THE UNIVERSITY OF MANITOBA

A PRELIMINARY ERGONOMIC ASSESSMENT OF FOUR GEOMETRICS OF WORKSTATIONS FOR PRINTED CIRCUIT BOARD ASSEMBLY

BY

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A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTERS OF SCIENCES

DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING

WINNIPEG, MANITOBA

JUNE 1996

0-612-23360-X

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

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ABSTRACT

Severe disorders of the upper extremities during printed circuit board (PCB) assembly work may be due to the repeated flexion of neck associated with elevated shoulders (Kilbom et al, 1985). This hypothesis is tested by a new method of PCB assembly designated as the Indirect vision method (IV). This method involves watching a magnified image of the PCB on a TV monitor during assembly which will permit the spine to maintain a more upright posture. The purpose of this study was to evaluate and compare the IV workstation with the existing PCB assembly workstation which employs the Direct Vision of PCB (DV). Twelve healthy male and female subjects of the Northern Telecom plant participated in this study. During assembly operation, subjects were timed in terms of "time per PCB". Further, the muscular activity of the right and the left trapezius muscle along with the anterior and posterior flexion and lateral flexion of the spine were recorded during PCB assembly. Finally, subjective testing was performed using primary and secondary questionnaires.

The statistical analysis of the data revealed that the productivity was lower on the IV method as compared to the DV method. Activity of the trapezius muscle in terms of percent maximum voluntery contraction (MVC) was lower on the IV method. The movements of the cervical and thoracic spine were lower on the IV method of assembly. The subjective measurement showed a higher level of satisfaction on the DV method however the level of comfort was higher on the IV method.

The following reasons restrict the use of current arrangmement of the IV method.

1. The productivity level was lower. Even after a training period of 500 days the subjects were not able to achieve productivity level of the DV method.
2. The lower muscular activity and movements of the spine may lead to static muscle loading and finally fatigue.
3. The correlation between productivity, physiological and subjective measurements was not significant as it was below 0.5.

The signigicance of present results can further be evaluated by conducting a few more studies by using a larger group of subjects.

ACKNOWLEDGMENT

The research described in this thesis was carried out as a join project between the University of Manitoba, Department of Mechanical and Industrial Engineering and Northern Telecom Canada Ltd. The main objective of this project was to design and experimentally assess a proposed new type of PC board assembly workstation. Financial assistance was obtained from Northern Telecom and NSERC.

I would like to express my gratitude to my thesis advisor, Professor A. B. Thornton-Trump, for his assistance, guidance and encouragement during the course of this thesis.

I would also like to thank Prof. V. Venda and the Northern Telecom for their support in conducting the experiments in their Wireless Systems plant in Calgary and also for providing the partial funding of this research. A special thanks is extended to the Department of Mechanical and Industrial Engineering for helping me out in difficult times by providing access to ergonomics laboratory and partially funding my research.

Finally, I would like to thank DR. Strong and Dr. S. Marinov for helping me to finish this project.

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NOMENCLATURE

APDF	= Amplitude Probability Distribution
BPF	= Band Pass Filter
B.Flex	= Back Flexion
B.Lat.	= Back Lateral Flexion
Cms	= Centimeters
Confi. In.	= Confidence interval
COMF	= Comfort
CTD	= Cumulative Trauma Disorders
DAU	= Data Accuation Unit
Distr. Parmtrs	= Distribution Parameters
DV	= Direct vision
EMG	= Electromyography
FM	= Frequency Modulated
H. Flex	= Head flexion
H. Lat.	= Head Laternal Flexion
Hz	= Hertz
IV	= Indirect vision
IVD	= Intervertebral Disc
Kurt	= Kurtosis
L. Trap	= Left Trapezius
N	= Number of PCBs assembled
NS	= Not significant
MAP	= Muscle fiber action potential
MAUPT	= Motor unit action potential Train
Max.	= Maximum
Min.	= Minimum
MSD	= Musculsokeletal Disorders
MUAP	= Motor unit Action Potential

MVC	= Maximum Voluntary Contraction
PC	= Personal Monitor
PCB or PC board	= Printed Circuit Board
PHY	= Physiometer
Prod.	= Productivity
r	= Pearson's coefficient of correlation
R. Trap	= Right Trapezius
RMS	= Root mean square Value
RSI	= Repetitive Strain Injuries
S	= Significant
SAT	= Satisfaction
SD	= Standard deviation
Sec.	= Seconds
$\sum T$	= Total assembly time in seconds
TQM	= Total quality management
TRAP	= Trapezius
VC	= Vertebral Column
VDT	= Video Display Terminal
WS	= Workstation

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CHAPTER ONE

INTRODUCTION

1.1 MUSCULOSKELETAL DISORDERS AND THEIR IMPACT

Musculoskeletal disorders (MSD) are being recognized as the leading cause of significant human suffering, loss of productivity and economic loss to society. In today's modern industrial world, many occupations such as, assembly work in electronic industries may result in musculoskeletal disorders of the upper extremities. These jobs involve long-lasting static and repetitive loads to the neck and shoulder region of the body. Musculoskeletal disorders can produce a high rate of injuries, absenteeism and, in some cases, early retirement (Westgaard and Aaras 1984). The higher rate of injuries can be justified from the fact that is year 1992 there was a time loss of 3,678 workhours due to upper and lower extremity injuries (Statistics Canada 1995).

Musculoskeletal disorders can further lead to repetitive strain injuries (RSI) or cumulative trauma disorder (CTD). The prevalence of these disorders can be judged from the fact that they range from office work to industrial work (Carter 1994, Keyserling 1993, Greco 1986, and Starr 1982). The incidence of musculoskeletal disorder is growing at a very rapid rate, as from 1987 to 1989 there was a 100% increase in the rate of cumulative trauma disorder (Carolyn 1993). Musculoskeletal disorders are very common in neck, shoulder and lower back regions of the human body (Carolyn 1993, Kumar 1993 and Jensen 1988). According to the Statistics Canada report (1995), between 1983 and 1989, the number of injuries rose every year, at an annual average rate of 4.7% and since then declined at an average rate of 9.1% a year.

1.2 EXISTING PROBLEM

The rate of musculoskeletal disorder is significantly high in electronic industries where manual assembly operations are involved (Carolyn 1993, Westgarrd 1984, and Kilbom 1985). The economic impact of these disorders can be realized from the fact that Northern Telelcom alone faces a cost of 1.2 million dollars every year for cumulative trauma disorder related injuries in their assembly line workers. The major cause of these disorders in electronic assembly may be due to prolonged sitting accompanied by the repetitive flexion and extension of the cervical spine. The flexion of the cervical spine during work is proposed as the major cause of the cèrvicobrachial disorders (Schuldt 1986, Kilbom 1985, Westgarrd 1984, Kvarnstrom 1983 and Hunting 1980). The hypothesis that flexion of the cervical spine during work can lead to muscle fatigue may be confirmed by the biomechanics model developed by Kumar and Scaife (cited in Chaffin 1987) and Moroney (1988). The analysis of the subjective report of workers by Genaidy 1993 and Kumar 1979 also indicates that the cervical spine flexion can be one of the major cause for the discomfort in the neck region.

Prolonged sitting can lead to a higher risk of occupational injuries due to static muscle loading (Schuldt 1986, Grieco 1986, Harms-Ringdahl 1986). Prolonged sitting may lead to postural fixity even at a low level of muscular contraction and may result in ischaemia (Armstrong 1993 and Kahn 1989). Another theory states that the fatigue during prolonged sitting even at low levels of contraction, may be due to the decrease in the level of potassium ion concentration in the arteries and veins (Saogaard 1988). One of the theories suggests that during low level contractions (low force and repetitive muscular movements) the waste products can accumulate in the muscles and results in muscle fatigue (Khan 1989) therefore, variation in muscle activity is important to reduce the harmful effect of by-products (Kilbom 1987).

The prolonged sitting posture can be avoided by adopting a standing posture (Carter 1994) but, it has some disadvantages (Chaffin 1990 and Bendix 1987). During electronic assembly work mostly anterior sitting posture (forward bending) is adopted in order to have a proper view of the work area (Chaffin 1987 and Kilbom 1985). Hence, it is suggested to relieve prolonged forward bending of the spine during work by periodic pauses (Colombini 1985).

The purpose of this research is to design, develop and test a trauma free assembly workstation. In order to avoid forward bending of the spine a new type of printed circuit board (PCB) assembly workstation has been designed and developed in the ergonomics laboratory of the University of Manitoba. This workstation was further tested in the industrial environment of Northern Telecom (Wireless) Calgary plant in terms of physiological, objective and subjective measurements and productivity.

CHAPTER TWO

LITERATURE REVIEW

2.1 DEFINITION OF CUMULATIVE TRAUMA DISORDER (CTD)

Musculoskeletal disorders are often named by different terms, the most common being 'cumulative trauma disorders' (CTD) and 'repetitive strain injuries' (RSI). A useful definition of CTDs can be constructed by combining the separate meanings for each word. 'Cumulative' indicates injuries which may develop gradually over period of days, weeks, months or even years due to repetitive stress on a particular body part. (This theory is based on the concept that each repetition of an activity produces some micro trauma or wear and tear on the tissues and joints of the body). Kilbom (1994) defined repetitive work of the upper extremity as the performance of similar work cycles, again and again. The term 'trauma' signifies bodily injury from mechanical stresses and the term 'disorder' refers to physical misalignments or abnormal condition " (Radin, 1976).

2.1.1 PREVALENCE OF CTD

The automation of many workplaces has resulted in fixed work posture associated with repetitive work. As defined above the repetition of work may result in CTD. Thus, the automation of workplaces and introduction of computers in industrial society can lead to musculoskeletal complaints. These disorders are becoming very common in all kinds of workplaces, from office environment where use of video display terminals (VDTs) is mandatory, to industries suchas, meat-cutting, catering, assembling, sewing, cleaning etc. (Carter and Banister, 1994, Keyserling et al, 1993 and Grieco, 1986). For example, Keyserling et al (1993) conducted a two page checklist survey in four different manufacturing work sites and concluded that in most of the jobs workers were significantly exposed to upper-extremity risk factors (approximately 81% of the jobs were highly repetitive).

2.1.2 OCCURRENCE OF CTDs

The rising pattern of CTDs is evident from the fact that during the period of 1987 to 1989 there was a 100% increase in CTD cases (Sommerich et al, 1993) and within Canada during the year 1989 there were 620,979 work related injuries (Statistics Canada 1995). Praemer et al (1992), also reported that CTD in the U.S., has significantly increased its frequency, and in the year 1988 accounted for 48% of all occupational illnesses. Musculoskeletal disorders have tremendous impact on the work force during their most productive years of life, between 18 to 64 compared to any other category of disorder (Putz-Anderson, 1988).

The major portion of these injuries consists of lower back (28%), neck and shoulder pain complaints and all other disorders in wrists, hands, and fingers are second to Statistics Canada (1995) report showed that during the year 1994 there were 11,329, 20,224, 12,3566 and 25,820 neck, arm, back and shoulder related injuries. In clinical frequency shoulder pain ranks second to back and neck pain (Sommerich et al, 1993). Other studies such as Jensen et al, in 1988 found that in the United States overexertion has been claimed as the main cause of lower back pain by over 60% of patients. Rowe (1969), Magora (1970), Stubbs et. al. (1983), and Kumar (1990) (cited in Kumar, 1993) also conclude that back pain injuries represent the main body of musculoskeletal disorders. Occupational Safety and Health Association (OSHA) suggested that if the current trend of these disorders were to continue, then, by year 2000, CTDs will account for fifty percent of all compensation (Hadler, 1990). This speculation is supported by the fact that in a large Swedish electronic plant half of all long-term sick leaves were due to musculoskeletal disorders (Sommerich et al, 1993). According to Statistics Canada (1995) report there were 54,041 fabrication, assembling and repairing work related injuries in 1994.

Economic impact of CTDs is apparent from the fact that in 1987 over 20,000 Ontario workers received compensation of $2500 or more for each CTD and the total work loss was equivalent to 600,000 work-days (Renzo and Andrew, 1990). The importance of CTDs may be established by the fact that these disorders have been included in the list of the ten leading causes of musculoskeletal disorders by the US National Institute of Occupational Safety and Health (NIOSH)(Sommerich et al, 1993). For the same reason in 1988 NIOSH has issued a technical report that recommended the use of ergonomic principles in the design of work stations, tools, and work methods to reduce CTD (Putz-Anderson, 1988). This review establishes the fact that CTDs play a major role in the loss of productivity and quality, and effects the economic viability of a product.

2.2 MAJOR CAUSES OF CTDs

2.2.1 PROLONGED SITTING

One major cause of musculoskeletal disorders can be prolonged sitting. Repetitive jobs associated with awkward posture and insufficient recovery time may lead to an increase in the static muscle loading of back, neck and shoulder muscles which may lead to CTDs (Keyserling, 1993, Schuldt et al, 1986 and Renzo and Andrew, 1990). Most of the authors in the literature hypothesized that individuals working in a prolonged sitting posture are at a significant risk of occupational injuries(Grieco, 1986, Harms-Ringdahl et al, 1986). In order to avoid prolonged fixed sitting posture, some authors have suggested that a standing posture has advantages over sitting posture (Carter and Banister, 1994). Chaffin and Andersson (1991) described that during standing work posture the spinal tissues are least stressed and the vertebral column is normally straight in the anterior plane and curved in the sagittal plane producing a compound curvature referred to as cervical lordotic, thoracic kyphosis and lumber lordosis curve. Normal lordotic curvature of the spine maintains a low pressure in the intervertebral discs (Andersson, 1974). According to Bendix (1987) standing posture has some disadvantages such as swelling of the legs and more energy expenditure which may cause fatigue as the whole of the body weight is on the legs. Whereas, on the other hand sitting posture is defined as a body position in which the weight of the body is transferred to a supporting area mainly consisting of the ischial tuberosities of the pelvis and their surrounding soft tissues (Schoberth, 1962 cited in Chaffin and Andersson, 1991). Compared with standing, sitting posture has some advantages such as:

a) sitting provides stability for the tasks which require more fine visual and motor skills, like assembling, typing work etc. (Chaffin and Andersson, 1991 and Bendix, 1987) ;

b) less stress and lower hydrostatic pressure on the lower extremity joints ; and,

c) less energy consuming than standing ;

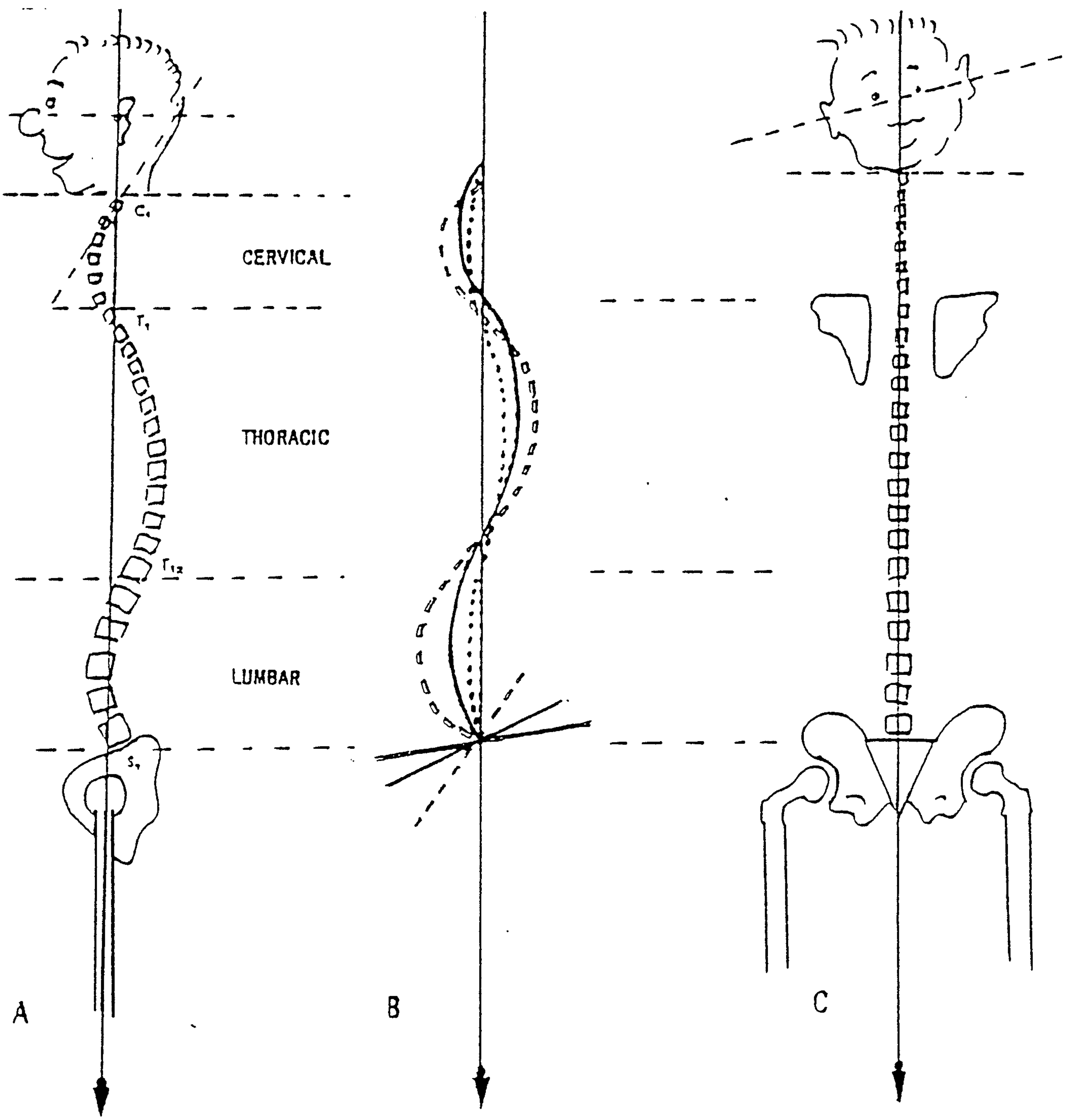


Figure 2.1 -
Static spine (a) Lateral view of erect posture (b) Change of superincumbent curves influenced by change of sacral angle (c) Anterior - Posterior plumb line view.

When considering the biomechanical aspects of sitting during office work, the spine is particularly important. Hence, it is necessary to understand the anatomy of the spine in order to understand the problems associated with musculoskeletal disorders. A brief description of the anatomy of spine is mentioned in Appendix 2.1 and is shown in Figure 2.1.

COMMON CAUSES OF PAIN IN THE SPINE

1. Degeneration of intervertebral disc:

A reduction in the thickness and a increase in the diameter of the disc reduces the available space for the nerve which passes from spinal chord to peripheral tissues. The change in dimensions of the disc compresses the nerve and causes pain. Disc degeneration is related to several factors, such as lack of nutrition, low blood flow and accumulation of the waste products due to static muscle loading (Carter and Banister, 1994).

2. Disc Herniation (slipping of disc):

Disc Herniation is caused when the disc protrudes posteriorly (backwards) from its normal position between the vertebral bodies and impinges on the spinal chord. Disc herniation may be caused by trunk flexion in the sitting position. The flexion of the trunk forces the vertebral bodies closer together on their anterior (front) surface, thus forcing them in the posterior direction. Disc herniation is related to weakness in the annulus or the posterior longitudinal ligaments. Another name for disc herniation is disc prolapse.

Neck and shoulder regions are at greater relative risk of musculoskeletal disorders than any other body region (Sauter and Schleifer, 1991). Therefore, the cervical spine is the portion of the vertebral column which is involved in musculoskeletal disorders of upper extremities (Sauter, Schleirer, 1991 and Schuldt et al, 1987). For example, Mandal in 1985, stated that office workers today have more complaints from the neck and shoulder than from the lumbar region, as in sitting work lumbar support only carries about 5% of the body weight. Almost all the neck disorders are associated with the cervical spine (Appendix 2.1) hence, a short description of the function of the cervical spine is important to understand.

FUNCTION OF CERVICAL SPINE

The following are the functions of the cervical spine.

1. The cervical spine provides musculoskeletal stability and support for the cranium, and a flexible and protective column for movement, balance adaptation and housing of the spinal cord and vertebral artery.
2. The posterior neck muscles constantly provide force to hold the head erect.
3. Neck muscles, especially masticatory, suprahyoid and infrahyoid groups act as a joint chain to join the anterior cranium to the shoulder girdle.
4. The Cervical spine provides support for the weight of the cranium.
5. Flexion, extension, lateral flexion, and circumduction are the basic movements of the cervical region.

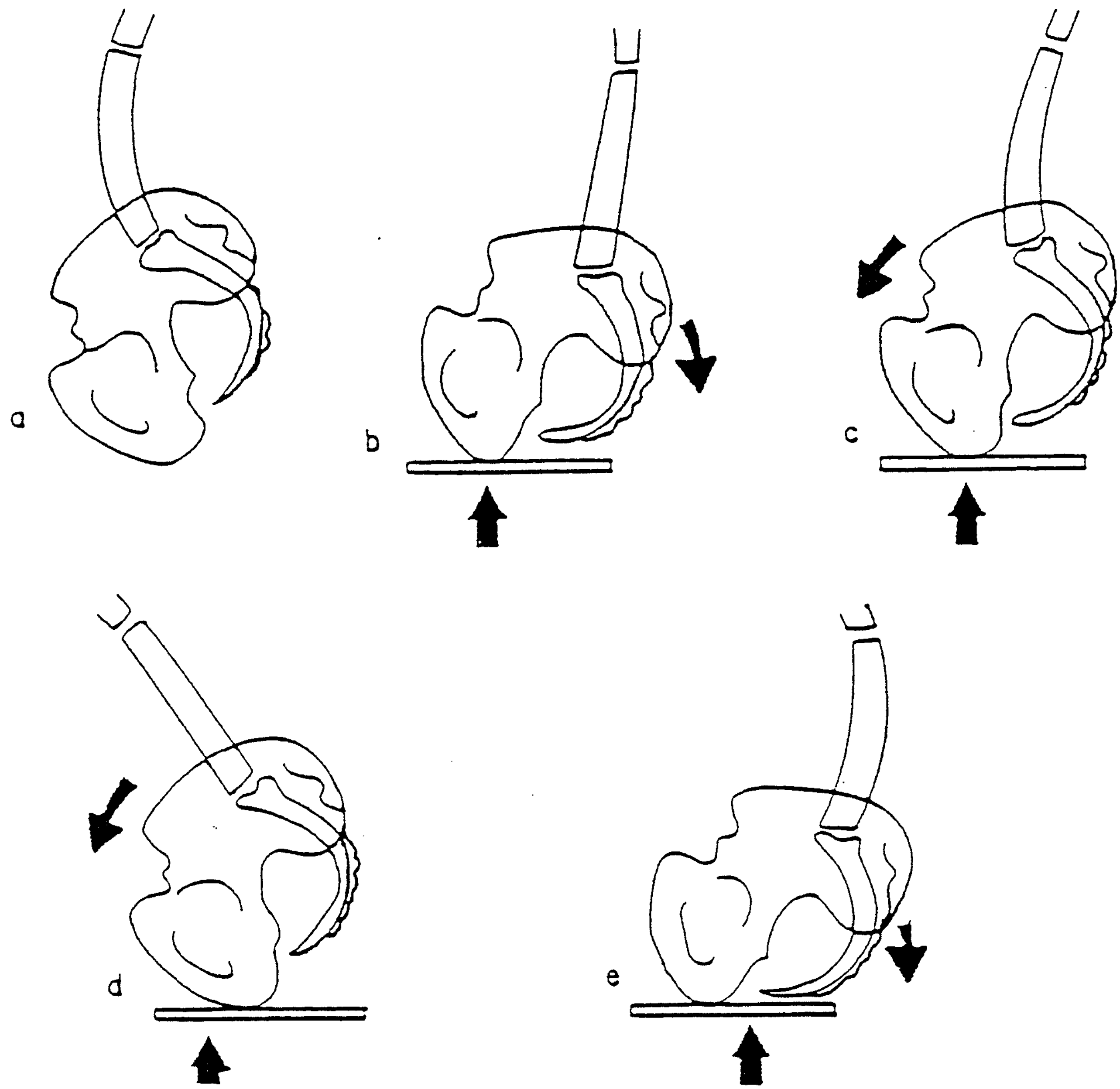


Figure 2.2 -
The pelvis and lumber part fo the spine when (a) standing (b) sitting relaxed unsupported in the middle position (c) sitting in the erect posture (d) sitting in the anterior posture (e) sitting in the posterior posture (source: Chaffin and Andersson , 1991)

2.2.2 NECK OR CERVICAL FLEXION

Prolonged sitting associated with neck flexion is the most common cause of musculoskeletal disorders. The neck and shoulder girdle are at a greater risk of injuries than any other body region for musculoskeletal discomforts (Evans, 1987, Hagberg and Wegman, 1987 cited in Sauter and Schleifer 1991). Improper design of the workstations associated with prolonged sitting leads to an awkward posture of the cervical and the lumbar portion of the spine (Chaffin and Andersson, 1991). Sitting can be divided into anterior, middle, and posterior postures depending upon the task (Figure 2.2). Generally, in all electronic assembly and inspection work the anterior sitting posture is preferred by the workers in order to have proper vision of the work area (Kilbom et, al, 1985) . The anterior (forward bending) posture can be achieved either by forward rotation of the pelvis with slight kyphosis of spine, or by little rotation of the pelvis, but with large kyphosis. The center of mass in this posture is in front of the ischial tuberosities and the floor supports more than 25% of the body weight through the legs (Chaffin and Andersson, 1991). This forward bending also influences the cervical spine as the field of vision needed to perform certain tasks may require the head to be in certain positions. In a study by Harms-Ringdahl et al, 1986, it has been suggested that sustained join load in an extreme position of the cervical spine has been the major cause of pain in shoulder and neck regions. Also, studies like Kvarnstrom (1983) and Westgaard and Aaras (1984) indicated that manufacturing work in the electronic industry is associated with a large prevalence of cervicobrachial disorders. The cervicobrachial disorders during assembly work can be associated with flexion of the neck. This fact is evident from the study of Kilbom et al, (1985), who in a electronic assembly manufacturing work found the frequency of mean flexion and extension of upper arm and forward flexion of neck (>20 degrees) per hour was 1400 and 728 movements respectively. The same study also anticipated that the severe disorders in upper extremities were due to forward flexion of neck and elevation of shoulders during assembly operations. Other studies, such as Ferguson (1976), and Hunting et al, (1980) indicated that flexion of the cervical spine in sitting work posture may be the main cause for neck pain complaints. Hagberg (1984 cited in Schuldt 1986) concluded that sustained tension in the neck and shoulder muscles has been considered a possible factor in the development of pain in upper extremities. A study by Colombini et al (1985) suggested that prolonged involvement of the cervical spine in forward bending of the head should be avoided by periodic pauses during which the neck is actively mobilized and should be relaxed on a proper head rest. The biomechanics model of neck flexion by Kumar and Scaife (cited in Chaffin and Andersson, 1991) described that the magnitude of the movements at cervical region and lumbar region are dependent on the flexion angle of the neck and the lumber. These movements are described as the muscle force or muscle contraction needed for holding the body in a state of equilibrium. For example, for even 30 degrees of inclination angle from vertical the muscle force requires to counter balance bending is more than 50% of the value achieved at 90 degrees (vertical). This fact is evident from Figure 2.3 which shows the predicted proportion of neck muscle force required to support the head at varied inclination angles (Chaffin and Andersson, 1991). Further, the relationship between neck flexion and muscle fatigue can be confirmed from the biomechanics model developed by Moroney et al, (1988 cited in Chaffin and Andersson, 1991).

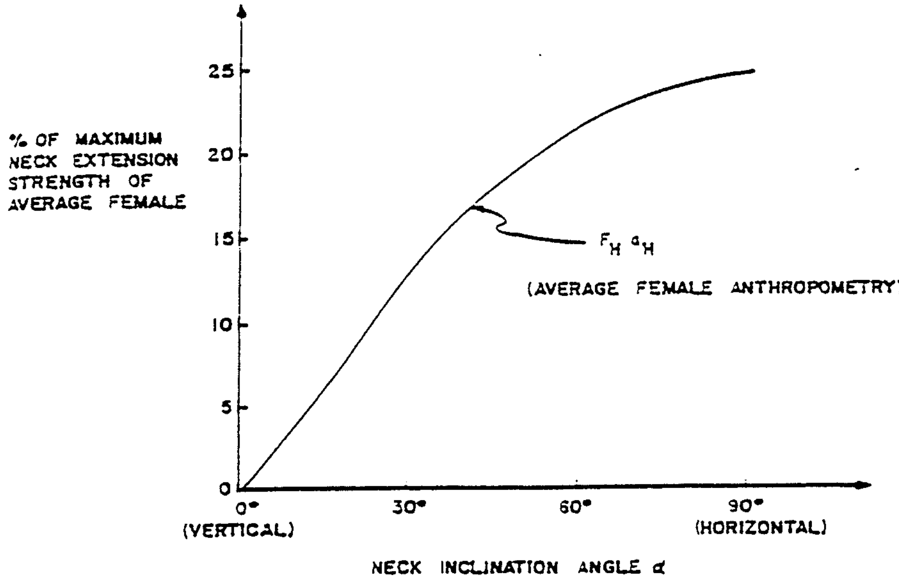


Figure 2.3 a -
Predicted proportion of neck strength required to support the head at varied inclination angles (for average women). (source: Chaffin and Andersson , 1991)

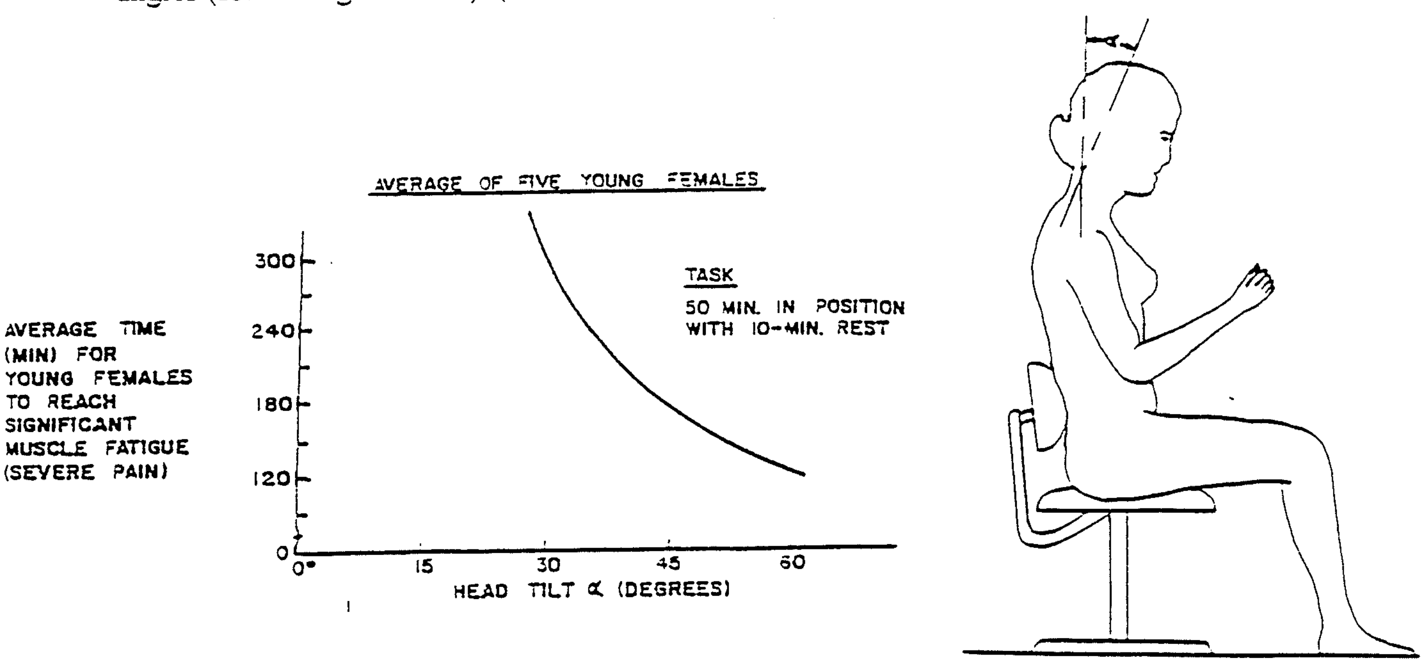


Figure 2.3b -
Neck extensor fatigue v/s head tilt angle. Head tilt is perpotional to the fatigue

Recently, a study by Harms-Ringdahl et al, (1986) conducted to assess eight different sitting work postures for assembly of printed circuit boards indicated that working in a posture with normal lordosis and the cervical spine in a straight position is the best working posture. The results of this study also shows that pain sensation from the cervical spine can be provoked when the neck was kept in an extreme flexed position which caused flexion in C7-T1(Harms-Ringdahl and Ekholm, 1986b). It was observed that the position of the cervical and atlanto occipital joint in different sitting postures was dominated by their flexion movements. The same study also concludes that the level of muscular activity in such a flexion positions is low. However, this low activity might be due to the fact that all the load is taken by the connective tissues and ligaments. Finally, excessive flexion of the cervical spine can lead to work related cervical spine disorders.

Kumar and Scaife (1979) analyzed the subjective reports on neck discomfort and found that these discomforts were related to the inclination of the neck. Another study by Genaidy and Karwowski (1993) based on subjective ratings indicated that pain due to neck flexion in sitting as well as in standing posture is third most common factor relative to the lateral bending, rotation and extension of the neck. A study was conducted using EMG (electromyography) measurements by Schuldt et al, (1986) in order to analyze the effect of different sitting postures on neck and shoulder activity and showed that the flexion of the whole spine leads to a higher level of static activity in the neck and shoulder muscles. Aaras and Westgaard (1987), also stated that there is a high linear correlation between the magnitude of low level static activity and the frequency of neck and shoulder disorders. In a study using EMG frequency shifts and subjective ratings (Chaffin, 1973) it was found that the average time to reach significant muscle fatigue in female workers was reduced with the increase in head tilt.

A controversial statement in a paper by Aaras (1987) stated that head and neck flexion seemed to have less influence on the load on the main trapezius muscle and on the development of musculoskeletal sick leaves related to time of employment when compared with flexion in the shoulder joint. The above statement is in agreement with the studies by Harms-Ringdahl (1985 cited in Aaras, 1987) showing that the flexion in the shoulder joint has much higher influence on the load on the main trapezius muscle than did head flexion.

The pain in the neck and shoulder region is a common cause of disability (Juntura et al, 1988), it is essential to assess the fatigue in concerned muscles such as trapezius and sternomastoid. Generally, the upper descending part of trapezius muscle is selected for the assessment of shoulder-neck complaints (Westgaard et al, 1993, Hansson et al, 1992, Westgaard, 1988 and Harms-Ringdahl et al, 1986). The trapezius muscle was found to be active during elevation or retraction of the shoulder and during flexion or abduction of the upper extremity (Basmajian and De Luca, 1985 and Hagberg, 1981). In order to assess the muscular activities electromyography is widely used. A brief description of this technique is mentioned in Appendix 2.1.

2.2.3 POSTURAL FIXITY

Another cause of CTD in the lumbar region may be postural fixity or enforced posture (Grieco, 1986 and Carter and Banister, 1994). Awkard sitting posture may lead to postural fixity which may further cause static muscle loading. Generally, light tasks often involve sustained static and highly repetitive isometric contractions (Sjogaard et al, 1988) which leads to a higher chance of work related myalgia in neck and shoulder regions (Schuldt et al, 1987). According to one theory in the majority of cases prolonged isometric contraction can cause a constant increase in intramuscular pressure which further could contract the blood vessels and cause ischaemia (Grieco, 1986 and Sjogaard et al, 1988). Ischaemia is the condition which involves reduced supply of nutrients to the muscles and accumulation of energy catabolism products (Kahn and Mond, 1989, Grieco, 1986 and Armstrong et al, 1993). For example, interamuscular pressure level exceeding 40 mm Hg (5.3 Kpa) during contraction reduced the muscle blood flow in the supraspinatus muscle (Kahn and Mond, 1989). In 1929, Dolgin and Lehmann (cited in Kahn and Mond, 1989) stated that inadequate blood flow has been the main cause of fatigue in muscles. The inadequate blood flow can create a mismatch between energy supply and energy consumption causing fatigue in muscle (Sjogaard et al, 1988).

As the level of blood flow depends on the rate of contraction of the muscle, it is important to know what level of contraction should be avoided to maintain adequate blood flow in muscles. Monod (1956) and Rohmert (1960) (cited in Caffier et. al. 1993) reported that contraction below 15-20% maximum voluntary contraction (MVC) can be maintained indefinitely without apparent interference to blood flow. Further, studies by Kahn and Monod (1989) stated that the onset of fatigue occurs more rapidly when force exerted is more than 15-20% of MVC. Sjogaard et al (1988 and 1986) showed evidences of sufficient amount of blood flow during low-level sustained contractions, as low as <10 % MVC. Nevertheless, muscular disorders have been reported when the occupational load was less than 1% MVC (Kvarnstrom, 1983). The same result was reported by Sjogaard et al, 1988. Hence, it might be concluded that an occupational load level which allows an unlimited duration of contraction cannot be defined (Caffier et al, 1993).

The other possible cause of disorder in muscles can be the loss of potassium ions in a muscle cell (Sjogaard et al, 1988, Sjogaard et al, 1986 and Grieco, 1986). In a study by Sjogaard et al, 1988 it has been shown that during both continuous and intermittent isometric hand grip contractions the concentration of potassium ion in arteries and veins decreased with respect to time. This theory also suggests that loss of potassium ion is indirectly prepositional to the amount of blood flow (Sjogaard et al, 1988).

Thirdly, the accumulation of impaired substrate within the muscles can cause muscular disorders even if the transport of substrate to the muscle is sufficient (Kahn and Monod, 1989). A study by Sjogaard et al, 1988 reported that during contraction of one hour at 5% MVC, the total increase in muscle water (lymph) contents was 10%. As the lymph does not have its own central lymph pumping system and its movement is dependent on the movement and contraction of muscle, the increase in quantity of muscle water contents indicates the need for more muscle movement in order to remove the lymph. Therefore, during sedentary work, complaints regarding tense and oedematous muscles specially in the neck and shoulder region may be high. For the same reason Kilbom (1987) and Winkel (1987) stated that a variation in the muscle activity is important to reduce harmful effects from accumulated by-products. This variation in muscle activity can be achieved by providing rest pauses in between work periods (Kahn and Monod, 1989). However, Sjogaard et al, (1988) reported that because of rest pauses the blood flow increases and in turn it lowers the percentage of potassium ion in muscle cells. Hence, the concept of providing resting periods is really questionable. However, changes in activity pattern may be beneficial.

One more hypothesis for the mechanism of muscle injury or disorder has been presented by Hagg (1991) and is called the Cinderella hypothesis. The theory states that during low-level static contractions, the same group of motor units are active repeatedly for prolonged time periods and this may cause injuries to muscles even at low level contractions. This hypothesis was supported by Veiersted (1993) who investigated the number and duration of pauses in EMG recordings from shoulder muscles for subjects performing machine-paced, repetitive, packing work. The results of this investigation and as well as one by Jensen (1993) supported the importance of micropauses for recovery.

2.3 PRESENT STUDY

CTDs are common in all types of industries, whether heavy, light, or office work. An example of the magnitude of financial losses from CTDs is the Northern Telecom plant located in Calgary. This plant currently looses 1.2 million dollars per year due to CTD related injuries amongst their assembly line workers alone. Research in the prevention of CTDs in assembly line workers is currently being studied at the University of Manitoba. The main operations performed by the operators in assembly of a printed circuit board (PCB) are inserting, bending and soldering of the components. These operations involve repetitive flexion and extension of the cervical and the lumbar spine. The repeated flexion and extension of cervical spine may result in muscular disorders of neck and shoulder muscles (Westgaard and Aaras, 1984 and Schuldt et al, 1986).

In order to reduce the range and frequency of flexion and extension of the cervical spine, a new method of assembling PCBs has been designed and developed in the Ergonomics Lab at the University of Manitoba. The new method of assembling PCBs involves watching a magnified image of the PCB on a high resolution TV monitor. A camera located above the PCB is used for projecting the image of the PCB on to a TV monitor located directly in front of the worker. This image is magnified by using a magnifying lens attached to the camera. The new method of assembly was studied in the industrial environment.

The objective of this study is to compare the two methods of assembling printed circuit boards, the proposed indirect vision method and the existing direct vision method of PCB assembly in terms of objective measurement, physiological measurements and subjective rating. A correlation among these variables may be related to worker cumulative trauma disorder (CTD) risk level.

CHAPTER 3

EXPERIMENTAL PROCEDURE AND DATA COLLECTING

3.1 FIELD EXPERIMENT

The new method of Printed Circuit Board (PCB and PC board) assembly was tested in an industrial environment at the Northern Telecom Wireless plant in Calgary. A team of four researchers from the University of Manitoba (A. Kaushik, D. Kuss, S. Marinov, and V. Venda) carried out the experiment.

The Northern Telecom wireless plant in Calgary is involved in the manufacturing of wireless equipment. The basic component of wireless equipment is the PC board. Generally, most of the PC boards assembly operations are carried out by robotic machines. However, if the component size is larger than the chuck holding capacity of the robotic machine, then the components are assembled manually. The manual assembly operation is also common for the components having non-standard legs. Manual assembling of PC boards involves operations such as, inserting of components in the PC board, bending their leads, soldering and trimming leads of the components.

The main objective of this project was to compare the assembly of PCBs in two different experimental conditions. The first condition involves the assembly of PC boards by directly watching them and was designated by the code 'DV' where, DV indicates the direct vision method of PC board assembly. This method is mostly used for the assembly in all the electronics industries. The second experimental condition involves the assembly of PC boards by indirectly watching their image on a high resolution TV monitor. The image of the PC boards is projected onto the monitor by using a camera having a zoom lens. This design is designated as the 'IV' method of PCB assembly. where, IV indicates the indirect vision method of assembling PCBs. These two experimental conditions were tested on two types of workstation. The first workstation was designated as Cutout and the second as Traditional.

The following parameters were taken into consideration for the comparison of two workstations.

1. Productivity in terms of time per PC boards.
2. Activity of upper left and right trapezius recorded by using the Physiometer (PHY).
3. Flexion and extension of the cervical spine in terms of angles recorded by the PHY unit.
4. Subjective report through a questionnaire.

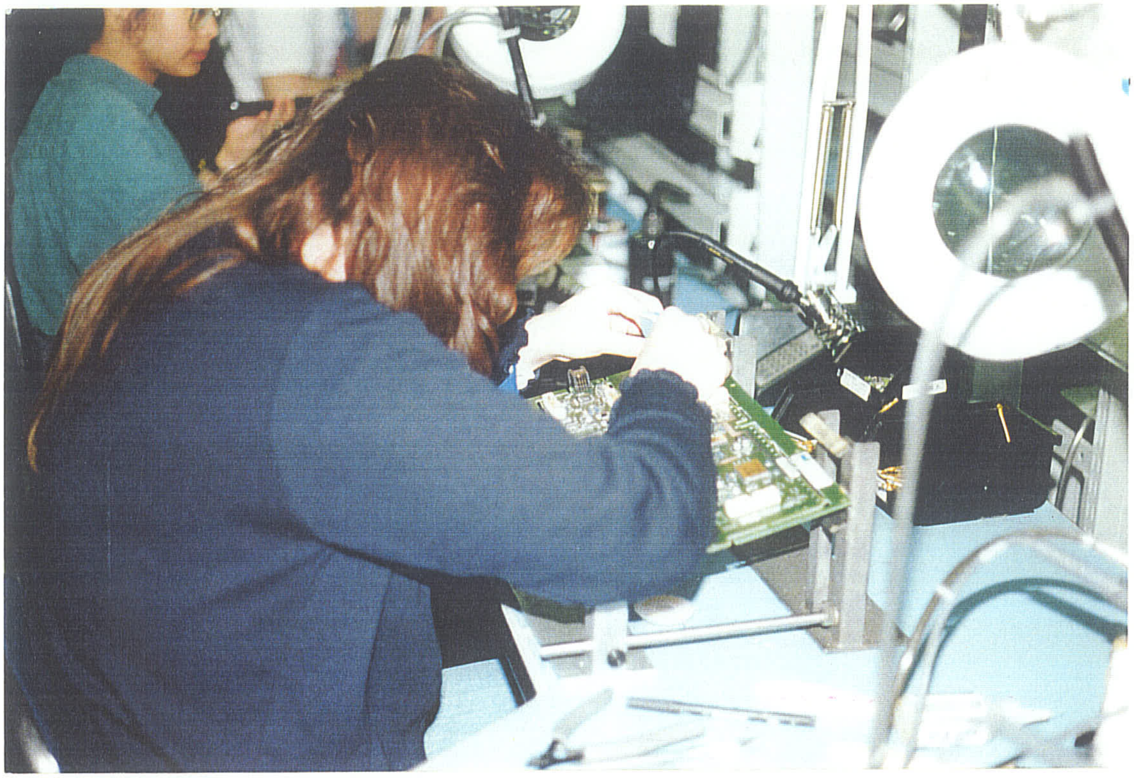
3.2 PARTICIPANTS

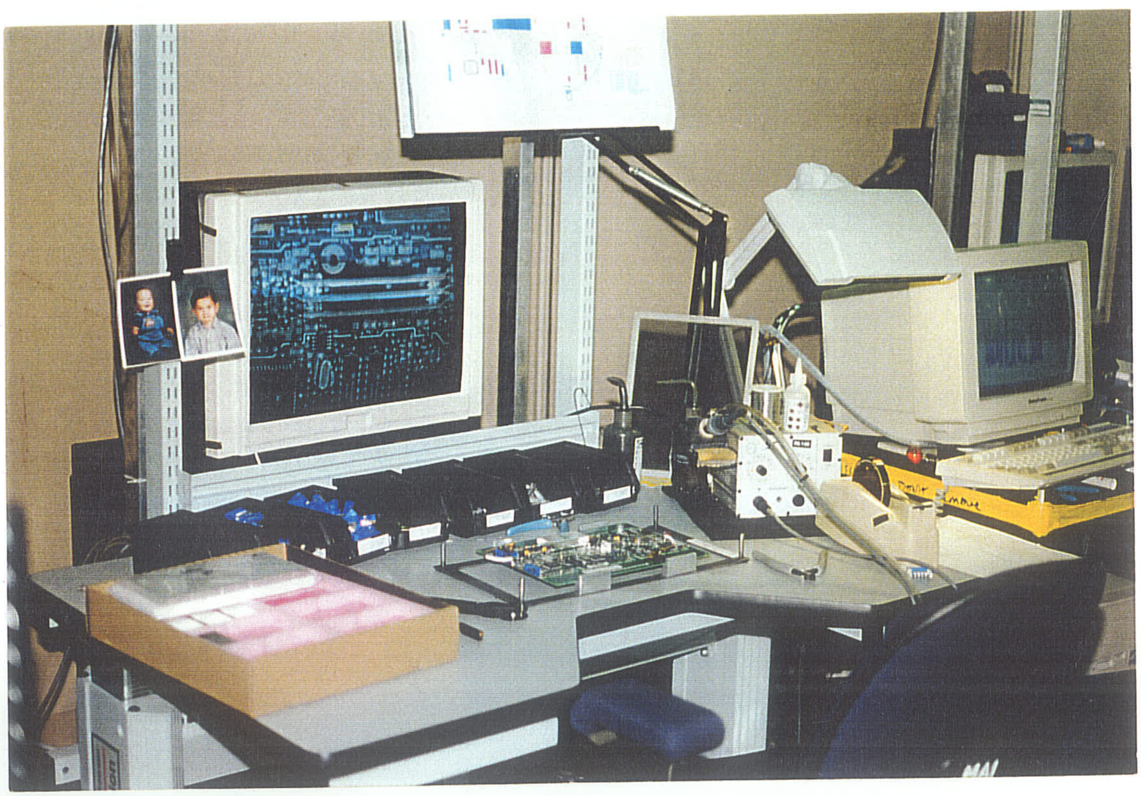
Twelve workers (seven females and five males) of the Northern Telecom wireless plant participated in the experiment. The workers were divided in two groups of six each. The first group participated in the experiment for the first two weeks while the second group participated for the last two weeks. Each subject worked on the DV traditional and cutout type of workstation on the first and the last day of the experiment. For the rest of the days every subject worked on the IV workstations (seven days). The two groups of six workers were further divided into three sub-groups of two workers as there were only two workstations available for the experimental study in a particular shift. During a shift, two workers were working in line, one of them on a traditional and other on a cutout workstation. The experimental study was conducted in all three shifts, morning, evening

Table- 3.1- Personal Demography Of Subjects

WORK EXPERIENCE (years)	**HEIGHT (Cm)**	**WEIGHT (Kg)**	**LATERALITY**	**VISIBILITY**
1.7	152.54	54.55	RIGHT	NORMAL
3	160.00		RIGHT	CORRECTED
1	177.50	80.91	RIGHT	CORRECTED
0.75	160.00		RIGHT	NORMAL
3.5	167	72.73	RIGHT	NORMAL
5	185	81.82	RIGHT	NORMAL
6	160	50	RIGHT	CORRECTED
0.83	152.50	56.82	RIGHT	CORRECTED
7	155.00	62.73	RIGHT	CORRECTED
-	177.50	72.73	RIGHT	CORRECTED
-	175.00	80.91	RIGHT	CORRECTED
-	155.00	70	RIGHT	CORRECTED
MEAN	164.75	68.32		

and night. For example, worker number one worked on the cutout workstation and worker number two on a traditional workstation on the morning shift during first week. All subjects worked at their own workpace during the experiment. Each worker was designated by the code which starts from W01 ...W12 where, WO1 is worker one and W12 is worker twelve. The subjects were selected randomly from a normal group of the assembly worker population. Average subject height was 164.74 cm while the mean weight of subjects was 68.32 kgs (Table 3.1). The design of the workstations was adequate to accumulate the 95th percentile of the population. Each subject had to sign a consent form before participating in the experiment (Appendix 3.1).





3.3 EQUIPMENT

The following equipment was used in this experiment.

3.3.1 WORKSTATION EQUIPMENT

TV monitor- In this experiment two high resolution 'PANASONIC' monitors (600 lines of resolution) were used. The monitors were mounted on a sliding stand (with casters) at the height of 78.75 cm.

Cameras- Two 'JVC' cameras (camera 1 and 2) were used for projecting the image of the PCB on to the TV monitors. The height of camera from the work table was 180 Cm. A separate zoom lens was mounted on these cameras so that the PCB magnification could be changed. The whole assembling procedure was recorded by two separate JVC cameras (camera 2 and 3) inclusive of movements of the head and upper back. These cameras were wired to the video cassette recorders for recording.

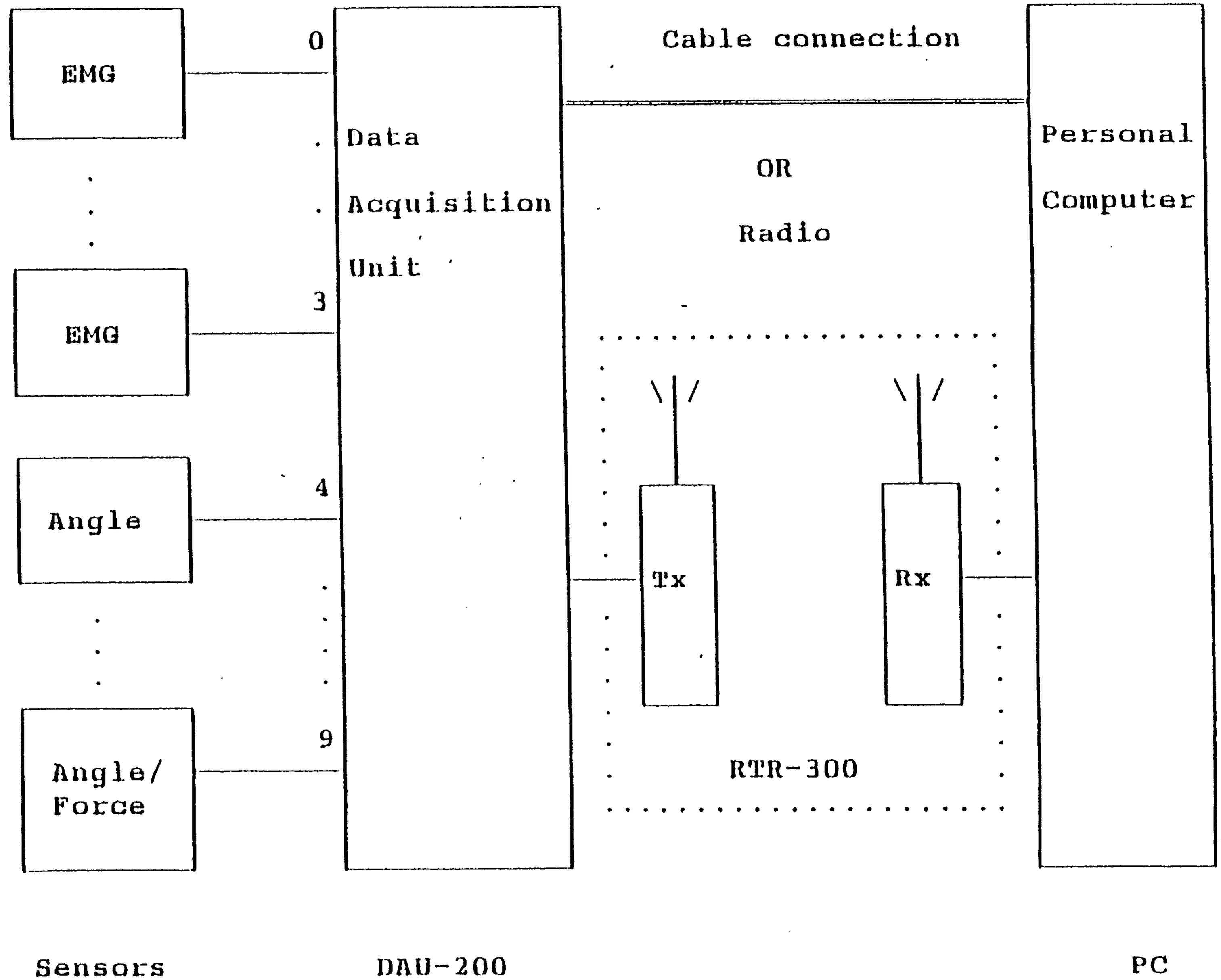
3.3.2 WORKSTATION

Two workstations were used in this experiment namely- the cutout and the traditional workstation (Figure 3.1). The cutout workstation was developed by the ergonomists in the Northern Telecom plant and had the following special features.

1. The height of the worktable was adjusted by 180 watt electrical motor.
2. A cut (space) was provided in the worktable so that the operators can slide their chair inside the cut out worktable and can support their arms on the surrounding table top.
3. The tilt of the worktable was zero degrees.

The second, the Traditional workstation was previously used in the same plant for PC board assembly. The traditional workstation was redesigned and modified to achieve

Figure 3.2-
General setup for the Physiometer (PHY)



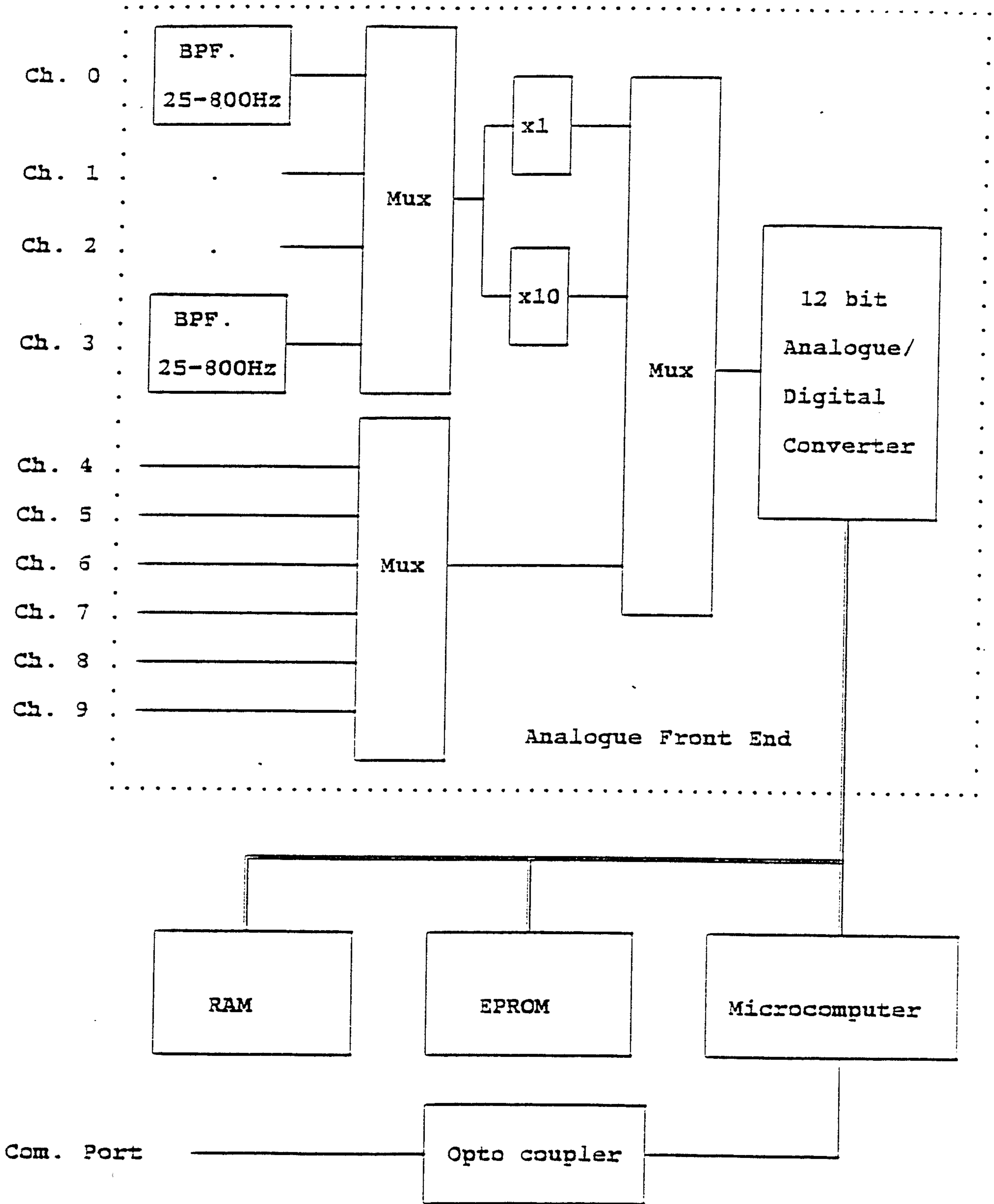


Figure 3.3-
Construction of Data Aquisition Unit

a negative tilt angle of worktable. Also, a piece of cardboard is placed over the metallic surface of the worktable in order to prevent the sliding of PC boards during assembly operation. The workstation was further modified by adding a separate unit for holding the TV monitor and camera. The component trays were mounted on the sides and in front of the work table.

3.3.3 DATA ACQUISATION EQUIPMENT

The physiometer unit PHY- 400 Permed, Norway was used for workload assessment in terms of electromyography (EMG) of the upper right and left trapezius muscles and postural angle measurements of cervical and thoracic spine movements. This physiometer unit calculates the Amplitude Probability Distribution Function (APDF) and the number of periods for the recorded signals. The physiometer unit consists of sensors and a battery operated Data Acquisition Unit (DAU). The general setup of the PHY is presented in Figure 3.2.

A block diagram of the DAU is shown in Figure 3.3. The DAU consists of a microcomputer with memory and an analogue front end which interfaces with the sensors. The analogue front end consists of four EMG band-pass filters with a cut-off frequency of 25 Hz and 800 Hz, multiplexer and a 12 bit A/D converter. The microcomputer (HD63A03YF) operates at 4.9 mega Hz and has 128 kByte of external RAM for data storage. It communicates with the host computer on an opto isolated, asynchronous serial interface, operating at 4800 baud.

The physiometer has a total of nine channels, the first four channels are for recording electromyography and the remainder of the six channels are for angle measurements. The primary EMG signals were sampled at a frequency of 1600 Hz and averaged over each sequential interval of 0.1 sec. EMG channels have two different gain settings, which can be automatically selected during measurement depending upon the magnitude of the input signal. The gain settings have a amplification factor of 1X and 10X. 10X amplification factor is used for low signals and 1X for high EMG signals. Since the EMG amplifier has a gain close to 215, the total gain of a low EMG signal will be 215 or 2150. The angular/force signals (channel 4-9) are sampled at 10 Hz and transmitted to the Data Acquisition Unit along with the RMS values of EMG signals (channel 0-3).

The unit was controlled by software, compatible with IBM personal computers. The PHY software provides two helpful options, the first is on-line measurement and the second is off-line analysis. The on-line measurement displays a graph of each channel in real time. On-line measurement displays a menu on the right side of the screen, where channel number, offset level, scaling, scan frequency and type of display can be selected. This measurement setting also provides a option by which marks can be attached to the specific places during recording by pressing the F7 key of the key board. For example, in this experiment the starting and the end of PCB assembly is marked (M1-M2). The off-line analysis stores all the calibrated files and displays them with the time and date of recording. All the recorded signals for a particular subject are saved as sub-files in the calibration file of the same subject. These sub-files of the recorded signals can be retrieved and their normalized amplitude distribution is displayed by selecting the display option from the menu provided on the right hand side of the recorded signal graph.

Further, the parts of the displayed recorded signal can be selected by using left and right markers provided by the software. Also, a corresponding distribution of the selected portion can be displayed and printed on a dot-matrix printer.

The PHY software provides a setup option for selection of the gain of EMG amplifiers. The set-up menu is also used for selecting printer type, type of graphic display and the color scheme of the display.

3.4 PROCEDURE

During the assembly operation, the subjects were timed in terms of "time per PCB". Further, the muscular activity of the right and the left trapezius along with the flexion and lateral flexion of the spine were recorded during PCB assembly. Finally, subjects were asked to answer primary and secondary questionnaires. The following procedure was adopted for the recording of all the above measurements.

3.4.1 GENERAL ASSEMBLY PROCEDURE

The procedure for the assembly of each PCB generally includes operations like inserting of components, fixing some of these components by tape or by soldering, bending and trimming of the component leads and visual inspection of the PCB. In this experiment the following PC board assembly procedure was adopted.

1. Insert the components in the PC board.
2. Soldering of the component leads by flipping PC board.
3. Taping of the two components on the PC board.
4. Trimming the leads of the components.
5. Visually inspecting the assembled PC board.

TABLE- 3.2 - PC board (PCB) assembly series in a single shift for Worker Six (W06) on the last day of work at the Cut-out workstation. Source of data PHY records.

Series	Number of PCBs	Time per PCB (sec)	Product. (PCB/sec)	Product. (Component /sec)
PCB/series 1	17	17	17	17
Mean		219	0.004686	0.000293
Max.		255	0.008	0.0005
Min.		125	0.003922	0.000245
SD		31	0.000928	0.000058
CoVr		0.143	0.198	0.198
PCB/series 2	18	18	18	18
Mean		206	0.004985	0.000312
Max.		242	0.008696	0.000543
Min.		115	0.004132	0.000258
SD		27	0.000973	0.000061
CoVr		0.131	0.195	0.195

Denotions- Max. - Maximal
Min. - Minimum
SD - Standard deviation
Co Vr - Covariance

The workers assembled varying numbers of continuous series of PC boards during the intervals between the regular breaks in the duration of each shift. The number of assembled PC boards included in each series as well as the numbers of series between the breaks and during the whole shifts were highly irregular. The rate of irregularity varied from 2 to 28 PC boards per series and there were 2 to 9 series per shift. For example, Table 3.2 and 3.3 illustrates the PC boards assembly series for Worker Six on the last day of work at the traditional workstation and similarly Worker Nine on the last day at the cutout workstation. This inconsistency in the number of series per shift was due to the irregular supply of PC boards from the previous operation. In some cases the workers had to wait for PC boards for one to two hours. In other words, this irregularity was due

TABLE- 3.3 - PC board assembly series in a single shift for Worker Nine (W09) on the last day of work at the Cut-Out workstation. Source of data PHY records.

Series	Number of PCBs	Time per PCB (sec)	Product. (PCB/sec)	Product. (Component/sec)
PCB/series 1	8	8	8	8
Mean		133	0.007852	0.000872
Max.		192	0.009901	0.0011
Min.		101	0.005208	0.000579
SD		28	0.001476	0.000164
CoVr		0.215	0.188	0.188
PCB/series 2	15	15	15	15
Mean		130	0.007869	0.000874
Max.		176	0.009901	0.0011
Min.		101	0.005682	0.000631
SD		22	0.00124	0.000138
CoVr		0.167	0.158	0.158
PCB/series 3	3	3	3	3
Mean		125	0.008117	0.000902
Max.		147	0.008929	0.000992
Min.		112	0.006803	0.000756
SD		16	0.000938	0.000104
CoVr		0.125	0.116	0.116
PCB/series 4	6	6	6	6
Mean		131	0.007696	0.000855
Max.		149	0.009346	0.001038
Min.		107	0.006711	0.000746
SD		13	0.000829	0.000092
CoVr		0.099	0.108	0.108
PCB/series 5	2	2	2	2
Mean		115	0.008696	0.000966
Max.		116	0.008772	0.000975
Min.		114	0.008621	0.000958
SD		1	0.000076	0.000008
CoVr		0.009	0.009	0.009

continued on the next page.

TABLE- 3.3 - continued
PC board assembly series in a single shift for Worker Nine (W09) on the last Day of work at the Cut-out workstation. Source of data PHY records.

Series	Number of PCBs	Time per PCB (sec)	Product. (PCB/sec)	Product. (Component/sec)
PCB/series 6	9	9	9	9
Mean		125	0.008064	0.000896
Max.		153	0.009804	0.001089
Min.		102	0.006536	0.000726
SD		13	0.000836	0.000093
CoVr		0.103	0.104	0.104
PCB/series 7	8	8	8	8
Mean		112	0.008996	0.001
Max.		139	0.010309	0.001145
Min.		97	0.007194	0.000799
SD		12	0.000848	0.000094
CoVr		0.104	0.094	0.094
PCB/series 8	6	6	6	6
Mean		136	0.007523	0.000836
Max.		166	0.008621	0.000958
Min.		116	0.006024	0.000669
SD		20	0.001041	0.000116
CoVr		0.146	0.138	0.138

Denotions - Max. - Maxima
Min. - Minimum
SD - Standard deviation
Co Vr - Covariance

to improper line balancing of the production procedure.

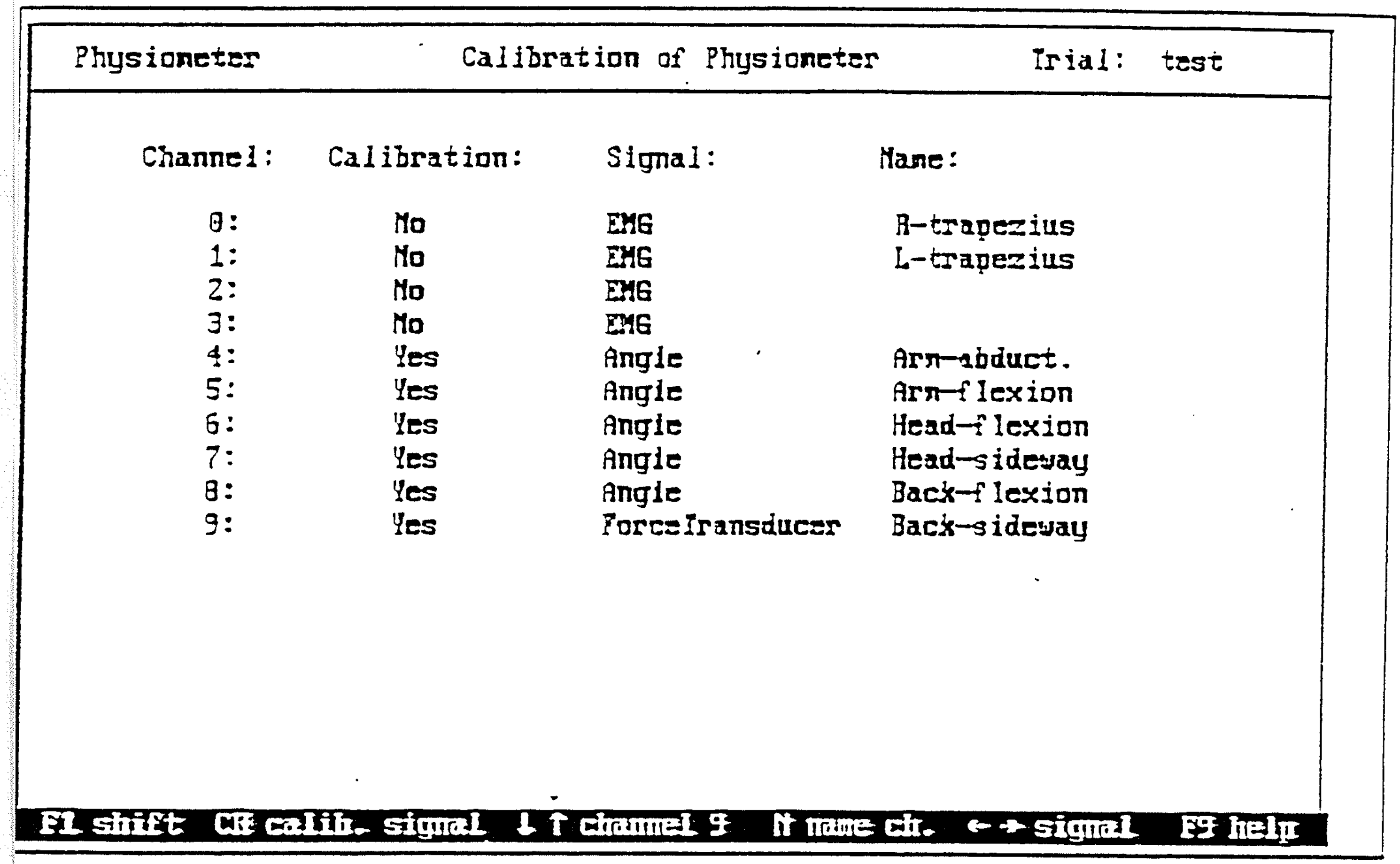
3.4.2 PRODUCTIVITY MEASUREMENTS

During assembly the data for productivity was collected by a continuous time study of the procedure. A stop watch was used for the measurement of time for assembly of a single PC board. A standard time sheet was provide to each researcher for keeping the track of assembly time and to write general observations. Each researcher was responsible for a particular shift. The data for productivity was also recorded on the PHY unit by putting marks on the on-line data. The whole of the assembly procedure was video taped.

3.4.3 PHYSIOMETER MEASUREMENTS

The measurement of muscular signals and postural angles was done by using the PHY unit. In this experiment, electrodes were placed on the right and left trapezius muscles for the assessment of workload and these two electrode cables were wired to channel 0 and 1 respectively of the PHY. The postural angles of the cervical and thoracic spine are measured by four transducers which are wired to channels 4, 5, 6 and 7 of the PHY unit. The first step before recording any measurement is to calibrate the channel in order to establish a relationship between the input signal and the actual parameter measured (EMG and angles). The following procedure was adopted for the electrode placement on right and left trapezius and the calibration of EMG channels.

Before placing the electrodes, the skin was cleaned in order to reduce its surface resistance. The skin was cleaned by rubbing with a mixture of 1/4 ether and 3/4 alcohol (spritius fortis) until the skin became pink. Bipolar electrodes (AgCl, 60 MEDI-TRACE Pellet electrodes) were used. The two pairs of bipolar electrodes were placed on the right and left upper trapezius and interelectrode distance between them was 20 -30 mm. The reference electrodes for both muscles act as an active output that cancels the common mode rejection ratio (CMRR) of the amplifier and helps in eliminating the noise in the electrical signal obtained from the muscle.



Physiometer Calibration of Physiometer Trial: test

Channel:	Calibration:	Signal:	Name:
0:	No	EMG	R-trapezius
1:	No	EMG	L-trapezius
2:	No	EMG	
3:	No	EMG	
4:	Yes	Angle	Arm-abduct.
5:	Yes	Angle	Arm-flexion
6:	Yes	Angle	Head-flexion
7:	Yes	Angle	Head-sideway
8:	Yes	Angle	Back-flexion
9:	Yes	ForceTransducer	Back-sideway

F1 shift CR calib. signal ↓ ↑ channel 9 N name ch. ← → signal F9 help

Figure 3.4-
Main menu for selecting Channel numbers

The PHY software provides three EMG calibration modes namely; 1) Normal mode from EMG and Force transducers, 2) Percentage of maximum voluntary contraction (%MVC) as fractions of Maximal EMG signal and 3) No modeling, signals are displayed in micro volts. The second model is less reliable as only the zero and maximal level of the EMG signals need to be established, without a force transducer. Similarly, the third modeling records the input signal directly without referring to %MVC. Thus, this method can't be used for comparisons of several measurements made using different calibrations. However, the first calibration model takes care of all these drawbacks. Hence, in this experiment the channels were calibrated by using the normal model for EMG and force transducers.

The calibration procedure was carried out by using a force transducer. The force transducer was hooked to the platform by a strap with handles on it. The first step in calibration is to establish the offset level for the force transducer (channel 9) by standing upright on the platform with the subject's arms holding the handles and resting straight down in a relaxed position (Figure 3.4). The height of the handles was adjusted so that the shoulders were relaxed when the pulling started and the shoulder could not be lifted without activating the force transducer. The second step in calibration was to select the channels to be calibrated. In this experiment, channel zero and one were selected for calibration (Figure 3.5). The subsequent step was to select the model for calibration and the duration of steady contraction and the upper limit of contraction (Figure 3.6 and 3.7). The duration and the upper contraction limit selected in this experiment is 10 sec. at 30% MVC. The next step was to establish the maximum level of EMG and force (Figure 3.8).

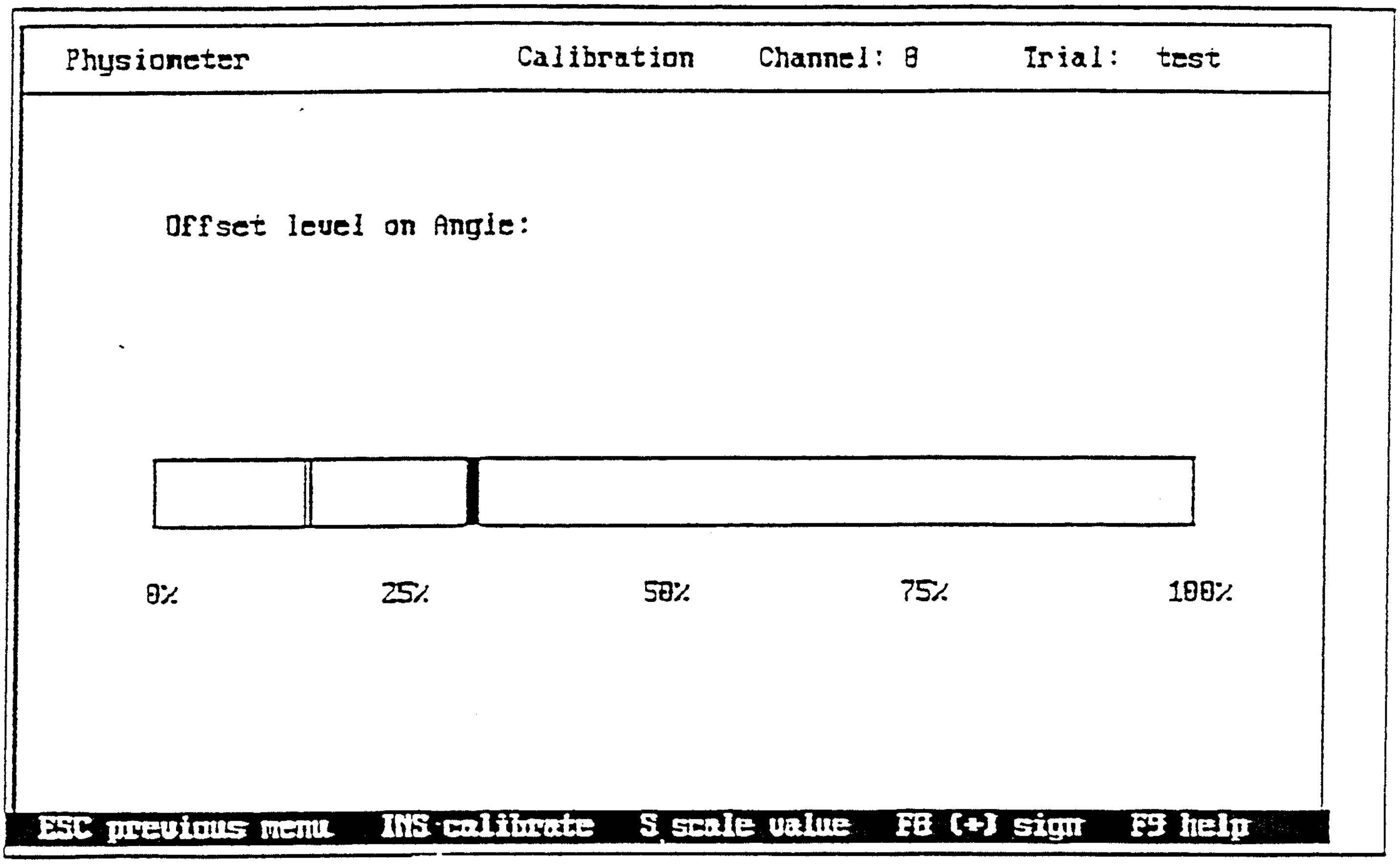


Figure 3.5-
Off-set level of force transducer

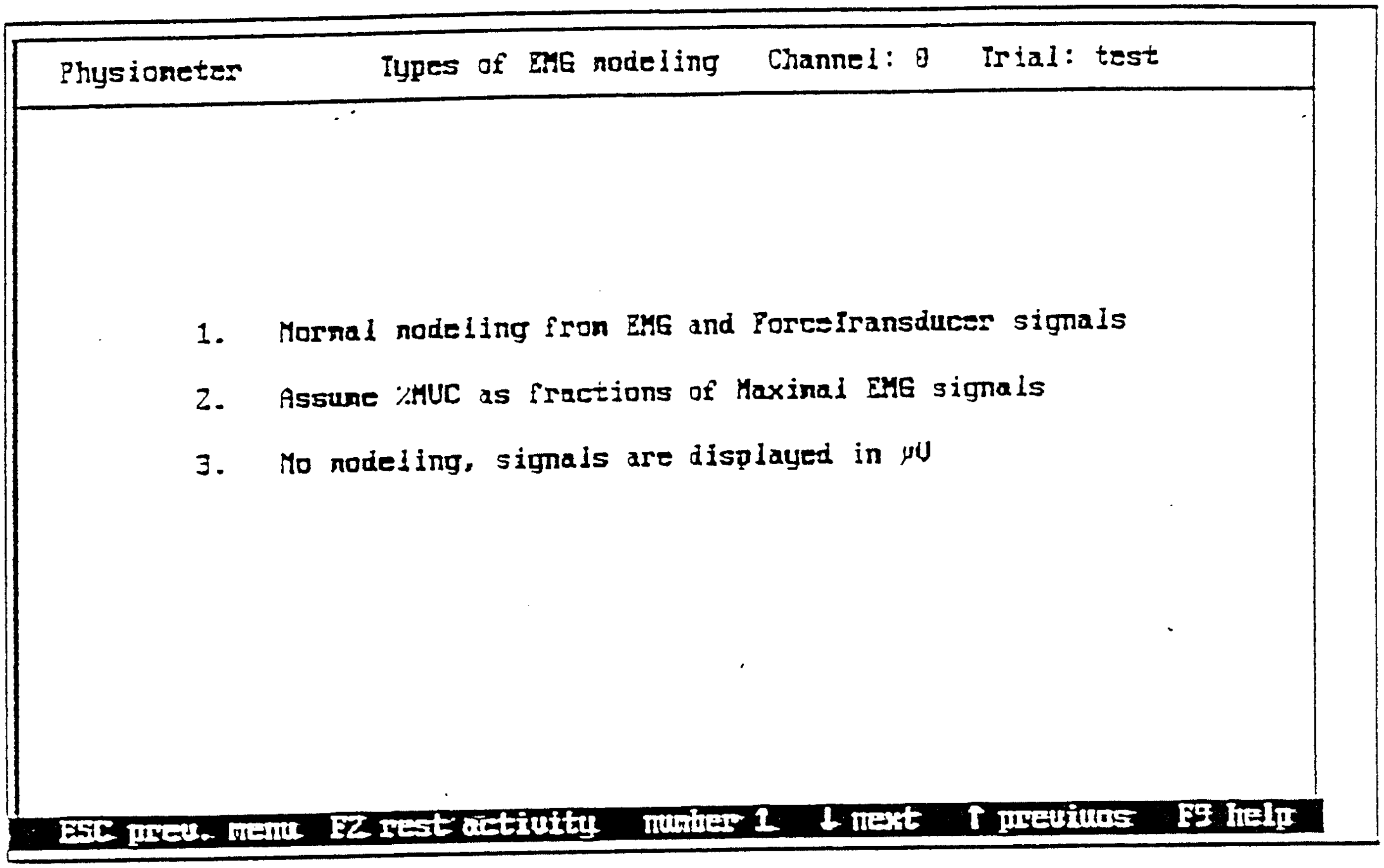


Figure 3.6 -
Three types of modeling which can be used for the calibration of EMG channels

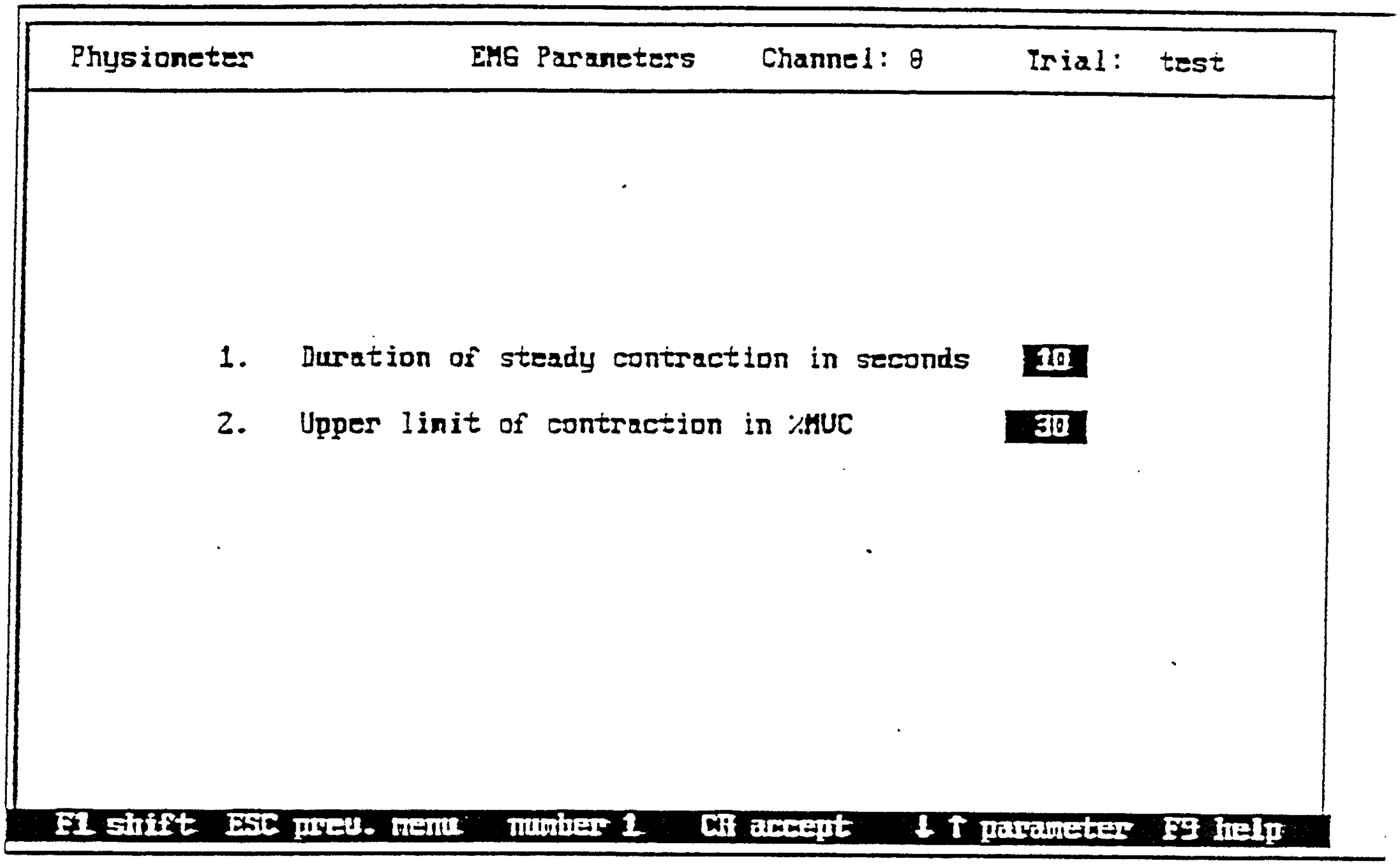


Figure 3.7-
Selection of the duration for contraction and upper limit of contraction in terms of %MVC

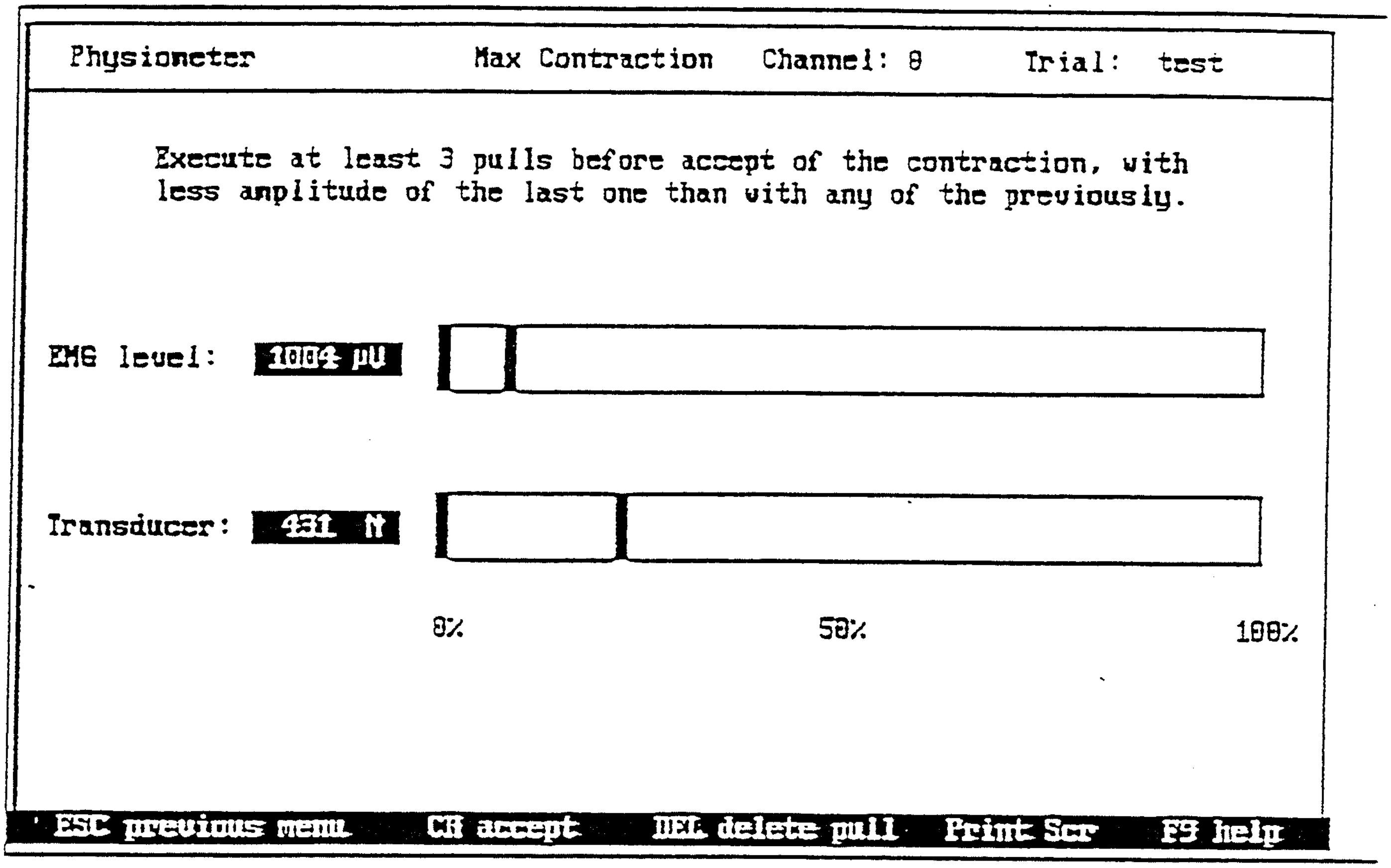


Figure 3.8-
Menu for establishing Maximum level of EMG and force by executing pulls for a maximum period of two seconds

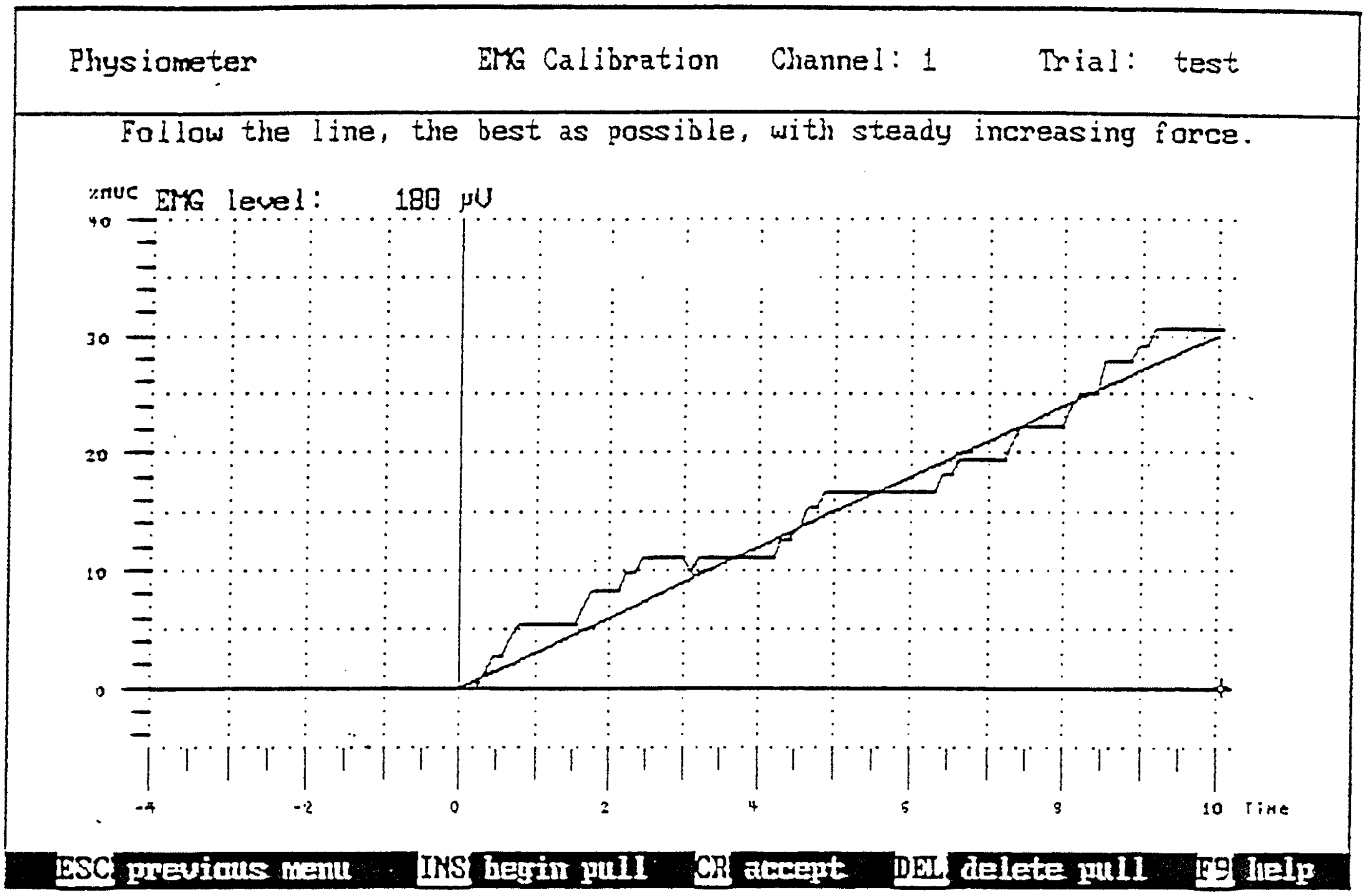


Figure 3.9-
Establishing a linear relationship between the EMG (in terms of rms value) and force for actual range of workload. Subjects were instructed to follow straight line on the PC screen for a duration of 10 seconds

Both of these signals are presented simultaneously. The maximum values of EMG and force were obtained by gradually pulling the handle, attached to the force transducer. During the pull it was made sure that the shoulders of the subjects were pressed straight upwards or in a slight retraction and not internally rotated in order to ensure the contraction of trapezius muscle. This maximum contraction was retained for a period of approximately one second in order to avoid fatigue of the trapezius muscle. Normally three trials were performed for establishing maximal contraction for EMG and force.

For the EMG signal there is not necessarily a linear relationship between the input signal and the actual force. Therefore, in order to do a proper calibration a relationship between EMG root mean square (RMS) value and force was established for the actual range of workload (Figure 3.9). In this study the range of workload was between 0 and 30% MVC. In this calibration the operators gradually increase the force (in Newton's) by pulling the handle of the force transducer in order to track a straight inclined line on the screen displayed on the PC monitor. The duration of this pull was 10 sec (as selected in Figure 3.7). The results of this calibration were further displayed on the PC screen where a calibration curve could be fitted to one of the possible mathematical functions: linear, power or exponential. For this experiment linear modeling is selected. The variation 'R' between the selected model and the actual calibration curve is represented by a number on the display PC screen. The results of the calibration were considered satisfactory when the value of this variation 'R' was equal to or greater than 0.70 (Figure 3.10). Calibration of EMG channels was carried out for all the workers. The EMG rms. / force relationship obtained during the calibration procedure was used to convert the EMG rms to % MVC

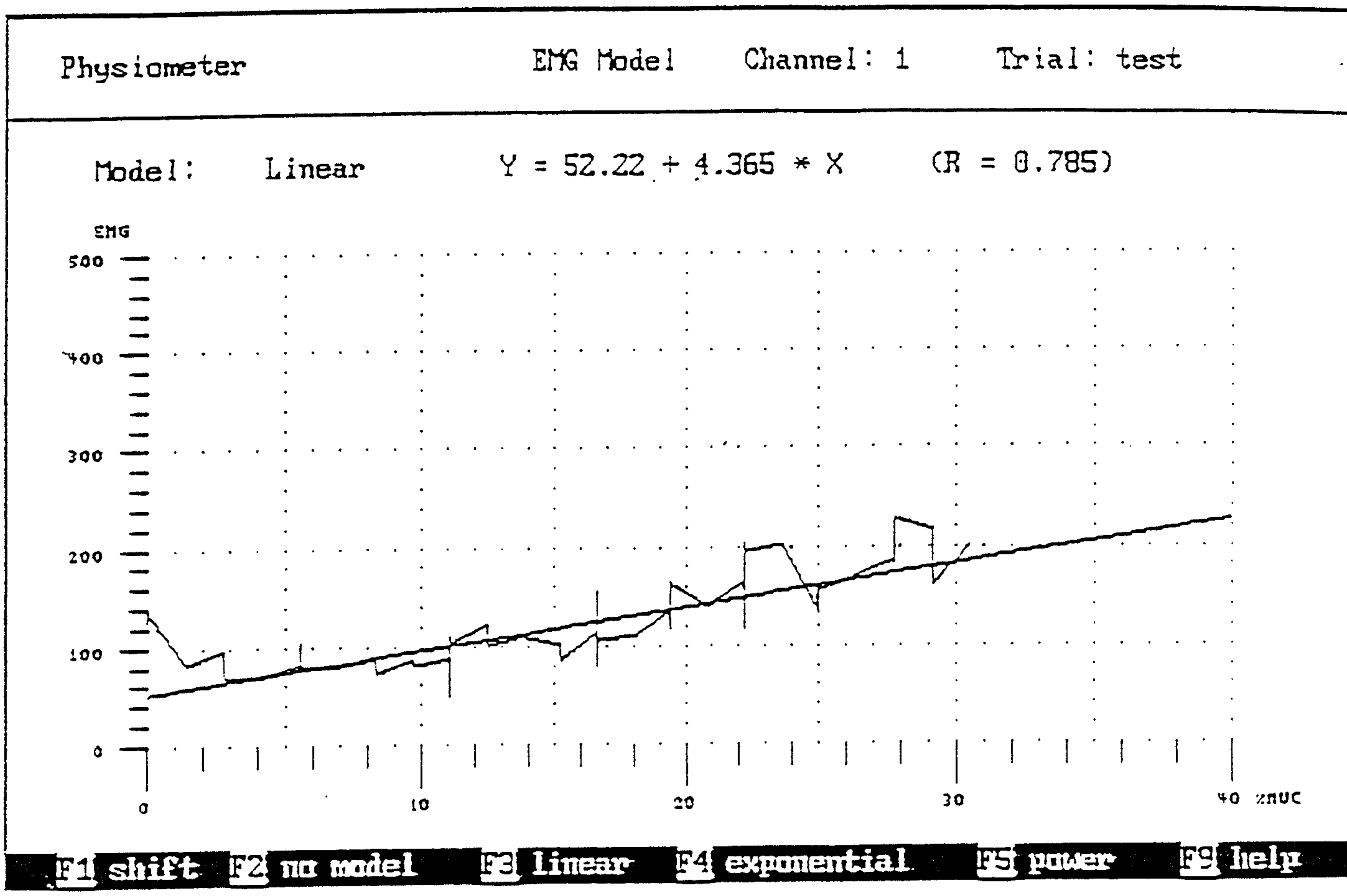


Figure 3.10-
Results of the calibration. The calibration was accepted if the value of "R" was atleast 0.70

PHYSIOMETER PHY-400

TECHNICAL SPECIFICATION

DATA ACQUISITION UNIT

EMG Inputs : 4 Differential channels
'Gain : 120,750,3600
Impedance : >5 Gohm
Noise : <5 µV
CMRR : >80 dB
'Rate : 1600 samples/s
'Processing . True RMS

Angle Inputs 6 Ratiometric channels
Excitation . 4.5 V dc at max 5 mA
'Rate : 10 samples/s

Memory . 32 kB RAM, 32 kB EPROM
RAM expansion up to 128 kB
A/D conv . 10 bit
Interface : Opto isolated, current loop, with
RS 232C adapter at 9600 baud
Power . 9 V dc, Battery 6LF22,
10 mA operating
Size : 120 mm x 80 mm x 80 mm
Weight : 400 g
* *For other requirements, please consult factory*

ANGLE SENSOR

Linearity : ± 2% up to 30 degrees
± 5% 30 to 60 degrees
Size : 30 mm Dia. x 60 mm Length
Weight : 60 g

FORCE TRANSDUCER

Accuracy : 0.5% of full scale
Load ranges : 5 kg to 500 kg

Specification subject to change without notice

EMG calibration of Trapezius

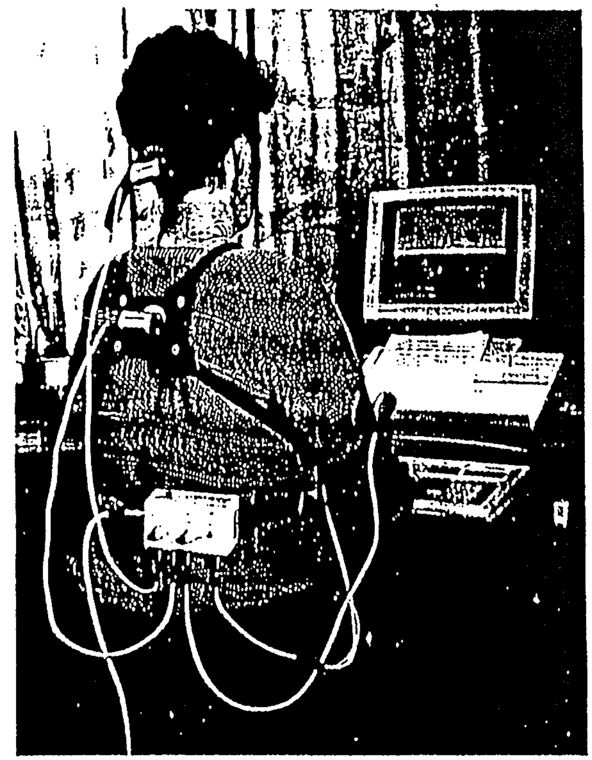


Figure-
3.11-General picture of the subject with PHY unit

during the actual analysis. This conversion of EMG rms value to %MVC can be formulated as follows:

%MVC = (EMGrms - m) * 100% / (a * Fmax)

where, Fmax. = Maximum force in Newton's obtained during MVC.

a = Slope of linear regression line in μV.

m = Minimum value of the EMGrms signal in μV.

Minimum EMGrms = Minimum value of EMGrms during a relaxed period

Similarly, four transducers were used for the angle measurement of movements (flexion and lateral flexion) of the cervical and thoracic spine. The function of these four transducers was to convert angular movements into an electrical signal which later can be analyzed by using the PHY software. These transducers were connected to the Physiometer unit through four different channels. These channels were precalibrated, unlike the EMG channels.

During the first two to three days both workers worked in turn with electrodes and postural sensors in order to obtain PHY records about the period of most intensive adaptation to the workstations. After this period the physiological measurements of each worker were recorded on alternate days up to the end of the experiment. Each experimenter was responsible for the quality of the PHY records and the written protocols as well. In accordance with a preliminary convention, the continuous PHY records and the protocol records were referred to each continuous series of PC Bs. The experimenter was also responsible for attaching a mark to the PHY record at the start of the assembly of each single PC BOARD. (Practically this was realized by pressing F7 on the keyboard of the controlling computer). Finally, on the first and last day of the experimental work, subjects filled out the preliminary and the final questionnaire.

3.5 DATA COLLECTION

In this experiment, the data was collected in three different ways namely ; objective (time per PC board), physiological (EMG and postural measurements) and subjective rating. The main objective of the data collection was to compare the direct vision method with the indirect vision method of PCB assembly.

3.5.1 OBJECTIVE MEASUREMENTS: PRODUCTIVITY OF ASSEMBLY

The productivity of assembling for this study is defined in terms of time spent for the assembly of a single PCB. The data was collected directly on a time sheet by using a stop watch. The alternative way used for the measurement of time for the assembly of a single PCB was by putting marks (M1.....Mn) on the on-line recording of the physiological measurements. The data collected by simple time study is referred as 'data from protocol' and data from physiometer as 'PHY records'.

3.5.2 PHYSIOLOGICAL MEASUREMENTS

The physiological measurements were recorded on the Physiometer (PHY). The signal was recorded with the preamplifier at electrode level. The preamplifier had a gain of 215, input impedance > 5GΩ and a common mode rejection ratio (CMRR) >100dB. This amplified signal was filtered from 25 Hz to 800 Hz, and amplified by a two step, variable gain amplifier. The signal was sampled at 1600 Hz and was digitized by a 12 bit analogue to digital converter. The RMS value of this signal was calculated in real time by a microcontroller at 100 ms intervals and the results were transmitted on an optically isolated serial port to the PC. The physiometer (PHY) was used for the measurements of the following physiological activities

3.5.2.1 EMG MEASUREMENTS

The channel number zero of the data acquition unit was used for the recording of muscular activity of upper right trapezius. Activity of the left trapezius muscle was recorded by channel number one. Both channels zero and one were initially calibrated and then the actual measurements of the activity of the trapezius muscle was observed on the on-line analysis. The on-line analysis was a option in the main menu of the PHY software where live recording of all channels can be displayed. This direct display of the muscular signal helps in detecting any noise in the signal.

3.5.2.2 POSTURAL MEASUREMENTS OF THE CERVICAL SPINE

The postural measurement of the cervical spine was recorded in terms of flexion and lateral flexion. The transducer was mounted on the rear side of the head with a belt. The transducer was wired to channel four and five of the data acquition unit. Channel four was used for recording the flexion of the cervical spine in terms of angles. Similarly, the lateral flexion of the cervical spine was recorded on channel five. The zero angle was assumed to be the standing position of the subject with straight head. The flexion and lateral flexion of the cervical spine were presented on a graph whose horizontal axis denotes angular movement and vertical axis represents the shifts in the signal.

3.5.2.3 POSTURAL MEASUREMENTS OF THORACIC SPINE

Another set of transducers was used for the postural measurement of the thoracic spine. These transducers were strapped on the thoracic spine for the measurement of its flexion and lateral flexion. The transducers were wired to channel six and seven of the data acquition unit. Similar to the cervical spine measurement, the data for thoracic spine movements are presented on a graph with angular variation on horizontal axis and shift in the signal on the vertical axis. The signal was sampled at 1600 Hz along with EMG signals.

The following semi-acronyms were used to name the corresponding EMG/Postural measurements:

R.TRAP -- EMG of Right trapezius muscle

L.TRAP -- EMG of Left trapezius muscle

C.FLEX -- Cervical spine flexion

C.LAT -- Cervical spine lateral flexion

T.FLEX -- Thoracic spine flexion

T.LAT -- Thoracic spine lateral flexion

3.5.3 SUBJECTIVE RATING MEASUREMENT

The questionnaire technique was used for the assessment of DV and IV method of assembly. The subjects rated both methods of assembly in terms of comfort and satisfaction. The questionnaire was divided into two parts. The first part of the questionnaire was filled out by all subjects before start of work using the IV method of assembly. The second part of the questionnaire was filled by the subjects on the last day of their experimental work.

3.6 SUMMARY

This chapter described the procedure adopted for the comparison of the two types of PC board (PCB) assembly methods in the industrial environment of the Northern Telecom Wireless Systems Calgary plant. The existing method of PC board assembly was called the Direct Vision (DV) method while the new method was called the Indirect Vision (IV) method. The IV method of PC board assembly was developed at the University of Manitoba, Department of Mechanical and Industrial Engineering. This method of PC board assembly requires the participants to look at the projected image of the PC board on to a TV monitor. It is hypothesized that the IV method will reduce the strain in the neck and the shoulder region during PC board assembly. This hypothesis was checked by comparing the two methods of PC board assembly in terms of productivity, physiological measure (EMG and postural) and subjective report through questionnaire. These two methods were tested on the Cutout and Traditional workstation. The Cutout workstation was developed by the ergonomists in Northern Telecom plant. In this study twelve healthy subjects were used.

CHAPTER 4

DATA ANALYSIS FOR PRODUCTIVITY AND TRAINING

4.1 DATA COLLECTION AND PRODUCTIVITY

The processing of data is divided into three phases for the comparison of Direct vision (DV) and Indirect vision (IV) PC board assembly methods. The first phase is referred to as productivity analysis (chapter 4). The second phase deals with the physiological measurements of body postures and muscle strains (chapter 5). Finally, the third phase compares the two workstations on the basis of subjective ratings obtained through questionnaires (chapter 6). In the present chapter the real time for assembly of single PC boards is considered for the comparison of the DV and the IV methods of PC boards assembly. Here, productivity is considered as a parameter of the time in seconds taken for the assembly of a single PC board. The higher value of time per PC board indicates a lower level of productivity and vice versa. For example, when the participants were working using the DV method, the average assembly time for a single PC board was 189.70 sec. while using the IV method the average assembly time was 266.5 sec., indicating that for the IV method the productivity was 28.8% lower (Table 4.1 and 4.2). Hence, average productivity or average time is formulated as follows:

$$\text{AVERAGE PRODUCTIVITY (Sec.)} = \sum T(\text{Sec.}) / N$$

where, $\sum T$ = Total assembly time (sec.)

and N = Total number of PCBs assembled in total time ($\sum T$)

Productivity can also be defined as number of PC boards assembled per minute.

The data for productivity measurement was collected in two different ways. First, the assembly time for a single PCB was Directly measured by using a stop watch. The data collected in this manner (time study) is referred as "Data from protocol". The data from protocol is contained in Table 4.3. The second set of data is collected by calculating the time intervals between the marks (M1 ---Mn) imprinted on physiometer (PHY) records. The data collected in this fashion is called "Data from PHY records". The data from PHY records is shown in Table 4.4. Marks M1, M2, ---, M13 in Figure 4.11 of Appendix 4.1 illustrate the number of PC boards assembled in a continuos time series.

In this chapter the data of Worker Nine is taken for the demonstration. Figures 4.11, 4.12 and 4.13 of Appendix 4.1 illustrate a part of the PHY record of the cervical flexion for Worker Nine (W09), during the 6th continuous series on the 4th day of work at the IV workstation. The vertical axis represents the deviation of head position from a preliminary chosen reference position arbitrarily designated as zero degrees. The horizontal axis indicates time from the beginning of a workcycle to its end. The marks M1, M2, etc. represent the beginning and end of a full cycle for the assembly of single PC board. In other words, the time from M1 to M2 corresponds to real time for the assembly of a single PC boards. Figures in Appendix 4.1 also illustrate a repeating pattern for the flexion and the extension of the cervical spine with respect to real time. The time scale used for these graphs in Appendix 4 is 15.9 sec/mm, 7.87 sec/mm, and 3.65 sec/mm respectively. These figures represent the signal from flexion of the cervical spine with different zones of assembly work activity. A repetitive sharp peak close to the marks (M1...M13) corresponds to the zone of extension of the cervical spine from its initial

Table - 4.3 - Average Time Per PC board (PCB in seconds) Versus Day Of Training. Source of data : Protocols.

Worker & WS	Parameter (Sec.)	DV	IV							DV	
	Day of training→	1	1	2	3	4	5	6	7	2	3
W01 C	PCB/day					35					
	Mean Time/PC B					272					
	SD					51					
W02 T	PC boards/day						17	50			
	Mean Time/PCB						282	284			
	SD						28	46			
W03 C	PC boards/day		11		50	15					
	Mean Time/PC B		480		334	271					
	SD		92		29	11					
W04 T	PC boards/day			35		40					
	Mean Time/PCB			449		328					
	SD			87		39					
W05 C	PC boards/day	58	20	55	60	67	60	77	62	72	
	Mean Time/PCB	179	376	242	206	185	174	164	167	133	
	SD	17	89	47	30	16	14	12	9	16	
W06 T	PC boards/day		35	38	32	46	43	32		51	
	Mean Time/PCB		442	364	335	328	316	308		213	
	SD		54	33	28	23	29	20		19	
W07 C	PC boards/day										
	Mean Time/PCB										
	SD										
W08 T	PCBs/day										
	Mean Time/PCB										
	SD										
W09 C	PCBs/day	68	41	55	54	60	57	49		65	
	Mean Time/PCB	136	261	208	176	159	162	160		123	
	SD	19	66	32	21	14	17	15		19	
W10 T	PCBs/day	37	40	53	57	39	51	40		41	
	Mean Time/PCB	223	356	289	260	226	229	228		181	
	SD	41	72	52	35	20	22	28		22	
W11 C	PCBs/day										
	Mean Time/PCB										
	SD										
W12 T	PCBs/day										
	Mean Time/PCB										
	SD										

Denotions : C / T - Cutout / Traditional WS, where, WS is workstation.
DV/IV - Direct Vision and Indirect Vision method of PC board assembly

TABLE - 4.4 - Average Time Per PC board (PCB in seconds) Versus Day of Training. Source of Data - PHY Records.

Worker & WS	Parameter (Sec.)	DV	IV							DV	
	Days of training→	1	1	2	3	4	5	6	7	2	3
W01 C	PCBs/day	39	7		35			49			
	Mean Time/PCB	155	459		285			215			
	SD	31	93		37			45			
W02 T	PCBs/day	42		23		46				31	
	Mean Time/PCB	204		386		306				190	
	SD	38		116		43				32	
W03 C	PCBs/day	25	21	40		28		42		59	
	Mean Time/PCB	211	465	416		332		286		193	
	SD	26	100	67		46		35		21	
W04 T	PCBs/day	19	13		40		42		37		
	Mean Time/PCB	221	559		381		317		280		
	SD	28	89		79		33		31		
W05 C	PCBs/day	60	21		63		60		69		
	Mean Time/PCB	180	361		204		177		174		
	SD	24	112		30		20		20		
W06 T	PCBs/day	17	36		33		43			35	
	Mean Time/PCB	252	431		342		318			212	
	SD	25	72		71		29			30	
W07 C	PCBs/day	45		16	23						
	Mean Time/PCB	272		458	491						
	SD	43		54	71						
W08 T	PCBs/day	2				24					
	Mean Time/PCB	203				300					
	SD	12				65					
W09 C	PCBs/day					58	52			57	
	Mean Time/PCB					163	161			127	
	SD					21	17			20	
W10 T	PCBs/day		35		52			37		24	
	Mean Time/PCB		345		266			229		200	
	SD		43		35			30		38	
W11 C	PCBs/day			46			50			59	
	Mean Time/PCB			326			273			184	
	SD			42			51			33	
W12 T	PCBs/day	60				32		43	51		
	Mean Time/PCB	279				381		348	322		
	SD	45				49		45	41		

Denotions : C / T - Cutout / Traditional WS, where, WS is workstation.
DV/IV - Direct Vision and Indirect Vision method of PC board assembly

Table - 4.5 - Average Time Per PC board (PCB in seconds) Versus Day Of Training. Source of data : PHY records and Protocols (indicated by symbol '*').

Worker & WS	Parameter (Sec.)	DV	IV							DV	
	Day of training →	1	1	2	3	4	5	6	7	2	3
W01 C	PCBs/day	39	7		35	35*		49			
	Mean Time/PCB	155	459		285	272		215			
	SD	31	93		37	51		45			
W02 T	PCBs/day	42		23		46	17*	50*		31	
	Mean Time/PCB	204		386		306	202	284		190	
	SD	38		116		43	28	46		32	
W03 C	PCBs/day	25	21	40	50*	28		42		59	
	Mean Time/PCB	211	465	416	334	332		286		193	
	SD	26	100	67	29	46		35		21	
W04 T	PCBs/day	19	13	35*	40	40*	42		37		
	Mean Time/PCB	221	559	449	381	328	317		280		
	SD	28	89	87	79	39	33		31		
W05 C	PCBs/day	60	21	55*	63	67*	60	77*	69	72	
	Mean Time/PCB	180	361	242	204	185	177	164	174	133	
	SD	24	112	47	30	16	20	12	20	16	
W06 T	PCBs/day	17	36	38*	33	46*	43	32*		35	
	Mean Time/PCB	252	431	364	342	328	318	308		212	
	SD	25	72	33	71	23	29	20		30	
W07 C	PCBs/day	45		16	23						
	Mean Time/PCB	272		458	491						
	SD	43		54	71						
W08 T	PCBs/day	2				24					
	Mean Time/PCB	203				300					
	SD	12				65					
W09 C	PCBs/day	68*	41*	55*	54*	58	52	49*		57	
	Mean Time/PCB	136	261	208	176	163	161	160		127	
	SD	19	66	32	21	21	17	15		20	
W10 T	PCBs/day	37*	35	53*	52	39*	51*	37		24	
	Mean Time/PCB	223	345	289	266	226	229	229		200	
	SD	41	43	52	35	20	22	30		38	
W11 C	PCBs/day			46			50			59	
	Mean Time/PCB			326			273			184	
	SD			42			51			33	
W12 T	PCBs/day	60				32		43	51		
	Mean Time/PCB	279				381		348	322		
	SD	45				49		45	41		

Denotions : C / T - Cutout / Traditional WS, where, WS is workstation.
DV/IV - Direct Vision and Indirect Vision method of PC board assembly

flexed position adopted during assembling operation. This sharp peak in the recording may also be due to the rotational movement of the cervical spine, as the subjects had to rotate to take a PC board from the carrier which was on their right hand side. The peaks of different amplitude as well as the zones of relatively low active motion of the cervical spine correspond to different assembly operations which can be easily identified from and synchronized with the video records collected during the experiment. The analysis of overall PHY records showed that some of the marks (M1...Mn) are missing because of human error. For example, Figure 4.11 highlights a missing mark between M12 and M13. The frequency of these missing marks is relatively rare in this experiment. Positions of these marks are determined by referring to the repetitive patterns of the PHY records.

Table 4.3 (data from protocols) and 4.4 (data from PHY records) illustrates the average time per PC board for all the subjects during their work on both types of workstations (DV/IV Cutout and Traditional). This data is averaged for each continuos series of PC board assembly operations. All the tables in this chapter display the Worker, the workstation he/she was working on, and the shift worked. A program was developed in Turbo Basic for the statistical analysis of the productivity data. The program gives a macro analysis of data producing mean, maxima, minima, standard deviation (SD) and coefficient of regression for time per PC board, PC board per second and components per second for a single continuous series. Further, these series are averaged in terms of PC boards/day and mean time per PC board (Table 4.3 and 4.4). A comparison between the data on productivity from protocol and PHY records (after determining of the missing marks) signifies that both sources of data have quantifies equal time for the assembly of a single PC board for all subjects. The only unexplained irregularity is in the data of Worker W03 during the 4th day of work at the IV Cutout workstation - 271 sec per PC board (data from protocols) and 332 sec per PC board (data from PHY records). Moreover, the equality of the two sources (protocol and PHY) of data for productivity of assembling can be highlighted by Figure 4.1. Figure 4.1 is a plot of average time per PC board (sec) v/s

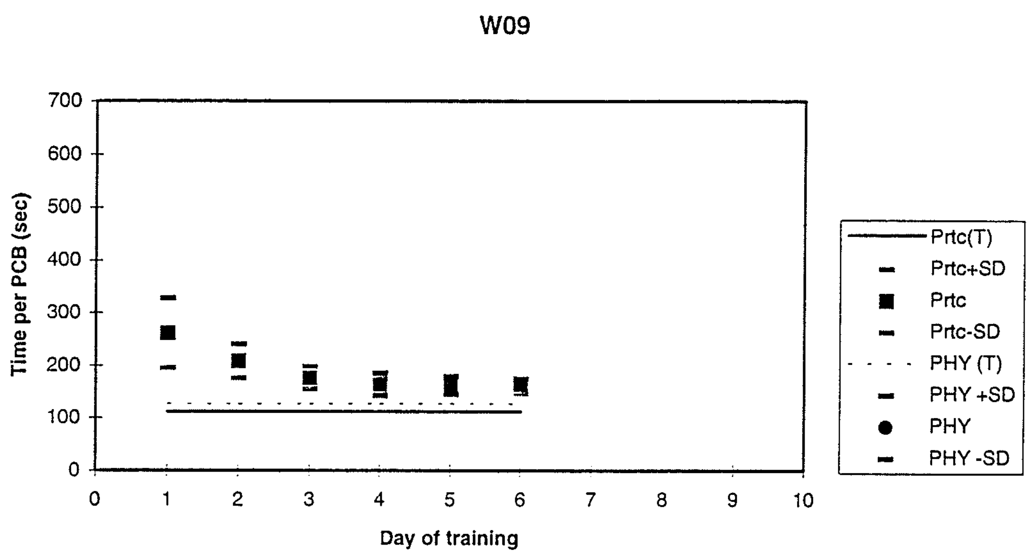


Figure 4.1 -
Illustrates monotonic nature of training and a comparison between protocol and PHY records. Training phenomenon is predicted in terms of average assembly time as a function of day of training for Worker nine.

day of training for the Worker Nine (W09). The graph demonstrates an overlapping pattern of averaged time per PC board for both sources of data. Considering the equality of data, the averaged data from two sources were combined in order to compensate for missing data (Table 4.5). For example, the first day's data for Worker One (W01) is missing in the protocol source (Table 4.3), therefore the data is taken from the PHY record (Table 4.4) and is combined in Table 4.5.

4.2 PRODUCTIVITY AND METHODS OF ASSEMBLY

The two methods (DV and IV) of PC board assembly are compared on the bases of the average time taken by each subject for the assembly of a single PC board. The data for the DV method of assembly is taken from the first day of their work at the Traditional and Cutout workstations. Similarly, the data for the IV method of assembly is taken from the last day of their work at the IV workstation. Table 4.1 and 4.2 shows the result of the comparison of the two methods.

As mentioned in chapter 3 the Workers 01, 03, 05, 07, 09, and 11 worked on the Cutout Direct and Indirect vision workstations, while the Workers 02, 04, 06, 08, 10 and 12 worked on the Traditional Direct and Indirect vision workstations. From Table 4.1, the overall average time for the assembly of a single PC board on the DV Cutout work station is 189.70 seconds. Similarly, time for a single PC board on the Indirect vision Cutout workstation is 266.5 seconds. Therefore, the average time for assembly is 28.8 % less in case of the DV method for the Cutout workstation. The standard deviation of productivity data for the DV method of assembly is 47.84 which is very low when compared to the standard deviation in productivity data for the IV workstation (121.14). Hence, the data from the Direct method of assembly is more reliable. The standard deviation in the difference of productivity for the two methods of assembly is 16.50. Individual data in Table 4.1 illustrates that only Worker Five (W05) has higher level of productivity on the IV Cutout workstation when compared to the DV Cutout workstation. However, for all other workers the level of productivity is lower on the

Table 4.1 - Indicates the comparison of the Direct vision (DV) and the Indirect vision (IV) Cutout workstation in terms of productivity (time per PCB).

WORKER	DV (First day) Time per PCB	IV (Last day) Time per PCB	Difference (DV-IV) Time per PCB
W01	155	215	-38.71
W03	211	286	-35.55
W05	180	174	3.33
W07	272	491	-80.51
W09	136	160	-17.65
W011	184	273	-48.37
MEAN	189	266.50	-40.51
SD	47.84	121.14	-153.24

Table 4.2 - Indicates the comparison of the Direct vision (DV) and the Indirect vision (IV) Traditional workstation in terms of productivity (time per PCB).

WORKER	DV (First day) Time per PCB	IV (Last day) Time per PCB	Difference (DV-IV) Time per PCB
W02	204	284	-39.22
W04	221	280	-26.70
W06	252	308	-22.22
W08	203	300	-47.78
W10	223	229	-2.69
W012	279	322	-15.41
MEAN	230	287.17	-24.67
SD	29.73	32.42	-9.06

IV Cutout workstation when compared to the DV Cutout workstation. Worker Seven (W07) has a maximum difference in productivity level (44.60%), this is because of the fact that he/she only worked for two days on the IV workstation and still was in a learning period. Therefore, the productivity data of Worker Seven (W07) is eliminated from the average data of workers who worked on the Cutout workstation. This elimination results in reduction of overall difference between the productivity of the two methods. The new overall productivity is 21.84% which is 6.99% less than the previous difference. Also, the deviation of difference in productivity data is reduced from 16.50 to 14.49 and thereby the mean value of productivity difference is more reliable.

When the subjects were working on the Traditional type of DV workstation (developed in the lab) their average productivity was 230.33 seconds per PC board. Similarly, their average productivity was 287.17 seconds per PC board on the IV method of assembly. Therefore, the productivity is 19.80 % higher for the subjects when they were working on the Traditional type of DV workstation. The deviation in the mean value of the DV method is less than that of the IV method. The low productivity for the IV method of assembly on both types of workstation might be due to the influence of the learning period. Table 4.5 shows an decreasing pattern in the time per PC board on a day-by-day basis for the IV assembly method. Thus, it is necessary to find the duration of training required by individual subject on the IV method in order to reach the same productivity level as that of the DV method.

4.3 TRAINING

In this section the individual dynamics for time of assembly of a single PC board on a day by day basis of training is considered. For example, the series of Figure 4.2, 4.3 and 4.4, illustrates the individual dynamics of Worker Nine (W09). The graphs are placed in chronological order starting from the first day of work at the DV Cutout workstation (the top graph in Figure 4.2), through the first, the second and so on days of work at the IV Cutout workstation, and finishing on the last day of work at the DV Cutout workstation (the bottom graph on Figure 4.4). The points of discontinuations in the plotted broken lines correspond to the beginning and the end of each continuous series of assembled PC boards. The discontinued straight lines correspond to the first and the last day of work at the DV workstation.

The most extraordinary feature of all the graphs illustrating individual dynamics on a day by day basis is the non-monotonous and wave-like shape of the variations of the time of assembly as a function of the number of trials. Such variations are typical not only for separate series of PC boards, but even for a group of continuous series of PC boards. This fact is evident from the top and the middle graphs in Figures 4.2, 4.3 and 4.4 that shows the data of Worker Nine (W09). Here, the shape of the broken curve is independent of the discontinuation. The non-monotonous character of variations can be easily explained as a result of statistical variations. However, the same explanation does not apply to the second phenomenon (wave-like variations). The explanation of the wave like behavior obviously can not be given in terms of statistical variations. Most of the authors stated that the overall learning phenomenon is of monotonous nature. This fact is evident from the Figure 4.1 which illustrates averaged assembly time as a function of day of training. This figure shows a decrease in the average time of assembly with respect to increase in the days of training. However, non-monotonous phenomenon for assembly time as a function of number of trials can be theoretically interpreted by the theory of learning developed by Venda and Venda (1995). The theory states that the phenomenon of learning (to perform some task) can be represented by a bell shaped curve of efficiency versus time spent using a particular strategy. This bell shaped curve is a typical function

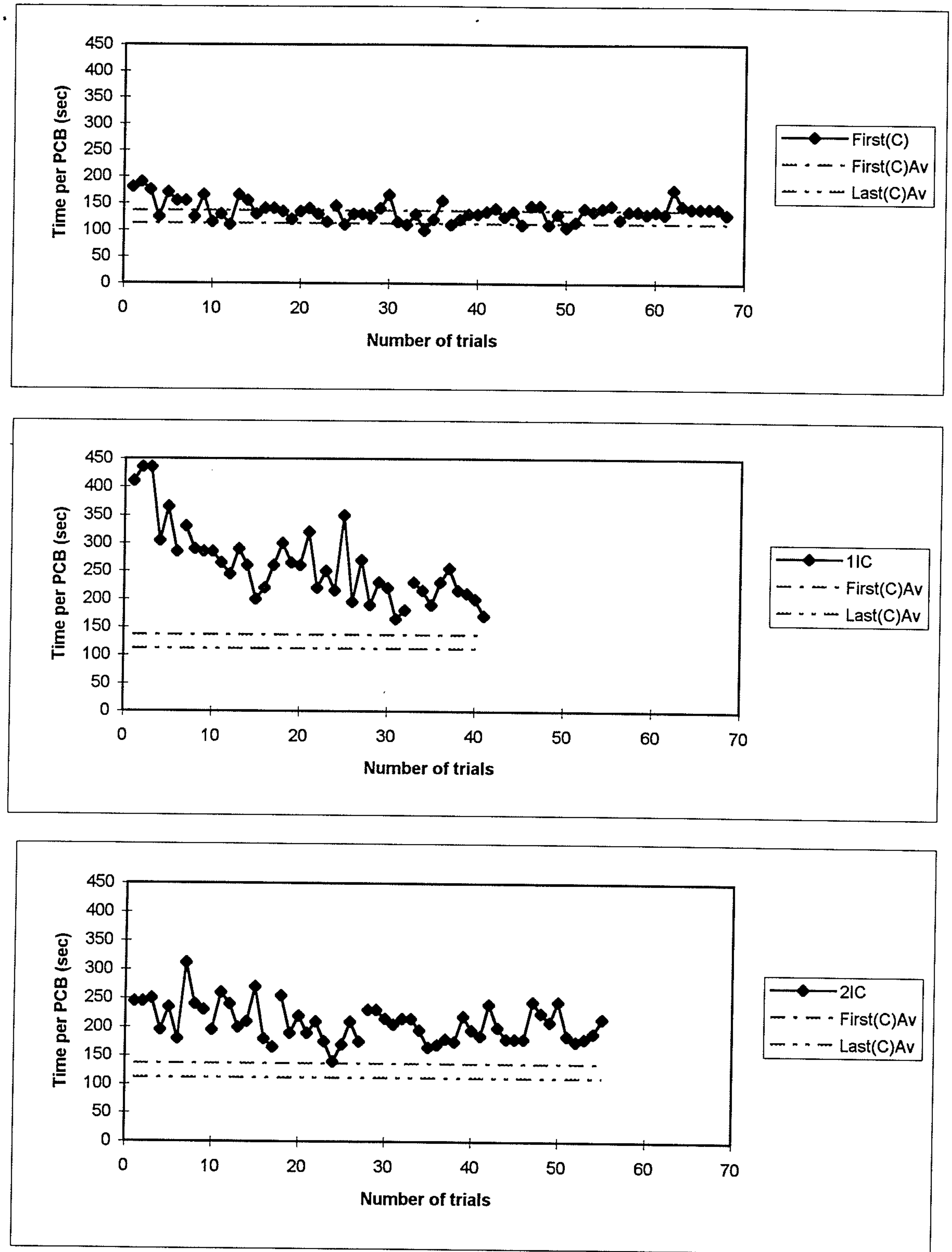


Figure 4.2-
Time per PCB as a function of number of trials for W-09. Here First(C)- 1st day on the cutout workstation Last (C)- Last day on the DV mehtod and 1IC, 2IC and 3IC are 1st,2st,3nd day on the IV mehtod when working on the Cutout workstation.

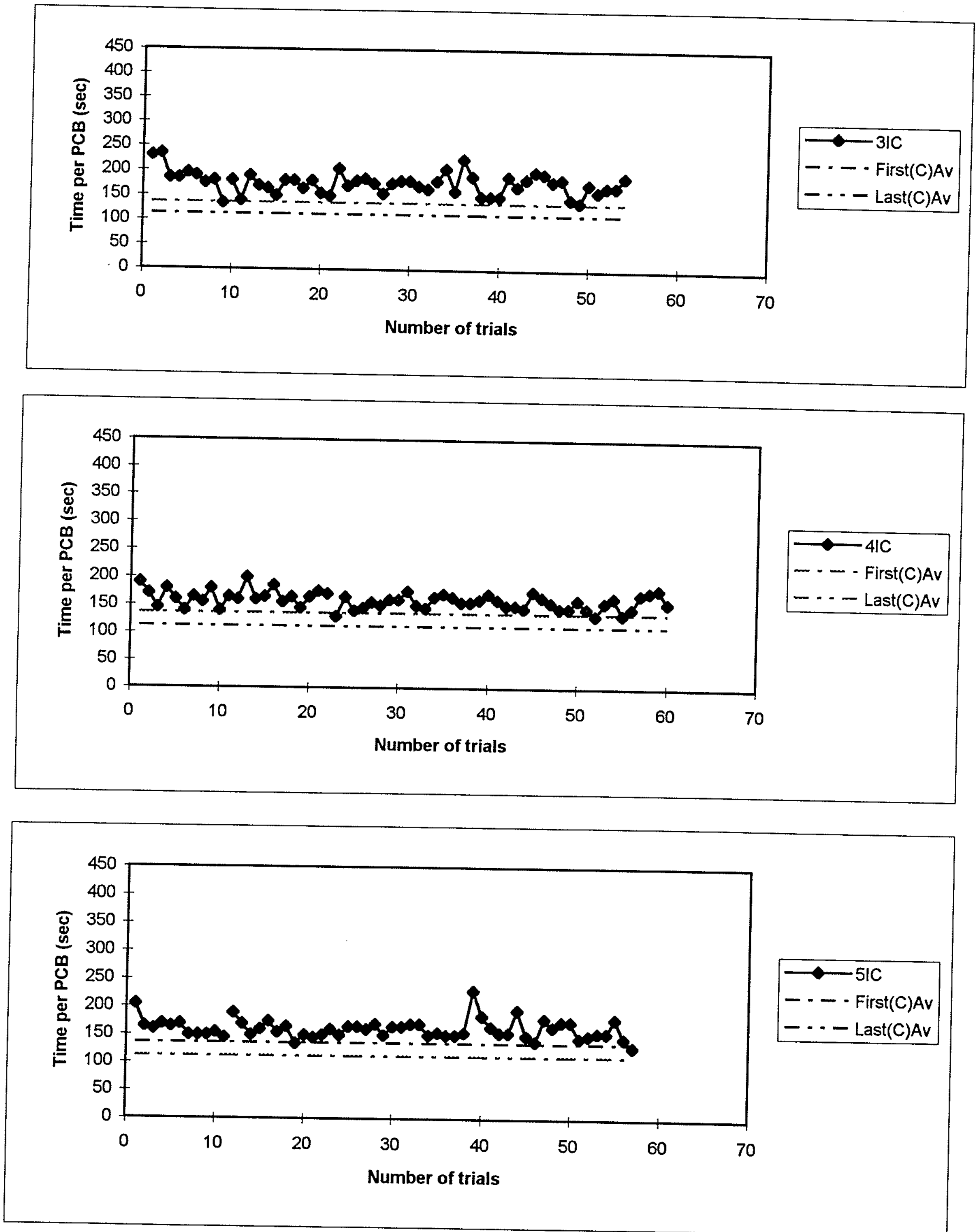
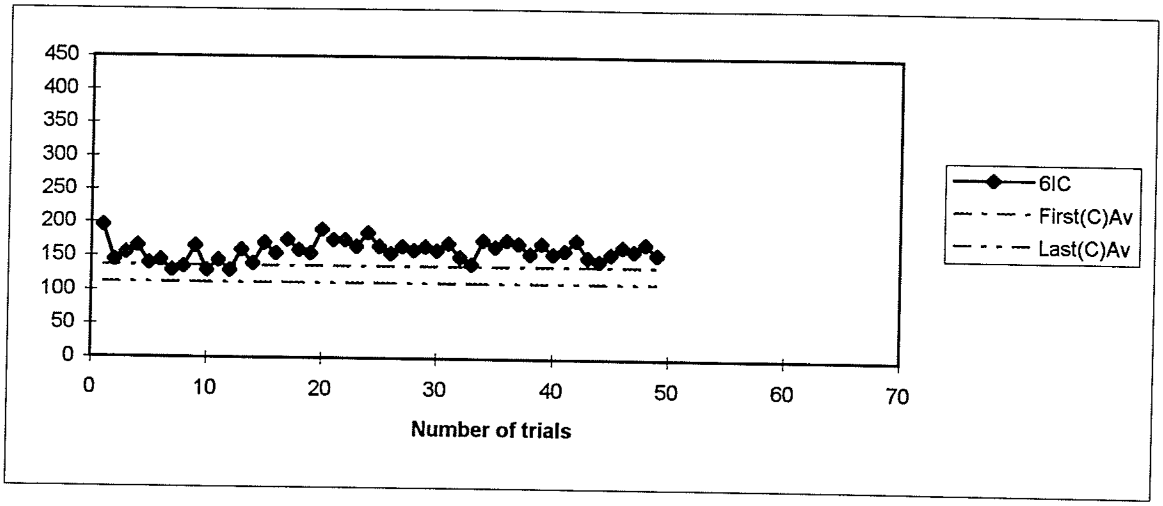
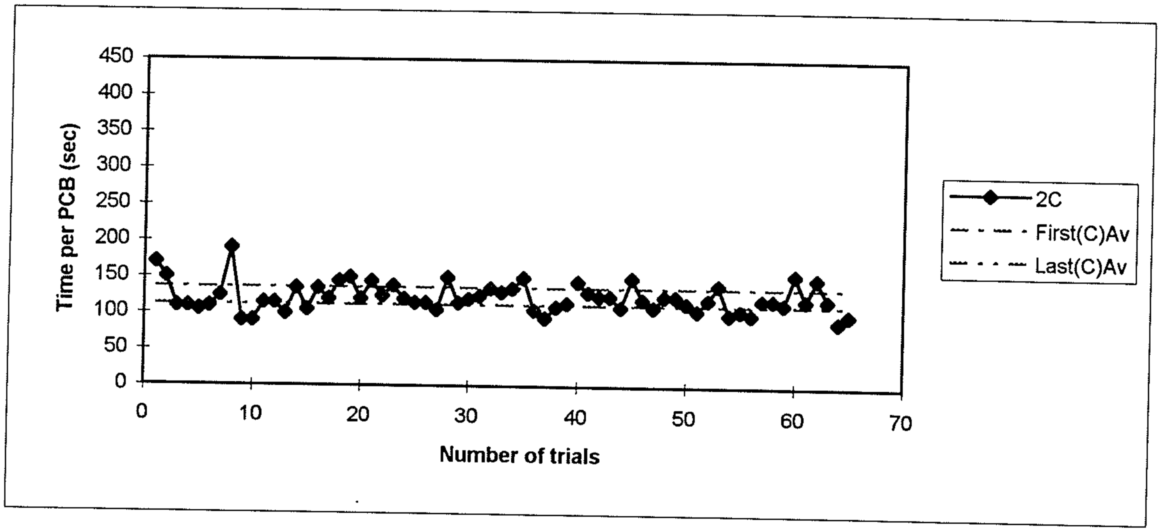


Figure- 4.3 -
Time per PCB as a function of number of trials for W-09. Here First(C)- 1st day on the cutout WS Last (C)- Last day on the DV mehtod and 1IC, 2IC and 3IC are 1st,2st,3nd day on the IV mehtod when working on the Cutout WS.





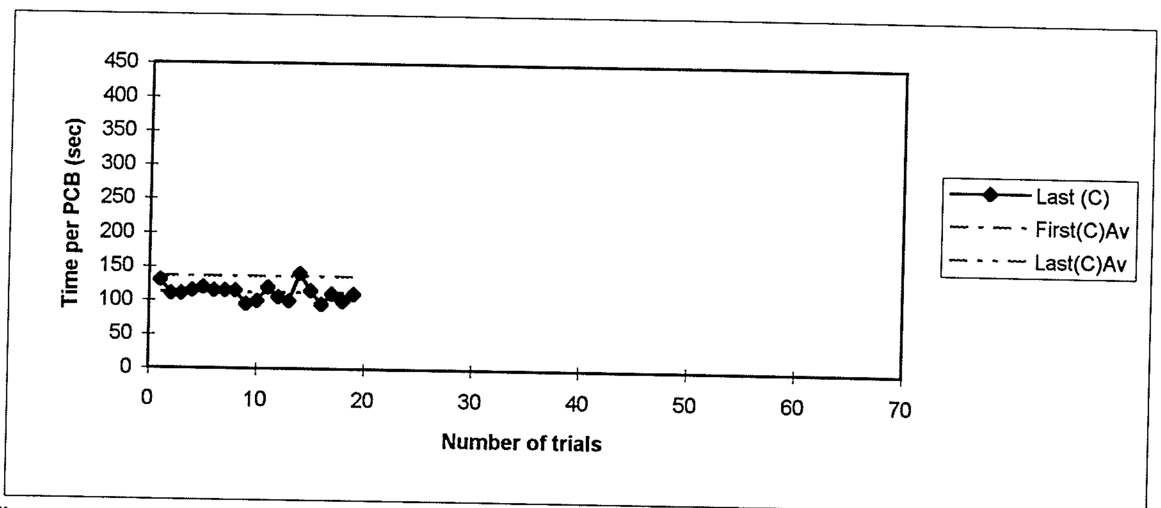


Figure- 4.4 -

Time per PCB as a function of number of trials for W-09. Here First(C)- 1st day on the cutout WS Last (C)- Last day on the DV mehtod and 6IC, 2C and Last(C) are 6th day on the IV mehtod and 2c and last(C) represents last day of work on the IV mehtod when working on the Cutout WS.

of efficiency and some work factor. According to this theory the non-monotonous behavior in learning is due to different strategies used during the performance of work. A consequence from this learning model is that the observable learning curve can have a non-monotonous shape where the peaks will correspond to the maximum efficiency of performance for some particular strategies while the local minima will correspond to the zone of transformation between different strategies. However, in this experiment the averaged assembly time as a function of day of training is (Figure 4.1) monotonic, indicating the Venda and Venda theory of learning represents short duration strategies. Also, the present data is unable to specify any particular single strategy that might have caused the wave-like shape of the curves in Figures 4.2, 4.3 and 4.4. Attempting to define such strategies is beyond the scope of this work but would be very appropriate to research in task efficiency studies.

During the first day of training at the IV workstation a specific effect in reduction of the time of assembly was observed (Figure 4.2). This specific effect is a common effect for nearly all kinds of training processes. Also the variation in the average time of assembly increases monotonously from the first day of work at the IV workstation (coefficient of variation 0.25) to the last day of work at the IV workstation (coefficient of variation 0.10). This monotonic increase is another common effect for training processes. For further analysis of training procedure, the averaged individual data on productivity of assembling has been considered. Table 4.5 contains mixed (Protocols and PHY records) data for average time of assembly as a function of day of training for all 12 subjects who participated in this experiment. For the explanation of training period, the data of Worker

Nine (W09) is considered for illustration. This data is shown in Figure 4.5. The discontinued straight lines in Figure 4.5 represents the first and the last day of work at the DV workstation. Whereas, the continuous smooth curve or line corresponds to three different regression models. Three regressions functions namely - Polynomial (Pol.regr.), exponential (Exp.regr.), and exponential-power (ExPw.reg.) were tested in order to determine the best model for the training process (in statistical sense) in the experimental data. Table 4.6 to 4.9 represents averaged time for assembly as a function of day of training for all the subjects. Further, Table 4.6 contains the results of approximation of the data for Worker W01, W02, W03, W04, W05, W06, W08 and W10 respectively. This table excludes workers who had worked less than four days for the experiment (W07, W08, W11 and W12). The last column for each regression model contains the Fisher's coefficient for global (overall) test of the zero hypothesis (all coefficients in the particular model are equal to zero). For the analysis of data, the coefficients for the three regression models were separately calculated for the IV Cutout and for the IV Traditional workstations (Table 4.6 to 4.9). The corresponding graphs are plotted in Figures 4.6, 4.7 and 4.8. The averaged regression curves were obtained by separately calculating the average of individual regression curves for Workers W01, W03, W05, W09 (Cutout workstation) and W02, W04, W06, W10 (Traditional workstation). Table 4.6 (for the individual regression models) and Table 4.7 (for the averaged regression models) give a plausible extrapolation of the data from this experiment (Figures 4.6, 7.7 and 4.8).

The regression models and their analysis is presented in Table 4.8 and 4.9. The following results are obtained from regression analysis.

4.3.1 POLYNOMIAL MODEL

Table 4.8 and 4.9 shows the results of this model. From this model it can be perceived that Worker Five (W05) needs a training period of four to seven days on the IV method to reach the same productivity level as that of the DV method of assembly. However, for rest of the workers this level of productivity can apparently never be achieved on the IV method of assembly.

4.3.2 EXPONENTIAL MODEL

The exponential model is monotonous in nature and due to this reason the curve generated by exponential model will always be crossing the horizontal lines of performance at the DV workstations. Hence, in reality exponential model can not describe the training period needed by subjects to reach the productivity level of the DV method when they were working on the IV method of assembly. However, for the individual curves this cross over is between the 5th and the 11th days of training. If individual training period is considered, then for Worker Ten (W10) it is minimum and for Worker Six (W06) it

is maximum. Similarly, Table 4.9 shows the averaged curve cross over is respectively between the 8th and the 9th days of training for the Cutout IV workstation. Also, the cross over point is between the 8th and the 10th day of training for the Traditional IV workstation. The above data shows that if workers are transferred to the IV method, that within eight to ten days they will be working at their previous productivity level. This is not true because of the monotonic character of the exponential regression curves. Thus, it can be conclude that this model is not the proper descriptor of the training period.

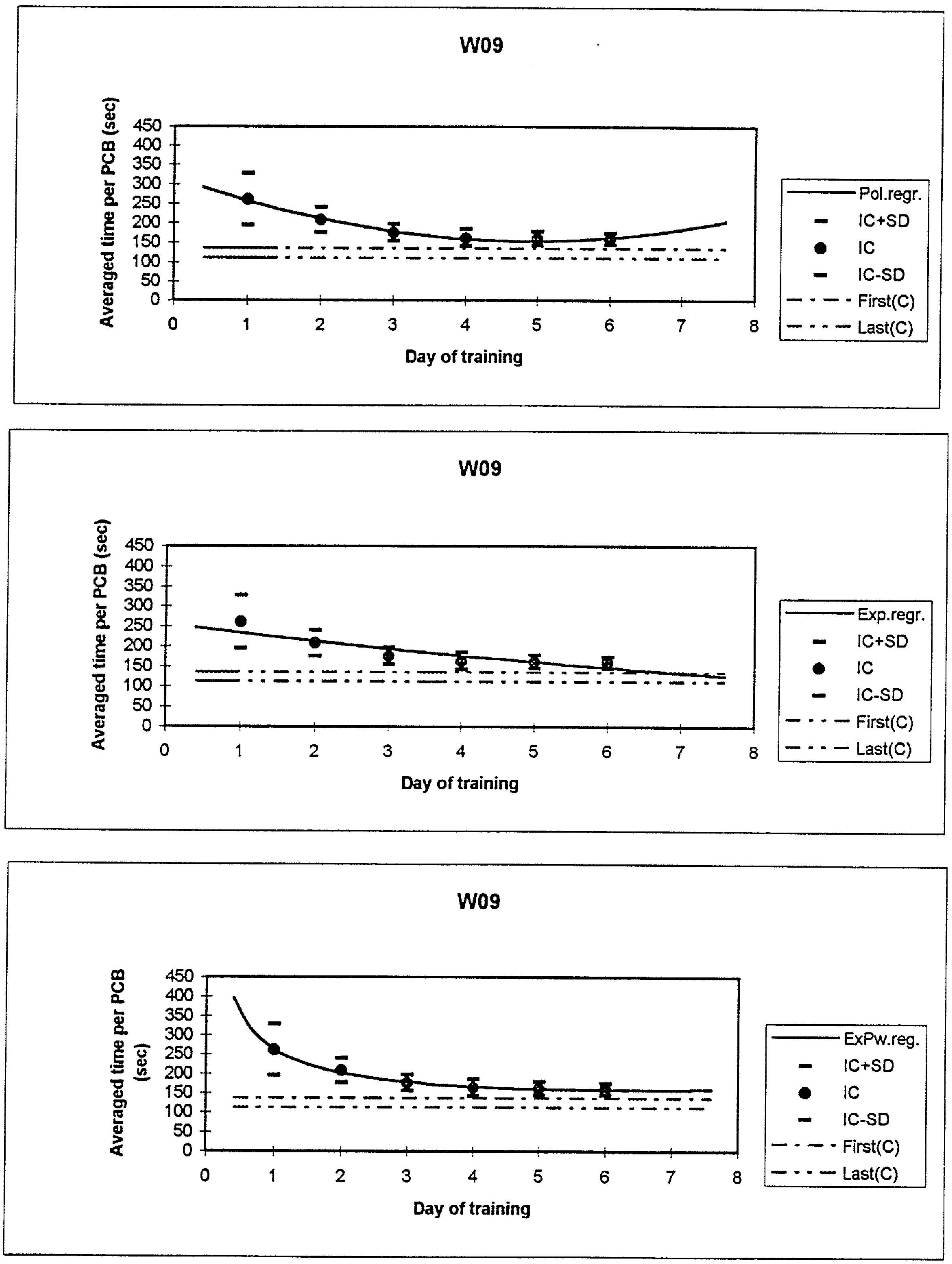


Figure- 4.5 -
Average assembly time as a function of day of training (W09). The curves indicates three regression models - polynomial (F=135), exponential (F=17) and power exponential (F=182)

Table - 4.6 - Testing of three regression models for the training period of the individual subjects: (Average time per PC board taken as function of training)

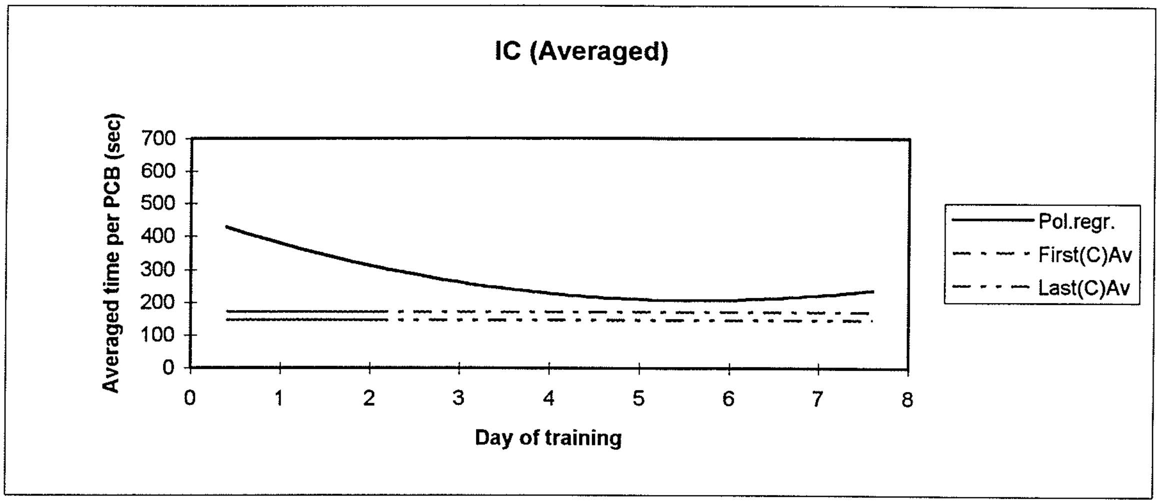
Worker	Total days of work	Regression Model										
		Polynomial				Exponential			Exponential Power			
		$C0+C1\times X+C2\times X^2$				$(A\times e^{B\times X})$			$A\times X^{B}\times e^{C\times X}$			
		C0	C1	C2	F	A	B	F	A	B	C	F
W01	4	562	-115.7	9.75	26	496	-0.148	28	465	-0.37	-0.015	72
W02	4	537	-90.4	8	211	443	-0.083	17	500	-0.63	0.09	65
W03	5	537	-80	6.39	25	487	-0.094	31	479	-0.20	-0.025	21
W04	6	660	-119.2	9.39	129	568	-0.113	39	564	-0.36	0.001	244
W05	7	435	-102	9.43	35	324	-0.111	16	323	-0.72	0.109	822
W06	6	481	-63.5	5.95	41	430	-0.062	25	417	-0.26	0.028	391
W07	2											
W08	1											
W09	6	317	-66.3	6.79	135	256	-0.093	17	244	-0.49	0.076	182
W10	6	408	-70.9	6.86	88	373	-0.098	17	337	-0.34	0.034	47
W11	2											
W12	3											
Mean F					86			24				230

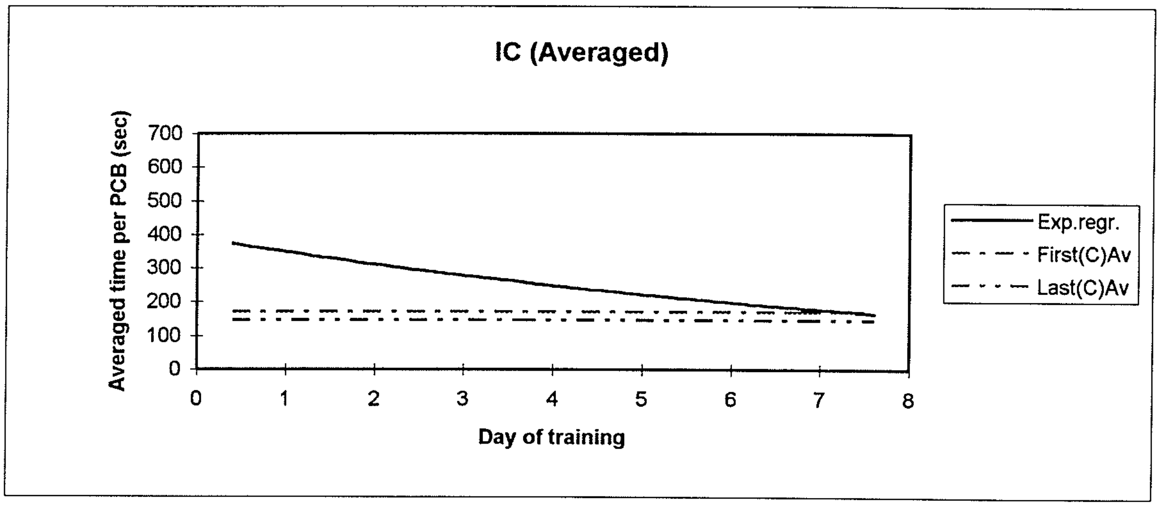
Denotation : F - Fisher's coefficient for the global (overall) test.

Table - 4.7 - Testing of three regression models for the Traditional and Cutout workstations.

Workstation	Regression Model							
	Polynomial			Exponential		Exponential Power		
	$C0+C1\times X+C2\times X^2$			$(A\times e^{B*X})$		$A\times X^{B}\times e^{C*X}$		
	C0	C1	C2	A	B	A	B	C
Traditional	521	-86.2	7.56	452	-0.089	454	-0.413	0.0412
Cutout	463	-90.1	8.08	389	-0.112	379	-0.418	0.0258

NOTE : The average regression curves are obtained by taking the average of the individual regression curves.





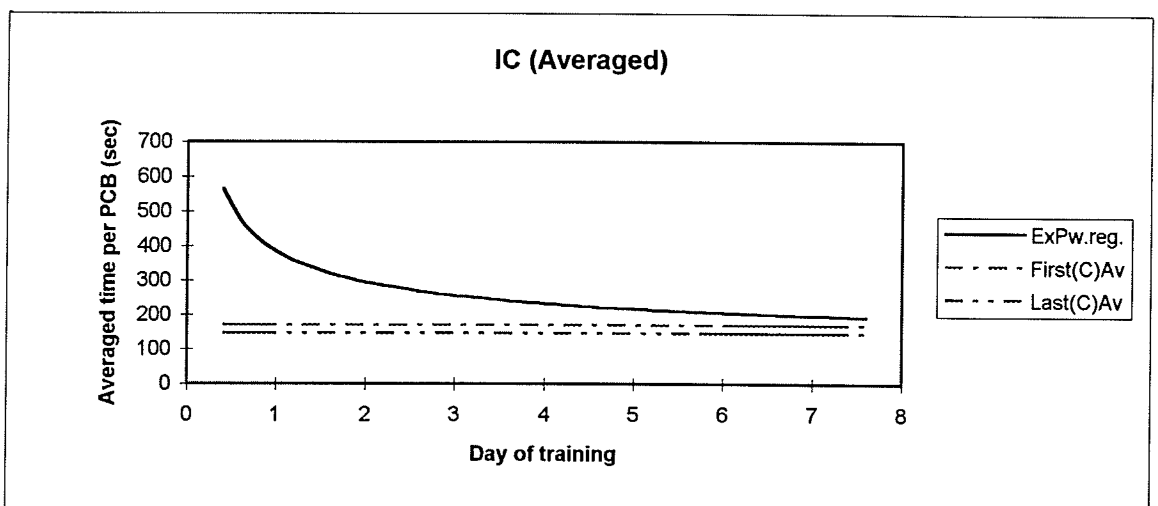
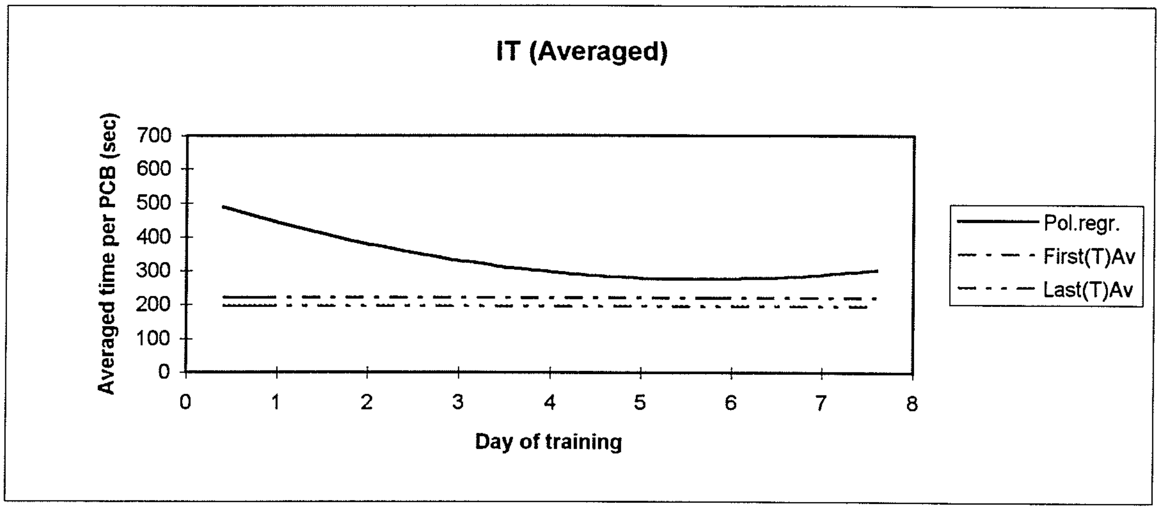
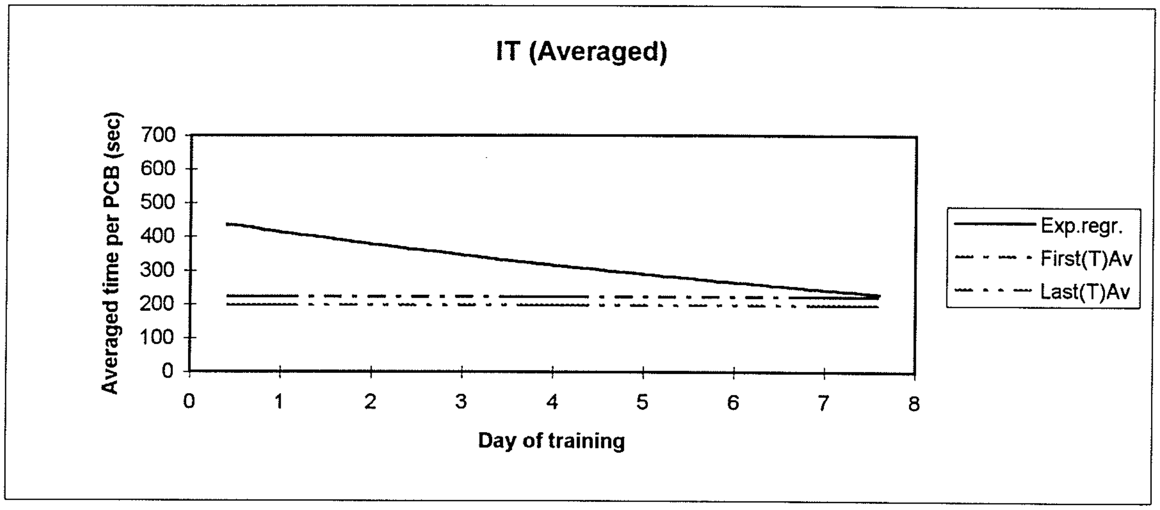


Figure- 4.6-
Average assembly time as a function of day of training (on cutout WS). The curves indicates three regression models were obtained after averaging individual regression curves.





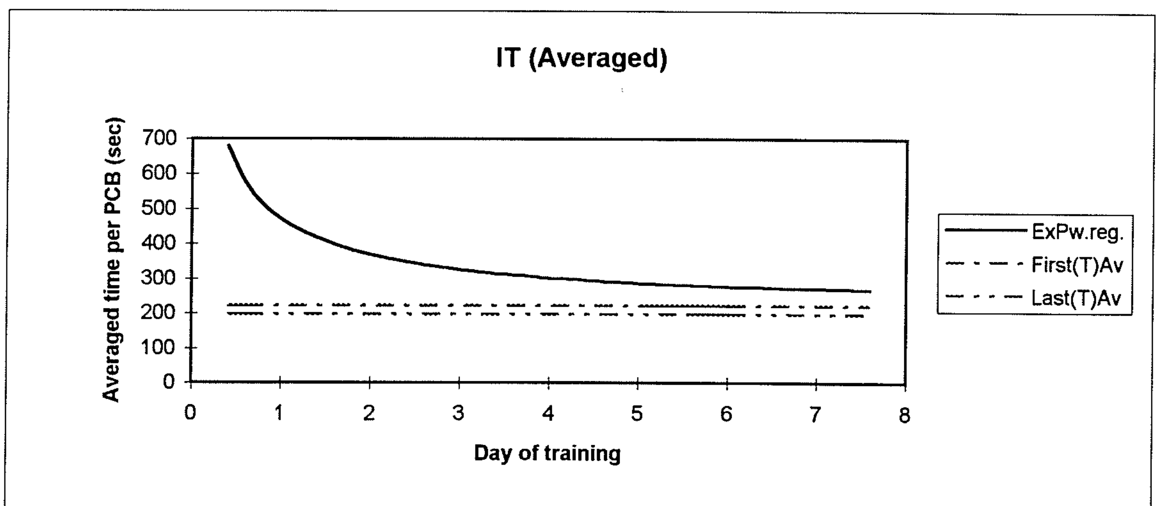
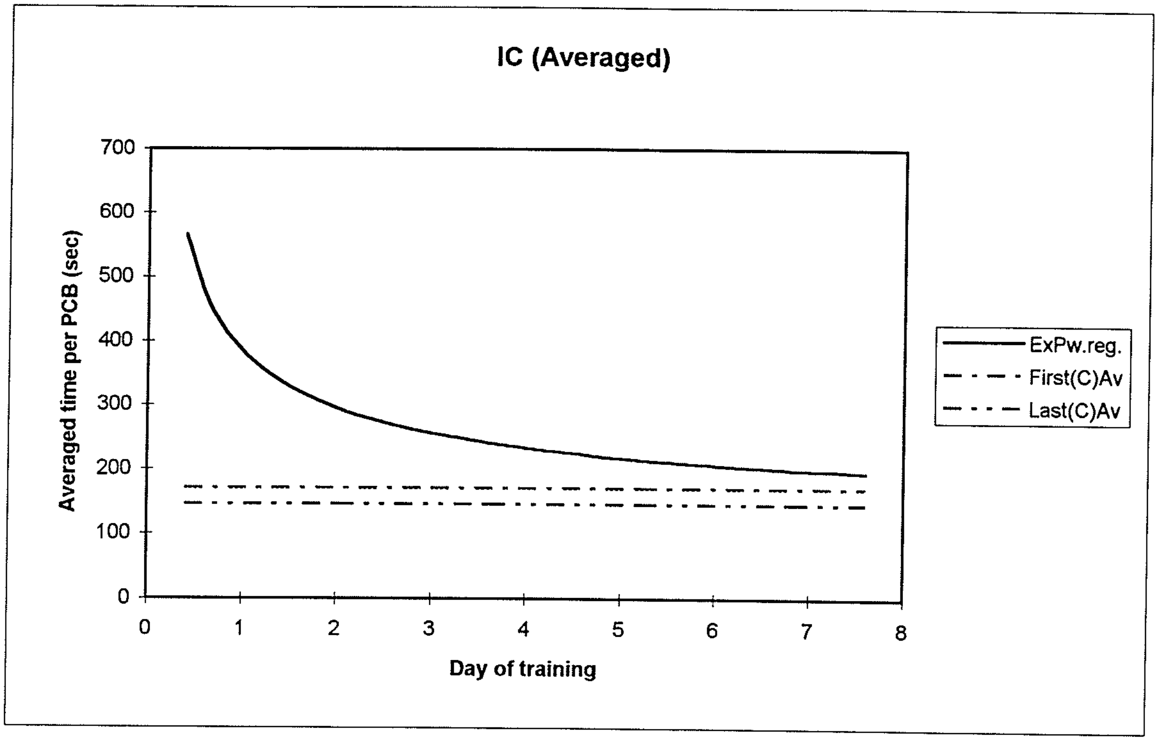


Figure- 4.7-
Average assembly time as a function of day of training (traditional WS). The curves indicates three regression models, obtained from average of individual regression curves of Workers 02,04, 06 & 10.



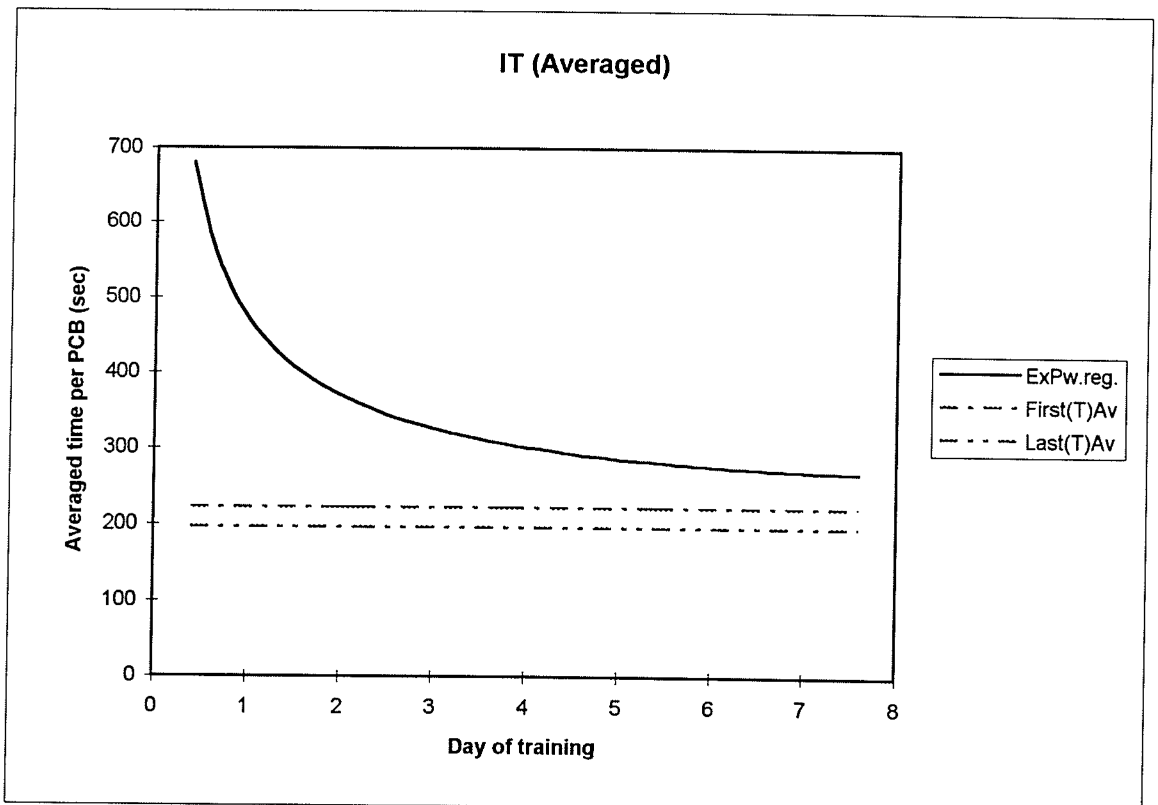


Figure- 4.8 -
Average assembly time as a function of day of training on the traditional and cutout workstation's.

Table - 4.8 - Extrapolation (individual data) models showing the number of days required to equal the productivity level of the DV method when subjects were working on the IV method of PCB assembly.

Regression models	**Day of work on the DV**	**Worker**							
		W01	W02	W03	W04	W05	W06	W09	W10
Polynomial	First	9999	9999	9999	9999	4, 7	9999	9999	9999
	Last	-	9999	9999	-	9999	9999	9999	9999
Exponential	First	8	9	9	8	5	9	7	5
	Last	-	10	10	-	8	11	9	7
Power Exponential	First	11	9999	12	13	4	9999	9999	6
	Last	-	9999	14	-	9999	9999	9999	9999

Denotations : DV/IV - Direct Vision / Indirect Vision Method of PCB assembly

'-' - no data

9999 - Indicates the subjects can not reach the productivity level of the DV method even within 500 days of training on the IV method of assembly

Table - 4.9 - Extrapolation (individual data) models showing the number of days required to equal the productivity level of the DV method when subjects were working on the IV method of PC board assembly at the two workstations (Traditional and Cutout).

Regression models	**Day of work on the DV**	**Workstation Type**	
		Traditional	**Cutout**
Polynomial	First	9999	9999
	Last	9999	9999
Exponential	First	8	8
	Last	10	9
Power Exponential	First	9999	9999
	Last	9999	9999

Denotations : DV/IV - Direct Vision / Indirect Vision Method of PCB assembly

'-' - no data

9999 - Indicates the subjects can not reach the productivity level of the DV method even within 500 days of training on the IV method of assembly

4.3.3 POWER-EXPONENTIAL MODEL

The individual regression curves for the exponential-power regression model shows that 62.2% of the workers intersect the level of performance at the DV workstation (Table 4.9). However, the two workers (W01 and W04) did not cross the level of their last day of work at the DV workstation. The averaged regression curves for this model do not cross the level of performance at the DV workstation in both cases of the Traditional and Cutout workstations (Table 4.8). These results are also plotted in Figure 4.8.

A comparison of the Fisher's coefficient in Table 4.6 shows that for almost all workers the exponential-power model gives a better (in terms of value of F) approximation of the data. The averaged value of 'F' for polynomial, exponential, and exponential-power models are respectively 86, 24, and 230 (Table 4.6). Thus, the exponential-power model can be adopted as the most representative one for analytical description of the data and respectively for extrapolation.

Simple numerical evaluation of the local minimum of the averaged regression curves for the exponential-power model shows that the curve for the IV Cutout workstation (Figure 4.8) reaches its minimum around the 16th day of training. Similarly, the curve for the IV Traditional workstation reaches its minimum around the 10th day of training. The values of this minima are respectively about 180 sec per PCB and about 265 sec per PCB. The slope of both curves around the point of minima is very small -- about 1 sec per 7 days (Cutout workstation) and 1 sec per 4 days (Traditional workstation). Therefore, the regression curves reach their minima in approximately 13 to 20 days for the Cutout workstation and in 9 to 12 days for the Traditional workstation. A comparison between the minimum values of the regression curves and the level of performance at the DV workstation shows that the minimum value for the time of assembly at the IV Cutout workstation exceeds the minimum value at the DV Cutout workstation by 6% (first day of work at the DV workstation) and by 19% at the last day of work at the DV workstation. The corresponding numbers for Traditional workstation are 19% and 35%. These last four numbers give a overall picture of the experimental evaluation the two workstations (DV & IV) on the basis of productivity.

4.4 SUMMARY

Data from the protocols and the PHY records were combined in order to compare the two types methods (DV and IV) for the assembly of PC board. The average data obtained from the combination of the protocols and the PHY records showed that the time taken for the assembly of a single PC board is (19 to 44%) greater on the IV method compared to the DV method of assembly. Hence, it can be concluded that the productivity level is higher for the DV method of PC board assembly. During work at the IV method of assembly the subjects never reached the productivity level of the DV method (except to Worker Five).

A regression analysis was conducted to find the duration of training required by the subjects to reach their maximum level of productivity on the IV method of PC board assembly. Three exponential models, the polynomial, exponential and power-exponential model, were used for the description of the training period involved during work at the IV workstations. The Fisher's test was conducted and it showed that the power-exponential model was the best descriptor for the training phenomenon. The slope of the regression curve showed that during work at the IV Traditional workstation, the minimum assembly time is reached approximately in 9 to 12 days. Similarly, the minima for the IV Cutout workstation can be reached in 13 to 20 days. However, this minimum assembly time for the IV method is still higher than that of the DV method. Hence, the use of the IV method for PC board assembly shows a lower level of productivity. Further investigation is required to improve the level of productivity for the IV method of assembly. Such investigation may be worth while if it can be shown that the risk of repetitive strain injury is truly reduced by the IV workstation arrangement.

CHAPTER 5

ANALYSIS OF PHYSIOMETER RECORDS

5.1 DATA COLLECTION

This chapter describes with the processing and critical examination of the following physiological measures:

1) electromyography (EMG) signals obtained from the upper right and left trapezius muscle.

2) postural measurements in terms of flexion and lateral flexion of the cervical and thoracic spine.

Finally, these physiometer measurements are to be correlated with subjective data regarding comfort and objective data regarding productivity. The object of the correlation is to determine how strongly or weakly correlated comfort and productivity may be a long term correlation between comfort and repetitive strain injury.

The physiometer-400 (PHY-400) was used for the recording of EMG signals and postural measurements (described in chapter 3). The signals are recorded in real time on-line measurements. The on-line measurement system displays a graph of all the active channels (channels used in the study) in real time on a PC monitor. The experimental signals are stored on the hard drive disk for off-line analysis. The off-line analysis program displays a list of all the calibrated files along with the normalized differential amplitude distribution of the recorded signal. The off-line analysis program provides the option of selecting a portion of the displayed signal by using right and left markers on a displayed record. The software calculates the normalized differential distribution for this selected portion of the signal and displays the distribution on a PC monitor. For example, if the total EMG recording is of two hours duration then a small part of the record, say two minutes, can be marked and a normalized and integral distribution for this part can be obtained. A printout of these distributions can be obtained by a dot matrix printer. An example of these distributions is shown in Appendix 5.1 (page 171) which contains samples of the distributions for worker W09.

PHY records were selected in order to establish a comparison of muscular activities between the direct and indirect (DV and IV) vision methods of PC board assembly. Usually, the first day of PCB assembly by the DV method was considered as a baseline for comparing with the last day of PC board assembly by the IV method. This was done since the subjects had been Traditionally working on the assembly line using DV method of assembly. The only exceptions were occasional cases where the data for the corresponding PHY records were either missing or of low quality. Fortunately occasional cases were rare. The term 'low quality' signifies noise in the EMG signal, electrodes working loose or damaged electrode cables etc. These poor signal condition represented less then 2% of the data. The selected data is marked by asterisks in Table 5.2.1 of Appendix 5.2 (page 185). The selected groups of graphically presented, normalized differential amplitude distributions were digitized by scrolling X and Y markers on the display. The X and Y coordinates for these markers were displayed on the distribution. These coordinate values were manually fed to a program developed in Turbo Basic. The program calculates area under the distribution and displays all the required statistical parameters such as mean, standard deviation (SD), maxima, minima and test of hypothesis. Finally, the analyzed data was converted into tables using Microsoft EXCEL software.

5.2 DATA PROCESSING

Analysis of the data showed that the distribution corresponding to both types of measurements (EMG and Postural) is unimodal. Hence, all the selected normalized differential amplitude distributions were standardized by the following numerical characteristics:

Numerical Characters Used For The Standardization Of The Distribution	
Xmin	- left-side minimum value of the distribution curve along %MVC (for EMG) or angle (for Posture) axis;
Xmax	- right-side minimum value of the distribution curve along %MVC (for EMG) or angle (for Posture) axis;
Xmode	- mode of the distribution;
Ymode	- value of the distribution that corresponds to **Xmode**;
Area	- area below the distribution;
High	- conditional height of the distribution calculated as **Area/(Xmax-Xmin)**;
Width	- conditional width of the distribution calculated as **Area/Ymode**;
Mean	- mean value along %MVC (for EMG) or angle (for Posture) axis, calculated as first moment of the distribution;
SD	- standard deviation, calculated as second central moment of the distribution;
Skew	- skewness or asymmetry of the distribution, calculated as the third central moment divided by $\mathbf{SD^3}$;
Kurt	- kurtosis or flatness of the distribution, calculated as $\mathbf{m_4/SD^4-3}$, where $\mathbf{m_4}$ is the forth central moment of the distribution.

Each of the characteristics listed above describes one or another side of the normalized differential amplitude distributions. For example, in the specific terms of the data discussed here, SD^2 (respectively the parameter Area) is proportional to $(\%MVC)^2$ for EMG measurements and $(angle)^2$ for Postural measurements. This allows an interpretation in terms of workload. However, the SD^2 parameter can not be considered in the same way for EMG and Postural measurements. For EMG measurements the mean value along the %MVC axis has to be considered in order to take into account the absolute workload of the muscles. Thus, two equal values of SD, but at different values of the parameter mean will correspond to different workloads and vice versa -- two equal values of mean but two different values of SD will correspond to different workloads. However, for postural measurements SD is sufficient to evaluate the workload, due to the arbitrary choice of the zero degree point along the angle axis (refer to distribution of channels 4,5,6 or 7). Furthermore, the two dimensionless parameters Skew (skewness) and Kurt (kurtosis) provides additional information about the shape of the corresponding distributions. A negative skewness illustrates a higher muscular workload (assuming equal mean and SD) for EMG measurement and in case of Postural measurements this parameter shows more positive angles. Respectively, a higher value of Kurt signifies a sharp and narrow distribution of the muscular workload for EMG. This parameter represents the same aspect for Postural measurement of the different motions of the body. In a similar manner, each of the above listed parameters can be used either solely or in combination to compare quantitatively two or more different distributions.

The parameters Xmode, mean, SD and Skew were considered for EMG measurements while SD, Skew and Kurt were considered for Postural measurements. Appendix 5.2 (page 184) contains individual data of ten workers for all the above listed parameters. The data of both worker W07 and W08 were excluded as they only participated in the experiment for a week. These individual data from Appendix 5.2 were grouped and averaged separately for different assembly methods, different workstations and different EMG/Postural measurements. The averaged data of the parameters of the distribution (Xmode, mean, SD and skewness) for right and left trapezius is presented in Tables 5.1 and 5.2. Similarly, Table 5.3 to 5.6 display averaged data of distributions (SD, skewness and Kurtosis) for postural measurements of cervical and thoracic spine (flexion and lateral flexion). Lateral flexion is graphically illustrated in Figures 5.1 ... 5.6.

Table 5.7 represents an overall comparison between the DV and the IV method of assembly in terms of %MVC for muscular activity and angles in degrees for postural measurements. The same parameters are graphically represented in Figure 5.7. Similarly, Table 5.8 and Figure 5.8 represents individual and averaged values of mean and SD (SD) for DV method of assembly. The mean and SD for EMG measurement is in terms of percentage maximum voluntary contraction (% MVC) and the same parameter for postural measurement is presented in terms of degrees.

5.3 COMPARATIVE ANALYSIS OF PHY RECORDS

The PHY records were divided in to the following two major sections. Each section will be discussed separately and the results related in the summary.

5.3.1 MUSCULAR ACTIVITY OF THE RIGHT TRAPEZIUS

The electrodes were placed on the upper right trapezius muscle of the workers. The DV and IV methods of assembly are compared on the basis of the muscular activity of the right trapezius muscle. Table 5.1 shows a comparison between four statistical parameters of the normalized differential amplitude distribution for the two methods of assembly in terms of % MVC. The values of Xmode and mean show a significant difference between the DV and the IV methods of assembly (first and second rows of

Figure 5.1). The corresponding values of SD are a little higher in the case of the DV method of assembly then for the IV method. However, Skewness is approximately equal for both methods. Therefore, the mean and Xmode can be considered as the major parameters for the description of the normalized distribution of the right trapezius.

The mean %MVC for the DV Traditional workstation is 14.18% and for the IV it is 5.38%. Low mean for the IV Traditional method may be due to the restricted flexion of the cervical spine. The ratio between these two means for the DV method and the IV method of assembly on Traditional workstation is 2.64 (Table 5.1). This ratio represents that the mean contraction of right trapezius is higher when the workers used the DV Traditional workstation for PC board assembly. Similarly, the mean contraction of the upper ® trapezius for the DV cut-out workstation is 22.48%. While a mean %MVC of 18.72% is observed when the subjects were working on the IV Cutout workstation. The ratio between these two means is 1.38 which further indicates a higher rate of contraction when the DV Cutout workstation is used for assembly. However, the SD is slightly increased for the IV Cutout workstation (12.54) as compared to the IV Traditional workstation (4.74).

The similar behavior of the parameters for Traditional and Cut-out workstations allows the averaging of the data of both workstations. The average data is graphically presented in the right column of Figure 5.1. Also, Table 5.1 highlights the average of four parameters for both of these workstations. The mean value of %MVC for the DV method of assembly is 19.96%, while it is 12.05% for the IV method. The ratio for the averaged mean is 1.66 with approximately the same SD (DV - 9.06 and IV - 8.64) for

Table- 5.1 -
Comparison between four representative parameters of the normalized differential amplitude distribution obtained from activity of the right trapezius muscle during work at the Traditional and Cutout workstation by using the Direct vision and the Indirect vision method of PC board assembly.

Muscle : Right Trapezius.

Assembly Method	Distribution Parameters	Traditional WS	Cut-out WS	Average for WS's
Direct Vision	Xmode	12.93	22.48	17.70
	Mean	14.18	25.74	19.96
	SD	7.03	11.08	9.06
	Skewness	1.27	0.85	1.06
Indirect Vision	Xmode	4.22	17.44	10.83
	Mean	5.38	18.72	12.05
	SD	4.74	12.54	8.64
	Skewness	1.32	1.19	1.26
Average for method	Xmode	8.58	19.96	
	Mean	9.78	22.23	
	SD	5.85	11.81	
	Skewness	1.30	1.02	

Denotation : **WS - Work station**

both methods. The ratio of 1.66 as an approximate estimation of the activity of Right trapezius (in %MVC) during assembly which occurred on both the Direct Vision and Indirect Vision methods of PC board assembly. The analysis of the averaged data for both workstations shows that the muscular activity of right trapezius is lower for the IV method of assembly irrespective of workstation type.

The individual data of each worker is shown in Appendix 5.2. Table 5.2.1(page 185) indicates values of four statistical parameters for the DV Cutout workstation. The

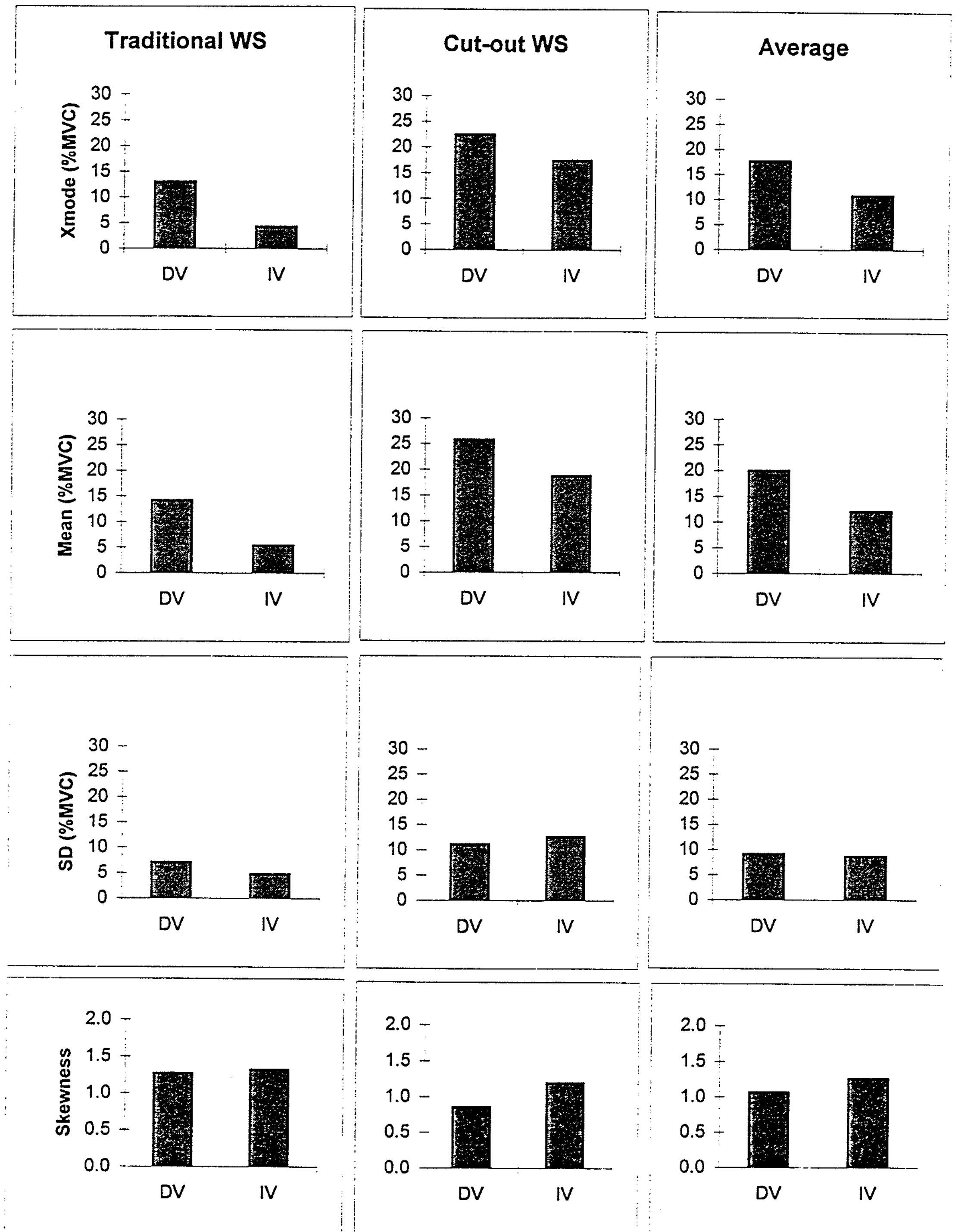


Figure 5.1 - Comparison between four representative parameters of the normalized differential amplitude distribution of muscular activity during work at different types of workstations and by the use of different assembly methods. Muscle: **Right Trapezius**. *Denotations:* **DV** - Direct Vision, **IV** - Indirect Vision

individual subjective mean (% MVC) value shows a high degree of variation in the data. For instance, for Worker Nine (W09) the mean is 11.60% MVC while for Worker Five (W05) this value is 38.70% of MVC. At the 95% confidence interval the variation in the mean value is 10.32 percent of MVC. Similar to the DV data, in the case of the IV Cutout workstation Worker Three (W03) has 33.80% of mean MVC and Worker Eleven (W11) has 11.10% of MVC (Table 5.2.3, page 187). For the Traditional method of assembly there is again high individual variability in the data. From Table 5.2.5 (page 189) it can be seen that for Worker Two (W02), mean MVC is 5.70% and it is 22.7% for Worker Six (W06), when they were working on the DV Traditional method. However, for the IV Traditional method this variability is very low except for Worker Ten (W10) (Table 5.2.7, page 191).

Thus, it can be concluded that variability between the individual subject's data (%MVC) for a specific type of workstation is large and may influence the overall responses. This variation between subjects may be due to the variable use of the TV monitor during assembly on the IV method. During assembly at any workstation using the IV method, the workers were instructed to use the TV monitor for the majority of their work. They were allowed to look directly at the PC board only if they could not perform some complicated operations when looking at the TV monitor. Therefore, the subjects with higher mean value of %MVC on the IV method might have looked directly at PC board for longer periods during assembly operations. This increased direct viewness could have caused more flexion of the cervical spine and in turn resulted in a higher contraction of the upper trapezius muscle. These variations in the individual data indicate that the workers have highly individual approaches to their work. Hence, training in task performance may be critical to avoid repetitive strain injuries. This fact can be further justified by conducting a study between training and its effect on the performance.

5.3.2 MUSCULAR ACTIVITY OF THE LEFT TRAPEZIUS

Figure 5.2 illustrates the four statistical parameters of the differential amplitude distribution for left trapezius muscle. The MVC of right trapezius is 14.18% for the DV

Table- 5.2 -
Comparison between four representative parameters of the normalized differential amplitude distribution obtained from activity of the Left trapezius muscle during work at the Traditional and Cutout workstation by using the Direct vision and the Indirect vision method of PC board assembly.
Muscle : Left Trapezius.

Assembly Method	Distribution Parameters	Traditional WS	Cut-out WS	Average for WS's
Direct Vision	Xmode	4.88	13.22	9.05
	Mean	6.68	14.48	10.58
	SD	4.60	6.32	5.46
	Skewness	1.58	1.28	1.43
Indirect Vision	Xmode	2.18	8.54	5.36
	Mean	4.56	10.30	7.43
	SD	4.76	6.32	5.54
	Skewness	1.79	1.43	1.61
Average for Method	Xmode	3.53	10.88	
	Mean	5.62	12.39	
	SD	4.68	6.32	
	Skewness	1.68	1.36	

Denotation : **WS - Work station**

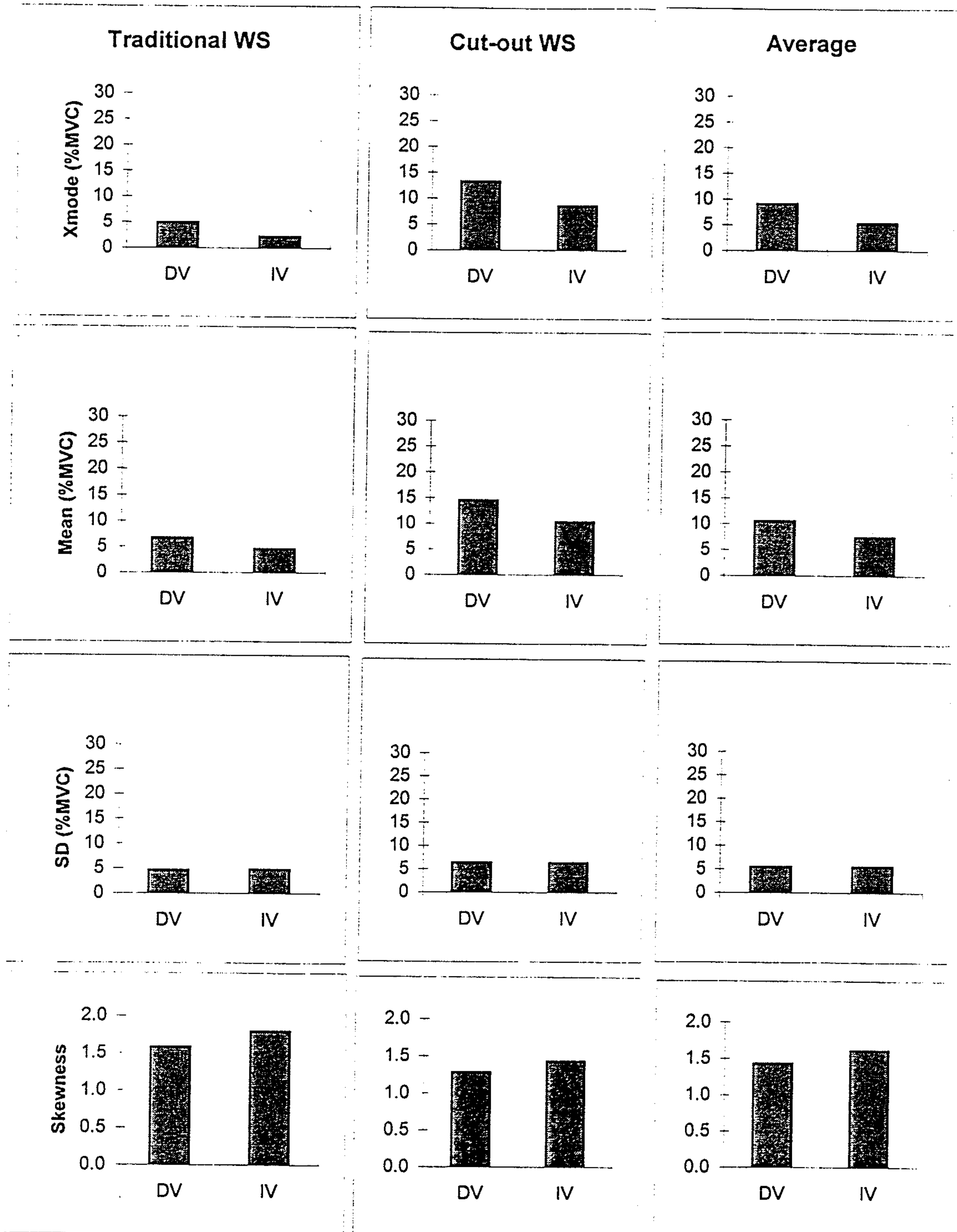


Figure 5.2 Comparison between four representative parameters of the normalized differential amplitude distribution of muscular activity during work at different types of workstations and by the use of different assembly methods. Muscle: **Left Trapezius.** *Denotations:* **DV** - Direct Vision, **IV** - Indirect Vision.

method and 5.38% for the IV method, while the same parameter for left trapezius is 6.68% and 4.56% for the DV and IV method. Hence, compared to the right trapezius the values of these parameters are lower. The values of mean and Xmode are higher for the DV Traditional workstation compared to the IV Traditional workstation. However, the skewness and SD are relatively equal for both types of workstation. Thus, mean %MVC is considered as the descriptor of the normalized distribution of muscular activity of left trapezius while values of skew and kurt are almost equal. The mean value for the DV Traditional method is 6.68% of MVC which is 2.12% of MVC higher than the IV Traditional method of assembly. Similarly, for the DV Cutout workstation mean value of muscular contraction is 14.48% which is 4.18% higher than the IV Cutout workstation. The average of both the DV and the IV method of assembly can describe the overall nature of muscular contraction of upper left trapezius. The %MVC is always higher for the DV method of assembly irrespective of workstation type. The value of the averaged mean of both workstations for the DV method is 10.58% which is 3.15% higher than for the IV method. Also, the ratio of mean between the Direct and Indirect Vision methods is 1.42. This difference however is not extremely large as the absolute values are very small (Table 5.2). Therefore, the results of % MVC for the left trapezius are similar to those of the right trapezius. The reason for these higher values of muscular contraction for the DV method could be the involvement of lateral flexion and flexion of the cervical spine during assembly work.

The individual data for the DV Cutout workstation shows that for Worker One (W01) the mean %MVC value is 36.70% while for Worker Nine (W09) this value is only

3.70% (Table 5.2.2 page 186). Hence, it can be concluded that there is a high variability between the existing individual data of mean %MVC. Also, Table 5.2.4 (page 188) illustrates the same result for the IV Cutout workstation. From these variations we can suggest workers use very different approach to assembly task. As for Worker One (W01), this %MVC value is 28.90% and for Worker Three (W03) it is only 1.80 % of MVC. In the same manner, variability in the data is high for both the DV and the IV Traditional workstation. The individual data for the Traditional type of workstation are presented in Table 5.2.6 and 5.2.8. The individual dynamics of each worker show that for all types of workstations their pattern of mean muscular activity is approximately the same. For example, in the case of Worker Six (W06) the mean value of %MVC for left trapezius is 12.40% on the DV Traditional workstation which is close to 12.70% for the IV Traditional workstation (Table 5.2.6 and 5.2.8). Therefore, the average of mean %MVC can be represented as a descriptor of overall comparison of the two PC board assembly methods.

The comparison of the overall activity of the left and right trapezius shows a lesser use of the left hand during assembly operations. This may be due to the fact that all the workers were right handed. Further, the analysis of video tapes and personnel observations revealed that during complicated operations such as, bending and soldering of components the subjects used their right hand while the left hand was only used for holding the components or PCBs, holding solder during soldering and flipping of the PC boards. All complex tasks and manipulations was performed by the right hand and arm.

5.3.3 POSTURAL MEASUREMENTS OF THE CERVICAL FLEXION

In the case of postural measurements, the distribution parameters that reflect the position of the distribution relative to the horizontal axis are not relevant because of the arbitrary choice of the zero degree point along the X-axis (sample of W09 in Appendix 5.1). Thus, the postural differences between the two assembly methods were evaluated

Table- 5.3 -

Comparison between three representative parameters of the normalized differential amplitude distribution obtained from flexion of the Cervical spine during work at the Traditional and Cutout workstation by using the Direct vision and the Indirect vision method of PC board assembly.
Motion: Flexion of the Cervical spine.

Assembly Method	Distribution Parameters	Traditional WS	Cut-out WS	Average for WS's
Direct Vision	SD Skewness Kurtosis	8.50 -0.23 -0.14	9.60 0.05 2.28	9.05 -0.09 1.07
Indirect Vision	SD Skewness Kurtosis	5.94 1.12 3.45	5.63 1.01 1.38	5.78 1.06 2.42
Average for Methods	SD Skewness Kurtosis	9.02 0.44 1.66	7.62 0.53 1.83	

Denotation : WS - Work station

in terms of SD (SD), skewness (Skew) and kurtosis (Kurt). The numerical values for these parameters are shown in Table 5.3. Also, Figure 5.3 graphically demonstrates the values of these parameters for cervical flexion. The SD in the mean value of the cervical

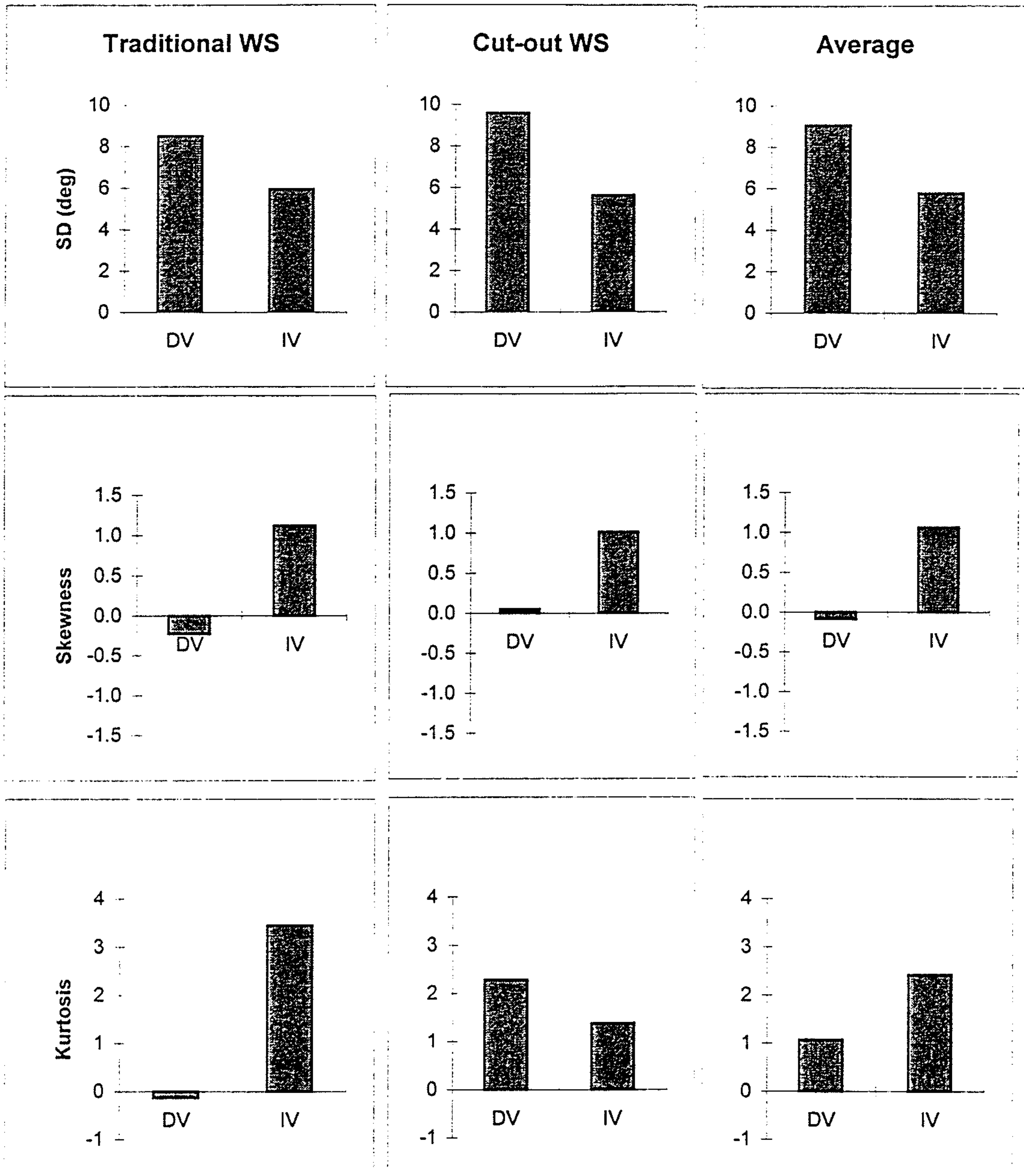


Figure 5.3-
Comparison between three representative parameters of the normalized differential amplitude distribution of body motions during work at different types of workstations and by the use of different assembly methods. Motion: **Cervical flexion.** *Denotations:* **DV** - Direct Vision, **IV** - Indirect Vision

flexion is higher for both the DV Traditional and the DV Cut-out workstations. In other words, the variation in the range of data is higher for the DV method of assembly. The value of SD for the DV Traditional method is 8.5 while for the IV it is 5.94. The corresponding ratios between these SDs is 1.43 for the Traditional workstation. Similarly, the SD for the DV Cutout workstation is 9.6 and 5.63 for the IV Cutout method. The ratio between the SD for the Cutout workstations is 1.71. Average SD for the DV method of assembly is 9.05 and for the IV it is 5.78. The average ratio of the DV and the IV methods is 1.57 respectively (Table 5.3). These ratios moderate a large range of motion for the DV workstation whether such motion is contained within a healthy range is not entirely clear.

The second parameter, skewness, is always lower for the DV method of assembly, irrespective of workstations type. The difference between the skewness of these two methods reflects that during assembly on the Indirect Vision method, the workers kept their cervical spine in a constrained position for longer periods of time when compared to the Direct Vision method. As the values of Skew are close to zero for both types of

workstations, it shows nearly a symmetrical distribution for flexion of cervical spine around the mean value. Further, for the DV Cutout workstation the value of skewness for all workers except for Worker Six (W06) was always negative and ranged from -1.57 to 1.07 while SDs vary from 4.4 to 14.30 respectively for the Cutout DV workstation (Table 5.2.9 and 5.2.17, Page 191 and 201) . Similarly, Table 5.2.17 illustrates that for the DV Traditional workstation skewness ranges from -.122 to 0.33 and SD varies from 3.6 to 12.30. Further, skewness ranges from 0.49 to 1.62 for the IV Cutout workstation and -0.5

to 1.71 for the IV Traditional workstation. In the same manner SD varies from 3.00 to 10.30 for the IV Cutout workstation and 3.9 to 9.8 for the IV Traditional workstation. These data are presented in Table 5.2.13 and 5.2.21 (page 197 and 205). Skewness for the IV method of assembly is always positive except for the value of Worker Ten (W10) (-0.05). From the above discussion it is obvious that the variability in the individual data for skewness is low compared to variability in SD data.

Finally, a comparison of the kurtosis shows a higher value for the IV method at the Traditional workstation. This higher value is an expected effect when the data are distributed close to the mean value. Therefore, for the IV method of assembly the data for the cervical flexion are distributed close to the mean value and there is a little variation in the data. Further, the data shows that most of the time the workers have a restricted cervical flexion when they were working on the IV method. However, this fact is only true for the Cutout type of workstation (Figure 5.3). The individual subjective kurtosis values are shown in Table 5.2.9 and 5.2.13 (page 193 &197) for the DV and IV Cutout workstations. The value of kurtosis for the DV is -0.14, while it is 3.45 for the IV Traditional workstations. In contrast, kurtosis is higher for the DV Cutout workstation (2.28) as compared to the IV Cutout workstation (1.38). This contradiction between the two workstations (DV and IV) is shown in Table 5.3. In other words, the cervical flexion data for all workers are distributed close to the mean value when they worked on the DV Traditional workstation, but more widely variable when they worked on the DV Cutout workstation.

The most common factor amongst the above three parameters is the SD. The SD reflects an amplitude characteristic of the measured motion therefore, it can be considered as a measure of the range of activity of the cervical flexion. The analysis of overall SD shows that the frequency and magnitude of the cervical flexion is lower for the IV method of PC board assembly.

5.3.4 POSTURAL MEASUREMENTS OF THE CERVICAL LATERAL FLEXION

Cervical lateral flexion is referred to as head sideways motion in the Physiometer software therefore, in some tables and Figures the cervical movements are referred as head

Table- 5.4 -
Comparison between three representative parameters of the normalized differential amplitude distribution obtained from the lateral flexion of the cervical spine during work at the Traditional and Cutout workstation by using the Direct vision and the Indirect vision method of PC board assembly.
Motion: Lateral flexion of the Cervical spine

Assembly Method	Distribution Parameters	Traditional WS	Cut-out WS	Average for WS's
Direct Vision	SD	7.00	7.28	7.14
	Skewness	0.23	-0.55	-0.16
	Kurtosis	0.71	1.21	0.96
Indirect Vision	SD	4.14	5.53	4.84
	Skewness	-0.14	0.27	0.06
	Kurtosis	2.38	2.36	2.37
Average for Methods	SD	5.57	6.40	
	Skewness	0.04	-0.14	
	Kurtosis	3.09	1.78	

Denotation : **WS - Work station**

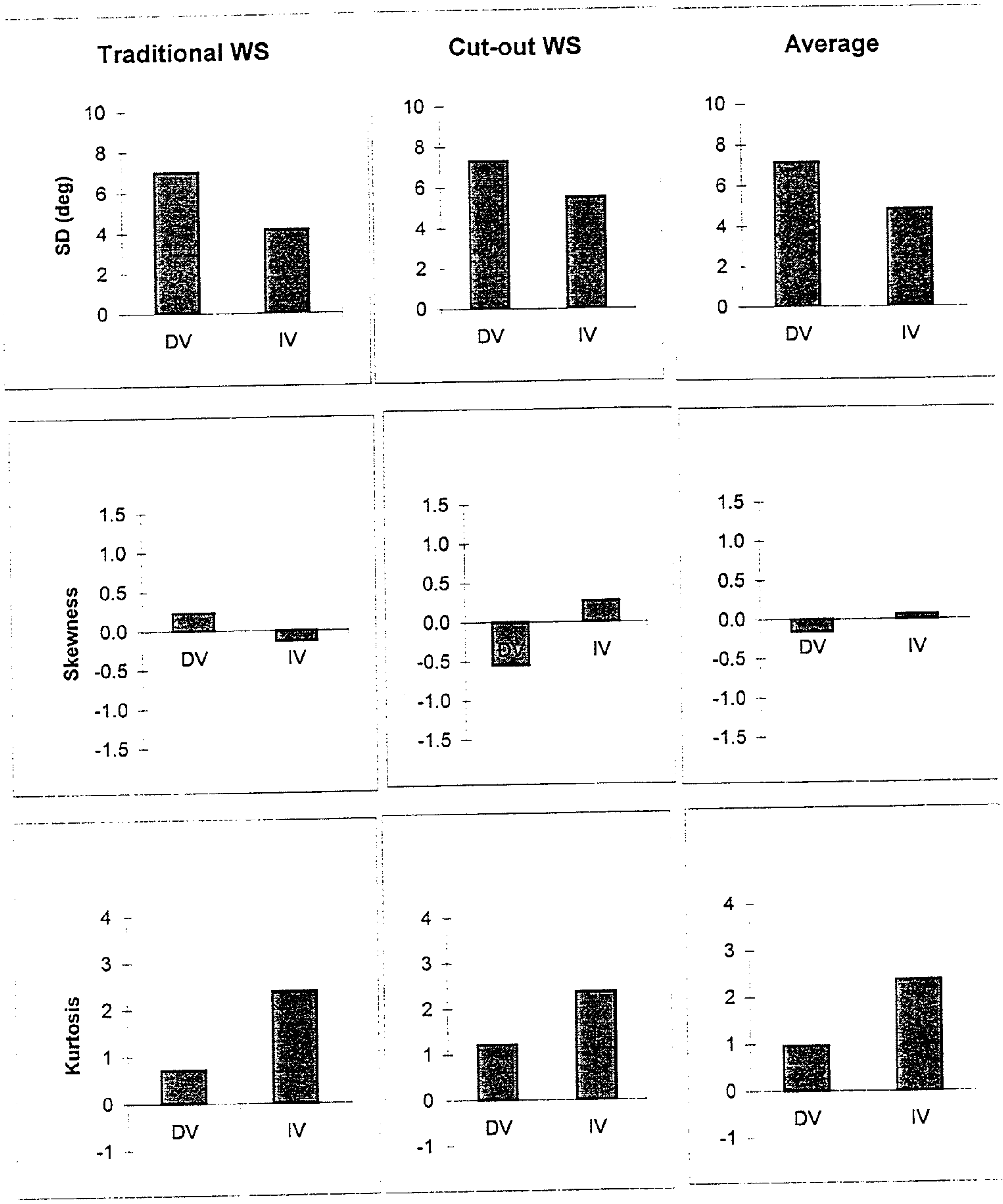


Figure 5.4-
Comparison between three representative parameters of the normalized differential amplitude distribution of body motions during work at different types of workstations and by the use of different assembly methods. Motion: **Cervical Lateral flexion.** *Denotations:* **DV** - Direct Vision, **IV** - Indirect Vision.

movements. The data analysis for the cervical lateral flexion is shown in Table 5.4. Similar to the cervical flexion, the main statistical descriptors of the cervical lateral flexion are SD, skewness and kurtosis. The value of SD for the DV Traditional workstation is

7.00 which is 1.69 times higher than for the IV method of assembly. Also, the value of SD for the DV Cutout workstation is 7.28. This value of SD is 1.32 times higher than that of the IV method. As the value of SD is higher for both of the DV workstations then for the IV workstations therefore, the average of both these DV workstations can be considered for comparing the two methods (DV and IV) of assembly. The average value of SD for the DV method is 7.14 and is 4.84 for the IV method of PC board assembly. The ratio between the two methods of assembly shows that SD for the DV is 1.48 times higher than the SD of the IV method. Further, a review of data in Table 5.2.10 and 5.2.18 for the DV Cutout (4.6 to 9.6) and the Traditional (4.4 to 10.7) workstation shows a higher individual variations in the range of SDs value. In contrast, for the IV Cutout (4 to 6.6) and Traditional (2.7 to 4.7) workstations the individual values of SDs has a lower range of variability (Table 5.2.14 and 5.2.22 of Appendix 5.2, page 206). Hence it can be concluded from the comparison of SDs of two methods of assembly that the IV method is associated with a lower level of the cervical lateral flexion during PCB assembly operation. This would be expected since the workers vision was to be directed to a single TV monitor.

The analysis of skewness shows a lower average value for the DV workstations when compared to the IV method. The skewness for the two methods of assembly are presented in Table 5.4. The value of skewness on the DV Traditional workstation is higher than the IV Traditional workstation, while it is the reverse for the Cutout workstation. The higher value of skewness may be the result of greater restricted lateral movement of the cervical spine during assembly on the IV workstations. Periodic direct viewing of at the PC board explains the direction of skewness, as most of the values of skewness are close to the mean value of the normalized distribution for both workstations (Figure 5.4).

The final parameter, Kurtosis is higher than zero for both the IV Cutout and the IV Traditional workstations. Kurtosis is graphically illustrated in Figure 5.4.

The behavior of these three parameters (SD, skewness and kurtosis) is similar to that for the cervical spine anterior and posterior flexion except for a small reversed ratio of skewness for the Traditional workstation. However, analysis of both the cervical flexion and lateral flexion supports the fact that the IV method involves less movements of the cervical spine which may further lead to postural fixity. The question of how much or how little flexion over what range is most healthy was not addressed in the workstation design.

5.3.5 POSTURAL MEASUREMENTS OF THE THORACIC SPINE FLEXION

The results for the thoracic spine flexion have a similar behavior to those of the cervical spine flexion. The results for the thoracic flexion are presented in Table 5.5 and graphically represented in Figure 5.5. The SD of mean thoracic flexion for the DV Traditional workstation is 5.84 which is 1.43 times more than for the IV Traditional workstation. Higher values of SD correspond to a greater flexion range of the thoracic spine. It may be concluded that the assembly operation on the DV Traditional workstation involves more flexion and extension of the thoracic spine in comparison with the IV Traditional workstation. In contrast to the Traditional workstation, the SD of the DV Cutout workstation (3.73) is lower than the IV Cutout workstation (4.10). The ratio

Table- 5.5 -
Comparison between three representative parameters of the normalized differential amplitude distribution obtained from flexion of the thoracic spine during work at Traditional and Cutout workstation by using the Direct vision and the Indirect vision method of PC board assembly.
Motion: Flexion of the Thoracic spine

Assembly Method	Distribution Parameters	Traditional WS	Cut-out WS	Average for WS's
Direct Vision	SD Skewness Kurtosis	5.84 0.36 0.29	3.73 -0.73 2.39	4.78 -0.18 1.34
Indirect Vision	SD Skewness Kurtosis	4.12 0.61 1.63	4.10 0.50 3.56	4.11 0.66 2.60
Average for Methods	SD Skewness Kurtosis	4.98 0.48 0.96	3.92 -0.12 2.98	

Denotation : WS - Work station

between the DV and the IV Cutout workstation is 0.91 (Table 5.5). The higher value of SD for the IV method may be due to the exceptional case of Worker Nine (W09). The average value of SD for worker nine is 8.40 and when compared with the SD of the other workers (2.7, 1.5 and 2.0 respectively) the value is too high. The individual dynamics for each worker for the IV Cutout workstation are presented in Table 5.3.16 (page 200). The

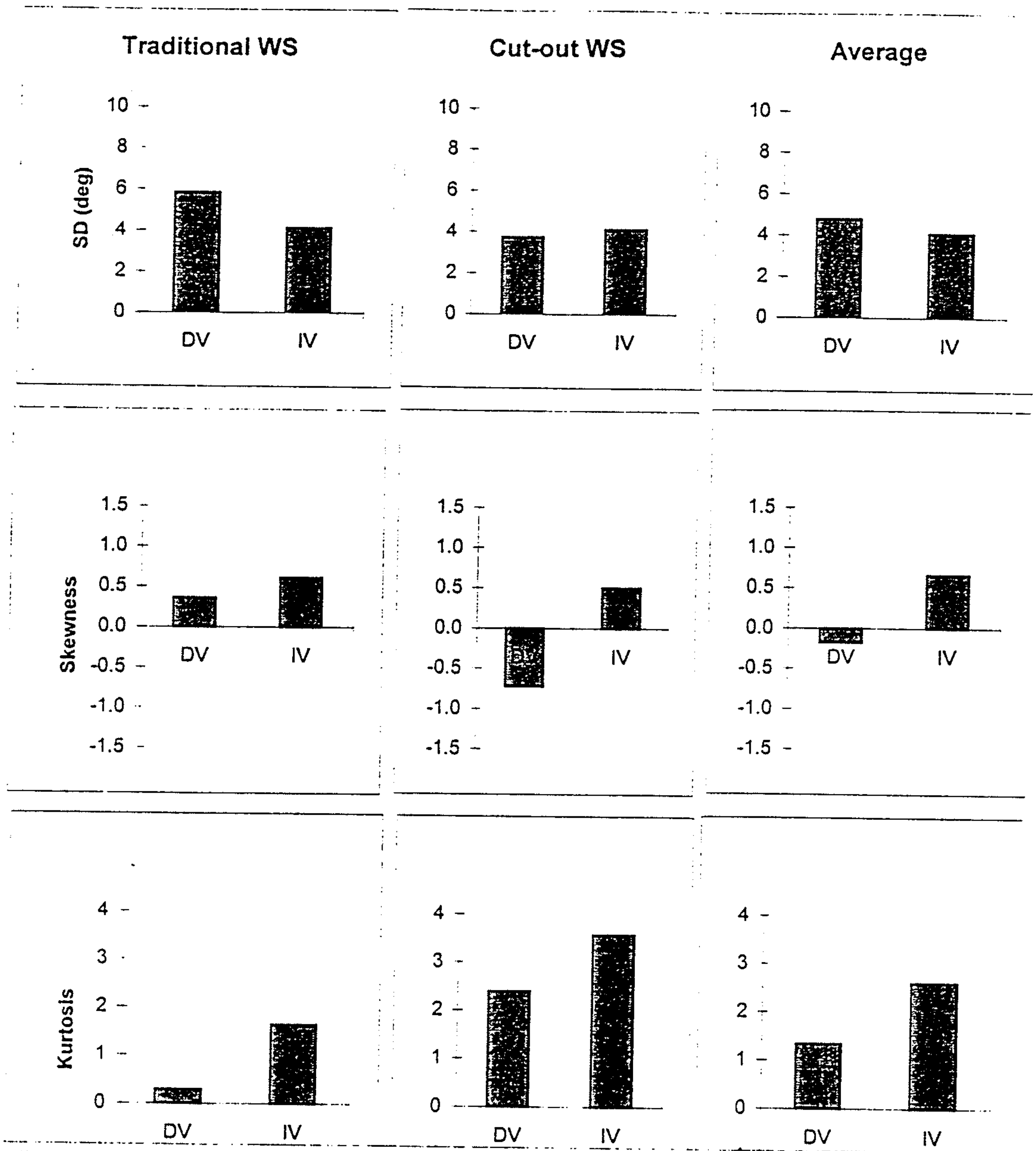


Figure 5.4.5- Comparison between three representative parameters of the normalized differential amplitude distribution of body motions during work at different types of workstations and by the use of different assembly methods. Motion: **Thoracic flexion.** *Denotations:* **DV** - Direct Vision, **IV** - Indirect Vision.

value of the same worker for the DV Cutout workstation is similar to the value of other workers (Table 5.3.12, page 196). Therefore, if the value of worker nine is eliminated for averaging, then the SD for the IV Cutout workstation is 2.07 which is still lower than that of the DV Cutout workstation (3.73).

The value of the second parameter, Skewness, is higher for the IV method of assembly. The average value is 0.66 for the IV method and its negative for the DV method (-0.18). The comparison of individual workstations is shown in Table 5.5 and graphically represented in Figure 5.5. Skewness is 0.36 for the DV Traditional workstation which is 0.25 less than for the IV Traditional workstation. Similarly the value of skewness for the DV Cutout workstation is negative (-0.73) which is 1.23 less than for the IV Cutout workstation. Therefore, the IV method of assembly involves less flexion of thoracic spine.

The final parameter of comparison is Kurtosis. The value of kurtosis is higher for the IV method of assembly irrespective of workstation type. The values of this parameter are presented in Table 5.5 for both workstations. The average value of kurtosis for the DV method is 1.34 which is 1.26 less than for the IV method of PC board assembly. This reduction in the value of kurtosis is a common effect if the value of the distribution lies close to the mean value. Thus, it can be concluded that the range of flexion of the thoracic spine is lower during PC board assembly on the IV type of workstation.

5.3.6 POSTURAL MEASUREMENTS OF THE THORACIC SPINE LAT. FLEXION

The value of SD for lateral flexion of the thoracic spine is higher for the DV method when compared with the IV method (Figure 5.6). In the case of the Traditional station, Skew and Kurt have nearly the same values for both methods of assembly (Table 5.6).

In the case of the Cut-out workstation, skew is significantly higher for the IV method (1.29). The higher value of skewness on the IV method is one more indication of

Table- 5.6 -
Comparison between three representative parameters of the normalized differential amplitude distribution obtained from lateral flexion of the thoracic spine during work on the Traditional and Cutout workstation by using the Direct vision and the Indirect vision method of PC board assembly.
Motion: Lateral flexion of the Thoracic spine

Assembly Method	Distribution Parameter	Traditional WS	Cut-out WS	Average for WS's
Direct Vision	SD	3.38	3.70	3.54
	Skewness	-0.36	-0.10	-0.23
	Kurtosis	2.18	2.26	2.22
Indirect Vision	SD	2.40	3.65	3.02
	Skewness	-0.54	1.29	0.38
	Kurtosis	2.09	3.90	3.00
Average for Methods	SD	2.89	3.68	
	Skewness	-0.45	0.60	
	Kurtosis	2.14	3.08	

Denotation : **WS - Work station**

the fact that workers kept their thoracic spine in a fixed position for longer periods of time when compared to the DV method. Finally, the kurtosis shows more narrow distribution of the thoracic motion around the mean value and hence can be concluded that the frequency of lateral flexion is low when the subjects worked on the IV method of PC board assembly.

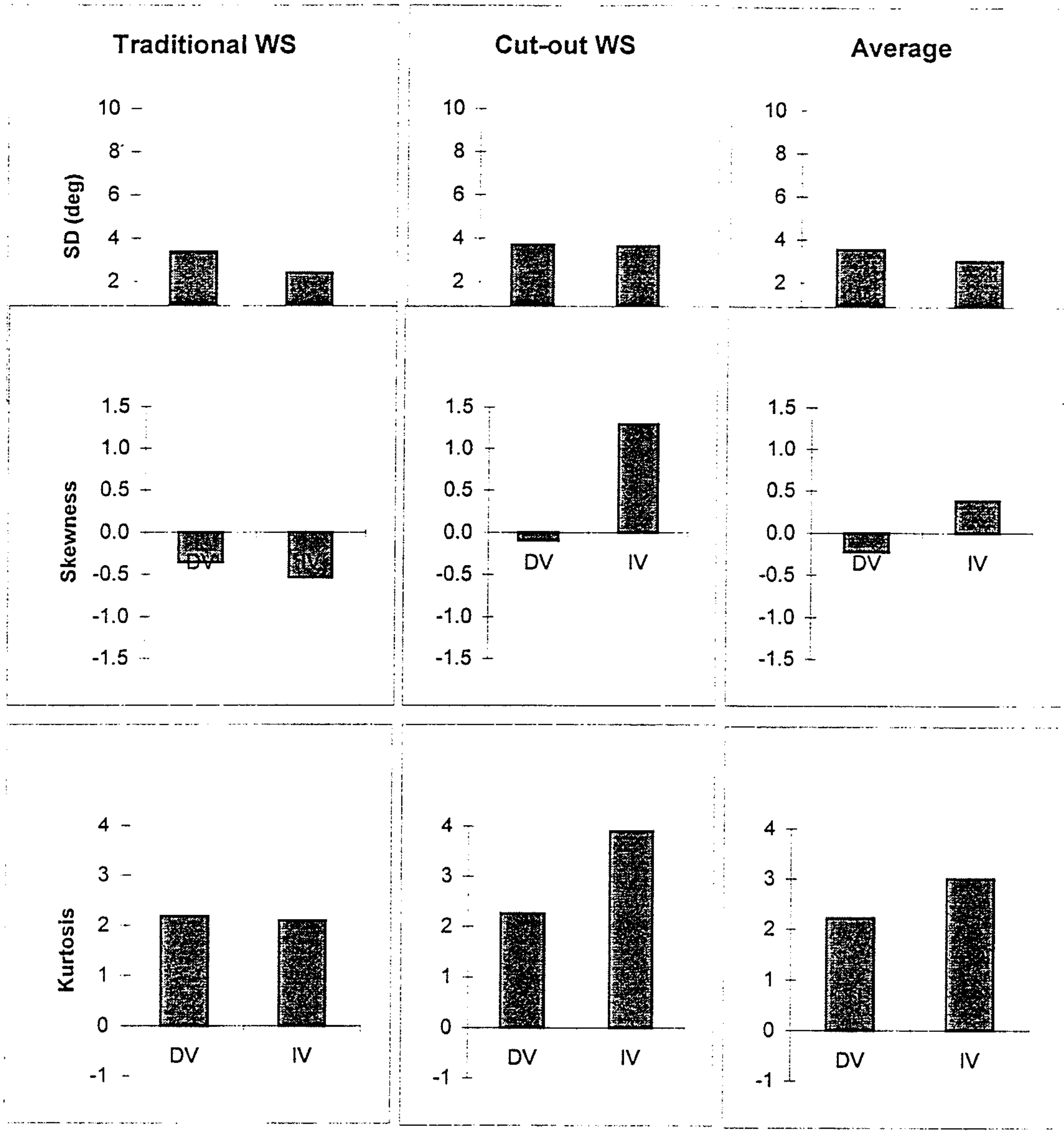


Figure 5.6- Comparison between three representative parameters of the normalized differential amplitude distribution of body motions during work at different types of workstations and by the use of different assembly methods. Motion: **Thoracic lateral flexion.** *Denotations:* **DV** - Direct Vision, **IV** - Indirect Vision.

5.4 COMPARISON OF WORKLOAD BETWEEN THE DV AND IV METHOD

The mean (in %MVC) for muscular activity measurements and SD (in degrees) for the postural measurements are presented in Table 5.7. The same parameters are graphically illustrated in Figure 5.7. These two parameters could be considered as a measure of workload for the DV and the IV workstations respectively. A simple comparison of these parameters in terms of the corresponding ratios (IV/ DV in Table 5.7)

Table - 5.7 -
Comparison between the Direct Vision and the Indirect Vision assembly methods in terms of workload. The averaged values of Mean (in %MVC) for muscular activity measurements and SD (in degrees) for Postural measurements are used. Both parameters reflect the workload for the corresponding parts of the body.

Denotations: R.TRAP- Right trapezius, L.TRAP - Left trapezius, C. FLEX - Cervical flexion, C.LAT. - Cervical lateral flexion, T.FLEX - Thoracic flexion, T.LAT. - Thoracic lateral flexion, **'*'- represents the level of significance lower than 0.70 during one tailed 't' test of differences.**

Code	R. TRAP.	L. TRAP.	C.FLEX.	C. LAT.	T.FLEX.	T. LAT.
DIRECT VISION						
Average	20.60	11.01	8.99	7.12	4.90	3.52
SD	11.48	10.36	3.46	2.55	2.60	0.66
95% Confidance Interval	7.50	6.77	2.26	1.66	1.70	0.43
INDIRECT VISION						
Average	13.39	7.43	5.80	4.75	4.11	2.96
SD	9.58	8.51	2.59	1.19	2.01	2.08
95% Cnf.In.	5.94	5.27	1.69	0.78	1.31	1.36
INDIRECT/DIRECT VISION						
Average	0.650	0.675	0.645	0.667	0.839	0.841
(DV-IV) is significant at level:	0.70	*	0.75	0.75	*	*

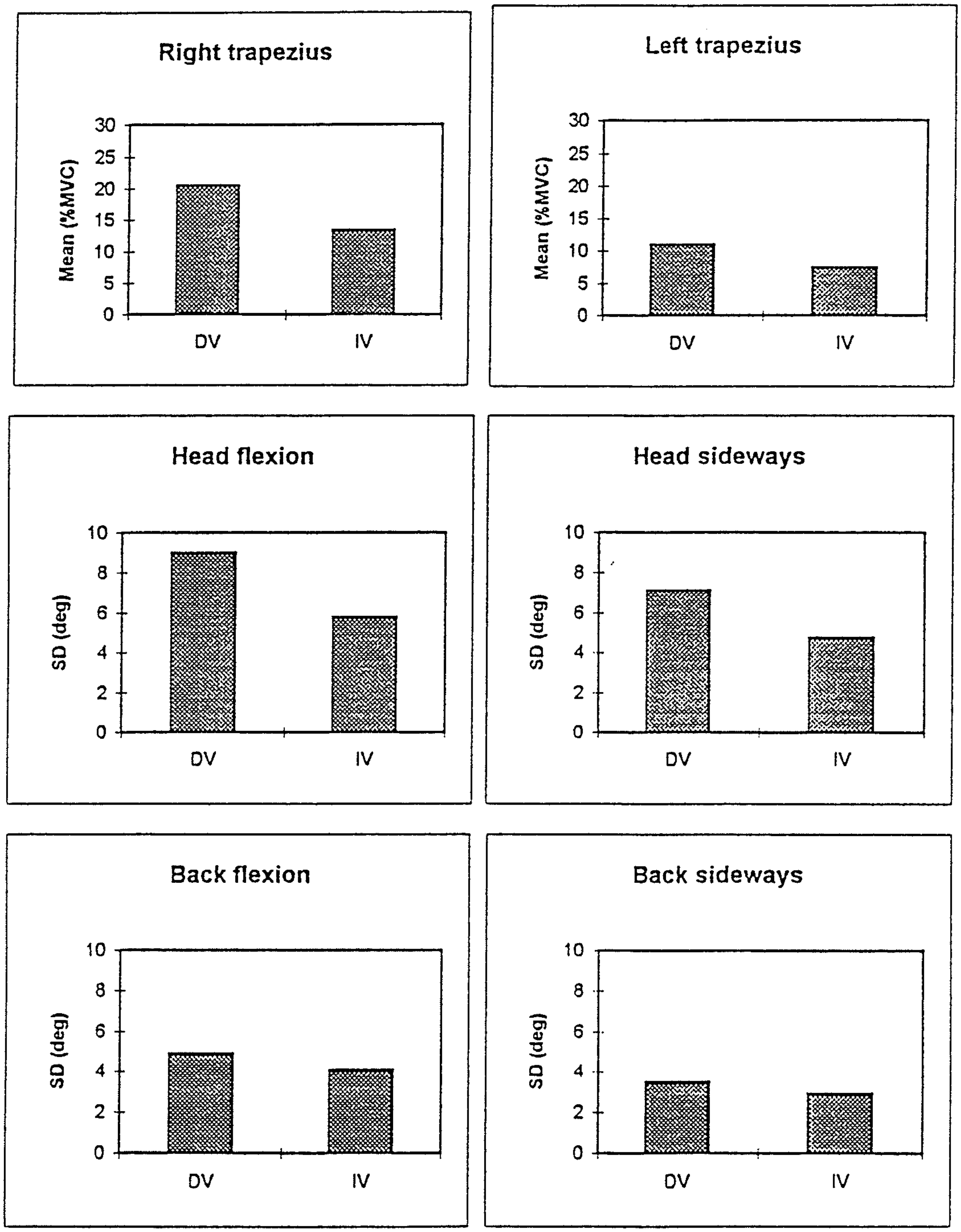


Figure 5.7- Comparison between **Direct Vision** and **Indirect Vision** assembly methods in workload. The averaged values of **Mean** (in %MVC) for EMG measurements and **SD** (in deg) for Postural measurements are used. Both parameters reflect the workload for the corresponding parts of the body.
Denotations: **DV** - Direct Vision assembly method, **IV** - Indirect Vision assembly method.

shows that the physiological workload is lower for the IV method of assembly when compared to the DV method. Table 5.7 shows that the difference between the workload of two methods of assembly (DV-IV) is significant[1] at the 0.75 level for both flexion and lateral flexion of the cervical spine. Similarly, this difference in workload is significant for muscular activity of the right trapezius muscle at a level of 0.70. The level of significance is lower than 0.70 for the left trapezius muscle and both directions of motion of the thoracic spine. However, in statistics the results can only be accepted if they are significant at a level of 0.95. In the light of the above, it is not reasonable to conclude that the IV method of assembly results in a statistically significant reduction in the workload for the right trapezius muscle and both flexion and lateral flexion of the cervical spine when measured relative to the horizontal axis (This statement is based on the fact that the motion of the cervical spine was measured relative to the two perpendicular horizontal axes). Further, no rotational measurements about the vertical axis were made thus no conclusions regarding tortional and shear load on vertebral discs can be drawn.

5.5 COMPARISON OF POSTURAL MEASUREMENTS BETWEEN THE DV AND THE IV METHOD

The postural angles for the cervical and thoracic spine during assembly operation at the DV and IV methods are compared in terms of the difference between the parameters Xmode and Xmin. The difference reflects the flexion of the cervical and thoracic spine with respect to the natural sitting position. This statement is based on the assumption that during assembly only flexion of the cervical spine is involved and not

[1] One-tail *t* test of difference was used.

Table - 5.8 -
Comparison between the Direct Vision and the Indirect Vision assembly methods in terms of postural angles. The difference (in degrees) between X mode and Xmin in the normalized differential amplitude distributions of the cervical and thoracic spine flexion are used. This difference reflects the bending of the corresponding parts of the body relatively natural straight position.

Denotations: C.FLEX - Cervical flexion, T.FLEX - Thoracic flexion; DV - Direct Vision method, IV - Indirect Vision method, Cnf.In. - Confidence interval and '*'- represents the level of significance lower than 0.70 during one tailed 't' test of differences

Code	**CERVICAL FLEXION FOR THE DV**	**THORACIC FLEXION FOR THE IV**	**CERVICAL FLEXION FOR THE IV**	**THORACIC FLEXION FOR THE IV**
W016V	-	-	-	-
W036V	23.10	10.50	9.10	15.40
W057V	42.80	21.20	17.20	11.50
W095V	35.00	17.30	21.10	22.60
W112V	34.50	22.00	14.00	13.90
W024V	18.20	7.70	12.50	17.70
W045V	22.10	16.80	14.40	11.50
W065V	24.90	24.50	15.40	14.40
W106V	26.40	15.40	20.60	16.30
W124V	46.60	32.20	12.50	38.40
Average	30.40	18.62	15.20	17.97
SD	9.82	7.40	3.90	8.38
95% Cnf.In.	6.42	4.83	2.55	5.47

DIFFERENCE BETWEEN THE DV AND THE IV METHOD OF ASSEMBLY

	C.FLEX.	**T.FLEX.**
(DV-IV)	15.20	0.65
(DV-IV) is significant at level:	0.90	*

extension. (The analysis of the video records confirmed this assumption). Thus, the left-side minimum value (Xmin) of the differential distribution for the flexion and the lateral

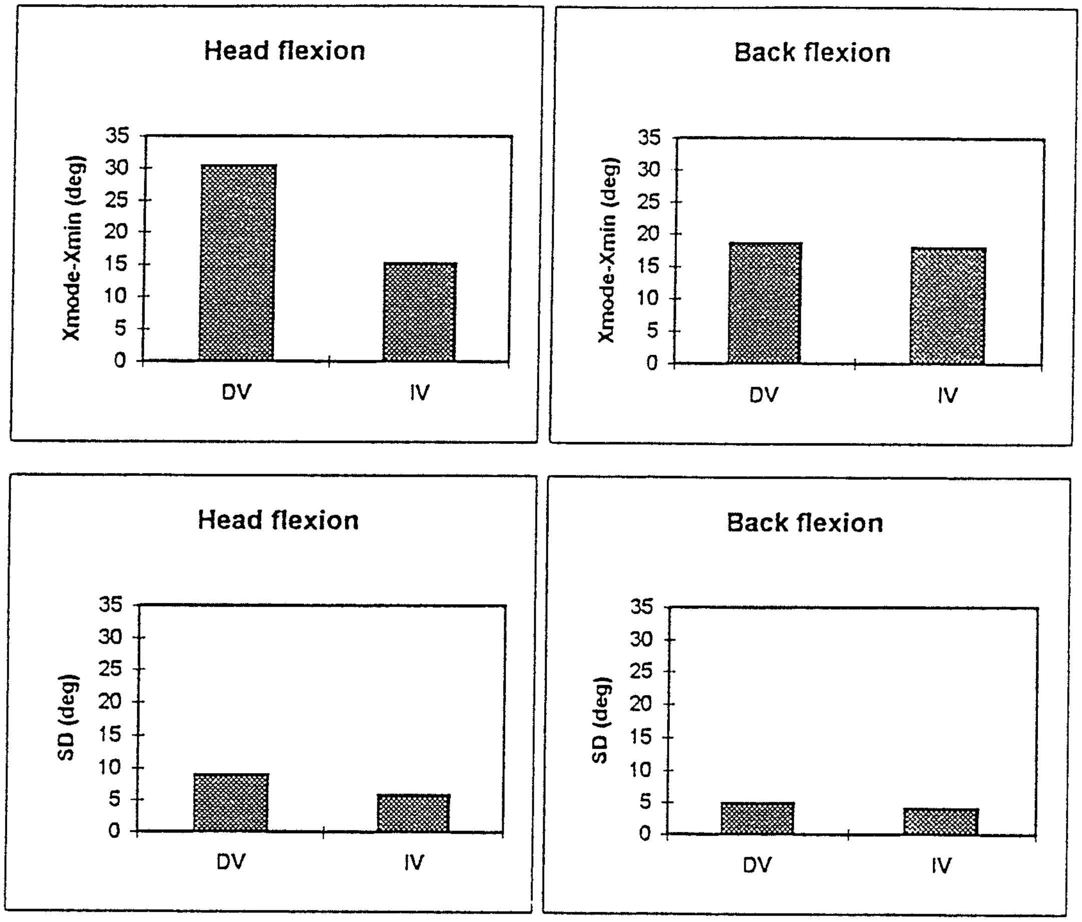


Figure 5.8- Comparison between **Direct Vision** and **Indirect Vision** assembly methods in postural angles. The difference (in deg) between **Xmode** and **Xmin** in the normalized differential amplitude distributions of Head and Back motion is used. This difference reflects the bending of the corresponding parts of the body relatively natural straight position. The lower two graphs show the workload (in terms of **SD**) plotted on the same scale.

Denotations: **DV** - Direct Vision assembly method, **IV** - Indirect Vision assembly method.

flexion of the cervical and thoracic spine is assumed to represent the reference (natural straight position) position for the calculation of flexion of the spine. The value of Xmode represents the most frequently adopted flexion or lateral flexion angle during PC board assembly operation. The difference between Xmode and Xmin shows a flexion angle of the cervical and the thoracic spine. Thus, the difference between Xmode and Xmin can be interpreted as the measure of static workload. Whereas, the parameter SD presents the mean square deviation of the motion (angles) around the mean value. This frequent deviation in the mean value represents a measure of dynamic workload.

Table 5.8 contains individual and averaged values of the difference Xmode-Xmin separately for the DV and IV methods of assembly. These averaged values are also plotted in Figure 5.8. The typical angles of the cervical and thoracic flexion are smaller for the IV method of assembly. The corresponding averaged angles are 30.4 degrees (DV) and 15.20 degrees (IV) for the cervical spine, and 18.62 degrees (DV) and 17.97 degrees (IV) for the thoracic spine. The difference between the DV and the IV method of PC board assembly for the movement of cervical spine is significant at a level of 0.90, while for the thoracic spine this level of significance is lower than 0.70. Thus, it may be concluded that the IV assembly method might leads to a statistically significant decrease in the flexion of cervical spine during assembly. This decrease is about a half of the value of flexion of the cervical spine during assembly on the DV workstation. The fixed working posture on the IV method of assembly leads to the lower flexion of the cervical spine. Thus, the IV method of assembly forces the subjects to work in a restricted position and this restricted movements of the spine combined with lower muscular activity may lead to a constraint posture and in turn cause static muscle loading (Cantoni et. al. 1984). This constraint posture can lead to musculoskeletal disorders (Bendix 1987, Grandjean 1988 and Grieco 1986). Static or constrained workposture at the IV workstation may also lead to the accumulation of impaired substrate (lymph) within the trapezius muscle and can result in muscle fatigue (Kahn and Monod 1989). Hence, it is required to have some movement in the muscle during work in order to move these accumulated by-products (as these accumulated products does not have their own pumping system and they move with the movement of the muscle).

The low level of contraction of the trapezius muscles during work on the IV method may result in the repeated activation of a small number of motor units. The repetitive use of the same group of motor units for longer duration of time may cause injuries in the muscle group associated with the motor units even at low levels of contractions (Hagg, 1991 and Veiersted 1993), since activity in the surrounding muscle group is required to remove muscle activity by-products. Accumulation of these by-products may result in motor unit damage.

5.6 SUMMARY

This chapter has described the analysis of the muscular activity and the postural measurements. The physiometer unit was used to record the activity of the right and the left trapezius muscle. The same unit was also used for the recording of flexion and lateral flexion of the cervical and the thoracic spine. The analysis of the muscular activity of the right and the left trapezius showed that the IV method of PC board assembly involves lower level of contractions. The movements of the cervical and the thoracic spine were also found to be reduced when the subjects used the IV method for the PC board assembly. However, the low muscular activity associated with low movements of the spine does not confirm that the IV method delivers a lower risk of repetitive strain free method of PC board assembly. The lower muscular activity and low movements of the spine may lead to static muscle loading, accumulation of the waste products such as lymph and finally damage of the motor units which are associated with the assembly operations. Some aspects of the IV workstation appear positive and need further investigation. Aspects of two and three dimensional perception need to be quantified and work methods developed to improve productivity on the stations. In terms of protocol parameters, healthy levels of muscle activity (% MVC) and variation in muscle length need to be better defined in order to be sure that repetitive strain injuries can be truly reduced.

CHAPTER 6

ANALYSIS OF QUESTIONNAIRE

6.1 THE QUESTIONNAIRE

Each subject filled out a standardized questionnaire on the comparison of DV (DV) and indirect vision (IV) methods regarding the PC board (printed circuit board) assembly. The questionnaire was divided into two major sections. The first section constituted a preliminary questionnaire and the second a final questionnaire. The main objective of the preliminary questionnaire was to allow the operator to subjectively evaluate their ergonomic experience and comfort level when working on the DV method of assembly. This preliminary questionnaire was filled by all the subjects before starting the comparative study on the two types of assembly workstations. On the other hand, the final questionnaire allows the operators to compare the two methods of assembly mainly on the basis of subjective comfort and satisfaction ratings. The subjects were asked to fill final questionnaires on the last day of experimental study. Further, the final questionnaire may help in indicating the better method of assembly in terms of subjective rating.

6.2 DESIGN OF QUESTIONNAIRE

6.2.1 PRELIMINARY QUESTIONNAIRE

The preliminary questionnaire was divided into the following two sections:

SECTION 1.1

The first section was designed to gather information about the subject's experience in the PC board assembly section and their comfort rating for the workstation Northern Telecom is currently using for PC board assembly. The five point scale which was used to document the ratings offers the choice of perceived levels between extremely uncomfortable and extremely comfortable.

- SECTION 1.2

In the second section of the preliminary questionnaire the subjects were asked to shade the body areas on the attached drawing of the human musculoskeletal system where they have a feeling of discomfort and/or pain while at work or at home (Appendix 6.1). The subjects were instructed to use the following scale for rating physiological discomfort and/or pain in the shaded area on the drawing of the human musculoskeletal system.

0 -	No discomfort whatsoever
.5 -	Extremely mild discomfort
1 -	Very slight feeling of discomfort
2 -	Slight feeling of discomfort
3 -	Moderate feeling of discomfort
4 -	Somewhat high feeling of discomfort
5 -	High feeling of discomfort
6 -	Moderately high feelings of discomfort
7 -	Very high feelings of discomfort
8 -	
9 -	
10-	Extremely high feelings of discomfort (maximal level)

6.2.2 FINAL QUESTIONNAIRE

The subjects were asked to fill out the final questionnaire on the last day of their work during the experiment. The final questionnaire was designed to compare the two PC board assembly methods in terms of level of comfort, satisfaction, use of TV monitor etc. The final questionnaire was divided into the following four sections.

- SECTION 1

The first section of the final questionnaire deals with the physiological aspects of participants such as, their height, weight, laterality and vision.

- SECTION 2

The second section of the final questionnaire asks the subjects to express their personal feelings of satisfaction and comfort for both types of PC board assembly methods.

The following scale was used for rating the comfort and the satisfaction levels.

RATING	SATISFACTION	COMFORT
1	Extremely unsatisfied	Extremely uncomfortable
2	Slightly unsatisfied	Slightly uncomfortable
3	Neutral	Unsure
4	Slightly satisfied	Slightly uncomfortable
5	Extremely satisfied.	Extremely comfortable

The same section also questions subjects about how often they used TV monitor during assembly task. The following scale was used to rate this parameter.

1. Always ; 2. Most of the time ; 3. About half of the time ; 4. Very little ; 5. Never

- SECTION 3

The third section deals with the subjective reports on the use of TV monitor for assembly. The design of section three helps to check the validity of the response of the subjects to the questions in section two. The following are the questions used for checking the validity of responses to section two.

1. Did the subjects find working on the IV for full time satisfactory or not.

2. Will you exclusively use the TV monitor to aid in the assembly task ? (The response to this question helps in confirming the answer for the above question. As the IV method of assembly involves exclusive use of TV monitor for PC board assembly).

3. If the subjects did not want to use TV monitor exclusively for assembly then they were further asked to state whether they would mostly use the TV monitor for assembly or not.

4. Do you feel you are more prone to making errors on the DV workstation compared to the IV workstation (This question helps to find out the reason for a no response to above three questions).

5. The subjects were further asked about their preference for the provision of additional arm and elbow support on both types of workstations (DV & IV). This might help in making workstations more comfortable.

The subjects were asked to respond to the above questions or statements by circling either the "yes" response or "no" response.

6. Further, in order to make these two workstations more comfortable the subjects were asked about their preference for using the tilt feature of the work table.

The subjects were given three options to answer this question and requested to circle one choice. The options are as follows: positive degree angle, zero degree angle or negative degree angle of the worktable. The positive angle indicates the inclination of worktable towards the operator and the negative angle shows inclination away from the operator. Zero degree is the neutral position.

- SECTION 4

The last section of the final questionnaire compares the DV and the IV methods on the basis of the subject's body posture during PC board assembly. This section also deals with the subject's personal recommendations and suggestions about the IV method of assembly. The following questions were asked in this section.

1. What did you like most about your body posture when working on the DV and IV ?
2. What did you like least about your body posture when working on the DV and IV ?
3. In what section and/or operation of the plant would the IV method be relevant ?
4. Do you have any suggestion for the improvement of the two PC board workstations ?

6.3 ANALYSIS OF SUBJECTIVE RESPONSE TO QUESTIONNAIRE

6.3.1 PRELIMINARY QUESTIONNAIRE

- SECTION 1.1

The macro analysis of the first section of the preliminary questionnaire indicated that the average work experience of subjects at the DV type of assembly workstation was 11.9 months. The range of experience varied from 3 months to 34 months with a standard deviation (SD) of 11.9 months.

The second question was only answered by six subjects (W03, W04, W05, W07, W08 and W09). The analysis of data for six subjects on the comfort rating for the current workstation Northern Telecom is using for assembly shows that the mean value is 3.70 with a SD of 1.03. This mean value corresponds to a slightly comfortable level. Further, calculation indicates that if the available data is part of a normal distribution at 95% of confidence level, the mean value was between 4.49 and 2.73. These values lie between slightly uncomfortable and slightly comfortable on the rating scale for a 95% level of confidence.

- SECTION 1.2

The analysis of section 1.2 is shown in Table 6.1. The analysis of physiological discomfort level based on subjective reports (shaded portions on the drawing of human musculoskeletal structure) shows that the neck, the shoulder and the lower back are the most affected body parts. According to the subjective rating, the average (mean) of neck and shoulder complaints was 4.3 on a ten point scale. This value of mean lies between "some feeling of discomfort and high feeling of discomfort". The observed data on neck

TABLE- 6.1-
The frequency of neck / shoulder and lower back pain in subjects when working on the Direct vision workstation.

COMPLAINS	NECK / SHOULDER	LOWER BACK
MEAN	4.3	5.00
MEDIAN	5.0	7.00
MODE	7.0	7.00
SD	2.7	1.92

and shoulder discomfort also reflects a SD of 2.70 in the mean value. Also, the value of median and mode for the observed data is 5 and 7 respectively. The mode of the data indicates that most of the subjects have a very high feeling of discomfort. Therefore, the high frequency of neck and shoulder complaints reported by the subjects is in agreement with the relevant literature (refer to chapter 2).

The incidence of lower back complaints is indicated as the major factor of pain by the subjects during work or at home. The range of lower back complaints varied from 3 to 7 with a mean value of 5 on a ten point scale. This mean value of lower back complaint indicates a high feeling of discomfort. The SD is 1.92 from the mean value of lower back complaints. Further, the value of median and mode are 7 and 7 respectively.

A comparison of these two types of complaints shows a high significance of lower back complaints compared to neck and shoulder complaints. This is evident from the fact that the mean rate of lower back complaints (5) is higher than neck and shoulder discomfort (4.3) on a ten point scale. However, the mode for both of these complaints is the same. Therefore, if mode is considered as the descriptor for normal tendency of these disorders, then both complaints may have the same impact on human suffering. The variation in the data of lower back pain is small (1.92) as compared to neck and shoulder disorders (2.7). However, this available data on the lower back, the neck and the shoulder may not be significant because of small sample size used in the experiment. Nevertheless, the literature review (Chapter 2) indicates an agreement with the available data on lower back, neck and shoulder complaints reported here and in literature found on complaints from seated work posture studies. Therefore, the data taken here on lower back, neck and shoulder complaints can be accepted and may be considered as a possible major cause of strain injuries in the plant during manual assembly operation.

6.3.2 FINAL QUESTIONNAIRE

- SECTION 1

The analysis of section 1 of the final questionnaire is shown in Table 2.1 of Chapter 2. This data describes the general physiological demography of all workers.

- SECTION 2 -

SATISFACTION

Results from the second section of the final questionnaire are shown in Table 6.2. The analysis of data shows that subjects rated the DV method of PC board assembly as more satisfactory than the IV method. The mean satisfaction rate is 3.67 for the DV

TABLE- 6.2-
Subjective rating of satisfaction and comfort.

WORKER	SATISFACTION		COMFORT	
	DV	IV	DV	IV
W01	3	1	2	4
W02	4	4	2	4
W03	5	4	4	4
W04	2	5	2	4
W05	4	4	4	4
W06	4	2	5	2
W07	4	4	2	2
W08	3	4	2	4
W09	4	2	4	4
W10	5	3	5	4
W11	4	2	4	2
W12	2	1	4	4
MEAN	3.66	3.00	3.33	3.50

method. In contrast, the mean value is 3.00 for the IV method of PC board assembly. The SD of these means are 0.98 and 1.35 respectively. Table 6.21 highlights that at a 95% confidence level the mean satisfaction rating for the DV method has closer limits than the IV method of PC board assembly. This fact signifies a lower variability in the mean satisfaction value for the DV method, which leads to a higher confidence in the available data.

TABLE - 6.21-
Macro statistics for satisfaction and comfort rating

VARIABLES	SATISFACTION		COMFORT	
WS	DV	IV	DV	IV
MEAN	3.67	3.00	3.33	3.5
SD	0.98	1.35	1.23	0.91
CONFI. (95%)	0.55	0.76	0.69	0.51
INTERVAL	4.22 & 3.12	3.76 & 2.24	4.02 & 2.64	4.01 & 2.99

Denotation - CONF. - Confidence
SD - Standard deviation
DV - Direct vision
IV - Indirect vision

Table 6.3 shows that 50% of the subjects rated the DV method as slightly satisfactory. In contrast only 41.66% of subjects reported the IV as slightly satisfactory. Further, 16.70% of the subjects reported that assembling on the IV method is extremely uncomfortable while the same parameter is 0.00% for the DV. The subjective rating for satisfaction indicates that the DV method of assembly is acceptable to all workers whereas the IV method is extremely difficult for a significant number of operators.

COMFORT

The subjective rating of work posture comfort shows a higher value of mean comfort level for the IV method of assembly compared to the DV method. The SD of the mean is 0.91 for the IV method which is 0.32 less than for the DV method of assembly. The analysis of the data for comfort rating at 95% confidence level signifies a lower variability in the mean value of comfort for the IV method of assembly. Table 6.21 shows the mean value is between 4.01 and 2.99 for the IV method of assembly. This range is higher for the DV method and is between 4.02 and 2.64 at 95% level of confidence. The individual rating analysis of the data shows that 75% of the subjects feel slightly more comfortable on the IV method of assembly and only 41.70 % of subjects feel the same on the DV method. Thus, 33.30% of the subjects rated the IV method as slightly more comfortable than the DV method of assembly. Further analysis of the data shows that 25% of the subjects rated the IV method as slightly uncomfortable which is only 16.70% for the DV method of assembly. However, 16.70% of the subjects expressed a feeling of extreme comfort when working on the DV method while for the IV the percentage is zero.

TABLE- 6.3-

Comparison of the Direct and the Indirect Vision method (subjective rating)

SATISFACTION	DIRECT VISION (DV)	INDIRECT VISION (IV)	DIFFERENCE (DV - IV)
Extremely unsatisfied	00.00%	16.70%	-16.70%
Slightly unsatisfied	16.70%	25.00%	-08.30%
Neutral	16.70%	08.33%	08.37%
Slightly satisfied	50.00%	41.66%	08.34%
Extremely satisfied.	16.70%	08.33%	08.37%
COMFORT			
Extremely uncomfortable	00.00%	00.00%	00.00%
Slightly uncomfortable	41.70%	25.00%	16.70%
Unsure	00.00%	00.00%	00.00%
Slightly comfortable	41.70%	75.00%	-33.30%
Extremely comfortable	16.70%	00.00%	16.70%

The subjective rating on comfort level does not corresponds with the subjective level of satisfaction for the two types of workstations. Psychological factors, such as the fact that the subjects were told before the start of the experiment that the introduction of new workstation (Indirect vision) may over come the drawbacks of the existing method might have encouraged the subjects to rate the IV method as a more comfortable method of PC board assembly. It is evident from Table 6.2 that the subjects, such as Worker one (W01) and Twelve (W02), rated the IV method as extremely uncomfortable, but on the other hand they rated the same workstation as slightly comfortable. Therefore, it may be concluded that the subjects were uncertain and might be psychologically motivated to state a higher level of comfort on the IV method while 'feeling' the questionnaire. Most of the subjects who participated in this experiment were working on a temporary basis and this fact could possibly negatively motivate their feelings about level of comfort on the IV method of assembly.

- SECTION 3

In this section the subjects were asked about their interest in exclusive use of the TV monitor for PC board assembly. The result shows that only 8.33% of the subjects wished to use the TV monitor exclusively for assembly (Table 6.4.1).

TABLE 6.4 -
Analysis of section three of final questionnaire

Table 6.4.1 -
Exclusive use of the TV monitor for PC board assembly

100 % USE OF TV FOR ASSEMBLY		
1	YES	8.33%
2	NO	91.67%

However, 45% of the subjects agreed with the use of the TV monitor for the majority of the time for PC board assembly (Table 6.4.2). It should also be noted that 25% of the subjects reported that they wished to work full time on the IV method for assembly operation. Therefore, most of the subjects did not wish to use the IV method of assembly for full time and wished to use the DV method for assembly at least some of the time. (Table 6.4.3).

Table 6.4.2 -
Frequent use of the TV monitor for PC board assembly

MOSTLY USE OF TV FOR ASSEMBLY		
1	YES	45%
2	NO	55%

Table 6.4.3 -
Preference for working full time using the IV assembly method

FULL TIME USE OF THE IV		
1	YES	25%
2	NO	75%

Table 6.4.4 -
Preference for the tilt of work table

TILT	ANGLE	%
1	POSITIVE	42%
2	ZERO	33%
3	NEGATIVE	0.83%

Analysis of section three shows that only 8.33% of the subjects noted higher rate of error on the DV assembly method (Table 6.4.5). This fact implies that approximately 91% of the subjects thought that they were more likely to make errors on the IV method when compared to the DV method of assembly. Most of the subjects suggested that the major cause for errors on the IV method was due to the lack of depth perception. As stated in Chapter Three the assembly procedure involves many complex and

Table 6.4.5 -
Subjective rating for the comparison of the rate of errors on the DV and the IV method

#	SUBJECTIVE RESPONSE	% OF SUBJECTS
1	YES	0.83%
2	NO	98.17%

precise processes such as soldering and bending of components leads, which need depth perception. For this reason 45% of the subjects might have agreed to use the TV monitor most of the time during PC board assembly, but must use the DV method for some part of the work.

- SECTION 4

The analysis of the first question shows that most of the subjects liked the DV method of assembly because of the following reasons:

a) better quality of soldering and Total Quality Management (TQM).

b) work flexibility may reduce the static muscle load.

c) wider field of view.

d) better perception of depth; and

e) comfortable body posture

The following reasons were given why the subjects liked the IV method of assembly:

a) reduction in neck and shoulder pain; and

b) body relaxed and more comfortable.

c) back support of chair can be used during assembly work.

The analysis of the second question (what subjects like least about the DV method) for the DV leads to the following conclusions:

a) neck and shoulder pain because of bending of the cervical spine during work.

b) improper location of component trays.

The responses to the same question for the IV method is as follows:

a) eye strains, headaches and sore neck.

b) lack of depth perception; and

c) restricted view of PC board.

d) difficult to perform complex operations such as soldering and bending of component leads.

e) chances of injuries

f) lack of resolution power of camera; and

g) constrained posture

The answer to question three shows that 50% of the subjects reported that the IV method can be used in the slide line area and wherever PC boards are assembled, inspected and repaired. In contrast, 16.66 % of subjects did not responded to this question. Finally, the remaining 33.34% reported that it can't be used anywhere in the plant.

The final question was to suggest the modifications that can be done in the IV method. The following were the suggestions reported by the subjects:

a) provide depth perception.

b) improvement in the resolution of camera; and

c) extra elbow support.

6.4 CORRELATION OF SUBJECTIVE RATING WITH PRODUCTIVITY AND MUSCULAR ACTIVITY

The productivity level of each subject has been correlated with their response to section two of the final questionnaire which deals with their personal comments on comfort and satisfaction when working on the DV and the IV method of assembly. For example, the increase in level of productivity when working on any one of the assembly work- stations may be related to higher rate of comfort or discomfort. This type of relationship between comfort, satisfaction, productivity and muscular activity of the left and the right trapezius has been established using Pearson's correlation [r]. The result of these correlation's is shown in Table 6.5.

6.4.1 COMFORT AND PRODUCTIVITY

DIRECT VISION

The coefficient of correlation between the subjective rating of comfort level and productivity for the DV method of assembly is 0.31. The positive value of the

TABLE- 6.5-

Correlation between satisfaction and comfort with productivity and electromyography measurements for both types of workstations

		COMF.	SAT.	COMF.	SAT.	COMF.	SAT.
	PROD.DV	0.31	0.06				
	PROD.IV	-0.60	0.22				
RIGHT	**EMG DV**			0.16	0.60		
TRAP	**EMG IV**			0.24	0.35		
LEFT	**EMG DV**					-0.46	-0.37
TRAP	**EMG IV**					-0.17	-0.47

Demotions - COMF. - Comfort
SAT. - Satisfaction
PROD. - Productivity
TRAP - Trapezius

TABLE- 6.6-

Square of coefficient of correlation (r)

		COMF.	SAT.	COMF.	SAT.	COMF.	SAT.
	PROD.DV	0.096	0.003				
	PROD.IV	0.36	0.048				
RT. TRAP.	**EMG DV**			0.0240	0.336		
	EMG IV			0.0576	0.122		
LT. TRAP.	**EMG DV**					0.211	0.136
	EMG IV					0.028	0.220

Demotions - COMF. - Comfort
SAT. - Satisfaction
PROD. - Productivity
TRAP - Trapezius

coefficient of correlation indicates a weak linear relationship between the two variables. However, the magnitude of this linear relationship is low. Further from the data set, only 9.61% of the observed variation is common to satisfaction and productivity. Hence, it can be concluded that the relationship between the two variables is not strong. Nevertheless, the positive value of correlation coefficient still signifies an increase in the level of comfort with the increase in productivity.

INDIRECT VISION

The correlation coefficient between productivity and comfort level on the IV method of assembling is - 0.60. The value of the coefficient of correlation is high and negative which indicates a moderate linear relationship between the two variables but in the undesirable direction showing productivity dropping as comfort rises. Therefore, in order to achieve a higher level productivity on the IV workstation it would seem to be necessary to sacrifice some level of comfort and this would be contrary to attempts to reduce Cumulative Trauma Disorder. Psychological factors like motivation can be one of the reasons for the negative linear relationship between comfort level and productivity. However, the factors , such as the lack of depth perception may mean operations take longer even though posture is more comfortable. Finally, the set of data signifies that 36% of the observed variation is common to comfort and productivity.

6.4.2 SATISFACTION AND PRODUCTIVITY

DIRECT VISION

The value of the coefficient of correlation between satisfaction and productivity is 0.06. This value indicates that there is no linear relationship between the two variables. Sometimes the value of the correlation coefficient (r) is close to zero, which correctly indicates a lack of linear relationship, but this does not mean there is no relationship between the two variables. There might be a parabolic relationship between the two variables. However, this can be proved by a scatter diagram.

INDIRECT VISION

The value of the correlation coefficient between satisfaction level and productivity is 0.22. This value expresses a low positive linear relationship between the two variables of satisfaction and productivity. Table 6.6 shows that only 4.84% of the observed variation is common to these two variables. The low level of correlation between variable may be due to the influence of some psychological factors associated with the learning period on the IV workstation.

6.4.3 COMFORT AND PHYSIOLOGICAL MEASUREMENT (R. TRAP)

DIRECT VISION

The value of the coefficient of correlation is 0.16 between comfort and the activity of the right trapezius muscle. This value shows a weak positive linear relationship between the two variables. A scatter diagram is plotted in order to check the pattern of the correlated data. Further, only 2.4% of the variations in the data are common with the two variables. Hence, it can concluded that there is a very weak relationship between the two variables.

INDIRECT VISION

Similar to DV method, the relationship between comfort and activity of the right trapezius muscle is 0.24. The factor of 0.24 shows a low level of positive linear relationship between the two variables. In order to confirm this relationship the variation in data is checked by squaring the value of 'r' and it's found that only 5.76% of the variations are common with comfort and activity of the right trapezius muscle. Thus, it is possible to conclude there is no real relationship between the two variables related to the two workstations tested.

6.4.4 SATISFACTION AND PHYSIOLOGICAL MEASUREMENT (R.TRAP)

DIRECT VISION

The coefficient of the correlation between satisfaction and activity of the right trapezius muscle is 0.60 which shows a moderate linear relationship. The stress on the right trapezius muscle is not directly proportional to the satisfaction rating of the subjects but, is 36% dependent on it. Therefore, it may be concluded that the subjective rating for satisfaction corresponds somewhat to the activity of the right trapezius muscle. Further, 36% of the variation in the observed data is common with the two variables. Therefore, the value of the correlation coefficient allows us to confirm the fact that the average subjective rating for satisfaction is higher for the DV method of PC board assembly. However, the analysis also indicates that several important parameters (as yet undefined) were not measured. The measurable factors such as, degree of depth perception etc., may be significant but were not quantified in this study.

INDIRECT VISION

The value of the correlation of coefficient is 0.35 for satisfaction and activity of the right trapezius muscle. The value of 0.35 shows a weak relationship between the two variables. This fact is further confirmed as only 12.25% of the variations are common with the two variables. However, the positive value indicates that an increase in muscular activity of right trapezius will lead to an increase in satisfaction level. This correlation indicate that the highly restricted muscular activity during work on the IV method may result in the decrease in level of satisfaction.

6.4.5 COMFORT AND PHYSIOLOGICAL MEASUREMENTS (L. TRAP)

DIRECT VISION

As shown in Table 6.5 the coefficient of correlation between physiological measurements from left trapezius and comfort rate is -0.46. The negative sign indicates a opposite correlation between the two variables. There is a variation of 21.16% in the observed data. Hence only 21.16 % of the variation is common with the two variables. This fact shows that there is a low linear relationship between the two variables and approximately 78% of the reasons for comfort do not relate to left trapezius activity. The correlation between the right trapezius and satisfaction is higher compared to the left trapezius and satisfaction.

INDIRECT VISION

The value of the correlation coefficient is -0.17. This indicates an extremely weak linear relationship between the comfort and activity of the left trapezius muscle. The negative value of the coefficient of correlation signifies an increase in muscular activity that leads to a very small decrease in the level of comfort. Further, in order to confirm this a scatter diagram is plotted and it was confirmed that both sets of data are scattered in a nonhomogenous fashion and shows a weak relationship between the two variables. The variation in data also show that only 2.9% of variations are common to left trapezius muscular activity and comfort. This small variation of 2.9% may be due to the fact that all the subjects were right handed. Hence, it can be concluded that the left trapezius muscle is almost unrelated to comfort.

6.4.6 SATISFACTION AND PHYSIOLOGICAL MEASUREMENT (LT.TRAPEZIUS)

DIRECT VISION

The coefficient of correlation between satisfaction and activity of the left trapezius muscle is -0.37. The magnitude of the coefficient of correlation is low and is insufficient to predict any linear relationship between activity of the left trapezius muscle and the subjective rating for satisfaction. Further, Table 6.6 shows that only 13.70% of the variations are common to the two variables. The negative value shows that with a increase in activity of the left trapezius muscle there is a decrease in the level of satisfaction rating. This is not too surprising , since subjects were all right handed and may find the need to use their left arm somewhat undesirable.

INDIRECT VISION

The value of the coefficient of correlation between satisfaction and activity of the left trapezius muscle is -.47 for the IV method of PC board assembly. This value shows a moderate linear relationship between the two variables. However, the variation common to both variable is only 22.09%. Further, the negative sign indicates that there is an inverse correlation between these two variables. This also signifies the fact that level of muscular activity and satisfaction are inversely proportional.

The overall correlation analysis indicates that the following list of variables showed somewhat moderate linear relationship. Again, since subjects were right handed, the negative relationship is not unexpected.

DIRECT VISION

1. Level of satisfaction and activity of the right trapezius muscle (0.6).
2. Level of comfort and activity of the left trapezius muscle (-0.46).
3. Level of satisfaction and activity of the left trapezius muscle (-0.37).

INDIRECT VISION

1. Level of comfort and productivity (-0.60).
2. Level of satisfaction and activity of the right trapezius muscle (0.35).
3. Level of satisfaction and activity of the left trapezius muscle (-0.47).

The hypothesis that there may be a significant linear relationship between the above variables is tested by using statistical test (T test) at 0.1 level of confidence for ten degree of freedom. The results are shown in Table 6.7. These results illustrates a significance in the correlation between level of satisfaction and activity of the right trapezius muscle on the DV method of assembly. The reason for this significant correlation may be due to the fact that subjects rated the DV workstation (section 2 of final questionnaire) as more satisfactory than the IV workstation. Also, the analysis of section 4 (final questionnaire) highlights that subjects felt more satisfied when working on the DV method. However the correlation between all the other variables is non-

TABLE- 6.7-

Testing the hypothesis at a 90% confidence by using students 't' test

DIRECT VISION					
	r	**(r*r)**	**'t' calculated**	**'t' at 0.1**	**RESULT**
SAT & RIGHT TRAP.	0.600	0.360	1.862	1.812	S
COMF. & LEFT TRAP.	-0.460	0.211	-1.439	1.812	NS
SAT. & RIGHT TRAP.	-0.370	0.136	-1.162	1.812	NS
INDIRECT VISION					
COMF. & PROD.	-0.600	0.360	-1.8629	1.812	S
COMF. & RIGHT TRAP.	0.350	0.122	1.099	1.812	NS
SAT. & LEFT TRAP.	-0.470	0.220	-1.469	1.812	NS

Denotion SAT. - Satisfaction
COMF. - Comfort
PROD. - Productivity
TRAP. - Trapezius
S - Significant
NS - Not significant

significant as the calculated 't' value at 90% confidence level for 10 degrees of freedom is less than the theoretical value of 't' which is taken from the standard tables.

Similarly, the same hypothesis testing for the IV method shows a significance between level of comfort and productivity at 90% confidence level. Whereas the correlation for all the other variables is non-significant at this level of confidence (Table 6.7). Generally, 95% confidence level is used for hypothesis testing but, because of small sample size only 90% level of significance is considered. The sample size is small and can be a questionable factor in making a firm conclusion about the data. However, in industrial experiments the cost involved in conducting these type of experiments is high due to loss in the productivity and effect on the normal planning schedule.

6.5 SUMMARY

The overall analysis of the questionnaire indicates that the subjects felt more satisfied and comfortable when they were using the DV method for PC board assembly. Although, the mean value of comfort rating was higher for the IV method of assembly, this mean value is in conflict with the responses to the questions regarding full time use of TV monitor for assembly, of section three in the final questionnaire. The correlation between all of the variables is very weak except to level of satisfaction and activity of the right trapezius muscle for the DV method and level of comfort and productivity for the IV method of assembly. The psychological factors and physiological factors such as constraints during performing operation on the IV method (depth perception and complicated operations etc.) may be the major causes for the low level of correlation between the variables. The small sample size can also be a major factor for the insignificant correlation. Hence, in order to get better results some more experiments are essential to be conducted in the industrial environment.

However, the questionnaire did show that several new parameters such as depth perception, TV monitor, camera resolution and posture mobility may be highly significant for comfort. The study also shows that a workstation that incorporated both monitor and good position of the workplace to reduce cervical flexion and extension may be desirable and would possibly increase both comfort and productivity.

CHAPTER 7

SUMMARY AND DISCUSSION OF THE STUDY

7.1 DISCUSSION

The productivity for the two types of assembly methods was calculated in terms of time taken for the assembly of a single PC board. The higher value of time taken for the assembly of a single PC board indicates a lower level of productivity. The productivity data was obtained by combining the protocols and the PHY records. This combined data showed that the average time for the assembly of a single PC board on the Direct vision (DV) Cutout and Traditional workstations was 189.67 sec. and 230.33 sec. respectively. In contrast, the average time per PC board was 266.50 and 287.1733 respectively for the Indirect vision (IV) Cutout and Traditional workstations (Table 4.1 and 4.2). The productivity can also be defined as the number of PC boards assembled per unit time. According to this definition productivity for the DV Cutout and Traditional workstation was 0.005 and 0.004 PC board per minute while for the IV Cutout and Traditional workstation productivity was 0.0037 and 0.0035 PC boards per minute. Therefore, irrespective of the workstation type, the level of productivity is higher by 20 to 28% for the DV method of PC board assembly. The within subject comparison also indicates that the Cutout workstation has a higher level of productivity compared to the Traditional type of workstation.

For almost all subjects the level of productivity was always lower on the IV method of assembly when compared to the DV method. However, the only exceptional and interesting case was of Worker five (W05). The average data of W05 shows that he/she only took 174 seconds to assembly a PC board on the IV method and it was 180 sec. on the DV method. Table 4.5 shows that the time per PC board was further reduced from 174 to 164 seconds on the sixth day of training on the IV method. This higher level of productivity in case of W05 on the IV method could be due to the use of a different strategy during assembly operation. The other psychological reason might be negative motivation, the subject was a temporary worker in the plant and perhaps in order to impress the manager he/she would have adopted the new working condition in a shorter time period. The personal demography of W05 such as age, height etc. and less work experience in the assembly line may also an have a influence in the adaptation to new working condition. However, other workers with the same physiological and psychological state apparently can not reach Worker five's (W05) level of productivity on the IV method of assembly. The regression analysis of the productivity data illustrates this fact. Table 4.6 shows the polynomial and power-exponential regression models. The polynomial regression model showed that on the IV method, Worker five (W05) only took 4 to 7 days to reach the same level of productivity as that of the DV method while for other workers the level was not reached even within 500 days.

The influence of negative motivation on the performance of Worker Five (W05) can be checked from his/her individual response to the questionnaire section. The responses showed that the W05 rated both the IV and the DV workstation as slightly satisfied and slightly comfortable. Worker Five (W05) also stated that during the experiments he/she mostly used the TV monitor for the assembly of PC boards. However, irrespective of the higher productivity on the IV method, W05 never agreed to exclusively use the TV monitor for the assembly of PC board, but was willing to use the TV monitor for a majority of the assembly time only. The same worker also reported that he/she did not like to watch the PC board on the TV monitor which is in contradiction with his/ her higher level of productivity on the IV assembly method. Still, the higher productivity shown and the limitations he/she placed on monitor use indicate novel approaches to the assigned tasks . This fact suggests that repetition of tasks and more flexible combinations of the IV and DV may lower the risk of Cumulative Trauma Disorder and result in higher productivity. Further, Worker five (W05) responded that the use of the IV method in the assembly line section is questionable.

Overall analysis of the questionnaire shows that 16.70% of subjects felt extremely satisfied on the DV method while on the IV method only 8.33% of the subjects felt extremely satisfied (Table 6.2 and 6.3). The average feeling of satisfaction on the DV method was between neutral and slightly satisfied while for the IV method it was neutral. The average data for the feeling of comfort was higher on the IV method of assembly (3.5) compared to the DV method (3.33). However, 16.70% of the subjects felt extremely comfortable on the DV method while 0.00% of the subjects felt the same about the IV method. Thus, the responses of Worker Five (W05) to the questionnaires were in agreement with the responses of all other workers. Hence, there are some other undefined variables for the comfort and satisfaction which can be related with the performance level of Worker Five (W05) on the IV method.

The quantitative analysis of electromyography (EMG) and postural data concluded that the IV method of assembly was significantly different from the DV method. The difference can be seen from the low level of activity of the trapezius muscle and lower moments of the cervical and the thoracic spine. The results showed that on the IV method percentage of maximum voluntary contraction (%MVC) was 12.05 and 7.43 respectively for the right and the left trapezius muscle. These results show a lower muscular activity with a low onset of fatigue as the value was less than 15-20% of MVC (Kahn and Monod 1989). However, the load levels which allow unlimited duration of contraction can not be defined (Chaffier et. al. 1993) as musculoskeletal disorders were reported when the contraction was less than 1% MVC (Kvarnstrom 1983). Thus, the lower level of muscular activity and spinal movements on the IV method may still cause muscle fatigue. Longer duration measurement and observation would be necessary before conclusions could be drawn. The major drawback of the IV method of assembly is fixed body posture as the operators were forced to remain in one position and look at a TV monitor for extended periods of time without postural movements. Requiring workers to hold a fixed body posture may lead to postural fixity or enforced posture which can be a leading cause of human suffering (Carter, 1994). During observation a fixed object, such as PC board on a TV monitor, the degree of postural fixity of the whole spine increases with the degree of complexity of the information being processed (Laville 1980, 1985). Postural fixity might further cause static muscle loading (Cantoni et. al. 1984) and hence musculoskeletal pain (Bendix 1987, Grandjean 1988 and Grieco 1986). As stated in the literature, constrained posture may results in Ischaemia (Grieco 1986, and Sjogaard et. al. 1988). Hence, the risk of Ischaemia may be higher when working on the IV method of assembly.

Further, the rate of blood flow through a muscle depends upon its contraction. This rate of blood flow is proportional to the loss of potassium ion gradient across the vein and artery cell membranes. Static or constrained workposture at the IV workstation may lead to the accumulation of impaired substrate (lymph) within the trapezius muscle and can result in muscle fatigue (Kahn and Monod 1989). The lymph does not have its own pumping system and its movement is dependent on the motion of the muscle. Therefore, during assembly operation some variations in the muscular activity and length preferably at low muscle force level (Kilbom 1987 and Winkel 1987) are required

The IV method involves a low level of static contractions that may result in the repeated activation of a very small number of motor units. Use of the same group of motor units for long duration of time may cause injuries in the muscle group associated with the motor units even at low levels of contractions (Hagg, 1991 and Veiersted 1993), since activity in the surrounding muscle group is required to remove muscle activity by-products. Accumulation of these by-products may result in motor unit damage.

One interesting aspect of the data obtained from physiological measurement is the large variability in motion and %MVC seen between workers on the same workstations. There appears to be many different ways of approaching each sub task in PC board assembly. Some of these approaches may lead to higher CTD risk than others. If this hypothesis was true, then training in performance of each sub-task may be even more significant in reducing risk than is the radical redesign of workstation. An example of such risk reduction through training is the teaching of manual material handling techniques in shipping areas, where risk can be reduced by greater than 95%. Perhaps the same principal applies to less dramatic physical manipulation.

Finally, the correlation analysis between the subjective rating, objective and physiological measurements showed that there was a very weak linear relationship between these variables. The following variables only showed a moderate linear relationship:

1. level of satisfaction and activity of the right trapezius muscle (36%) for the DV method; and

2. level of comfort and productivity (36%) for the IV method of assembly.

Even the above two values shows that there are still more than 50% of the significant variables undefined for the comfort and satisfaction relationship. Further, the psychological factors and the physiological factors may be the major causes for the low level of correlation between the variables. The other factor for the lower value of the coefficients of correlation may be small sample size (12 subjects). However, in an industrial environment it is not possible to have a sample size of 25 subjects, for a preliminary study such as this, as it is not cost effective in terms of labor cost, loss of productivity and the effect of the experiment on the production planning. However in order to reach a firm conclusion regarding injury potential it is necessary to conduct some more experiments in the industrial environment.

From the data gathered and the correlation's developed in this study it is apparent that other significant variables must be defined. Some of these were expressed as problem areas by the worker's replies to the questionnaire. Monitor resolution, depth perception, range of view and posture mobility are a few such parameters. The majority of causes for lower of higher productivity have not yet been isolated and measured.

7.2 SUMMARY

The analysis of the objective, physiological and subjective measurements has shown some interesting and controversial results. The results highlight that use of the Indirect Vision (IV) method of assembly in the industrial environment in its present form is really questionable due to the following reasons:

1. the level of productivity is lower for the IV method. Hence, the total output in terms of the number of PC boards assembled will be low;
2. irrespective of lower activity of the trapezius muscle and lower movements of the cervical spine, the chances of postural-fixity-related problems is higher on the IV method; and
3. the subjective response on the questionnaire is unclear as there were too many unknown variables of comfort and satisfaction. Even the correlation between physiological (muscular activity of trapezius muscle) and subjective rating parameters (comfort and satisfaction) was very low.

However, to conform the findings of the present experiment, some more similar studies are required. Further, the data gathered and the correlation developed showed that there are some other significant variables which must be defined. Similarly, the majority of the parameters for fluctuation in productivity have not yet been isolated and measured.

CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

8.1 CONCLUSION

In this experiment productivity, physiological and psychological measurements were used for comparing the two types of assembly methods. The following can be concluded from the comparison of Direct Vision (DV) and the proposed Indirect Vision (IV) method of PC board assembly.

1. Objective measurement

1.1 The level of productivity is higher for the DV method of assembly when compared to the proposed IV method irrespective of workstation type. For the DV Cutout workstation the level of productivity was 40.50% higher while for the DV Traditional workstation this parameter was 24.68% higher than for the same workstation using the IV method. The level of productivity was highest on the DV Cutout workstation when between subject data was compared.

1.2 The regression analysis of the productivity data concluded that the subjects reached their maximum productivity level on the IV cut-out workstation in 13 to 20 days of training. Similarly, subjects took 9-12 days of training to reach their maximum productivity level on the IV Traditional workstation. However, this maximum productivity level on the IV method was shown by prediction to never reached the maximum productivity level of the DV method even after 500 days of training.

1.3 The only contradiction to the conclusion of productivity is the data of Worker Five (W05). The productivity level of Worker Five (W05) was 3.5% higher on the IV Cutout workstation when compared to the DV Cutout workstation by 3.5%.

2. Electromyography (EMG) measurement

2.1 The analysis of EMG data concluded that for the IV workstation of assembly, the activity of upper right and left trapezius muscles was reduced by 7.91% MVC and 3.15% maximum voluntary contraction (MVC) when compared to the DV workstation.

2.2. Assembly operation by using the IV method of assembly reduces the range of cervical flexion by 50% (significant at a 90% level of confidence) while for the thoracic spine this reduction was only 3.5%.

2.3. During work on the IV workstation for assembly the workers kept their cervical and thoracic spine in a straighter position for relatively longer time periods as is shown by the value of skewness which was always lower for the IV method of assembly. Hence, the frequency of flexion and lateral flexion of the spine was lower on the IV workstation method of assembly and may lead to constrained posture problems.

However, the restricted movements of the cervical and the thoracic spine (low frequency of flexion and lateral flexion of the spine) along with the lower muscular activity of the trapezius muscle shows that the IV workstation may lead to physiological discomfort due to greater restriction of the spine movement as the physical movements were compensated by eye movement. The low muscular activity associated with the restricted movements of the spine may lead to static muscle loading. Further, the indication of lower trapezius muscular load may be due to the fact that most of the load is shared by the corresponding deltoids during assembly work at the IV workstations. Hence, it is questionable to conclude from physiological data that the IV method of assembly really reduces discomfort. The above conclusion may further be supported by the subjective ratings of the subjects as reported in the questionnaire.

3. Subjective ratings

3.1 The analysis of subjective reporting on the preference of the type of assembly method showed a high rate of satisfaction for the DV method (3.67) compared to the IV method (3.00). Further, 16.7% of subjects rated the DV method as extremely satisfactory while only 8.33% rated the same for the IV method.

3.2 The average rate of comfort was higher for the IV method (3.5) when compared to the DV method (3.33) of assembly. However, 16.7% of the subjects rated DV method as extremely comfortable while 0.0% rated the same for the IV method. Hence, it can be concluded that irrespective of higher average comfort rating (3.5) for the IV method, the DV method is more comfortable.

3.3 The correlation between subjective rating and physiological measurement was very low for all workstation. The only significant correlation was between level of satisfaction and activity of the right trapezius muscle (0.6) for the DV method and a negative correlation between comfort and productivity for the IV method (-0.6). The low correlation can further be justified through experimenters observations, as one subject mentioned that if he/she has to work on the IV method of assembly then he/she will quit the job.

3.4 From the statistical analysis, the correlation coefficients indicate that there are too many undefined variables associated with productivity. The correlation between productivity and comfort showed that 50% to 64% of the reasons for comfort are yet undefined.

As a result of observations of operators and data analysis, several new parameters appear to be of importance to both comfort and productivity.

a) Certainly TV camera and monitor resolution must be improved to avoid headaches and eyestrain.

b) It also became apparent that depth perception is important to speed of assembly as well as to quality of production.

c) New geometrical workplace and workpiece positions and tasking techniques would appear to offer some possible productivity increase with higher comfort if aspects of the DV and the IV workstation could be combined.

4. Hence, the overall results of productivity, physiological measurements and subjective reports concludes that the use of the IV method for mass assembly operation at this stage of development would be questionable. Also, it is still controversial to state that the IV method of assembly reduces the chances of Repetitive Strain Injuries or Cumulative Trauma Disorders. However, this workstation may be used for some other intermittent operations, such as inspection.

8.2 RECOMMENDATIONS

The following recommendations may be considered for further study.

1. The present design of workstation lacks depth perception. The use of fiber optics technique or introduction of a second camera to capture the side view of assembly operation could be used to introduce the depth perception (third dimension). The TV screen can be divided into two parts so that one part can show the top view and the other can show the side view. However, the use of another camera will result in the increase of workstation cost. A much cheaper solution could be replacement of overhead camera by a prism and the TV monitor by a mirror. However, some constraints such as, reflection of objects other than the PC board on the glass mirror may not allow us to use this concept.

2. Simple vigilance camera was used for magnifying the image of PC board on to the TV monitor and hence, the resolution power of the camera was low. Therefore, it is necessary to use high resolution cameras with higher focusing power. The use of high resolution cameras may improve the level of productivity when compared to the level of productivity of the present IV workstation. Introduction of high resolution cameras may further increase the subjective rating of comfort and satisfaction on the IV method. However, high resolution cameras are expensive and will increase the overall cost of the IV workstation.

3. The hypothesis that working on the IV method of assembly may result in static muscle loading should further be tested by using intramuscular pressure and by performing Fast Fourier Transforms (FFT) over the raw EMG signals periodically.

4. The assembly operations for a single PC board could be performed by using a combination of the DV and the IV workstations. The operations such as, soldering, trimming of component legs and forming of component legs should be performed by using the DV method. On the other hand, operations which do not involve much of the depth perception could be performed by using the IV method. The combination of both the methods may reduce the chances of RSIs in upper extremity as well as static muscle loading. However, initially this concept should be tested in laboratory and then may be further tested in the industrial environment. Further, both of these results should be correlated. A simulation technique could be used for the testing of these two concepts.

5. Further, experiments should include video analysis. Reference markers should be placed on the subjects so that resulted joint moments of the cervical spine, wrist, shoulder and elbow can be obtained and correlated with the EMG measurements and subjective measurements.

Finally, methods of automatically repositioning the workpiece for each sub task during assembly may improve productivity for both assembly methods. The IV method may prove to be unnecessary if the workpiece is properly positioned and speed and accuracy as well as reduced hyper extension and flexion may also be achieved. In any research, a parallel study of this approach should be done on the basis of its potential cost effectiveness.

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APPENDIX 2.1

Contents **:** A short desctiption of the following

1. An introduction to the spine
2. Electromyography

AN INTRODUCTION TO THE SPINE

The vertebral column is composed of a series of bony units called vertebrae. The articulating parts of these vertebrae are vertebral bodies, which are separated by facet joints and pads of fibrocartilage known as intervertebral discs (Figure 2.1). The vertebral column is also called the spine. The location of the vertebral column is in the mid-dorsal region of the body and it serves as the main support for the body posture. The design of the vertebral column enables it to provide adequate and smooth motions of the head, trunk and pelvis. The vertebral column serves as a pivot for the head i.e. the skull rests on its superior end, called the thorax, and it also gives direct attachment to the pelvic girdle at the inferior end. Basically vertebral column acts as a shock absorber apparatus which transfers bending moments of the upper body to the pelvis. The other main function of vertebral column is to provide support and protection to the spinal chord which passes through the vertebral canal formed by the vertebras. The spinal chord is covered by three membranes called the dura matter, the arachnoid and the pia matter which are separated from each other by two spaces, the subdural space and the subarachnoid space.

There are openings between vertebras called intervertebral foramina. The function of these opening is to provide passage for paired spinal nerves which carry nervous impulses to and from the spinal chord. The vertebral column is the point of origin for skeletal muscles which produce movements of the column as well as movements of other parts with respect to the column. The intervertebral column joint functions as a static weight bearing joint whereas facets work as dynamic sliding and gliding joints. About 75% of spinal length is contributed by the vertebral bodies and the rest 25% is composed of intervertebral disc material. However, the intervertebral discs are not uniformly distributed throughout the spine. The intervertebral disc height in the lumber region contributes to approximately 30% of lumber length, while 20% of the combined cervical and thoracic spine length is from disc height.

2.2.1.2 CONSTRUCTION OF THE SPINE

Basically, the spine consists of four major regions which are defined on the basis of the curvature of the spine. These regions are as follows (Figure 2.1.1).

1. Cervical
2. Thoracic
3. Lumber
4. Sacral (consists of 5 sacral and 4 coccygeal vertebrae)

The spine has a total of 33 vertebrae which are subdivided into 7 cervical vertebra (C1-C7), 12 thoracic vertebrae (T1 -T12), 5 lumber vertebrae, 5 sacral, and 4 coccygeal. The vertebra of first three regions remains distinct throughout the life however, 5 sacral fuses with 4 coccygeal and this region is called Sacral. The five fused sacral form the sacrum and the 4 coccygeal form the coccyx. The sacrum is almost completely fixed to the pelvis.

THE CERVICAL SPINE

The cervical spine is both a structural, static support and a mobile kinetic mechanism. The cervical spine is a assembly of superimposed functional units. The main units include seven vertebrae from the cervical lordotic portion of the vertebral column with each two adjacent vertebrae and their interpose tissues forming a functional

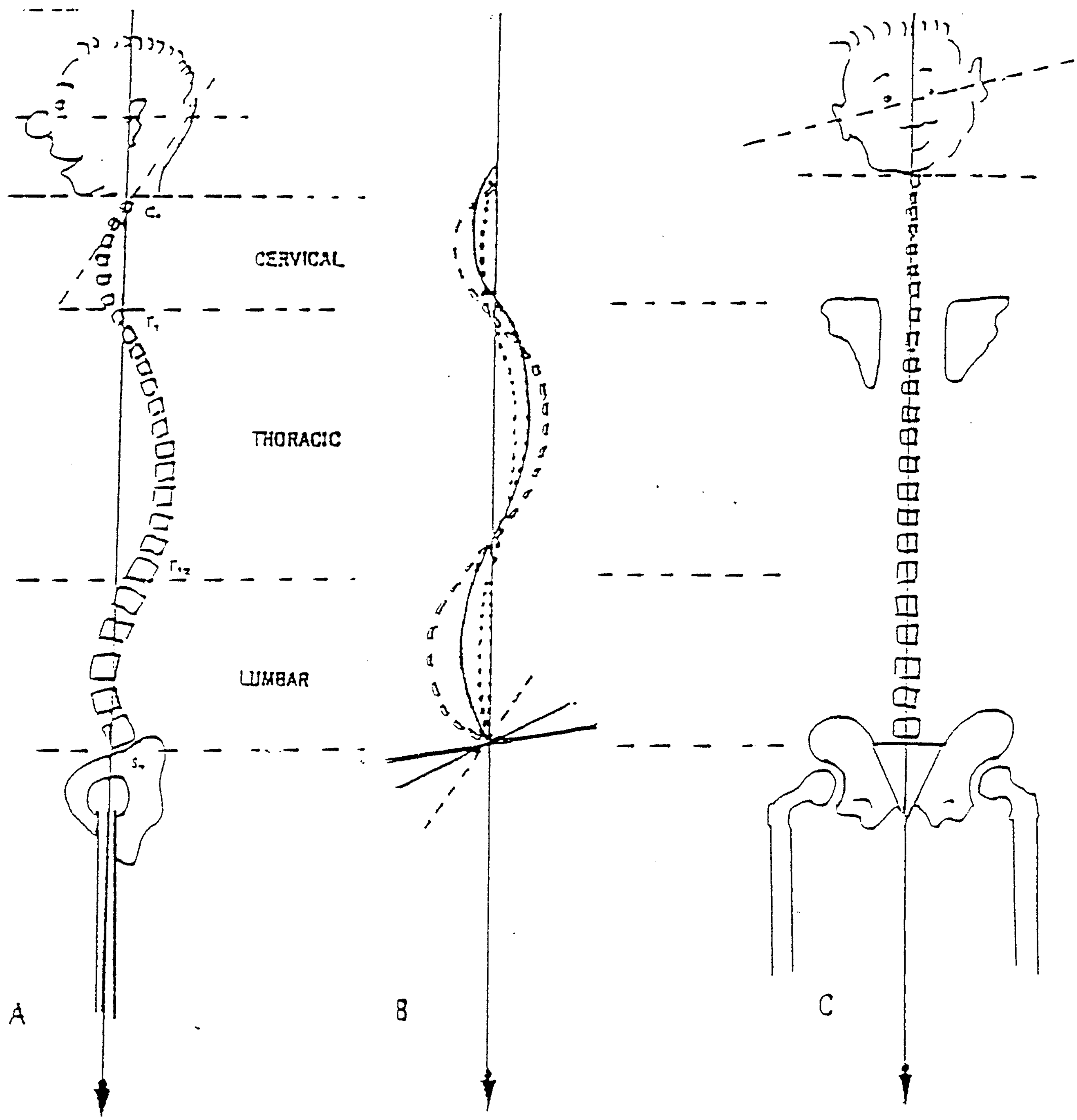


Figure 2.1 -
Static spine (a) Lateral view of erect posture (b) Change of superincumbent curves influenced by change of sacral angle (c) Anterior - Posterior plumb line view.

unit. These seven vertebrae are connected together by facet joints which allow a gliding motion of the vertebrae above and below. The first vertebra (atlas) articulates with the occiput portion of the skull and the odontoid process of the second vertebra (axis) and forms a separate unit. Whereas, the third through sixth vertebrae also forms a functional unit. The seventh vertebra acts as a thoracic vertebra.

When compared to the lumbar unit all the functional units are basically similar except for two functional units, namely occipito atlanto (skull and the first cervical vertebra) and the atlanto axial unit (C1 - C2). The vertebras are separated by intervertebral discs. These discs have a self-contained fluid elastic system that absorbs shock, permits transient compression, and allows fluid displacement within its elastic container, thus permitting movement and distortion of the functional unit The upper and lower plates of the disk are the end plates of the vertebral body. These end plates are articular hyline cartilage in direct contact and adherent to the underlying bones of the vertebral bodies. The outer wall of the disk is called the annulus. This annulus is a interwoven fibroelastic mesh that includes total circumference of the upper and lower endplates and which encapsulates the gelatinous matrix of the disk. The function of the annulus is to permit rocking motion of one vertebra over the other about an axial and a horizontal axis.

The matrix of intervertebral disc contains nucleus pulposus, which is contained within the fibrous resilient wall of the annulus and between floor and ceiling formed by the endplate of the vertebrae. This nucleus contains a fluid which follows the principal of Pascal's law (fluid in a closed container) and the function of this fluid is to create an intradiskal pressure that forces the vertebrae apart and in turns keeps the annulus fibers taut. Intradiskal pressure is maintained as some of the relaxing annulus fibers allow movement in any direction and the rest remains taut. The reduction in the intradiskal pressure can be caused due to lack of elasticity in fibers and loss of intradiskal fluid.

LIGAMENTS IN THE CERVICAL REGION

Motion in the neck region is limited by ligaments that connects the vertebrae of the functional units. These ligaments are broadly classified in four categories namely, anterior longitudinal ligaments, posterior longitudinal ligaments, interspinous ligaments and ligamenta flava. Anterior longitudinal ligaments are a strong band of longitudinally oriented fibers that cover the entire length of the vertebral column anteriorly. Similarly, posterior longitudinal ligaments attach to the posterior margin of the vertebrae and intervertebral disks. These ligaments are strong and broad in the upper cervical spine compared to their geometry in the lower cervical spine. Interspanious ligaments are less developed structures which connect adjoining vertebra, ligamenta flava and supraspinous ligaments. Finally, liagmenta flava connects the laminae of the adjacent vertebrae. The major function of the liagmenta flava is to permit controlled flexion of the cervical spine.

MUSCLES IN THE CERVICAL REGION AND THEIR FUNCTION

Flexion of the neck is controlled primarily by sternocleidomastid (C2-medial clavicle), longus colli (C2-C6), longus capitis (C1-C3), rectus capitis anterior(C1-C2),, and rectus capitis lateralis(C1-C2). Flexion is assisted by the sxalenes and hyoid muscles. The chief action of the logus colli, which is one of the prevertebral cervical muscles, seems to be flexion of the cervical spine and straightening of the cervical lordotic. In relaxed sitting or standing sternocleidomastid and logus colli are almost inactive (Schuldt et al, 1986). Extension is controlled by the paravertebral extensor mass consisting of the trapezius, the splenius group, and the erector spinae.

ELECTROMYOGRAPHY (EMG)

In recent years surface EMG (electromyography) has been widely used for monitoring the activity of muscles (Veiersted, 1994., Van Dieen et al, 1993, Sundelin and Hagberg, 1992, Oberg et al, 1992 and Basmajian and De Luca, 1985). The basic structural unit of muscle is its fiber called muscle fibers. Muscle fibers can be described as the small fine threads whose length ranges from a few millimeters to 30 cm and a diameter of 10 to 100 micrometers (Basmajian and De Luca, 1985). Muscles controlling fine movements and adjustments have fewer muscle fibers per motor unit (Basmajian and De Luca, 1985).

Any physical activity in the muscle results in very rapid contraction and relaxation of muscle fibers. This phenomenon of contraction and relaxation of muscle fibers is termed as firing of muscle fiber. Firing of muscle fibers is never individual but, always involves a group of fibers. The possible reason for this group activity of fibers can be explained by the fact that muscle fibers are connected to terminal branches of nerve fiber (also called axone) which emerge from the interior horn of spinal gray matter (this neural structure whose cell body is located in the interior horn of the spinal gray matter is called the alpha-motoneuron. The junctions of muscle fibers and axon are called endplates or nuromuscular junctions). The combination of muscle fibers, axone and a single alpha-motoneuron constitutes a motor unit. As a result of firing of muscle fibers a voltage impulse is generated which propagates down a motoneuron causing all the muscle fibers in one unit to become activated and thus contract simultaneously. These impulses depolarize the postsynaptic membrane of the muscle fiber (the depolarization propagates in both directions along the fiber) which, along with the movement of ions , generates an electromagnetic field. This electromagnetic waveform resulting from depolarization is called muscle fiber action potential (MAP). The summation of all these motor unit action potentials is called a motor unit action potential (MUAP) and the repetition sequence of motor unit action potentials is further termed a motor unit action potential train (MUAPT).

The voltage generated by this ionic movement in the muscle fibers is detected by the detection surface of an electrode. Electrodes can be defined as the device through which an electrical current enters and leaves the electrolyte. Electrodes are broadly divided into two groups for the study of muscle behavior namely; surface (skin) and inserted (needle and wire) electrodes.

Surface electrodes can be of active or passive type. Active electrodes are also referred to as dry or pasteless electrodes. In the active configuration of electrodes the input impedance of the electrodes is greatly increased thus making it less sensitive to the electrode-skin interface. On the other hand, passive configuration electrodes consist of a detection surface which senses the voltage through the skin-electrode interface.

Wire electrodes are generally used in kinesiological studies involving characteristics of specific motor units, firing rate of motor units etc. They are also used for deep muscle studies. Whereas surface electrodes are generally used in studies involving surface muscles and for sensing EMG signals from broader muscle groups.

In electromyography, electrodes are used individually or in pairs and are referred to as monopolar and bipolar. The electrical activity of muscles can be detected by placing a single electrode with only one detection surface on the muscle with respect to a reference electrode. The reference electrode has to be placed in a environment which is electrically quiet or unrelated to those being detected. This type of electrode confiuration is called a monopolar

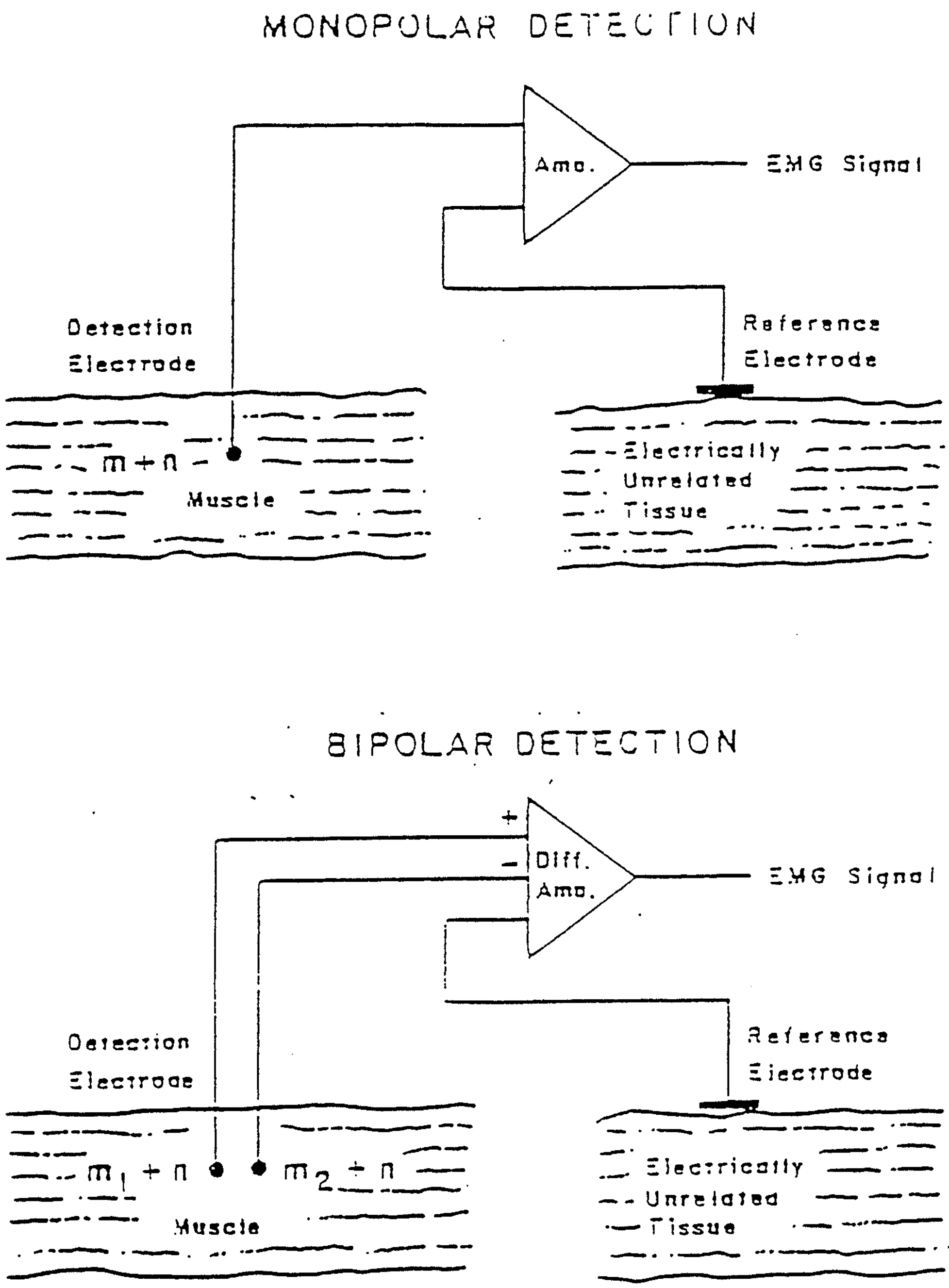


Figure 2.5 -
(Top) Monopolar detection arrangement. (Bottom) Bipolar detection arrangement.
(Source : Basmajian and De Luca, 1985).

configuration. The major drawback of the monopolar configuration. The major drawback of the monopolar configuration is that it detects all the electrical signal in the vicinity of the detection surface. This vicinity includes muscles which are not under investigation. In order to overcome this drawback a new configuration is introduced which is called the bipolar configuration (figure 2.11). In this configuration instead of a single electrode two electrodes are placed on the muscle tissue to be investigated with respect to reference electrodes. The signals picked by each electrode are different due to the localized electrochemical events occurring in contracting muscles. These two electrodes are further connected to differential amplifiers where the amplitude of the AC noise signal and DC noise signal are subtracted. This way the unwanted noise signals are eliminated and the elimination of common mode signals is called common mode rejection.

In the procedure of recording electrical impulses generated by motor units, the muscle fibers acts as low pass filter, the detection surface as a high pass filter and the bipolar electrode configuration as a band pass filter. This filtered signal further passes through amplifiers which also act as a band pass filter and after amplification it is recorded digitally or by analogue recorder. Having detected and amplified the signal, it is necessary to record it on some device such as a frequency modulated (FM) tape recorder or computer storage media. The main requirement of a recorder is that its band width should be greater than that of the amplified signal. Similarly, digital sampling rates must be at least twice the maximum frequency of the filtered signal.

The recorded signal is further analyzed by using time domain analysis. The root mean square value of the rectified signals (RMS) and frequency domain analysis using Fast Fourier transformations (FFT) may also be used.

Appendix 3.1

Contents **:** A copy of concent form filled by the subjects before stating the experiments

TO the NT-WSC plant workers participating in the experiment

Dear Friends,

Thank you very much for your good will to participate in this experiment. Advanced Cut out workstations were implemented recently at the WSC plant. Now WSC and the University of Manitoba Ergonomics Laboratory are collaborating on the design and evaluation of new assembly workstations - The Indirect Vision (IV). Instead of bending your spine (cervical and thoracic) and elevating your shoulders, the new workstation will permit you to sit in a neutral posture as the image of the PC board will be projected on the TV monitor. The IV method of assembly may help in reducing the risk of upper back and upper extremity (neck, shoulder and the spine) injuries. We hope the new workstation will not lower the level of productivity and quality of work however, some difficulties in the initial phase of training are inevitable.

In order to compare the IV workstation with that of present workstation (DV), we need to measure and compare the activity of your upper right trapezius muscle as well as the flexion and lateral flexion of the cervical and the thoracic spine. We will also be video taping the assembly procedure in order to analysis the movement of the joint angles.

The participating subjects are also suppose to answer a questionnaire that will help in evaluating the subjecting rating of comfort and satisfaction on both the workstations.

Your participation is appreciated. Please sign here to confirm your consent to participate in the experiment.

Signature (Date)

APPENDIX 4.1

Contents : Physiometer (PHY) records of Head flexion for Worker Nine (W09) on the fourth day of training on the Indirect vision PC board assembly workstation. Marks M1 to M13 are considered for the calculation of time taken for assembling 13 PC boards in a single series. The time between M1 and M2 indicates the time taken by worker nine to assembly a single PC board.

FIGURE 4.11 -
PHY records of head flexion for Worker 09 on 4th day of work at the IV workstation (6th series). Marks M1.....M13 represents number of PCBs assembled in a particular series.
Time scale : 15.9 sec. Per mm.

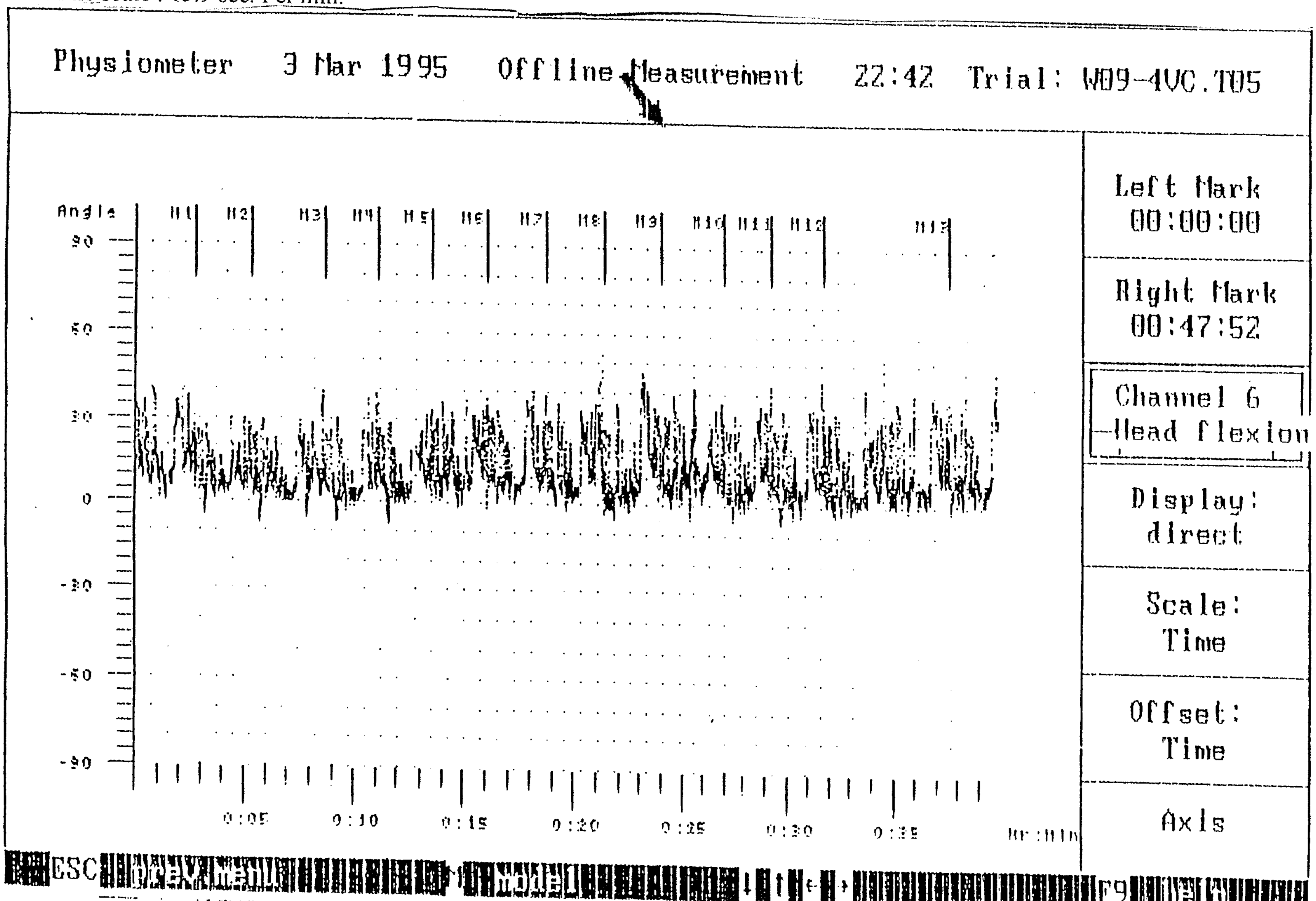


FIGURE 4.12 -
PHY records of head flexion for Worker 09 on 4th day of work at the IV workstation (6th series). Marks M1.....M7 represents number of PCBs assembled in a particular series.
Time scale : 07.87 sec. Per mm.

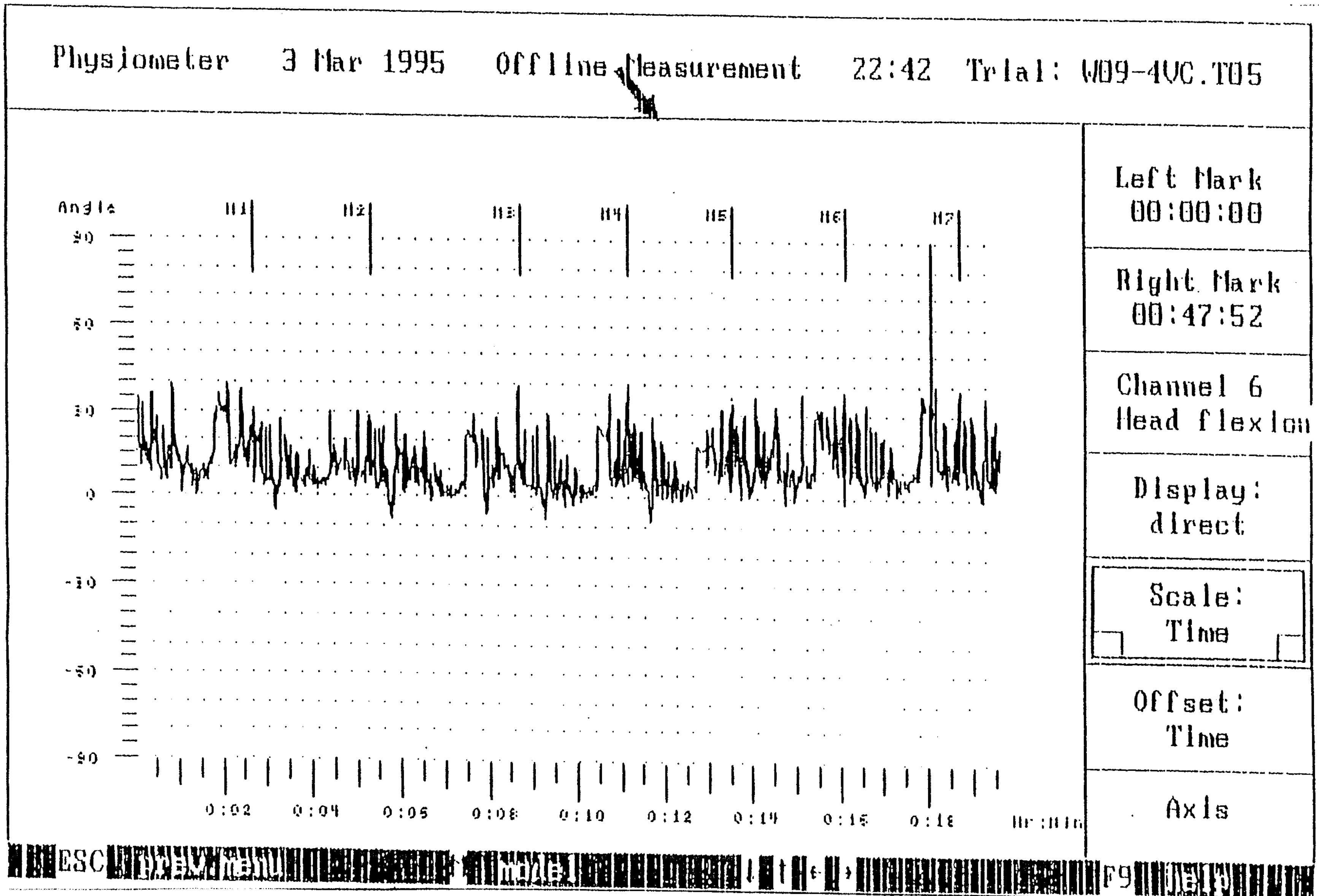
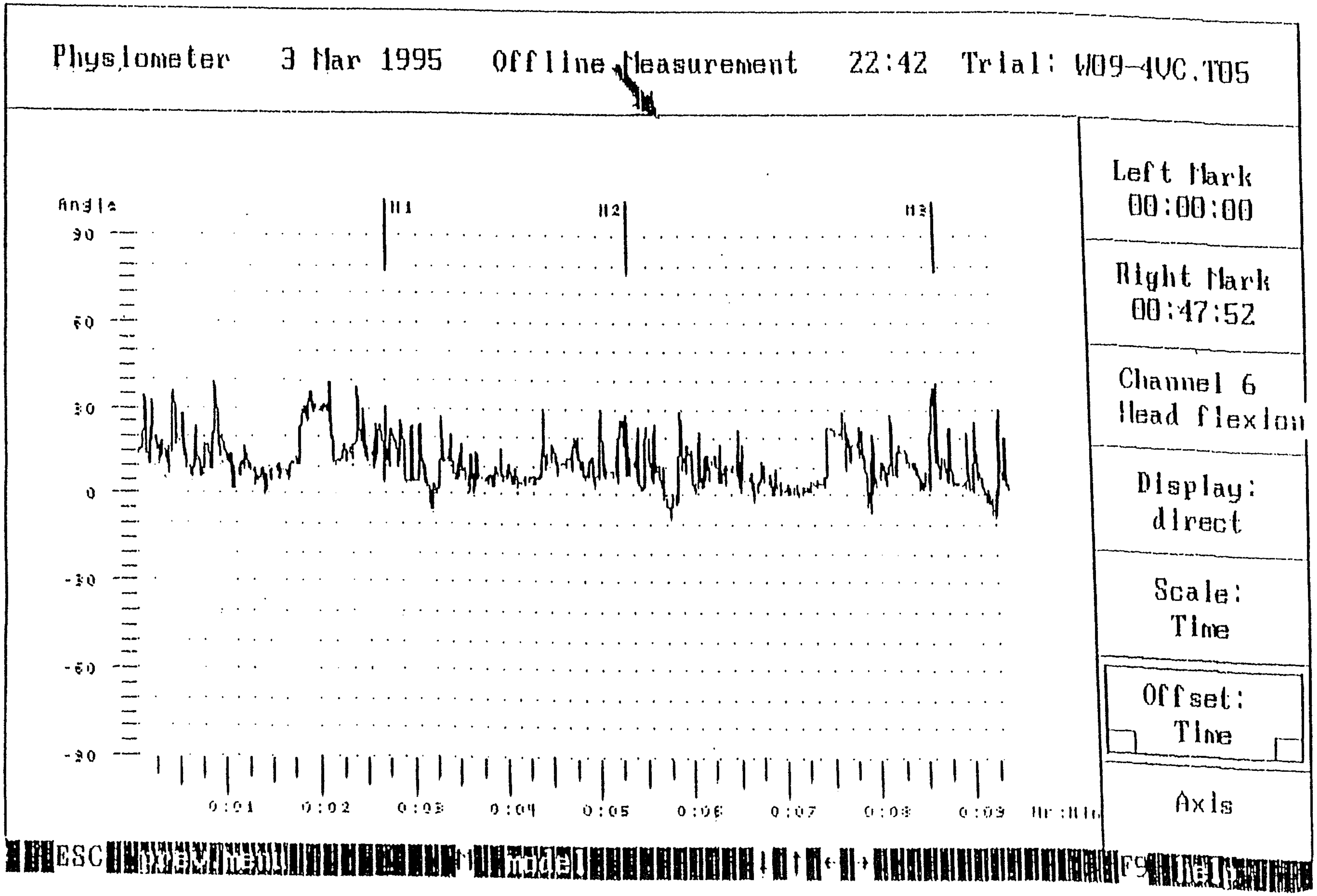


FIGURE 4.13 -
PHY records of head flexion for Worker 09 on 4th day of work at the IV workstation (6th series). Marks M1.....M3 represents number of PCBs assembled in a particular series.
Time scale : 03.65 sec. Per mm.



APPENDIX 5.1

Contents : For the demonstration the following PHY records of normalized amplitude distribution for the muscular activity and the spine motion of Worker Nine are presented in this appendix.

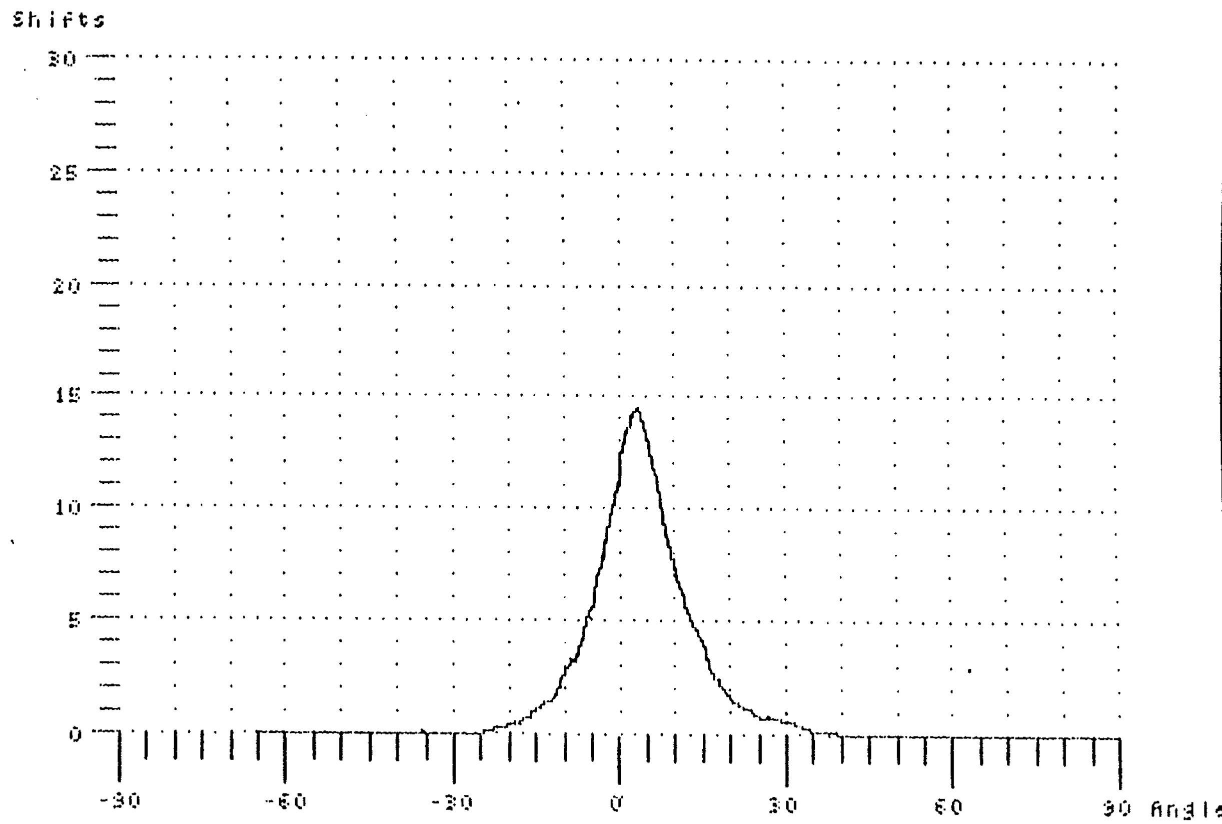
1. The normalized distribution for the muscular activity of Right Trapezius muscle on the cutout workstion by using the Direct vision (DV) and Indirect vision (IV) method of assembly.

2. The normalized distribution for the muscular activity of Left Trapezius muscle on the cutout workstion by using the Direct vision (DV) and Indirect vision (IV) method of assembly.

3. The normalized distribution for flexion and lateral flexion of the cervical spine on the cutout workstion by using the Direct vision (DV) and Indirect vision (IV) method of assembly.

4. The normalized distribution for flexion and lateral flexion of the thoracic spine on the cutout workstion by using the Direct vision (DV) and Indirect vision (IV) method of assembly.

Physiometer 6 Mar 1995 Offline Measurement 10:05 Trial: W09-5VC.T01



Left Mark
00:00:00

Right Mark
00:53:37

Channel 7
BACK SIDEWAY

Display:
level

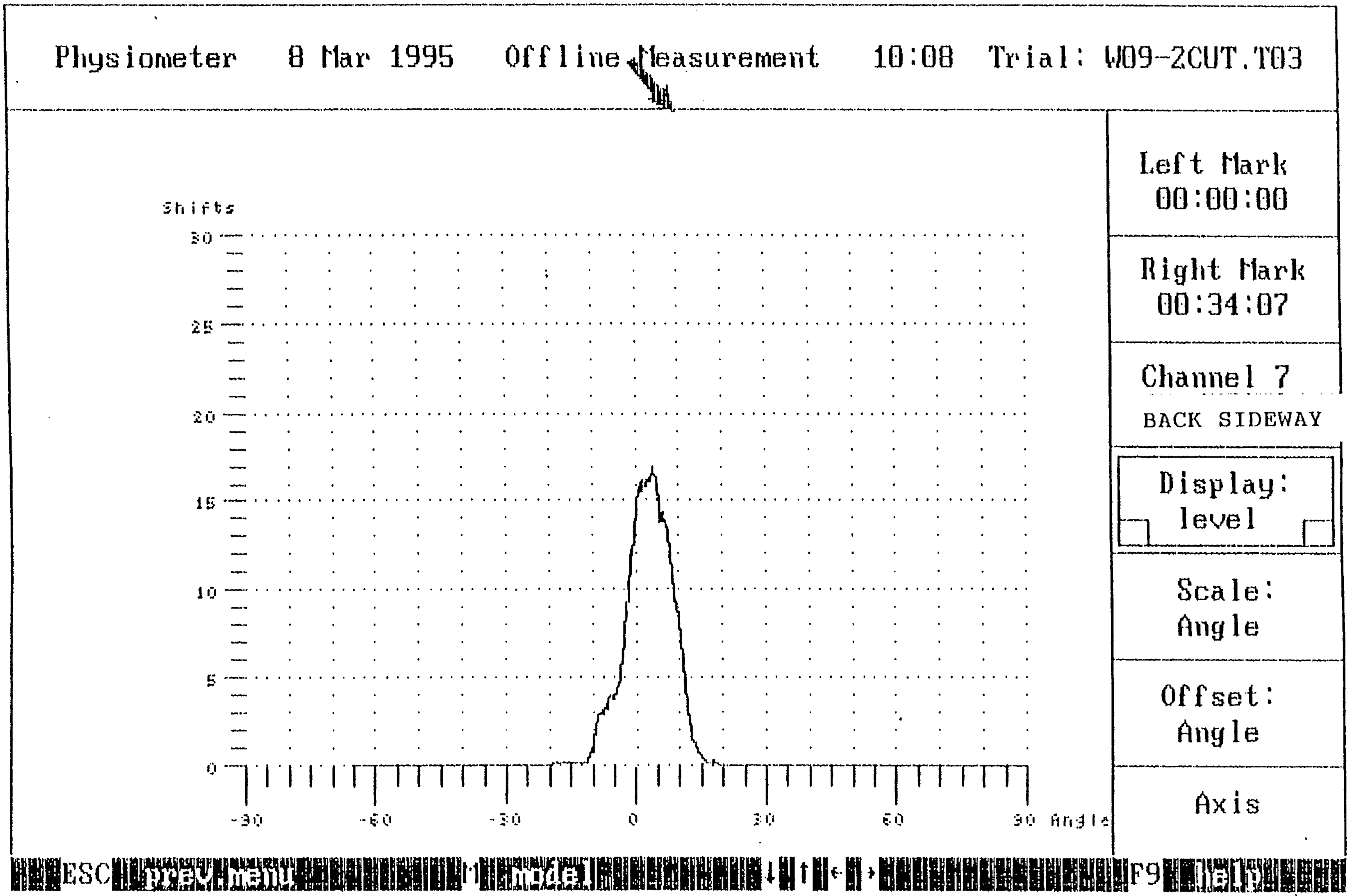
Scale:
Angle

Offset:
Angle

Axis

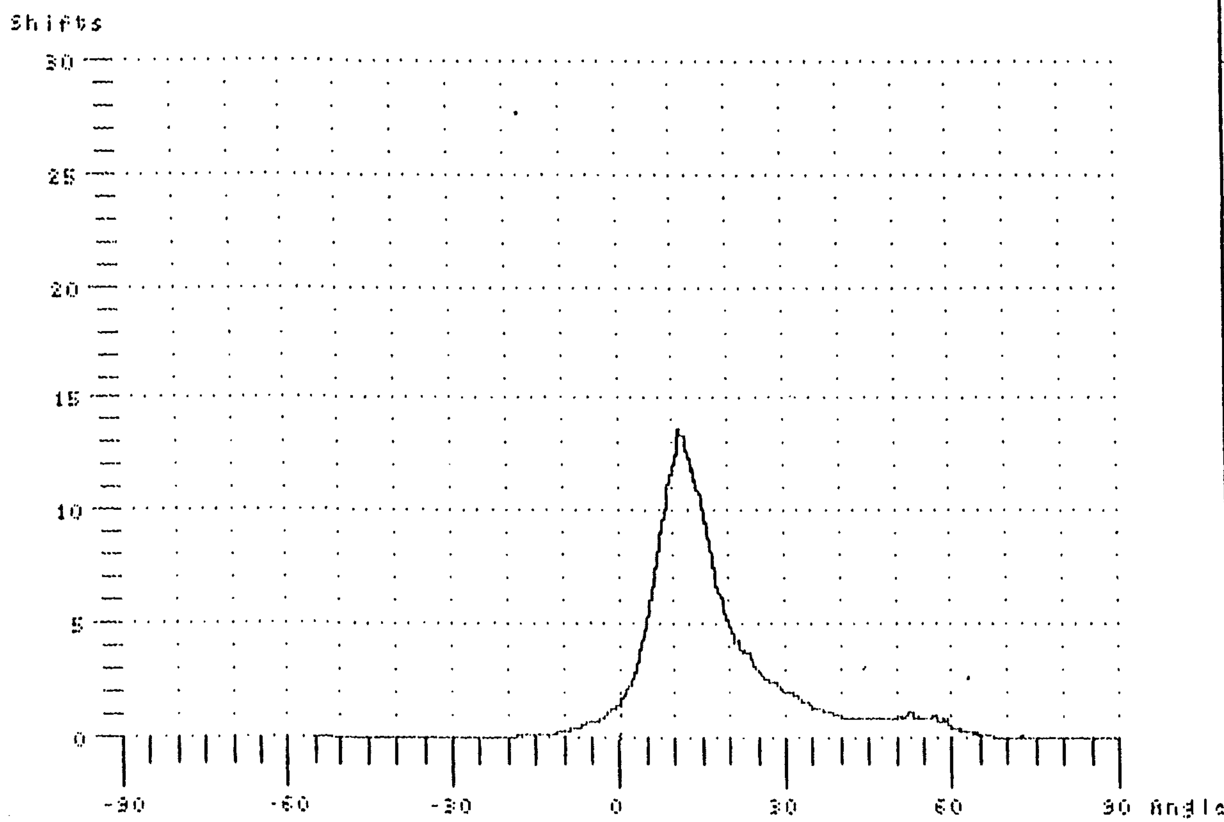
ESC prev.menu ↑ mode ↓ ↑ ← → F9 help

Worker: W09
Station: Cut-out
Method: Indirect Vision (Venda)
Channel: Back sideway



Worker: W09
Station: Cut-out
Method: Direct Vision
Channel: Back sideway

Physiometer 6 Mar 1995 Offline Measurement 10:05 Trial: W09-5VC.T01



Left Mark
00:00:00

Right Mark
00:53:37

Channel 6
BACK FLEXION

Display:
level

Scale:
Angle

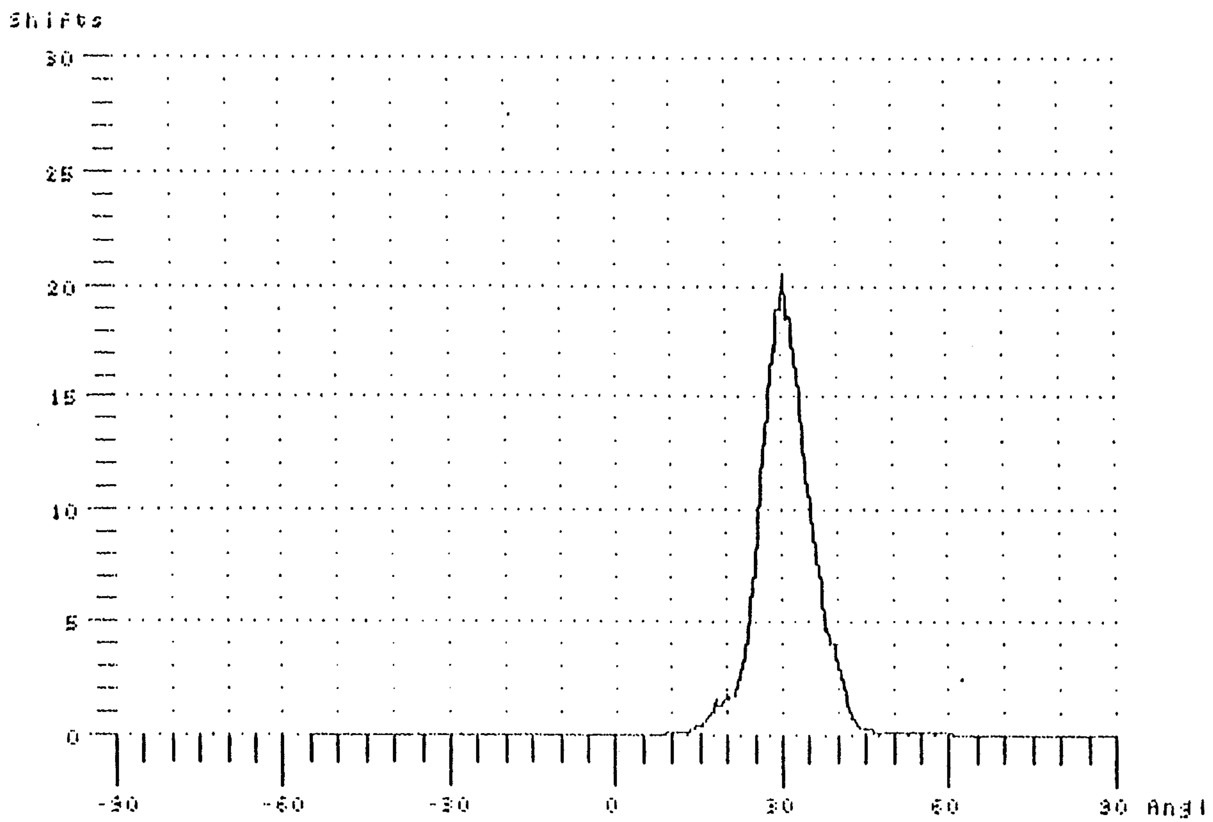
Offset:
Angle

Axis

ESC prev menu M mode ↓ ↑ ← → F9 help

Worker: **W09**
Station: **Cut-out**
Method: **Indirect Vision (Venda)**
Channel: **Back flexion**

Physiometer 8 Mar 1995 Offline Measurement 10:08 Trial: W09-2CUT.T03



Left Mark
00:00:00

Right Mark
00:34:07

Channel 6
BACK FLEXION

Display:
level

Scale:
Angle

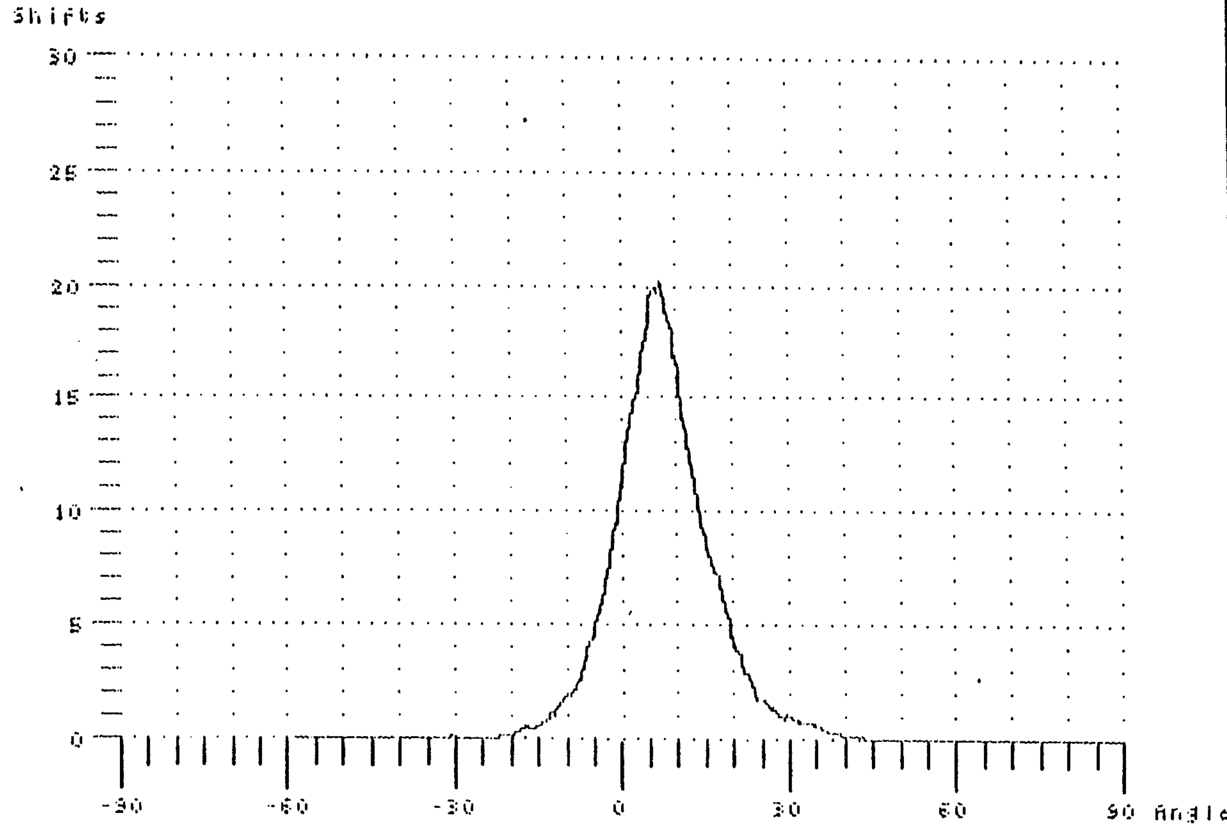
Offset:
Angle

Axis

ESC prev. menu M mode ↓ ↑ ← → F9 help

Worker: W09
Station: Cut-out
Method: Direct Vision
Channel: Back flexion

Physiomotor 6 Mar 1995 Offline Measurement 10:05 Trial: W09-5VC.T01



Left Mark
00:00:00

Right Mark
00:53:37

Channel 5
HEAD SIDEWAY

Display:
level

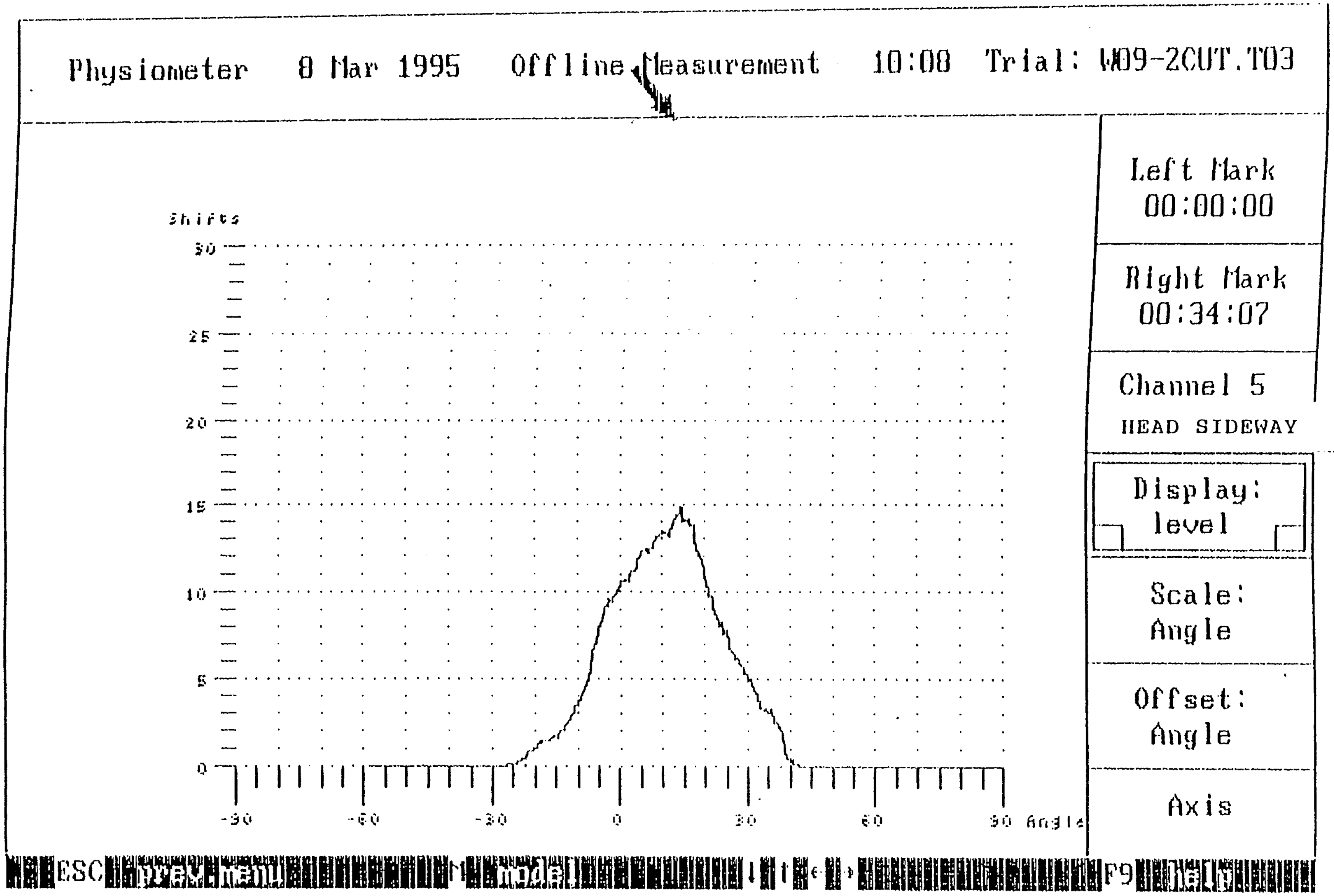
Scale:
Angle

Offset:
Angle

Axis

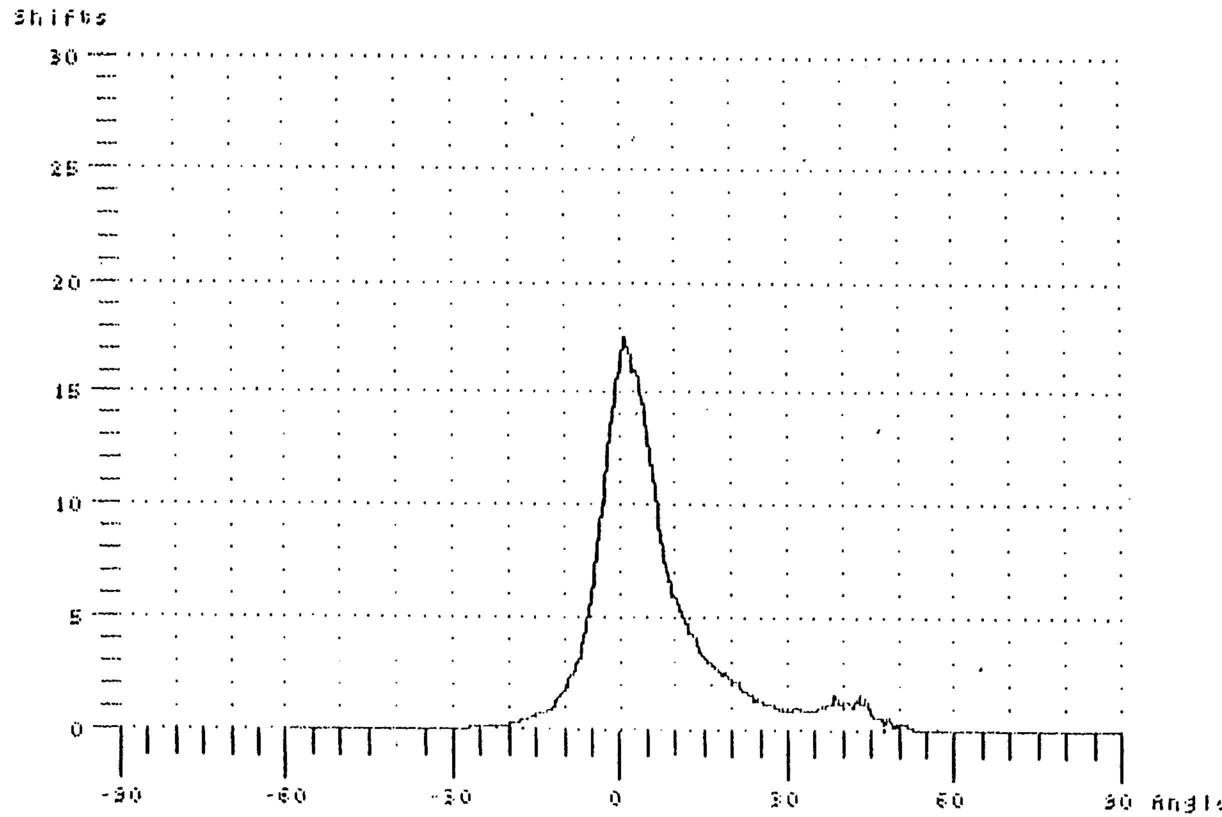
ESC F9

Worker: W09
Station: Cut-out
Method: Indirect Vision (Venda)
Channel: Head sideway



Worker: W09
Station: Cut-out
Method: Direct Vision
Channel: Head sideway

Physiometer 6 Mar 1995 Offline Measurement 10:05 Trial: W09-5VC.T01



Left Mark
00:00:00

Right Mark
00:53:37

Channel 4
HEAD FLEXION

Display:
level

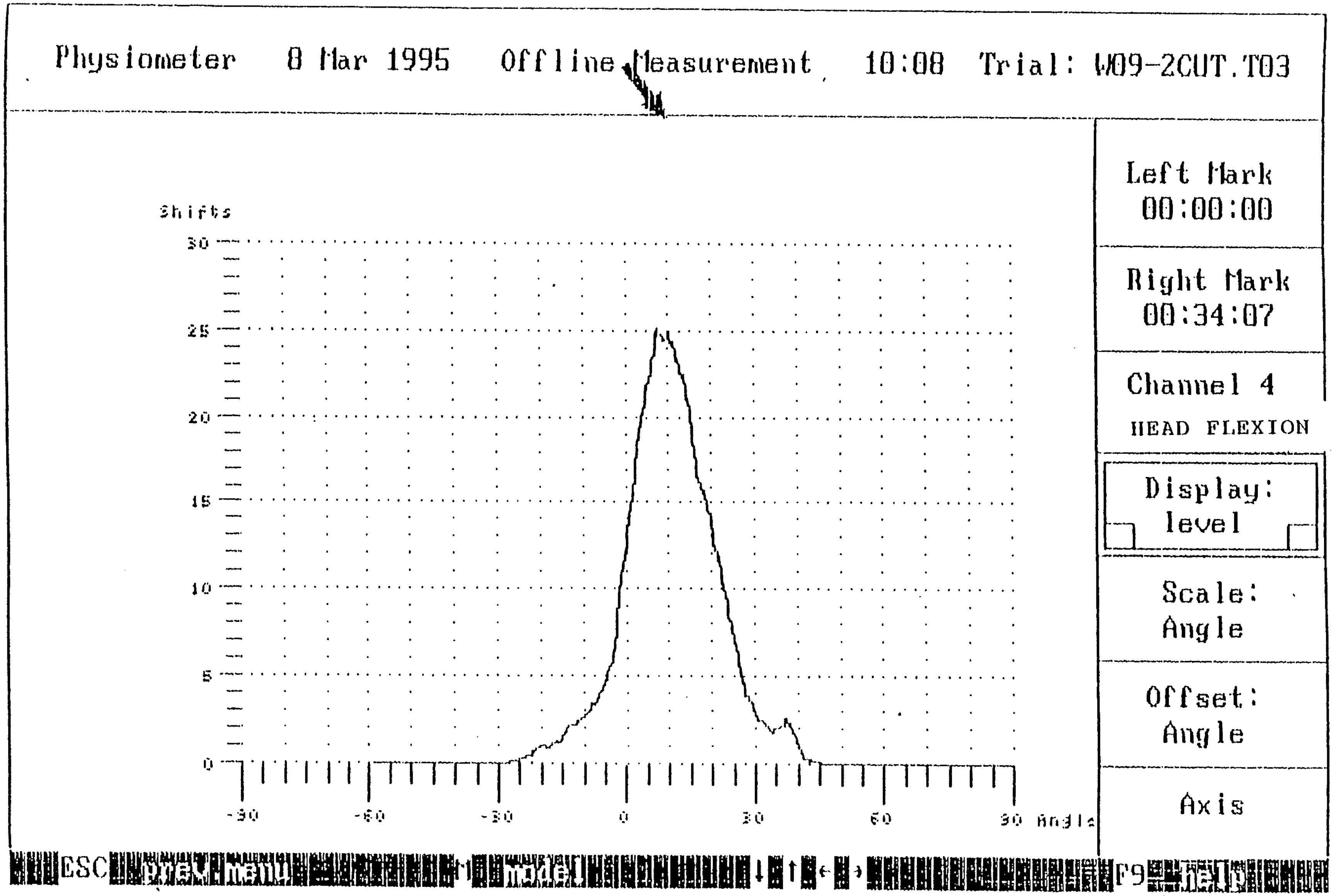
Scale:
Angle

Offset:
Angle

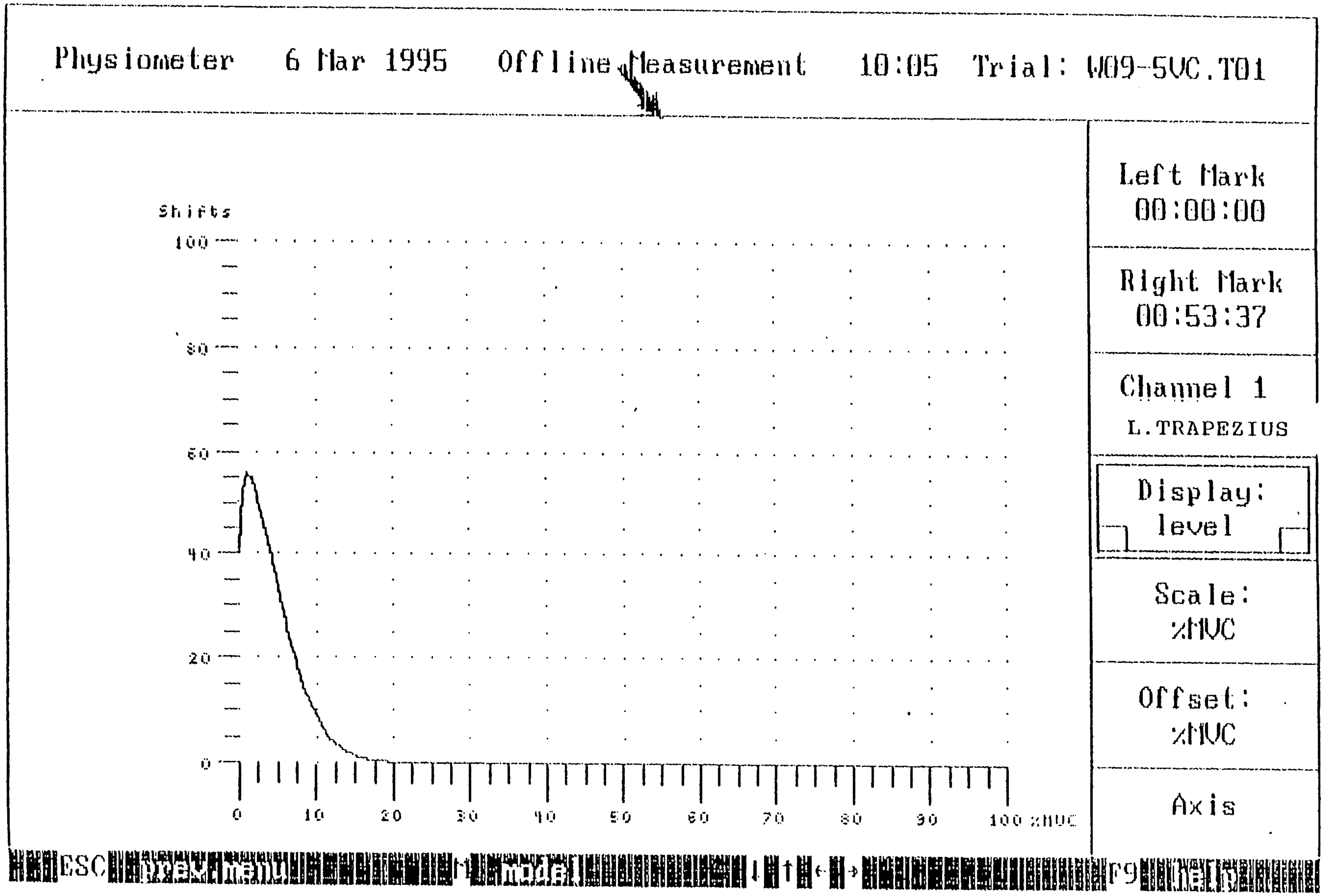
Axis

ESC mode F9

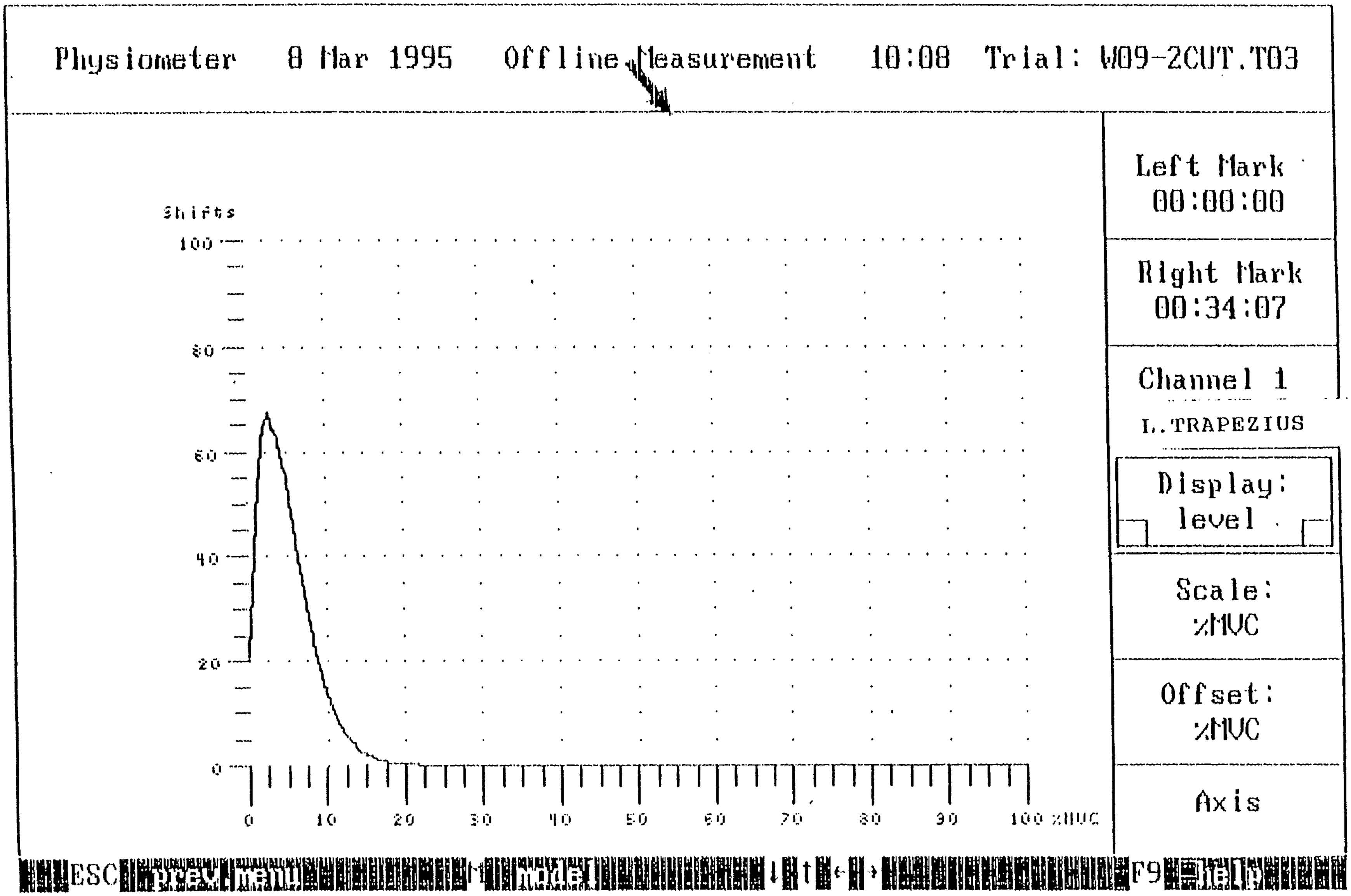
Worker: W09
Station: Cut-out
Method: Indirect Vision (Venda)
Channel: Head flexion



Worker: W09
Station: Cut-out
Method: Direct Vision
Channel: Head flexion

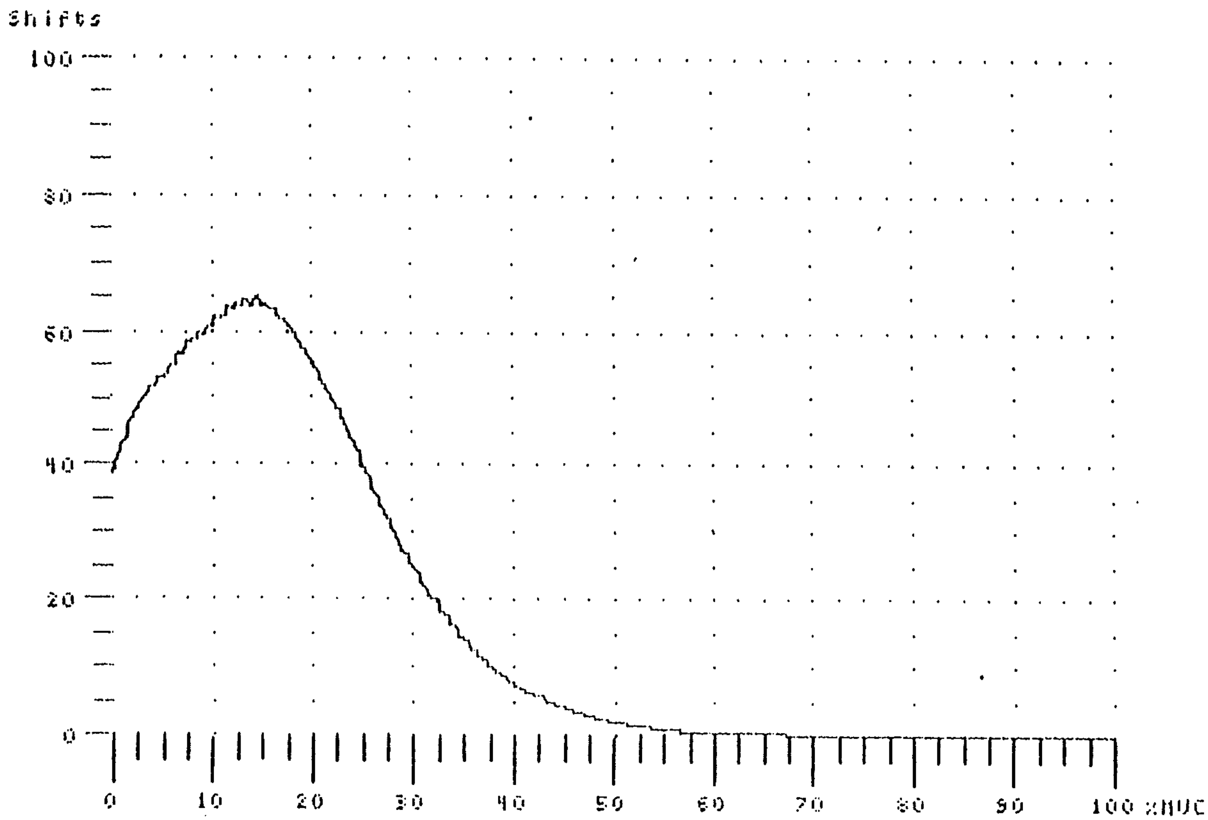


Worker: W09
Station: Cut-out
Method: Indirect Vision (Venda)
Channel: Left Trapezius



Worker: W09
Station: Cut-out
Method: Direct Vision
Channel: Left Trapezius

Physiometer 6 Mar 1995 Offline Measurement 10:05 Trial: W09-5VC.T01



Left Mark
00:00:00

Right Mark
00:53:37

Channel 0
R.TRAPEZIUS

Display:
level

Scale:
%MVC

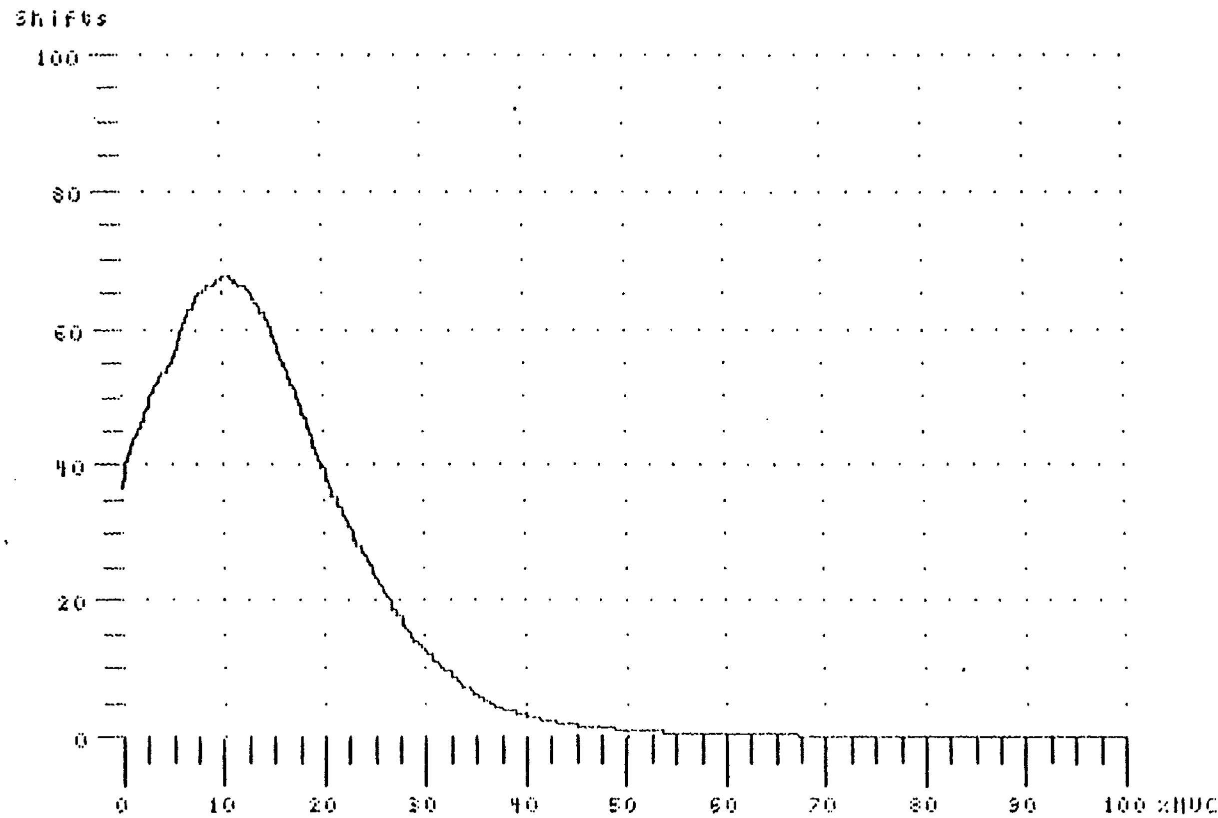
Offset:
%MVC

Axis

ESC prev menu | mode ↓↑←→ F9 help

Worker: W09
Station: Cut-out
Method: Indirect Vision (Venda)
Channel: Right Trapezius

Physiometer 8 Mar 1995 Offline Measurement 10:08 Trial: W09-2CUT.T03



Left Mark
00:00:00

Right Mark
00:34:07

Channel 0
R.TRAPEZIUS

Display:
level

Scale:
%MVC

Offset:
%MVC

Axis

ESC prev.menu F1 model F9 help

Worker: W09
Station: Cut-out
Method: Direct Vision
Channel: Right Trapezius

APPENDIX 5.2

***Contents* :** The Appendix 5.2 contain tables which represents the individual parameters of normalized amplitude distributions of muscular activity / postural measurements at different workstations (Cut-out and Traditional w/s) by using the Direct Vision (DV) and the Indirect Vision (IV) methods of PCB assembly.
The following different parameters of normalized differential distribution were used to calculation of the mean, the standard deviation, the skewness and the kurtosis.
a. Xmin, b. Xmax, c. X mode, d. Ymode, e. Area, and f. Height

1. The above parameters are calculated for the individual muscular activities of the Right and the Left Trapezius muscle when the subjects were working on the traditional and cutout workstations by using the DV and the IV method of assembly (Table 5.2.1 to 5.2.8).

2. The same parameters are calculated for the individual flexion and lateral flexion of the cervical and the throacic spine (flexion and lateral flexion), during work on the traditional and cutout workstation by using the IV and the DV method of assembly (Table 5.2.9 to 5.2.24).

3. Table 5.2.25 and 5.2.26 presents the individual and averaged data for the activity of upper trapezius muscle and postural angles.

4. Tables in this Appendix also represents the average, the standard deviation and the 95% confidence limit of the above calculated parameters for all the subjects.

Note : The following denotions are used in the subsiquent Tables.

DV	- Direct Vision
IV	- Indirect Vision
C.FLEX	- Cervical flexion
T.FLEX	- Thoracic flexion
C.LAT.	- Cervical lateral flexion
T.LAT.	- Thoracic lateral flexion
R.Trap	- Right Trapezius muscle
L.Trap	- Left Trapezius muscle
SD	- Standard deviation

Table 5.2.1-
Individual value of each subject for activity of the Right Trapezius muscle muscle

Workstation : Cutout
Method : Direct Vision (DV)
Channel : Right Trapezius muscle

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W010C	R.Trap	1.10	92.00	26.70	80.00	2091.00	23.00
W031C	R.Trap	0.00	100.00	30.00	80.00	3485.00	34.90
W051C	R.Trap	0.00	100.00	34.40	74.20	2994.00	29.90
W092C	R.Trap	0.00	46.60	10.40	67.50	1451.00	31.10
W112C	R.Trap	3.20	53.90	10.90	66.50	944.00	18.60
Average		0.86	78.50	22.48	73.64	2193.00	27.50
SD		1.39	26.12	11.14	6.52	1052.60	6.58
95%Confidence interval		1.22	22.90	9.77	5.71	922.62	5.76

Code	Channel	Width	Mean	SD	Skew	Kurt
W010C	R.Trap	26.10	28.30	10.10	1.38	2.49
W031C	R.Trap	43.60	34.50	14.90	0.35	-0.01
W051C	R.Trap	40.40	38.70	15.00	0.38	0.96
W092C	R.Trap	21.50	11.60	7.80	0.81	0.66
W112C	R.Trap	14.20	15.60	7.60	1.32	0.67
Average		29.16	25.74	11.08	0.85	0.95
SD		12.52	11.77	3.67	0.49	0.93
95%Confidence interval		10.97	10.32	3.21	0.43	0.81

Table 5.2.2-
Individual value of each subject for activity of the Left Trapezius muscle

Workstation : Cutout
Method : Direct Vision (DV)
Channel : Left Trapezius muscle

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W010C	L.Trap	0.00	100.00	34.70	84.50	2607.00	26.10
W031C	L.Trap	0.00	21.30	6.10	78.00	597.00	28.00
W051C	L.Trap	0.00	58.90	12.30	68.90	1635.00	27.70
W092C	L.Trap	0.00	17.60	2.90	67.50	460.00	26.10
W112C	L.Trap	3.20	30.70	10.10	74.00	756.00	27.50
Average		0.64	45.70	13.22	74.58	1211.00	27.08
SD		1.43	34.40	12.54	6.94	905.07	0.91
95%Confidence interval		1.25	30.15	10.99	6.09	793.31	0.80

Code	Channel	Width	Mean	SD	Skew	Kurt
W010C	L.Trap	30.90	36.70	12.30	1.10	1.76
W031C	L.Trap	7.70	7.00	3.40	0.69	1.11
W051C	L.Trap	23.70	12.60	8.80	1.32	1.87
W092C	L.Trap	6.80	3.70	3.50	1.28	0.63
W112C	L.Trap	10.20	12.40	3.60	2.02	3.13
Average		15.86	14.48	6.32	1.28	1.70
SD		10.82	12.98	4.06	0.48	0.94
95%Confidence interval		9.48	11.38	3.55	0.42	0.83

Table 5.2.3-
Individual value of each subject for activity of the Right Trapezius muscle

Workstation : Cutout
Method : Indirect Vision (IV)
Channel : Right Trapezius muscle

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W016V	R.Trap	0.00	62.70	10.40	52.00	1423.00	22.70
W036V	R.Trap	0.00	100.00	29.90	85.00	3880.00	38.80
W057V	R.Trap.	0.00	97.10	22.90	67.00	2349.00	24.20
W095V	R.Trap	0.00	56.80	13.90	65.10	1738.00	30.60
W112V	R.Trap	0.00	84.00	10.10	48.00	1295.00	15.40
Average		0.00	80.12	17.44	63.42	2137.00	26.34
SD		0.00	19.66	8.68	14.57	1056.05	8.82
95%Confidence interval			17.23	7.60	12.77	925.65	7.73

Code	Channel	Width	Mean	SD	Skew	Kurt
W016V	R.Trap	27.40	11.70	10.40	1.37	1.36
W036V	R.Trap	45.60	33.80	16.90	0.68	0.64
W057V	R.Trap.	35.10	24.20	13.20	1.21	1.14
W095V	R.Trap	26.70	12.80	10.30	0.74	-0.02
W112V	R.Trap	27.00	11.10	11.90	1.97	4.79
Average		32.36	18.72	12.54	1.19	1.58
SD		8.19	10.00	2.71	0.53	1.87
95%Confidence interval		7.18	8.76	2.38	0.46	1.64

Table 5.2.4-
Individual value of each subject for activity of the Left Trapezius muscle

Workstation : Cutout
Method : Indirect Vision (IV)
Channel : Left Trapezius muscle

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W016V	L.Trap	0.00	100.00	24.30	52.00	2516.00	25.20
W036V	L.Trap	0.00	13.10	1.60	90.00	451.00	34.50
W057V	L.Trap.	0.00	40.00	8.00	63.20	859.00	21.50
W095V	L.Trap	0.00	17.60	1.30	55.50	355.00	20.20
W112V	L.Trap	3.50	28.50	7.50	79.00	501.00	20.00
Average		0.70	39.84	8.54	67.94	936.40	24.28
SD		1.57	35.20	9.36	16.13	903.37	6.08
95%Confidence interval		1.37	30.86	8.20	14.14	791.83	5.33

Code	Channel	Width	Mean	SD	Skew	Kurt
W016V	L.Trap	48.40	28.90	17.80	0.71	0.89
W036V	L.Trap	5.00	1.80	2.30	1.74	1.98
W057V	L.Trap.	13.60	9.00	5.20	1.38	1.88
W095V	L.Trap	6.40	2.20	3.10	1.66	1.37
W112V	L.Trap	6.30	9.60	3.20	1.65	2.25
Average		15.94	10.30	6.32	1.43	1.67
SD		18.46	11.02	6.51	0.42	0.54
95%Confidence interval		16.18	9.66	5.70	0.37	0.48

Table 5.2.5-
Individual value of each subject for activity of the Right Trapezius muscle

Workstation : Traditional
Method : Direct Vision (DV)
Channel : Right Trapezius muscle

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W021T	R.Trap	0.00	38.40	4.80	89.00	1418.00	36.90
W041T	R.Trap	2.90	60.50	18.90	80.00	1662.00	28.90
W061T	R.Trap	0.00	93.90	20.80	61.70	2253.00	24.00
W121T	R.Trap	0.00	25.60	7.20	76.00	610.00	23.80
Average		0.73	54.60	12.93	76.68	1485.75	28.40
SD		1.45	29.90	8.09	11.37	681.00	6.14
95%Confidence interval		1.42	29.31	7.93	11.14	667.36	6.01

Code	Channel	Width	Mean	SD	Skew	Kurt	
W021T	R.Trap	15.90	5.70	5.70	1.66	2.80	
W041T	R.Trap	20.80	19.60	6.70	1.61	3.70	
W061T	R.Trap	36.50	22.70	12.50	1.78	4.42	
W121T	R.Trap	8.00	8.70	3.20	0.01	1.05	
Average		20.30	14.18	7.03	1.27	2.99	
SD		12.02	8.24	3.94	0.84	1.45	
95%Confidence interval		11.78	8.08	3.86	0.82	1.43	

Table 5.2.6-
Individual value of each subject for activity of the Left Trapezius muscle

Workstation : Traditional
Method : Direct Vision (DV)
Channel : Left Trapezius muscle

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W021T	L.Trap	0.00	20.50	5.60	65.00	563.00	27.40
W061T	L.Trap	0.00	80.00	8.30	62.20	1165.00	14.60
W103T	L.Trap	1.60	14.90	4.30	45.00	255.00	19.10
W121T	L.Trap	0.00	27.70	1.30	65.00	617.00	22.20
Average		0.40	35.78	4.88	59.30	650.00	20.83
SD		0.80	29.95	2.91	9.62	378.55	5.38
95%Confidence interval		0.78	29.35	2.85	9.43	370.97	5.27

Code	Channel	Width	Mean	SD	Skew	Kurt
W021T	L.Trap	8.70	5.90	3.00	0.86	0.43
W061T	L.Trap	18.70	12.40	9.00	1.78	3.68
W103T	L.Trap	5.70	5.50	1.60	1.85	3.02
W121T	L.Trap	9.50	2.90	4.80	1.84	2.04
Average		10.65	6.68	4.60	1.58	2.29
SD		5.61	4.04	3.21	0.48	1.41
95%Confidence interval		5.50	3.96	3.15	0.47	1.38

Table 5.2.7-
Individual value of each subject for activity of the Right Trapezius muscle

Workstation : Traditional
Method : Indirect Vision (IV)
Channel : Right Trapezius muscle

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W024V	R.Trap	0.00	39.50	5.60	73.00	1197.00	30.30
W045V	R.Trap	0.00	43.70	5.60	65.00	873.00	20.00
W065V	R.Trap	0.00	40.80	8.00	78.90	1111.00	27.20
W106V	R.Trap	0.00	0.00	0.00	0.00	0.00	0.00
W124V	R.Trap	0.00	29.90	1.90	51.00	663.00	22.20
Average		0.00	30.78	4.22	53.58	768.80	19.94
SD		0.00	17.97	3.21	31.73	477.90	11.86
95%Confidence interval			15.75	2.82	27.81	418.89	10.40

Code	Channel	Width	Mean	SD	Skew	Kurt
W024V	R.Trap	16.40	7.00	6.70	1.63	2.24
W045V	R.Trap	13.40	6.10	6.20	1.66	2.47
W065V	R.Trap	14.10	9.60	5.00	1.40	2.69
W106V	R.Trap	0.00	0.00	0.00	0.00	0.00
W124V	R.Trap	13.00	4.20	5.80	1.92	2.37
Average		11.38	5.38	4.74	1.32	1.95
SD		6.50	3.58	2.72	0.76	1.10
95%Confidence interval		5.69	3.14	2.39	0.67	0.97

Table 5.2.8-
Individual value of each subject for activity of the Left Trapezius muscle

Workstation : Traditional
Method : Indirect Vision (IV)
Channel : Left Trapezius muscle

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W024V	L.Trap	0.00	20.30	0.00	42.00	306.00	15.10
W045V	L.Trap	0.00	20.50	0.00	52.00	314.00	15.30
W065V	L.Trap	0.00	71.20	8.50	69.90	1404.00	19.70
W106V	L.Trap	1.30	12.50	2.40	77.00	155.00	13.80
W124V	L.Trap	0.00	19.70	0.00	56.50	329.00	16.70
Average		0.26	28.84	2.18	59.48	501.60	16.12
SD		0.58	23.91	3.68	14.02	509.34	2.25
95%Confidence interval		0.51	20.96	3.23	12.29	446.45	1.97
Code	**Channel**	**Width**	**Mean**	**SD**	**Skew**	**Kurt**	
W024V	L.Trap	7.30	2.90	5.10	1.31	-0.02	
W045V	L.Trap	6.00	2.30	3.30	1.78	2.32	
W065V	L.Trap	20.10	12.70	10.30	1.51	2.03	
W106V	L.Trap	2.00	2.90	1.10	2.77	7.07	
W124V	L.Trap	5.80	2.00	4.00	1.56	0.67	
Average		8.24	4.56	4.76	1.79	2.41	
SD		6.92	4.57	3.42	0.57	2.77	
95%Confidence interval		6.06	4.00	3.00	0.50	2.43	

Table 5.2.9-
Individual value of each subject for flexion of the cervical spine

Workstation : Cutout
Method : Direct Vision (DV)
Channel : Cervical flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W031C	C.FLEX	-35.80	12.70	-12.70	12.00	213.00	4.40
W051C	C.FLEX	-19.00	64.60	23.80	8.20	343.00	4.10
W092C	C.FLEX	-27.60	42.00	7.40	24.80	578.00	8.30
W112C	C.FLEX	-50.60	12.20	-16.10	9.00	219.00	3.50
Average		-33.25	32.88	0.60	13.50	338.25	5.08
SD		13.45	25.33	18.62	7.71	170.70	2.18
95%Confidence interval		13.18	24.82	18.25	7.55	167.28	2.14

Code	Channel	Width	Mean	SD	Skew	Kurt
W031C	C.FLEX	17.80	-11.60	4.40	-1.57	7.67
W051C	C.FLEX	41.90	20.70	14.30	0.21	-0.70
W092C	C.FLEX	23.30	9.70	9.80	1.07	2.30
W112C	C.FLEX	24.40	-15.80	9.90	0.50	-0.15
Average		26.85	0.75	9.60	0.05	2.28
SD		10.44	17.36	4.05	1.14	3.82
95%Confidence interval		10.23	17.02	3.97	1.12	3.75

Table 5.2.10-
Individual value of each subject for lateral flexion of cervical spine

Workstation : Cutout
Method : Direct Vision (DV)
Channel : Cervical lateral flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W031C	C.LAT.	-4.60	33.40	12.70	24.00	396.00	10.40
W051C	C.LAT.	-41.00	26.60	-5.00	16.40	472.00	7.00
W092C	C.LAT.	-24.70	40.60	14.20	14.90	485.00	7.40
W112C	C.LAT.	-17.50	38.20	13.20	17.50	332.00	6.00
Average		-21.95	34.70	8.78	18.20	421.25	7.70
SD		15.18	6.17	9.20	4.01	71.28	1.89
95%Confidence interval		14.88	6.05	9.02	3.93	69.85	1.86

Code	Channel	Width	Mean	SD	Skew	Kurt
W031C	C.LAT.	16.50	15.30	4.60	-0.37	0.86
W051C	C.LAT.	28.90	-4.90	8.70	-0.48	2.08
W092C	C.LAT.	32.50	9.80	9.60	-1.16	-0.12
W112C	C.LAT.	19.00	9.50	6.20	-0.19	2.01
Average		24.23	7.43	7.28	-0.55	1.21
SD		7.69	8.64	2.29	0.42	1.05
95%Confidence interval		7.53	8.47	2.25	0.42	1.03

Table 5.2.11-
Individual value of each subject for flexion of thoracic spine

Workstation : Cutout
Method : Direct Vision (DV)
Channel : Thoracic lateral flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W031C	T.FLEX	-5.50	17.50	5.00	14.00	125.00	5.40
W051C	T.FLEX	5.00	44.40	26.20	16.10	269.00	6.80
W092C	T.FLEX	13.20	44.90	30.50	21.00	268.00	8.50
W112C	T.FLEX	7.00	45.40	29.00	14.00	122.00	3.20
Average		4.93	38.05	22.68	16.28	196.00	5.98
SD		7.78	13.71	11.92	3.30	83.73	2.24
95%Confidence interval		7.62	13.43	11.68	3.24	82.05	2.20
Code	**Channel**	**Width**	**Mean**	**SD**	**Skew**	**Kurt**	
W031C	T.FLEX	8.90	5.40	3.20	0.67	-0.31	
W051C	T.FLEX	16.70	26.50	5.10	-0.19	1.77	
W092C	T.FLEX	12.80	29.70	2.60	-3.05	7.32	
W112C	T.FLEX	8.70	29.90	4.00	-0.33	0.77	
Average		11.78	22.88	3.73	-0.73	2.39	
SD		3.79	11.75	1.08	1.61	3.40	
95%Confidence interval		3.71	11.52	1.06	1.58	3.33	

Table 5.2.12-
Individual value of each subject for lateral flexion of thoracic spine

Workstation : Cutout
Method : Direct Vision (DV)
Channel : Thoracic lateral flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W031C	T.LAT.	-19.00	16.10	0.70	14.80	177.00	5.10
W051C	T.LAT.	-13.20	19.90	0.20	25.50	211.00	6.40
W092C	T.LAT.	-12.20	16.10	4.10	16.50	206.00	7.30
W112C	T.LAT.	-11.80	12.70	-0.70	17.00	140.00	5.70
Average		-14.05	16.20	1.08	18.45	183.50	6.13
SD		3.35	2.94	2.10	4.79	32.64	0.95
95%Confidence interval		3.29	2.88	2.06	4.70	31.99	0.93
Code	**Channel**	**Width**	**Mean**	**SD**	**Skew**	**Kurt**	
W031C	T.LAT.	12.00	0.60	4.40	-0.26	1.73	
W051C	T.LAT.	8.30	0.40	3.30	0.46	2.44	
W092C	T.LAT.	12.50	1.40	4.30	-0.11	1.33	
W112C	T.LAT.	8.20	-1.10	2.80	-0.49	3.54	
Average		10.25	0.33	3.70	-0.10	2.26	
SD		2.32	1.04	0.78	0.40	0.97	
95%Confidence interval		2.27	1.02	0.76	0.40	0.95	

Table 5.2.13-
Individual value of each subject for flexion of the cervical spine

Workstation : Cutout
Method : Indirect Vision (IV)
Channel : Cervical flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W036V	C.FLEX	-42.50	-9.80	-33.40	20.00	186.00	5.70
W057V	C.FLEX	-21.80	22.80	-4.60	22.70	240.00	5.40
W095V	C.FLEX	-19.90	53.00	1.20	17.40	276.00	3.80
W112V	C.FLEX	-47.80	-9.80	-33.80	13.00	126.00	3.30
Average		-33.00	14.05	-17.65	18.28	207.00	4.55
SD		14.22	30.17	18.57	4.13	65.45	1.18
95%Confidence interval		13.93	29.57	18.20	4.05	64.14	1.16

Code	Channel	Width	Mean	SD	Skew	Kurt
W036V	C.FLEX	9.30	-31.70	3.00	1.43	0.57
W057V	C.FLEX	10.60	-2.80	4.60	0.49	0.94
W095V	C.FLEX	15.90	5.30	10.30	1.62	3.60
W112V	C.FLEX	9.70	-32.10	4.60	0.49	0.39
Average		11.38	-15.33	5.63	1.01	1.38
SD		3.07	19.42	3.21	0.60	1.50
95%Confidence interval		3.00	19.03	3.14	0.59	1.47

Table 5.2.14-
Individual value of each subject for lateral flexion of the cervical spine

Workstation : **Cutout**
Method : **Indirect Vision (IV)**
Channel : **Cervical lateral flexion**

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W036V	C.LAT.	-5.50	34.80	17.50	30.00	333.00	8.30
W057V	C.LAT.	-8.90	41.00	9.80	27.30	354.00	7.10
W095V	C.LAT.	-19.90	40.60	6.50	20.00	383.00	6.30
W112V	C.LAT.	-20.40	18.00	-1.20	21.00	269.00	7.00
Average		-13.68	33.60	8.15	24.58	334.75	7.18
SD		7.61	10.78	7.75	4.85	48.39	0.83
95%Confidence interval		7.45	10.56	7.60	4.75	47.42	0.81

Code	Channel	Width	Mean	SD	Skew	Kurt
W036V	C.LAT.	11.10	17.30	5.10	-0.41	1.24
W057V	C.LAT.	13.00	11.10	6.40	0.98	1.01
W095V	C.LAT.	19.20	6.20	6.60	0.24	2.99
W112V	C.LAT.	12.80	-2.90	4.00	0.26	4.18
Average		14.03	7.93	5.53	0.27	2.36
SD		3.55	8.53	1.21	0.57	1.50
95%Confidence interval		3.48	8.36	1.19	0.56	1.47

Table 5.2.15-
Individual value of each subject for flexion of the thoracic spine

Workstation : Cutout
Method : Indirect Vision (IV)
Channel : Thoracic flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W036V	T.FLEX	9.80	39.60	25.20	30.00	417.00	14.00
W057V	T.FLEX	20.40	47.30	31.90	29.00	202.00	7.50
W095V	T.FLEX	-11.30	67.40	11.30	13.50	209.00	2.70
W112V	T.FLEX	30.00	50.60	43.90	15.00	110.00	5.40
Average		12.23	51.23	28.08	21.88	234.50	7.40
SD		17.72	11.73	13.60	8.84	129.76	4.82
95%Confidence interval		17.37	11.49	13.33	8.66	127.16	4.72

Code	Channel	Width	Mean	SD	Skew	Kurt
W036V	T.FLEX	13.90	22.60	3.10	-0.58	-1.07
W057V	T.FLEX	7.00	32.30	2.60	0.75	3.50
W095V	T.FLEX	15.50	14.30	8.80	2.61	10.68
W112V	T.FLEX	7.40	42.30	1.90	-0.77	1.12
Average		10.95	27.88	4.10	0.50	3.56
SD		4.38	12.11	3.17	1.56	5.10
95%Confidence interval		4.29	11.87	3.11	1.53	5.00

Table 5.2.16-
Individual value of each subject for lateral flexion of the thoracic spine

Workstation : Cutout
Method : Indirect Vision (IV)
Channel : Thoracic lateral flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W036V	T.LAT.	-14.20	23.80	-4.60	17.00	135.00	3.60
W057V	T.LAT.	-3.60	13.70	0.70	31.10	167.00	9.60
W095V	T.LAT.	-24.70	34.80	3.10	14.50	250.00	4.20
W112V	T.LAT.	-14.20	10.30	-6.00	18.50	143.00	5.90
Average		-14.18	20.65	-1.70	20.28	173.75	5.83
SD		8.61	11.04	4.31	7.40	52.62	2.70
95%Confidence interval		8.44	10.82	4.22	7.25	51.57	2.64

Code	Channel	Width	Mean	SD	Skew	Kurt	
W036V	T.LAT.	8.00	-5.30	2.70	0.75	3.05	
W057V	T.LAT.	5.40	1.20	1.50	2.50	4.24	
W095V	T.LAT.	17.20	2.70	8.40	0.05	-0.17	
W112V	T.LAT.	7.70	-6.80	2.00	1.85	8.48	
Average		9.58	-2.05	3.65	1.29	3.90	
SD		5.21	4.70	3.20	1.10	3.58	
95%Confidence interval		5.11	4.61	3.14	1.07	3.51	

Table 5.2.17-
Individual value of each subject for flexion of the cervical spine

Workstation : Traditional
Method : Direct Vision (DV)
Channel : Cervical flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W021T	C.FLEX	-30.00	-0.20	-11.80	14.20	147.00	4.90
W041T	C.FLEX	-39.60	14.60	-17.50	11.00	262.00	4.80
W061T	C.FLEX	-24.20	36.20	0.70	8.20	227.00	3.80
W103T	C.FLEX	-19.90	30.00	6.50	33.50	626.00	12.50
W121T	C.FLEX	-44.40	19.40	2.20	16.50	348.00	5.40
Average		-31.62	20.00	-3.98	16.68	322.00	6.28
SD		10.27	14.14	10.17	9.92	184.62	3.53
95%Confidence interval		9.00	12.40	8.92	8.69	161.83	3.09

Code	Channel	Width	Mean	SD	Skew	Kurt
W021T	C.FLEX	10.30	-14.10	3.60	-0.10	0.40
W041T	C.FLEX	23.80	-13.50	10.40	-0.11	-0.55
W061T	C.FLEX	27.80	4.80	12.30	0.30	-0.95
W103T	C.FLEX	18.70	10.20	7.30	-0.01	-0.54
W121T	C.FLEX	21.10	-1.00	8.90	-1.22	0.93
Average		20.34	-2.72	8.50	-0.23	-0.14
SD		6.55	10.86	3.30	0.58	0.78
95%Confidence interval		5.74	9.52	2.90	0.51	0.68

Table 5.2.18-
Individual value of each subject for lateral flexion of the cervical spine

Workstation : Traditional
Method : Direct Vision (DV)
Channel : Cervical lateral flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W021T	C.LAT.	-6.50	25.70	8.40	18.00	220.00	6.80
W041T	C.LAT.	-30.50	41.50	13.20	20.00	397.00	5.50
W061T	C.LAT.	-8.90	59.80	13.70	10.30	304.00	4.40
W103T	C.LAT.	-7.40	32.40	8.90	14.20	181.00	4.50
W121T	C.LAT.	-20.40	30.00	-0.20	11.00	282.00	5.60
Average		-14.74	37.88	8.80	14.70	276.80	5.36
SD		10.44	13.55	5.58	4.25	83.09	0.98
95%Confidence interval		9.15	11.87	4.89	3.73	72.83	0.86

Code	Channel	Width	Mean	SD	Skew	Kurt
W021T	C.LAT.	12.20	8.90	4.40	-0.31	0.42
W041T	C.LAT.	19.80	13.10	9.70	-0.08	0.30
W061T	C.LAT.	29.40	19.50	10.70	0.12	-0.30
W103T	C.LAT.	12.70	7.60	4.40	0.96	3.83
W121T	C.LAT.	25.70	5.40	5.80	0.47	-0.71
Average		19.96	10.90	7.00	0.23	0.71
SD		7.67	5.57	3.00	0.50	1.80
95%Confidence interval		6.72	4.88	2.63	0.44	1.58

Table 5.2.19-
Individual value of each subject for flexion of the thoracic spine

Workstation : Traditional
Method : Direct Vision (DV)
Channel : Thoracic flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W021T	T.FLEX	19.90	40.60	27.60	19.00	117.00	5.70
W041T	T.FLEX	-8.40	19.90	8.40	10.20	143.00	5.00
W061T	T.FLEX	4.10	53.50	28.60	10.20	139.00	2.80
W103T	T.FLEX	-17.50	55.90	32.90	6.90	162.00	2.20
W121T	T.FLEX	-9.40	59.80	22.80	8.00	174.00	2.50
Average		-2.26	45.94	24.06	10.86	147.00	3.64
SD		14.60	16.24	9.46	4.77	21.99	1.59
95%Confidence interval		12.80	14.24	8.29	4.18	19.27	1.40

Code	Channel	Width	Mean	SD	Skew	Kurt
W021T	T.FLEX	6.20	27.50	2.10	1.04	3.72
W041T	T.FLEX	14.00	4.90	3.40	-0.11	-1.63
W061T	T.FLEX	13.60	31.60	6.80	0.79	-0.03
W103T	T.FLEX	23.50	36.20	6.70	0.30	-1.39
W121T	T.FLEX	21.80	18.80	10.20	-0.22	0.78
Average		15.82	23.80	5.84	0.36	0.29
SD		6.99	12.35	3.19	0.55	2.16
95%Confidence interval		6.13	10.83	2.79	0.48	1.89

Table 5.2.20-
Individual value of each subject for lateral flexion of the thoracic spine

Workstation : Traditional
Method : Direct Vision (DV)
Channel : Thoracic lateral flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W021T	T.LAT.	-22.30	-0.70	-12.20	25.00	179.00	8.30
W041T	T.LAT.	-31.40	6.00	-5.50	18.00	185.00	4.90
W061T	T.LAT.	-14.20	12.20	-2.20	13.80	148.00	5.60
W103T	T.LAT.	-19.00	7.40	-5.00	16.30	146.00	5.50
W121T	T.LAT.	-15.10	13.70	0.70	13.00	148.00	5.20
Average		-20.40	7.72	-4.84	17.22	161.20	5.90
SD		6.95	5.70	4.80	4.78	19.12	1.37
95%Confidence interval		6.09	4.99	4.21	4.19	16.76	1.20

Code	Channel	Width	Mean	SD	Skew	Kurt	
W021T	T.LAT.	7.20	-12.50	2.50	-0.08	2.60	
W041T	T.LAT.	10.30	-7.50	4.00	-0.64	0.35	
W061T	T.LAT.	10.80	-1.00	3.10	0.29	3.75	
W103T	T.LAT.	9.00	-5.30	3.70	-0.18	0.18	
W121T	T.LAT.	11.40	2.10	3.60	-1.20	4.01	
Average		9.74	-4.84	3.38	-0.36	2.18	
SD		1.67	5.68	0.59	0.57	1.83	
95%Confidence interval		1.47	4.98	0.52	0.50	1.60	

Table 5.2.21-
Individual value of each subject for flexion of the cervical spine

Workstation : Traditional
Method : Indirect Vision (IV)
Channel : Cervical flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W024V	C.FLEX	-36.70	2.60	-24.20	17.00	148.00	3.80
W045V	C.FLEX	-22.30	40.10	-7.90	23.00	193.00	3.10
W065V	C.FLEX	-10.80	35.80	4.60	12.30	192.00	4.10
W106V	C.FLEX	-19.90	35.80	0.70	21.00	316.00	5.70
W124V	C.FLEX	-40.10	20.90	-27.60	10.00	142.00	2.30
Average		-25.96	27.04	-10.88	16.66	198.20	3.80
SD		12.20	15.48	14.49	5.53	70.04	1.27
95%Confidence interval		10.69	13.57	12.70	4.85	61.39	1.11

Code	Channel	Width	Mean	SD	Skew	Kurt	
W024V	C.FLEX	8.70	-24.40	3.90	0.92	3.59	
W045V	C.FLEX	8.40	-6.80	5.10	1.44	6.47	
W065V	C.FLEX	15.60	5.20	6.50	1.71	3.50	
W106V	C.FLEX	15.00	-2.40	4.40	-0.05	1.81	
W124V	C.FLEX	14.20	-22.90	9.80	1.58	1.87	
Average		12.38	-10.26	5.94	1.12	3.45	
SD		3.53	12.97	2.37	0.72	1.89	
95%Confidence interval		3.10	11.37	2.08	0.63	1.66	

Table 5.2.22-
Individual value of each subject for lateral flexion of the cervical spine

Workstation : Traditional
Method : Indirect Vision (IV)
Channel : Cervical lateral flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W024V	C.LAT.	-9.80	24.70	9.80	26.00	261.00	7.60
W045V	C.LAT.	-16.10	30.00	8.90	27.00	299.00	6.50
W065V	C.LAT.	-7.90	38.20	9.40	17.10	227.00	4.90
W106V	C.LAT.	-5.50	20.40	7.90	23.00	190.00	7.30
W124V	C.LAT.	-12.70	24.20	3.10	14.00	157.00	4.20
Average		-10.40	27.50	7.82	21.42	226.80	6.10
SD		4.14	6.89	2.73	5.66	56.14	1.49
95%Confidence interval		3.62	6.04	2.40	4.96	49.21	1.31

Code	Channel	Width	Mean	SD	Skew	Kurt	
W024V	C.LAT.	10.00	9.50	4.20	-0.38	0.90	
W045V	C.LAT.	11.10	7.90	4.60	-0.27	2.40	
W065V	C.LAT.	13.30	11.70	4.50	0.78	3.91	
W106V	C.LAT.	8.20	7.70	2.70	-0.74	4.13	
W124V	C.LAT.	11.20	4.40	4.70	-0.07	0.56	
Average		10.76	8.24	4.14	-0.14	2.38	
SD		1.86	2.68	0.83	0.57	1.65	
95%Confidence interval		1.63	2.35	0.72	0.50	1.45	

Table 5.2.23-
Individual value of each subject for flexion of the thoracic spine

Workstation : Traditional
Method : Indirect Vision (IV)
Channel : Thoracic flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W024V	T.FLEX	4.60	36.20	22.30	15.00	149.00	4.70
W045V	T.FLEX	12.70	59.80	24.20	14.50	150.00	3.20
W065V	T.FLEX	26.20	64.10	40.60	16.50	120.00	3.20
W106V	T.FLEX	13.20	57.80	29.50	10.30	131.00	2.90
W124V	T.FLEX	-7.90	55.00	30.50	6.80	117.00	1.90
Average		9.76	54.58	29.42	12.62	133.40	3.18
SD		12.54	10.80	7.14	3.98	15.60	1.00
95%Confidence interval		10.99	9.46	6.26	3.49	13.67	0.88

Code	Channel	Width	Mean	SD	Skew	Kurt	
W024V	T.FLEX	9.90	21.00	3.70	0.06	1.25	
W045V	T.FLEX	10.30	26.60	4.00	1.47	3.33	
W065V	T.FLEX	7.20	40.20	3.20	0.05	1.44	
W106V	T.FLEX	12.70	33.90	4.70	0.75	-0.04	
W124V	T.FLEX	17.20	29.10	5.00	0.71	2.18	
Average		11.46	30.16	4.12	0.61	1.63	
SD		3.76	7.29	0.73	0.59	1.24	
95%Confidence interval		3.29	6.39	0.64	0.52	1.09	

Table - 5.2.24 -
Individual value of each subject for lateral flexion of the thoracic spine

Workstation : Traditional
Method : Indirect Vision (IV)
Channel : Thoracic lateral flexion

Code	Channel	Xmin	Xmax	Xmode	Ymode	Area	Height
W024V	T.LAT.	-8.90	11.30	1.70	21.20	145.00	7.20
W045V	T.LAT.	-24.70	8.40	-2.20	16.80	125.00	3.80
W065V	T.LAT.	-17.00	10.80	-1.70	18.40	145.00	5.20
W106V	T.LAT.	-7.40	14.60	2.20	28.50	164.00	7.40
W124V	T.LAT.	-18.00	-0.70	-8.40	15.90	106.00	6.10
Average		-15.20	8.88	-1.68	20.16	137.00	5.94
SD		7.10	5.79	4.24	5.08	22.15	1.49
95%Confidence interval		6.23	5.08	3.72	4.45	19.41	1.31

Code	Channel	Width	Mean	SD	Skew	Kurt
W024V	T.LAT.	6.90	1.00	2.20	-1.42	3.16
W045V	T.LAT.	7.40	-3.70	2.40	-0.05	1.58
W065V	T.LAT.	7.90	-2.10	2.90	-0.80	3.92
W106V	T.LAT.	5.80	1.80	2.00	-0.46	0.94
W124V	T.LAT.	6.70	-8.80	2.50	0.03	0.84
Average		6.94	-2.36	2.40	-0.54	2.09
SD		0.79	4.24	0.34	0.59	1.38
95%Confidence interval		0.69	3.72	0.30	0.52	1.21

Table - 5.2.25 -
Individual and averaged values of Mean (in % MVC) for EMG measurements and SD (in degrees) for Postural measurements during PC board assembly operation by using the Direct Vision method. Both parameters reflect the workload for the corresponding parts of the body.

Denotations: R.Trap - Right Trapezius muscle, L.Trap - Left Trapezius muscle, C.FLEX - Cervical flexion, C.LAT. - Cervical lateral flexion, T.FLEX - Thoracic flexion, T.LAT - Thoracic lateral flexion, '-' denotes either missing or some human errors.

Code	R.Trap	L.Trap	C.FLEX	C.LAT.	T.FLEX	T.LAT.
W010C	28.30	36.70	-	-	-	-
W031C	34.50	7.00	4.40	4.60	3.20	4.40
W051C	38.70	12.60	14.30	8.70	5.10	3.30
W092C	11.60	3.70	9.80	9.60	2.60	4.30
W112C	15.60	12.40	9.90	6.20	4.00	2.80
W021T	5.70	5.90	3.60	4.40	2.10	2.50
W041T	19.60	12.40	10.40	9.70	3.40	4.00
W061T	22.70	5.50	12.30	10.70	6.80	3.10
W103T	-	-	7.30	4.40	6.70	3.70
W121T	8.70	2.90	8.90	5.80	10.20	3.60
Average	20.60	11.01	8.99	7.12	4.90	3.52
SD	11.48	10.36	3.46	2.55	2.60	0.66
95% Confidence interval	7.50	6.77	2.26	1.66	1.70	0.43

Table - 5.2.26 -
Individual and averaged values of Mean (in % MVC) for EMG measurements and SD (in deg) for Postural measurements during assembling by the use of Indirect Vision method. Both parameters reflect the workload for the corresponding parts of the body.

Denotations: R.Trap - Right Trapezius muscle, L.Trap - Left Trapezius muscle, C.FLEX - Cervical flexion, C.LAT. - Cervical lateral flexion, T.FLEX - Thoracic flexion, T.LAT. - Thoracic lateral flexion; '-' denotes either missing or low quality data.

Code	**R.Trap**	**L.Trap**	**C.FLEX**	**C.LAT.**	**T.FLEX**	**T.LAT.**
W016V	11.70	28.90	-	-	-	-
W036V	33.80	1.80	3.00	5.10	3.10	2.70
W057V	24.20	9.00	4.60	6.40	2.60	1.50
W095V	12.80	2.20	10.30	6.60	8.80	8.40
W112V	11.10	9.60	4.60	4.00	1.90	2.00
W024V	7.00	2.90	3.90	4.20	3.70	2.20
W045V	6.10	2.30	5.10	4.60	4.00	2.40
W065V	9.60	12.70	6.50	4.50	3.20	2.90
W106V	-	2.90	4.40	2.70	4.70	2.00
W124V	4.20	2.00	9.80	4.70	5.00	2.50
Average	13.39	7.43	5.80	4.76	4.11	2.96
SD	9.58	8.51	2.59	1.19	2.01	2.08
95% Confidence interval	5.94	5.27	1.69	0.78	1.31	1.36