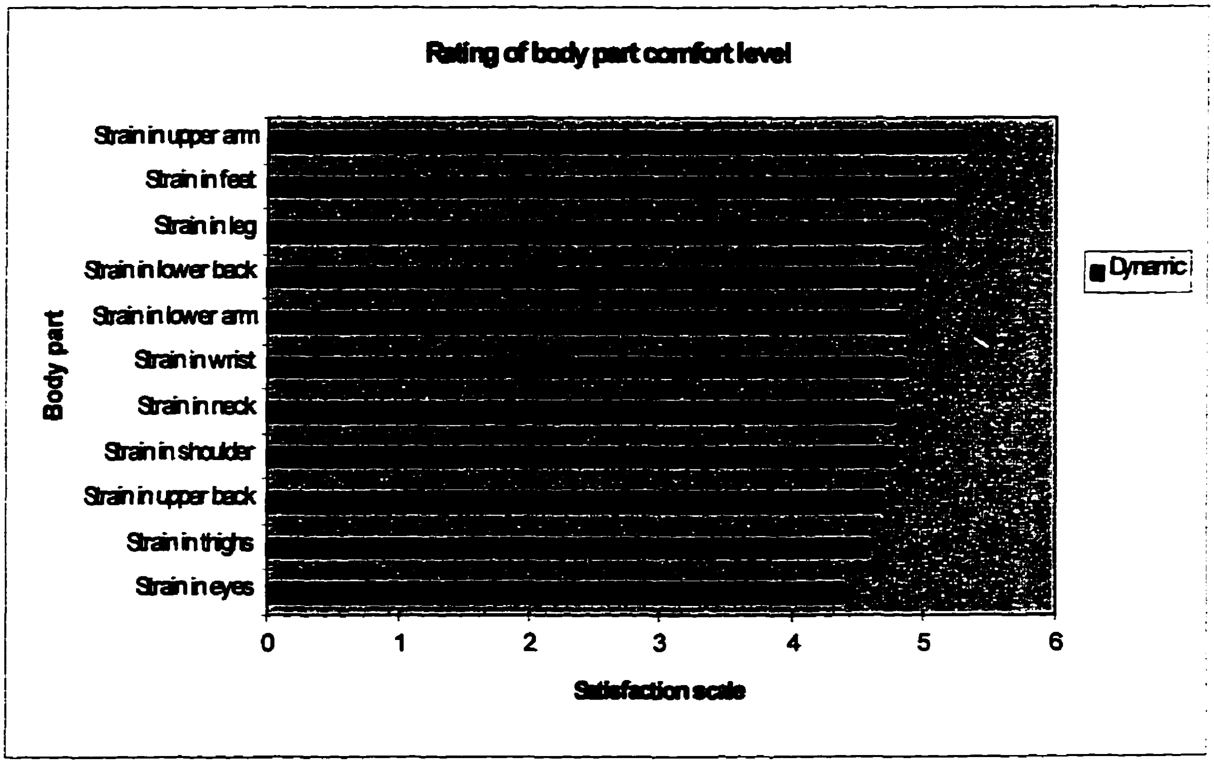


Figure 6.8 Rating of comfort level using dynamic workstation.

The comfort rating for the dynamic workstation is shown in Figure 6.8. In this figure, strain in eyes was rated to be least comfortable when using the dynamic workstation. This is due to the difficulty in focusing the work area by alternating the use of the television monitor and looking down directly at the printed circuit board. Upper arm and feet were assessed to be the most comfortable when using this workstation.

The subjective measurement of comfort level indicated that the direct observation workstation whether in the sitting or standing position, poses a substantial stress level to the neck and back region compared to other body parts. This corresponds to the postural angle measurement which indicated excessive bending of the head when using the direct observation workstation. Strain in eyes is the other major complaint when using the television monitor in the indirect observation workstation. An improvement in the resolution of the video camera and television monitor can certainly reduce eyestrain and headaches to the subjects when using the indirect observation workstation.

Chapter 7
Conclusion

7.1 Summary

The direct and indirect observation workstations were evaluated in this study in terms of static, median and peak loads, micropauses and postural angle displacements of the head, trunk and upper arm. These workstations were also assessed in terms of the sitting and standing postures. In addition, a combination of using the direct and indirect observation workstations in the sitting and standing positions were also evaluated in the laboratory experiment.

The indirect observation workstation, which uses a television monitor to project the image of the work area, is capable of reducing excessive bending of the head up to 80% compared to the direct observation workstation. Less static loading and longer micropauses durations in trapezius muscle were found when subjects performed the task in an upright posture. Reduced static load will evidently lead to less muscular fatigue because a continuous supply of blood flows through the respective groups of muscles, providing energy rich sugar and oxygen contained in it and at the same time removing waste products. Longer micropauses will also assist in the oxygenation of lactic acid back to glycogen to fuel new muscular activity.

Static load on the anterior deltoid muscle was not found in any of the workstations. In addition, the anterior deltoid muscle exhibited a longer duration in micropauses in the predominantly sitting position. This is mainly due to the support provided by the lower arm or elbow.

The null hypothesis of having the same muscle activities in the trapezius and anterior deltoid muscle when performing the same task using the direct and indirect observation workstations should be rejected. A significantly lower number of muscle contractions were recorded for the trapezius muscle when using the indirect observation workstation compared to the direct observation workstation in both the sitting and standing positions (p=0.0001 and p=0.02 respectively). There was also a significant difference in the muscular activities of the anterior deltoid muscle when using the direct and indirect observation workstations (p=0.0001 for the sitting position and p=0.04 for the standing position).

The muscle activities in the trapezius muscle have a profound correlation with the head inclination. From the regression analysis, an increase in the head angle displacement from the vertical position is accompanied by an increase in the number of muscle contractions. Therefore, in addition to stabilize the scapula during arm movements, the trapezius muscle is also indirectly involved in stabilizing the flexion of the head along with other neck muscles. The laboratory study corresponds to the field study performed at the Northern Telecom Plant which also found a reduction in static loading of the trapezius muscle using the indirect observation workstation.

Analysis of static load and micropauses of the trapezius muscle clearly indicates that the standing position is able to elevate a substantial amount of load compared to the predominantly sitting position.

Productivity and quality of the newly developed indirect observation workstation were not as high as the direct observation workstation. This is because subjects were unfamiliar with the two dimensional image projected by the television monitor and hence have difficulty in judging the depth perception. However, through the learning curve analysis, it was found that productivity can be enhanced through training and by performing more tasks at this workstation to increase familiarity.

Subjective evaluation in terms of comfort level and usability indicated that the indirect observation workstation in the sitting position is preferred compared to other workstations. Physiometer PHY-400 that was used to measure the muscle activity in terms of EMG indicated an excellent reproducibility through analysis of variance. Identical experimental data was also obtained for the postural angle measurement using goniometers.

7.2 Conclusion

This research has identified several key advantages of the newly developed indirect observation workstation compared to the direct observation workstation:

1. Static loading in the trapezius muscle was found to be less than the recommended 2 %MVC limit as suggested by leading researchers in the ergonomic field, hence significantly reducing muscle strain and consequently, risk of musculoskeletal injuries in the upper extremity. This was also supported by the data collected from the field study conducted at Northern Telecom Plant.
2. There is less muscle contractions in the trapezius muscle when using the indirect observation workstation in both the sitting and standing positions, as measured by the longer micropause durations.
3. The indirect observation workstation allows workers to be seated or standing in an upright, neutral position thus reduces excessive bending of the head.
4. The indirect observation workstation incorporates the use of a remote camera to enlarge magnification of the work area. This is particularly useful for jobs which require workers to insert small-sized integrated circuits into PCBs.

5. The use of an indirect observation workstation provides workers with an option to work in an upright posture when neck and shoulder pain become intolerable due to excessive bending of the head when using the traditional workstation.
6. The indirect observation workstation allows those workers who already suffer from neck and back injuries and who cannot work at the traditional workstation to return back to work.

Although the standing posture is found to reduce static loading and extend the duration of micropauses in the trapezius muscle compared to the sitting posture, it would not have a practical implication in industries. Standing straight for an eight hour shift would certainly be detrimental to the lower extremities particularly to the feet, knee and thighs. Hence, a combination of sitting and standing is recommended with emphasis of using the indirect observation workstation particularly if the tasks involve repetitive motions. Although an increase in static loading of the trapezius muscle using the sitting posture is inevitable, it can be compensated by the reduction of physical stress in the lower extremities. Alternating between the sitting and standing postures would also prevent the workers from being locked in a single position in front of the workstation.

7.3 Recommendations and future work

Based on these conclusion, further analysis regarding the proportion of time spent in sitting and standing using the indirect observation workstation is required in order to optimize the muscle activities in the upper extremities as well as to determine the stress placed on the ligaments and skeletal system in the lower extremity. EMG analysis of the lower extremities would be beneficial particularly to determine the type of standing work posture which can be sustained for a long period of time without any detrimental effect. In addition, analysis of other shoulder and neck muscles which are highly involved in movements of the head and shoulder should be investigated to further the understanding of musculoskeletal injuries in the upper extremity.

An adjustable-height table is also recommended which will allow workers to adjust table heights to work at the most comfortable position for a relaxed shoulder position as much as possible. This would also allow workers to change positions between sitting and standing positions while maintaining a comfortable table height.

Depth perception is important to speed of assembly as well as to quality of production. However, using the indirect observation workstation, the depth perception is lost as the work area is projected in a two dimensional image. Further studies should be conducted to determine the effect of new geometrical work piece positions (for example, tilting the angle of the PCB) and tasking techniques on enhancing the productivity.

Another area of future research is to investigate the use of mirrors as a replacement for the television monitor and video camera. Mirrors can be positioned to allow workers to indirectly view the work area similar to the indirect observation workstation.

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APPENDIX

Reproducibility test

One way analysis of variance for muscle contraction (shifts/min) within subjects

Subject 3

Stand(direct)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	477	119	0.81	0.531
ERROR	30	4440	148		
TOTAL	34	4917			

Stand(indirect)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	78.9	19.7	0.76	0.558
ERROR	30	776.5	25.9		
TOTAL	34	855.4			

Sit(direct)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	1642	411	1.01	0.418
ERROR	30	12208	407		
TOTAL	34	13850			

Sit(indirect)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	722	180	0.61	0.659
ERROR	30	8884	296		
TOTAL	34	9606			

Analysis of variance for cumulative amplitude distribution function within subjects

Subject 5

Stand(direct)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	140.6	35.1	0.38	0.823
ERROR	30	2790.1	93.0		
TOTAL	34	2930.6			

Stand(indirect)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	54.4	13.6	0.81	0.531
ERROR	30	505.9	16.9		
TOTAL	34	560.2			

Sit(direct)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	3017	754	1.17	0.345
ERROR	30	19393	646		
TOTAL	34	22410			

Sit(indirect)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	2905	726	2.06	0.111
ERROR	30	10565	352		
TOTAL	34	13470			

Analysis of variance for muscle contractions (shifts/min) between subjects

Stand(direct)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	383.8	96.0	1.01	0.418
ERROR	30	2850.4	95.0		
TOTAL	34	3234.2			

Stand(indirect)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	18.95	4.74	0.63	0.647
ERROR	30	226.48	7.55		
TOTAL	34	245.44			

Sit(direct)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	1036	259	0.55	0.700
ERROR	30	14098	470		
TOTAL	34	15134			

Sit(indirect)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	761	190	0.83	0.517
ERROR	30	6876	229		
TOTAL	34	7637			

Dynamic

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	2286	572	1.48	0.234
ERROR	30	11619	387		
TOTAL	34	13906			

Analysis of variance for cumulative amplitude distribution function between subjects

Stand(direct)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	50.1	12.5	0.93	0.459
ERROR	30	403.9	13.5		
TOTAL	34	454.0			

Stand(indirect)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	0.671	0.168	0.21	0.932
ERROR	30	24.214	0.807		
TOTAL	34	24.886			

Sit(direct)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	762	190	0.54	0.710
ERROR	30	10639	355		
TOTAL	34	11401			

Sit(indirect)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	250.7	62.7	1.04	0.402
ERROR	30	1802.9	60.1		
TOTAL	34	2053.6			

Dynamic

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	218.7	54.7	1.56	0.210
ERROR	30	1050.0	35.0		
TOTAL	34	1268.7			

One way analysis of variance for head-flexion

Stand(direct)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	299.2	74.8	1.55	0.226
ERROR	20	965.5	48.3		
TOTAL	24	1264.7			

Stand(indirect)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	699	175	1.07	0.397
ERROR	20	3265	163		
TOTAL	24	3963			

Sit(direct)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	258.6	64.7	2.13	0.114
ERROR	20	606.1	30.3		
TOTAL	24	864.7			

Sit(indirect)

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	4	204.0	51.0	4.52	0.009
ERROR	20	225.4	11.3		
TOTAL	24	429.4			

Regression analysis

Summary of regression analysis for head inclination vs. muscle contractions (trapezius muscle)

The regression equation is
shift = 27.7 + 1.20 angl

Predictor	Coef	Stdev	t-ratio	p
Constant	27.727	7.520	3.69	0.000
angl	1.1958	0.2782	4.30	0.000

s = 32.11   R-sq = 22.1%   R-sq(adj) = 20.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	19038	19038	18.47	0.000
Error	65	66998	1031		
Total	66	86036			