EXAMINING THE RELATIONSHIP BETWEEN RAPID UPPER LIMB ASSESSMENT'S (RULA) POSTURAL SCORING SYSTEM AND SELECTED PHYSIOLOGICAL AND PSYCHOPHYSIOLOGICAL MEASURES

by

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Abstract

Workplace injuries, known as musculoskeletal disorders (MSD), are an increasing health hazard facing office employees today (Harvey and Peper, 1997; Sauter et al., 1993). Ideally a "gold standard" is required which would effectively identify risk factors, estimate the true magnitude of risk and systematically evaluate the efficacy of prevention and return to work programs. The research presented in this thesis contributes to the achievement of this goal.

The Rapid Upper Limb Assessment (RULA) survey, designed by McAtamney and Corlett (1993), is a posture sampling tool used specifically to examine the level of risk associated with upper limb disorders of individual workers. No studies have been found to date that examine the postural scoring system set out by RULA and its relationship with objective physiological response measures. The study presented here examines the relationship between RULA's postural scoring system and the physiological measurement techniques of EMG (RMS), heart rate response, and blood pressure, as well as the psychophysiological measurement technique of self-reports of discomfort.

Twenty subjects were recruited from various companies to participate in this study. Each subject performed a 30-minute typing task on a computer in three working postures based on RULA's scoring system. Kinematic data were collected for the neck, shoulder, elbow and wrist, to verify the subjects' tested postures against RULA's defined posture system. Six quasi-random samples of EMG were collected over each 30-minute testing condition for the upper trapezius, anterior deltoid, biceps brachii and forearm extensors. Each subject's heart rate was recorded every five seconds over each 30-minute testing. Blood pressure and body discomfort scores were collected pre- and post-testing conditions.

A multi-way repeated measures ANOVA was used to analyse the EMG (RMS) and kinematic data, while a one-way repeated measures ANOVA was used for heart rate, blood pressure, perceived discomfort and performance measure. In general there were statistically significant effects due to posture for all the kinematic measures. In terms of the physiological measures, the only statistically significant effect was due to time for the forearm extensor muscles. Finally, there were significant differences found for the perceived discomfort and work performance measures.

The resultant contradiction in physiological versus psychophysiological results may be explained in three ways: 1) there is no physiological difference in the body's state across the three tested postures; 2) the physiological measures used here in this study are not effective means for measuring physiological changes while performing computer tasks in the three tested postures or; 3) the statistical power was too low to demonstrate a statistically significant difference. The results of this study would suggest that RULA's scoring system may be too general in nature, and therefore, weaknesses in its specific application to computer workstations have emerged. It is the author's opinion that RULA can be improved into an even more powerful tool through the development of task specific RULA versions.

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Chapter One: Introduction

Workplace injuries, known as musculoskeletal disorders (MSD), are an increasing health hazard facing office employees today (Harvey and Peper, 1997; Sauter et al., 1991). Work related MSD are defined as disorders and diseases of the muscles, tendons and nerves (soft tissues) having proven or hypothesized work related causation. Various media sources, such as radio and newspaper, are reporting on the growing incidence of employee sick leave, medical claims and litigation from MSD. According to data published by the National Council on Compensation Insurance (NCCI) in the United States, the fourth most costly lost-time claims in 1994-1995 were classified as 'occupational disease/cumulative trauma,' with an average incurred total costs per claim of $11,479 (National Safety Council, 1997). While in British Columbia, MSD are reported as the fastest growing workplace injury and account for 35% of the workers' compensation claims (WCB of BC, 1996). In order to reduce these costs, ergonomists and organizations must be able to identify and eliminate the risk factors, thereby preventing MSD.

Ergonomists today are in need of improved methods to identify individuals at risk. Currently, they consider records kept by the Occupational Health and Safety Committee within an organization, along with surveys, questionnaires and checklists as valuable information sources. In the study by Silverstein *et al.* (1997) the percentage of work related MSD were higher from data collected using self-administered symptom questionnaires, interviews, and physical examinations than from data collected within an organization based on pre-existing surveillance, for example the companies' health data sources and WCB/OSHA 200 log. Therefore an organization's records are not, for the most part, reliable sources for identifying the prevalence of high-risk jobs and employees at risk. Instead, they represent claims that have been reported to the Health and Safety Individual or Committee. On the other hand, surveys and questionnaires represent more than simply the level of risk or discomfort but individuals' attitudes as well. When looking at Workers' Compensation claims, and sickness and accident data sources for surveillance, the individuals placed in high-risk environments are not usually identified until their problem or disorder has resulted in lost work time. At this point, a preventable disorder may have become irreversible. Therefore, not only are company records an unreliable source of information but more importantly, the prevention component in the ergonomic process has been overlooked. Ideally a "gold standard" is required which would effectively identify risk factors, estimate the true magnitude of the employees at risk and systematically evaluate the efficacy of prevention and return to work programs. The research presented in this thesis will contribute to the achievement of this goal.

The Rapid Upper Limb Assessment (RULA) survey, designed by McAtamney and Corlett (1993), is a tool for ergonomic consultants to use during investigations of the workplace. RULA was developed specifically to examine the level of risk associated with upper limb disorders of individual workers. This tool is used to sample working postures at one instant in time. This instant is determined by the ergonomist and the nature of the work on any particular day. By using a coding system, RULA generates an action list, which determines the level of intervention required to reduce the risk of workplace injuries. The purpose of RULA is to provide a quick method for screening a variety of workstations and to give results that can be incorporated into wider ergonomic programs. Ergonomists must feel confident about RULA's efficiency for screening and identifying risks, in order to carry out their jobs of prevention and reduction of injuries.

The RULA checklist measures postures on a scoring system scale from one to seven. The initial validation and reliability studies were performed on RULA using a data-entry computer task as a model and are described in McAtamney and Corlett (1993). Sixteen experienced computer users were assessed to determine whether RULA provided a good indication of "musculoskeletal loading, which might be reported as pain or discomfort in the relevant body region," (McAtamney and Corlett, 1993). Subjects were divided into two groups based on RULA's scoring system. Group one consisted of subjects with an acceptable RULA grand score of one; group two consisted of subjects with a RULA grand score greater than or equal to two, which was deemed unacceptable. A data entry task was performed for 40 minutes and the right side of the body was assessed using RULA. Subjects were asked to complete a body part discomfort survey before and after the 40-minute trial.

The RULA scores for each body part (Figure 1) were compared with the subjects' self-report of experienced pain or discomfort. Only the neck and upper arm revealed a statistically significant relationship between the RULA postural score and the reported discomfort. The authors also examined this relationship with the functional unit A and functional unit B. The postural scores for the upper arm, lower arm and wrist were tallied, using Table "A" in Figure 2, to yield a score for the functional unit A. While the functional unit B score was tallied for the neck, trunk and legs, using Table "B" in Figure 2.

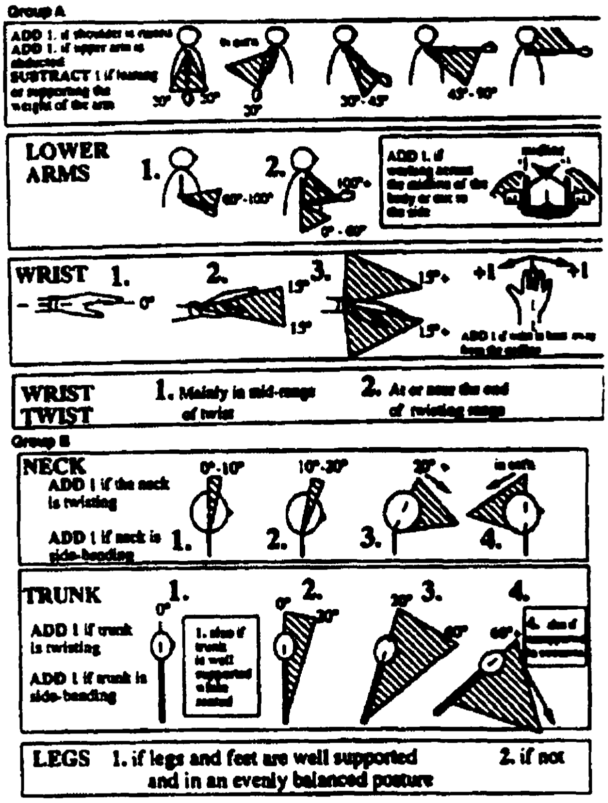


Figure 1: RULA's postural score.

TABLE A Upper Limb Posture Score

UPPER ARM	LOWER ARM	WRIST POSTURE SCORE 1, TWIST 1	WRIST POSTURE SCORE 1, TWIST 2	WRIST POSTURE SCORE 2, TWIST 1	WRIST POSTURE SCORE 2, TWIST 2	WRIST POSTURE SCORE 3, TWIST 1	WRIST POSTURE SCORE 3, TWIST 2	WRIST POSTURE SCORE 4, TWIST 1	WRIST POSTURE SCORE 4, TWIST 2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	6	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

TABLE B Neck, Trunk, Legs Posture Score

NECK POSTURE SCORE	TRUNK POSTURE SCORE 1, LEGS 1	1, LEGS 2	2, LEGS 1	2, LEGS 2	3, LEGS 1	3, LEGS 2	4, LEGS 1	4, LEGS 2	5, LEGS 1	5, LEGS 2	6, LEGS 1	6, LEGS 2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Figure 2: RULA's functional unit score.

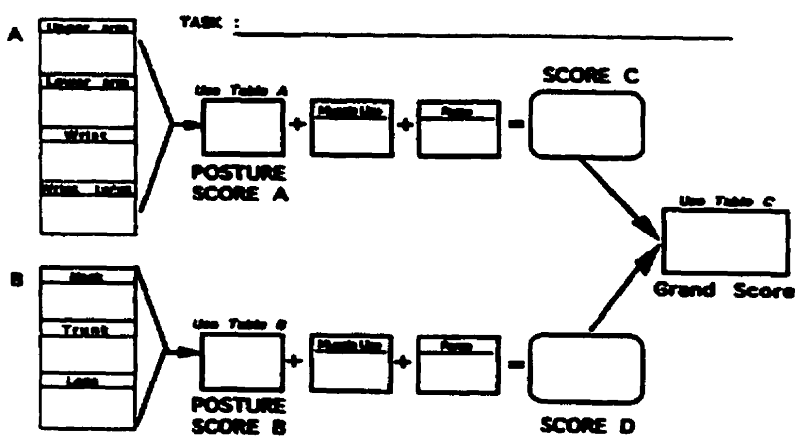


Figure 3: RULA's grand score.

A significant relationship was found between RULA's functional units score and perceived discomfort. This is not surprising since the upper arm falls under the functional unit A, while the neck falls under functional unit B comprising the two areas of greatest concern. Also, the trapezius muscle, a muscle of the shoulder girdle, plays two functions: 1) for lateral flexion of the neck; and 2) for elevation, upward rotation and adduction of the scapula. Therefore, if the neck is experiencing discomfort and the trapezius muscle is tense, then there may also be resulting discomfort in the shoulder or upper arm region. It should be noted that the trapezius muscle fixes the scapula as the deltoid muscle pulls on the humerus. Thus, it may be difficult to make any distinction between neck and upper arm (shoulder) discomfort.

Problems can arise with the validity and reliability of using self-reports of pain or discomfort as the sole means of assessing the worker's risk of developing a MSD. In a number of studies, it was found that upper extremity MSD, based on questionnaires alone, had prevalence rates twice those based on questionnaires and physical examinations (Hales *et al.*, 1994; NIOSH, 1989). Problems with self reports are twofold: 1) it is difficult to make the distinction between the external stimulus (stressor) and its subjective appraisal by the individual (Kahn, Byosiere, 1992), and 2) confusion of hypothesized causes and effects often emerges through self reports of perceived discomfort and the external stimulus (stressors) (Kahn, Byosiere, 1992). Therefore, it is crucial that researchers include reliable and valid methods of both self-reports and objective data collection techniques in future research. Norman et al. (1998) found that both biomechanical (physical) and psychosocial variables are statistically significant and contribute independently to the risk of lower back pain (LBP) and those who report LBP.

No studies have been found to date that examine the postural scoring system set out by RULA and its relationship with direct, objective physiological response measures. The study reported on in this thesis has attempted to determine whether there is a systematic change in the body's physiological response related to changes in RULA's postural scores. For the purpose of this study muscle activity (EMG), heart rate, and blood pressure measures formed the physiological basis, while self-reports of discomfort formed the psychophysiological basis. These measures were correlated to musculoskeletal loading.

Purpose of the Study

This thesis work has examined the relationship between RULA's postural scoring system and a number of physiological and psychophysiological parameters in a laboratory setting. The assessment of RULA included objective measures of electromyography (EMG), heart rate response, and blood pressure, as well as self-reports of perceived discomfort to observe the body's response to various computer-working postures. As a second purpose the object of this thesis has examined whether a relationship existed between various job attitude factors and perceived discomfort scores.

The objectives were tested using the following six Null Hypotheses:

1. There will be no significant difference in EMG (RMS) activity of the upper trapezius, anterior deltoid, biceps, and forearm extensors across the three working postures.

2. There will be no significant difference in heart rate response across the three working postures.
3. There will be no significant difference in systolic and diastolic blood pressure across the three working postures.
4. There will be no significant difference in perceived discomfort scores across the three working postures.
5. There will be no significant difference in performance, as measured by a word count, across the three working postures.
6. There will be no significant relationship between the on-site perceived discomfort scores and on-site job attitude questionnaire scores among the subjects.

Assumptions

For this research it has been assumed that quantitative guidelines, based on RULA's postural scores, and short term physiological responses were valid in terms of determining musculoskeletal health. Epidemiological studies in combination with vocational EMG recordings have shown an increased risk of MSD at mean load levels below 5% maximum voluntary contraction (MVC) in some repetitive work tasks (Westgaard and Winkel, 1996). Pan and Schleifer (1996) have observed a positive correlation between muscular fatigue and musculoskeletal discomfort in the shoulder and elbow. They have also noted that musculoskeletal discomfort and fatigue are higher in the afternoon versus the morning during a full day of testing. The object of the thesis has assumed that by reducing muscular effort, there will also be a reduction in muscular fatigue and risk of developing a MSD.

For this thesis it is also assumed that a bilateral symmetry exists with respect to muscular activity and joint kinematics when typing on a keyboard. The proposed sample selection was assumed to be representative of a normal population with regard to the physiological and psychophysiological responses to working postures. Finally, it was assumed that the subjects would follow the described pre-testing instructions.

The study reported on here has been limited, in external validity, by the standardized testing conditions, which are necessary to ensure a valid comparison of the physiological and psychophysiological responses between subjects and working postures. The testing took place in a laboratory setting adjusted to represent a standard office work setting. Another limitation was the duration of data recording. Although a normal workday may consist of anywhere from six to ten hours, this study tried to derive a representative sample by recording data for a limited duration of 30 minutes. The inclusion criteria required that subjects have no known MSD of the trunk and upper extremities, no known cardiovascular disease, were not heavy caffeine drinkers, were non-smokers and have worked at a job over the past two years that requires the use of a computer for at least four hours per day. In selecting the population these criteria represented a delimitation.

Operational Definitions

Blood Pressure - the pressure exerted by the blood on the vessel walls and is expressed by systolic pressure, ventricular systole of the heart, and by diastolic pressure, ventricular diastole of the heart (Wilmore and Costill, 1994).

Electromyography (EMG) - the record of electric currents generated by a person's muscles and measured in millivolts (mV) (Basmajian and Deluca, 1985).

Heart Rate - the number of heartbeats in one minute measured using a Polar Vantage XL Heart Rate Monitor.

Perceived Discomfort - a psychophysiological measure of the sensation of discomfort reported by subjects and may include pain, numbing, tingling, limited range of motion, weakness, and "pins and needles"; measured using a Likert scale.

Physiological - pertaining to the science of functions and phenomena of living organisms and their parts (The Concise Oxford, 1982).

Psychological - pertaining to the science of the nature, functions, and phenomena of the human mind (The Concise Oxford, 1982).

Psychophysiological - branch of physiology dealing with mental phenomena and the relations between mind and body (The Concise Oxford, 1982).

Root mean square (RMS) - amplitude analysis that expresses the EMG signal in terms of its magnitude and defines the average value of the rectified EMG signal (Moty and Khalil, 1987); $\boldsymbol{RMS} = \sqrt{\frac{\sum_{i=1}^{N} x_i^2}{N}}$ where x is the raw EMG value of the i^{th} sample and N the total number of samples in each one second sample (1024). This value is calculated for each muscle value.

Chapter Two: Review of Literature

The focus of this thesis is to examine the relationship between RULA's postural scoring system and the physiological and psychophysiological signals at different RULA scoring levels. The applied issues are related to the factors which are caused in work related musculoskeletal disorders (MSD) and the physiological signals. Consequently, a number of different literature sources are pertinent to it and this review will present the relevant work in the following areas: upper extremity musculoskeletal disorders (MSD), posture sampling, electromyography (EMG), heart rate response, blood pressure, perceived discomfort, job attitudes, and environmental factors.

The following review will demonstrate that relationships between MSD, working postures and muscular effort do exist. The physiological and psychophysiological measures described in the review of literature, may or may not be an effective means of appraising this relationship. In order to properly address this relationship all of the above factors must be examined.

Upper Extremity Musculoskeletal Disorders

Based on the literature reviewed below, there seems to be sufficient evidence to conclude that prolonged work in awkward or biomechanically stressful postures increase the risk of musculoskeletal pain and discomfort. The measurement and analytical criteria for differentiating between acceptable and unacceptable body postures based on various loads (force), frequency (repetition) and duration of work has yet to be determined.

According to the study by Himmelstein et al. (1995), work related upper extremity disorders are broadly defined as "symptom complexes" characterized by pain, parethesias, and/or weakness affecting the upper extremities or neck attributed by the patients and/or their physicians. This definition lacks objectivity in diagnosis and the causal relationship to work. Other definitions of work related MSD have been used throughout the literature but for the most part also lack objectivity (Bridger, 1995; Putz-Anderson, 1988; Silverstein, 1995). For the purpose of this thesis, MSD are defined as disorders of the muscles, connective tissues, peripheral nerves, or vascular system consistent with the definition supplied in ANSI Z-365 (1996). A disorder may be defined as a disturbance to the normal state of body (Concise Oxford, 1982) and may manifest itself in a variety of symptoms that can differ among individuals. These disorders may be caused, precipitated or aggravated by intense, repeated or sustained exertions and/or insufficient tissue recovery. The major physical risk factors of MSD include repetition, load and awkward postures. Although there is a certain optimum level of these factors necessary for health, excessive loads will have negative effects on the individual. Graphing these effects would resemble an inverted "U" with the y-axis representing negative and positive effect and the x-axis representing load (Figure 4).

The inverted "U" curve may differ in size depending on the individual (Nigg et al., 1984). An individual's coping strategies to stressors, for example shifting one's weight when seated for prolonged periods of time, as well as personal lifestyles will play a role in determining the size of the graph. It is important to note that these risk factors do not occur exclusively in the working environment. Repetition on its own may not be enough to result in a MSD. However, repetition for long periods of time without the opportunity for recovery will drastically increase the potential to develop a MSD. Therefore, each risk factor may compound the negative effects of the other.

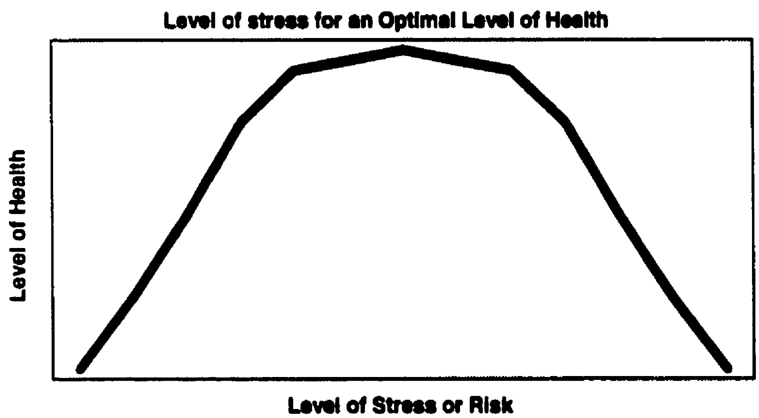


Figure 4: Optimal level of health.
(Adapted from Yerkes and Dodson, 1908)

The continuous exposure of various areas of the body to workplace risk factors has been shown to negatively affect tissues and joints (Carayon and Smith, 1996). The two areas of the body most frequently involved in workplace MSD are the upper extremities, and the back (National Safety Council, 1997; WCB of NS, 1996; Mital, 1996). Work related MSD of the upper extremities are common among office workers who use video display terminals (VDT) (Kuorinka and Forcier, 1995).

According to Derebery (1998), MSD involving tendons (i.e. tendonitis, tenosynovitis and peritendinitis) are associated with acute trauma, unaccustomed tasks and systemic disease. Tendonitis, however, is more likely the result of repetitive activity if the worker is unaccustomed to the work or if a significant increase in workload is introduced (Derebery, 1998). The risk factor of repetition, when examined in isolation, has been challenged because it can have a positive outcome on individuals. Walking, running and blinking are repetitive movements that do not produce negative outcomes, and it is repetition that is beneficial as a method of conditioning and maintaining health. Using the analogy of a weight lifter, repetition helps to build strength only if the lift is within the athlete's ability (force) and/or if proper lifting techniques are employed (posture). Only in combination with excessive loads, awkward postures or unaccustomed tasks, repetition may increase the athlete's potential of developing an injury. The same can be said for "occupational athletes". Repetition will exacerbate the negative effects of excessive force and awkward postures on the body.

Pascarelli and Kella (1993) examined 53 symptomatic keyboard operators who complained of pain in the forearms, elbows, wrists, shoulders and hands and who spent the major portion of their day working at the computer keyboard. Evaluations of the individuals consisted of medical history, physical examination and video recording. From their study, the authors were convinced that awkward postures (wrists in dorsiflexion and ulnar deviation, alienated thumb posture, fifth finger motion and joint hypermobility), poor technique and physical condition played a role in predisposing a worker to MSD. Computer users often assume awkward, static seated postures for long periods of time. These awkward, static seated postures increase joint forces while the long periods of time yield excessive static loads on the musculature of the back, neck, shoulders and upper extremities (Sauter and Schnorr, 1992). These conditions may lead to local ischemia, muscle fatigue and pain, which in turn may lead to MSD.

The work related risk factors most consistently identified, according to Kuorinka and Forcier (1995) include: 1) repetitive work; 2) high physical load and forces; 3) static or constrained neck and shoulder postures; 4) increased intensity or duration of exposure; and 5) working in twisted or bent postures (awkward postures). The effects of duration are seen when there is an increase in the exposure duration and there is a subsequent increase in the prevalence of symptoms. If, however, the exposure duration is shortened, the onset of symptoms is merely postponed instead of being prevented entirely (Kuorinka and Forcier, 1995).

Westgaard and Winkel (1996) critiqued ergonomic guidelines in their focus on exposure level, without taking into account repetition or duration. Load (force) varies depending on the number of lifts over “x” number of hours. Silverstein (1995) however, argued that force is a more important risk factor than repetition for hand-wrist MSD. These findings reinforce the need to look at risk factors in combination and to study their cumulative effect on the body. Putz-Anderson (1988) have alluded to the environment-fit theory by stating that there must be a balance between work demands and the worker's capacity to respond to those demands. Keeping this in mind, the combined effects of force, repetition and awkward postures must exceed the individual's abilities as well as provide insufficient recovery.

A list of authors and their studies that have shown a significant relationship between the risk factors examined in this review and the development of MSD can be seen in Table 1.

Table 1: Studies that show a significant relationship between physical risk factors and the development of MSD.

Author	High workload/force	Repetitive work	Awkward postures	Static postures	Duration
Derebery (1998)	✓	✓			
Kuorinka and Forcier (1995)	✓	✓	✓	✓	✓
Mital (1996)	✓		✓	✓	
Pascarelli and Kella (1993)			✓		
Sauter et al. (1992)	✓	✓	✓	✓	
Silverstein (1995)	✓				
Westgaard and Winkel (1996)		✓			✓

Posture Sampling

The human body controls and maintains its posture either through conscious or subconscious central responses to sensory input from the periphery (McLean, 1998). The sensory input includes information on muscle length, tension, and joint loading. The muscles involved in postural control are typically made up of type I (slow oxidative) muscle fibers. These fibers are recruited for small and/or sustained contractions.

Measurement of working postures serves two important occupational health applications. Firstly, jobs may be evaluated to quantify postural stress and identify specific causes of awkward posture and, secondly, for epidemiological studies of posture-related injury, exposure data must be obtained (Santos and Wells, 1997). There are many checklist methods for analyzing workplace postures, for example the Posturegram (Priel, 1974), Hand-Arm-Movement Analysis (HAMA) (Christmansson, 1994), the Ovako Working Posture Analysis System (OWAS) (Karhu et al., 1977), and RULA. The object of the thesis will only examine RULA and the relationship between its postural scoring system and physiological measures. Only one previous study has examined the validity and reliability of RULA and it was performed by McAtamney and Corlett (1993). McAtamney and Corlett (1993) investigated the relationship between RULA's risk categories and psychophysiological measures. RULA was initially designed around the basis of physical ergonomics in order to determine the load at which tissue damage would result. The authors, however, used self-reports of perceived discomfort as a measure of physical risk for their validity study. These self-reports are more likely to correlate with the likelihood of an individual to make a disability claim and not necessarily with the actual physical loading on the body.

Psychosocial factors affect whether or not an individual will make any such claim. These factors were not directly considered by McAtamney and Corlett (1993). How an individual perceives their working environment will play a major role in their level of perceived discomfort and reports of these discomforts. Consideration of these factors has been included in the present thesis.

Electromyography (EMG)

Electromyography (EMG) is a useful tool for analyzing muscular performance in the workplace. The EMG data determines the level of muscle activation and duration of activity in the measurement of physical requirements for occupational tasks (Chaffin and Andersson, 1991). EMG measures three things: temporal aspects or phasic activation patterns; force; and fatigue. To assess musculoskeletal stress associated with awkward working postures and the validity of ergonomic principles, EMG is often administered (NIOSH, 1992). One method of evaluating a muscle's performance, uses surface EMG. The surface EMG records the spatial and temporal summation of action potentials from a group of muscle fibres. The amplitude and shape of the recorded surface EMG will depend on the characteristics of the muscle fibre; the spatial orientation of the surface electrodes to the muscle fibre; the filter characteristics of the electrodes and surrounding tissue; and the specifications of electronic instrumentation (NIOSH, 1992).

Surface electrodes provide a general representation of the muscle's electrical activity (i.e. the summation of several motor units firing simultaneously). The advantages of using surface electrodes include the ease of application and accessibility. When using surface electrodes, one must be cognizant of their limitations. It is difficult to record activity of deep muscles since surface electrodes only record the electrical activity of the most superficial muscle fibres. During dynamic activity, the muscle moves under the skin creating different volumes of muscle tissue. Finally, surface electrodes may pick up electrical activity from small, superficial muscles, which lay adjacent to each other, known as cross talk (NIOSH, 1992). Electrode placement must be well defined and consistent in order to control for reliability within and among subjects. Jensen et al. (1996) found considerable improvement in reproducibility of EMG signal in the trapezius pars descendens when the electrodes were positioned 2 cm laterally to the midpoint, instead of at the midpoint between cervical vertebra seven (C7) and the acromion. In order to compare the EMG of various subjects, trials, and muscles, normalization of the myoelectric activity to a reference contraction is important. Submaximal isometric contractions are more accurate than using maximal voluntary contractions as a reference contraction (NIOSH 1992). The reference contraction must be defined in terms of electrode placement, type of contraction and joint position. Normalization of the EMG signal is required to improve the reliability of testing over many days, as well as to make between subject comparisons.

According to Wiker (1989), any increase in the EMG signal amplitude is possibly the result of an increase in motor unit recruitment, an increase in motoneuronal stimulation in response to reduced muscle contractility (rate coding), slowing of muscle membrane potential conduction rates or an increase in synchronization of recruited motor unit activation. This author also noted that the recovery of the EMG upon cessation of an exertion has been shown to be rapid, especially when the levels of fatigue are small. Oberg (1994) analyzed the EMG signal, with respect to RMS amplitude, of subjects who performed two contractions of the right trapezius muscle by raising the right arm 90 degrees of abduction with a 0 kg load for five minutes and a 2 kg load for 2 to 5 minutes. There was a statistically significant increase in RMS with increased load dose, as well as an increase in subjective fatigue scores. However, the authors failed to relate these to a percent MVC that makes the comparison more difficult. In the case of a typing task involving dynamic contractions of the forearm muscles, a force production of about 20 to 30 percent MVC would be expected

(McLean, 1998). The muscles of the neck, shoulders, upper arm and trunk perform primarily static contractions while typing at a computer.

EMG and Muscle Fatigue

Fatigue and discomfort can occur whenever stress is placed on the body over extended periods of time or when many repetitions of the same movement are performed. Any deformation of body tissue when subjected to excessive force or mechanical stress may result in tissue deformation and may interfere with basic physiologic processes and result in mechanical failure. McLean et al. (1997) defines muscle fatigue as a momentary inability of a muscle to maintain the production of a particular force or power output due to previous activity within the same muscle. Fatigue is a multi-factorial process that depends upon the duration and intensity of contraction, the form of contraction, the muscle fiber type recruited, environmental conditions, and the capacity of the individual.

In muscular exertions, fatigue may occur at the local level and is known as localized muscle fatigue (LMF). Chaffin (1973) proposed the use of the term LMF to describe fatigue experienced in regional muscles in response to postural or focused exertion stress. If the working muscle is not adequately perfused, then noxious catabolites begin to concentrate, adenosine triphosphate (ATP) stores will decrease, tissue pH levels decrease while muscle enzyme behaviour and electrolyte concentration changes may occur (Wiker et al., 1989). The above mentioned factors are proposed as bases for reduced muscle excitability, reduced force production, and for the onset of signs and symptoms of LMF (Wiker et al., 1989). Some visible symptoms of LMF include loss of force production capabilities, localized discomfort and pain (NIOSH, 1992).

Another type of muscular fatigue is "central" fatigue. Central fatigue affects an individual as a whole and involves a reduced motor drive resulting in a failure to maintain a given level of muscle activation (McLean, 1998). An individual's response to "central fatigue" will vary, due to factors such as an individual's level of attention, attitude and motivation.

In order for a muscle to contract, a nerve impulse must travel along a motor nerve to a motor neuron end plate in the muscle fiber. An action potential is then initiated in that muscle fiber from the secretion of a neurotransmitter (acetylcholine). The action potential will travel along until it reaches the sarcoplasmic reticulum in the muscle fiber and release calcium ions (Ca^+) into the myofibril. According to Huxley's cross bridge theory, the release of Ca^+ increases the attraction of the actin and myosin filaments creating a sliding action of one filament over the other. The Ca^+ is then actively pumped back into the sarcoplasmic reticulum with the help of ATP. Even though nerve impulses continue to travel to the muscle fiber, muscular performance can be impaired through a change in Ca^+ distribution and the activity of the myofilaments causing fatigue. Neural fatigue can occur when an action potential fails to cross from the motor neuron to the muscle fiber at the neuromuscular junction.

The Rohmert curve (Chaffin and Andersson, 1991) (Figure 5) describes the time it takes for a muscle to fatigue based on the level of contraction or percent MVC. According to Rohmert's curve, muscle contractions below 15% MVC can be held indefinitely, without any effect of fatigue. There are however, studies that have found both subjective and objective signs of fatigue, including an increase in EMG amplitude, for muscle contractions below 15% MVC (Schuldt et al., 1986; Jorgensen et al., 1988). Various methods of processing EMG data have been used in the literature to measure fatigue. This makes it difficult to quantify the state of muscular fatigue using EMG. Therefore, it becomes difficult to assess the validity and reliability of methods used to measure fatigue.

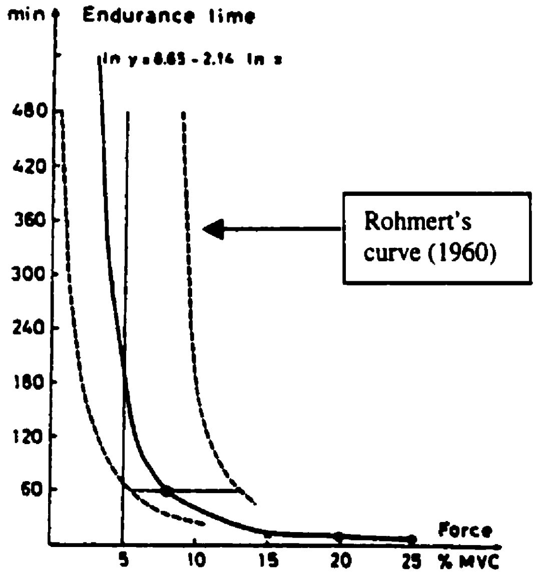


Figure 5: The relationship between muscle effort and maximum holding time.
(Adapted from The Occupational Ergonomics Handbook, 1999)

Traditionally, EMG has been used to identify localized muscle fatigue by studying the changes in the power density spectrum. Kadefors et al. (1968) found that EMG indicators of fatigue become unreliable when exertions are less than 10% MVC. Jorgensen et al. (1988) found a significant decrease in the mean frequency of the power spectrum in the triceps at

7% MVC, however, the biceps did not change under the same conditions. Therefore, the use of EMG power spectrum analysis has not been well established for muscular fatigue that occurs at low levels of muscular contractions. It should be noted that changes in muscle lengths or tensions occurring with subtle postural shifting, could have a significant impact upon EMG records.

Westgaard and Winkel (1996) summarized the guidelines used for measuring mechanical exposure in the shoulder-neck region from widely cited textbooks. Of the four books cited by them, two used fatigue as a guideline for physical exposure, Grandjean (1988), and Ayoub and Mital (1989). Fatigue was measured using O_2 consumption, heart rate, observation (i.e. posture), and other physiological variables. A study conducted by Pan and Schleifer (1996) also used fatigue, along with discomfort, to explore the relationship between biomechanical factors and right arm musculoskeletal discomfort and fatigue during a video display terminal (VDT) data entry task. Fatigue was measured using self-ratings and the authors found a positive correlation between the self-reports of fatigue and the self-reports of musculoskeletal discomfort. It should be noted, that some individuals might have had difficulty differentiating between fatigue and discomfort thereby giving them the same score.

A study conducted by Moore, Wells and Ranney (1991) examined methods of describing musculoskeletal loads in the hand and wrist during manual tasks. The authors summarized four major musculoskeletal disorders and their injury mechanisms. Several authors believe fatigue and overuse are the main injury mechanisms for chronic muscle strain

(Jonsson, 1988; Westgaard 1988; Aaras 1987; Sjogaard 1986; Johnsson 1982; Simons 1976; Hagberg 1981). McLean et al. (1997) used EMG to measure muscle fatigue during prolonged computer work. The authors believe that muscular fatigue is a potential risk factor in the development of MSD. Theoretically, for activities requiring less than 5% MVC, the reduction in force output would be due to the central fatigue process (McLean, 1998).

EMG, Force and Fatigue

An increase in muscle force is generated by the central nervous system by either increasing the recruitment of motor units, or by increasing the firing frequency of motor units. Therefore, the amplitude of the myoelectric signal is dependent on the level of activation, whereby high amplitude is attributed to a large contraction (Jonsson and Hagberg, 1974). However, the amplitude also increases with the duration of an isometric contraction and has been suggested to reflect the fatigue processes of muscles (McLean, Ph.D. 1997). The relationship between EMG, fatigue and force is not easily distinguishable at low levels of muscular contractions.

Therefore, this thesis has examined both the level of muscular activity and how this level of activity changes in various working postures.

EMG and Posture

Studies have shown that workstation design does affect working postures and therefore muscular activity. Black and Rickards (1997) found that the trapezius EMG activity decreases with lower keyboard placement and with arm-hand support, representing a neutral working posture. During mouse use, Wells et al. (1997), found the highest level of muscle activation in the trapezius when working without arm support while the highest level of muscle activation in the forearm extensors and flexors resulted when subjects leaned on their wrists. Harvey and Peper (1997) found a significant increase in muscle activation in the upper back, shoulders and arm with the mouse positioned to the right of a keyboard as opposed to a track ball located in the center of the keyboard. The authors also noted that even the best "ergonomically" designed workstation is insufficient to prevent injuries if workers are unaware that they are tensing their muscles.

Schuldt et al. (1986) examined at the level of muscular activity in the neck, shoulders and spine while subjects performed a task in various seated postures. A more significant increase in muscular activity was observed in the flexed seated posture than the straight vertical posture, while the straight vertical posture demonstrated a more significant increase in muscular activity than the backward inclined posture. Another study, conducted by Hansson et al. (1992), noted a significant increase in the level of muscular activity in the neck and shoulders for a seated endurance task. Hansson et al. (1992) results showed a marked increase in RMS amplitude for the trapezius muscle while the deltoid RMS curves remained constant. The authors explained the increase in RMS curves of the trapezius to be due to the recruitment of new motor units during the endurance task in order to stabilize the shoulder joint. The strain on the trapezius increased even though the net moment at the shoulder remained constant. The increase in RMS curve has been hypothesized to be a neuromuscular reaction to LMF rather than a primary sign of fatigue (Hansson et al., 1992).

To summarize the above review, at low levels of muscular contraction over a long period of time, the use of EMG to measure fatigue has resulted in conflicting data. The use of the EMG power spectrum to measure fatigue at a low percentage of MVC has not been well established. Studies are however, showing consistent data when using the level of muscular activity to assess various seated working postures and tasks. Therefore, the object of the thesis looks at the level of muscular activity, or the amplitude of the signal (RMS), across various seated working postures.

Heart Rate Response

The heart rate (HR) reflects the amount of work that the heart must do in order to meet the increased demands placed on the body when engaged in an activity (Wilmore, Costill, 1994). More specifically, it represents the cardiovascular response of the body. An average resting heart rate (RHR) ranges between 60 to 80 beats per minute. It is difficult to measure an individual's true RHR prior to testing due to an anticipatory response, which raises the HR through the release of the neurotransmitters, norepinephrine and epinephrine. Therefore, the RHR that was used as a baseline measure in this thesis is in fact an anticipatory HR, which may be higher than the subject's true RHR.

A sedentary individual with a RHR of 80 beats per minute can lower their RHR with moderate endurance training. This training effect can in fact lower a person's RHR by 1 beat per minute per week for the first few weeks of training (Wilmore, Costill, 1994). In the case of computer work, one would not expect to see a training effect from computer work alone when working at a specific posture over time. However, if the subject is "learning" a skill, either a new working posture or work task, then we might expect a reduction in RHR response over time as the subject becomes familiar with the posture or task. Other extraneous variables such as personal stress or caffeine would have more profound effects on HR at rest and during work.

When objectively measuring the subject's physiological responses to various working postures, the object of the thesis is in fact looking at the steady state heart rate (SSHR). The SSHR is the optimal HR for meeting the circulatory demands of the body at that specific rate of work (Wilmore, Costill, 1994). If the rate of work is held constant at a sub maximal level of activity, the HR will increase fairly rapidly until it reaches a plateau. This occurs within 1 to 2 minutes (Wilmore, Costill, 1994). In general, a person's subjective experience of a paricular workload is more closely related to heart rate than it is to oxygen uptake since, heart rate (work pulse), as well as actual work load, also reflects emotional factors, heat, and the size of the activated muscles (Rodahl, 1989).

According to work done by Schleifer and Ley (1994), HR increases as a result of physical activity and stress. When a stressful situation unfolds, the body's "fight or flight" response is triggered during which time hormones (catecholamines and cortisol) are released into the bloodstream. The body responds to these hormones with an increase in muscle tension, heart rate, blood pressure and respiration. Therefore the increased demands of the body may be due to stress and not solely physical activity. Schleifer and Ley have also found that even light activity, such as keyboarding, can significantly alter HR and HR variability. A significant increase in HR from relaxation to a data-entry task was observed. The authors also found a significant increase in HR from morning testing to afternoon testing denoting a time of day effect.

A study by Schreinicke et al. (1990) examined 77 healthy subjects who each performed a 30-minute computer task, which required high speed and accuracy. Blood pressure, heart rate and respiratory rate were recorded continuously during the computer work and at rest. The results demonstrated a significant increase in HR, blood pressure and respiratory rate from rest to computer work. The greatest increase was found in the systolic blood pressure as opposed to the diastolic blood pressure, HR and respiratory rate. According to these authors, the stress reactions, as seen with increased HR, blood pressure and respiratory rate, seem to be linked with psychosocial stressors of the job and not necessarily the activity of keyboarding itself.

Mathiassen (1993) assessed seven protocols of exercise/rest schedules for a one hour neck and shoulder exercise at 14 to 18% MVC. The results demonstrated a significant increase in heart rates during all exercise protocols. Five minutes after each exercise protocol heart rate recovered to below pre-exercise value and RHR was reached.

Some authors have found that during simulated repetitive work there is a decrease in heart rate (Floru et al. 1985; Laville 1965). These findings may be due to the fact that the RHR was initially elevated due to an anticipatory response, while during testing the subjects relaxed and became more comfortable with their surroundings. In summary, HR represents how hard the cardiovascular system must work in order to meet both physical and psychosocial demands. According to the literature cited here, heart rate as a physiological measure, can show conflicting results. However, in studies related to computer work, heart rate as a measure was successful even during light work such as keyboarding.

Blood Pressure

Blood pressure is the result of pressure generated from the heart as it contracts and forces blood to flow through the vascular system and is maintained by the elastic properties of the arteries. The systolic blood pressure (SP) reading represents the maximum pressure reached during peak ventricular ejection while the diastolic blood (DP) pressure reading represents the minimum pressure which occurs just before ventricular ejection begins (Vander, Sherman, Luciano, 1990). The mean arterial pressure (MAP) represents the pressure driving the blood into the tissues averaged over the entire cardiac cycle. This value is calculated by $MAP = DP + 1/3\,(SP - DP)$. The average male's systolic pressure is 100 plus their age, but does not exceed 150 mmHg while the average diastolic ranges between 60 to 90 mmHg (Hafen, Karren, Mistovich, 1996). The average female's systolic pressure is 90 plus their age, but does not exceed 140 mmHg while the average diastolic ranges between 50 to 80 mmHg (Hafen, Karren, Mistovich, 1996). During mild exercise, the SP increases by 50% while the DP will not increase (Vander, Sherman, Luciano, 1990).

Blood pressure measurements taken in a clinical environment are subject to both physiological variation and error. The reasons for variations and error may include the incorrect cuff size, improper inflation or deflation techniques and patient apprehension known as the white-coat syndrome. Mion and Pierin (1998) studied the accuracy and reliability of mercury and aneroid sphygmomanometers. The aneroid sphygmomanometers studied were found to have an error range from 4 to 13 mmHg, where 32% of those tested fell in an error range of 4 to 6 mmHg. Another study, conducted by Stolt et al. (1993), examined the validity of the standard blood pressure cuff. These authors found that on average the cuff significantly underestimated the systolic blood pressure by 3.2 +/- 11.4 mmHg, while the diastolic blood pressure was significantly overestimated by 8.8 +/- 8.5 mmHg (Stolt et al., 1993).

The study by Schreinicke et al. (1990), described above under Heart Rate, demonstrates that blood pressure, especially systolic blood pressure, increases significantly from rest to computer work and is a measure of increased physical activity and stress. Mathiassen (1993) studied seven protocols of exercise/rest schedules for a one hour neck and shoulder exercise at 14 to 18% MVC. The results demonstrated a significant increase in MAP for all the exercise protocols. Five minutes after each exercise protocol the blood pressure did not return to resting levels. According to the literature cited, blood pressure is a useful indicator of physiological load and psychosocial stress even at low levels of muscular contractions.

Perceived Discomfort

Discomfort is a difficult term to define since it possesses both objective and subjective components. Bridger (1995) describes discomfort as resulting in an "urge to move" caused by a number of physical and physiological factors. The Concise Oxford Dictionary (1982) defines discomfort as an uneasiness of body or mind. The authors Corlett and Bishop (1976) believe that an individual's level of discomfort has been an indicator of the inadequacies of the match between the person and their work. The perceptions of postural pain were related to discomfort and would be linearly related to the time of exposure to risk factors (Corlett, Bishop, 1976).

In a study conducted by Vasseljen and Westgaard (1995), involving assembly line workers and office workers, consistent associations between pain and signs of increased muscle activation was found in the upper trapezius for assembly line workers, however, there was no association within office workers. Another study conducted by Hagberg and Sundelin (1986) looked at discomfort and load on the upper trapezius muscle while working at the computer for five hours of continuous work, for three hours of continuous work, and for three hours of intermittent work. These authors reported a significant increase in discomfort among all working conditions, with the greatest increase in the first condition (five hours) and with the least increase in the third condition (intermittent three hours). There was no significant difference in the level of muscular activity in the trapezius for the three conditions. Mathiassen (1993) also found a significant increase in self reported ratings of fatigue in the neck and shoulders over one hour of neck and shoulder exercises.

Hagg, Oster and Bystrom (1997) looked at two groups of automobile assembly line workers, one with low prevalence of self-reported forearm/hand symptoms (LPS) and the other with high prevalence of self-reported forearm/hand symptoms (HPS). Upon studying their workstations, the authors found ulnar deviation to be more frequent with HPS while a more neutral or radial deviated wrist postures were more frequent among LPS. These authors were able to correlate wrist deviation or posture to the self reported symptoms.

Wells, Lee and Bao (1997) studied the EMG signals of the upper limb during mouse use with various arm supports; elbow support, forearm support, no support and resting on the wrist. Every half hour, a body discomfort survey (BDS) was administered during a 3-hour game-playing task. The highest level of discomfort was reported in those conditions without any arm support while the lowest level of discomfort was reported in the condition with elbow support. These authors were able to relate arm support conditions, which in fact results in the level of effort or force required, to self-reported discomfort.

Subjects who performed a seated handling task were asked to report discomfort based on Corlett and Bishops (1976) body discomfort map to see how frequency, posture and task duration affected localized musculoskeletal discomfort (Kruizinga et al., 1998). The authors found significant back, neck and shoulder discomfort. This discomfort was explained as being due to a static load generated work tasks demanding continuous arm movements. Trunk inclination and handling frequency also played a major role in developing discomfort. To summarize, studies have shown a relationship between self reports of discomfort and the level of muscle activation and load.

Job Satisfaction

Job satisfaction can be defined as the pleasurable or positive emotional state resulting from the appraisal of one's job or job experience (Locke, 1976). Locke (1976) stated that job satisfaction results when the perception of the job fulfills one's important job values, providing that those values are congruent with one's needs. Typically, an individual will base their job satisfaction on both past and present work experiences. Hocking (1987) stated that studies conducted by Ryan et al. (1985) and Graham (1985) found job satisfaction correlated with the presence of MSD better than the ergonomic variables in their study. Smith (1997) demonstrated that highly monotonous computer work was associated with an increase in psychosomatic complaints and a decrease in job satisfaction. The authors Floru, Cail and Elias (1985) found that monotony, boredom, dissatisfaction and lack of control over the workplace were common job stressors reported by operators. Job satisfaction has been shown in the literature to affect reports of body discomfort (Norman et al., 1998; Smith, 1997; Hales et al., 1993).

Therefore, the object of the thesis examined the relationship between job attitude scores, (specific job satisfaction, general job satisfaction, work motivation and job involvement) and BDS scores at the workplace.

Environmental Factors

In order to control for internal validity and reliability among testing days, environmental factors must be manipulated within acceptable limits. Temperature has been shown to have a significant effect on the EMG amplitude. A study conducted by Winkel and Jorgensen (1991) found that by cooling the superficial tissues from a mean skin temperature of 32.9°C to 21.7°C (ambient temperatures of 30°C to 14°C) the EMG amplitude of the soleus muscle doubled. Heat can also affect physiological measures by increasing blood lactate levels and heart rate (Bridger, 1995).

Noise has been found to be a stressor, which can elevate heart rate and reduce cardiac efficiency (Bridger, 1995). The maximum noise levels recommended to avoid annoyance for administrative work and private office should not exceed 55 dB (Dul and Weerdmeester, 1993).

Chapter Three: Methodology

This chapter will illustrate the research design, subjects, instrumentation, procedures and analysis employed in this thesis. The following is a detailed description of the methods and procedures used for data collection.

Research Design

The study is quasi-experimental with a randomized block design. There were three levels of the independent variable (treatment), and each subject acted as their own control. These levels of treatment were randomized into six conditions as shown in Table 2 to help control for external validity (multiple-treatment interference).

Table 2: Randomized block design

Group	Conditions and Order of Presentation Working Postures			# of Subjects
A	1	2	3	3
B	1	3	2	4
C	2	1	3	3
D	2	3	1	5
E	3	1	2	2
F	3	2	1	3

Subjects were randomly assigned to one of six test groups. Assuming that each group was identical at the beginning of the study, this randomization should have improved the internal validity of the study, for example factors such as past history, maturation, and testing (Thomas and Nelson, 1990). This study design allowed for one-day of testing for each subject and was chosen to decrease the chances of subject "mortality". The one-day of testing also eliminated the effects of between day trial reliability and equipment reliability. Since every subject participated in all conditions, subjects served as their own control.

The dependent variables were categorized as physiological (3) and psychophysiological (1) responses. The three physiological measurements were EMG (RMS), heart rate, and blood pressure (systolic and diastolic). The psychophysiological measure was self-reports of perceived discomfort. Blood pressure and perceived discomfort scores were measured pre- and post-testing while the heart rate response and EMG were monitored continuously throughout the testing protocol. In order to control for threats to the internal validity, extraneous variables such as previous injury, environmental factors, and food and liquid intake were controlled to eliminate other possible explanations for the testing outcomes. Therefore any changes in the physiological and psychophysiological responses (effect) could be attributed to the changes in working posture (cause).

Subjects

Twenty subjects were recruited from various companies and had been working at jobs that required at least three hours of computer work per day over the past two years. The inclusion criteria required that subjects had no known MSD of the trunk and upper extremities, no known cardiovascular disease, were non-smokers, were not heavy caffeine drinkers and were not pregnant.

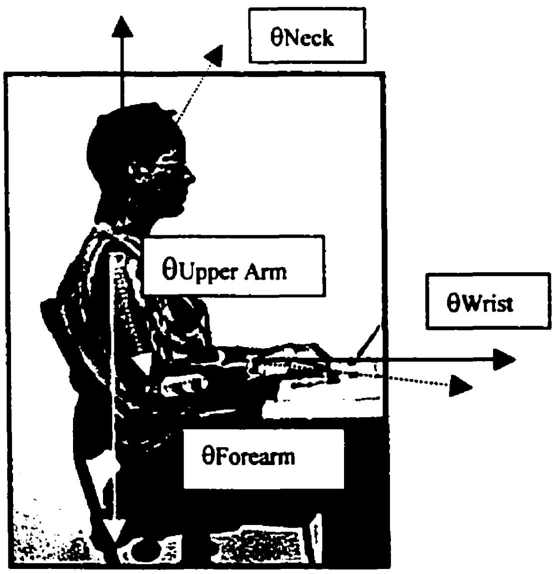
The purpose and procedures of the study were explained to each subject prior to testing and they were each given the opportunity to ask questions at any time prior to or during the testing. All subjects provided a document of informed consent (Appendix A). The procedures and consent form were approved by the Human Ethics Committee at Dalhousie University. The researcher ensured that their rights and well being were maintained throughout the entire process. These rights included the right to withdraw from the consent or participation in the study at any time, the right to privacy, the right to remain anonymous, the right to confidentiality, and the right to expect researcher responsibility (Thomas and Nelson, 1990).

Instrumentation

The equipment utilized, the equipment set up, as well as the equipment reliability, for the collection of kinematic data, EMG, heart rate, blood pressure, perceived discomfort, and job attitudes are described as follows.

Kinematic Data

The sagittal plane view of the right side of the subject's body was video recorded at 30 Hz using a VHS Hitachi model VM 2400A Video Camera while each subject performed a computer task in various working postures. A mirror was positioned within the camera's field of view and reflected a plan view of the keyboard, mouse, and the subjects' wrists. Using a quasi-random sampling technique, 3 one-second samples were randomly collected within 6 pre-determined five minute intervals. Therefore a total of 18 one-second samples of kinematic data were taken over each thirty minute testing period. For each one-second sample, one frame was digitized and the mean joint angle value calculated for each joint over the 18 samples.



Each angle is measured from the solid line to the broken line for a positive direction.

Figure 6: Definition of measurement parameters for kinematic data.

Reflective markers were placed on the right side of the subjects' body to help define the anatomical landmarks. The anatomical landmarks included: the outer canthus of the eye and the tragus (ear-eye line of sight); the spinous process of the C7 (neck); acromion (shoulder); lateral condyle of the humerus (elbow); styloid process of the ulna (wrist); and the distal end of the fifth metacarpal (hand). In McAtamney and Corlett's (1993) paper, the authors did not define their anatomical landmarks used to measure the joint angles. Therefore, this study used the most common landmarks for the neck, shoulder, elbow and wrist found in the literature (Bhathager and Dury, 1985; Burgess-Limerick et al., 1998; Liao and Drury, 2000; Ortiz et al., 1997; Sauter and Schleifer, 1991). The sampled VHS clips were converted to audio-visual interweaved (AVI) files using Adobe Premier 5.1. Each sampled frame was digitized using the computer software Human Movement Analysis Program (Hu-M-An) Version 2.0, operating on an IBM compatible computer. The Hu-M-An program measured the joint angles based on criteria different from RULA. The RULA, and this thesis, joint angle definitions can be seen above in Figure 6.

The equipment used for the video analysis consisted of a VHS Hitachi VM 2400A camera, tripod, level, masking tape, two plum lines, seven joint markers, linear scale and a trial recorder. Due to the size of laboratory, the camera was positioned 6.7 meters (22 feet) from the plane of motion. Using a level the camera was aligned in the fore-aft and side to side directions. Two plum lines along the centre line perpendicular to the plane of motion were positioned approximately two feet apart to ensure that the camera was centered on the subject. A linear scale was filmed twice within the subject plane, pre- and post-testing.

Laboratory chair and work surface

The chair and work surface, donated by Ergoworks ® for the purpose of this thesis, had the desired specifications and adjustments in order to manipulate each subject's working postures. The chair adjustments included: pneumatic height range, backrest height and tilt adjustment as well as a seat pan angle adjustment. There were no armrests on the chair. The workstation consisted of two separate height adjustable surfaces, the monitor work surface and the keyboard and mouse work surface. The various working conditions were set up based on the three working postures seen in Figure 7. For postures one and two, the home row keys of the keyboard and the monitor were aligned with the midline of the subject's body. For posture three, the midline of the subject's body was centered on the keyboard. By centering each subject on the keyboard, this forced the subjects to position their hands laterally to the left of their midline, in order to operate the home row keys. Attached to the monitor was a copyholder, which was utilized for both postures one and two, but not for posture three. Reference material was positioned flat on the work surface to the right of the keyboard for posture three. The heights, angles and locations of the work surfaces and accessories defined the envelope of body postures attainable by the subjects.

Once the chair and workstation were adjusted, a manual goniometer was used to measure the each subject's joint angles in a static posture. These joint angle measurements were used to confirm the workstation set up based on RULA's postural scoring as seen in Figure 7.

Posture One	
θNeck	0 – 10 degrees
θShoulder	0 – 20
θElbow	60 – 100
θWrist	0

Posture Two	
θNeck	10 – 20 degrees
θShoulder	20 – 45
θElbow	100+ or <60
θWrist	+/- 15

Posture Three	
θNeck	20+ degrees & twisted
θShoulder	45 - 90
θElbow	100+ or <60 & across midline
θWrist	> +/- 15

Figure 7: Definition of testing parameters for working postures.

Electromyography (EMG)

In order to record muscle activity two surface electrodes were positioned on the trapezius pars descendens (upper trapezius), deltoideus pars acromialis (anterior deltoid), biceps brachii and extensor digitorum communis (forearm extensors). The descending part of the trapezius is activated during shoulder flexion, abduction, elevation, and retraction. The trapezius muscle is also a mover of the head. Although it may play a minor part in head movement, the trapezius is the most superficial muscle and therefore is easiest to palpate relative to other head movers. The deltoideus pars clavicularis was used to measure the effort of the arm since it shows an increase in activity during forward flexion (Jonsson and Hagberg, 1974). This muscle is superficial and easy to palpate. The biceps brachii is activated when flexing the elbow (NIOSH, 1992). The forearm extensors are activated when performing wrist extension.

The skin surfaces of the four muscle sites were prepared by cleaning the area with alcohol swabs, and for some subjects the area was shaved. The electrode sites were then marked on the skin and all electrode placements were made using these references. The electrodes were positioned unilaterally, 2 cm apart, on the subjects' right side. The landmarking for each muscle group is detailed below. A reference electrode was placed on the medial epicondyle of the elbow.

Upper Trapezius (U Trap) - along the line of axis between the C7 and acromion, 2cm laterally from the midpoint (Jensen et al., 1996).

Anterior Deltoid (A Delt) - along the line of axis between the acromion and suprasternal notch, one fifth medially from the acromion and one fifth distally from this point along the line of axis to the lateral epicondyle of the humerus (NIOSH, 1992).

Biceps Brachii (Bic Bra) - along the line of axis between the acromion and the tendon of the biceps muscle in the cubital fossa, one third from the cubital fossa (NIOSH, 1992).

Forearm Extensors (For Ext) - along the line of axis between lateral epicondyle of humerus to the styloid process of the ulna, one-fourth from the olecranon; the subjects were asked to flex and extend their index finger to ensure landmarking of the extensors and not the brachialis (NIOSH, 1992).

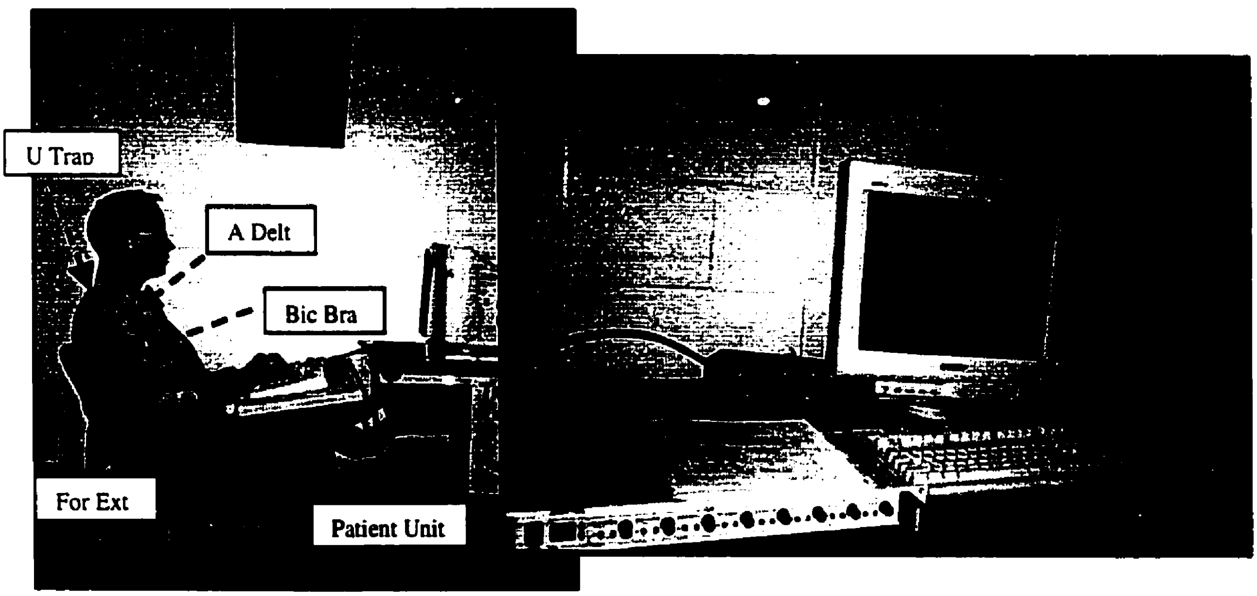


Figure 8: Location of surface electrodes and EMG data recording system.

EMG Apparatus

The electrodes were attached to an eight channel AMT-8 EMG Bortec system which uses a patient unit. The APE 100 Patient Unit was then attached to the receiving unit. The technical specifications of the unit include a frequency response of 10 Hz to 1000 Hz flat for each channel with an input impedance of 10 Gohm. There is a variable gain from 100 to 10,000 times and a common mode rejection ratio (CMRR) of 115 dB. The four analog channels were attached to the A/D converter for recording (Figure 8). For each time interval, the signal was sampled at a sampling rate of 1024 Hz for a one-second period.

A total of six one-second samples were collected for the duration of the half hour testing period. Using a quasi-random sampling technique, each one-second sample was randomly collected within 6 pre-determined, five-minute intervals using Labview software. Computer software was generated within Labview to calculate the sample time by randomly choosing a number from 2 to 4, plus or minus one. This quasi-random sampling technique was utilized to ensure that each subject would have an equal number of samples collected for every five minutes tested. For example, if some subjects were only capable of completing 20 minutes of testing, while the others completed the entire 30 minutes, each subject would have at least 20 minutes of data. Therefore, each subject would have at least four one-second samples of raw EMG for analysis.

For each one-second sample, a total of 1024 raw EMG data points were collected. Over each 30-minute testing period, six one-second samples were recorded and collected within one Labview file, yielding a total of 6144 raw EMG data points. The raw EMG data were corrected for bias within a Microsoft Excel spreadsheet for further data processing. The RMS values were calculated for each of the six, one-second samples (1024 raw data). These six RMS values were then averaged to yield a mean RMS value for each muscle tested. The mean RMS values were then corrected for gain and the final mean RMS values in millivolts were used for statistical analysis.

Normalization

A reference voluntary contraction (RVC) was performed for each muscle group in order to normalize the EMG data. This normalization was required as a means of comparing the EMG levels among the subjects as a percent of the reference contraction. A standard reference position was used for all trials. The RVC was comprised of the average of three maximal isometric contractions, in the standard position, for each muscle group on the subject's right side. This contraction may or may not be an actual maximal contraction for each of the muscle groups tested. The RVC was defined by the following:

Upper Trapezius – with a straight right arm hanging by the side of their body, the subject was asked to elevate their right shoulder (shoulder shrug).

Anterior Deltoid – with the right arm flexed posteriorly and at 90 degrees from the trunk, the subject was asked to flex at the shoulder.

Biceps Brachii – with the right elbow in 90-degree flexion and the hand in pronation, the subject was asked to flex at the elbow.

Forearm Extensor - with the right wrist straight and the hand in pronation, the subject was asked to extend at the wrist.

There is a quantitative relationship, during isometric contractions at one joint position, between EMG signal amplitude and the level of muscle force, however this relationship is non-linear. The amplitude is relative and it must be related to some kind of reference contraction (Oberg, 1995). A maximum voluntary contraction (MVC) often results in an overestimation of the force produced. Therefore the procedure of normalization is improved when the level of reference activity is close to the activity under investigation (NIOSH, 1992).

Heart Rate

The subjects' heart rate was recorded every five seconds over each 30-minute testing period using a Polar Vantage XL ® Heart Rate Monitor (Figure 9). This portable heart rate monitor consisted of a wrist monitor, sensor/transmitter, and chest band. The Polar Vantage XL ® Heart Rate Monitor has been found to be the most accurate and sophisticated exercise performance monitor available (Wolf, 1989). It has been shown to be valid and reliable to within +/- 6 beats per minute 90% of the time at rest, 95% of the time during exercise and 97% of the time during recovery (Godsen, R., Carroll, T., Stone, S., 1991).

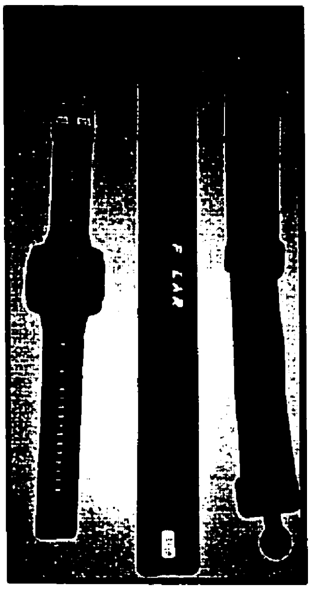


Figure 9: Polar Vantage XL ® Heart Rate Monitor

The Polar Vantage XL ® Heart Rate Monitor recorded a total of 360 heart rate values for each subject over each 30-minute testing period. These values were then downloaded into an Excel spreadsheet for the calculation of the mean and standard deviation for each testing condition. The mean heart rate value was used for statistical analysis.

Blood Pressure

Each subject's blood pressure was measured using the Klock® Automated blood pressure wrist cuff (Figure 10) by IEM (Industrielle Entwicklung Medizintechnik), a German company. The Klock® Automated blood pressure wrist cuff satisfied the CE 0434 European regulations which are based on the Medical Devices Directive (MDD). This device had been calibrated by the manufacturer in 1999 and is valid for two years. The reliability for this wrist cuff was +/- 3 mmHg for a systolic blood pressure range of 70 to 260 mmHg and a diastolic blood pressure range of 45 to 180 mmHg. The manufacturer noted that heavy arteriosclerosis and other circulatory problems such as spasms in the lower arm may result in erroneous readings. The inclusion criteria for subject recruitment eliminated any possible erroneous readings due to circulatory problems.

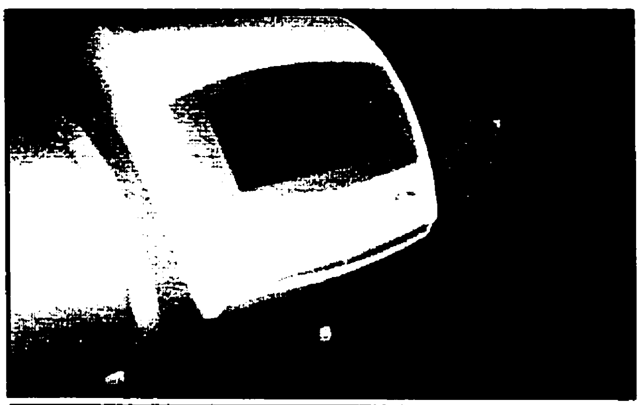


Figure 10: Klock® Automated blood pressure wrist cuff

For each treatment condition a pre- and post-blood pressure measure was collected. To control for accuracy and reliability among various blood pressure cuffs, the same Klock® wrist cuff was be used throughout the data collection period. To improve accuracy of the reading, the same measurement protocol was followed for every subject. This protocol asked that the subjects place the wrist cuff on their left wrist, remain seated in a relaxed position with both feet flat on the floor. The subject held their wrist at the same height as their heart and did not speak. If there were any "error" readings, a second blood pressure measurement was taken after 3 minutes. Only one blood pressure reading was taken for each pre- and post-testing condition, unless an "error" reading occurred, to ensure that the reading was reflective of the condition measured.

Perceived Discomfort

A postural discomfort assessment survey was developed to measure the subject's perceived discomfort, both global (total) and localized. The body discomfort survey (BDS) (Appendix B) was modified from the method developed by Corlett and Bishop (1976) by including the addition of the left and right sides of the body. Subjects were asked to rate their perceived level of discomfort based on a Likert scale of 0 to 7, where 0 represented no discomfort and 7 represented extreme discomfort. Discomfort was described to subjects as any sensation of discomfort experienced, which may include pain, tingling, limited range of motion, weakness, and "pins and needles".

Levels of perceived discomfort were collected for every pre- and post-testing condition. The pre- and post-testing discomfort scores for the neck, shoulder, upper arm, forearm/elbow, and wrist/hand were entered into an Excel spreadsheet. The difference between the post score and the pre score was calculated for all body parts mentioned above. The delta perceived discomfort scores were then summed to yield a total delta body discomfort score. The total delta body discomfort score was used for statistical analysis.

Job Attitudes

A job attitude questionnaire (JDS Scales) (Appendix C) was administered to all subjects at their workplace, one day prior to the testing sessions. Subjects were asked to complete the questionnaire while working at their workstation around mid morning. The Job Attitude Questionnaire used a Likert scale and measured four factors: specific job satisfaction, general job satisfaction, job involvement, and work motivation. The subjects were ranked based on a total Job Attitude score that was calculated from the sum of each factor score.

Performance (word count)

The subject's performance was evaluated over the testing period by using the word count feature on the word processing software to determine the total number of words entered in 30 minutes. The total number of words typed were tabulated at the end of each 30-minute testing condition and was used for statistical analysis.

Procedures

The research study presented here, required each subject to participate in a one-day data collection session which included all three working postures (Figure 7). Prior to the day of testing, each subject met with the tester to familiarize themselves with the laboratory and the testing equipment. At this time, each subject's anthropometric data were collected and he/she was informed of the study's methods and procedures and was asked to sign an informed consent form (Appendix A). This helped to reduce subject anxiety and was intended to improve the heart rate and blood pressure reliability. Since there was only one tester and one day of testing for each subject, the variability in electrode placement between days and the inter-tester reliability concerns were eliminated. Therefore, instrumentation validity was improved upon.

Preliminary Instructions for Subjects

The subjects wore a loose fitting short sleeved shirt for ease of electrode placement. Subjects were asked to refrain from food or drink two hours prior to testing. However, water was acceptable and provided upon request. Subjects were also asked to avoid exercise six hours prior to testing.

Data Collection

Anthropometric data were collected on standing stature, standing shoulder, standing elbow, seated eye, seated shoulder, and seated elbow height (Table 3). For the standing measurements, each subject wore their preferred, typical pair of work shoes. For the seated measurements, the subject's chair was adjusted such that their knees were at a 90-degree angle with both feet supported flat on the floor. While monitoring their heart rate, subjects were asked to fill out a questionnaire to determine whether they had satisfied the inclusion criteria and followed the preliminary instructions. The subject's resting heart rate (RHR) was recorded for five minutes using the Polar Heart Rate Monitor while seated. Resting blood pressure (RBP) was also collected after five minutes in a relaxed, seated posture.

Surface electrodes were applied to the muscle bellies of the upper trapezius, anterior deltoid, biceps brachii, and forearm extensors using a bipolar configuration. While seated at the workstation, the subjects then performed three reference contractions for each muscle group. These contractions were later averaged and the mean value used for the RVC. The workstation was then adjusted according to the testing condition. Each subject then completed a Body Discomfort Survey (preBDS), and his/her heart rate (preHR) and blood pressure (preBP) were measured.

Subjects were instructed to remain seated throughout the testing period while keeping their back against the chair's backrest. The laboratory floor was marked for the appropriate chair position so that subjects would not move their chair. The video camera began recording and subjects began the first thirty-minute testing condition. During the testing, subjects were video recorded while muscle activity was quasi-randomly sampled at 1024 Hz for 6, one-second samples. Blood pressure was collected (post BP) immediately after the thirty minute testing period as well as after the completion of a Body Discomfort Survey (postBDS).

Subjects were given a 30 minute rest period at which time they were able to read a book quietly.

The workstation was re-adjusted for the second testing condition. After the rest period a preBDS, and preBP were recorded. Subjects began the second thirty minute testing condition and the above mentioned steps repeated until the completion of the third testing condition. The reference material was standardized for each testing condition.

Data Analysis

The kinematic data were examined initially to ensure that each subject's joint angle results were congruent with the pre-determined RULA postural scoring (Figure 7) for each of the three working postures. The subject's digitized, mean joint angle was used to calculate the RULA score for that particular posture (Appendix D). It was determined that the study's landmarks for the neck angle were too stringent. According to the landmarks, several subjects' digitized neck angles were measured outside of the posture one condition. RULA does not define its anatomical landmarks for measuring joint angles and a visual assessment is used in the occupational application of this tool. Therefore, a visual assessment was used for these subjects' neck position. The visual assessment placed the neck angles into the postural scoring condition for posture one of RULA. The digitized neck angle was then re-calculated. For each subject, three angles were collected based on a visual representation of the neutral (posture 1) angle. The digitized neck angles were summed and averaged to create a standard neck angle. The standard neck angle was subtracted from the digitized angles to create an adjusted neck angle. The adjusted neck angle was used for analysis. Once the testing conditions (postures 1 through 3) were confirmed against the digitized joint angles (RULA grand score), the analysis of the physiological and psychophysiological measurements began (Table 5).

Any changes in the blood pressure or perceived discomfort data were derived by subtracting the post-test measurement from the pre-test measurement. This difference value was utilized for comparison among the three working postures. A one way repeated measures analysis of variance (ANOVA) was conducted on the delta systolic blood pressure (ΔSBP), delta diastolic blood pressure (ΔDBP), delta body discomfort scores (ΔBDS), mean heart rate (HR) and the word count performance measure. The mean scores for joint angles, and mean EMG (RMS) adjusted for gain in millivolts were used for analysis. A 3 (posture) x 6 (time) x 3 (trial/sample) multi way repeated measures analysis of variance (ANOVA) model was administered for the kinematic data. A 3 (posture) x 6 (time/sample) multi way repeated measures analysis of variance (ANOVA) model was administered for the EMG (RMS) data. The statistical models applied in this thesis are summarized in Table 3. A total of twenty subjects was tested under all three conditions and was implicitly factored into the ANOVA analysis.

The on-site Body Discomfort Scores were used to rank each subject. These rankings were correlated with the rankings of subjects in the JAQ. The reason for using a JAQ was twofold: 1) this study hoped to gain practical experience using such a tool; and 2) this study anticipated that these results might be hypothesis generating.

Table 3: Statistical Models

Kinematic Data Multi-Way Repeated Measures ANOVA

Neck	Po (3)	Ti (6)	Tri (3)	Po*Ti	Po*Tri	Ti*Tri	Po*Ti*Tri
Shoulder	Po (3)	Ti (6)	Tri (3)	Po*Ti	Po*Tri	Ti*Tri	Po*Ti*Tri
Elbow	Po (3)	Ti (6)	Tri (3)	Po*Ti	Po*Tri	Ti*Tri	Po*Ti*Tri
Wrist	Po (3)	Ti (6)	Tri (3)	Po*Ti	Po*Tri	Ti*Tri	Po*Ti*Tri

EMG (RMS) Multi-Way Repeated Measures ANOVA

Upper Trapezius	Po (3)	Ti (6)	Po*Ti
Anterior Deltoid	Po (3)	Ti (6)	Po*Ti
Biceps Brachii	Po (3)	Ti (6)	Po*Ti
Forearm Ext.	Po (3)	Ti (6)	Po*Ti

One-Way Repeated Measures ANOVA

Heart Rate	Po (3)
Systolic BP	Po (3)
Diastolic BP	Po (3)
BDS	Po (3)
Word Count	Po (3)

(Po = Posture; Ti = Time; Tri = Trial)

Power analysis was calculated for the heart rate response data, as well as the blood pressure data. The power calculation for one factor with fixed effects was utilized and the beta value was determined using the operating characteristic curve for a fixed effects model ANOVA (Montgomery, 1997). In order to determine the beta value, phi squared (Φ^2) was calculated using the following equation:

$$\Phi^2 = \frac{nD^2}{2a\delta^2}$$

where, "n" is the sample size; "D" is the difference expected; "a" is the levels of treatment; and "σ^2" is the variance.

Chapter Four: Results

The following section describes the results for the subject's descriptive data, power analysis, kinematic data, EMG (RMS), HR response, blood pressure, perceived discomfort, word count and job satisfaction. The statistical analysis was run on all twenty subjects, as well as the eleven subjects identified as being tested in the appropriate RULA scoring system. When comparing the results for the kinematic data, EMG (RMS), HR response, blood pressure and word count between N=20 and N=11, there was no difference in significance level at $p<0.05$. The only difference was found in the perceived discomfort post hoc results, where N=11 found no significant difference between postures 1 and 2, while N=20 found a significant difference at $p=0.05$. Since there was very little difference in the results, the twenty-subject analysis is presented below. The results of the eleven-subject analysis can be found in Appendix F.

Subjects

A total of twenty subjects was recruited for testing. The general descriptive statistics, including anthropometric information and inclusion criteria on these subjects are provided in Table 4.

Power Analysis

A power analysis was calculated for heart rate response and blood pressure. Based on the instrument reliability and descriptive statistics, the "D" value (difference expected) for heart rate response and blood pressure was 6 and 3, respectively. At a 95% confidence interval, a sample size of 30 would be required for the heart rate data, while a sample size of 55 is recommended for systolic blood pressure. In terms of the diastolic blood pressure, a sample size of 20 provides enough power.

Table 4: Descriptive characteristics and inclusion criteria of subjects.

	Measure	Mean	SD	Min	Max
	Age (years)	31.8	8.6	21.0	55.0
	Mass(kg)	76.6	16.4	44.0	107.0
Standing (cm)	Stature	174.2	10.6	157.5	193.0
	Shoulder Ht.	143.9	9.0	129.0	159.5
	Elbow Ht.	108.9	8.3	97.0	129.5
Seated (cm)	Eye Ht.	121.8	7.7	102.5	133.0
	Shoulder Ht.	102.0	4.9	91.0	109.0
	Elbow Ht.	68.0	4.0	57.0	77.0
	Seat pan Ht.	49.3	3.1	43.0	53.0
	Male	13			
	Female	7			
Computer	Hrs/day	6.6	1.7	3.0	8.5
Coffee	Cups/wk	7.3	5.7	0.0	15.0

(n=20)

Kinematic Data

The RULA scores were computed using the RULA tables (Figures 1 through 3). The scores "D" and "C", calculated from the RULA tables, were then entered into Figure 11 in order to determine RULA's grand score. The mean joint angle score, derived from digitization, was used to calculate each subject's grand score in each posture.

Upon verification of testing conditions, it was determined that nine of the twenty subjects were outside of the pre-determined testing posture. One subject's RULA grand scores for each trial, and therefore each working posture, correlated to a posture 1 condition. As seen in Table 5, for those subjects tested in posture one, 19 of the 20 had a grand score that correlated to the posture 1 condition, while only 12 subjects in posture 2 correlated with a grand score for the posture 2 condition. Sixteen subjects tested in posture three had a grand score that correlated with the posture 3 condition. To conclude, a total of 27 trials had subjects working in a posture 1 condition, while 16 worked in a posture 2 condition, and 17 in posture 3 condition.

SCORE D (Neck, trunk, leg)								
SCORE C (Upper limb)		**1**	**2**	**3**	**4**	**5**	**6**	**7+**
	1	1	2	3	3	4	5	
	2	2	2	3	4	4		
	3	3	3	3	4			
	4	3	3	3				
	5	4	4					
	6	4						
	7							
	8							

Where Posture 1 = □ Posture 2 = ▩ Posture 3 = ■

<u>Figure 11</u>: RULA Grand Score and corresponding posture
(Amended from McAtamney and Corlett, 1993.)

Table 5: RULA Testing Posture VS Digitized Actual Posture

TESTING POSTURE	ACTUAL POSTURE 1	2	3
1	19	1	0
2	7	12	1
3	1	3	16

The descriptive statistics for the kinematic data, for all 20 subjects, can be seen in table 6.

Table 6: Kinematic Descriptive Statistics (in degrees)

	NECK			SHOULDER			ELBOW			WRIST		
	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3
Mean	26	25	29	15	25	34	93	98	91	2	16	15
SD	10	10	10	6	7	7	4	7	7	4	7	8
Max	50	42	49	30	45	46	101	109	107	12	29	27
Min	10	9	6	6	13	19	87	84	79	0	0	-4

N=20

The multi way repeated measures ANOVA showed a significant difference in neck angle ($F=6.56$, df 2/36, $p<0.00$), shoulder angle ($F=77.72$, df 2/36, $p<0.00$), elbow angle ($F=12.44$, df 2/36, $p<0.00$) and wrist angle ($F=86.24$, df 2/36, $p<0.00$) across the three working postures. The Tukey HSD post hoc test revealed that there was no significant difference between the neck angle for posture 1 (mean=25) and posture 2 (mean=25) ($p=1.00$). The Tukey HSD post hoc test revealed that there was no significant difference between the elbow angle for posture 1 (mean=93) and posture 3 (mean=90) ($p=0.17$). The Tukey HSD post hoc test revealed that there was no significant difference between the wrist angle for posture 2 (mean=16) and posture 3 (mean=16) ($p=0.90$).

There was a time effect, over the duration of the 30-minute testing periods, for the neck angle ($F=4.02$, df 5/90, $p<0.00$) and shoulder angle ($F=4.50$, df 5/90, $p<0.00$). The Tukey HSD post hoc test revealed that a significant time effect for the neck angle was found between time 1 (mean=25) and time 2 (mean=27) ($p=0.00$); and time 1 and time 3 (mean=27) ($p=0.01$). The Tukey HSD post hoc test revealed that a significant time effect for the shoulder angle was found between time 1 (mean=27) and time 4 (mean=24) ($p=0.00$); time 1 and time 5 (mean=25) ($p=0.01$); and time 1 and time 6 (mean=25) ($p=0.04$). There was an interaction effect of time and posture for the shoulder angle ($F=1.97$, df 10/180, $p<0.04$).

EMG

The descriptive statistics for the maximum, isometric RVC (RMS) in millivolts can be seen in Table 7 below.

Table 7: RVC (RMS) Descriptive Statistics in millivolts.

	UT	AD	BB	FE
Mean	0.2934	0.2443	0.0923	0.3596
SD	0.1085	0.0839	0.0464	0.0914
Max	0.4006	0.4166	0.1754	0.4847
Min	0.0417	0.1051	0.0163	0.1134

N=20

Although maximum, isometric RVCs were collected in a standard reference position for all three testing conditions, the percent RVC was not used for statistical analysis. The object of this thesis is not concerned with the absolute values obtained in the percent RVC, but is more interested in the intra-individual differences across the three working postures.

The descriptive statistics for the EMG data can be seen in table 8.

Table 8: EMG (RMS) Descriptive Statistics in millivolts.

	Upper Trapezius			Anterior Deltoid			Biceps Brachii			Forearm Extensor		
	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3
Mean	0.0283	0.0500	0.0293	0.0334	0.0420	0.0315	0.0305	0.0317	0.0226	0.1321	0.1423	0.1335
SD	0.0185	0.0505	0.0206	0.0508	0.0436	0.0226	0.0402	0.0569	0.0270	0.0523	0.0557	0.0695
Max	0.0681	0.2197	0.0799	0.2175	0.1648	0.0959	0.1359	0.2611	0.0936	0.2257	0.3285	0.2426
Min	0.0077	0.0108	0.0075	0.0023	0.0053	0.0049	0.0026	0.0035	0.0029	0.0447	0.0811	0.0095

N=20

The multi way repeated measures ANOVA and the Tukey HSD post hoc test revealed a non significant difference in the upper trapezius (F=2.03, df 2/34, p<0.15), anterior deltoid (F=0.48, df 2/38, p<0.62), biceps brachii (F=0.37, df 2/38, p<0.69) and forearm extensors (F=0.35, df 2/38, p<0.70) across the three working postures.

Heart Rate Response

The descriptive statistics for the heart rate data can be seen in Table 9.

Table 9: Heart Rate Response Descriptive Statistics in beats per minute.

	Posture 1	Posture 2	Posture 3	RHR
Mean	72	74	75	65
SD	9	9	9	10
Max	85	92	88	90
Min	49	54	53	44

N=20

The one-way repeated measures ANOVA and the Tukey HSD post hoc test showed a non-significant difference in heart rate (F=3.09, df 2/36, p<0.06) across the three working postures.

Blood Pressure

The descriptive statistics for both systolic and diastolic blood pressure can be seen in the table below.

Table 10: Delta Blood Pressure Descriptive Statistics in mmHg.

	Delta Systolic Blood Pressure				Delta Diastolic Blood Pressure			
	Post 1	Post 2	Post 3	Rest (mmHg)	Post 1	Post 2	Post 3	Rest (mmHg)
Mean	3	5	3	115	3	2	3	73
SD	9	11	7	17	6	7	8	13
Max	16	41	14	159	16	24	28	97
Min	-11	-10	-12	92	-5	-1	-8	52

N=20

The one-way repeated measures ANOVA and the Tukey HSD post hoc test revealed a non-significant difference in systolic blood pressure (F=0.27, df 2/38, p<0.76) and in diastolic blood pressure (F=0.19, df 2/38, p <0.83) across the three working postures. It should be noted that although the means are different (Table 10), the values may in fact represent the same number due to the instrument reliability of +/- 3 mmHg.

Perceived Discomfort

The descriptive statistics for the delta BDS data can be seen in Table 11.

Table 11: Delta Body Discomfort Scores Descriptive Statistics.

	Posture 1	Posture 2	Posture 3
Mean	0	5	7
SD	3	6	6
Max	7	20	26
Min	-7	0	0

N=20

The one-way repeated measures ANOVA test demonstrated a significant difference in perceived discomfort ($F=16.01$, df 2/38, $p<0.00$) across the three working postures. The Tukey HSD post hoc test revealed a non-significant difference in perceived discomfort between posture 2 and posture 3 ($p=0.12$).

Performance (Word Count)

The descriptive statistics for the word count data can be seen in Table 12.

Table 12: Performance (word count) Descriptive Statistics.

	Posture 1	Posture 2	Posture 3
Mean	901	906	777
SD	368	368	304
Max	1679	1593	1438
Min	392	388	341

N=20

The one-way repeated measures ANOVA demonstrated a significant difference in word count ($F=26.50$, df 2/38, $p<0.00$) across the three working postures. The Tukey HSD post hoc test revealed a non-significant difference between postures one and two ($p=0.97$).

Job Attitudes

Each subject was ranked in ascending order based on his/her total score calculated from the on-site BDS. Subjects were then ranked in descending order based on the total score calculated from the on-site Job Attitude Questionnaire (JAQ). The Pearson product moment correlation was performed on the data and resulted in a coefficient of $r=-0.08$.

Summary of Results

For ease of comparison across the dependent measures and the independent effects, Table 13 has been developed which highlights the overall statistical analysis of the study presented here. In general there were statistically significant effects due to posture for all the kinematic measures. There were also time and posture*time effects for some measures. In terms of the physiological measures, the only statistically significant effect was due to time for the forearm extensor muscles. Finally, there were significant differences found for the perceived discomfort and work performance measures.

Table 13: Summary of Results

Dependent Variable	**Independent Variable**						
	Po	**Ti**	**Tri**	**Po*Ti**	**Po*Tri**	**Ti*Tri**	**Po*Ti*Tri**
Kinematic							
Neck	S	S	S	NS	NS	NS	NS
Shoulder	S	S	NS	S	NS	NS	NS
Elbow	S	NS	NS	NS	NS	NS	NS
Wrist	S	NS	NS	NS	NS	NS	NS
EMG							
UT	NS	NS	-	NS	-	-	-
AD	NS	NS	-	NS	-	-	-
BB	NS	NS	-	NS	-	-	-
FE	NS	S	-	NS	-	-	-
Other							
Heart Rate	NS	-	-	-	-	-	-
Sys BP	NS	-	-	-	-	-	-
Dias BP	NS	-	-	-	-	-	-
BDS	S	-	-	-	-	-	-
Word Count	S	-	-	-	-	-	-

N=20 (S = Significant; NS = Not Significant)

Chapter Five: Discussion

Conventional physiological measurement techniques, EMG (RMS), heart rate response and blood pressure, did not produce a significant difference while the psychophysiological measure of perceived discomfort did result in a statistically significant difference. This resultant contradiction may be explained in three ways: 1) there is no physiological difference in the body's state across the three tested postures, 2) the physiological measures used here in this study are not effective means for measuring physiological changes while performing computer tasks in the three tested postures or, 3) the statistical power was too low to demonstrate a statistically significant difference.

Kinematic Data

At the beginning of each testing period, the height adjustable table, chair and computer accessories were positioned while the subjects were seated with their hands on the keyboard and their eyes looking at the middle of the computer monitor. A manual goniometer was used to verify that each joint angle fell within the pre-defined joint angle range (Figure 7) in order to yield a specific RULA score corresponding to the desired testing posture. Although the testing equipment was manipulated to force each subject to maintain a controlled body envelope, individual typing styles and personal preferences affected the ultimate joint angles. For example, the wrist angle was dependent upon typing style and how an individual holds his/her arms. Some subjects would rest their wrists on the work surface while others would maintain a "neutral posture" regardless of the height and angle of the keyboard.

Individuals would also adopt various neck angles regardless of the monitor positioning. Some participants would move their eyes when referencing the keyboard, the reference materials and monitor, while others would move their entire head. Based on observations, it seems that the neck angle is dependent upon an individual's typing style. Those subject's who were "touch typists" did not need to constantly look at the keyboard while inputting information, they merely glance at the keyboard periodically. These individuals maintain their gaze at the reference material, while periodically glancing at the monitor screen or keyboard. For those subjects who are "finger" typists, they must reference the keys while inputting information. Therefore, they are frequently looking at the reference material, then to the keyboard and then to the monitor for verification. Such variability in neck angle, which results in dynamic contractions, will have a profound effect on the kinematic and EMG (RMS) data. A study by Burgess-Limerick et al. (1998) examined the effects of three computer monitor heights, which they termed as "high, middle and low", on neck angle. Their study used the same landmarks for the neck angle as employed in this thesis; however, they used an included angle as opposed to a relative angle (horizontal). Their results showed a non-significant difference in neck angle ($p=0.06$) across the various monitor heights, while the ear-eye line relative to the horizontal and the gaze angle relative to the horizontal was significantly different at $p<0.001$. Although the present study found a significant difference in neck angle at various monitor heights, it was observed that some subjects did not vary their neck angles but changed their gaze instead.

The subjects tested were instructed to maintain an upright posture with their backs firmly against the chair's backrest. It was qualitatively noted that subjects would lean forward in their chair, especially during testing conditions for postures 2 and 3. The examiner would then instruct subjects to lean back during the testing protocol. The postural neck and wrist deviations, as noted above, were also observed by the examiner. However, the subjects were left to adapt and change their posture to allow for a more applied workplace situation.

Upon further investigation of the kinematic results seen in table 5, it appears that the testing condition posture 2 was the most difficult to control. Only 12 of the 20 subjects tested in posture 2 were actually found to be working within posture 2 parameters as defined by RULA. Seven of the subjects tested under posture 2 conditions were found to be in fact working with a RULA score corresponding to a testing condition of posture 1, while the other subject fell into testing condition posture 3. Nineteen subjects tested under posture 1 condition successfully obtained a RULA score corresponding to Posture 1, while the other subject fell into posture 2. The RULA scoring range for the neck and wrist were too fine for practical use in posture 1 and posture 2, while the elbow angle range was too broad. The fine measurement range made it difficult to maintain either a posture 1 or a posture 2 joint angle envelope. The testing condition of posture 3 resulted in 16 subjects with a RULA score corresponding to posture 3, while only three subjects fell under posture 2 and one under posture 1. Based on these numbers, the success rate for testing postures 1, 2 and 3, were 95%, 60% and 80% respectively. The statistical kinematic results coincide with the success rates, since the neck, shoulder and wrist angle were all significantly different between postures 1 and 3. Statistically, there was no significant difference in neck angle between posture 1 and 2 as well as 2 and 3, while the change in wrist angle was not significant between postures 2 and 3.

The elbow angle demonstrated a non-significant difference between postures 1 and 3. Taking a closer look at RULA's scoring system for the elbow angle, a score of 1 is given to an elbow angle between 60 and 100 degrees while a score of 2 is allotted to an elbow angle greater than 100 degrees or less than 60 degrees. The mean elbow angle for each subject, and in all three postures, was between 60 and 100 degrees, with the exceptions of seven subjects in posture 2 and one subject in posture 3. These exceptions, however, did not exceed an elbow angle of 110 degrees. An elbow angle greater than 100 degrees or less than 60 degrees is not realistic when working at a computer in an occupational setting.

For the purpose of this thesis, a total of 18 static posture samples were randomly collected over each 30-minute testing period. In an applied situation, ergonomists or users of RULA, would sample a workstation or an individual, fewer times than that. It should also be noted that ergonomists are not using objective measuring techniques when measuring an individual's joint angles on-site at a workplace. For the most part, individuals are observed over a shorter period of time than the 30-minute testing period employed here. Visual estimations of joint angles are used when selecting the corresponding RULA score as opposed to using objective video analysis.

EMG

The EMG (RMS) measurement technique was found to be insensitive to muscle activation and discomfort in the upper trapezius, anterior deltoid, biceps brachii and forearm extensors. Although there was no statistically significant difference in EMG (RMS) across the three working postures, EMG should not be discarded. Instead, it is recommended that the EMG processing techniques be improved for future research. Upon closer examination of the results in Table 8, it was noted that the variance is high relative to the means. Therefore, any differences across working postures would be difficult to detect. It is possible that the six samples of raw EMG data collected over each 30-minute testing period were not representative of the muscle activation patterns.

According to Wiker (1989), EMG analysis of fatigue in the shoulder complex may be a less powerful measurement technique than what other studies have suggested. The difficulties with using EMG for the shoulder lie in the structural complexity of the shoulder, as well as the low levels of muscular activity required to produce postural stress. Although the shoulder (anterior deltoid) is acting as a postural muscle (static contraction), it was observed that some subjects were in fact quite active with their upper arms when reaching to turn the pages of their reference materials (approximately 3 pages in a half hour). As some subjects became uncomfortable, they would shift their weight, scratch their face or stretch their arms in order to relieve their experienced strain. These non-task related movements were observed (see kinematic data) by the examiner and were permitted in the testing conditions in order to create an applied situation. It should be noted that these movements may have contributed to the high variance.

Jonsson and Hagberg (1974) found that vocational studies show the least myoelectric activity in the anterior deltoid that corresponds to an elbow joint angle between 90 to 100 degree flexion. The results of the present thesis show an overall mean elbow joint angle between 90 and 100 degrees for all three postures. In the testing condition posture 3, the mean joint elbow angle was closest to 90 degrees (90.5) and the corresponding mean anterior deltoid RMS value was lowest in this posture. These results agree with Jonsson and Hagberg (1974) findings.

As described in the kinematic data, the neck angle was observed to change frequently throughout the testing periods due to personal preferences and typing styles. The neck angle had the greatest standard deviation (10 degrees) of all four tested joints. The variability in neck angle and dynamic component may in fact contribute to the non-significant difference in the upper trapezius muscle across the three testing conditions. Palmerud et al. (1995) suggest that it is not possible to rely solely on the trapezius EMG measures while estimating total shoulder load, since there is a significant voluntary effect in this muscle despite a fixed total shoulder load. Therefore, it is possible that the subjects tested in this thesis would "relax" periodically through the non-task related movements and affect the EMG signal.

The overall mean elbow angles for all subjects within each of the three testing conditions, fell within the same RULA scoring. Therefore, according to McAtamney and Corlett's (1993) body part scoring, there was no difference in the overall mean elbow angle across the three postures. Graphically, the kinematic results for the elbow angle and the mean biceps brachii EMG (RMS) follow the same pattern. There was however, no statistically significant difference in the biceps brachii EMG (RMS) across the three postures and, according to RULA, there was no difference in scoring either. These results reinforce RULA's scoring parameters. However, there is still the possibility of a type 2 (beta) error (accept null hypothesis when should not) and therefore, further investigation is required.

With respect to the wrist angle, there was definitely a change in RULA scoring between the overall mean for posture 1 and each of postures 2 and 3, as well as a statistically significant difference. There was however, no change in scoring and no statistically significant difference between posture 2 and 3.

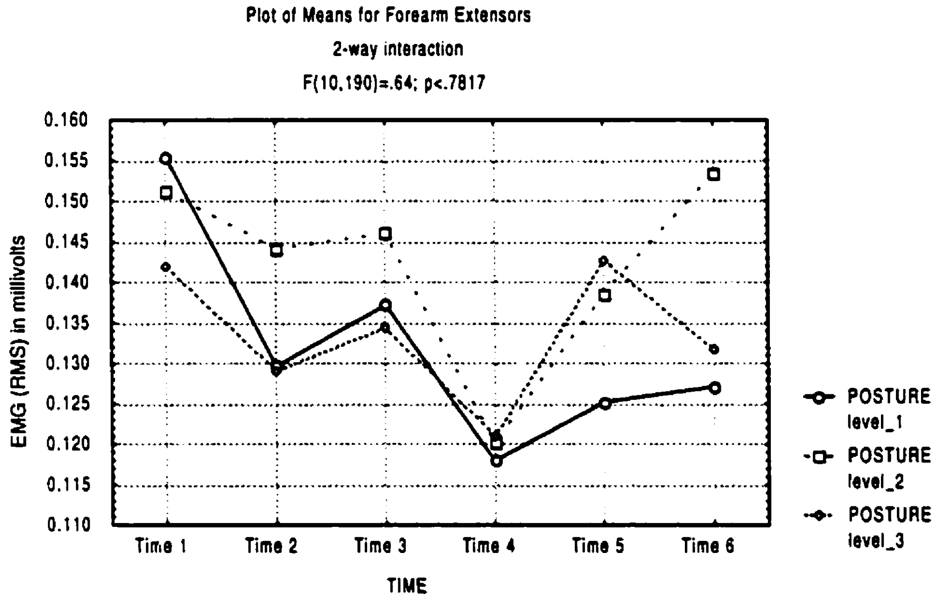


Figure 12: Time effects for the Forearm Extensors in millivolts.

In terms of the EMG (RMS) values for the forearm extensor, there was no significant difference, nor was there a trend in the graphs across the three postures. It should be noted that a significant time effect emerged for the forearm extensors. All three postures demonstrated a similar trend over time (Figure 12).

Subtle postural shifts (non-work related movements) during testing may have increased the potential for surface electrode movement and therefore its proximity to the electrical activity of the muscle in question. This would result in an increase in variability in the EMG recording. The subtle shifts, such as scratching ones head, will cause changes in muscle lengths and tensions thereby significantly impacting upon the EMG recording. Studies have shown that frequencies of postural shifts (non-task related movements) increase with the development of discomfort and fatigue (Karwowski et al., 1994; Liao and Drury, 2000).

Although a maximum, isometric RVC was collected for each muscle group in a standard reference position, the percent RVC was not used for statistical analysis, since the normalization procedures were not successful. When examining the percent RVC, it was noted that these contractions might not represent a true maximum contraction. The descriptive statistics of the EMG results in the form of percent RVC can be seen in Table 14 below. Since each subject acted as their own control, the mean RMS values were used for analysis. Instead of using a RVC, this author believes that a "posture bias" sample would have been a more useful technique for normalization.

It should also be noted, that a fatigue effect may have occurred in the EMG (RMS) data, however, it was not observed due to "posture bias". The design of this thesis was such to minimize any fatigue effects that may occur due to testing condition order. Also, the statistical results did not demonstrate a fatigue effect within each testing condition (time). The mean RMS values consist of both a static (posture) component of EMG as well as a dynamic (work) component. In order to see a fatigue effect within each testing condition, the fatigue effect must be greater than the sum of the static and dynamic component. Therefore, for future experiments, it is recommended that a static EMG sample be collected for each posture condition with the subject holding the corresponding posture to act as a "posture bias" value. This posture bias value would then be subtracted from the raw EMG data prior to the calculation of the RMS. Had these steps been taken, we may have seen an increase in the mean RMS values.

Table 14: EMG Descriptive Statistics in percent RVC

	Upper Trapezius			Anterior Deltoid			Biceps Brachii			Forearm Extensor		
	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3
Mean	14.2	25.7	11.9	18.6	18.1	13.3	61.0	49.2	38.4	39.3	41.1	39.2
SD	16.3	38.0	9.8	41.0	17.0	7.9	100.0	74.0	59.4	16.3	14.3	17.4
Max	72	165	43	187	65	30	364	273	251	89	73	77
Min	2	3	2	1	3	2	2	2	2	19	22	3

N=20

The object of this thesis work was unable to find EMG indicators of systematic changes in muscle activity (force or fatigue) during a word processing task, despite the fact that significant changes in perceived discomfort did result. Similar results were found in Hagberg and Sundelin's (1986) study in which there was no significant difference in the upper trapezius muscle, while a significant difference was found in perceived discomfort. When postural exertions are low, and these exertions are not static in nature, there is a greater potential risk that EMG measures will fail in detecting uncomfortable and fatiguing postures. Another plausible reason for the non-significant differences may be due to a low statistical power. The object of the thesis attempted to increase statistical power through prolonged sampling and averaging of amplitude (mean RMS) as well as through the use of a repeated measures experimental design to minimize the effects of inter subject differences.

Heart Rate Response

No significant difference was found in heart rate across the three testing conditions. Further analysis was performed in order to see if there was a time effect. Once again, no difference was found (Appendix G). A study by Kahn et al. (1997) found heart rate measures to remain stable over 65 minutes of static contractions held at 10% MVC. Schreinicke et al. (1990) compared heart rate response at rest and after computer work. A significant increase in heart rate from rest (mean=77.1 bpm) to computer work (mean=87.1 bpm) was found ($p<0.01$). The results of this thesis seem to agree with the Schreinicke et al. study with an increase in heart rate from rest (RHR mean=65.1 bpm) to computer work (posture 1 mean=72.2, posture 2 mean=73.8, and posture 3 mean=74.8).

Based on the results of this thesis work, as well as the literature (Floru et al., 1985), mean heart rate is not a sensitive physiological indicator for systematic changes in discomfort and effort during different computer terminal tasks.

Blood Pressure

No significant difference in delta systolic blood pressure and delta diastolic blood pressure across the three testing conditions was found in this thesis work. A study by Kahn et al. (1997) however, found systolic blood pressure to progressively increase by 24 mmHg in 28 minutes of static contraction at 10% MVC, followed by a plateau until the end of 65 minutes of testing. The results of this thesis do not agree with Kahn et al.'s results. Over a 30-minute testing period of dynamic contractions, there was a minimal, mean increase in systolic blood pressure of 2.8 mmHg, 4.5 mmHg, and 3.0 mmHg for postures 1 through 3 respectively. The results of Mathiassen (1993) also disagree with the results of this thesis. These authors found a significant increase in MAP for activities ranging from 14 to 18% MVC. Although it is possible that the muscular activity in posture 1 of this thesis work may fall below 5% MVC, it is believed that some muscle groups in posture 3 fall within the range of 14 to 18% MVC. No attempt was made to quantify the actual MVC percentage.

Schreinicke et al. (1990) compared blood pressure at rest and after thirty minutes of computer work. A significant increase in systolic and diastolic blood pressure from rest (mean=129 mmHg; mean=91.9 mmHg) to computer work (mean=143 mmHg; mean=95.9 mmHg) at $p<0.001$. The results of this thesis disagree with the Schreinicke et al. study with no change in systolic and diastolic blood pressure from rest (sys mean=115; dias mean=73) to computer work (sys mean1=115, sys mean2=115, and sys mean3=116; dias mean1=76, dias mean2=74, and dias mean3=74). The high speed and accuracy demands placed upon the subjects of Schreinicke's study most likely contributed to their overall stress response, thereby increasing blood pressure. The subject's of the thesis study presented here, however, did not have the same stressful demands placed upon them.

Perceived Discomfort

A statistically significant difference was found in perceived discomfort from posture 1 to posture 3, however, no difference was found between postures 1 and 2, and between 2 and 3. The fine RULA measurement ranges for the neck and wrist may explain this fact, and the broad range for postures 1 and 2. This may impact the non-significant difference between posture 1 and posture 2 with respect to perceived discomfort results.

The validity tests performed by McAtamney and Corlett (1993), resulted in a significant difference in perceived discomfort between those postures deemed as acceptable versus those postures deemed as unacceptable. Further analysis was performed in order to compare the results of this thesis with those from McAtamney and Corlett (1993). A closer look at the results revealed that seven subjects in testing condition posture 1, actually had a resultant RULA score that would be deemed acceptable and their testing conditions posture 2 and 3 as unacceptable by McAtamney and Corlett's standards. The results of this analysis can be seen in tables 15 and 16. The results of this analysis agree with the results from McAtamney and Corlett (1993) based on psychophysiological measures.

Table 15: Perceived discomfort results of acceptable versus unacceptable postures.

Perceived Discomfort: One Way Repeated Measures ANOVA

	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
Posture	2	69.90	12	7.13	9.81	0.00

N=7

Table 16: Tukey HSD post hoc test for acceptable versus unacceptable postures.

Perceived Discomfort: Tukey HSD test

	Post 1	***Post 2***	***Post 3***
Post 1		0.06	0.00
Post 2	0.06		0.21
Post 3	0.00	0.21	

N=7

It should be noted here, that statistical analysis of these seven subjects was also run on the EMG (mean RMS), heart rate and delta blood pressure data. Once again, no significant differences were found in these measures between the acceptable and unacceptable working postures.

According to Wiker (1989), levels of perceived discomfort were most severe in muscle groups which are heavily taxed when the arms are flexed from the torso. This agrees with the results from this thesis. In posture three, subjects reported the greatest discomfort with the greatest shoulder angle of 33 degrees.

Job Satisfaction

In an article by Hocking (1987), he states that studies conducted by Ryan *et al.* (1985) and Graham (1985) found job satisfaction to correlate with the presence of MSD better than the ergonomic variables used in their studies. The results of other studies (Smith, 1997), have shown that highly monotonous computer work was associated with increased psychosomatic complaints and decreased job satisfaction. The results of this thesis however, found no relationship between job satisfaction and perceived discomfort while subjects were working at their own workplace. It should be noted that the subjects for this thesis were volunteers, and were more likely to be motivated individuals with positive affectivity. The prevalence rate among self-reports of discomfort may be attributed to negative affectivity as described by Burke *et al.* (1993). Individuals with a high level of negative affectivity will focus on the negative aspects of their work environment, while individuals with positive affectivity will not.

Performance (Word Count)

There was a significant difference in the number of words typed across the three postures where the overall mean words typed increased from testing condition posture 1 through to posture 3. This thesis work can not assume a cause and effect relationship on performance and working postures, since subjects noted that the reference material for posture three was more technical in nature than that for postures 1 and 2. Also, the Tukey HSD post hoc test revealed a non-significant relationship between the mean word count of postures 1 and 2. The difference in text difficulty for posture 3 versus 1 and 2, explains the greater number of words typed for posture 1 and 2 and the fewer words typed in posture 3.

Posture Sampling and RULA

According to Corlett (1999), there is a lack of methodology for the assessment of upper limb disorder, use of the results of such assessment tools, and a lack of indicators for the best direction of change. For these reasons, McAtamney and Corlett (1993) developed RULA as a system for assessing whether the workplace could present a hazard to a worker, which may place that individual at a risk of developing an upper limb MSD. Corlett (1999) also states that the final score, derived from the grand score table (Figure 11), gives an estimate of the risk potential for a specific task. As the final score moves from the top left corner to the bottom right corner, Corlett (1999) proposes a greater risk of MSD symptoms. There are however, limitations to this posture sampling approach. Although muscular force and repetition are addressed, other measures (equipment positioning based on ergonomic guidelines, body discomfort surveys, and user feedback) are crucial in the ergonomic assessment of a workplace.

Li and Burke (1999) in their review of technology for assessing physical exposure to work-related MSD, emphasized that most scoring systems associated with posture sampling have been largely hypothetical. In 1995, Genaidy et al. noted a need to rank the stressfulness of body segment (joint angles) deviations from neutral postures in order to better understand their effects on the workforce and the development of MSD.

The object of this thesis has attempted to quantify physiologically as well as psychophysiologically the scoring system found in RULA. The only conclusive link found was between RULA's scoring system and the level of perceived discomfort experienced by individuals. It is difficult to calculate a "grand score" level of risk that a task or workstation may place on an individual when we are still unable to determine with any degree of certainty the risk factors, combinations of these risk factors, and the "amount" of risk factors that lead to the development of MSD. From the results of this thesis, we can conclude that further investigation is crucial in quantifying exposure levels and that other methods of measuring the body's response to various working postures are essential.

Chapter Six: Conclusion

The purpose of this thesis work examined the relationship between RULA's postural scoring and a number of physiological and psychophysiological parameters in a laboratory setting. The assessment of RULA included objective measures of electromyography (EMG), heart rate response, and blood pressure, as well as self-reports of perceived discomfort to observe the body's response to various computer-working postures. As a second purpose this thesis work examined whether a relationship exists between various job attitude factors and perceived discomfort scores.

The results have led to the following conclusion:

1. Do not reject Null Hypothesis. There was no significant difference in EMG (RMS) activity of the upper trapezius, anterior deltoid, biceps brachii, and forearm extensors across the three working postures.
2. Do not reject Null Hypothesis. There was no significant difference in heart rate response across the three working postures.
3. Do not reject Null Hypothesis. There was no significant difference in systolic and diastolic blood pressure across the three working postures.
4. Reject Null Hypothesis. There was a significant difference in perceived discomfort scores across the three working postures.
5. Reject Null Hypothesis. There was a significant difference in performance (word count) across the three working postures.
6. There was no significant relationship between the on-site perceived discomfort scores and job attitude questionnaire scores among the subjects.

Recommendations

Further investigation is crucial in understanding the relationship between perceived discomfort and signs of systematic physiological change while performing seated computer tasks. Other methods of measurement worth exploring include recording the number of non-work related movements or postural shifts, biomechanical analysis of the joints in question (joint moments and forces), measuring stress indicators such as catecholamines and cortisol (Schreinicke et al., 1990), and measuring end-tidal PCO_2 as an index of psychophysiological activity (Schleifer and Ley, 1994). Another technique for continuous measurement of joint angle uses Flock of Birds, an electromagnetic system. This system tracks the position and angular orientation of different lightweight receivers. The advantages of the system include joint motion which can be continuously measured and several joint movements which can be recorded simultaneously.

Research design recommendations include using test subjects with equivalent keyboard skills and comparing the results of various keyboarding styles, for example "touch typists" versus "finger" typists. Also, a longer testing period may prove useful along with a longitudinal study. Although no significant difference was found in perceived discomfort from posture 1 to 2, as well as from posture 2 to 3, this author believes, with a constant load, that a longer testing period would elicit a difference in perceived discomfort across all three postures. Any subtle change in posture becomes more noticeable with a longer exposure time. For the purpose of normalization, it is recommended to utilize the "posture bias" technique as described on page 70 under the discussion section.

The results of this study would suggest that RULA's scoring system may be too general in nature, and therefore, weaknesses in its application to computer workstations have emerged. It is the author's opinion that RULA can be improved into an even more powerful tool through the development of task specific RULA versions, for example a RULA for office tool and a RULA for industry tool. Further work is required to expand upon the results of this thesis and develop the necessary revisions to RULA.

Appendix A

Consent Form

Consent Form

Dear participant,

Thank you for your interest in participating in a research project that is examining the relationship between the Rapid Upper Limb Assessment (RULA) postural scoring and physiological and psychophysiological signals. The knowledge gained from this study may be used to improve upon RULA as a tool for ergonomic assessment and reduce the risk of injury.

The task that you would be performing will require you to work at a computer workstation for three half hour testing periods with two half hour rest periods between each test. The total time, including set up, would be approximately three and a half hours. During testing, measures of your heart rate, blood pressure, muscle activity and self reported body discomfort will be collected. A Polar heart rate monitor will record your heart rate throughout the three trials and two rest periods for analysis. This will ensure recovery during the rest periods. Additionally, you will be video recorded using a VHS video camera. Prior to testing, reflective markers will be attached to your skin on the outside of your eye, ear, neck, shoulder, elbow, wrist and little finger. Surface electrodes will be placed on the right side of your body over the muscles of the neck, shoulder, arm, and forearm. These electrodes measure the electrical activity of your muscles and do not cause any discomfort. Verbal instructions will be given prior to all testing and you will have an opportunity to ask questions.

The complete protocol will require your participation for a half hour orientation session prior to testing and 3.5 hours on one day for testing. Both the orientation and testing will take place in the Dalplex Occupational Biomechanics and Ergonomics Laboratory. The day before your testing, you will be asked to complete a job attitude questionnaire and body discomfort survey at your workplace. These forms will take approximately 20 minutes to complete.

Due to the nature of the working postures, there is a potential of experiencing some muscular discomfort. This muscle soreness tends to disappear within a couple of minutes and can be greatly reduced by stretching. Skin irritation may occur due to the adhesive on the surface electrodes and the joint markers but this is only as irritating as the removal of a Band-Aid.

If you feel any discomfort during a test, you may terminate the session without coercion to continue or other repercussions. Should you choose to terminate further testing, all records of your participation and all data pertinent to you will be omitted from any research publications. If you are dissatisfied with the study or your treatment, please inform us immediately and we will do everything possible to correct the problem. If our response is not satisfactory, you may contact the research advisor Dr. John Kozey at 494-1148 or Leslie Fountain at 494-3589.

Although you will not receive any direct benefits as a result of your participation in this study, you will provide valuable information on the efficiency of RULA's postural scoring based on physiological signals and help improve the risk assessment phase of the ergonomic process. To thank you for your participation, a complimentary Ergonomic Office Assessment valued at $150.00 will be offered to you by Leslie Fountain.

Your participation and any data collected during this study will be held in the strictest of confidence. All data will be kept under the control of the study's principal investigator, Leslie Fountain, until the completion of the study. After this time, the thesis supervisor, Dr. John Kozey will maintain all data, until such time as the results of the study are published in peer review journals. Your name will not appear on any published documents or in any results. Your data will be represented by subject number, which is used for identification purposes. All data will be represented by subject number and will be grouped for the purposes of analysis and interpretation. Additionally, all information is confidential to this study's principle investigator, Leslie Fountain.

If you have concerns about this study, please feel free to contact Leslie Fountain at (902) 494-3589 or via email at *lfountai@is2.dal.ca.*

I, ____________________________, have read and understood the purpose of the present study provided by the researcher and hereby consent to take part in this study.

______________________________ ______________

Signature Date

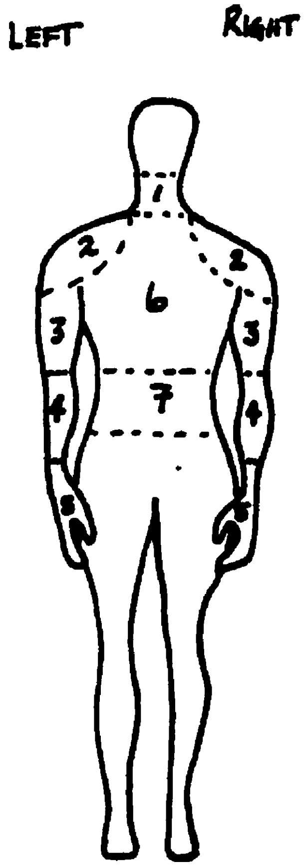
Appendix B

Body Discomfort Survey

BODY DISCOMFORT SURVEY

Date: __________ Name: ________________ Test: *1 2 3* *Pre* *Post*

Are you experiencing any discomfort, numbness, or pain at this moment? For each body part listed, please check the level of discomfort you are experiencing right now:



Back View

#	Body Part	No Discomfort			Moderate				Extreme Discomfort
	Right Side								
2	Shoulder	0	1	2	3	4	5	6	7
3	Upper Arm	0	1	2	3	4	5	6	7
4	Forearm & Elbow	0	1	2	3	4	5	6	7
5	Wrist & Hand	0	1	2	3	4	5	6	7
1	Neck	0	1	2	3	4	5	6	7
6	Upper/Middle Back	0	1	2	3	4	5	6	7
7	Lower Back	0	1	2	3	4	5	6	7
	Left Side								
2	Shoulder	0	1	2	3	4	5	6	7
3	Upper Arm	0	1	2	3	4	5	6	7
4	Forearm & Elbow	0	1	2	3	4	5	6	7
5	Wrist & Hand	0	1	2	3	4	5	6	7
1	Neck	0	1	2	3	4	5	6	7
6	Upper/Middle Back	0	1	2	3	4	5	6	7
7	Lower Back	0	1	2	3	4	5	6	7

Appendix C

Job Attitudes Questionnaire

JOB ATTITUDES QUESTIONNAIRE

Dalhousie University
School of Health and Human Performance
6230 South Street
Halifax, Nova Scotia

The following is a set of questions that will be used to gather information regarding your job attitudes at your current place of employment. Considering all aspects of your present work situation, please answer all questions to the best of your ability and understanding. If you have any questions please ask the researcher for assistance.

Please note that your identity will be kept confidential.

Name: ______________________________

Date: ______________________________

Please answer the following questions before proceeding:

Time you have worked with current employer: ____Years ____Months

Time you have been working at your current position: ____Years ____Months

Current job title: ______________________

JOB ATTITUDES (JDS SCALES)

Please answer the following questions on the seven -point scales.

1. With respect to the amount opportunity to participate in the determination of methods, procedures and goals in my job, I am:

Extremely dissatisfied	Very dissatisfied	Dissatisfied	Fairly satisfied	Satisfied	Very satisfied	Extremely satisfied
1	2	3	4	5	6	7

2. Generally speaking, I am extremely satisfied with my type of job.

Strongly disagree	Disagree very much	Disagree	Fairly agree	Agree	Agree very much	Strongly agree
1	2	3	4	5	6	7

3. My feelings of self-esteem increase when I do my job well.

Strongly disagree	Disagree very much	Disagree	Fairly agree	Agree	Agree very much	Strongly agree
1	2	3	4	5	6	7

4. With respect to the feeling of meaningful accomplishment in my job, I am:

Extremely dissatisfied	Very dissatisfied	Dissatisfied	Fairly satisfied	Satisfied	Very satisfied	Extremely satisfied
1	2	3	4	5	6	7

5. The amount of pressure I feel because I am personally accountable for my actions is:

Low pressure	Very little pressure	Little pressure	Fair pressure	Large pressure	Very large pressure	High pressure
1	2	3	4	5	6	7

6. I almost live, eat and breathe my job.

Strongly disagree	Disagree very much	Disagree	Fairly agree	Agree	Agree very much	Strongly agree
1	2	3	4	5	6	7

7. I never think of quitting my job.

Strongly disagree	Disagree very much	Disagree	Fairly agree	Agree	Agree very much	Strongly agree
1	2	3	4	5	6	7

8. The amount of pressure I feel to perform high quality work is:

Low pressure	Very little pressure	Little pressure	Fairly pressure	Large pressure	Very large pressure	High pressure
1	2	3	4	5	6	7

9. With respect to the scope of independent thought and action in my job, I am:

Extremely dissatisfied	Very dissatisfied	Dissatisfied	Fairly satisfied	Satisfied	Very satisfied	Extremely satisfied
1	2	3	4	5	6	7

10. I derive a great sense of personal satisfaction when I perform well in my job.

Strongly disagree	Disagree very much	Disagree	Fairly agree	Agree	Agree very much	Strongly agree
1	2	3	4	5	6	7

11. Generally speaking, I am extremely pleased with my job.

Strongly disagree	Disagree very much	Disagree	Fairly agree	Agree	Agree very much	Strongly agree
1	2	3	4	5	6	7

12. Personally, I am extremely involved in my work.

Strongly disagree	Disagree very much	Disagree	Fairly agree	Agree	Agree very much	Strongly agree
1	2	3	4	5	6	7

13. With respect to the feeling of self-esteem or self-respect that I derive from my job, I am:

Extremely dissatisfied	Very dissatisfied	Dissatisfied	Fairly satisfied	Satisfied	Very satisfied	Extremely satisfied
1	2	3	4	5	6	7

14. The amount of pressure I experience because of the need to producing a large quantity of work is:

Low pressure	Very little pressure	Little pressure	Fair pressure	Large pressure	Very large pressure	High pressure
1	2	3	4	5	6	7

15. My job involvement is the most important thing that happens to me.

Strongly disagree	Disagree very much	Disagree	Fairly agree	Agree	Agree very much	Strongly agree
1	2	3	4	5	6	7

16. I feel miserable when I perform my job badly.

Strongly disagree	Disagree very much	Disagree	Fairly agree	Agree	Agree very much	Strongly agree
1	2	3	4	5	6	7

17. I am satisfied with the opportunity for personal growth and development in my job.

Strongly disagree	Disagree very much	Disagree	Fairly agree	Agree	Agree very much	Strongly agree
1	2	3	4	5	6	7

18. I like the prestige of my job in the company.

Strongly disagree	Disagree very much	Disagree	Fairly agree	Agree	Agree very much	Strongly agree
1	2	3	4	5	6	7

Appendix D

Statistical Results and Graphs for N=20:

Kinematic Data, EMG (RMS), Heart Rate, Blood

Pressure, Perceived Discomfort and Job Attitudes.

Kinematic Data

Table D1: Summary of all Effects for the neck

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Po	2	2166.83	36	330.53	6.56	0.00
Ti	5	107.42	90	26.70	4.02	0.00
Tri	2	80.84	36	25.52	3.17	0.05
Po*Ti	10	51.41	180	34.39	1.49	0.14
Po*Tri	4	44.84	72	23.19	1.93	0.11
Ti*Tri	10	23.57	180	23.76	0.99	0.45
Po*Ti*Tri	20	29.49	360	28.39	1.04	0.41

N=20 (Po = Posture; Ti = Time; Tri = Trial)

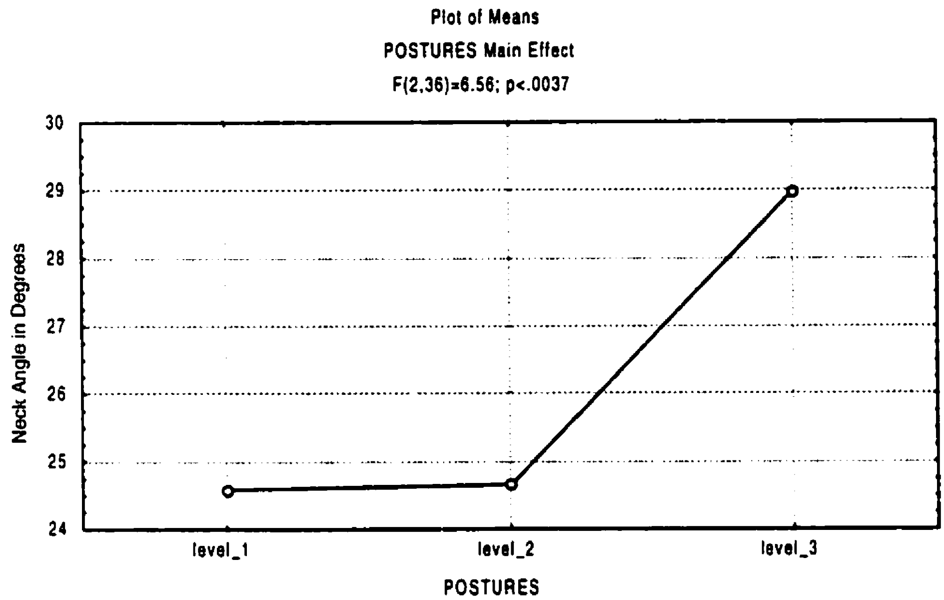
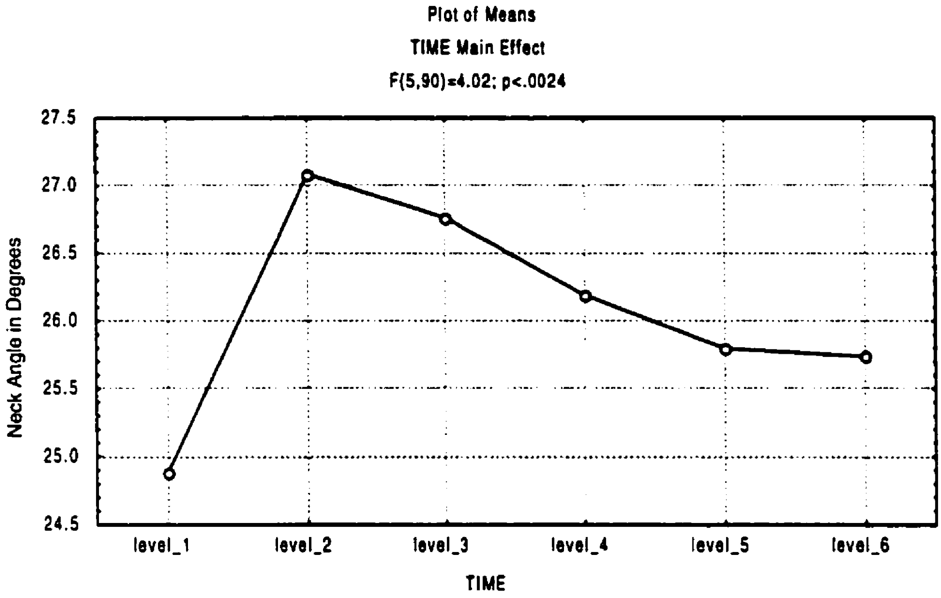
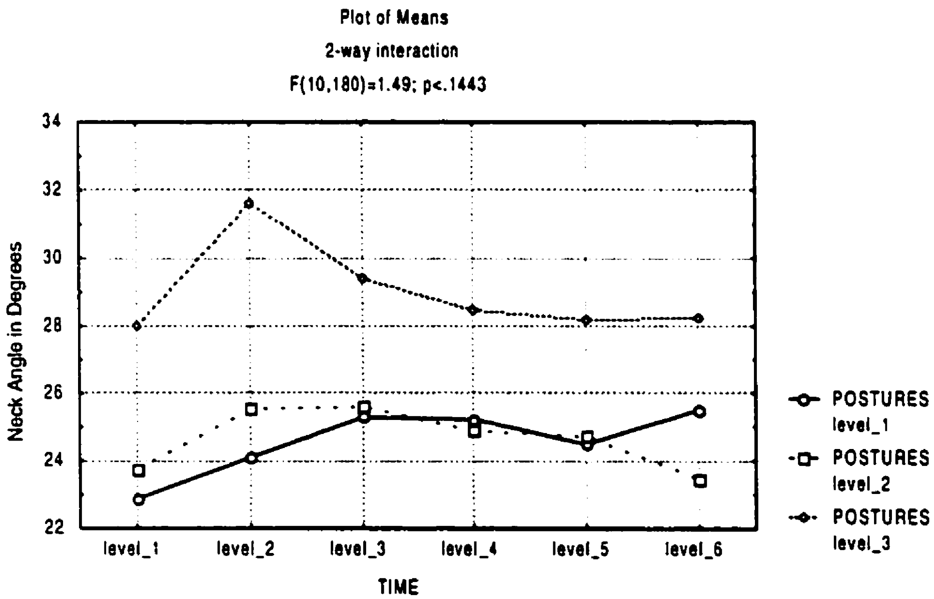


Figure D1: Plot of means for the neck across postures



<u>Figure D2</u>: Plot of means for the neck across time



<u>Figure D3</u>: Plot of means for time and posture effects for the neck

Table D2: Summary of all Effects for the shoulder

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Po	2	31255.35	36	402.16	77.72	0.00
Ti	5	143.21	90	31.80	4.50	0.00
Tri	2	1.70	36	29.35	0.05	0.94
Po*Ti	10	54.49	180	27.72	1.96	0.04
Po*Tri	4	11.44	72	17.91	0.63	0.63
Ti*Tri	10	23.12	180	23.78	0.97	0.47
Po*Ti*Tri	20	22.16	360	23.75	0.93	0.54

N=20 (Po = Posture; Ti = Time; Tri = Trial)

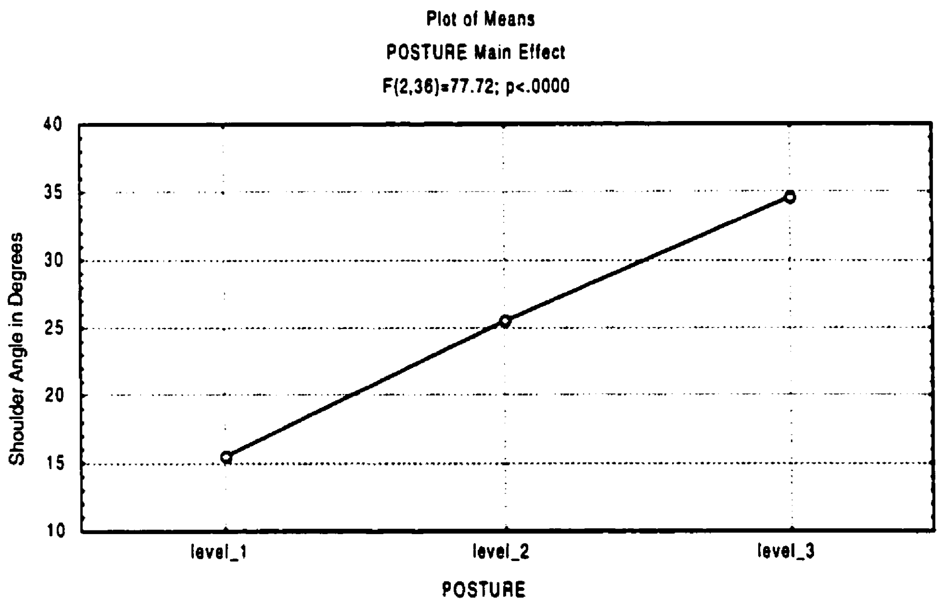


Figure D4: Plot of means for the shoulder across postures

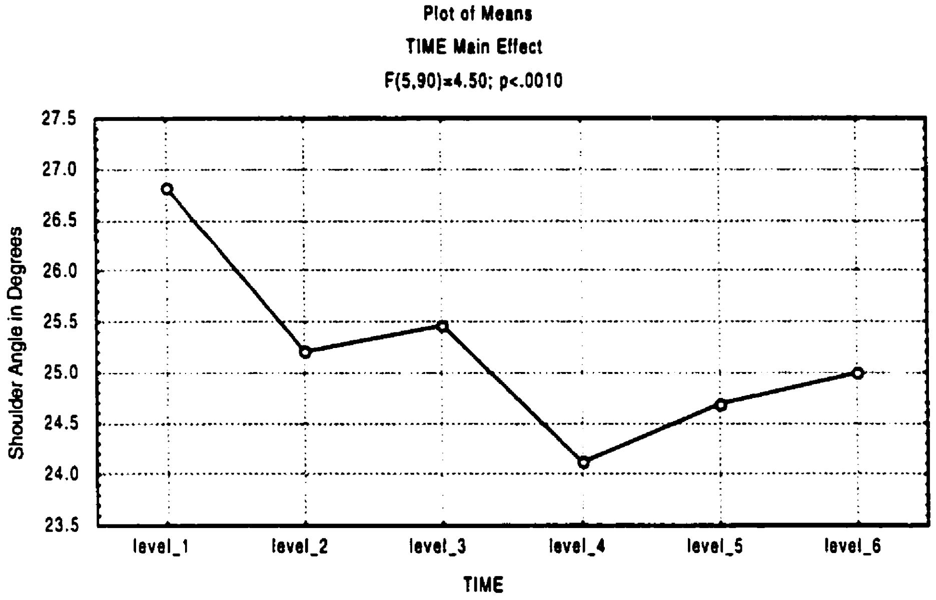


Figure D5: Plot of means for the shoulder across time

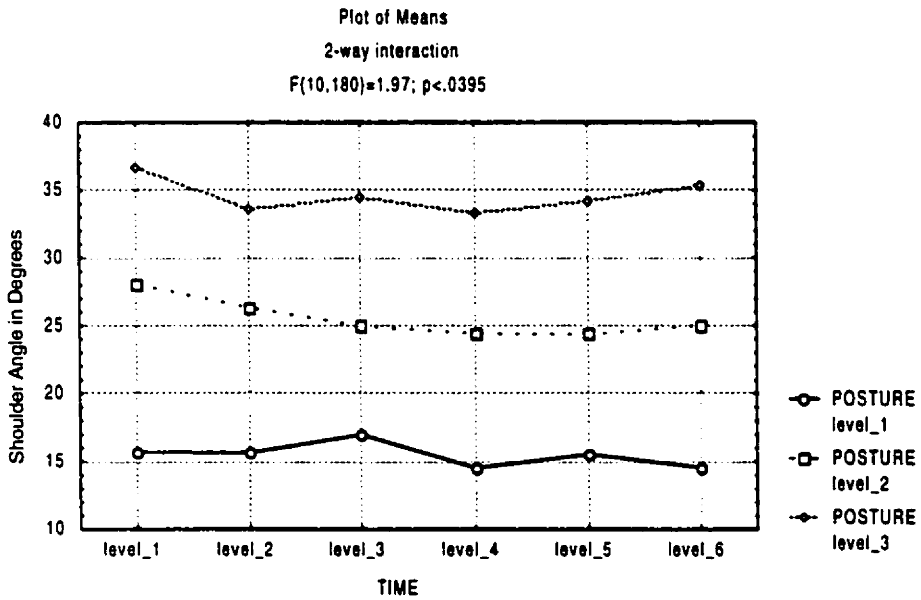


Figure D6: Plot of means for time and posture effects for the shoulder

Table D3: Summary of all Effects for the elbow

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Po	2	5062.02	36	406.92	12.43	0.00
Ti	5	19.17	90	20.05	0.95	0.45
Tri	2	16.09	36	8.71	1.84	0.17
Po*Ti	10	16.99	180	15.12	1.12	0.35
Po*Tri	4	4.12	72	8.47	0.48	0.75
Ti*Tri	10	13.45	180	11.71	1.14	0.33
Po*Ti*Tri	20	14.02	360	10.64	1.31	0.16

N=20 (Po = Posture; Ti = Time; Tri = Trial)

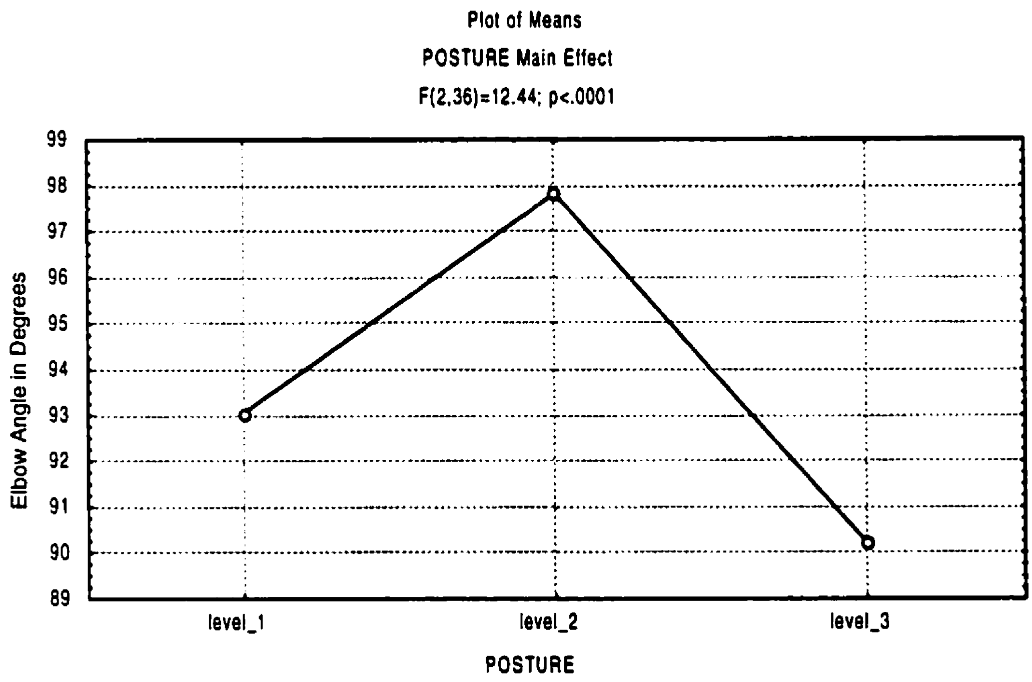


Figure D7: Plot of means for the elbow across postures

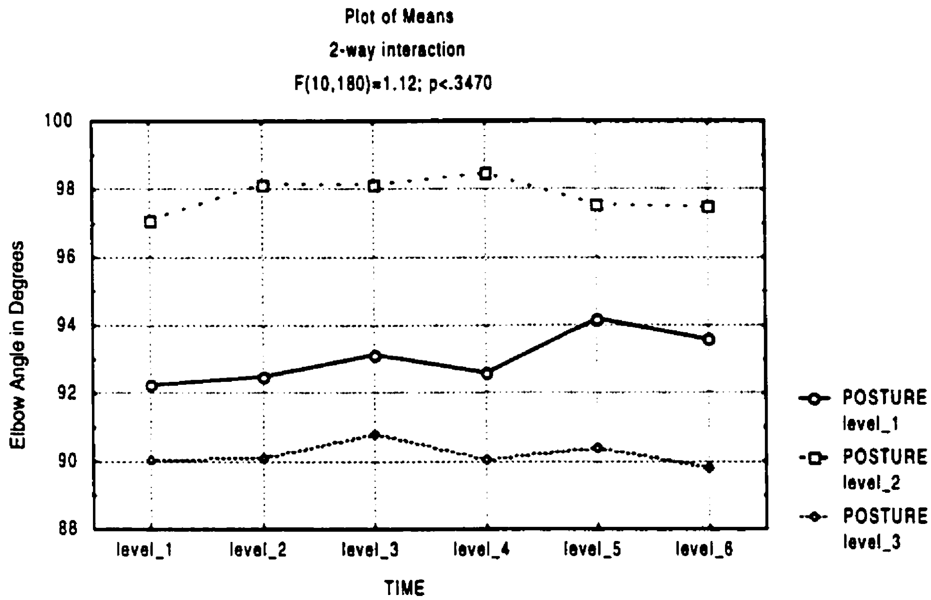


Figure D8: Plot of means for time and posture effects for the elbow

Table D4: Summary of all Effects for the wrist

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Po	2	22490.39	36	260.79	86.24	0.00
Ti	5	55.02	90	33.86	1.62	0.16
Tri	2	13.98	36	35.37	0.40	0.68
Po*Ti	10	23.87	180	30.41	0.79	0.64
Po*Tri	4	30.14	72	33.36	0.90	0.47
Ti*Tri	10	31.66	180	30.96	1.02	0.43
Po*Ti*Tri	20	39.78	360	32.27	1.23	0.22

N=20 (Po = Posture; Ti = Time; Tri = Trial)

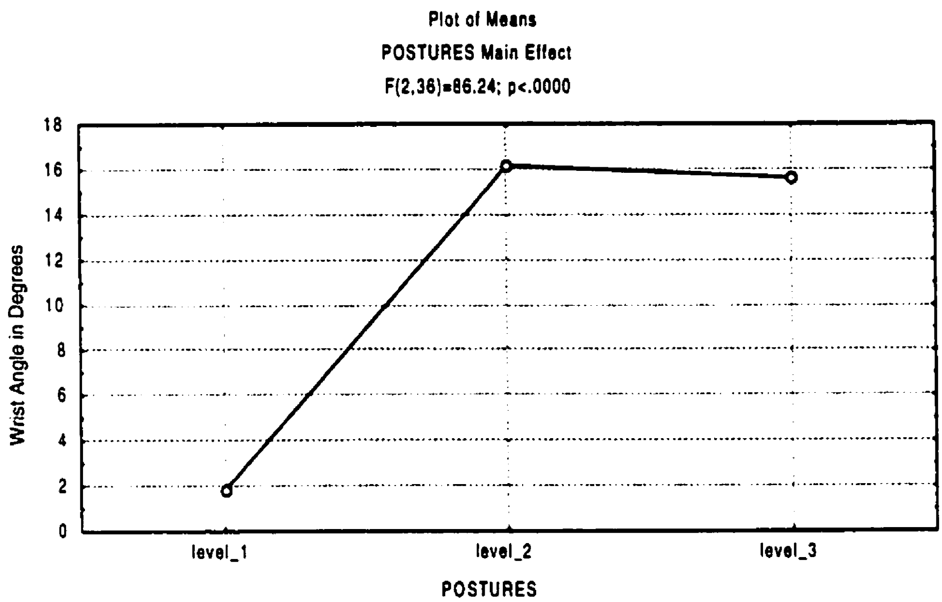


Figure D9: Plot of means for the wrist across postures

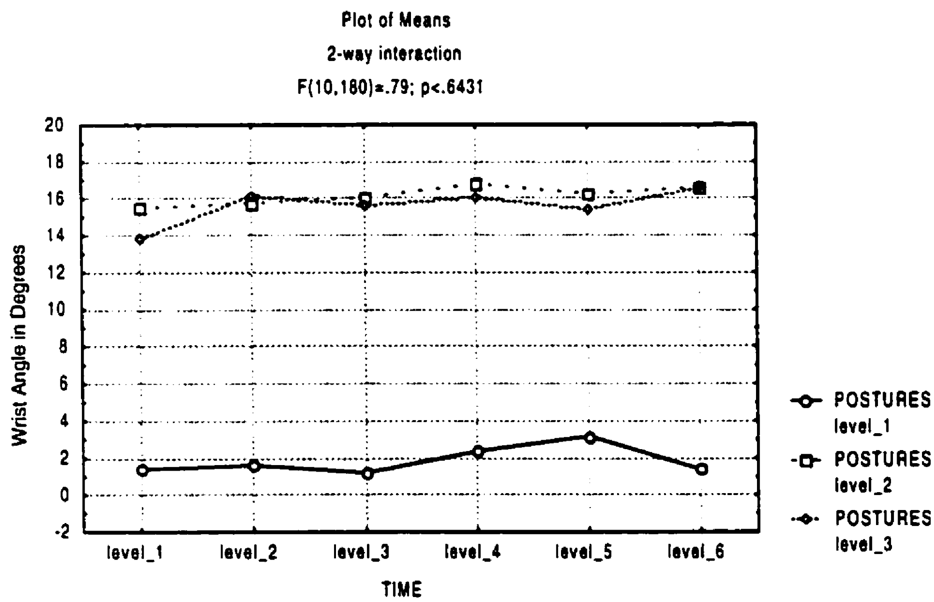


Figure D10: Plot of means for time and posture effects for the wrist

EMG

Table D5: Summary of all Effects for Upper Trapezius

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Po	2	0.01	34	0.00	2.03	0.15
Ti	5	0.00	85	0.00	1.26	0.29
Po*Ti	10	0.00	170	0.00	0.73	0.70

N=20 (Po = Posture; Ti = Time)

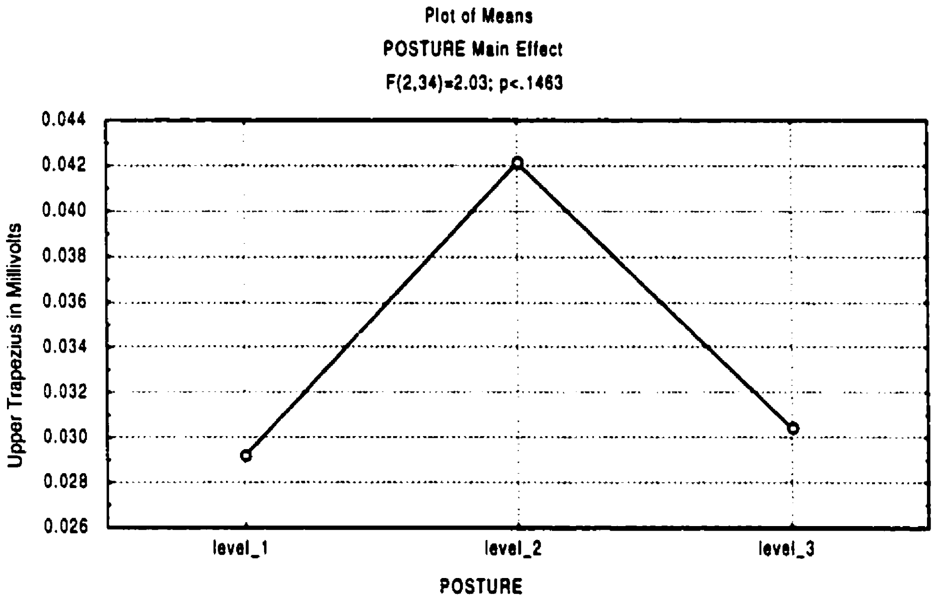


Figure D11: Plot of means for upper trapezius across postures

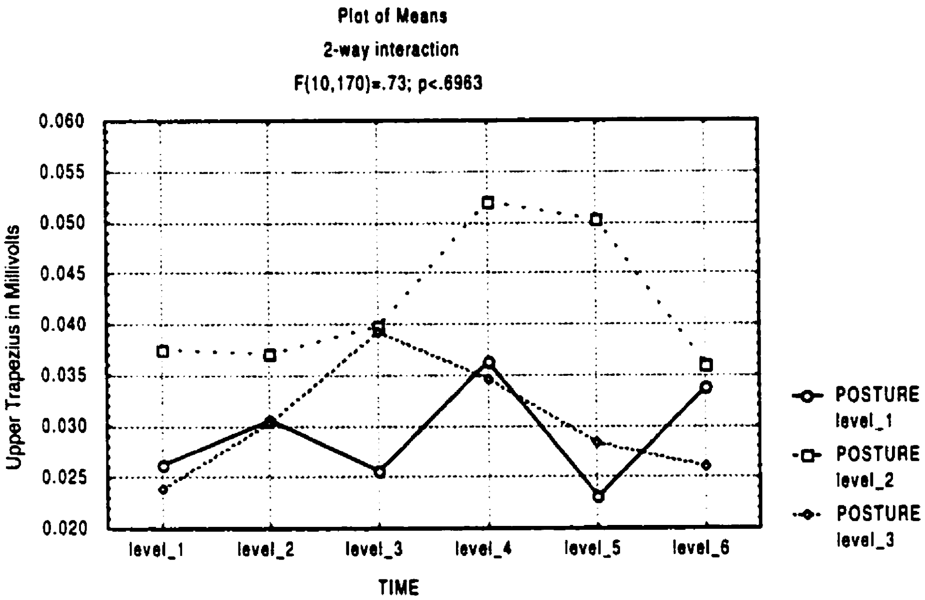


Figure D12: Plot of means for time and posture effects for upper trapezius

Table D6: Summary of all Effects for Anterior Deltoid

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Po	2	0.003758	38	0.007817	0.480753	0.622027
Ti	5	0.001300	95	0.001217	1.068364	0.382877
Po*Ti	10	0.001035	190	0.001573	0.657759	0.762468

N=20 (Po = Posture; Ti = Time)

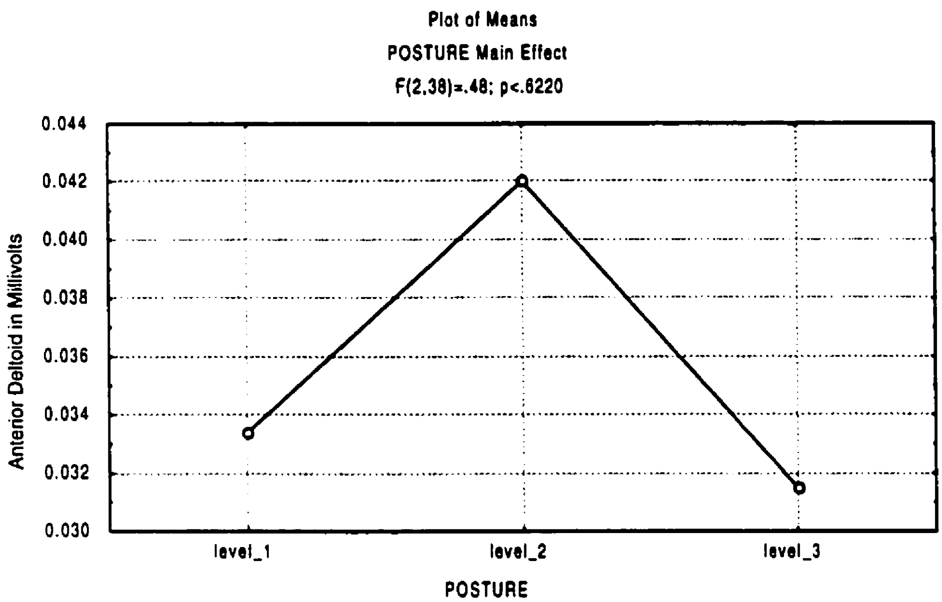


Figure D13: Plot of means for Anterior Deltoid across postures

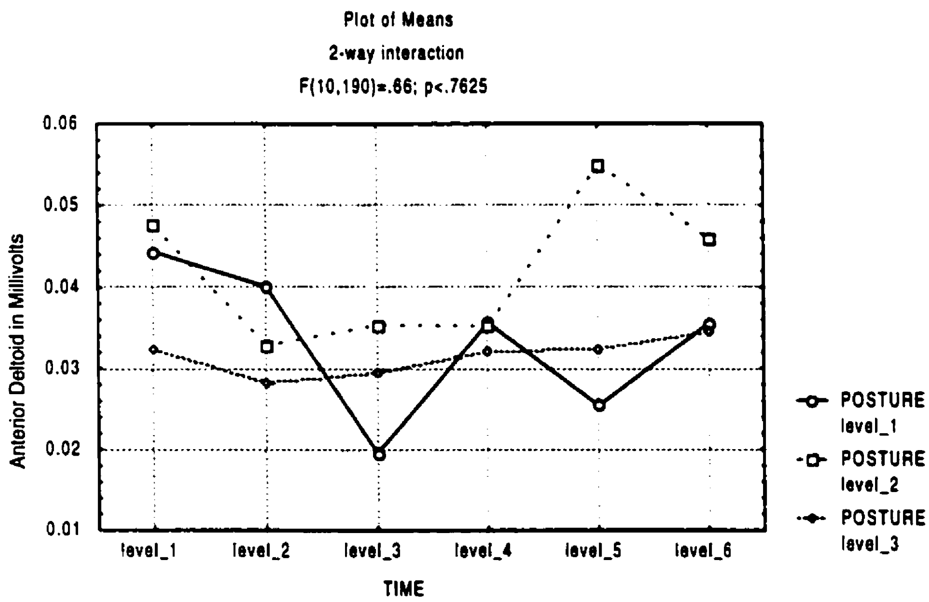


Figure D14: Plot of means for time and posture effects for Anterior Deltoid

Table D7: Summary of all Effects for Biceps Brachii

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Po	2	0.002925	38	0.007934	0.368622	0.694133
Ti	5	0.000928	95	0.003105	0.298840	0.912399
Po*Tri	10	0.003535	190	0.002123	1.665012	0.091560

N=20 (Po = Posture; Ti = Time)

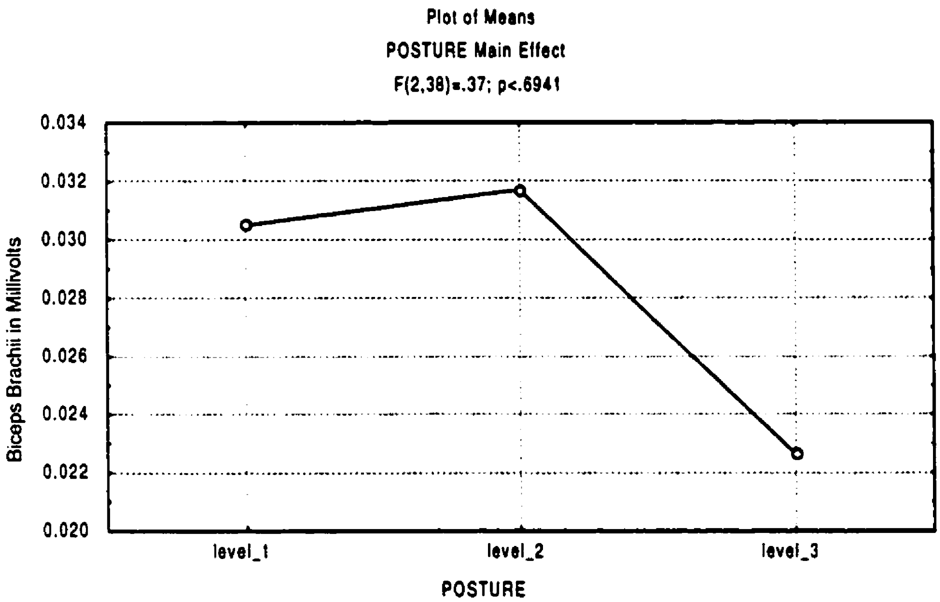


Figure D15: Plot of means for biceps brachii across postures

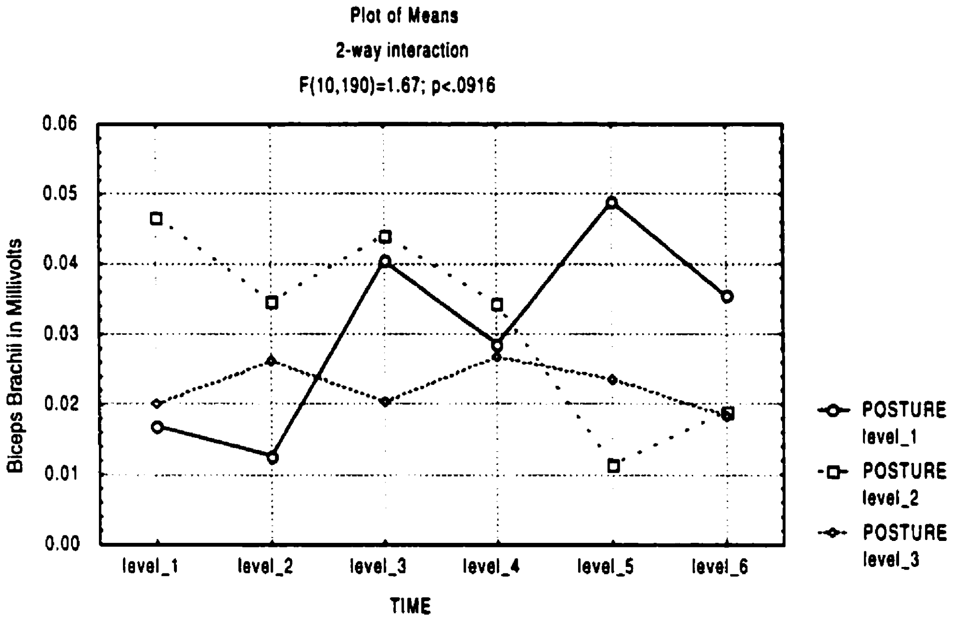


Figure D16: Plot of means for time and posture effects for biceps brachii

Table D8: Summary of all Effects for Forearm Extensors

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Po	2	0.00	38	0.01	0.35	0.70
Ti	5	0.01	95	0.00	3.23	0.01
Po*Ti	10	0.00	190	0.00	0.64	0.78

N=20 (Po = Posture; Ti = Time)

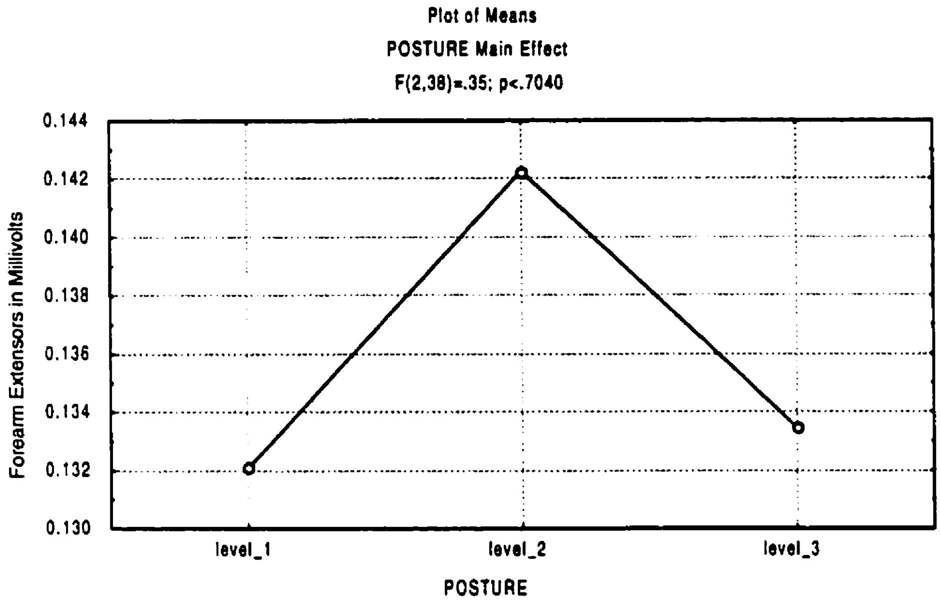


Figure D17: Plot of means for forearm extensors across postures

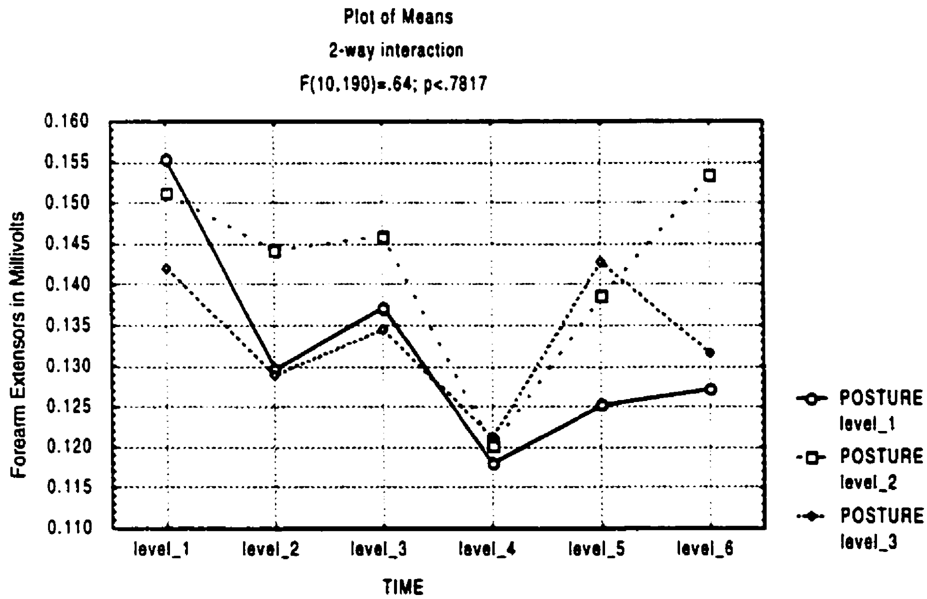


Figure 18: Plot of means for time and posture effects for forearm extensors

Heart Rate Response

Table D9: Summary of all Effects for Heart Rate Response

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Posture	2	32.30	36	10.45	3.09	0.06

N=20

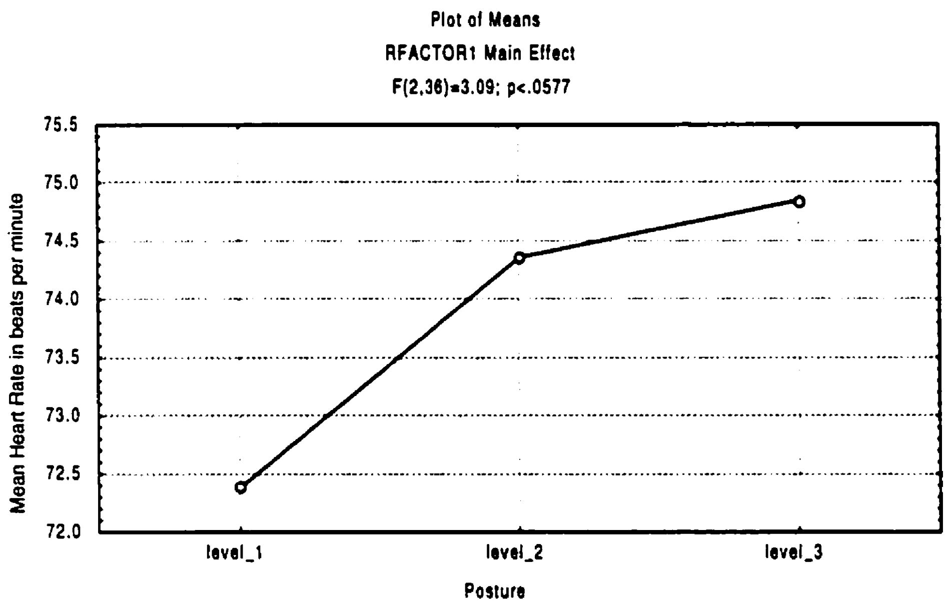


Figure D19: Plot of means for heart rate response across postures

Blood Pressure

Table D10: Summary of all Effects for Systolic Blood Pressure

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Posture	2	16.22	38	60.08	0.27	0.76

N=20

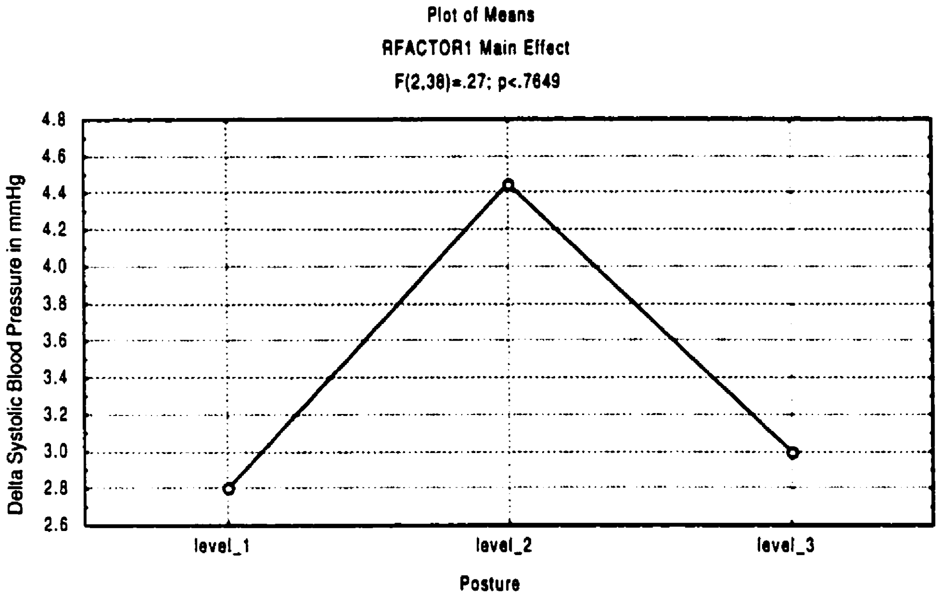


Figure D20: Plot of means for delta systolic blood pressure across postures

Table D11: Summary of all Effects for Delta Diastolic Blood Pressure

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Posture	2	4.87	38	25.46	0.19	0.83

N=20

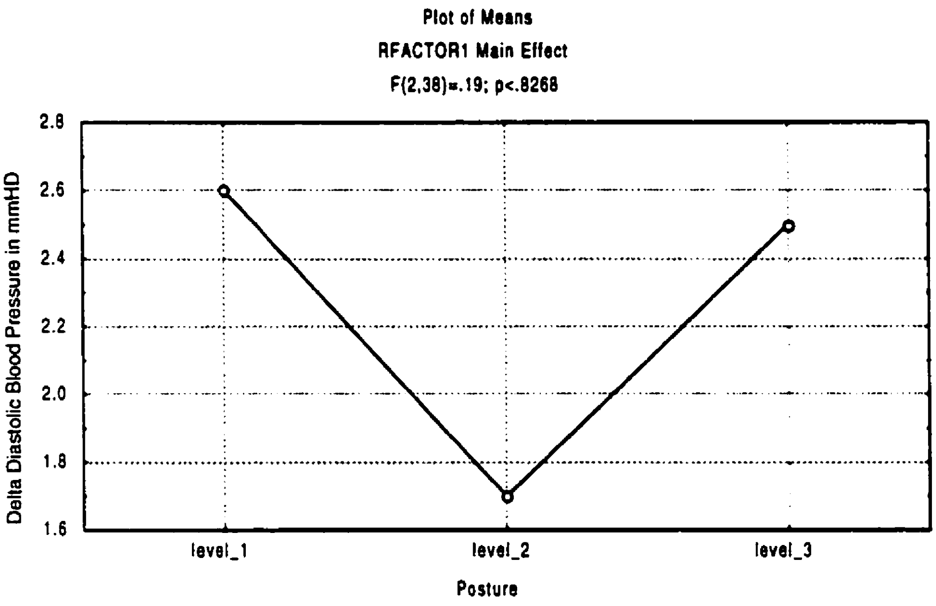


Figure D21: Plot of means for delta diastolic blood pressure across postures

Perceived Discomfort

Table D12: Summary of all Effects for Delta Body Discomfort Scores

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Posture	2	247.85	38	15.48158	16.01	0.00

N=20

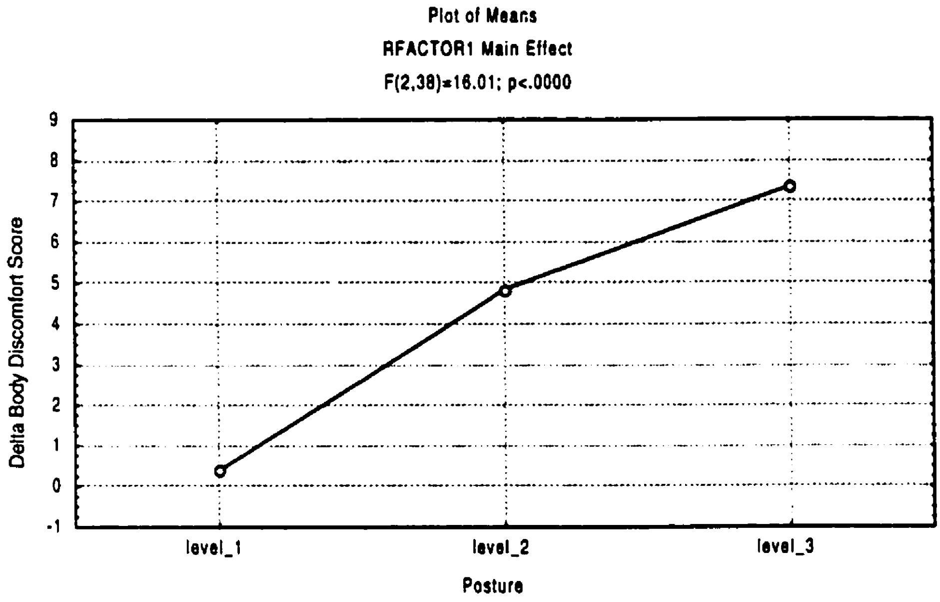


Figure D22: Plot of means for delta body discomfort scores across postures

Job Attitudes

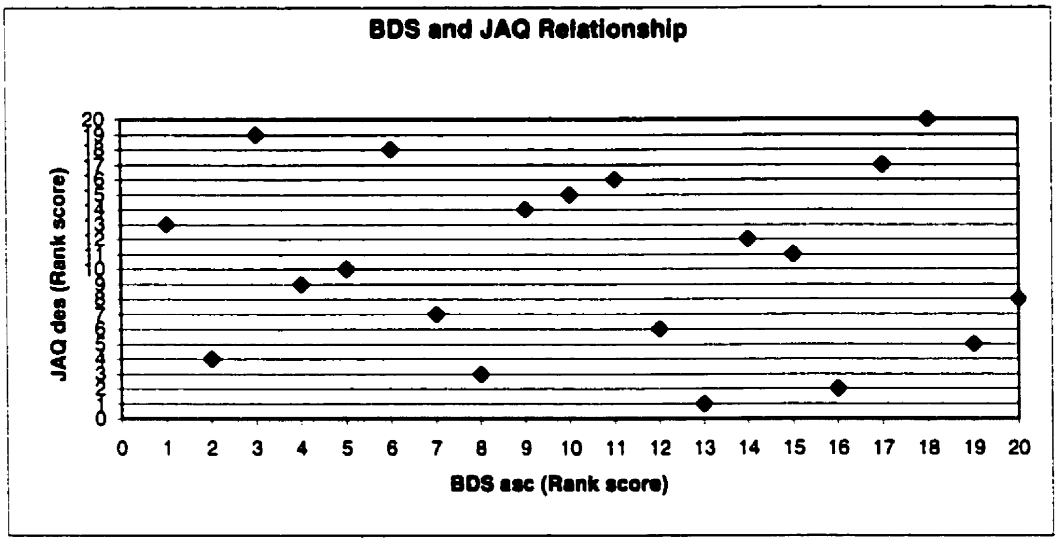


Figure D23: Relationship between job attitude scores and body discomfort scores

Appendix E

Statistical Results for N=11:

Kinematic Data, EMG (RMS), Heart Rate, Blood Pressure, Perceived Discomfort and Word Count.

Table E1: Kinematic Descriptive Statistics

	NECK			SHOULDER			ELBOW			WRIST		
	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3
Mean	30	31	33	13	25	33	94	97	91	4	20	18
SD	10	8	8	4	7	8	4	7	7	3	6	7
Max	50	42	49	19	45	45	101	109	107	12	29	27
Min	16	17	22	6	18	19	88	84	82	0	8	9

N= 11

The multi-way repeated measures ANOVA showed a significant difference in the neck angle (F=3.46, df 2/18, p<0.05), shoulder angle (F=37.12, df 2/18, p<0.00), elbow angle (F=5.23, df 2/18, p<0.02) and wrist angle (F=57.38, df 2/18, p<0.00) across the three working postures. The Tukey HSD post hoc test revealed that there was no significant difference between posture 1 (x=94) and posture 2 (x=96) (p=0.44) as well as between posture 1 and posture 3 (x=90) (p=0.15) for the elbow angle. The Tukey HSD post hoc test revealed that there was no significant difference in wrist angle between posture 2 (x=20) and posture 3 (x=19) (p=0.79). The Tukey HSD post hoc test revealed that there was no significant difference between posture 1 (x=29) and posture 2 (x=30) (p=0.72), as well as between posture 2 and posture 3 (x=33) (p=0.20).

There was a time effect for the neck angle (F=3.68, df 5/45, p<0.01) and shoulder angle (F=3.73, df 5/45, p<0.01). The Tukey HSD post hoc test revealed that a significant time effect for the neck angle was found between time 1 (x=29) and time 2 (x=32) (p=0.01); and time 1 and time 3 (x=32) (p=0.02). The Tukey HSD post hoc test revealed that a significant time effect for the shoulder angle was found between time 1 (x=26) and time 4 (x=23) (p=0.02); and time 1 and time 5 (x=23) (p=0.01).

Table E2: EMG (RMS) Descriptive Statistics in millivolts.

	Upper Trapezius			Anterior Deltoid			Biceps Brachii			Forearm Extensors		
	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3	Post 1	Post 2	Post 3
Mean	0.0304	0.0544	0.0287	0.0428	0.0438	0.0273	0.0113	0.0135	0.0155	0.1232	0.1510	0.1433
SD	0.0209	0.0611	0.0200	0.0668	0.0430	0.0141	0.0088	0.0069	0.0183	0.0606	0.0659	0.0656
MAX	0.0681	0.2197	0.0655	0.2175	0.1648	0.0605	0.0252	0.0257	0.0688	0.2197	0.3285	0.2234
MIN	0.0077	0.0129	0.0079	0.0032	0.0067	0.0057	0.0031	0.0053	0.0040	0.0447	0.0956	0.0180

N=11

The multi way repeated measures ANOVA and the Tukey HSD post hoc test revealed a non significant difference in the upper trapezius (F=0.88, df 2/18, p<0.43), anterior deltoid (F=0.49, df 2/20, p<0.62), biceps brachii (F=0.36, df 2/20, p<0.70) and forearm extensors (F=1.29, df 2/20, p<0.30) across the three working postures. There was a time effect for the forearm extensors (F=2.48, df 5/50, p<0.04). The Tukey HSD post hoc test demonstrated a significant time effect between time 1 (x=0.1540) and time 4 (x=0.1181) (p=0.02).

Table E3: Heart Rate Response Descriptive Statistics in beats per minute.

	Posture 1	Posture 2	Posture 3
Mean	72	74	75
SD	12	12	11
Max	85	92	88
Min	49	54	53

N=11

The one-way repeated measures ANOVA and the Tukey HSD post hoc test showed no significant difference in heart rate (F=2.14, df 2/20, p<0.14) across the three working postures.

Table E4: Delta Blood Pressure Descriptive Statistics in mmHg.

	Systolic Blood Pressure			Diastolic Blood Pressure		
	Posture 1	Posture 2	Posture 3	Posture 1	Posture 2	Posture 3
Mean	1	5	4	3	2	6
SD	9	14	6	5	9	8
Max	14	41	14	13	24	28
Min	-11	-10	-8	-5	-1	-8

N=11

The one-way repeated measures ANOVA and the Tukey HSD post hoc test revealed a no significant difference in systolic blood pressure (F=0.70, df 2/20, p<0.51) and in diastolic blood pressure (F=1.64, df 2/20, p <0.22) across the three working postures.

Table E5: Delta Body Discomfort Scores Descriptive Statistics.

	Posture 1	Posture 2	Posture 3
Mean	1	4	8
SD	3	6	6
Max	5	20	26
Min	3	6	7

N=11

The one-way repeated measures ANOVA test demonstrated a significant difference in perceived discomfort (F=9.26, df 2/20, p<0.00) across the three working postures. The Tukey HSD post hoc test revealed a non significant difference in perceived discomfort between posture 2 and posture 3 (p=0.13); and between posture 1 and 2 (p=0.08).

Table E6: Performance (word count) Descriptive Statistics.

	Posture 1	Posture 2	Posture 3
Mean	725	733	638
SD	238	254	221
Max	1180	1240	1023
Min	392	388	341

N=11

The one-way repeated measures ANOVA demonstrated a significant difference in word count ($F=23.78$, df 2/20, $p<0.00$) across the three working postures. The Tukey HSD post hoc test revealed a non significant difference between postures one and two ($p=0.86$).

Appendix F

Statistical Results for Delta Heart Rate over Time

Table F1: Summary of all Effects for delta Heart Rate over time

Source	DF Effect	MS Effect	DF Error	MS Error	F	P
Posture	2	0.33	36	7.39	0.06	0.96

N=20

Table F2: Delta Heart Rate over time Descriptive Statistics

Source	Mean	SD	Max	Min	Variance
Post1	1.65	2.78	7	-3	7.71
Post 2	1.40	2.80	7	-5	7.83
Post 3	1.68	3.38	10	-3	11.45

N=20

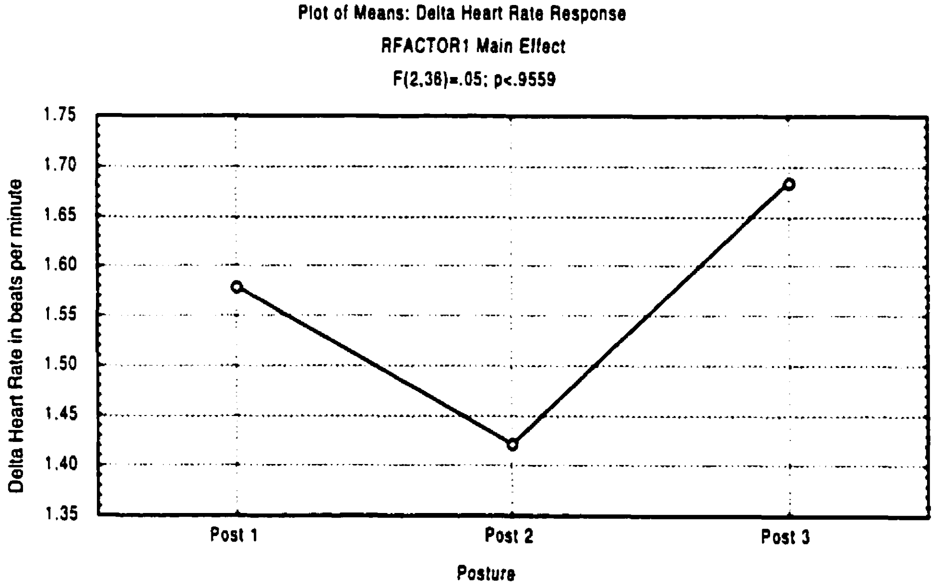


Figure F1: Plot of means for delta heart rate over time across postures

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