School of Physiotherapy

An Analysis of Posture, Muscle Activity and Keyboard Dynamics in Computer Users with and without Work-Related Neck and Upper Limb Disorders

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ABSTRACT

Computer technology has advanced rapidly in the past few decades and computers have become a very important and powerful tool in our everyday lives. Prolonged computer use by office workers has been reported to result in an increased risk of developing Work-related Neck and Upper Limb Disorders (WRNULD) (Bernard et al., 1994; Faucett & Rempel, 1994; Tittiranonda et al., 1999). The occupational risk factors associated with prolonged computer use include static posture and the speed and force of keyboard operation. Past studies have examined different aspects of these risk factors through measuring muscle electrical activity (EMG), kinematics and keyboard forces. However, most of these studies have been conducted on healthy painfree subjects and even the few Case-Control studies have not clearly established any direct relationships between the risk factors and WRNULD.

The present research project consisted of a series of three studies aimed at investigating whether there were intrinsic differences among different individuals in response to different physical stressors. These intrinsic differences may have important implications to help explain why some individuals would develop WRNULD while others do not. The individuals' responses to the demands of three physical stressors: static posture, speed and force of keyboard operation were assessed. The internal exposure measures of kinematics, EMG, keyboard dynamics and subjective discomforts were used to evaluate the inter-individual differences.

Study 1 was a field investigation comparing the neck-shoulder kinematics between symptomatic ("Case", n=8) and asymptomatic ("Control", n=8) office workers. Results showed trends for consistently greater head tilt and neck flexion angles, and greater ranges of movements in the Case Group than the Control Group. The Case Group also exhibited a trend for increased acromion protraction compared to the Control Group. The Case Group also reported significantly greater discomfort scores compared to the Control Group ($F_{1,14}$=39.3, $p<.0001$). Neither the discomforts nor the kinematics displayed any significant changes over a working day.

Study 2 was a laboratory study comparing the responses of Case and Control Groups in terms of EMG, kinematics and subjective discomforts, while a standardised computer task was performed continuously for one hour. The responses of Case (n=23) and Control (n=20) Groups were compared to examine the effects of static posture. The results showed similar trends to those in Study 1, with increased neck flexion mean angles and ranges of movements in the Case Group compared to the Control Group. In terms of EMG results, there were trends for EMG amplitude differences in the right upper trapezius (UT) and cervical erector spinae (CES) muscles between Case and Control Groups. These trends became statistically significant when the Case subjects were sub-divided into the High (n=15) and Low (n=8) Groups based on their mean discomfort scores.

Study 3 was also a laboratory study to compare the Case (n=21) and Control (n=20) Groups when they were challenged by the physical stressors of speed and force of keyboard operation. In this study, each subject's EMG and discomforts were examined in three typing conditions of normal speed and force, increased typing speed and increased typing force. The Case Group showed trends for higher increases in both UT and CES muscle activities than the Control Group, and when divided into the High-Low Groups, the High Group (n=8) showed trends for much higher muscle activities in all

three conditions. Beside muscle activity changes, the High Group subjects also demonstrated a trend for much higher within-subject Speed and Force Variabilities in their keystroke performance, compared to the Low Group and the Control Group. This result implied that the High Group subjects had a more erratic motor control of the keystroke actions.

Based on these results, conceptual models were developed to describe the relationships among the physical stressors, internal exposure responses and discomforts. The Altered Motor Control Model refers to the programmed changes in motor control strategies involving muscle recruitment and joint movement patterns, and these changes were closely related to the subjects' musculoskeletal discomforts. The Heightened Sensitivity Model describes the higher sensitivity levels of individuals with more severe discomforts, in response to the demands of physical stressors. These models are closely related and heightened sensitivity may be an 'effect-modifier" of the motor control mechanisms and the perception of discomforts or pains within the individual.

In conclusion, the present research has identified important differences between individuals on the basis of their motor control strategies which may contribute to the development of WRNULD. While the present research has mainly examined the individual responses to three physical stressors, it is possible that the models developed may be applicable to other physical stressors. These findings may also have important implications for future ergonomic research, emphasising the need to address inter-individual differences in ergonomic interventions to workers. Further research should be directed towards better understanding of these intrinsic individual differences in both physical and non-physical factors that contribute to the development of WRNULD.

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This thesis has been the most intense project I have pursued in my whole life; of course, still second place to having two children by caesarean sections 13 and 10 years ago. I have many good teachers, friends and family to thank for all this!

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I am also deeply grateful to many past and present colleagues who have given me advice and support along the way, Professor S.K. Lo, Dr. Roger Scudds, Dr. Andrew Smith, Dr. Margaret Mak, and Dr. Marie Blackmore. I must also thank our most efficient technical staff, Mr. M. Cheung, K. Kan, S. C. Siu, and Mr. Wong, without their support I could not have managed all the complex technical procedures involved in this study. I would also like to acknowledge the assistance of Susan Peng and Eugenie Ho in the data collection process, and all the subjects who have been most cooperative throughout this research project.

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Finally, my heart goes to my family - my husband Sun and my two children Cameron and Rebecca, who have stood by me in all these years. My parents, brothers and sisters have also been most supportive to me. To my beloved Cameron and Rebecca, for the many Saturdays and Sundays that you have worked with me as my "research assistants", I promise to make it up to you for all the "lost" times in the future.

DECLARATION BY CANDIDATE

I, Pui Yuk Grace Szeto, declare that the thesis titled "An analysis of posture, muscle activity and keyboard dynamics in computer users with and without work-related neck and upper limb disorders" is my own work and contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief it does not contain any materials previously published by any other person except where due acknowledgment has been made.

Pui Yuk Grace Szeto

CO-AUTHORSHIP OF PAPERS

PhD Thesis

"An analysis of posture, muscle activity and keyboard dynamics in computer users with and without work-related neck and upper limb disorders

by

Pui Yuk Grace Szeto

I, the supervisor of the Doctoral Thesis of Pui Yuk GRACE SZETO, declare that, although I am the joint author of the paper she has produced during the course of the course of her research at Curtain University of Technology, the work presented is essentially her own.

The ideas generated in this thesis, the analytical work undertaken and the interpretation are the work of the student. My involvement has been in providing guidance, training and financial support during the course of her studies; the normal activities associated with supervision. With respect to the published papers, I have also provided editorial advice.

Signed:

Associate Professor Leon Straker

Supervisor

LIST OF ABBREVIATIONS

ACR-X	Acromion displacement along the X axis
ACR-Y	Acromion displacement along the Y axis
AD	Anterior deltoid
A/D	Analog to digital conversion
Ag-AgCl	Silver-silver chloride
ANOVA	Analysis of variance
APDF	Amplitude Probability Distribution Function
C7	Seventh cervical vertebra
CES	Cervical erector spinae
CV	Coefficient of variation
ECG	Electrocardiogram
EVA	Exposure variance analysis
EMG	Electromyography
HT	Head tilt
ICC	Intraclass correlation
LT	Lower trapezius
MANOVA	Multivariate analysis of variance
%MEMG	Percentage of Maximum electrical muscle activity
MF	Median frequency
MPF	Mean power frequency
MSD	Musculoskeletal disorders
MVC	Maximal voluntary contraction
NF	Neck flexion
OWAS	Ovako Working Posture Analysis
RMS	Root mean square
RULA	Rapid Upper Limb Assessment
SD	Standard deviation
SPSS	Statistical Package for the Social Sciences
T1-5	Trial 1-5
T6	Mean of Trial 1-5
UT	Upper trapezius
VDU	Visual display unit
WRNULD	Work-related Neck and Upper Limb Disorders
cm	centimeters
g	grams
Hz	Hertz
K ohms	Kilo-ohms
mm	Millimeters
ms	Milliseconds
N	Newton

STUDIES AND CHAPTERS

Study 1

A Field Comparison Of Neck And Shoulder Postures And Discomforts In Symptomatic And Asymptomatic Office Workers

Chapter 3
A Field Comparison Of Neck And Shoulder Postures In Symptomatic And Asymptomatic Office Workers

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A Comparison Of Neck And Shoulder Postures And Movements In Symptomatic And Asymptomatic Office Workers Performing Monotonous Keyboard Work

Study 3

A Laboratory Study To Compare EMG, Keystroke Performance And Discomfort Between Symptomatic And Asymptomatic Office Workers In Response To Increased Typing Speed And Increased Typing Force

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Chapter 8
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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

The use of computers is growing at an astonishing rate and the associated health problems are also rising rapidly. The collective group of disorders affecting the musculoskeletal system can be termed Work-related Neck and Upper Limb Disorders (WRNULD). These disorders are affected by a number of major occupational risk factors that may have different effects on different individuals.

This chapter is an introductory chapter to the thesis and it contains two parts. Part (A) is the Introduction that will briefly describe the worldwide trends of computer domination, the rising rates and definitions of WRNULD. The scope of the present research study will be defined and the research output produced from this work will be reported. Part (B) contains an extensive review of the literature relevant to the present research study. The overall research question will be presented at the end of this chapter.

CHAPTER 1

(A) INTRODUCTION

1.1 WORLDWIDE TRENDS OF INCREASING COMPUTER USE AND RELATED MUSCULOSKELETAL PROBLEMS

Computerization is rapidly overtaking many aspects of people's lives, including work and activities of daily living (National Telecommunications and Information Administration, or NTIA, 2002). The number of computer users is accelerating at an astonishing rate, especially in the business sector. In the United States of America alone in 2001, 65 million out of 115 million adults (56.7%) who were employed and aged over 25, used a computer at work (NTIA, 2002). In Australia, 66% of all adults (9.2 million) used a computer in the 12 months up to November 2000 (Australian Bureau of Statistics, 2000).

The worldwide trend is for people to also use computers for longer periods each day, due to the widespread growth in computer-related applications to control and facilitate many aspects of business and leisure. There is thus a potential increase in the risk of musculoskeletal disorders associated with computer use.

1.2 DEFINITIONS OF WORK-RELATED NECK AND UPPER LIMB DISORDERS (WRNULD)

WRNULD are common problems in office workers, especially among those who use the computer intensively (Bergqvist, 1993; Bernard, Sauter, Peterson, Fine, & Hales, 1994; Hagberg et al., 1995; Hagberg & Wegman, 1987; Kamwendo, Linton, & Moritz, 1991a & b; Tittiranonda, Burastero, & Rempel, 1999). Other names that have been used for these disorders include: work-related musculoskeletal disorders, cumulative trauma disorders, repetitive strain injuries, occupational cervicobrachial disease, and occupational overuse injury (Hagberg et al., 1995; Hagberg & Wegman, 1987; National Institute for Occupational Safety and Health, "NIOSH", 1997; Silverstein, Fine, & Armstrong, 1986). The term WRNULD is used throughout this thesis as it emphasizes the location of the problems - the neck and upper limb region, as well as the "work-relatedness", which are the foci of this research work.

The definition of WRNULD used in this thesis excludes musculoskeletal accidents and refers to disorders presenting with discomfort or pain in the neck and upper limb regions that are aggravated or related with work (Buckle & Devereux, 2002; Hagberg et al., 1995). The present research mainly focuses on the work tasks related to computer use, as computers have become the main instrument used by office workers everyday.

1.3 SCOPE OF THE PRESENT RESEARCH

Past ergonomic research has identified the occupational risk factors of static posture, speed and force of movements, as factors contributing to WRNULD. However, occupational research studies have often only examined the responses of healthy painfree individuals. The present body of research work attempts to examine whether individuals with a past and present history of WRNULD would show similar responses as those without problems, when they are exposed to the same doses of physical stressors in their work. This approach may reveal important intrinsic differences within individuals that contribute towards the development of WRNULD.

The present research work consisted of a series of three studies, Study 1 being a field investigation while Studies 2 and 3 were laboratory based. The aims of the three studies were to examine and compare the internal exposure responses of symptomatic and asymptomatic female office workers, when they were exposed to the physical stressors of static posture, increased speed and increased force of keyboard operation.

The following section in Chapter 1 (Part B) contains a review of the background literature on the topics relevant to this thesis, culminating in the formulation of the overall Research Question. Chapter 2 is a synopsis of the research designs and method issues involved in the three studies. Chapters 3 – 8 contain the detailed description of the research methods and results of the three studies. As the three studies involved complex procedures of data collection including motion analysis systems, electromyography (EMG) and measurement of keyboard dynamics, the results of the three studies were presented separately in several chapters in order to allow sufficient in-depth discussions of the different types of findings.

Chapter 3 is specifically about Study 1. Chapters 4-6 describe three important aspects of EMG amplitude analysis, EMG median frequencies and kinematics analysis that have been produced from Study 2. The findings of Study 3 are presented in Chapters 7 and 8, on the EMG analysis and keyboard dynamics respectively. Chapter 9 is an overall discussion linking together the results of the three studies, leading to the development of two conceptual models. These models explore the relationships between the physical stressors, the internal exposure responses and the development of musculoskeletal discomforts in different individuals.

1.4 RESEARCH OUTPUT

One of the present studies has already been published in a peer-reviewed journal and some of the findings have been presented at international scientific conferences. Chapter 3 is a write-up of Study 1 which has been published in the journal of Applied Ergonomics, 2002. Chapters 4-8 have been written in the format of scientific papers and they are in the process of being submitted to internationally recognized journals. Some of these findings have also been and will be presented at international ergonomic conferences, such as the International Ergonomics Association triennial conferences. .

Here is a list of publications associated with the present research:

Szeto, G. P. Y., Kirtley, C., Raine, S., & Straker, L. M. (2000). Evaluating neck and shoulder posture in keyboard operators. In D. Worth (Ed), *Moving In on Occupational Injuries* (pp. 148-159). Melbourne: Butterworth Heinemann.

Szeto, G. P. Y., Straker, L., Raine, S., & Kirtley, C. (2000). Relationship of neck and shoulder posture and musculoskeletal discomfort in VDU workers. Poster presentation at the IEA XIVth Triennial Congress, San Diego, California, U.S.A., Jul 30-Aug 4, 2000.

Szeto, G. P. Y., Straker, L., & Raine, S. (2002). A field comparison of neck and shoulder postures in symptomatic and asymptomatic office workers. *Applied Ergonomics, 33*, 75-84.

Szeto, G. P. Y., Straker, L. M., & O'Sullivan, P. (2003). The roles of upper trapezius and cervical erector spinae in controlling the neck-shoulder postures in symptomatic office workers performing continuous keyboard work: towards developing an etiological model for work-related neck and upper limb disorders. Full conference paper accepted by the IEA XVth Triennial Congress, Seoul, Korea, Aug 25-29, 2003.

Szeto, G. P. Y., Straker, L. M., & O'Sullivan, P. (2003). Intrinsic differences in individual responses when performing the same task in the same environment: A critical factor in the etiology of work-related neck and upper limb disorders. Full conference paper accepted by the IEA XVth Triennial Congress, Seoul, Korea, Aug 25-29, 2003.

(B) LITERATURE REVIEW

1.5 RISING PREVALENCE RATES OF WORK-RELATED NECK AND UPPER LIMB DISORDERS IS RELATED TO THE INCREASING USE OF COMPUTERS

The collective disorders known as WRNULD are prevalent all over the world. For example, in the Netherlands and Belgium, the 12 month prevalence rates of WRNULD were reported at 30% and 40% respectively (Buckle & Devereux, 2002). In a recent survey of over 600 office workers in Hong Kong, the 12-month period prevalence rate of work-related neck and shoulder discomforts associated with computer use was 56% (Siu & Chan, 1998). Prevalence rates in the range of 20-80% have been reported in a number of studies internationally – the large variations in figures reported may be partly due to differences in case definitions used in different studies. Such figures have been reported either inclusive of all occupations (Buckle & Devereux, 2002; Hagberg & Wegman, 1987; Grieco, Molteni, De Vito, & Sias, 1998; NIOSH, 1997; Silverstein et al., 1986; Sommerich, McGlothlin, & Marras, 1993), or solely for office workers (Bernard et al., 1994; Bergqvist, Wolgast, Nilsson, & Voss, 1995; Faucett & Rempel, 1994; Hagberg, Tornqvist, & Toomingas, 2002; Kamwendo et al., 1991a; Marcus & Gerr, 1996; Siu & Chan, 1998; Tittironanda et al., 1999).

There are current trends for this group of disorders to increase not only in frequency rates, but also in terms of severity, resulting in long-lasting work disabilities (Buckle & Devereux, 2002; Hagberg et al., 2002; Pransky, Benjamin, Hill-Fotouhi, Fletcher, & Himmelstein, 2002).

Among office workers, there is evidence from epidemiological studies that the prevalence rates of WRNULD are higher among computer users compared to non-computer users, especially in those who use the keyboard intensively (Bernard et al., 1994; Faucett & Rempel, 1994; Green & Briggs, 1990; Hales et al., 1994; Kamwendo et al., 1991a; Marcus & Gerr, 1996; Tittiranonda et al., 1999).

Among the musculoskeletal problems in the upper body that are related to computer use, the proximal region (neck and shoulder) has consistently been reported to have higher prevalence rates than the distal region (elbow or wrist-hand) (Bernard et al., 1994; Bergqvist et al., 1995; Kamwendo et al., 1991a & b; Westgaard, Jensen, & Hansen, 1993). Westgaard et al. (1993) reported a 48% prevalence of neck-shoulder symptoms in office workers, whereas the distal arm region had only 18%. Marcus and Gerr (1996) reported 63% of office workers with symptoms in the neck or shoulder region, while 34% reported arm-hand symptoms. Bernard et al. (1994) conducted a survey of over 900 newspaper workers and they also reported higher one-year prevalence rates in the neck and shoulder (26 and 17%), followed by elbow and hand-wrist (10 and 22 %). Similar figures have also been reported in Hong Kong (Siu & Chan, 1998). These figures reflected that the neck-shoulder region is more commonly affected than the distal regions, and therefore the present research has mainly focused on the proximal region.

1.6 STATIC POSTURE, SPEED AND FORCE OF MOVEMENTS ARE MAJOR OCCUPATIONAL RISK FACTORS FOR WRNULD

The occupational risk factors associated with WRNULD can be broadly divided into external risk factors and internal risk factors; both groups are thought to interact and together they influence the development of WRNULD (Aaras & Ro, 1999; Hagberg et al., 1995; Winkel & Westgaard, 1992). External factors refer to conditions in the physical work environment, work organization and the nature of work tasks (Hales et al., 1994; Tittironando et al., 1999). Internal risk factors include those of individual characteristics (age, gender, psychological profile, general health status, past injuries) (Bongers, De Winter, Kompier, & Hildebrandt, 1993; Bernard et al., 1994; Faucett & Rempel, 1994; Hagberg et al., 1995; Jensen, Nilsen, Hansen, & Westgaard, 1993a; Westgaard et al., 1993); as well as internal physiological responses activated in performing the work task (muscle forces, joint movements, etc) (Forde, Punnett, & Wegman, 2001; Kumar, 2001; Westgaard, 1999; Winkel & Westgaard, 1992).

The term "exposure" or "exposure level" is often used in relation to occupational risk factors. Exposure can be defined as the extent to which an individual is "exposed" to or in contact with the risk factor (Hagberg et al., 1995; Winkel & Westgaard, 1992). Winkel and Westgaard (1992) emphasized the three important aspects in quantifying exposures: level (intensity), repetitiveness and duration. Internal exposure is the body's response to the demands of work, and has been frequently studied in terms of muscle forces, muscle activities, joint loading and other physiological measures (Aaras, Fostervold, Ro, & Thoresen, 1997; Bansevicius, Westgaard, & Jensen, 1997; Hagg & Astrom, 1997; Jensen et al., 1993a; Kleine, Schumann, Bradl, Grieshaber, & Scholle, 1999; Larsson, Oberg, & Larsson, 1999; Larsson, Bjork, Elert, & Gerdle, 2001; Madeleine, Lundager, Voigt, & Arendt- Nielsen, 1999; Mathiassen & Winkel, 1991; Nordander et al., 2000; Vasseljen & Westgaard, 1995 & 1997; Westgaard, Vasseljen, & Holte, 2001). As the computer tasks performed by office workers and their contribution towards WRNULD was the main interest of this thesis, it was appropriate to examine the internal exposures in terms of muscle activities in the major stabilizing muscles as well as the joint movements in the neck-shoulder region involved in performing computer tasks.

Recently, the term "physical stressor" has been used in a number of reports to indicate a physical condition that is applied in an experimental study to impose "stress" on the body, and the resultant responses of the body would be assessed as the outcome (National Research Council, 1999; Westgaard, 1999). In studying the influences of the occupational risk factors, researchers attempt to establish a "dose-response" relationship, in which a certain quantified amount (or "dose") of the risk factor is applied to the subject, and a certain measurable outcome (or "response") is expected (Armstrong et al., 1993). The studies reported in this thesis investigated the effects of doses of three physical stresses (static posture, increase in keying speed, and increase in keying force) on muscle activities, joint kinematics, keystroke dynamics and discomfort responses.

Several major reviews have been published to critically appraise the evidence for work-relatedness of various risk factors in an attempt to examine the strengths of association for establishing causal inferences of the various occupational factors (Armstrong et al., 1993; Buckle & Devereux, 2002; Faucett & Rempel, 1994; Grieco et al., 1998; Hagberg et al., 1995; NIOSH, 1997; Tittiranonda et al., 1999). NIOSH (1997) reported that prolonged static load associated with maintaining a static posture was an important risk factor for neck disorders, and this association has also been supported in other reviews (Ariens et al., 2001; Buckle & Devereux, 2002; Kumar, 2001; Hagberg et al., 1995).

There was also evidence for a causal relationship between highly repetitive work and neck-shoulder musculoskeletal disorders (MSDs) (Buckle & Devereux, 2002; Hagberg et al., 1995; NIOSH, 1997; Silverstein et al., 1986). Repetitiveness is related to the speed and frequency of movements in performing work tasks. The faster the movements are performed, the more repetitions of work cycles can be completed within a set period of time. In operating a keyboard, the speed of keystroke actions is directly related to the number of keys hit in a set period of time. Thus the number of words typed per minute, or the number of keys hit per minute have been used as measures of speed and repetitiveness of typing.

A third commonly identified risk factor was "forceful exertions". Some of the research evidence has developed or originated from studies of industrial workers performing heavy manual handling tasks as well as light industrial or service industry jobs (Grieco et al., 1998; Hagberg et al., 1995; Silverstein et al., 1986), and other evidence has come from studies of keystroke forces in office workers (Armstrong, Foulke, Martin, Gerson, & Rempel, 1994; Sommerich, Marras, & Parnianpour, 1996a; Feuerstein, Armstrong, Hickey, & Lincoln, 1997).

Where work-related MSDs are concerned, posture, repetitiveness and force are three of the most commonly identified physical risk factors, although the extent of associations of each of these risk factors with various musculoskeletal problems have not been clearly established yet (Buckle & Devereux, 2002; Forde et al., 2001; Hagberg et al., 1995; NIOSH, 1997).

As viewing of the display screen and typing on the keyboard are the most frequently performed computer tasks carried out by the majority of office workers everyday, the present research has chosen to focus on studying these tasks in relation to the three selected occupational risk factors. Through a series of experiments, the present research has focused on the effects of performing a prolonged keyboard task requiring a sustained static posture, as well as the effects of changing the speed and force of keyboard operation on individual responses during some standardized computer tasks. The speed of keyboard operation is directly related to the repetitiveness of the keying actions, and the force of striking the keys is a measure of the "forceful exertions". Thus in the present situation, the experimental tasks involving the sustained posture, the increase in keying speed as well as the increase in keying force investigated the effects of these risk factors or "physical stressors" on the responses of the individuals in terms of muscle activities, joint kinematics as well as subjective discomfort sensations.

Symptomatic individuals may have different patterns of physiological responses contributing to their development of symptoms, and on the other hand, they may also develop different response patterns as a result of their discomforts or pains. Fig. 1.1 depicts the potential relationships that the three studied physical stressors may have on the internal exposure factors of joint kinematics and muscle activities, which may be affected differently in symptomatic and asymptomatic persons. These potential differences in internal responses of different individuals may be important to the development of WRNULD.

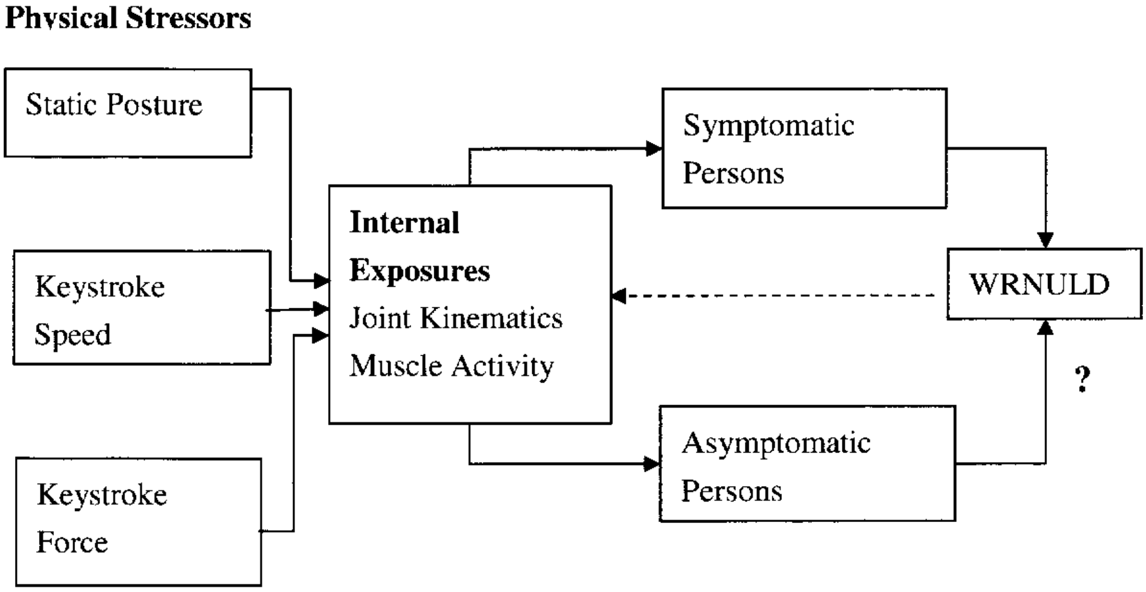


Fig. 1.1: Schematic diagram depicting the potential relationships of the 3 studied physical stressors and their effects on internal exposure factors and WRNULD

1.6.1 Studies on static posture in office workers

From studies on office workers, static posture, often measured or described as long typing hours, has been commonly identified as an important risk factor for musculoskeletal problems (Bernard et al., 1994; Bergqvist et al., 1995; Faucett &

Rempel, 1994; Kamwendo et al., 1991a; Tittironanda et al., 1999). Kamwendo et al. (1991a) have reported that computer work of 5 hours or more would lead to increased risk of developing WRNULD. These studies have based the association between static posture and WRNULD on data collected from self-reported health measures.

In office workers, static postures usually involve the more proximal joints of the neck and shoulders to provide stability of the upper limbs, while the forearm and hand segments are more involved in performing fine repetitive movements in using the keyboard and/or the mouse. Observational studies with video analyses or measurements of work posture have provided more objective data (Aaras et al., 1997; Bansevicius et al., 1997; Burgess-Limerick, Plooy, Fraser, & Ankrum, 1999; Liao & Drury, 2001; Szeto et al., 2002; Vasseljen & Westgaard, 1997; Villanueva, Sotoyama, Jonai, Takeuchi, & Saito, 1996). In viewing the computer display, there may be only small amounts of head-neck movements involved (Aaras et al., 1997; Burgess-Limerick et al., 1999; Szeto et al., 2002). Research evidence has come from measures of kinematics or static postural angles of the head, neck and thorax segments in studies examining the effects of changing different aspects of the physical environment, such as the display screen height (Aaras et al., 1997; Burgess-Limerick et al., 1999; Villanueva et al., 1996). The static posture in computer use has also been associated with low-level static muscle activities in the neck-shoulder stabilizers, held for prolonged periods due to long working durations (Bansevicius et al., 1997; Kleine et al., 1999; Hagg & Astrom, 1997). The static postural angles and static muscle activities may put the joints and the muscles under substantial strain and these may be important factors contributing to the development of WRNULD.

Evidence of static muscle activities has been reported from research on electromyography (EMG) measures comparing the performance of different computer tasks (Cooper & Straker, 1998; Jensen, Finsen, Hansen, & Christensen, 1999a; Roe, Bjorklund, Knardahl, Waersted, & Vollestad, 2001; Waested & Westgaard, 1997; Westgaard & Bjorklund, 1987), or comparing the effects of changing the physical environment (Aaras et al., 1997; Burgess-Limerick et al., 1999; Cook, Burgess-Limerick, & Papalia, 2002; Erdelyi, Sihvonen, Helin, & Hanninen, 1988; Schuldt, Ekholm, Harms-Ringdahl, Nemeth, & Aborelius, 1987; Straker & Mekhora, 2000; Turville, Psihogios, Ulmer, & Mirka, 1998). Most of these studies have focused on within-subject comparisons in terms of posture or EMG changes. There have also been a number of studies comparing different occupational groups in terms of EMG and kinematics (Jensen et al., 1993a; Larsson et al., 2000; Nordander et al., 2000; Vasseljen & Westgaard, 1995; Vasseljen & Westgaard, 1997; Westgaard et al., 2001). In most of these studies there has been no differentiation between symptomatic and asymptomatic persons, in studying the different responses in individual workers.

Westgaard (1999 & 2000) has addressed the issue of the large inter-individual differences in terms of muscle loading, when workers perform the same work. While past research has provided some evidence as to the responses in the musculoskeletal system as a result of prolonged static posture, these findings were mainly produced in painfree subjects and as such there has been no consensus as to the "normal" individual responses. In order to better understand how prolonged static posture is related to the development of WRNULD, it is important to study the responses of symptomatic individuals.

1.6.2 Studies on the risk factor of keystroke speed

Research on industrial workers have already identified strong associations between the risk factors of speed (or repetitiveness) and force, and WRNULD (Hagberg et al., 1995; Silverstein et al., 1986; Sommerich et al., 1996a & b). It is well recognized that speed and force are two inter-related factors and are commonly studied in related research (Aoki & Kinoshita, 2001; Feuerstein et al., 1997; Gerard, Armstrong, Martin, & Rempel, 2002; Radwin & Jeng, 1997; Sommerich et al., 1996 a & b).

In the research area of office ergonomics, speed of typing in terms of keystrokes per hour, and the number of keystrokes performed in a whole day have been related to the prevalence of musculoskeletal problems in office workers through self-reported studies (Bernard et al., 1994; Bergqvist et al., 1995; Faucett & Rempel, 1994; Green & Briggs, 1990). The different typing styles with either all fingers or only certain fingers, involving different speeds and forces, have also been linked with various upper extremity symptoms (Pascarelli & Kella, 1993).

From a biomechanical perspective, the speed and force of keyboard operation have been mainly studied in relation to different keyboard designs (Armstrong et al., 1994; Dennerlein, Diao, Mote, & Rempel, 1998; Gerard, Armstrong, Franzblau, Martin, & Rempel, 1999; Rempel, Dennerlein, Mote, & Armstrong, 1994, Rempel et al., 1997). Usually the distal joint kinematics of the wrist and finger joints, as well as the muscle activities of the forearm regions have been the examined outcome measures

(Armstrong et al., 1994; Gerard et al., 2002; Martin et al., 1996; Rempel et al., 1997; Sommerich et al., 1996a). The subject samples mostly consisted of healthy painfree individuals, who were either university students, or actual office workers. Only a few studies have examined the effects of the speed and force of keying on neck and shoulder muscle activities (Birch, Juul-Kristensen, Jensen, Finsen, & Christensen, 2000; Laursen, Jensen, & Sjogaard, 1998). These have been mainly done on painfree subjects in cross-sectional field investigations or laboratory studies.

Biomechanical studies examining keystroke speed have reported on the differences in forearm muscle activities between faster and slower typists, and found that faster typists had more "efficient" muscle recruitment patterns with lower muscle activity levels for performing the same work (Gerard et al., 2002). But again only those with no past or present discomforts were studied, and it is not known whether typists with chronic musculoskeletal problems may have similar responses in their typing speed or force performance.

1.6.3 Studies on the risk factor of keystroke force

Feuerstein et al. (1997) was one of the few studies that compared keystroke forces between symptomatic and asymptomatic persons, and reported significantly higher keystroke forces in symptomatic subjects. Other studies have reported that forces exerted during key strike were 2-4 times greater than activation requirements (Armstrong et al., 1994; Rempel et al., 1994). There have also been insightful information generated about muscle activities from studies examining simulated key tapping actions – but these were mainly done with 1-2 fingers only, and mostly distal muscle and joint dynamics were measured (Aoki & Kinoshita, 2001;

Dennerlein et al., 1998; Kitahara, Schnoz, Laubli, Wellig, & Krueger, 2000; Radwin & Jeng, 1997; Rempel et al., 1994 &1997). More detailed review of the related studies in this area can be found in Chapter 8.

In summary, little is known about the responses of the neck-shoulder stabilizing structures when exposed to the controlled doses of the physical exposures of increased speed or increased force of keyboard operation. In particular, the responses of symptomatic individuals have not been examined in any depth compared to the painfree control subjects.

1.7 APPROACHES TO MEASUREMENT OF PHYSICAL RISK FACTORS - KINEMATICS, EMG, SUBJECTIVE DISCOMFORTS

Many of the occupational research studies have examined the biomechanical loading through measuring postures or kinematics, and muscle activities during work through electromyography (EMG). These measures can be considered the "interim" variables that are indicators of the articular loading or the strain on the muscles likely to lead to WRNULDs.

1.7.1 Study of postures and kinematics – examining joint movements and joint loading during work

The study of postures and kinematics in joints has also been commonly used to investigate the physical exposures in workers. (Posture is defined as more a static position, while kinematics is the study of movements). In the research work associated with office workers, postures and movements of major body segments have been studied in response to changes in physical factors such as display screen heights (Aaras et al., 1997; Burgess-Limerick et al., 1999; Villanueva et al., 1996). Again, most of these ergonomic intervention studies have been done on normal healthy subjects, on the assumption that adverse postural changes produced in these individuals would mean increased risk of developing musculoskeletal symptoms.

Comparing the kinematics of the neck-shoulder regions of symptomatic and asymptomatic workers can provide insight into whether there are differences in their joint movements and loading that may possibly explain why some individuals would develop symptoms and others do not. Although the tasks of viewing the display screen and operating the keyboard may involve only small extents of movements in the neck or the upper limb, these small movements performed repeatedly or the lack of movements may all affect the biomechanical strain on the joints as well as the muscle efforts required to perform such movements. When symptomatic and asymptomatic persons are compared in a controlled setting, we can establish their innate differences in postures and kinematics.

Postures and kinematics have been measured using a number of different methods, from the simple use of still photographs to two-dimensional (2D) and three-dimensional (3D) motion analysis systems. The advantages and disadvantages of using the different methods to study movements in ergonomic research have been reviewed by Chaffin, Andersson, and Martin, (1999) and Li and Buckle (1999). The more simple systems have the advantage of less technical procedures and equipment, and may be more suitable for field investigations; but usually the data generated would be more limited. The more complicated systems such as the 3D systems would provide more detailed information of positional coordinates and segmental angles in multiple planes, but they usually required the use of multiple cameras or bulky tracking equipment and would be more suitable for laboratory studies. Anglin and Wyss (2000) reviewed the recent studies on 2D and 3D motion analysis involving the shoulder complex and the upper limb; and provided a good summary of the major issues including marker positioning, definitions of segments and rotations, as well as reliability and accuracy of measurements.

It is important to study both movements and muscle activities, as the two types of data can be linked together to provide a more complete picture of musculoskeletal loading during the performance of occupational tasks. By measuring these biomechanical data directly on living individuals and conducting within-subject and between-subject comparisons, it provides a more realistic understanding of variations in individual responses. This type of information is not available in using other approaches such as calculating muscle loads and joint moments based on biomechanical modeling produced from population norms, or from studying cadaveric models.

1.7.2 Surface EMG measures

Surface electromyography (EMG) has been studied in terms of amplitude domain variables such as the Amplitude Probability Distribution Function (APDF) (Jonsson, 1982), and the temporal pattern of amplitude changes in terms of EMG gaps (Veiersted, Westgaard, & Andersen, 1990 & 1993), or Exposure Variance Analysis (EVA) (Mathiassen & Winkel, 1991). These three measures have been commonly used to study the muscle activities and efforts in performing occupational tasks

(Aaras et al., 1997; Bansevicius et al., 1999; Hagg & Astrom, 1997; Jensen et al., 1993a; Jonsson, 1982; Kleine et al., 1999; Larsson, Bjork, Elert, & Gerdle, 2000; Madeleine, Lundager, Voigt, & Arendt-Nielsen, 1999; Nordander et al., 2000; Schuldt et al., 1986; Veiersted et al., 1993; Westgaard et al., 2001). EMG changes in terms of increased amplitudes, decreased EMG gaps or decreased variances have been interpreted as signs of increased biomechanical and/or physiological loading resulting in increased risk for developing WRNULD.

1.7.2.1 *EMG amplitude measures*

The concept of EMG APDF was first introduced by Jonsson (1982). The analysis of APDF has been widely used as an indicator of low ("static"), middle ("median") and high ("peak") levels of muscle activities in studies of real or simulated occupational tasks; and these three levels were equated to the 10th, 50th and 90th percentile (%) values of the APDF. Jonsson proposed that different types of work could be characterized by their APDF profiles, and the shifting of the APDF curve to the right would indicate increased muscle contraction levels, or increased muscle effort, in performing the work. He also suggested a set of "acceptable limit values" for performing constrained work for one hour: that the 10th%APDF should be within 2-5%MVC, 50th% at 10-14%MVC, and 90th% at 50-70%MVC (Jonsson, 1982 & 1988). While these figures represented an attempt to quantify muscle efforts objectively, they were based on EMG measurements during a certain type of work task and only the trapezius muscle was studied. Whether they could be generalisable to different occupations and different muscles remains arguable.

Although the APDF was mainly developed from EMG studies of the upper trapezius muscle, this approach has been adopted by many authors to study other neck-shoulder stabilizing muscles, including the cervical erector spinae, deltoids, infraspinatus, rhomboids, and lower trapezius (Balogh, Hansson, Ohlsson, Stromberg, & Skerfving, 1999; Birch et al., 2000; Hermans & Spaepan, 1995; Kleine et al., 1999; Nordander et al., 2000). Some studies have focused on studying the low (or "static") level muscle activities (10th%APDF) in performing sedentary work such as computer tasks, as they considered this lower level of muscle activity to be an appropriate variable reflecting the continuous muscle load in static stabilizing muscles such as the trapezius. Veiersted et al. (1990) reported a correlation between the 10th% level of muscle activities and musculoskeletal pain, but other studies have reported no demonstrable relationship between the two (Roe et al., 2001; Vasseljen & Westgaard, 1995; Westgaard et al., 2001). Others have focused on examining the 50th%APDF as they considered this value to be a more accurate indicator of the average muscle activity in performing work tasks throughout the work period (Aaras et al., 1988 &1997; Hermans & Spaepen, 1995; Nakata, Hagner, & Jonsson, 1992). Yet other studies reported on both the low and median levels of APDF, or all three levels of APDF (Kleine et al.; 1999; Nordander et al., 2000; Westgaard et al., 2001).

Some authors have noted that the APDF only provided information on the amplitude levels for the work tasks, and it does not indicate the temporal profile of such amplitude changes or repetitiveness of muscle activities. Veiersted et al. (1990) introduced the concept of "EMG gaps" to evaluate the temporal pattern of muscle activity, and the "gaps" were identified as short intervals (0.2s or more) of very low EMG amplitudes (below 0.5%MEMG) which could be considered as rest periods for the muscle. There have been several reports suggesting that musculoskeletal disorders may be related to a reduced number of EMG gaps but these were not always statistically significant (Hagg & Astrom, 1997; Nordander et al., 2000; Westgaard et al., 2001).

Exposure variance analysis (EVA) was developed by Mathiassen and Winkel (1991) and it deals with the time patterns of different amplitude levels and the frequencies of these patterns. The method aims to study changes in repetitiveness of muscle activity patterns during work. Some researchers have regarded EVA as a measure of the "monotony" of the EMG pattern, and reported that symptomatic subjects may have a more monotonous pattern at low load levels (1-5%MVC) (Hagg & Astrom, 1997; Jensen et al., 1993a & 1999a; Nordander et al., 2000; Westgaard et al., 2001). Again different results have been reported in different studies and no firm conclusion can be drawn regarding the relationship of various EMG variables in relation to the development of WRNULD.

1.7.2.2 *EMG frequency measures*

The study of frequency changes in EMG has also been used to examine the muscle fatigue phenomenon when work is performed. In clinical research the study of median frequency changes has been used to investigate the characteristics and pathomechanics of chronic low back pain (Biedermann, Shanks, Forrest, & Inglis, 1991; Edgerton, Wolf, Levendowski, & Roy, 1996; Roy & De Luca, 1996; Roy, De Luca, & Casavant, 1989). The three most commonly used frequency indexes are mean power frequency (MPF), median frequency (MF) and the number of zero crossings (Hagg, 1992). Downward shifting of the frequency index has been accepted as a physiological indicator of muscle fatigue (Hagg, 1992). Only a few studies have examined the muscle fatigue indexes in occupational tasks involving the upper limbs (Christensen, 1986; Madeleine et al., 1997; Hansson et al., 1992), and these studies have mainly examined manual repetitive tasks and not during computer tasks. Research studies and relevant findings in the study of frequency changes have been reviewed more extensively in Chapter 5.

1.7.3 Selection of neck-shoulder structures for the study

As the main focus of our research is work-related neck and shoulder pain, we have selected the major articular segments and stabilizing muscles in the neck-shoulder region for investigation. As viewing of the display screen and the keyboard involves small amounts of head and neck movements, the postures and kinematics of the head on the cervical spine as well as the movements of the cervical spine in relation to the thorax are important to study. The cervical spine is intricately related to the shoulder girdle which consists of the acromio-clavicular joint, glenohumeral joint and the scapulothoracic joint. The arm movements in performing the typing actions on the keyboard would also affect the movements in the cervical and thoracic spine. Hence we have elected to examine movements in the head-neck segment, the upper arm, the thorax and the scapular segments in the motion analysis. Many ergonomic studies that examined motions in these segments during work tasks involved healthy painfree subjects (Aaras et al., 1997; Burgess-Limerick et al., 1999; Vasseljen & Westgaard, 1997; Villanueva et al., 1996). On the other hand, clinical studies that reported differences in symptomatic-asymptomatic postures were done in relaxed standing or sitting, and not during occupational tasks (Braun, 1991; DiVeta, Walker, & Skibinski, 1990; Griegal-Morris, Larson, Mueller-Klaus, & Oatis, 1992). The present study aimed to examine the symptomatic-asymptomatic differences during computer operation in response to different physical stressors.

In terms of the major stabilizing muscles, we have selected four muscles that have major roles in stabilising the neck-shoulder region while the arms perform the dynamic actions of typing. In addition, these muscles are also more accessible for the measurement of surface EMG. Anatomically the trapezius muscle has commonly been regarded as a major stabilizing muscle whenever the arm is in some degree of flexion or abduction. Studies measuring EMG in shoulder muscles in healthy subjects have reported high activities in the upper trapezius (UT) muscle in various positions of shoulder flexion and abduction (Hagberg, 1981; Herberts, Kadefors, & Broman, 1979; Mathiassen & Winkel, 1990). Winkel and Westgaard (1992) also pointed out that all functional arm movements require the continuous activation of muscles that control both the shoulder girdle and the glenohumeral joints. They further commented that UT is the principal "anti-gravitational" muscle of the arm, as it bears the load transmitted to the scapula from the glenohumeral joint.

The trapezius muscle has also been the most commonly investigated muscle where neck and shoulder pain is concerned. It has also been commonly reported that patients with chronic neck and/or shoulder pain often present with increased tenderness and/or increased muscle tension in the trapezius, particularly the UT (Janda 1994; Elert, Rantapaa-Dahlqvist, Henrikkson-Larsen, Lorentzon, & Gerdle, 1992; Jull, Barrett, Magee, & Ho, 1999). Based on previous research evidence from Larsson and associates, Elert et al. (1992) proposed that the high demand on the trapezius both as a shoulder fixator and a scapular rotator may have contributed to the morphological changes of "moth-eaten" fibres in this muscle, which has been reported by a number of researchers (Larsson, Oberg, & Larsson, 1999; Larsson et al., 2000; Lindman et al., 1991). Trapezius has also been classified as a "global stabilizer" of the spine as it spans over many segments in the cervical and thoracic spine (Bergmark, 1989; Commerford & Mottram, 2001; Jull et al., 1999). Yet, despite all the occupational EMG research, there has been no firm conclusion demonstrating a direct causal relationship between trapezius muscle activity and WRNULD (Westgaard, 2000).

The cervical erector spinae (CES) muscles are the main extensors of the cervical spine and they also have a very important anti-gravity function to counteract the forward flexion of the head (Chaffin et al., 1999; Johnson, Bogduk, Nowitzke, & House, 1994; Keshner, Campbell, Katz, & Peterson, 1989; Vasavada, Li, & Delp, 1998; Winkel & Westgaard, 1992). These muscles are considered the primary segmental stabilizers of the cervical spine and they support the deep, less accessible deep cervical extensors (Commerford & Mottram, 2001; Janda, 1994; Keshner et al., 1989; Winkel & Westgaard, 1992). Thus it is important to examine the different roles of the CES muscles as opposed to the UT muscles in neck-shoulder stabilization comparing symptomatic and asymptomatic persons.

The decision was made to examine the activity in the lower trapezius (LT) muscle as the clinical community has suggested that there is an imbalance of muscle activation patterns of the upper and lower trapezii in patients with chronic neck and shoulder pain (Janda, 1994; Jull et al., 1999). The concept of "scapular stabilization", proposed that retraining the LT to assume an active scapular stabilizing role may help to correct this "imbalance" of muscle function, and relieve the strain or tension in the upper trapezius (Janda, 1994). Yet there is very little objective research evidence to demonstrate this "imbalance" phenomenon. Examining the activities of the UT and LT muscles in relation to the movements of the scapula in the present study may provide objective evidence to either support or disprove this theory of scapular stabilization.

The deltoid muscle is one of the largest muscles acting on the shoulder joint. The anterior deltoid muscle is a prime mover of the shoulder joint in forward flexion of the upper arm, which may act as both a dynamic mover as well as a static stabilizer during typing (Kleine et al., 1999; Winkel & Westgaard, 1992). Again there has been very little research examining how this muscle functions in symptomatic persons especially when they are subjected to different physical stressors.

While these various structures, especially the UT muscle, have been investigated in different studies of a clinical or occupational nature, there has been very little research investigating the coordinated functions of these different muscles in occupational tasks especially, in comparing symptomatic and asymptomatic persons. Based on these rationales, we decided on the anatomical structures to be examined in the present research project.

1.7.4 Definitions of discomfort versus pain

Hagberg et al. (1995) described discomfort, fatigue and pain as the most common first symptoms of work-related musculoskeletal disorders. Discomfort is defined as a perceptual, subjective phenomenon that is more diffuse than pain (Hagberg et al., 1995). Pain has been defined as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage" (Merskey, 1979). Kuorinka (1983) (as cited in Straker, 1999), described "discomfort" as "a phenomenon of perception" that is related to pain, or perceived exertion. Discomfort has also been described as an "uncomfortable sensation" which can be associated with a wider range of unpleasant sensations such as muscle cramp, soreness, aching, tiredness and so on.

Straker (1999) reviewed the discomfort assessment tools and found that discomfort was a more sensitive measure in assessing noxious sensations at lower stimuli levels. While discomfort is associated with pain and may be considered the same by some individuals, it is commonly found that milder "pains" or "unpleasantness" may be described as "discomforts", and pain is usually perceived to be a more specific sensation which may be considered similar to the higher severities in discomforts. Discomfort assessment is also used as an early indicator, as a sign of stress or strain to the body prior to the development of frank disorders (Straker, 1999). In recent years, discomfort assessment has been commonly used in ergonomic research as an outcome measure of the effects of performing different work tasks, and this is the approach adopted in the present study.

1.8 RESEARCH DESIGNS: NEED TO STUDY SYMPTOMATIC – ASYMPTOMATIC DIFFERENCES

1.8.1 Epidemiological studies with cross-sectional design are more common in ergonomics

Different studies have used different research designs and different outcome variables to examine the dose-response relationship between risk factors and work-related MSD. There have been cross-sectional and case-control studies examining different occupational risk factors in office workers. These included studies on the effects of changing workstation settings such as display screen heights (Aaras et al., 1997; Burgess-Limerick et al., 1999; Takala & Viikari-Juntura, 1991), the effects of performing paper versus computer tasks (Waested & Westgaard, 1997), and the effects of prolonged work durations (Bansevicius et al., 1999; Kleine et al., 1999; Hagg & Astrom, 1997; Hermans & Spaepan, 1995). These studies have shown some associations of risk factors with outcome measures, but associations have often been weak and inconsistent between studies. The inability to demonstrate strong evidence for these risk factors may be partly due to the large variations in human responses.

Past ergonomic studies often examined responses in “normal” (healthy painfree) subjects and assumed that increased strain in the healthy individuals as reflected by increased EMG amplitudes or increased postural angles would indicate increased risk for the general population. However, symptomatic persons may respond differently compared to normal healthy individuals; and even among different persons with the same past history, they may respond differently to the same physical demands. Therefore, there is certainly a need to study the specific responses of symptomatic persons and compare these with asymptomatic persons, and Case-Control research design is one appropriate method to examine between-subject differences.

Generally, longitudinal studies or prospective studies are regarded as high level evidence, and these have been done on a large scale using self-reported health measures to collect epidemiological data on office workers (Ariens et al., 2001; Bergqvist et al., 1995; Bernard et al., 1994; Faucett & Rempel, 1994; Marcus & Gerr, 1996). However, with regard to physical exposures, it has been reported that workers may over-estimate or under-estimate their work exposure factors (Bernard et al., 1994; Faucett & Rempel, 1994). Thus, in order to study the effects of specific physical exposure factors, it is more appropriate to use objective measurement tools to quantify such exposures (for example, using EMG to measure muscle effort), rather than relying on subjective reports from workers to determine the extent of exposure.

Additionally, in large scale cross-sectional or longitudinal studies, it is often difficult to control or standardize the risk factors, due to the difficulty of controlling what the workers do in their daily work (except in industries that involve highly monotonous and repetitive job tasks). For more specific or objective investigations on the effects of various physical risk factors, laboratory studies involving objective measurements of exposures and responses are preferred. Westgaard (2000) has commented that it is much more difficult to demonstrate exposure-response relationship for musculoskeletal problems in field studies compared to laboratory investigations where conditions can be controlled.

1.8.2 Field versus laboratory studies

Both field and laboratory studies have been done to examine the effects of occupational risk factors in ergonomic research, and in this thesis, we have also utilized these two approaches. In Study 1, we have performed a field investigation in order to compare the realistic working postures between symptomatic and asymptomatic subjects in their actual workstations. However, in a field investigation we could not control the various physical factors, and the outcome measures that could be obtained were also limited. For the research aims of Studies 2 and 3, the laboratory study design enabled us to control and standardize the dosages of the various physical stressors in the experimental conditions. It also allowed the same computer workstation to be used by all subjects, in order to eliminate the additional effects caused by using different furniture. The same applied to the computer task. Thus if all the external conditions were standardized, we can deduce that the differences in the biomechanical measures of EMG and kinematics, as well as the subjective discomfort reports, were valid evidence for the inter-individual differences between subject groups in their intrinsic response systems.

1.8.3 Case-Control study design

Studying the muscle activities in normal healthy subjects may not be the most appropriate way to examine the effects of different physical risk factors in causing WRNULD, as different persons may react differently to the demands of physical stressors. It is generally agreed that the etiology of WRNULDs is multifactorial, and the interactions of intrinsic and extrinsic factors may simultaneously operate within each person (Forde et al., 2002; Kumar, 2001; Sjogaard, Lundberg, & Kadefors, 2000; Westgaard, 1999; Westgaard et al., 2001). It may be the different interactions of these factors that caused symptomatic persons to have adverse reactions when exposed to certain physical stressors while asymptomatic persons were somehow able to cope. Hence a Case-Control research design is a valid way to examine the effects of controlled physical stressors in comparing the responses of symptomatic and asymptomatic persons. However, the results can only provide evidence of associations between the risk factor and the response, but not the causal relationship between the two.

1.9 POTENTIAL MECHANISMS/MODELS FOR THE ETIOLOGY OF WRNULD

1.9.1 WRNULD is generally considered as "muscle pain" – is it proven?

It is widely considered that WRNULD is a "muscle" pain (Edwards, 1988; Elert et al., 1992; Johansson & Sojka, 1991; Kadi et al., 1998; Larsson et al., 1999, 2000 & 2001; Roe et al., 2001; Westgaard, 1999; Westgaard et al., 2001). The terms "trapezius myalgia" and "tension neck syndrome" have been commonly used by these authors (Elert et al., 1992; Kadi et al., 1998; Larsson et al., 1999, 2000 & 2001; Roe et al., 2001; Veiersted et al., 1993; Westgaard 1999; Westgaard et al., 2001). These terms imply that the source of pain lies within the muscle, and that the source of pain is due to some pathology within the muscular structure. However, there is often a lack of evidence to clearly demonstrate that the pain is indeed solely arising from the trapezius muscle. Certainly, the trapezius muscle is a likely source, if localized tenderness or pain is provoked when the muscle is probed or placed under stress (Hagg & Astrom, 1997; Onishi, Sakai & Kogi, 1982; Takala & Viikari-Juntura, 1991). However, very often these individuals complaining of generalized, widespread and bilateral neck pain as well as bilateral shoulder pain, and these various painful areas may or may not be tender on palpation. Past research has not been able to clearly establish a relationship between muscle activities during work tasks and the development of WRNULD (Roe et al., 2001; Vasseljen & Westgaard, 1995; Westgaard 1999 & 2000; Westgaard et al., 2001).

There are also other structures in the neck-shoulder regions that may be the source of pain, such as the articular structures (zygapophyseal joints, intervertebral discs, ligaments and neural tissues) in the cervical spine that contain an abundant supply of nociceptors (Bogduk & Marsland, 1988; Bogduk, 1995). There may also be central nociceptive pathways that can be activated contributing to the pain sensation (Coderre, Katz, Vaccarino, & Melzack, 1993; Graven-Nielsen& Mense, 2001; Mense, 1993; Sheather-Reid & Cohen, 1998). These central processes include convergence and/or summation of nociceptive input as well as sensitization of nociceptors; and they may either magnify or dampen the pain sensation. The patterns of referred pain from articular structures may be somewhat different from those of referred pain arising from muscles, but the areas can be overlapping, and both can be affected by alterations of central nociceptive processing (Arendt-Nielsen & Svensson, 2001; Graven-Nielsen & Mense, 2001; Mense, 1993; Sheather-Reid & Cohen, 1998; Travell & Simons, 1983).

While the present research only involved measurements of muscle activities and joint kinematics from the body surface, these measures can provide some useful information about the possible biomechanical and/or neurophysiological mechanisms that may contribute towards the development of WRNULD in symptomatic individuals.

1.9.2 Models on musculoskeletal pain – different types of research generating different models

There has been a large body of research investigating the etiology and pathomechanics of musculoskeletal pain disorders. Clinical research on various clinical syndromes such as mechanical / chronic low back pain have focused on these patients' muscle activity patterns and compared these with responses of control (painfree) subjects (Edgerton et al., 1996 & 1997; Hodges, 2000; Marras, Davis, Heaney, Maronitis, & Allread, 2000; O'Sullivan et al., 1997; Roy et al., 1996). In the neck and upper limbs, clinical research interest has mainly focused on studying the conditions of whiplash injuries, headaches and fibromyalgia (Bansevicius et al., 1999; Edgerton et al., 1996; Edgerton, Wolf, Levendowski, & Roy, 1997; Elert et al., 1992; Jull et al., 1999; Larsson et al., 1999; Watson & Trott, 1993). These studies have reported on important differences of muscle activation patterns in symptomatic persons compared to asymptomatic controls. However, the findings from patients with low back pain may not be generalisable to persons with neck and shoulder problems; and responses of persons with whiplash or fibromyalgia may also be different from those with WRNULD. It is important to study these individuals' (with WRNULD) specific responses directly during occupational tasks as they may have developed physiological and morphological adaptations due to the chronic nature of their disorders.

There have also been research studies on the responses of human subjects under conditions of experimental pain induced by injections of hypertonic saline into muscles (Arendt-Nielsen, Graven-Nielsen, Svarrer, & Svensson, 1996; Graven-Nielsen, Arendt-Nielsen, & Svensson, 1997; Lund, Donga, Widmer, & Stohler, 1991; Svensson, Arendt-Nielsen, & Houe, 1998). The advantage of studying experimental pain is that it allows the investigator to control and manipulate the stimulus intensity, duration and modality (Arendt-Nielsen et al., 1996). Although these studies have generated important information towards the understanding of neurophysiological mechanisms for musculoskeletal pain, experimental pain is mainly a simulation of the acute pain response. Work-related musculoskeletal disorders often involve cumulative micro-trauma that may take a long time to develop, and there may be functional and structural changes within the body systems. Furthermore, ongoing pain is associated with emotional and psychological adaptations that could not be reproduced instantly through externally introduced stimuli. Therefore, studying the responses of office workers with a long history of work-related discomforts would provide a more realistic understanding of their physiological responses.

Another approach involved the use of *in vitro* cadaveric specimens or mechanical models to simulate the human cervical spine, in order to study the biomechanical forces and loads generated in the various structures such as the zygapophyseal joints, the muscles and the intervertebral discs (Bernhardt et al., 1999; Miura et al., 2002; Panjabi et al., 2001; Patwardhan et al., 2000; Vasavada et al., 1998). These biomechanical modeling studies have generated very useful information about the predicted forces and moments generated by various structures. However, such information would mainly be applicable to the "normal" population, and the exact responses of different individuals, especially those with realistic symptoms, still require investigations in the *in vivo* situation.

All the various types of research discussed above, have generated a number of theories or models about the etiology or physiological processes that may occur internally in humans with musculoskeletal pain. The most widely accepted model is the "vicious cycle" model which predicted that pain and increased muscle tension worked in a self-perpetuating vicious cycle, based on observations in fibromyalgia and chronic pain patients (Johansson & Sojka, 1991; Travell & Simons, 1983). The "pain adaptation" model argued against the vicious cycle model and proposed that pain would cause inhibition of muscle activities – but this theory was based on research in acute experimental pain (Lund et al., 1991). Both the type of subjects involved and the nature and level of pain provoked may affect the responses in individuals, and most importantly how different individuals may respond differently to the same stimuli have not been adequately addressed in past research.

1.9.2.1 *Motor control strategies at whole muscle level - muscle substitution*

At the whole muscle level, there has been evidence of altered muscle recruitment patterns or "muscle substitution" phenomena reported in subjects with clinical low back pain (Edgerton et al., 1996; Hodges, 2000; O'Sullivan et al., 1997) as well as traumatic neck pain patients (Edgerton et al., 1996 & 1997). These phenomena refer to deviations in the normal motor control strategies in recruiting different muscles while performing different functional tasks (Basmajian & De Luca, 1985; Edgerton et al., 1996; O'Sullivan et al., 1997).

In the concept of "muscle imbalance" proposed by Janda (1994), the upper trapezius muscle is found to be over-active in patients with neck pain while other cervical stabilizers such as the cervical erector spinae are hypoactive. This has been proposed to be a typical muscle substitution phenomenon. However, there has been little research evidence to demonstrate this phenomenon objectively, especially in relation to work-related musculoskeletal disorders. Limited evidence of muscle substitution and muscle imbalance has been published on whiplash patients (Edgerton et al., 1996) and patients with cervicogenic headache so far (Jull et al., 1999; Watson & Trott, 1993). These proposed pathological mechanisms may have important implications on the effects of prolonged physical exposures during the performance of repetitive work tasks. The resultant changes in the motor control strategies of the musculoskeletal system may contribute in the development of chronic discomforts in WRNULD and therefore detailed investigations are warranted.

1.9.2.2 *Motor control strategies at motor unit level*

There have also been advances in surface EMG and intramuscular EMG research providing more insight into how muscles work in relation to musculoskeletal pain as well as during work situations. The intramuscular EMG studies mainly involved the study of single motor units and the "cindarella hypothesis" has been proposed (Hagg, 1991). The cindarella hypothesis suggested that during prolonged low-level contractions, a small pool of low-threshold motor units was first to be recruited and last to relax, like "cindarella" (Hagg, 1991; Kadefors, Forsman, Zoega, & Herberts, 1999).

Studies on single motor unit activities in the trapezius involving computer tasks as well as light manual work have reported supporting evidence for the cindarella hypothesis as well as "motor unit substitution" (Kadefors et al., 1999; Westgaard & DeLuca, 1999; Kitahara et al., 2000; Sjogaard et al., 2000; Thorn et al., 2002; Waested, Eken, & Westgaard, 1996). However, most of the studies on motor unit activities have been done on normal painfree subjects who may not have the same responses as symptomatic persons (Kadefors et al., 1999; Kitahara et al., 2000; Sjogaard et al., 2000; Thorn et al., 2002; Westgaard & De Luca, 1999).

Larsson et al. (1999 & 2001) have produced a series of studies demonstrating morphological differences in type I muscle fibres of patients with chronic "trapezius myalgia", in the form of "ragged red fibres". Thus at the motor unit level, there appeared to be some evidence for structural degenerative changes as well as changes in neurophysiological functions involving mainly Type I motor units. How the morphological changes in the muscle fibres tie in with the low-threshold motor unit functions during occupational tasks; and their contribution towards chronic work-related neck and shoulder pain is still unclear. There remains a need to study larger populations of different individuals with various problems or backgrounds, and to examine these motor unit functions during various occupational tasks.

1.9.2.3 *Neurophysiological mechanisms affecting the sensation of pain*

Regardless of where the anatomical origin of pain lies, there are neurophysiological mechanisms influencing the perception of pain or discomfort in the human body. Although there has been a large body of research information generated from both animal and human studies, there remain a lot of uncertainty. Different studies have used different methods to provoke or elicit pain, such as through injection of substances into body tissue, use of physical agent such as electrical stimulation or dry needling to provoke pain. However the resultant pain responses may not be the same as those produced by work-related exposures, which involved repetitive biomechanical strains to different musculoskeletal structures (Mense, 1993; Sheather-Reid & Cohen, 1998).

The neurophysiological mechanisms take place at both peripheral and central levels, as reviewed by major researchers in this area (Coderre et al., 1993; Graven-Nielsen et al., 1997a; Mense, 1993; Sheather-Reid & Cohen, 1998). These processes include peripheral and central sensitization and convergence of nociceptive input, and they represent alterations in nociceptive processing, affecting the perception of on-going pain (Coderre et al., 1993; Mense, 1993; Sheather-Reid & Cohen, 1998). These processes must be taken into consideration when examining the etiology of WRNULD.

The problems with studying patients with real pathologies lie with their highly individualized variations in symptom manifestations, clinical progressions and subjective perceptions of pain; which make it difficult to standardize baseline measurements of individual subjects and make between-subject comparisons of outcomes (Mense, 1993; Westgaard, 2000). Yet these are also precisely the reasons why it is important to study the responses of patients with realistic symptoms and pathologies, as it is not possible to simulate such long-term changes in healthy control subjects.

1.9.2.4 *Models on musculoskeletal injuries at work*

Armstrong et al. (1993) proposed one of the most widely accepted conceptual frameworks of an exposure-response relationship in work-related musculoskeletal disorders. This model highlighted the cumulative nature of disorders resulting from external exposure factors causing a cascading chain of internal exposure responses which accumulate and eventually resulting in musculoskeletal disorders. This model may describe the link from the external risk factor to the internal responses but the factors were not specifically described (Fig. 1.2).

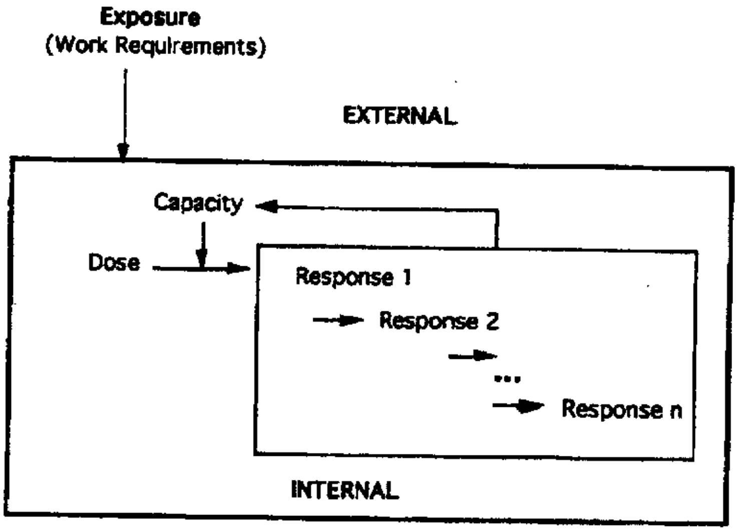


Figure 1. The proposed model contains sets of cascading exposure, dose, capacity, and response variables, such that the response at one level can act as a dose at the next level. In addition, the response to one or more doses can diminish (impairment) or increase (adaptation) the capacity for responding to successive doses.

Fig. 1.2: Conceptual framework for WRNULD adopted from Armstrong et al., (1993, pp. 76)

Winkel and Westgaard (1992) proposed the "exposure-effect model" depicting the interactions of various types of internal and external exposure factors which included physiological, psychological and individual factors. Their model has highlighted the important differentiation of internal and external factors affecting musculoskeletal health (Fig. 1.3). In his recent papers, Westgaard (1999 & 2000) has emphasized the importance of studying the intrinsic responses and understanding why and how individuals would respond differently when exposed to the same exposure factors; rather than assuming that all individuals would respond similarly, as in many ergonomic research studies.

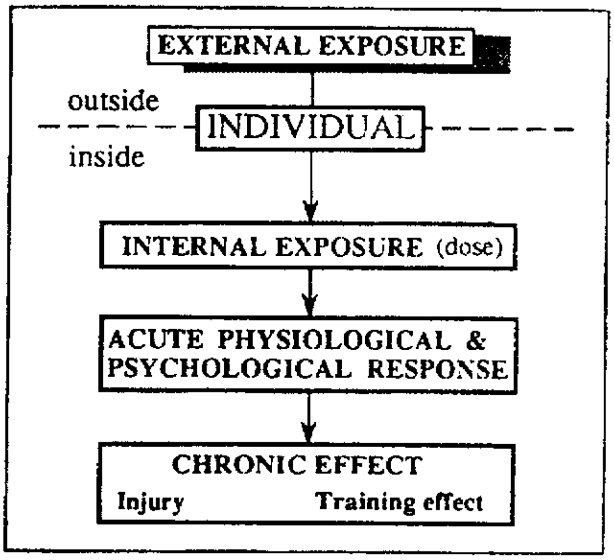


Fig. 1.3: Exposure-effect model proposed by Winkel & Westgaard (1992, pp.87)

Kumar (2001) proposed a more global view of all the biomechanical factors in the "theories of musculoskeletal injuries", which included the multivariate interaction theory, differential fatigue theory, cumulative load theory and overexertion theory.

individual. Kumar's theories provided a comprehensive overview of the biomechanical stresses on the different musculoskeletal structures such as the muscles, joints, ligaments and intervertebral discs, that are imparted by occupational tasks.

Recently more evidence is emerging to illustrate the important roles of the individual risk factors, which include personal factors such as age and gender (Bongers, De Winter, Kompier, & Hildebrandt, 1993; Jensen et al., 1993a; Linton, 2000; Marras et al., 2000). Psychosocial and cognitive work factors have also been modeled regarding their contributions to musculoskeletal disorders in workers (Bongers et al., 1993; Moon & Sauter, 1996). Some authors consider the personal factors such as age and gender as "effect modifiers", as they may not be direct causal factors but rather act as an indirect influence on the internal exposure processes and development of musculoskeletal problems (Winkel & Westgaard, 1992). These non-physical factors may have a very important role in explaining the question of why some individuals get symptoms and others do not, when they perform the same work tasks.

All these models have provided valuable insights into the pathways and mechanisms through which an individual can be exposed to the risk factors of WRNULD, yet the importance of inter-individual variations in response to different external and internal exposures has not been highlighted. However, many authors have acknowledged that different individuals may respond differently to the same occupational risk factors, or when they are exposed to different physical stressors (Kumar, 2001; National Research Council, 1999; Westgaard, 1999 & 2000), hence research on inter-individual differences is critical to provide more answers.

1.10 AIMS OF RESEARCH AND OVERALL RESEARCH QUESTION

The present research study has focused on the differences in individual responses when exposed to the same physical stressors. Specifically, the responses of symptomatic and asymptomatic office workers were compared when they were exposed to the same set of physical stressors in performing computer tasks.

Overall Research Question:

Are the internal physical exposure responses (i) muscle activity, (ii) kinematics/posture, (iii) keystroke performance, and (iv) discomfort, of symptomatic persons different to those of asymptomatic persons when exposed to different physical stressors of static posture, increased speed and increased force of keyboard operation?

CHAPTER 2

METHOD

The research project consisted of a series of 3 studies with Case-Control designs. Study 1 was a field investigation to examine postural differences between symptomatic and asymptomatic office workers in their actual workplaces. Studies 2 and 3 were laboratory studies with a Case-Control quasi-experimental design to compare the differences in physiological responses between symptomatic (Case) and asymptomatic (Control) office workers.

This chapter is a synopsis of the research designs, subject selection criteria, experimental procedures and methodological considerations of the three studies. It will provide the rationale for selecting the instrumentation, experimental procedures and technical aspects. The major methodological issues will be discussed systematically by the types of data collected and the data management process. The detailed description of the precise experimental procedures of all the three studies can be found in Chapters 3-8.

2.1 RESEARCH DESIGN

The research project aimed to examine the effects of three physical stressors: static posture, speed and force of keyboard operation. Study 1 was a field investigation with the aim to examine whether symptomatic and asymptomatic office workers maintained similar static postures when they worked in their own environment. Study 2 was designed to examine the effects of a controlled dose of static posture on the kinematics and muscle activities of the Case and Control Groups. Study 3 focused on the effects of controlled doses of increase in the speed and the force elements of keyboard operation, in terms of the EMG and keystroke dynamics in the Case and Control Groups. In all three studies, the subjective discomforts in the upper body areas bilaterally were assessed. In Studies 2 and 3, both the task performed and the work environment were standardized.

In the three studies, the dependent variables were measures of

1. neck and shoulder kinematics (Studies 1 and 2),
2. neck and shoulder EMG (Studies 2 and 3),
3. keystroke speed and force (Study 3 only)
4. subjective discomfort scores (Studies 1, 2, 3).

All three studies have recruited female office workers and the same method to recruit and classify into Case and Control Groups was used throughout. Where possible the same dependent variables were measured in different studies, for example in examining EMG in Studies 2 and 3, the same variables of EMG amplitudes (APDF) and median frequencies (MF) were compared.

In both Studies 2 and 3, the same muscles were examined (CES, UT, LT and AD). These four muscles were selected as they are the major stabilizing muscles in the neck-shoulder region, and both left and right sides were studied in order to better understand how the musculoskeletal loads were distributed during keyboarding tasks, which were basically symmetrical tasks. The muscle activities of the bilateral muscles were examined in relation to the discomforts experienced by the subjects.

The same regions were studied in the kinematics measurements as these were closely related to the muscle activities. The static postures and movements of the head-neck and shoulder regions were the focus of the kinematics analyses. However, due to the environmental factors, two different motion analysis systems were used in Studies 1 and 2. Study 1 was a field investigation and therefore we were limited by the equipment we could use and the space available. Studies 2 and 3 were conducted in a laboratory that allowed us to have better control of the physical environment and the equipment used.

We strove to employ the same instruments where possible, as well as consistent and standardized methods in data collection. By using the same or similar equipment and studying the same dependent variables, results of the three studies could be compared directly in order to identify common or different patterns of responses from the subjects.

The following are brief summaries of the research designs and protocols of the three studies.

Study 1: A field comparison of neck and shoulder postures and discomforts in symptomatic and asymptomatic office workers

Specific Research Questions	1. Do Case and Control subjects have different neck-shoulder postures? 2. Do the neck-shoulder postures of Case and Control subjects differ between resting and working? 3. Do the neck-shoulder postures of Case and Control subjects change over time in a typical working day?
Research Design	Case-Control Observational Study
Independent variables	1. Group (Case vs Control) 2. Task (reference/resting vs working) 3. Time-at-task (5 repeated trials)
Dependent variables	1. Posture: (i) head tilt angles, (ii) neck flexion angles, (iii) acromion protraction - displacement, (iv) acromion elevation – displacement, 2. Discomfort scores – 10 body areas, verbal numerical rating scale 0-10
Procedures	Each subject's 2D kinematics was captured 5 times (x 15 min each) across a day, and discomfort ratings were collected after each video capture.
Subjects	Computer using female office workers Case = 8, Control = 8

Study 2: A laboratory study to compare kinematics, EMG and discomfort between symptomatic and asymptomatic office workers in response to a continuous typing task involving static posture for 1 hour

Specific Research Questions	1. Do Case and Control subjects have different responses in terms of posture, EMG and discomfort in performing keyboard work? 2. Do these dependent variables of Case and Control subjects change over time in performing a typing task requiring a static posture for 1 hour?
Research Design	Case-Control Quasi-experimental Study
Independent variables	1. Group (Case vs Control) 2. Time-at-task (5 repeated trials) 3. Side (left and right)
Dependent variables	1. Kinematics: mean angles and ranges (i) Head-Neck flexion, side flexion, rotation (ii) Thorax flexion, side flexion (iii) Shoulder flexion, abduction (iv) Scapular flexion, abduction, rotation 2. EMG: 4 muscles bilateral (i) APDF – 10th%, 50th%, 90th% (ii) MF 3. Discomfort scores: same as Study 1
Procedures	Each subject's 3D kinematics and EMG was captured (x 60s) for 5 times in a one-hour non-stop typing task, discomfort recorded after each video capture.
Subjects	Computer using female office workers: Case = 23, Control = 20

<u>Study 3:</u> A laboratory study to compare EMG, keystroke performance and discomfort between symptomatic and asymptomatic office workers in response to increased typing speed and increased typing force

Specific Research Questions	1. Do Case and Control subjects have different EMG, keystroke performance, and discomfort responses? 2. Do these responses differ under "normal", "faster" and "harder" typing conditions?
Research Design	Case-Control Quasi-experimental Study
Independent variables	1. Group (Case vs Control) 2. Conditions (Normal, Faster, Harder) 3. Time-at-task (5 repeated trials) 4. Side (left and right) – in EMG variables
Dependent variables	1. EMG –same muscles and same variables studied (i) APDF – 10th%, 50th%, 90th% (ii) MF 2. Keystroke speed and force variables: (i) Mean speed (ii) Mean force (iii) Speed variability (iv) Force variability 3. Discomfort scores – same as Studies 1 & 2
Procedures	Each subject performed typing task x 3 conditions (20min each). EMG was measured 5 times (x 40s each) and discomfort rated 3 times during each typing condition.
Subjects	Computer using female office workers Case = 21, Control = 20

2.2 SUBJECTS

Throughout the series of 3 studies, only female subjects were recruited. One practical reason was the convenience as there are generally more females among office workers working in administrative and clerical types of jobs. This was also done in order to eliminate the variable of gender which has been identified as a potentially significant factor in previous research (Bernard et al., 1994; Hales et al., 1994; NIOSH, 1997). Many of the cross-sectional studies examining EMG and kinematics variables in workers have also selected to examine female subjects only (Balogh et al., 1999; Birch et al., 2000; Hagg & Astrom, 1997; Veiersted et al., 1993; Westgaard et al., 1993).

The subjects for Study 1 were all recruited within the local university in a sample of convenience. For Studies 2 and 3, subjects were recruited from a variety of different businesses and industries, and therefore they represented a more heterogeneous group of office workers. The same inclusion and exclusion criteria were used in all three studies and these have been described clearly in the Chapters 3 (Study 1) and 4 (Study 2). Basically the main inclusion criteria involved the average hours of daily computer use (2-4 hours minimum), and the type of computer tasks had to be mostly administrative or clerical in nature. This criterion was set in order to select those subjects who were proficient text-typists, as the research was more designed to study the text-typing task in keyboard use. In addition, subjects must be proficient with typing in English as the typing packages used in the studies were all in English, and those whose daily computer work involved languages other than English were excluded. Other types of office workers whose daily tasks involved more the use of numeric pad or the mouse as inputting devices were also considered not suitable for the present research. The subjects were then classified into Case and Control Groups after they were admitted into the studies.

The questionnaire designed to classify the subjects into Case and Control Groups provided important information on the personal profiles of the subjects, their work experiences, working hours and job task analysis. Their past and present experience of upper body discomforts was assessed based on questions modified from the Standardised Nordic Questionaire (Kuorinka et al., 1987). We have modified the body chart in the Nordic Questionaire to exclude the lower body areas, as these were not in the scope of the present research work. Thus the same 10 upper body areas of the neck, shoulders, elbows, wrist/hand and upper back regions were assessed in the questionnaire as well as in the discomfort evaluation during the experimental conditions in all three studies (see Appendix I). This allowed us to compare the subjects' past discomfort experiences with their "task-induced" discomforts during the three studies.

The Standardised Nordic Questionaire has been widely used to assess musculoskeletal symptoms for a 12-month period in an occupational context (Ekberg et al., 1994; Karwowski, Eberts, & Salvendy, 1994; Kuorinka et al., 1987; Magnusson, Pope, Wilder, & Areskoug, 1996; Palmer, Smith, Kellingray, & Cooper, 1999). According to Kuorinka et al. (1987), test-retest reliability of the Nordic Questionnaire showed that the number of non-identical answers varied from 0-23%. Dickinson et al. (1992) reported a 0-26% of non-identical answers on various questions for the Nordic Questionaire. Palmer et al. (1999) evaluated the repeatability of the Nordic Questionaire in assessing neck, shoulder and upper limb symptoms and reported a very high rate of agreement ranging from 85%-90% for the questions on pain in the past week and pain in the past year for the shoulder, elbow, wrist/hand and neck regions.

The other part of the questionnaire was constructed to obtain more detailed information about the subject's experience in using computers, their style of typing, as well as an estimated breakdown of average hours of keyboard use and mouse use in their daily computer work. The nature of computer tasks in terms of word-processing, data entry etc was also asked. These data allowed us to compare the individual characteristics and work profiles of the subject groups, in an attempt to link these to the physiological measures of EMG, kinematics and subjective discomforts in the various studies.

2.3 EMG METHOD ISSUES

The evaluation of surface EMG was conducted on the same four muscles of CES, UT, LT, AD bilaterally in Studies 2 and 3. The same method of skin cleansing, electrode placement and normalization was employed in both studies, and all these procedures were performed by the Primary Investigator personally. In the pilot study, the Investigator had examined the muscle fibre orientations on cadavers, reviewed past studies, and compared the electrical signals in 3 positions (higher, mid and lower) in each muscle on a few subjects. The EMG signals were also compared between different methods of resisting maximal contractions, in identifying the best method to produce maximal activities from the different muscles for normalization.

For both studies, the same dependent variables: APDF, MF and EVA of each muscle were computed using the Labview program. Resting EMG data was captured before the start of normalization and again before the start of the typing trial(s). In Study 2, normalization for each muscle was done before the start of typing task, and post-task MVC was also recorded from each muscle. In Study 3, only pre-task MVC were measured. The following sections address the various methological issues regarding surface EMG that are relevant to this body of research work.

2.3.1 Instrumentation

In both Studies 2 and 3, the Noraxon Telemyo System (Noraxon, U.S.A. Inc., U.S.A.) was used to capture the EMG signals which were channeled into the Vicon 370 system (Oxford Metrics Ltd., U.K) as analogue signals. The Noraxon system has an intrinsic frequency of 1000Hz and a bandwidth of 10-500Hz. The raw EMG signals first went through an A/D conversion (1000Hz) from the transmitter to the receiver of the Noraxon system, then these signals underwent A/D conversion again in Vicon at a sampling rate of 1920Hz. The analog channels in the Vicon system were set with a voltage range of ±5V (or 10V peak-to-peak) and the A/D converter was 12 bits (offset=±2048). The resolution of the EMG signals could be calculated as 5V/2048=0.00244V/bit. The eight channels of EMG signals were pre-amplified close to the electrodes with a gain factor of 2143.5±15.1, as checked by the VC-11 Memory Oscillscope (Nihon Kohdan, Japan).

In Study 2, EMG data was collected for a 60-second period for five trials (at the 5th 20th, 35th, 50th and 60th minutes) during the 1-hour typing session. In Study 3, EMG data were captured for a shorter period of 40 seconds, repeated at the 5th, 10th, 15th and 20th minute of each 20-minute typing trial, as this was found to be sufficient to elicit a typical pattern of muscle activity during the typing tasks.

2.3.2 Electrode application issues

While there have been large variations in application procedures concerning surface EMG measures in occupational studies, there have been a few major review papers and texts that provided good guidelines summarizing all the different issues regarding EMG methodolgy (Aaras, Veierod, Larsen, Ortengren, & Ro, 1996; Basmajian & De Luca, 1985; Jensen, Vasselijen, & Westgaard, 1993b; Kumar & Mital, 1996; Mathiassen, Winkel, & Hagg, 1995). These references have provided very useful information to help establish the procedures used in the present research.

For the present research, the smaller size electrodes (15mm in diameter) were selected and the inter-electrode distance was kept to a minimum of 20mm. The skin cleansing procedure can be considered a vigorous one involving cleansing with water, sand paper and alcohol. Input impedance was reduced to a minimum (< 2k ohms) as checked with an impedance meter. These steps would contribute towards ensuring a good quality of EMG signals.

EMG electrode positions and method of application have been adopted from a number of past research studies (Aaras et al., 1996; Attebrant, Mathiassen, & Winkel, 1995; Jensen et al., 1993b; Mathiassen & Winkel, 1990; Veiersted, 1991; Zipp, 1982). The electrode positions are also fully listed in Table 4.2 and pictured here in Fig. 2.1. The EMG results produced from Studies 2 and 3 have demonstrated consistent results in repeated captures of EMG data in the various experimental conditions. There were also a few subjects who participated in both Study 2 and Study 3, and the consistency of their EMG results provided evidence to support the reliability of the methods used. This was also partly due to the same investigator being responsible for conducting all the electrode attachments and normalization procedures throughout the studies.

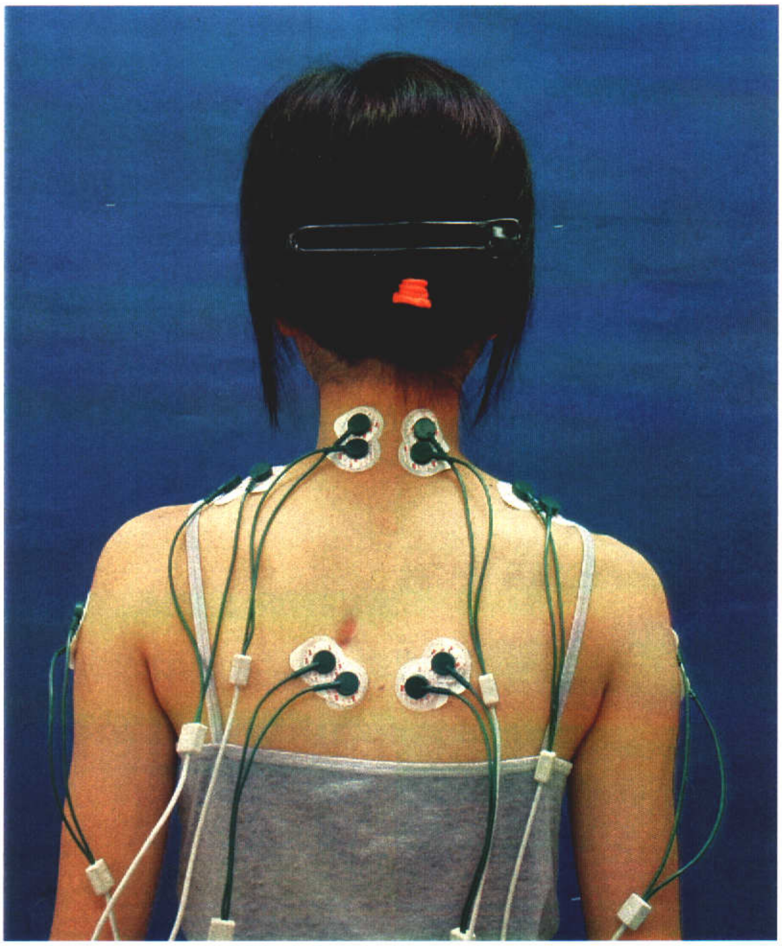


Fig. 2.1: Photograph showing the electrode positions for the bilateral CES, UT, LT and AD muscles

2.3.2.1 *Pilot tests on EMG procedures*

Prior to the start of the actual data collection process, a series of pilot trials were conducted in order to ensure the validity and reliability of the experimental procedures. Pilot trials were conducted on 3 female subjects were performed to compare the quality of EMG signals at different electrode positions. For each position, 3 trials of MVC were performed on both the left and right sides. From these tests, the final positions of the electrodes were selected as the ones where the best quality of EMG signals were observed.

Table 2.1: Electrode positions tested in pilot study

Muscle	Electrode Positions tested	Final Selected Position
Upper Trapezius (UT)	▪ "midpoint" between electrodes at half-distance between acromion and C7	✓
	▪ move "midpoint" 1 cm medial	
	▪ move "midpoint" 1 cm lateral	
Cervical Erector Spinae (CES)	▪ 1.5cm from midline, "mid-point" (between 2 electrodes) at C5	✓
	▪ 1.5cm from midline, mid-point at C6	
Lower trapezius (LT)	▪ 2cm lateral to midline, centre of electrode horizontal to T4,T5	
	▪ 2cm lateral to midline, centre of electrode horizontal to T5,T6	✓
Anterior Deltoid (AD)	▪ midpoint (between 2 electrodes) at ½ distance between acromion and deltoid tuberosity	✓
	▪ move "midpoint" up proximally 1 cm	
	▪ move "midpoint" down distally 1 cm	

2.3.3 EMG normalization

The present study has adopted the EMG normalization procedures used in previous studies with some modifications (Aaras et al., 1996; Mathiassen et al., 1995; Veiersted, 1991). Mathiassen et al. (1995) proposed six essential issues that must be reported in EMG normalization procedures, which included: outcome variable, electrode location, posture and attempted movement, load and duration of reference contractions, signal processing, and number of repetitions. This approach was adopted in our documentation of the normalization procedures in Chapters 4 and 7, and all the 6 essential issues have been clearly described in the "methods" sections in these chapters. We have also developed a special chair with adjustable metal bars for fixating the load cell used to record the force produced in the normalization contractions. Photographs of the subject performing normalization contractions are presented in Fig. 2.2 - 2.5.

A number of ergonomic studies have adopted the testing of simultaneous bilateral shoulder abduction as the muscle actions for recording the maximum voluntary contractions (MVC) of the UT muscles (Aaras & Westgaard, 1987; Aaras et al., 1996; Attebrant et al., 1995; Christensen, 1986; Jensen et al., 1993b; Veiersted et al., 1990). In our present research, we have selected to test each side separately in order for the subject to concentrate on performing the maximal effort for the muscle being tested.

Previous studies have often tested maximum contractions of the UT muscle in 90^0 abduction or elevation – as this was found to produce a strong EMG signal (Nakata et al., 1992; Schuldt et al., 1986; Veiersted et al., 1990; Westgaard et al., 1993).

However, the action of shoulder elevation with the upper arm in neutral abduction may be more appropriate in this case, as it would more closely simulate the arm positions during computer work.

In the present study, the CES muscles were the only ones where contractions were recorded bilaterally, as it was difficult to test sides separately.

The use of amplitude normalization to enable comparison between muscles and between subjects has been well accepted. This approach has been used in many EMG studies recording upper limb muscle activities in occupational tasks (for reviews, see Mathiassen et al., 1995; Westgaard, Jansen, & Jensen, 1996). However, some studies have supported the use of submaximal reference voluntary contractions as opposed to MVC, as MVC could be subject to high variability. Submaximal reference contractions have either been a series of reference contractions at known constant forces or against fixed weights (Balogh et al., 1999; Mathiassen & Winkel, 1990; Milerad, Ericson, Nisell, & Kilbom, 1991; Takala, Lammi, Nieminen, & Viikari-Juntura, 1993), or ramp contractions from 0% to 30-50% (Aaras et al., 1996; Jensen et al., 1993b; Sundelin & Hagberg, 1989; Yang & Winter, 1983). However, submaximal normalization only allows comparison within muscle and within subject, and for this research comparison across muscles and subjects was required. Many of the studies cited above have also used a similar approach as the present study, involving both maximal and submaximal contractions in the normalization procedures.

MVC normalization has been performed using maximum force output and maximum electrical activity output. Where no estimation of forces is attempted, the use of maximum electrical activity has been recommended (Mathiassen et al., 1995).

In the present research we piloted the use of a submaximal ramp contraction normalization (%MVC), a maximum voluntary contraction force normalization (%Max) and a maximum voluntary contraction electrical activity normalization (%MEMG). The three formulae computed were as follows:

$$\%MVC = 100\% \times \frac{(EMG \times slope) + intercept}{N100\%MVCMean}$$

$$\%Max = 100\% \times EMG \times \frac{N30\%MVCMean}{EMG100\%MVCMean \times N100\%MVCMean}$$

$$\%MEMG = 100\% \times \frac{EMG}{EMG100\%MVCMean}$$

Various mathematical equations have been used in past research, using linear, exponential or least-squared regression models to normalize EMG amplitudes. The formulae listed here were similar to methods used in Aaras et al. (1996); Attebrant et al. (1995) and Mathiassen and Winkel (1990).

The EMG data on 5 subjects were examined after being normalized with all 3 procedures. It was found that the maximum electrical muscle activity ("MEMG") procedure produced the better quality EMG data and this procedure was selected to be the parameter for computing all the typing trial data. The ramp contraction was kept in the study protocol as part of the quality control of establishing a valid contraction.

In the normalization procedures, a series of 5 second MVC for each muscle were performed, followed by 30%MVC "ramp" contractions. Subjects were given one preliminary trial MVC then 3 repetitions of MVC were recorded. Three repetitions were chosen as a compromise between improved consistency with learning and muscle fatigue from repetition (Basmajian & De Luca, 1985; Mathiassen et al., 1995). The exact procedure to perform the 30% ramp contraction was very similar to that by Aaras et al. (1996), except that the contraction lasted 5 seconds instead of 10. From the MVC contractions a 30% level was calculated and a ramp from 0% to 30% was drawn on an oscilloscope screen. Subjects were given a trial of increasing the contraction to follow the ramp displayed on the screen. The visual feedback assisted subjects performing a smooth ramp contraction and the second trial was recorded (for quality control of the subject's contraction performance).

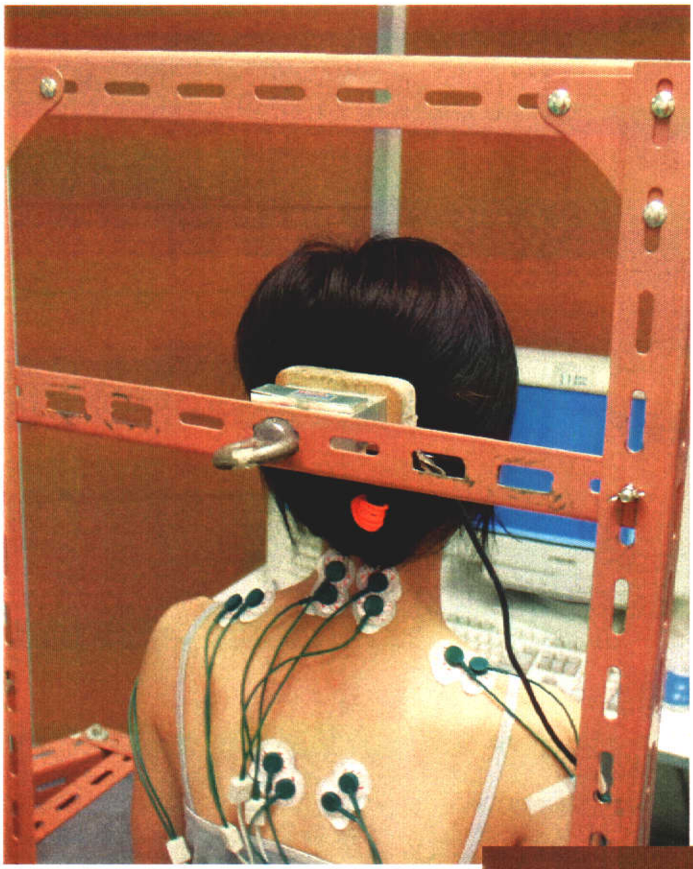


Fig. 2.2: Photograph showing subject performing a resisted neck extension for recording MVC of bilateral CES muscles

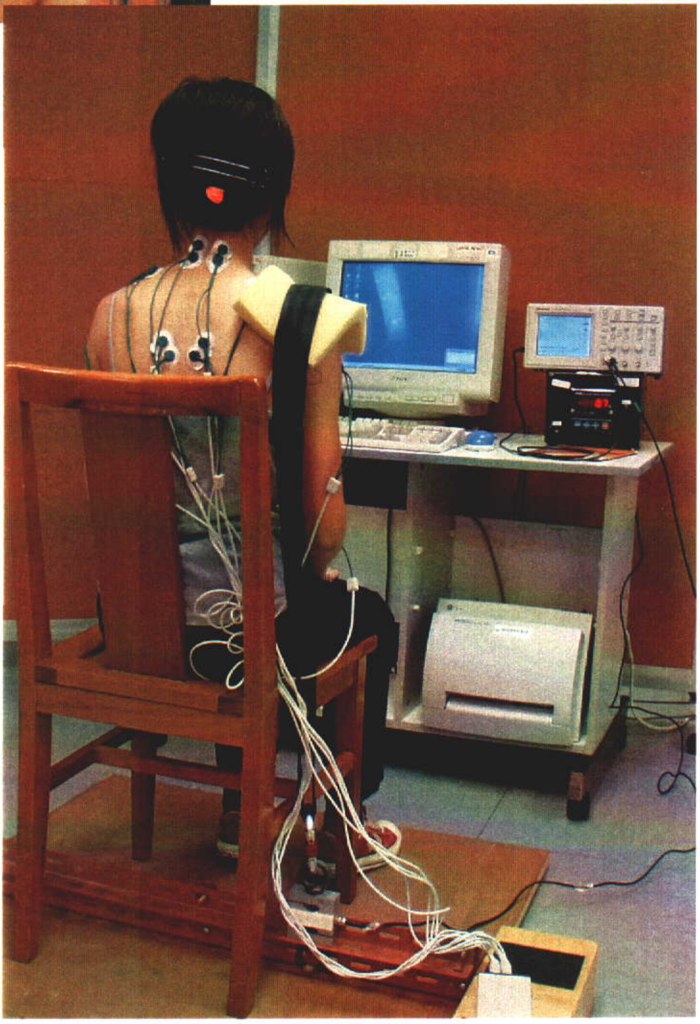


Fig. 2.3: Photograph showing subject performing a shoulder elevation against a shoulder strap for recording MVC of the right UT muscle

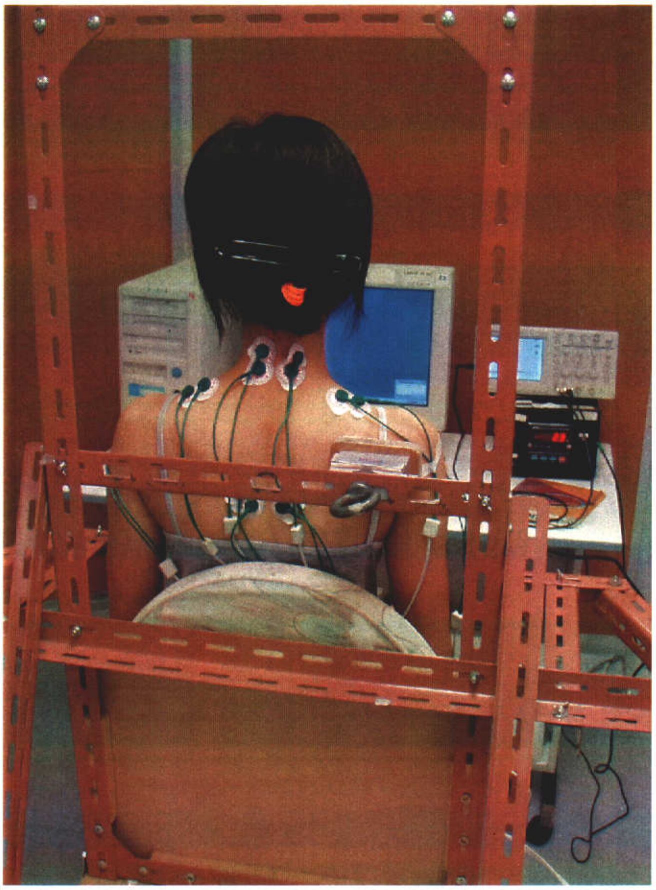
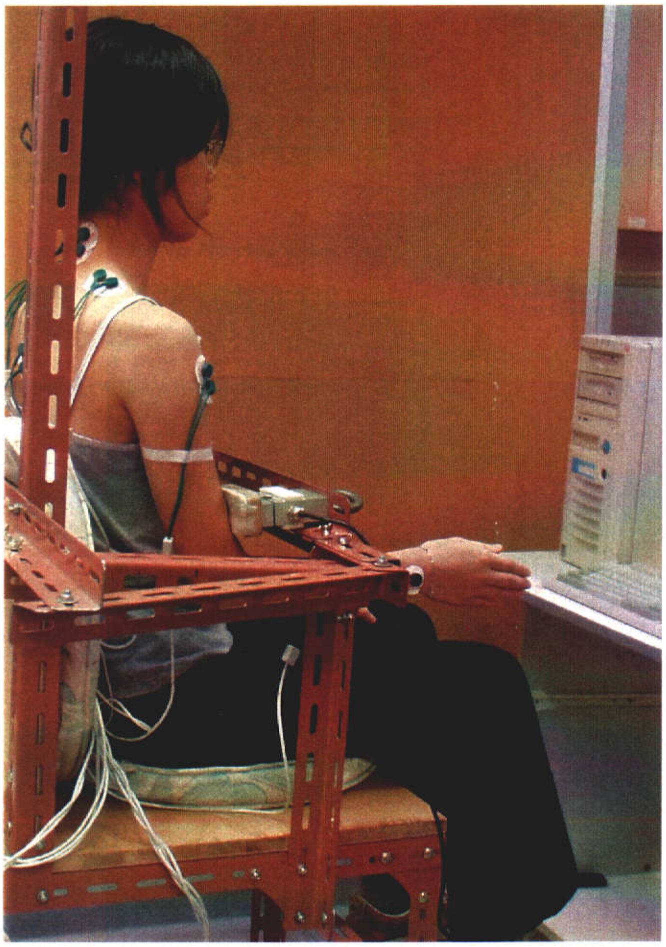


Fig. 2.4: **Photograph showing subject performing a right scapular retraction for recording MVC of the right LT muscle**

Fig. 2.5: **Photograph showing a subject performing a forward flexion of the right upper arm for recording MVC of the right AD muscle**

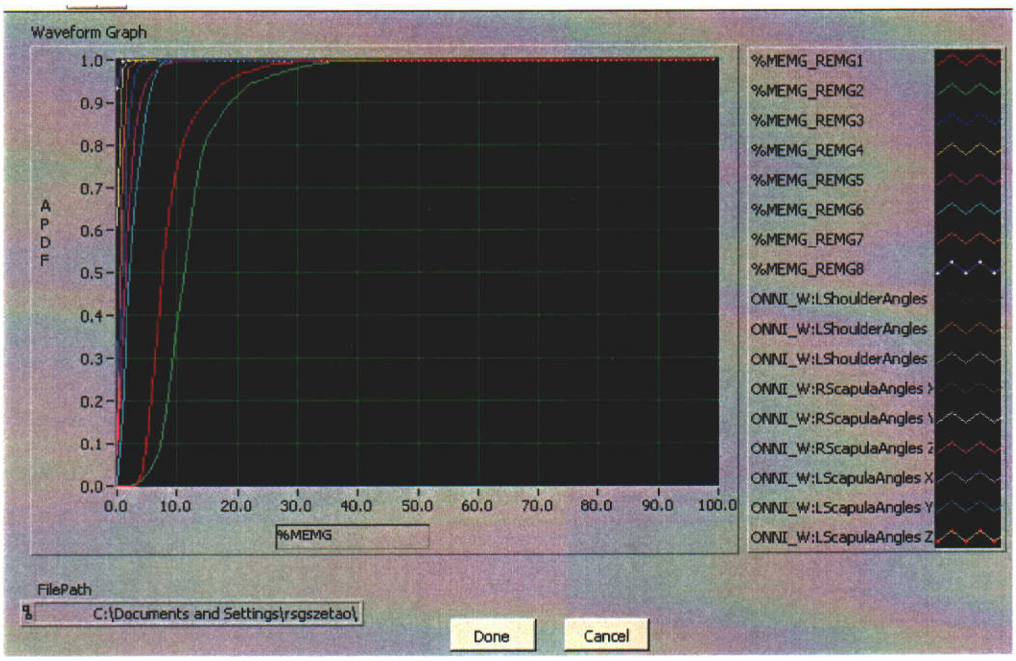


2.3.4 Processing of EMG data

The EMG output files produced by the Vicon system were in the .C3D format (a binary format) which had to be converted into a text file format before the data could be readable for further processing. A Labview program was written to read the binary C3D files, and there were functions designed to allow the user to select any of the appropriate analog channels from the Vicon system and arrange the data in the appropriate columns in the text file format.

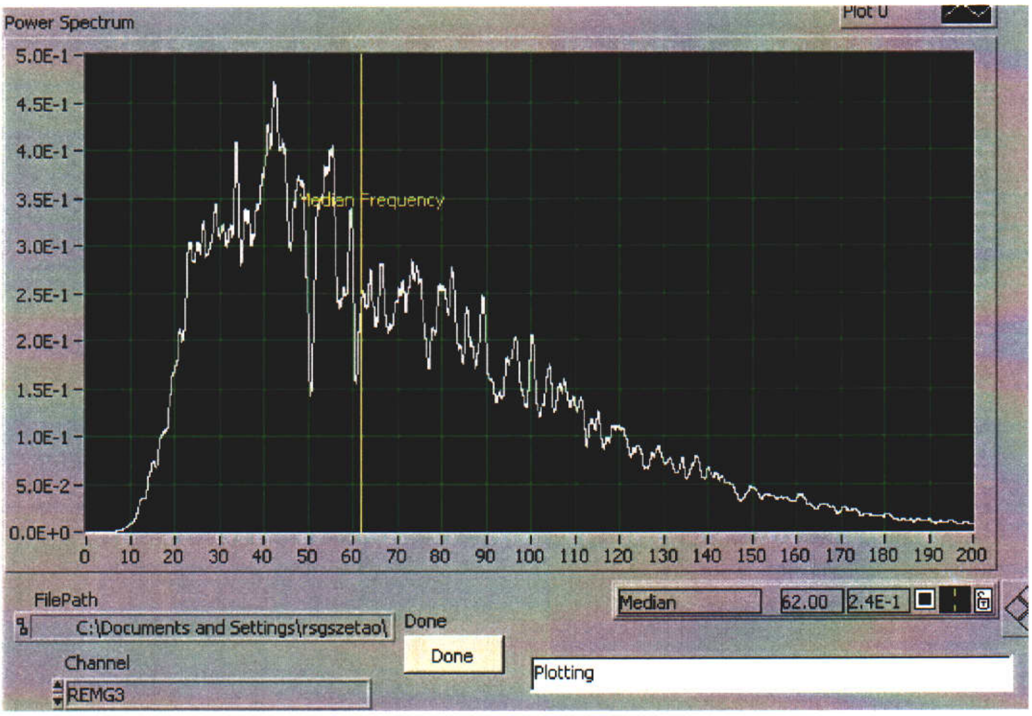
For the EMG normalization trials, both the load cell force data and the EMG data were processed by the Labview program. The EMG raw signals of the normalization trials were put through a process of down-sampling and half-wave rectification to reduce the data to 10Hz RMS values. For the 100%MEMG trials, a slice of 1 second data of the EMG signal at a plateau was selected for processing. From the sliced data the mean values of the 100%EMG levels were computed. (In the pilot normalization the 100% Force value from this slice was also used. Also for the pilot normalization the EMG and force signals for the 30% ramp contractions were viewed and the data from 0% force up to the maximum level for a 5-second duration was sliced for processing the 30% EMG and 30% force values.) The EMG for each muscle required its own normalisation constants (100% EMG, the slope and the intercept) for constructing the regression formula. After obtaining the normalisation constants for each of the 8 EMG channels, all of the normalised data were stored in a data file which would be used in the subsequent analysis of the typing trial data for each subject. Appendix IV contains the detailed instructions for the Labview program in processing EMG data.

The typing trial data in Studies 2 and 3 were processed to compute the functions of APDF (expressed in %MEMG) and MF. The function of Exposure Variance Analysis (EVA) was also computed for all the trial data but they would not be reported here in the thesis. To facilitate quality control, the program also provided graphic displays of the computed functions so that a visual inspection and comparison of the data from different muscles of each subject were possible. A typical APDF graph contained the APDF lines for all 8 muscles in one trial, as seen in Fig.2.6. The power spectrum was also graphically displayed separately for each muscle as part of the quality control of the data (see Fig. 2.7).



FilePath: C:\Documents and Settings\rsgszetao\

Fig. 2.6: Typical APDF graph of 8 muscles in a typing trial as displayed in the Labview program



FilePath: C:\Documents and Settings\rsgszetao\

Channel: REMG3

Median 62.00 2.4E-1

Plotting

Fig. 2.7: Typical graphic display of power spectrum with MF from the right UT muscle as seen in the Labview program

2.3.5 Problems with EMG signals

2.3.5.1 *Quality control of EMG signals*

The recording of surface EMG is well known to be affected by a large number of physical factors that can influence the quality of signals produced and their reproducibility (Aaras et al., 1996; Basmajian & De Luca, 1982; Jensen & Westgaard, 1995; Mathiassen et al., 1995; Winter, 1996). These factors include those about the electrode management (type of electrode, placement, inter-electrode distance, contact) and tissue preparation (skin temperature, skin resistance) that can be controlled by the investigator (Aaras et al., 1996; Basmajian & De Luca, 1982; Jensen & Westgaard, 1995; Mathiassen et al., 1995; Winter, 1996). Based on experience from past research, these problems were reduced as much as possible, in order to ensure a good quality of signals.

Regarding the subjects, the variables that may influence the quality of EMG signals include the thickness of the skin and subcutaneous fatty tissues, the bulk of the muscle, the alignment of the electrodes with the muscle fibres, and the reduction of skin impedance (Basmajian & De Luca, 1985; Winter, 1996). There may also be the interference of signals from nearby muscles ("cross-talk"), which can be a considerable problem with surface EMG recordings (Basmajian & De Luca, 1985; De Luca & Merletti, 1988; Winter, Fuglevand, & Archer, 1994). In the case of the UT muscle, there may be cross-talk from the supraspinatus (Winter, 1996), and for the LT muscle, rhomboids and thoracic erector spinae may also interfere. By using smaller electrodes and keeping the inter-electrode distance to a minimum, the amount of cross-talk from other muscles may be reduced (Winter, 1996).

2.3.5.2 *Noise and artifacts*

The problem of non-biological or electrical interference from other sources within or around the laboratory was noted, and by introducing a low-pass filter of 200 Hz, some of these unwanted signals were eliminated. Electrical noise at 50 Hz and 60 Hz were noted and notch filters of 50 Hz and 60 Hz were added in the Labview Program, to eliminate the unusual peaks in the power spectrum at these frequencies (Basmajian & De Luca, 1985; Clancy, Morin, & Merletti, 2002). However, occasionally, some of the EMG recordings still displayed abnormal curves in the power spectrum and these trials were discarded and replaced with adjacent trials that were "normal". It is estimated that about 5 % of the typing trial data were replaced in this manner.

Another major source of interference was from the electrocardiogram (ECG) signals. These signals have been well known to affect EMG recordings in upper limb muscles. The high-pass filter of 20 Hz was introduced in order to reduce the ECG signals. The ECG signals were most noticeable when the LT muscle activities were at low levels (<10%MEMG) during the typing trials. In the MVC normalization trials, muscle activities would over-ride the ECG signals. Ortengren (1996) and Clancy et al. (2002) addressed the difficulty in eliminating the ECG disturbances completely, as there were substantial overlaps of the power spectra between EMG and ECG signals. It would be very difficult to completely filter out all the ECG signals without taking out a considerable amount of EMG amplitudes. Thus in our present research, we have not implemented any automatic artifact removal functions, apart from the 20Hz high-pass filter. However, each EMG trial was carefully screened by the Primary Investigator in the Labview program, and abnormal sections would be replaced by "normal" portions of the recording through the use of the "cut-and paste" function.

2.3.5.3 *Variability of EMG data*

Jensen and Westgaard (1995) reported that normalized EMG activity levels could be expected to vary within a range of approximately 20%. Surface EMG recordings are well known to be highly variable, partly due to the individual variations in motor control and tissue composition; and partly attributable to the factors affecting the signal recording (electrode type and location, skin impedance etc). The type of muscle actions involved and the presence of dynamic movements during the occupational task would also affect the variability. Balogh et al. (1999) compared the inter-individual differences in EMG activities and reported coefficients of variations (CV) ranging from 20% to 100% in the trapezius and infraspinatus muscles, when subjects performed a standardized industrial manual task. Mathiassen, Burdorf and van der Beek (2002) reviewed a large number of trapezius EMG studies and reported CV's ranging from 15% to about 84% for most studies (one study Vasseljen & Westgaard, 1995, had a CV of 150%). Mathiassen et al. (2002) recommended certain measures to help improve statistical power, such as multiple measurements within a day and/or for a few days. Subjects engaged as their own controls in a "paired design" would also increase the power considerably.

The present sample size consisted of exactly 100 subjects in all three studies. The sample size in Studies 2 and 3 with over 20 subjects in the Case Group and 20 subjects in the Control Group could be considered fairly large in comparison with past research. In Chapter 4, we have described that in order for the UT and CES 50th%APDF to detect a 20% difference in the group effect, the necessary numbers of subjects would be 90 and 152 per group respectively ($p \leq .05$, power=0.8) (Borenstein, Rothsden, & Cohen, 1997). Thus it is indeed very difficult to achieve statistical significance for many of the observed differences between groups. In addition there may also be different patterns of EMG changes due to interactions among the group, time and side factors.

Another source of variability of the EMG signals came from the variations in normalization data of the various muscles. Although most of the subjects were able to produce consistent force and EMG levels with the 3 repetitions of MVC, there were large variations between subjects and these differences would be reflected in the normalized EMG amplitude values. For example, in 1-2 subjects in the Case Group, their MVC for the UT muscles were very small in values, and their subsequent EMG amplitudes would then become very high numbers (up to 99%MEMG) for the 50th%APDF. However, these phenomena were only observed in some of the muscles for these subjects while their other muscles recorded fairly "reasonable" values in the normalization. Thus these subjects were retained in the statistical analysis, as taking out the extreme numbers could "wash out" some of the group differences in the EMG measures.

2.4 KINEMATICS METHOD

2.4.1 Instrumentation

Two different motion analysis systems have been used in the present research. Study 1 measured the two-dimensional neck and shoulder postures using the Peak 5 motion analysis system (Peak Performance Technologies Inc., 1992), which only required one single video camera and was more suitable for a field investigation. The Peak system allowed the user to specify the marker locations and to define the joint angles by joining the lines connecting the markers. This approach facilitated the more detailed examination of the Head Tilt and Neck Flexion angles in the sagittal plane.

Studies 2 and 3 utilised the Vicon 370 system, Version 3.1 (Oxford Metrics, Oxford, U.K.) for the simultaneous capture of kinematics and EMG. The Vicon system was equipped with a sophisticated software package for biomechanical modeling (the Bodybuilder for Biomechanics, Version 3.5, Oxford Metrics Limited, Oxford, U.K.), and joint angles and marker locations were already defined.

Ehara et al. (1997) examined the performances of several 3D camera systems for motion analysis using a standardized method to study the accuracy and reliability of movements measured. The Vicon 370 system produced one of the lowest values (0.94mm) in absolute mean error of marker movements, with the maximum error in the range of 4.37-8.57mm. The 2-D Peak 5 system used in Study 1 had a reported mean absolute error of 5.3mm (Ehara, Fujimoto, Miyazaki, Tanaka, & Yamamoto, 1995). Hence it can be deduced that the Vicon system had a higher degree of accuracy or resolution than the Peak system, which still had a small mean absolute error.

However, the quality and accuracy of motion data are not only affected by the camera system. There are also the issues of marker / landmark locations and skin movements which can increase the margin of error considerably. In our study, we have attempted to reduce this error to the minimum by having the same investigator perform all palpations of landmarks and positioning of markers. Prior to Study 1, a pilot study was conducted to evaluate the intra-rater reliability for placing the markers consistently in the correct and same positions on the subjects' head, neck and shoulder bony landmarks (Szeto, Kirtley, Raine, & Straker, 2000). The procedures consisted of one tester performing the marker attachment procedures on five subjects repeated on three occasions within a day. The subjects' sagittal profiles were captured by a video camera and the images digitized by the Peak system. The results showed a high intra-rater reliability with a $ICC_{3,3} = 0.62\text{-}0.81$. This finding indicated that when the same investigator was responsible for placing all the markers on the subjects, there was a high level of reproducibility.

For both the Peak system and the Vicon system, standardized calibration procedures were strictly followed according to the Operation Manuals for the systems (Peak5 Users' Reference Manual, 1992; Vicon 370 Users' Manual). All the technical procedures in using the Peak system have been described in detail in a previously published paper (Szeto et al., 2000) and in Chapter 3. In using the Vicon system, static and dynamic calibration procedures were carried out to ensure that the "Calibration Residual" values were below 0.1% of the reconstruction volume, before data capture commenced. A full description of the calibration procedures and definitions of body segments and joint angles can be found in Chapter 3 (Study 1) and Chapter 7 (Study 2).

2.4.2 Body segment and joint angle definitions

In Study 1, 4 markers were used to define the sagittal head tilt angle and the neck flexion angle separately. The displacements of the acromion marker on the x-axis and the y-axis were used as indicators of the acromion movements.

In Study 2, the definitions of the body segments and the coordinate systems followed those suggested by the biomechanical model ("Ethelred") from the Bodybuilder program which produced Euler's angles (x,y,z) for the segments defined. These body segment definitions are similar to those commonly adopted in major research studies on motion analysis in the upper limb, and these have been reviewed by Anglin and Wyss (2000).

Although the Vicon system produced angles in three planes, the associated biomechanical model defined the head and cervical spine as one segment. However, after converting the joint angles with reference to the vertical, the results showed consistent values for the head-neck angles between the two systems in Studies 1 and 2. This confirms the validity of the present methods for measuring kinematics.

The definitions of the upper arm segment and the scapular segment also involve very complex 3D coordinate systems. In recent years there has been a rising interest in studying the upper limb motions and more standardized methods to define the axis and planes of shoulder and scapular movements are emerging (Barnett, Duncan, & Johnson, 1999; van der Helm, 1994; van der Helm & Pronk, 1995; Veeger, Yu, An, & Rozendal, 1997). Measuring 3D movements at the shoulder joint is known to have the problem of gimbal lock (Anglin & Wyss, 2000; Zatsiorsky, 1998). This problem occurs when the humerus is parallel to the trunk, and the plane of elevation cannot be distinguished from humeral rotation. Thus the angles measured can result in an 180° rotation. For example, a 5° shoulder flexion can become 185°. In dealing with this problem, we have introduced an angle correction program in the Labview package for processing the joint angle data. The angle correction program also recalculated joint angles to be referenced to the vertical, as opposed to the thorax segment which was the reference (parent segment) in the BodyBuilder program.

The three planes of movements in the scapular segment were referenced to the thorax segment, and represented movements in the three anatomical planes. The precise biomechanical modeling of the scapula is very complex and it could involve several local coordinate systems (van der Helm & Pronk, 1995), and for the purpose of the present research, we have adopted the more simplistic approach from Vicon to consider the scapular movements in the 3 anatomical planes only.

For the shoulder angles, medial/lateral rotation component was considered not meaningful as the subjects' upper arms were mainly in quite similar positions of rotations during keyboard operation. Thus in the results presented in Chapter 7, there were only 2 joint angles (flexion/extension and abduction/adduction) reported for the shoulder.

The problems of marker location and visibility, as well as movement artefacts caused by skin movements have been well recognized as the most difficult issues with respect to motion analysis in the upper limb (Anglin & Wyss, 2000; Rau, Disselhorst-Klug, & Schmidt, 2000). In the present research, these problems are minimized due to the selection of marker locations over bony prominences that are widely used in defining head-neck and shoulder segments. For the scapular segment, markers are placed on the inside border at the inferior angle and the medial end of the spine of scapula. The stability of the marker positions was also assisted by the relatively static positions of the subjects performing only small movements in the typing actions. As such we can expect a high degree of accuracy of the kinematics data. Fig. 2.8 shows an example of the graphic display of the reconstructed body segments, with running graphs of joint angles and marker coordinates. These displays were carefully checked for each subject in order to screen for abnormal data or missing markers.

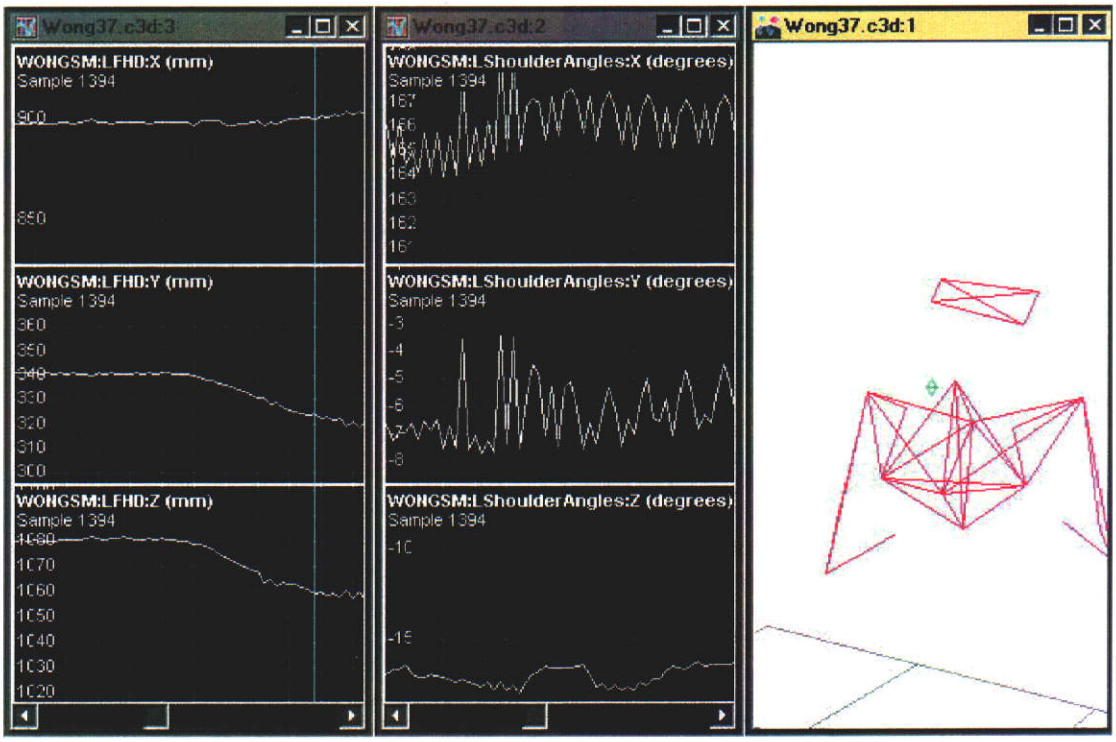


Fig. 2.8: Typical display of coordinate positions and joint angles together with a 3D reconstruction of the upper body segments displayed in the Vicon program

2.4.3 Kinematic variables studied

As the computer task did not involve any movements of large extents, the mean joint angles were considered to be representative of the typical posture. In Study 1, the mean joint angle within a typing trial was taken as the mean posture of that joint. Specifically there were the head tilt and neck flexion mean angles for the 5 typing trials across a working day. The acromion protraction and elevation were indicated by the displacement of the acromion marker along the X and Y axis respectively; and the mean value was taken as the mean position of the acromion for that particular movement. In Study 2, the APDF function was used to analyse the amplitude data for both the kinematics as well as the EMG data. Thus the 50th%APDF value of each joint angle was used to represent the average posture of the joint.

Besides the average angles, the extents of the movements were also computed in terms of the difference between the maximum and minimum angles. The extents of movements of the joints may be related to the biomechanical strain imparted to the joint as well as the muscle actions required to control such movements. In Study 1, this difference was termed the "excursion" of the segment, which was calculated from the difference between the minimum value and the maximum value in the specific joint angle data of a trial. In Study 2, the term "range" was used and this was calculated as the difference between the 90th% and the 10th%APDF values of each joint angle. The use of the 90th% and 10th% values to represent the maximum and minimum angles has the advantage that it is less affected by very "extreme" angles.

2.5 KEYBOARD DYNAMICS

2.5.1 Instrumentation

In Study 3, a "force platform" was fabricated in order to study the vertical forces produced during individual keystroke actions. Four load cells (Piezotron® load cells Model 9712B5, Kistler Instrument Corporation, Amherst USA) were mounted on a rigid platform which held the keyboard. The 4 load cells were coupled to the Vicon system which was used to capture all the analog data. The coupler (Model 5134A, Kistler Instrument Corporation, Amherst USA) was a four-channel signal conditioner for low impedance piezoelectric transducers. The A/D conversion took place in the Vicon system at a sampling rate of 1920 Hz for all analogue channels which included the 4 keyboard load cell channels. Thus the keystroke force data were synchronized with the EMG data collected during the typing trials in the various experimental conditions.

2.5.2 Calibration procedures

Prior to starting Study 3, a series of calibration tests were performed using known weights (20g-200g) placed vertically onto various keys at different locations on the keyboard. The captured voltage signals for the various known weights were used to establish the regression formula from which the experimental keystroke speed and force data were computed. A sample of one of the calibration trials for constructing the regression formula of the keystroke forces is presented in Appendix VI.

2.5.3 Comparison of present method with previous studies

Sommerich et al. (1996a & b) have utilized the same piezoelectric load cells as our present study but they only used 2 load cells instead of 4. Our rationale for using 4 load cells under the four corners of the keyboard was that it would provide a more stable base while all keystroke forces over the entire keyboard can be captured effectively by this system. Theoretically there should be no difference in the summed forces from either 2 or 4 load cells, and our data have been compatible with those reported by Sommerich et al. (1996a & b). Other previous research performed by Rempel and associates measuring single keystroke forces with a load cell placed under a specific key cap have reported lower levels of peak forces (Rempel et al., 1994 & 1997). In Chapter 8 we discussed the problems of measuring forces under single keys only and the justification for our present approach in the force platform design and method of measuring keystroke dynamics was presented.

2.5.4 Processing of keystroke data

A Labview program was also developed to batch process the keystroke data. The analog signals from the 4 load cells were processed and reduced at a sampling rate of 96 Hz by using a window size of 20. The down-sampled data from the 4 load cells were summed, scaled, half-wave rectified and smoothed using a 3-point moving average. The summed data were analysed to identify the keystroke peaks. The start of each keystroke was identified as being where the smoothed data rose one half of a standard deviation (of the un-smoothed data) above zero (see Fig. 8.2). A keystroke ends at the last sample before the next keystroke "start" point. The keystroke peak was determined as the highest value in each keystroke. A sample of the output file on the processed keystroke data from a typing trial is presented in Appendix VI.

2.5.5 Keystroke variables studied

For each typing trial, four variables were examined in statistical analysis to compare the subject's performance between trials, and to compare between subject groups.

Keystroke speed was computed as the number of keystrokes per minute, which was calculated from the peak-to-peak intervals in ms. The keystroke force was computed as the mean value of the peak forces in each trial in Newtons (N). The within-subject variability in keystroke speed and force were also recorded in terms of the standard deviations of the speed and force data for each trial.

In summary, the keystroke dynamics were studied in terms of the 4 variables of:

1. Mean Speed (number of keystrokes per minute)
2. Mean Force (mean Peak Force in N)
3. Speed Variability (mean of within subject SD in speed, units=number of keystrokes per minute)
4. Force Variability (mean of within subject SD in force, units=N)

2.6 DISCOMFORT ASSESSMENT

The same body area discomfort form was used to assess the subjective discomfort reports of the subjects in all three studies (see Appendix III). The demarcation of the body areas were based on those defined in the Standardised Nordic Questionaire (Kuorinka et al., 1987), but only the upper body areas were adopted. Thus there were 10 body areas examined in total – bilateral neck, shoulder, upper back, elbow, and wrist/hand.

Discomfort scores were assessed using a 0-10 numerical rating scale (0=no,1=minimal, 10=extreme/intolerable discomfort). The 0-10 (11 point) numerical rating scale for discomfort assessment has been shown to be a valid and reliable tool for evaluating pain intensity in a great variety of patients (Dalton & McNaull, 1998; Jensen, Karoly, & Braver, 1986; Jensen, Turner, Romano, & Fisher, 1999c; Von Korff, Jensen, & Karoly, 2000). Jensen et al. (1999c) reported on the test-retest stability coefficients of the 0-10 (11 point) scales of current and average pain ratings being in the range of 0.67-0.82, and that these rating scales were sensitive to the effects of changes in activity levels.

We have selected to use the 11-point numerical scale for assessing the subjects' past and present discomforts, as this scale is valid and is easy to administer. As we had to assess the subjects' discomforts at frequent intervals during the various experimental conditions, this scale was most appropriate as it would not distract the subjects unnecessarily from their tasks and did not require a change of posture (like a Visual Analogue Scale would).

The subjective discomfort results were analysed in terms of the number of areas and the summed score for each trial. The location of the discomfort areas were also correlated with the muscle activity patterns and kinematics in Studies 2 and 3.

Study 1 examined discomfort patterns throughout the course of a working day, and provided a broader view of the changes in discomfort patterns in the two subject groups. Studies 2 and 3 involved the study of controlled physical stressors, and the discomfort patterns were studied mainly during the periods of the experimental tasks. In all 3 studies the discomforts experienced by the subjects in the experimental tasks were also compared to their past discomforts.

2.7 THE COMPUTER TASK AND THE COMPUTER WORKSTATION

In Study 1, as the subjects were supposed to carry on with their normal work duties, the video capture was timed to coincide with the occasions where they were performing some form of typing tasks. Thus some of the variations in their postures and movements may be related to the tasks performed and whether the subject was referring to any paper documents on the side. By the same reason, the subjects were not required to change their furniture settings as they were supposed to assume their usual working postures. However, we had to select those subjects with the workstations in reasonably good alignment, that is, the body, the keyboard and the screen were aligned in the sagittal plane; otherwise there may have been parallax errors of the joint angles on the videotapes.

For Studies 2 and 3, we have selected a screen-based copy-typing task as the standard computer task in all the experimental conditions. With on-screen typing programs, the subject would mainly be focusing on the screen eliminating the need to look sideways at other documents. If the subject had to view a printed document on the side of the display screen, it would create unnecessary head movements sideways and this will affect the kinematics results.

Commercially available typing-training packages were used to provide the typing materials. The TypingMaster program (Aquarian Technologies, Maldon, Australia) was used in Study 2, and it displayed well-known children stories for typing practice. In Study 3 we selected another package FasType® (Trendtech Corporation, Scottsdale USA), as this program contained an instantaneous display of typing speed in terms of number of words per minute. This feature was very useful in monitoring the immediate changes in typing speed throughout the different typing conditions in Study 3.

The same computer desk with an adjustable slide-out keyboard tray and the same standard office swivel chair (adjustable in height) were used in Studies 2 and 3. Before starting the typing trials in both studies, the subjects were allowed to adjust their chair heights and keyboard heights in order to achieve a comfortable position. The instruction to the subjects was for them to assume a comfortable, supported and reasonably erect posture that allowed the subject to type comfortably for the duration of the experimental condition. The display screen height was adjusted so that the first line on the viewable part of the screen was at approximately the eye level of the subject, in order to ensure that the head-neck segment would be in a neutral position at the start.

As different subjects may have different physical build, we have decided to standardize their postures into one of good support to the forearms and the back. This would eliminate the confounding variable of discomfort caused by poor body support from the furniture. In this way the main stresses to the body would be arising from the task performed, as the physical environment and the posture of the subject has been standardized.

2.8 DATA MANAGEMENT AND ANALYSIS

The same approach to statistical analysis was employed for all 3 studies. Graphs and trends were examined first before statistical results. A mixed model MANOVA was used, with *group* x2 levels as the between-subject factor; *time* (x5 levels) and *side* (x2 levels) as the within-subject factors. In Study 3, condition (x3 levels) was an additional within-subject factor.

In Studies 2 and 3, the dependent variables APDF and MF of the EMG data were analysed separately. In Study 2, APDF was analysed separately for each muscle; for example the 10^{th}, 50^{th} and 90^{th}% APDF of the CES muscle were examined in one analysis. In Study 3, all the 50^{th}% APDF of the 4 muscles were examined in one analysis. For both Studies 2 and 3, MF of all 4 muscles were analysed together. The EVA results will be analysed separately to this thesis.

In terms of kinematics, Study 1 had slightly different variables compared to Study 2 due to the different motion analysis systems used. Both studies examined the mean posture and the "range" of the neck and shoulder movements. In Study 1, all the joint angles and excursions (ranges) were examined in the same analysis. In Study 2, each segment was analysed separately (e.g. Head X,Y, Z –10^{th}, 50^{th}, 90^{th}%APDF).

Keyboard speed and force variables were measured in Study 3 only, and these were examined in terms of the mean speed, mean force, speed variability and force variability within the same analysis.

Subjective discomfort rating using an 11-point scale was recorded in all three studies. The summed score from all body areas reported in each trial was the dependent variable examined in the three studies.

2.8.1 Data processing

The designing and refining of the Labview program to process all the massive amounts of kinematics, EMG and keystroke data was a laborious process. Different additional procedures had to be inserted at different times in order to enhance the quality of the data, for example, adding the "cut-and-paste" function to replace abnormal EMG data in a trial. After processing the data for each typing trial (e.g. EMG APDF), all the computed functions of that trial were collated into a text file. The data files from all the various typing trials for each subject had to be pooled together into one file (in Excel), and then all the data from all the subjects in the same study were put together into a single file before the data could be transferred into the SPSS program for statistical analysis.

2.8.2 Statistical analysis

A mixed-model MANOVA was used to perform all the major statistical analysis of the main variables. In all 3 Studies, the kinematics data and EMG data involved multiple independent and dependent variables, and a separate analysis was performed for each type of data. Within-subject factors included *time-at-task* (number of data trials) and *side* (left vs right), and the between-subject factor was *group* (Case vs Control).

For Studies 2 and 3, further analysis was conducted by sub-dividing the Case Group subjects into a High and a Low Group according to their discomfort scores. It was found that greater extents of group differences were revealed when the High Group was compared to the Low Group and the Control Group. However, these more apparent differences were only found in terms of EMG amplitudes and some joint angle variables such as the neck flexion angles, as well as the keystroke speed and force variables. Other kinematics data as well as the MF data did not show any greater differences in the High-Low Group comparisons. Subsequently, oneway ANOVA with pairwise contrasts (High-Low, High-Control and Low-Control) were performed on those dependent variables that showed trends for more apparent differences in the High-Low Groups. Some of these pairwise contrasts did reach statistical significance and these were mainly in Study 2. Both the EMG and keystroke variables failed to reach statistical significance in Study 3. This may be due to the insufficient sample sizes as well as the large standard deviations in the data.

There was a large number of variables in the studies. The APDF computations produced three parameters of $10^{th}\%$, $50^{th}\%$ and $90^{th}\%$ for analysis. In Study 2, each of the 4 muscles on both sides would have the same 3 dependent variables recorded in 5 typing trials, yielding a total of 120 columns in the SPSS data file. Hence in Study 2, the APDF variables for each of the 4 muscles were analysed separately at first, and it was found that the 3 levels of APDF showed similar outcomes in statistical measures. Subsequently only the $50^{th}\%$ APDF of the 4 muscles were analysed in Study 3, as this study had the additional independent variable of "condition" with 3 levels (Normal, Faster and Harder). As the $50^{th}\%$APDF represented the median level of muscle activity throughout the trials, this variable would be an appropriate indicator on the average muscle activity involved in performing the postural stabilizing task.

To examine the relationships between different types of variables, for example, the discomfort scores and the muscle activities, Pearson correlation coefficients were computed. These were performed between the discomfort scores of the different body areas, and the mean values of 50^{th}%APDF of the 8 muscles. Correlations were also examined between mean joint angles and muscle activities for the various regions.

To reduce type I errors from multiple testing, multivariate analyses were used to screen for differences prior to univariate testing. Due to the nature of the variables measured it is indeed very difficult to obtain statistically significant differences, that is, the chance for type II errors is high. For example in Study 2 a post hoc power calculation for the EMG amplitude data revealed that 90 and 152 subjects per group would be required, in order to detect a 20% difference in the group effect for the UT and CES 50^{th}%APDF ($p \leq .05$, power=0.8) (Borenstein et al., 1997). The difficulties associated with power in EMG studies have been outlined by Mathiassen et al. (2002) and discussed in Chapter 4. Therefore to best balance type I and type II errors, we used an alpha probability of 0.05 as the critical level and no Bonferroni adjustment was made, but results between 0.10 and 0.05 were also presented as 'trends'.

CHAPTER 3

STUDY 1

A field comparison of neck and shoulder postures in Symptomatic and Asymptomatic office workers

(Published in Applied Ergonomics, 2002, 33, 75-84)

This chapter describes Study 1 and is based on the scientific paper published in the journal of Applied Ergonomics (2002). The content of the paper is reproduced from the published article but the text format is changed to be similar to the other chapters.

The present study aimed to evaluate and compare the head, neck and shoulder postures of office workers with and without symptoms in these regions, in their actual work environments. The Case Group reported significantly higher discomfort scores compared to the Control Group. The results of the two-dimensional motion analysis showed trends for increased head tilt and neck flexion postures in the symptomatic subjects of the Case Group (n=8), compared to the asymptomatic subjects of the Control Group (n=8). Symptomatic subjects also tended to have more protracted acromions compared with asymptomatic subjects and showed greater movement excursions in the head segment and the acromion. All subjects demonstrated an approximately 10% increase in forward head posture from their relaxed sitting postures when working with the computer display, but there were no significant changes in posture as a result of time-at-work.

3.1 INTRODUCTION

3.1.1 Prolonged 'forward head posture' may be associated with musculoskeletal disorders in office workers

There has been mounting evidence in recent years identifying static neck and shoulder posture, such as that frequently assumed by office workers, as a possible risk factor in *work-related neck and upper limb disorders* (WRNULD). There is evidence linking prolonged static posture with increased muscle loading and subsequently increased risk for developing symptoms in the upper body (Aaras et al., 1997; Schuldt et al., 1986; Winkel & Westgaard, 1992). There is also evidence of a dose-response relationship between posture and discomfort. For example in a cross-sectional survey study of 420 medical secretaries, a significantly increased risk of neck and shoulder pain was reported when five or more hours were spent working with office machines (Kamwendo et al., 1991a).

The "forward head posture" that is commonly adopted by office workers involves a combination of lower cervical flexion, upper cervical extension (head tilt) as well as "rounded shoulders" (scapular protraction and elevation). It is a common clinical observation that patients presenting with neck and shoulder pain frequently demonstrate such a posture (Braun & Amundson, 1989; Hanten, Lucio, Russell, & Brunt, 1991). However, it is very difficult to establish the cause-and-effect relationship of posture and pain. There is evidence that sustained forward flexion of the cervical spine results in increased compressive loading in the cervical spine and a creep response in the tissues (Gooch, 1993; Harms-Ringdahl, Ekholm, Schuldt, Nemeth, & Arborelius, 1986; Twomey & Taylor, 1982). These phenomena may occur concurrently with increased electromyographic (EMG) activity in the cervical musculature as demonstrated by Schuldt et al. (1986). The increased loading in the joints and muscles of the cervical spine as a result of the forward head posture may be a major contributing factor to WRNULD in office workers.

Modern office work frequently involves prolonged viewing of a visual display unit (VDU). Looking down to a VDU will increase lower cervical flexion causing increased demands on neck extensor muscles to support the weight of the head (Chaffin et al., 1999; Straker & Mekhora, 2000). Looking up to a VDU will increase upper cervical extension which may cause increased load on deep sub-occipital muscles (Burgess-Limerick, 2000).

Both the epidemiological and biomechanical evidence suggest that prolonged forward head posture may be a causal factor in the development of WRNULDs and increasing computer use may increase the prevalence of this risk factor.

3.1.2 Limitations of available evidence

The majority of data on office workers' head and neck postures come from studies on the effects of changing VDU settings (for review see Aaras & Ro, 1999; Carter & Banister, 1994). Most of these investigations have concentrated on artificial or simulated VDU workstations (Bauer & Wittig, 1998; Burgess-Limerick, Plooy, Fraser, & Ankrum, 1998; Burgess-Limerick et al., 1999; Straker & Mekhora, 2000; Turville et al., 1998; Villanueva et al., 1996). In addition, the investigations have mainly involved work tasks of only short durations (10-20 minutes) for the purpose of data collection. A few studies have analysed the head and neck posture changes in a realistic office environment, but these have used visual observational rating methods such as OWAS (Karhu, Kansi, & Kuorinko, 1977) and RULA (McAtamney & Corlett, 1993).

In a realistic office situation workers may have to perform sedentary and repetitive computer tasks continuously for hours, with limited space and less-than-ideal workplace design. In addition, the nature of the work tasks may also affect the posture and movement patterns in the neck and shoulder region. The cumulative effects of these working conditions demanding static posture may make an important contribution to the development of musculoskeletal discomfort (Mekhora, Liston, Nanthavanij, & Cole, 2000).

Previous ergonomic studies analysing posture or movements at work tended to mainly focus on "normal" healthy workers, that is, those without work-related problems. It is not clear if there are differences in the postural patterns or behaviours of workers with symptoms that may contribute towards the development of pain and discomfort. Braun (1991) and Griegel-Morris et al. (1992) reported consistent differences in the amount of forward head posture and shoulder posture between symptomatic and asymptomatic persons suggesting a relationship between posture and symptoms. However these were based on measurements of static resting posture and therefore cannot be generalised to postures during work activities.

Recording neck and shoulder postures and movements in office workers at their actual workstations has important implications in understanding the development of WRNULD. Only limited information on the precise kinematics of sagittal head tilt and neck flexion in VDU workers in a field situation is currently available. This approach would provide a realistic picture of the workers' natural posture in their real work environment, and the postural patterns that develop throughout the working day could be evaluated.

3.1.3 Study aims

The present study aimed to investigate whether office workers with neck and shoulder pain had different neck and shoulder postures compared to those without pain. It also aimed to evaluate the effect of time at work on the changes in posture and discomfort in the two groups of workers.

A two-dimensional (2-D) motion analysis system was used to examine the head, neck and acromion movements in the sagittal plane of office workers by periodic sampling in the course of a typical working day.

3.2 METHOD

3.2.1 Subjects

Sixteen female subjects were recruited for this field investigation (age range = 22-40, mean age=31.4 years). The subjects were recruited from the clerical staff at a local university and their job titles ranged from personal secretaries and administrative officers to clerical officers. The inclusion criteria were that the subjects had to perform a minimum of 4 hours of computer work daily. Prior to participating, the subjects were asked a series of questions to gather information about their history of computer work as well as any previous history in the past 12 months or current complaints of neck and upper limb discomfort. The information on the past history of discomfort was obtained based on questions adopted from the Standardised Nordic Questionaire (Kuorinka et al., 1987)

Those subjects with a current complaint and a past history of neck and shoulder discomfort were classified as the Case subjects (n=8). The presence of "current complaint" was defined by a score of > 2/10 on the discomfort scale reported by the subjects during the testing period. Other subjects without any current discomfort ($\leq$ 2/10 during trials) or past history of pain were grouped as Control subjects (n=8). The subjects were reasonably matched in terms of age (Case: mean =32.2±5.6, Control: mean=30.7±6.6), job duties and work settings. All subjects underwent the same research procedures.

3.2.2 Variables

The independent variables of the present study consisted of three main factors:

(1) group -- 2 levels (Case versus Control),

(2) trial -- 6 levels (Trials 1-5 were spread across the day with subjects performing their normal work, Trial 6 was the reference sitting posture),

(3) segments – 2 levels (2 video segments selected from each trial).

The dependent variables can be classified as two major groups, posture and discomfort. Four posture variables were measured:

(i) Head tilt – angle between the forehead-to-tragus line and the y-axis (analysis of our results found this angle to be 19-20^0 less than the eye-ear-y axis angle),

(ii) Neck flexion – angle between the tragus-to-C7 line and the y-axis,

(iii) Acromion elevation – displacement of the acromion along the y-axis with reference to the C7 marker in terms of centimeters above or below C7,

(iv) Acromion protraction – displacement of the acromion along the x-axis with reference to the C7 marker in terms of centimeters anterior to C7.

The postural angles and movements were defined using 4 markers placed on the relevant anatomical landmarks of the subject. They were:

(1) midpoint of forehead,

(2) tragus of ear,

(3) C7 spinous process,

(4) acromion process (see Fig. 3.1).

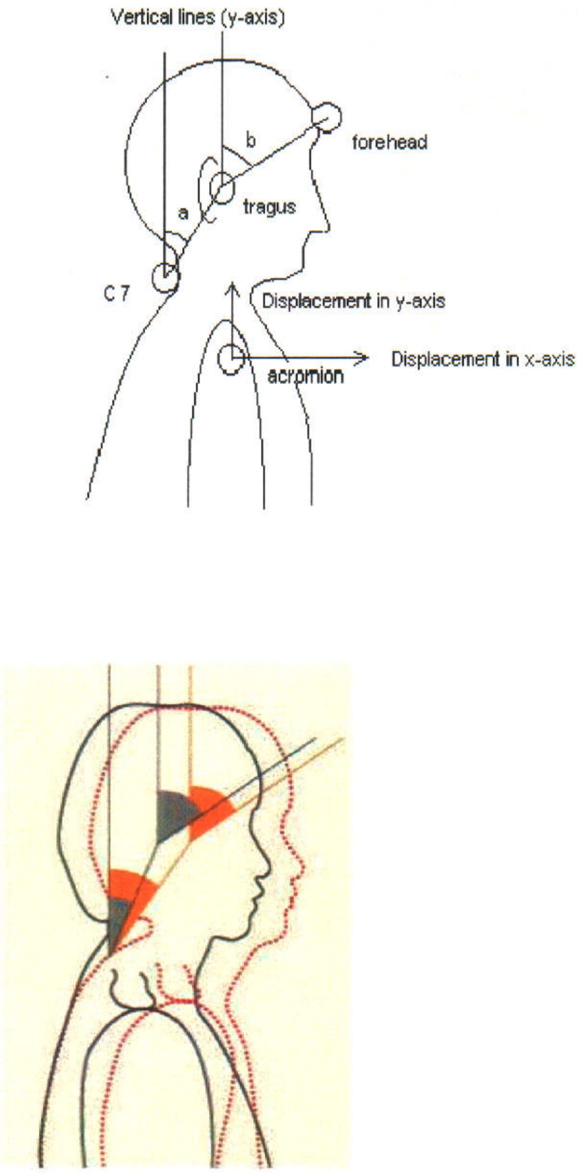


Fig. 3.1: i) Diagram showing the defining lines of the joint angles of head tilt (b) and neck flexion (a). Acromion displacements in the x-axis and y-axis define the movements of protraction and elevation respectively (arrows show directions of positive displacement)

ii) Diagram of the mean working postures of Case and Control subjects: black head representing the Control subject and the grey (dotted) head representing the Case subject

Each of the posture variables was evaluated in 2 parameters: the mean posture and the excursion. The mean posture of "head tilt" was defined as the mean of the head tilt angles within each trial. The excursion was defined as the difference between the maximum and the minimum angles within each trial. Neck flexion and acromion data were also analysed in terms of the mean and the excursion.

The discomfort data were collected in terms of subjective ratings of discomfort on a 10-point scale (1=minimal discomfort, 10=unbearable discomfort). The discomfort of the subjects was assessed following trials 1-5. Both the area of discomfort and the intensity rating were recorded.

3.2.3 Research procedures

Each subject was videotaped to capture the sagittal profile of the upper body using a single video camera (Panasonic NV-DX100EN) for 10-15 minutes when performing VDU work, for 5 trials within the same working day. The exact timing of the trials had to be flexible in order to fit in with the work routines of the subjects. All subjects were able to complete two trials in the morning and three trials in the afternoon (with approximately 1- hour gaps in between 2 consecutive trials).

The Peak5 motion analysis system (Peak Performance Technologies Inc., 1992) was used to digitise the posture data recorded on the videotapes. The Peak system had a sampling rate of 50 Hz for digitization, producing raw data in terms of pixel co-ordinates that were used to compute joint angles and displacements. The calibration and recording procedures were described in a previous paper (Szeto et al., 2000).

White foam balls of 2.5cm diameters were used as skin markers and they were placed on the 4 named anatomical landmarks. This procedure was always carried out by the same investigator in order to reduce the variability in marker placement. Pilot studies demonstrated good intra-rater reliability (ICC 3,3=0.62-0.81).

The video camera was set up at approximately 1.5m away from and perpendicular to the subjects' sagittal plane. Subjects were asked to carry on with their normal work duties and they were instructed to be as natural as possible assuming their normal postures. The only restriction was that they were advised not to swivel on the chair if possible, to reduce out-of-plane artifacts. Since the subjects were videotaped in their actual VDU workstations, there was no control or standardisation of the position or height of the monitor or the keyboard. Most subjects had their visual displays at or slightly below the eye level, so that their visual angles were within the recommended preferred zone of $0\text{-}30^0$. All the subjects had their keyboards placed directly in front of the visual display at a reasonable height. There was no distinguishable difference in the VDU settings between the two subject groups.

In the first and the last period of recording, that is, during the morning and again in the late afternoon, 2 minutes of reference sitting posture was recorded as a baseline measurement to reflect the subject's normal relaxed sitting posture when not working. The instructions to the subject were to look straight ahead, with the arms resting on lap and the back resting on the backrest of the chair. After each video-recording period, the markers were removed and subjects continued with their normal work routines.

From each videotaping trial, two film segments of 10 seconds each were selected for digitisation. The video segments were selected on the basis that they represented the typical posture of the subject using the computer, and that there were minimal out-of-plane movements.

3.2.4 Data management

The posture data consisted of 8 parameters. Head tilt and neck flexion (means and excursions) were measures of joint angles in degrees. The acromion elevation and protraction (means and excursions) were measures of displacement from a center of origin (C7) in centimeters. Among the posture data, there were some missing values due to problems in video capture and digitisation, and they were replaced by mean values taken of the remaining data of the same category.

The dependent variables were analysed using a mixed model ANOVA with 3 factors (group, trial and segment). Post-hoc analyses of within-subject contrasts were conducted to examine differences among the 6 trials. Generally no significant differences were found between the two segments in each trial and subsequently the mean of the two video segments was used to represent the mean of each trial in further analyses.

The discomfort data were analysed in terms of the intensity rating scores which were compared between the two groups. Where there was more than one area of discomfort reported and more than 1 rating score in the trial, the higher value was taken as the representative score of the trial for analysis. ANOVA was performed on the scores with "trial" as a within-subject factor with 5 levels and "group" as a between-subject factor.

The study was approved by the Curtin University of Technology Human Research Ethics Committee, as well as the Hong Kong Polytechnic University Human Research Ethics Committee.

3.3 RESULTS

3.3.1 Musculoskeletal discomfort

During the study, the subjects were asked to rate their musculoskeletal discomfort on a 10-point numerical scale. The reported areas of discomfort and the mean intensity scores are summarised in Table 3.1. Neck and shoulder regions were the most commonly affected in all the Case subjects and in some of the Control subjects. Five of the Case subjects started with discomfort in the neck only during Trial 1, and then reported discomfort in the neck and shoulder regions bilaterally for the subsequent trials. Most of the Control subjects reported 0-1 in the discomfort score.

The Case subjects had a mean (±SD) discomfort score of 4.2 (±1.8) and the Control subjects' mean was 0.2 (±0.2). This difference between the two groups was statistically significant ($F_{1,14}=39.3, p<0.001$). However, there was no significant difference comparing among the different trials (time-at-work effect) within each group ($F_{4,56}=1.3, p=0.271, power=0.388$).

Table 3.1: Summary of subjects' discomfort profiles in the past 12 months, compared to their discomfort scores on day of testing

	Number of subjects in Case Group (n=8)	Number of subjects in Control Group (n=8)
Region of Discomfort	Neck only x2 Shoulder only x1 Neck and shoulder x5	Neck only x1 Shoulder only x1
Left/right side	Bilateral x4 Left x1 Right x3	Right x2
Discomfort during the last 12 months	8	4
Discomfort <30days In last 12 months	2	2
Discomfort >30days In last 12 months	6	2
Discomfort during the last few days	8	3
Discomfort on day of testing	8	2
Mean Discomfort Score on day of testing	4.2 (±1.8)*	0.2 (±0.2)*
	($p = 0.000$*)	

3.3.2 Posture data

3.3.2.1 *Group effects*

3.3.2.1.1 *Group effects on mean working postures*

Comparing the posture data in the working trials between the Case and the Control subjects, some consistent trends were produced for the head tilt (HT) and neck flexion (NF) angles (see Fig.3.2). The Case subjects had a mean head tilt of 60.6° ($\pm$6.1) in the working trials which appeared about 5% greater than the Control subjects (mean=$57.1^{0} \pm 6.2$). The group effect in mean head tilt posture failed to reach statistical significance ($F_{1,14}$=1.2, p=0.282, *power*=0.181), which may be partly attributed to the large individual variations in posture and the limited sample size. The pattern of mean neck flexion posture in the working trials was similar to that of head tilt. The Case subjects had a mean neck flexion of 59.3^{0} ($\pm$10.0), about 13% more than the Control subjects' mean of 52.5^{0} ($\pm$7.1). The apparent difference between the two groups in mean neck flexion also failed to reach statistical significance ($F_{1,14}$=2.5, p=0.134, *power*=0.317).

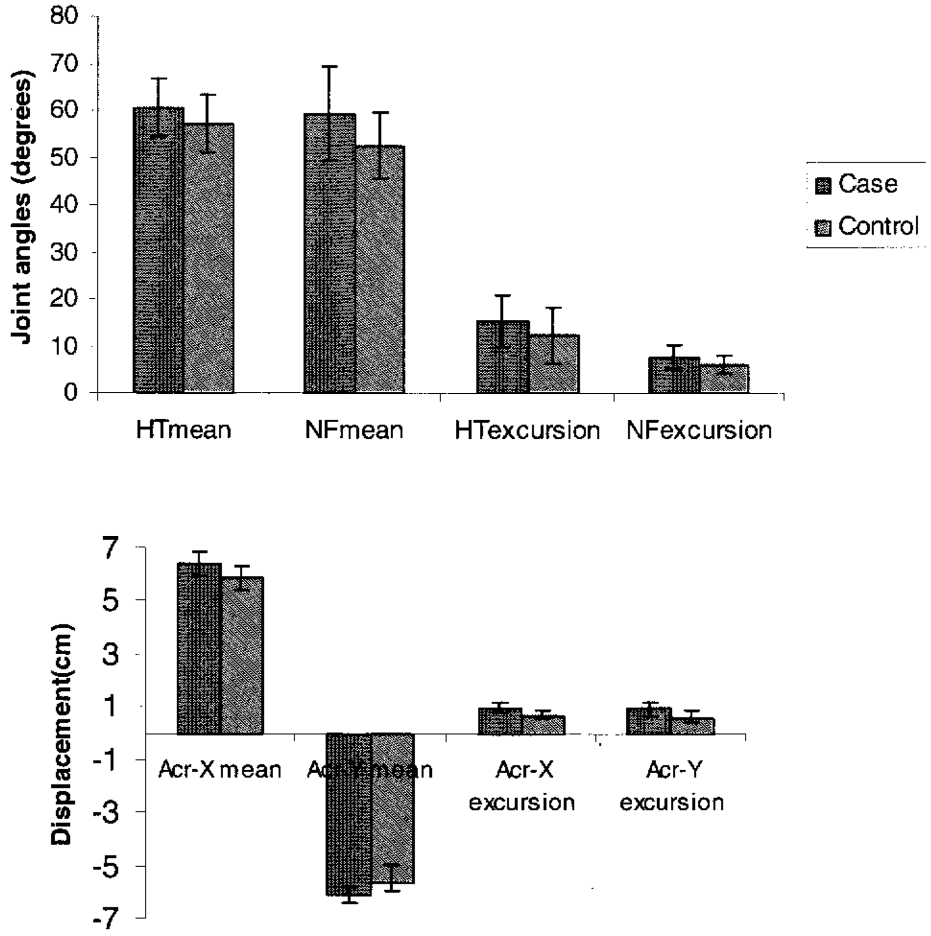


Fig. 3.2: Case vs Control subjects: (a) HT and NF mean working posture and excursions; (b) Acromion protraction (X) and elevation (Y) mean displacement and excursion. Error bars show standard deviations.

The mean acromion postures in the x-plane representing protraction (ACR-X) were 6.4cm (±0.5) for the Case subjects and 5.9cm (±0.5) for the Control subjects. The mean acromion postures in the y-plane representing elevation (ACR-Y) were –6.1cm (±0.3) for the Case subjects and -5.6cm (±0.7) for the Control subjects. The results suggested slightly more protraction and less elevation in the Case subjects (see Fig. 3.2). However, no significant difference was found between the two groups in the mean acromion protraction and elevation data ($F_{1,14}$=0.3, p=0.594, *power*=0.080; $F_{1,14}$=0.5, p=0.510, *power*=0.097).

Fig.3.2 shows mean working postures for subjects and illustrates the consistent trend for Case subjects to have greater head tilt and neck flexion as well as greater acromion protraction but similar elevation.

3.3.2.1.2 *Group effects on working posture excursions*

The excursions of head tilt and neck flexion were examined, as this parameter was an indicator of the extent of movement of each segment. For both head tilt and neck flexion, the excursions appeared consistently greater for the Case subjects than the Control subjects, although no statistically significant difference was found between groups (for HT excursion: $F_{1,14}$= 1.1, p = 0.311, *power*=0.165; for NF excursion: $F_{1,14}$=2.6, p=0.126, *power*=0.328). However a significant difference was found between groups in the excursion of the acromion protraction and elevation data, with Case subjects exhibiting more excursion (for ACR-X: $F_{1,14}$=5.1, p=0.040; for ACR-Y: $F_{1,14}$=7.6, p=0.015) (see Figure 3). Together with the results on the mean acromial posture, these results suggested that the Case subjects tended to hold their acromions in more protraction and moved their acromions in a greater extent.

The range of excursion was greater for head tilt compared to neck flexion. When the mean excursions were compared between the two posture variables using paired t-tests, a significant difference was found for both groups (Case subjects : t_7=3.9, p=0.006; Control subjects: t_7=4.4, p=0.003). These results suggest that there were significantly greater head tilt movements compared to neck flexion movements in both groups.

3.3.2.1.3 *Group effects on mean reference postures*

There was also a trend for the Case subjects to have greater mean head tilt (55.4^0 ±5.5) and neck flexion (54.5^0 ±9.35) in the reference posture, compared with the Control subjects (HT=54.8^0±5.5, NF=47.0^0±4.7). This trend was not statistically significant for head tilt (t_{14}=0.2, p=0.845) but approached significance for neck flexion ($t_{10.27}$=2.0, p=0.068). For the mean acromion reference posture, there was no significant difference in acromion protraction ($t_{11.99}$= -0.5, p=0.634), but again approached significance for acromion elevation (t_{14}= -2.0, p=0.062).

3.3.2.2 *Time-at-work (trial) effect*

Fig.3.3 shows the mean head tilt and neck flexion and mean acromion protraction and elevation positions for Case and Control subjects across the five working trials within the one working day. No obvious trend can be observed in either subject group. The time-at-work effect was not significant for head tilt ($F_{4,56}$=0.5, p=0.760, *power*=0.152), neck flexion ($F_{4,56}$=0.9, p=0.457, *power*=0.274) and the acromion protraction posture ($F_{4,56}$=2.0, p=0.104, *power*=0.569). The acromion elevation posture was the only parameter that showed a significant difference across the five working trials ($F_{4,56}$=3.1, p=0.024). Post-hoc analysis revealed significant differences between trials 1 and 2, 2 and 3, and 2 and 4 (p<0.05). The lower group mean acromion position was caused by a single subject having an unusually low acromion in Trial 2 and therefore should not be interpreted as important.

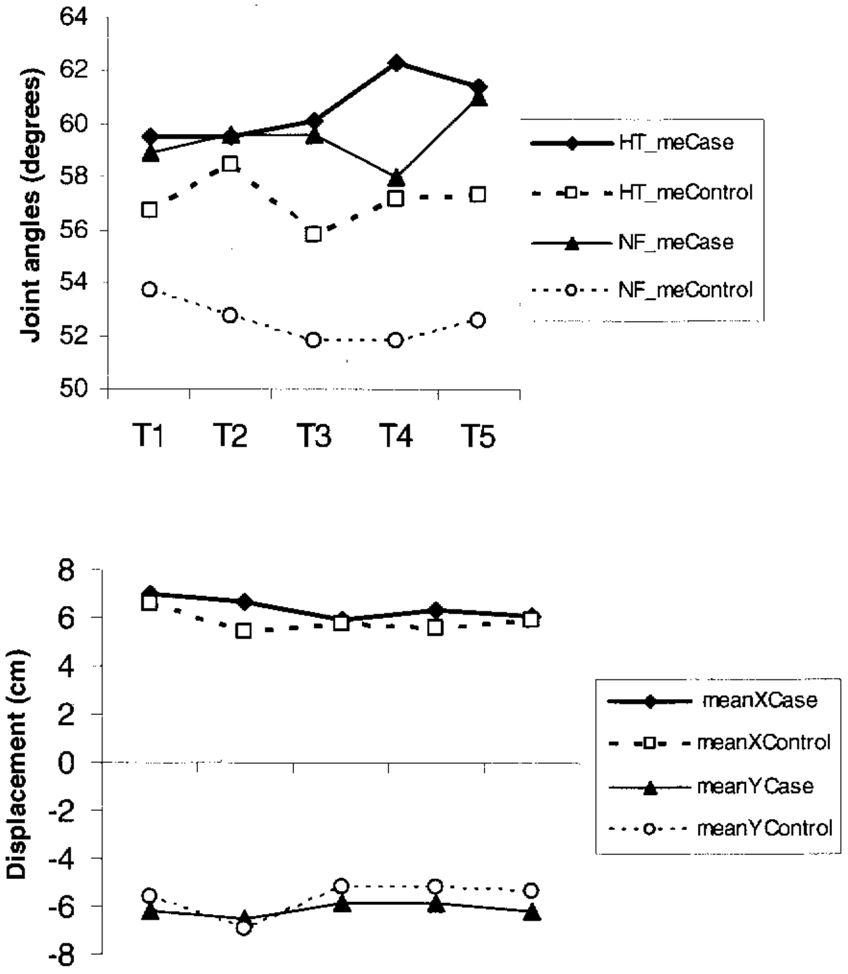


Fig. 3.3: Time-at-work effect on (a) mean working postures of HT and NF; (b) Acromion protraction (X) and elevation (Y) for Case and Control subjects

3.3.2.3 *Reference versus working posture*

Mean head tilt and neck flexion postures appeared consistently greater in the working posture compared to the reference posture (see Fig. 3.4). Results of repeated measures ANOVA confirmed that there were significant differences between the working trials (T1-5) and the static reference trial (T6) for neck flexion ($F_{5,70}$=6.4, p<0.001), with head tilt posture difference approaching significance ($F_{5,70}$=2.2, p=0.063, *power*=0.688). These results implied that when subjects performed VDU work, they would assume a more flexed posture as compared to their relaxed sitting posture.

The mean posture of the acromion appeared slightly more elevated in the working trials but less protracted (see Figure 4). The acromion elevation difference was marginally significant ($F_{5,70}$=2.3, p=0.051, *power*=0.717), and acromion protraction was non-significant ($F_{5,70}$=1.8, p=0.125, *power*=0.583).

Repeated measures ANOVA revealed that the 5 working trials showed significantly greater excursions as compared to the reference sitting trials for all four posture variables (HT: $F_{5,70}$=14.6, p<0.001; NF: $F_{5,70}$=12.4, p<0.001; ACR-X: $F_{5,70}$=7.9, p<0.001 and ACR-Y: $F_{5,70}$=3.9, p=0.003).

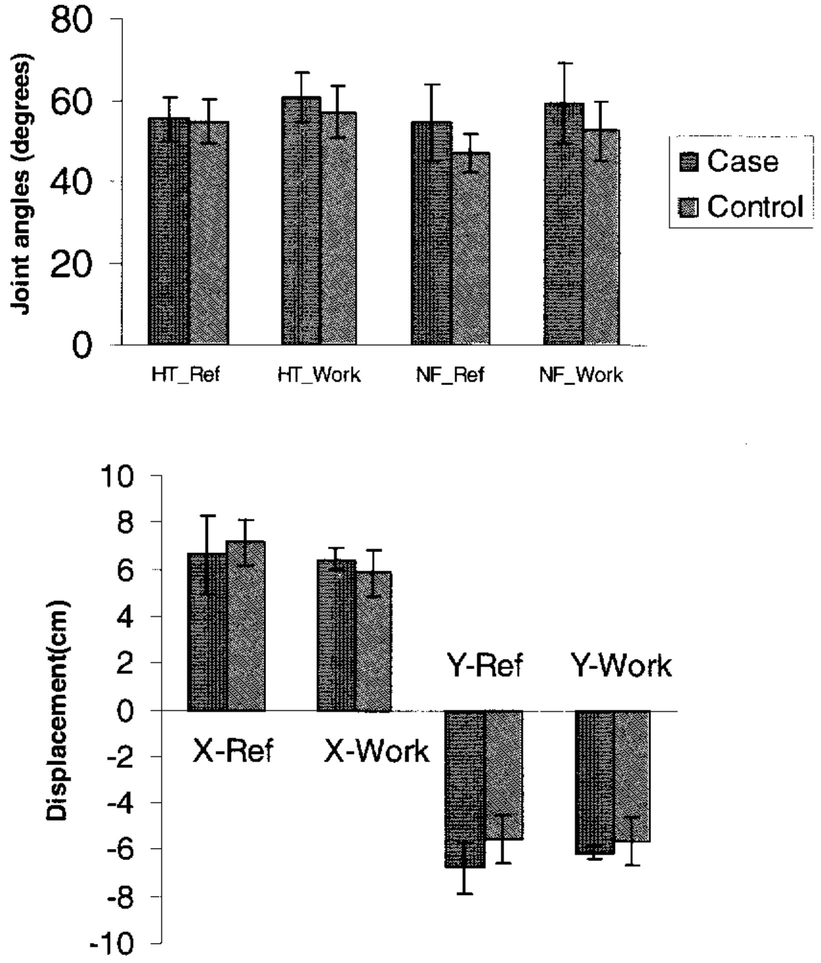


Fig. 3.4: Comparison of working and reference postures for Case and Control subjects, in terms of HT and NF, acromion protraction (X) and elevation (Y)

3.4 DISCUSSION

3.4.1 Group effects on mean head, neck and shoulder postures

The present results have demonstrated some interesting trends for increased head tilt and neck flexion posture in the Case subjects compared to the Control subjects. These trends were consistent across the whole working day. The apparent differences in mean posture between the two groups seemed to be more evident in the neck flexion component compared to the head tilt component. The difference in mean posture was of a greater relative magnitude in neck flexion between the two groups (13%), compared to that of head tilt (5%). This suggested that the Case subjects had a tendency to hold their lower cervical spines in more forward flexion when focusing on the computer display.

Previous studies on work posture in VDU workers have mainly measured the head and the cervical spine as one segment (Karwowski et al., 1994; Life & Pheasant, 1984; Villanueva et al., 1996; Wrigley et al., 1991). As such, the present results are consistent with those of previous studies reporting increased neck flexion and associated increased gross muscle activities in the superficial stabilising muscles of the neck-shoulder region (Schuldt et al., 1986); as well as increased compressive loading in the articular structures with increased lower cervical flexion (Harms-Ringdahl et al., 1986).

However, the forward head posture involves a combination of upper cervical extension and lower cervical flexion. The head tilt posture reflects the absolute position of the head segment when the worker views the computer display. Similarly the neck flexion reflects the absolute position of the neck segment. However the upper cervical angle is a function of both the head tilt and lower cervical flexion, and therefore it varies with these. Although the Case subjects had a greater mean head tilt angle of 60^0 compared to Control subjects (57^0), due to the increased lower cervical flexion the overall upper cervical angle (angle between the neck and head) was in more extension in the Case subjects (179^0). The mean upper cervical extension angle for the Case subjects was 4^0 greater than for the Control subjects (175^0). The head tilt angle is closely related to the gaze angle and therefore it may not vary greatly as subjects focused their visual fields on the screen. However the Case subjects in this study did demonstrate a more 'forward head position' with greater lower cervical flexion and upper cervical extension.

Upper cervical extensor muscles are short and it has been proposed that even a small increase in extension can place these muscles in an inefficient range of their length-tension relationship (Burgess-Limerick, 2000). This may leave these muscles more vulnerable to fatigue. Thus it may be a preferred strategy for some workers to increase the total neck moment (with more lower cervical flexion) and reduce loading in the smaller upper cervical muscles.

Either the general biomechanical loading or the specific loading of some structures may contribute to the musculoskeletal discomfort in the workers, and these factors are likely to play a major role in the present situation, perhaps explaining the difference in posture between the Case and Control subjects. However, it may also be possible that the increased forward head posture (especially the increased lower cervical flexion) in the Case subjects is a result of the discomfort in a vicious cycle between pain and increased muscle loading. To investigate the causal relationship between posture and pain, it may be more informative to study the postures of the same subjects on different days; or to study the posture of workers before and after they get pain. It would also be useful to compare their postures on days with low discomfort ratings versus days with high discomfort ratings.

A recent study by Hermans, Hautekiet and Spaepen (1998) studied the neck and shoulder muscle activities in two groups of VDT workers across a whole working day. Their overall design is similar to our study, but they had only 5 subjects in each group. Their study was also a field study in the subjects' actual work environment, but their subjects only performed VDT work. They reported significantly increased muscle activity for all subjects in both groups, and the symptomatic group had more pronounced changes although not reaching statistical significance.

In addition, the amount of cervical flexion and head tilt is also closely related to the angle of the upper thoracic spine. It has been proposed that when the thoracic spine is leant backwards by $10\text{-}15^0$, the cervical spine is still in flexion but the muscle load in the neck is lowered (Aaras & Ro, 1999). In the present study, the subjects were mostly sitting with their backs resting against the back of the chair. The exact thoracic angle was not measured, but most subjects were in a reasonably upright position.

There are other possible factors that may account for the differences in posture between the two subject groups. Psychosocial stress factors and individual characteristics have been studied to determine their contributions or associations with increased muscle activities and neck-shoulder pain (Vasseljen & Westgaard, 1995; Waersted et al., 1991). However, this is a complex issue and the interactions among the many possible factors make it difficult to identify the specific contribution of various factors. Surprisingly, the study by Vasseljen and Westgaard (1995) actually reported no relationship between perceived general tension and muscle activities in office workers.

3.4.2 Group effects on excursion of the head, neck and acromion

The measurements of "excursions" were conducted to evaluate the different extents of movements of the body segments. The present findings suggested that the symptomatic workers tended to hold their neck in more flexion while they had greater excursions in the head tilt movement. The excursions of the head tilt movement were performed as the subjects moved their gaze between the visual display and the keyboard, or to view the document for typing. Increased excursion may lead to increased loading in periarticular tissues, as well as increased muscle activities. Liao and Drury (2000) reported that frequent postural shifts were positively correlated with the prevalence of body discomfort. The exact extents of the postural changes were not documented and this may have an impact on the results.

However, the current method of data sampling was of a limited duration (10 seconds) due to the time-consuming process of digitisation. While we can see the pattern of movements during this period, no measurement was taken of the frequency of movement. This is a limitation of the present study. The total number of data samples for each subject (10 samples of 10 seconds) compensates for this limitation to some extent. By examining the various excursions within each subject, it was identified that some subjects had a consistent tendency to move frequently and/or to a large extent, while other subjects tended to move infrequently and/or in very small excursions. Future studies should examine both the extent of the excursion as well as the frequency of postural changes in workers.

The present findings were only recorded from a limited number of subjects, and the postulations need to be substantiated with more detailed measurements of posture over a longer period and if possible, in three-dimensions. The present two-dimensional method is only a simplified and practical solution, to provide some useful information on the position of the acromion process and the scapula in relation to the neck and trunk region. To analyse the scapular movements fully would require the use of multiple cameras as there are many different axes of rotation in the scapula. This was beyond the scope of the present study.

3.4.3 Movement patterns

The present results confirmed that head tilt and neck flexion movements contributed to a "forward head posture" in VDU workers. When the movement data of the head tilt and neck flexion angles were plotted and examined in individual trials, some interesting patterns emerged. In general, four patterns could be identified among all the working trials in all the subjects. Fig. 3.5a-d show examples of the typical patterns of the neck and head movements during various trials. Generally head tilt movements occurred to a greater extent than neck flexion, as subjects looked between the display and the keyboard during typing. This trend was more pronounced in the Case subjects than the Control subjects.

In some subjects the two movements were highly correlated and tended to follow a similar pattern, as in Fig.3.5a. Fig.3.5b shows the two movements occurring in opposite directions and this was also a common pattern. Fig. 3.5c shows neck movements occurring independently from the head movements, while in Fig. 3.5d the neck segment was static with most of the movements occurring in the head segment. These were the four most commonly observed relationships between the head tilt and neck flexion movements. By far, the most commonly observed were the first and second situations (Fig. 3.5 a&b).

The differences in movement patterns may be attributed to a number of factors: individual variations in postural habits, the presence or absence of discomfort, as well as the nature of work tasks performed. The different natures of computer work tasks may imply different demands for head and neck movements. The work tasks routinely performed by the subjects included word-processing, data-entry, and text-editing. Tasks such as reading email messages and editing/composing documents would not require frequent head movements, and the subjects tended to focus on the computer display. Subjects who were performing data entry tasks would require more frequent movements of the head and neck region, to look between the source document and the computer display. This aspect was evaluated by Bauer and Wittig (1998) who reported that the amount of head rotation between the display and the document holder would vary between individuals. In fact, it is difficult to isolate the influence of the individual's postural habits from the influence of the work tasks and the VDU setting. It is clear that the individuals' work experience, postural habits and organisation of space would add to the variations in the present results.

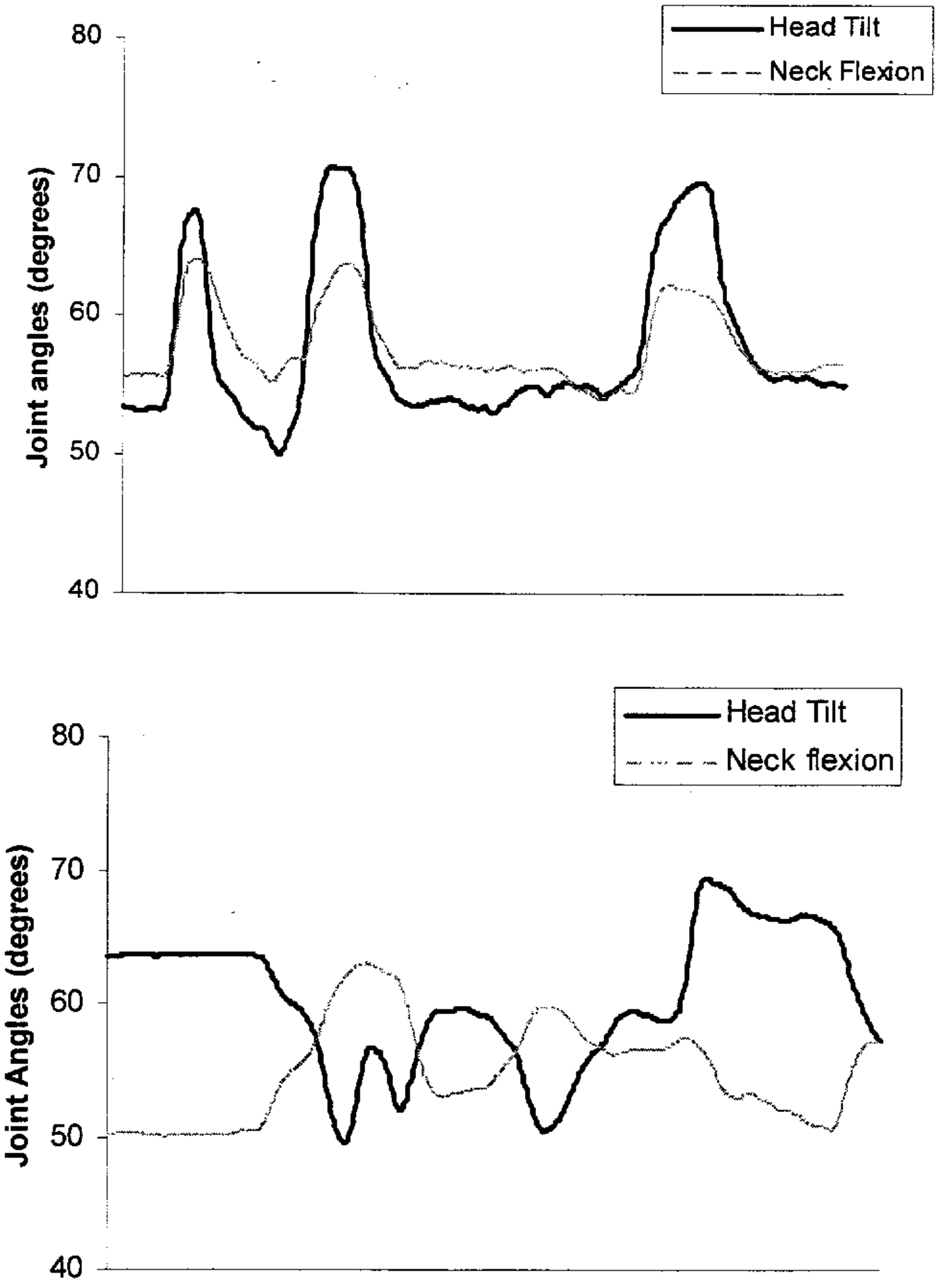


Fig. 3.5a & b: Examples of HT and NF movement patterns during office work: (a) correlated movements, (b) movements in opposite directions

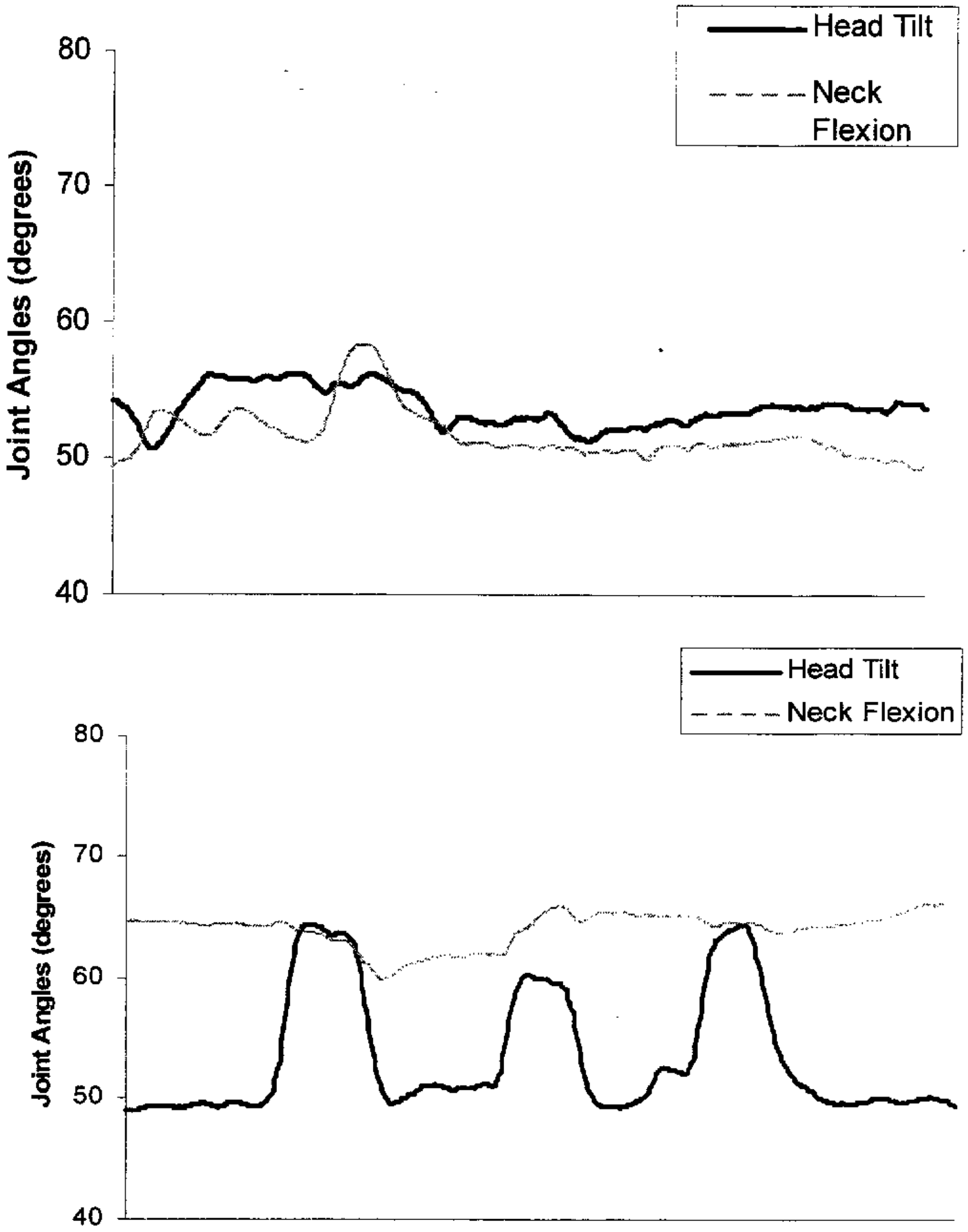


Fig. 3.5 c & d: Examples of HT and NF movement patterns : (c) independent movements, (d) head movements on static neck

3.4.4 Time-at-work effects

Examining the mean head and neck posture data in the different working trials, there was no obvious pattern of change from morning to afternoon. This finding is in contrast to the common anecdotal belief that there would be an increasing trend towards more forward head posture with prolonged seated work, especially VDU work. This may possibly be due to the varied nature of the subjects' work tasks, as subjects were not constrained to remaining at their desks interacting with the computer in the whole working day. The earlier study by Turville et al. (1998) on display heights also reported consistent measurements of neck muscle activities throughout a working day.

Previous studies have reported a positive relationship between time-on-task and discomfort (Hagberg & Sunderlin, 1986; Karwowski et al., 1994). Karwowski et al. (1994) studied workers performing a highly repetitive data entry task, with fixed work/rest schedules. The workers recruited in the present study were not pure "typists'' as such, but were office workers who performed a variety of office/administrative duties required in an academic institution. In the periods between videotaping trials, the workers may change to other work tasks not involving the computer at all. This may have accounted for their ability to maintain their head and neck postures within a consistent range throughout the day. It is still possible that if the computer work was sustained for a prolonged period (>1 hour), the head and neck posture recorded may show a more detectable pattern of change. In future, the investigation may be extended to include workers who perform keyboard work for longer periods of up to 6-8 hours per day.

3.4.5 Reference vs working posture

The present results showed a significantly greater mean posture of head tilt and neck flexion in the working postures compared to the reference sitting posture. However the shoulder posture showed no significant difference between relaxed sitting and working. This may suggest that the workers tended to put their heads and necks more forward while maintaining their shoulders in relatively similar positions when working.

The present study has provided some field data to demonstrate the position of the shoulder in terms of protraction and elevation when workers performed VDU work. The trends in the data are consistent with previous studies on "normal" standing and sitting postures in both symptomatic and asymptomatic individuals, showing persistent increased shoulder protraction in symptomatic persons (Braun, 1991; Griegel-Morris et al., 1992; Raine & Twomey, 1997). This may suggest that the postures of symptomatic persons are habitual and therefore tend to remain consistent across various tasks.

3.5 CONCLUSION

This field study aimed to investigate whether there were differences in the head, neck and shoulder postures between symptomatic and asymptomatic office workers and whether there were postural differences over the course of a working day. The results showed trends for symptomatic office workers to have greater head tilt and neck flexion, and greater acromion protraction. The study also found differences in the extents and patterns of movement. No substantial evidence for posture changing over a working day was found.

The present findings would support the clinical perception that symptomatic office workers had a generally more forward head posture than asymptomatic workers. However the precise relationship between discomfort and posture requires further investigation.

CHAPTER 4

STUDY 2 PAPER 1

Altered Muscle Recruitment Patterns in the Neck-Shoulder Stabilisers of Symptomatic Office Workers performing monotonous repetitive keyboard work

This chapter is the first of a series of three papers on Study 2. Study 2 was a laboratory study examining kinematics and EMG activities in symptomatic and asymptomatic office workers. This paper is specifically about the results of EMG amplitude analysis and the subjective discomforts reported by the two subject groups.

The present study compared the muscle activity patterns of the major neck-shoulder stabilizers of the Case Group (n=23) compared to the Control Group (n=20), when they had to perform a 1-hour computer task under the same conditions. Results showed that the Case Group had a trend for a higher muscle activity pattern in the right UT muscle, while the Control Group had a trend for higher activities in the right CES muscles. The Case Group was subsequently sub-divided into a High Group and Low Group based on their mean discomfort scores, and the High Group had significantly higher muscle activity in the right UT muscle than the Low Group and the Control Group. The results suggested that altered muscle recruitment pattern was an important factor associated with the development of WRNULD, and the potential mechanisms involved will be discussed in this chapter.

4.1 INTRODUCTION

4.1.1 Proximal work-related neck and upper limb disorders (WRNULD) are common problems in computer users and are likely to increase

Work-related neck and upper limb disorders (WRNULD) are common problems among office workers, especially among those who are intensive computer users (Berqvist, 1993; Bernard et al., 1994; Hagberg & Wegman, 1987; Kamwendo et al., 1991a & b; Tittiranonda et al., 1999). A high prevalence of neck and upper limb complaints in computer using office workers have been consistently reported in both eastern and western countries (Bernard et al., 1994; Hagberg & Wegman, 1987; Kamwendo et al., 1991a & b; Yu & Wong, 1996). For example, in a recent survey of over 600 office workers in Hong Kong, the 12-month period prevalence of work-related neck and shoulder discomforts associated with computer use was over 56% (Siu & Chan, 1998).

The proximal (neck and shoulder) region has consistently been reported to have higher prevalence rates than the distal (elbow or wrist-hand) region (Bergqvist et al., 1995; Bernard et al., 1994; Kamwendo et al., 1991a; Westgaard et al., 1993). For example, Westgaard et al. (1993) reported a 48% prevalence of neck-shoulder symptoms in office workers, whereas the distal arm region had only 18%. Therefore the present study has focused on the more prevalent neck-shoulder problems.

The worldwide trend is for people to use computers for longer periods daily, due to increased computer based tasks at work and due to increased computer based leisure activities. In the USA in 2001, 65 million out of 115 million adults (56.7%) who were employed and aged over 25, used a computer at work (NTIA, 2002). In Australia, 66% of all adults (9.2 million) used a computer in the last 12 months up to November 2000 (Australian Bureau of Statistics, 2000). Similar figures are expected in other developed countries. It is therefore likely that the prevalence rates for WRNULD will continue to rise steadily alongside the rapid advancement in computer technology into more aspects of work and home life.

4.1.2 Combination of duration of work and static posture may increase risk

Whilst the physical demand of computer work may be considered light in terms of forces and moments required, the static posture associated with viewing the display screen and working with the keyboard has been identified as a major risk for computer users (Aaras et al., 1997; Bergqvist et al., 1995). A prolonged duration of computer work may further increase the risk for WRNULD (Hagberg & Sunderlin, 1986; Kleine et al., 1999; Nordander et al., 2000). In particular, the static neck and upper limb postures associated with computer use has been linked with prolonged low-level muscle activity in neck-shoulder stabilizers, which in turn may cause a substantial strain in the musculoskeletal system (Hagg & Astrom, 1997; Westgaard et al., 2001).

A number of studies have reported positive associations between static muscle load in the trapezius measured during occupational tasks and discomfort in this region (Bansevicius et al., 1997; Christensen, 1986; Jonsson et al., 1988; Veiersted et al., 1993; Westgaard et al., 2001). It was suggested that if the static muscle load exceeded a certain level, it may lead to increased risk of developing musculoskeletal disorders (Jonsson, 1982).

Other ergonomic intervention studies have often examined the mean or median muscle load and assumed that higher levels of these measures of muscle activities during work in healthy painfree subjects, represented higher risks for developing musculoskeletal discomforts (Aaras et al., 1997; Bansevicius et al., 1997; Cooper & Straker, 1998; Kleine et al., 1999; Turville et al., 1998). However the evidence to support such an assumption is limited, as it is not clear whether symptomatic individuals would respond in the same way as asymptomatic ones.

4.1.3 Intrinsic factors may be important

It is generally agreed that the etiology of work-related musculoskeletal disorders is multifactorial, and the interactions of intrinsic and extrinsic factors may simultaneously operate within each person (Forde et al., 2002; Kumar, 2001; Westgaard, 2000). Interactions of these various factors may cause different responses in individuals when they are exposed to physical and/or psychosocial stressors. Previous ergonomic research has tended to focus on the influence of external factors such as changes in workstation setting or changes in work tasks performed, and often assumed that all individuals would respond in the same way. The lack of consistent evidence regarding the etiology of WRNULD may be due to the lack of understanding about these intrinsic factors and differences in individual responses.

In Study 1 with 16 office workers, we reported that symptomatic subjects had a trend towards maintaining greater forward head posture compared to asymptomatic subjects, and these patterns did not vary as a result of time-at-work. It was postulated that these differences were more likely the subjects' intrinsic postural habits rather than responses to the work situation.

Hagg and Astrom (1997) compared the electromyography (EMG) patterns in a group of 14 symptomatic female medical secretaries against 9 asymptomatic counterparts. They found that the symptomatic group had a more monotonous load pattern at low load levels as well as significantly fewer episodes of relaxed muscle activity (EMG "gaps"). Hermans and Spaepan (1995) also reported increased muscle activity levels in subjects with more discomfort but the sample size was very small (5 in each group). Kleine et al. (1999) reported increased muscle activity with increased time at computer work, but the subjects were normal healthy workers. However, Nordander et al. (2000) found no difference in muscular rest (accumulated EMG gap time) between office workers with a history of discomforts and those without. Jensen et al. (1993a) reported a weak correlation between symptoms of shoulder pain and the 10^{th}% EMG level as well as frequency of EMG gaps.

While the relationship between prolonged computer work and development of work-related musculoskeletal discomforts is not completely clear, there is some evidence that differences between symptomatic and asymptomatic workers may be related to motor control variations between individuals (Roe et al., 2001; Westgaard, 2000). The underlying mechanisms involved for these motor control changes may be biomechanical, neurophysiological, morphological, psychosocial and / or environmental in nature; and some of these processes may act at the organ or tissue level, while others may act more at the cellular level.

4.1.4 Possible motor control mechanisms for developing WRNULD from prolonged static muscle activity

There are multiple sources of musculoskeletal pain of which muscle is commonly regarded as the most likely source. One of the most well known pain models is the "vicious cycle" model which proposed that pain and muscle activation may reinforce each other in a self-perpetuating cycle, based on clinical observations in patients with fibromyalgia (Johansson & Sojka, 1991; Travell & Simons, 1983). The "pain adaptation model" has challenged this vicious cycle model and proposed that in response to muscle pain, there may be an inhibition on muscle activities. This model was mainly developed based on observations of experimental pain (Lund et al., 1991). Whether these models could be applied to explain the development of work-related musculoskeletal pain has not been extensively investigated.

These models generally assume that muscle is the source of pain. However whiplash studies in the cervical spine and low back pain studies rarely suggested muscle to be the source of pain (Bogduk & Twomey, 1987; Bogduk, 1995). Rather, evidence from diagnostic tissue blocks have identified the cervical zygapophyseal joints as an important source of neck pain due to their abundant supply of nociceptors (Bogduk & Marsland, 1988; Bogduk, 1995). It has been suggested that the resultant reflex muscle activation / altered motor control were more the outcome of these pains rather than the cause of pain (Bogduk, 1995). Of course one can argue that work-related musculoskeletal pain may have a different mechanism of injury from whiplash, but studies in occupational situations have also not been able to establish a clear relationship between muscle activity and work-related discomforts (Westgaard, 2000).

In clinical studies of neck and back pain patients, muscle recruitment deficits presenting as altered timing and/or altered patterns of recruitment, have been reported in association with musculoskeletal pain (Edgerton et al, 1996 & 1997; Hodges, 2000; O'Sullivan et al., 1997). These phenomena have been suggested to give rise to "muscle imbalance", and they may be a cause of or an adaptation to work-related musculoskeletal pain (Janda, 1994; Jull, 1994). The altered motor control mechanisms for the spine have been reported as reductions of activities in segmental stabilising muscles (such as the multifidus) which provide control but minimal stress on the articular structures, and increased activation of more global muscles which have less segmental influence, but a greater torque producing potential (such as the long spinal extensors – iliocostalis and longisimus) (Bergmark, 1989; Richardson & Jull, 1995). This phenomenon is commonly referred to as muscle substitution and it has been hypothesised to result in a net increase in the load on the articular structures with resultant sensitisation and pain (Bergmark, 1989; Comerford & Mottram, 2001; Jull et al., 1999).

However, the *in vivo* evidence for muscle substitution in the cervical region has mainly come from clinical studies of individuals with neck pain from traumatic whiplash injuries or cervicogenic headaches (Edgerton et al., 1997; Jull et al., 1999). Furthermore, the muscle activity was usually studied either at rest or during resisted contractions, and not during sustained low-level work activities. These factors would limit the application of this evidence to occupational settings.

Muscle substitution has only been briefly mentioned in a few occupational studies that examined the upper trapezius activity in conjunction with other muscles such as the infraspinatus (Nakata et al., 1992) or rhomboids (Takala & Viikari-Juntura, 1991). It is possible that in symptomatic individuals, the "normal" motor unit recruitment between synergistic muscles controlling the head / neck / shoulder region is disrupted, resulting in altered loading of the musculoskeletal structures with resultant pain. The cause of this altered motor control could be multifactorial. Thus it is important to study the muscle recruitment patterns in symptomatic persons performing sustained occupational tasks such as computer work.

In summary, while there is evidence to suggest differences between symptomatic and asymptomatic persons in performing tasks involving postural stabilization, there are gaps in knowledge in terms of muscle recruitment patterns and motor control strategies between individuals with and without pain. A number of theories and models are based on the assumption that muscles are the source of pain and these theories have not yet been fully validated. It is especially unclear how the intrinsic mechanisms affect different persons in performing prolonged occupational tasks such as sustained computer work. Given the difficulty in conducting controlled experimental studies in humans to clearly prove direct cause-effect relationships, a case – control comparison may be a useful approach to examine the potential role of motor control as an intrinsic factor in the development of WRNULD.

4.1.5 Aim of study

The aim of the present study was to investigate the muscle activity in the neck and shoulder regions in symptomatic and asymptomatic office workers when they performed a prolonged and standardized computer task under standardized conditions. Any differences in motor control may help the understanding of the role of intrinsic factors in the development of WRNULD.

4.2 METHOD

4.2.1 Design

The present research employed a case-control quasi-experimental design where subjects were divided into Case and Control Groups based on their past and present discomfort profiles. Each subject worked for 1 hour at a standard task in an adjusted workstation and muscle activity, discomfort and posture were assessed.

4.2.2 Subjects

Female office workers were recruited as subjects through convenience sampling mainly from health promotion activities and from staff at the local university. Subjects had to meet the inclusion criteria of a minimum of 4 hours of computer work daily, and only those who performed clerical and/or administrative duties (mainly word-processing) were included. Those with past traumatic injuries or surgical interventions in their neck and upper limb regions were excluded.

A total of 43 subjects were accepted into the study, and 23 were allocated to the Case Group (symptomatic), 20 to the Control Group (asymptomatic). The allocation into groups was based on the subjects' answers to a modified version of the Standardised Nordic Questionaire (Kuorinka et al., 1987). Additional questions were asked to gather information on their past and present musculoskeletal discomforts, their computer work habits and nature of work tasks. Subjects were assigned into the Case Group if they responded positively to a majority of the following questions: that their past/present discomfort was related to computer use, that their discomforts lasted more than 3 months in the past year, that they had discomfort in the past 7 days and that they had discomfort on the day of testing. Control subjects must have had no or minimal discomfort on the day of testing, and had no discomfort in the past 7 days. If they had reported discomfort in the past 12 months, it must have been of a short duration (<3 months) and the condition resolved at least 3 months prior to participation.

The experimental procedures were explained to each subject and informed consent was obtained before the experiment began. Subjects could have withdrawn if they felt intolerable discomfort anytime during the testing procedures but none actually withdrew from the study. The study was approved by the Curtin University Human Research Ethics Committee.

Table 4.1 shows the general characteristics of the two groups. The subjects were reasonably matched in terms of physical build, handedness and work profiles.

Table 4.1: Subject profiles for the Case and Control Groups in Study 2

		Case Group (n = 23)	Control Group (n = 20)	Group Difference Statistics
Subjects' Background Information	Age (years) [mean (sd; range)]	$\bar{x}$ = 36.0 (4.6; 29 – 46)	$\bar{x}$ = 31.3 (7.2; 21 – 48)	$t = 2.528$ $p = .017^{*}$
	Body Height (cm) [mean (sd; range)]	$\bar{x}$ = 158.3 (6.4; 143.0 – 170.2)	$\bar{x}$ = 157.2 (6.7; 139.0 – 167.6)	$t = .475$ $p = .638$
	Body Weight (kg) [mean (sd; range)]	$\bar{x}$ = 53.4 (12.2; 45.5 – 98.0)	$\bar{x}$ = 52.0 (5.3; 43.0 – 60.0)	$t = .443$ $p = .661$
	Hand Dominancy [count (expected count)]	Left = 0 (.5) Right = 23 (22.5)	Left = 1 (.5) Right = 18 (18.5)	$^{a}\chi^2 = 1.616$ $^{a}p = .204$
	Work Experience [mode (range)]	mode = >3 yrs (0-6 mon - >3 yrs)	mode = >3 yrs (0-6 mon - >3 yrs)	$^{b}Z = -1.575$ $p = .115$
	Working Hours per week [mean (sd; range)]	$\bar{x}$ = 42.5 (6.9; 20 – 60)	$\bar{x}$ = 43.0 (4.1; 30 – 48)	$t = -.299$ $p = .767$
	Computer Usage at Work in Hrs/Day [mode (range)]	mode = 4 – 6 hrs (2-4 hrs - > 8 hrs)	mode = 2-4 hrs & 4-6 hrs (2-4 hrs - > 8 hrs)	$Z = -1.320$ $p = .187$
	Keyboard Use in Hrs/Day [mode (range)]	mode = 2 – 4 hrs (2-4 hrs - > 8 hrs)	mode = 4 – 6 hrs (0-2 hrs – 6-8hrs)	$Z = -.586$ $p = .558$
	Mouse Use in Hrs/Day [mode (range)]	mode = 0 – 2 hrs (0-2 hrs – 4-6 hrs)	mode = 0-2 hrs (0-2 hrs – 6-8 hrs)	$Z = -.324$ $p = .746$
	Previous Typing Training [count (expected count)]	Yes = 15 (15.3) No = 8 (7.7)	Yes = 13 (12.7) No = 6 (6.3)	$\chi^2 = .048$ $p = .826$
	Typing Method Adopted [count (expected count)]	Proper Touch-type = 21 (21.9) Certain Fingers only = 1 (.5) Others = 1 (.5)	Proper Touch-type = 19 (18.1) Certain Fingers only = 0 (.5) Others = 0 (.5)	$^{a}\chi^2 = 2.491$ $^{a}p = .288$
Past Discomfort	Duration of Discomfort in Past 12 months [mode (range)]	mode = > 6 months (8-30 days - > 6 months)	mode = 0 day (0 day - > 6 months)	$Z = -3.9$ $p < .000^{**}$
	Prevalance of Discomfort in Past 7 Days [count (expected count)]	Yes = 20 (13.1) No = 3 (9.9)	Yes = 4 (10.9) No = 15 (8.1)	$\chi^2 = 18.453$ $p < .001^{**}$

[*] *p value significant at $\alpha = .05$ level*

[a] 1 cell or more have expected count < 5. Likelihood ratio is used.

[b] *Mann-Whitney U Test*

4.2.3 Variables

The independent variables were *group* (Case versus Control), *side* (left versus right) and *time* (5 repeated trials during 1-hour typing task). The dependent variables were muscle electrical activity amplitudes and discomfort.

4.2.4 Muscle electrical activity

The eight muscles being studied were the bilateral cervical erector spinae (CES), upper trapezii (UT), lower trapezii (LT) and anterior deltoids (AD). These muscles were selected as they are the major stabilising muscles of the neck and shoulder region, they are accessible to surface EMG and they may be subjected to considerable biomechanical strain in performing computer tasks requiring static posture.

4.2.4.1 *Instrumentation*

The Noraxon Telemyo System (Noraxon, U.S.A. Inc., U.S.A.) was used to capture EMG signals (intrinsic frequency of 1000Hz and a bandwidth of 10-500Hz). The raw EMG signals collected by the Noraxon system were channeled into the Vicon 370 system (Oxford Metrics Ltd., U.K) that sampled the analog signals at 1920Hz. The eight channels of EMG signals were pre-amplified close to the electrodes. EMG data was collected for a 60-second period for five trials (at the 5th, 20th, 35th, 50th and 60th minutes) during the 1-hour typing session.

4.2.4.2 *Electrode application*

For EMG measurement, eight pairs of bipolar Ag-AgCl surface electrodes (3M^{TM} Infant Red Dot^{TM} electrodes, 15mm in diameter (3M Hong Kong Limited, Hong Kong) were placed on the skin of the eight muscles examined. The inter-electrode distance was fixed at 20mm. The locations of the electrodes on the eight muscles are presented in Table 4.2. The skin was carefully prepared by cleaning the located area with water, fine sand paper and 2% alcohol (and shaved if necessary) before electrode placement. After electrodes were applied, impedance was checked and 2k ohms or below was considered acceptable.

Table 4.2: Electrode positions and muscle actions tested in normalization for 8 muscles

Muscle	Electrode position	Starting Position	Muscle Action & Application of Load
Cervical Erector Spinae (CES)	Distal: 1cm lateral to C5 spinous process Proximal: 20mm above distal	Head in upright position	Neck extension – against transducer at posterior occiput
Upper trapezius (UT)	Midpoint between electrodes at mid-point between acromion and C7 spinous process	Arm in 0^0 flexion & abduction Scapula in neutral elevation	Scapular elevation – against adjustable strap on acromioclavicular joint
Lower trapezius (LT)	Distal: 2.5-3cm lateral to T6 Proximal: at 45 ^{0}parallel to muscle fibres and 20mm above distal	As above	Scapular retraction – against transducer at the posterior aspect of scapula at lateral half of spine of scapula
Anterior Deltoid (AD)	Midpoint between electrodes at 2 cm anterior to midpoint between acromion and deltoid tuberosity	Shoulder in 30^0 forward flexion, elbow in 75^0 flexion	Forward flexion of shoulder joint – transducer at just above elbow joint

4.2.4.3 *EMG Normalisation*

Prior to the typing trials, EMG normalisation procedures were carried out by having the subject perform 3 trials of resisted maximum voluntary isometric contractions (MVC) and 1 trial of sub-maximal "ramp-up" contraction from 0-30%MVC for each muscle. EMG signals recorded during the typing trials were expressed as percentages of the EMG activity during MVC (%MEMG).

The force exerted in MVC was measured by a strain-gauge transducer connected to an adjustable strap (for UT), or an adjustable metal bar (for CES, LT and AD), for resisting the isometric muscle contraction. Each MVC was performed for a 5 second hold. Subjects were instructed to perform each MVC with a maximal effort of that particular action while keeping the rest of the body relaxed. For each muscle, the 30%MVC was determined from the highest value of the 3 MVC trials, and a line was drawn on the oscilloscope screen to trace the "ramp" from 0% to 30%MVC across 5 seconds. After some initial practice, the subject would perform 1 trial of the 30% ramp contraction. The visualisation of force output and EMG output were used to ensure subjects were performing smooth controlled contractions and to ensure the quality of the data.

All subjects started with the CES muscles with left and right sides tested simultaneously. The other 3 muscles (UT, LT and AD) were tested on the right side first followed by the left. The muscle actions tested are listed in Table 4.2.

All the EMG signals were processed in a specially designed Labview (National Instruments^{TM}, Austin, U.S.A) program with a high-pass filter at 20Hz, a low pass filter at 200Hz and notch filters at 50Hz and 60Hz to reduce the noise levels. Then the signals were down-sampled to 10Hz root mean square (RMS) values. Muscle electrical activity was analysed in terms of normalized %MEMG expressed as 3 levels (10th%, 50th%, 90th%) of Amplitude Probability Distribution Function (APDF) (Jonsson, 1982).

4.2.5 Discomfort ratings

Immediately after each EMG capture during the typing trial, the subject was also asked to verbally rate her subjective discomfort in ten upper body regions (left and right neck, upper back, shoulders, elbows, wrists/hands) on a numerical scale of 0 to 10 with 0 = no discomfort, 1=minimal discomfort and 10 = extreme/intolerable discomfort. The boundaries of the various upper body regions were adopted from those in the Standardised Nordic Questionaire (Kuorinka et al., 1987). For statistical analysis the discomfort data were analysed in terms of the summed score (total score of all discomfort areas in a trial) and the number of areas (total number of areas of discomfort reported in each trial).

4.2.6 Controlled variables

4.2.6.1 *Computer workstation*

The workstation included a standard computer desk with an adjustable slide-out tray for keyboard and an adjustable height swivel chair with no arm rests (See Fig. 4.1). The subject was instructed to adjust the keyboard tray and the chair in order to assume a position of comfort, with hip, knee, and elbow joints approximately at 90 degrees.

The monitor height, distance and angle were adjusted to a comfortable level for the subject (top of monitor at approximately the horizontal eye height), so that the head-neck region was in a reasonably erect posture and the subject could rest part of her forearms on the rounded edge of the adjustable keyboard tray. After the adjustments the subject was asked if she felt she could be comfortable for the duration of the typing task, and whether this posture simulated her workstation setting at work. The adjustments were only considered adequate when the subjects indicated positive answers to these questions.

4.2.6.2 *Computer task*

Each subject performed a standardised task of copy-typing well-known children's stories displayed on screen using TypingMaster (Aquarian Technologies, Maldon, Australia) software and the subject was instructed to work at her normal speed and pace. The subject was instructed to continue typing and typing errors can be corrected at her own discretion.

4.2.7 Data management

The EMG amplitude data computed as the 10th%, 50th%, 90th% APDF were compared. A mixed model MANOVA was used to examine the effects of *group* (between-subject factor), *side* and *time* (within-subject factors), on the 3 levels of APDF for each of the 4 muscles. As the results of the statistical analyses for the 10th% and the 90th% exhibited similar trends as the 50th% APDF, only the 50th% data are presented here. The 50th% APDF represented the "median" level of amplitude and would be a good indicator of the average level of muscle activity during the experimental task.

The discomfort results were also analysed using a *group* and *time* MANOVA model. The dependent variables were the summed discomfort score for each trial and the number of areas with discomfort.

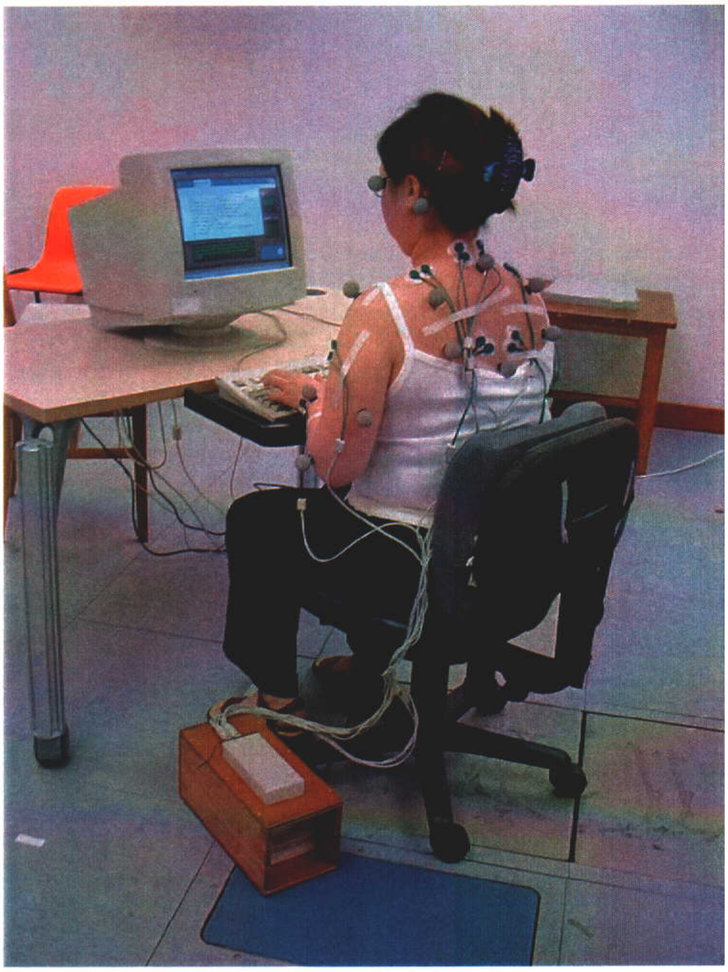


Fig. 4.1: Experimental setup with subject in the typing position, with the Vicon markers and EMG electrodes attached

4.3 RESULTS

4.3.1 Muscle activities of Case and Control Groups

Fig. 4.2 shows the means (±SD) of the 50^{th}% APDF of the 8 muscles over 5 trials for the Case and Control Groups. Typically there were large variances in the EMG data for all muscles. The main differences between groups appeared to be the higher right UT activity in the Case Group and higher right CES activity in the Control Group. Generally all muscles seemed to have trends for higher activities on the right side compared to the left. The differences between sides were more apparent in the CES muscle for the Control Group, the UT muscle for the Case Group, and in the AD muscle for both groups.

Fig. 4.3 shows the time trends of the means of the 50^{th}% APDF of the 8 muscles over the 5 trials. There appeared to be consistently large gaps between sides in UT for the Cases but very similar between sides for the Controls. The reversed trends were observed for the CES, with large gaps between sides in Controls and similar values in the Cases. The right CES appeared to have a steadily upward trend across time in the Controls, but the left CES in Controls and both sides of CES in Cases appeared to be very similar across time. The right UT and the bilateral LT seemed to have an up-and-down trend in Cases, while both sides of LT appeared to have a downward trend across time in the Controls.

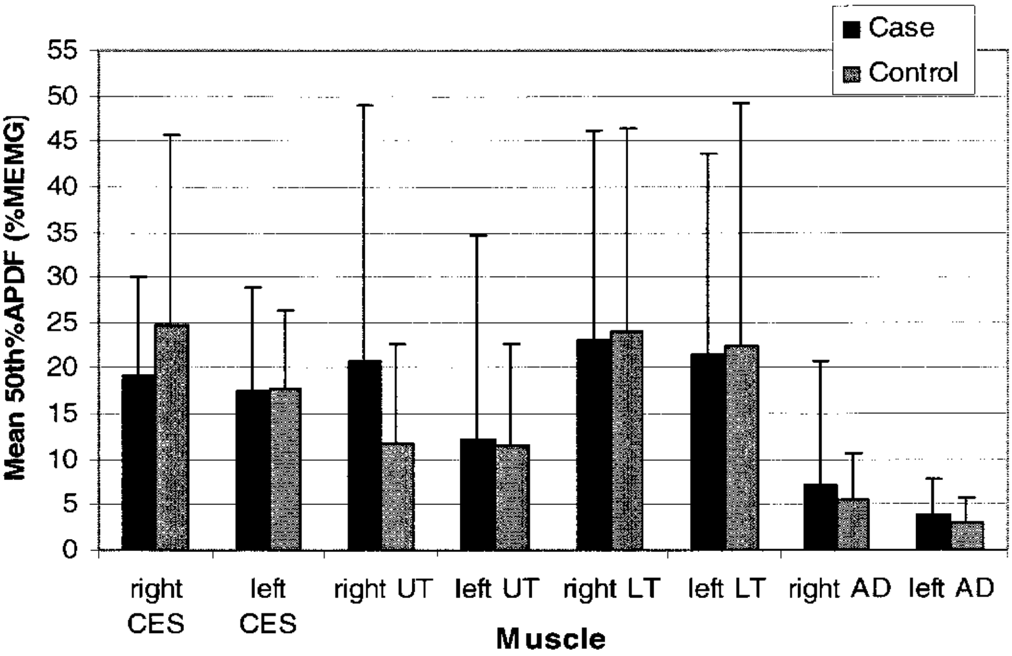


Fig. 4.2: Comparison of the mean (±SD) 50th% APDF of the 8 muscles in the Case and Control Groups

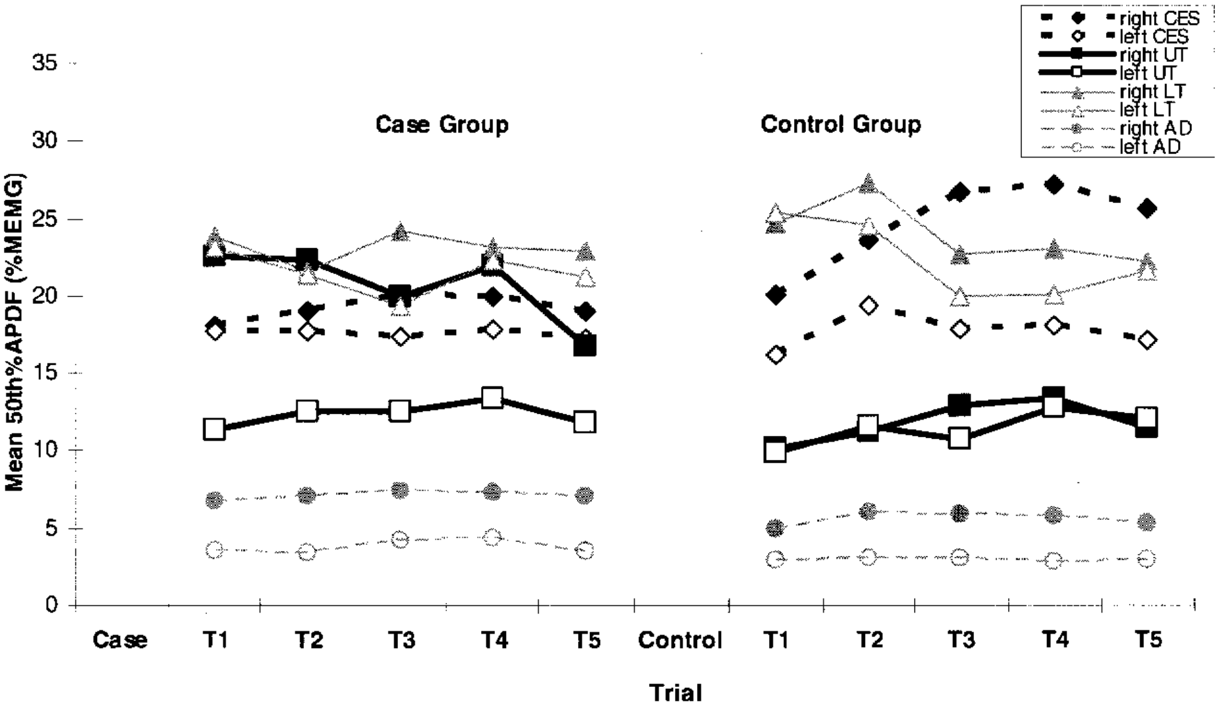


Fig. 4.3: Trial means of 50th%APDF of the 8 muscles for Case and Control Groups

4.3.1.1 *Cervical erector spinae (CES)*

A mixed model (between subjects *group* factor, within subjects *side* and *time* factors) MANOVA of the CES muscle activities was performed on the 10th%, 50th% and 90th% APDF variables. A significant effect was found for *group* ($F_{3,39} = 3.34$, $p = .027$), a strong trend for *side* ($F_{3,39} = 2.43$, $p = .079$), and a significant effect for *time* ($F_{12,30} = 2.76$, $p = .012$). No 2-way or 3-way interactions were significant.

In the univariate analysis for the 50th% APDF, we found no significant *group* effect ($F_{1,41} = 0.65$, $p = .425$), but significant *side* ($F_{1,41} = 3.26$, $p = .044$) and *time* ($F_{2.2, 90.1} = 3.26$, $p = .039$) effects and a significant *time* x *side* interaction ($F_{1.6,64} = 3.55$, $p = .045$). The results for 10th% and 90th% showed similar trends for statistical significance.

These results suggest there was a difference in the CES muscle activity between *groups*, with right CES activity being higher in the Control group, and the difference increasing over *time*, as was apparent in Fig. 4.3.

4.3.1.2 *Upper trapezius (UT)*

In the multivariate analysis for UT (between subjects *group* factor, within subjects *side* and *time* factors), no significant effect was found for *group* ($F_{3,39} = 1.03$, $p = .391$), *side* ($F_{3,39} = 1.91$, $p = .144$), nor *time* ($F_{12,30} = 1.27$, $p = .280$). The 2-way and 3-way interactions were also not significant.

The univariate analysis for 50th% APDF also showed no significant *group* effect ($F_{1,41} = 0.76$, $p = .308$), nor *time* effect ($F_{2.1,86.9} = 1.27$, $p = .287$). But there was a strong *side* effect ($F_{1,41}$=6.02, *p*= .019) and a significant *side* x *group* interaction ($F_{1,41}$= 4.99, *p* = .031). The other 2-way and 3-way interactions were not significant. The results for 10th% and 90th% showed similar trends for statistical significance. The significant *side* effect and the *side* x *group* interaction confirmed the trends observed in Fig. 4.2 and 4.3. The results showed that the right UT was significantly higher in activity than the left UT mainly in the Case Group, while the Control Group had more similar activities between the left and right UT muscles.

4.3.1.3 *Lower trapezius (LT)*

In the multivariate analysis for LT (between subjects *group* factor, within subjects *side* and *time* factors), no significant effect was found for *group* ($F_{3,39}$ = 0.25, *p* = .859), *side* ($F_{3,39}$ = 0.20, *p* = .898), nor *time* ($F_{12,30}$ = 1.05, *p* = .430). The 2-way or 3-way interactions were also not significant.

The univariate analysis for the 50th% APDF also showed no significant *group* effect ($F_{1,41}$ = 0.02, *p* = .896), *side* ($F_{1,41}$ = 0.26, *p* = .616) nor *time* effect ($F_{3.4, 139.3}$=1.21, *p* = .308). There were no significant 2-way or 3-way interactions. The results for 10th% and 90th% showed similar trends for statistical significance.

These results suggested that there were no major differences in the LT muscle activities between Case and Control groups.

4.3.1.4 *Anterior deltoid (AD)*

For AD, the multivariate analysis demonstrated no significant *group* effect ($F_{3,39} = 1.40, p = .256$), a close -to- significance *side* effect ($F_{3,39} = 2.35, p = .087$), and no *time* effect ($F_{12,30} = 0.58, p = .844$). The 2-way or 3-way interactions were also not significant.

In the univariate analysis, there was no significant *group* effect ($F_{1,41} = 0.40, p = .528$), nor *time* effect ($F_{3.3, 133.9} = 1.24, p = .296$). The *side* effect was significant ($F_{1,41} = 4.14, p = .048$), but there were no significant 2-way or 3-way interactions. The results for 10th% and 90th% showed similar trends for statistical significance.

Thus the results implied that whilst there was no difference in the AD muscle activity between groups, there was significantly more activity in the right side for both groups.

4.3.2 Subjective discomfort

The Case subjects reported discomfort most frequently in the right shoulder, followed by the left shoulder, both sides of the neck, right wrist/hand and left wrist/hand. Fig. 4.4 shows the changes of the discomfort scores (summed over all body regions) for each trial (T0-T5) comparing the Case group and the Control group. The mean of the summed discomfort scores over all trials was 13.8 (±7.8) for the Case group and 1.4 (±2.3) for the Control group.

A mixed model MANOVA was used to evaluate the effects of the between-subject *group* factor (Case vs Control) and within-subject factor of *time* (T0=start of testing session, trials 1-5 during the typing trial). There was a significant *group* effect

($F_{2,40}$=39.72, *p*<.0001), significant *time* effect ($F_{10,32}$=3.66, *p*= .002), and a significant *time* x *group* interaction ($F_{10,32}$=3.13, *p*= .006). The univariate analysis for summed score also showed significance for *group* effect (F1,41=47.92, *p*= .000), *time* effect (F $_{3.1,126.9}$=13.94, *p*<.0001), and a *time* x *group* interaction ($F_{3.1,126.9}$=5.20, *p*= .002). For the number of areas, there was a significant *group* effect ($F_{1,41}$=58.14, *p*<.0001), and *time* effect ($F_{3.1,\ 126.7}$=10.11, *p*<.0001) but the *time* x *group* interaction was not significant ($F_{3.1,\ 126.7}$=1.58, *p*=.197).

The results demonstrated significant differences between groups in both the severity of discomfort and area of discomfort, with the severity of discomfort experience by the Case Group increasing more rapidly during the 1 hour typing task, compared to the Control Group.

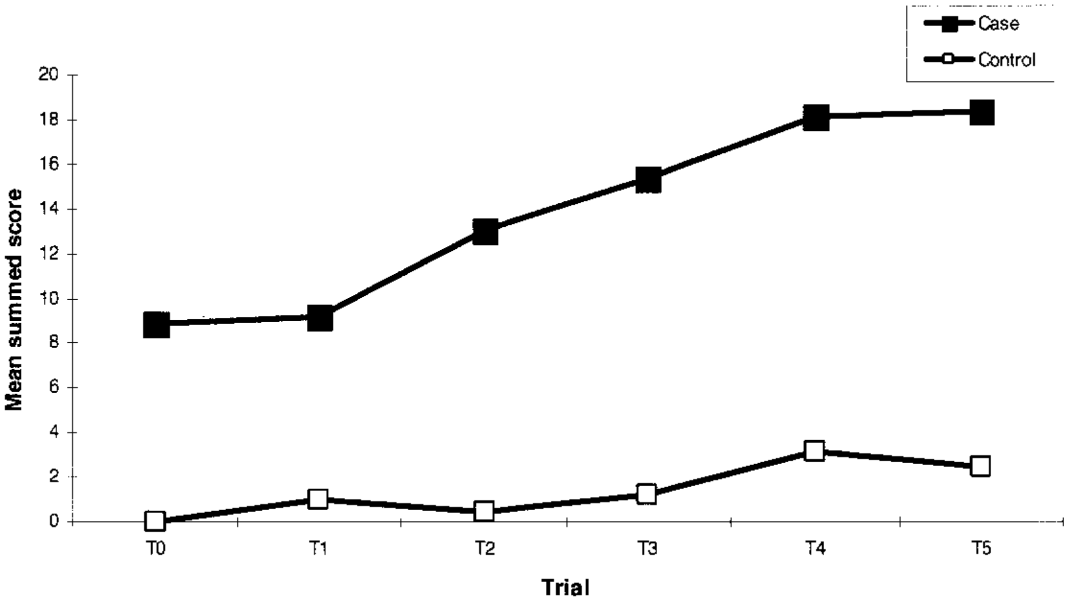


Fig. 4.4: Trial means of summed discomfort scores comparing Case and Control Groups

4.3.3 Dividing Case Group into High and Low Groups

When the results of the Case Group were examined further, it was found that there were distinguishable patterns between those with more severe discomforts and those with less severe discomforts. Hence the Case Group subjects were sub-divided into a "High" Group (n=15) and a "Low" Group (n=8) based on the means of the summed discomfort scores from the five trials. The "High" Group was defined by a mean discomfort score >12 (from all areas). The trends of the discomfort scores of the "High" and "Low" Groups can be seen in Fig. 4.5. It was apparent that the Low Group had a very similar trend of discomfort scores as the Control Group, and both these groups were very different to the High Group.

The mean discomfort score over 5 trials was 18.6 (±8.8) for the High Group, 4.9 (±3.5) for the Low Group and 1.4 (±3.8) for the Control Group. In a one-way ANOVA with pairwise contrasts to compare the differences among the three groups, High Group was significantly different from the Low Group (t_{40}= 4.42-7.55, p<.0001) and from the Control Group (t_{40}= 7.05-11.69, p<.0001). The Low Group was only significantly different from the Control at the start of the typing trial, T0 (t_{40}=6.99, p= .013) and in trial 5, T5 (t_{40}=2.28, p= .028), but there was no significant difference in T1-4 (t_{40}=0.73-1.85, p>.05).

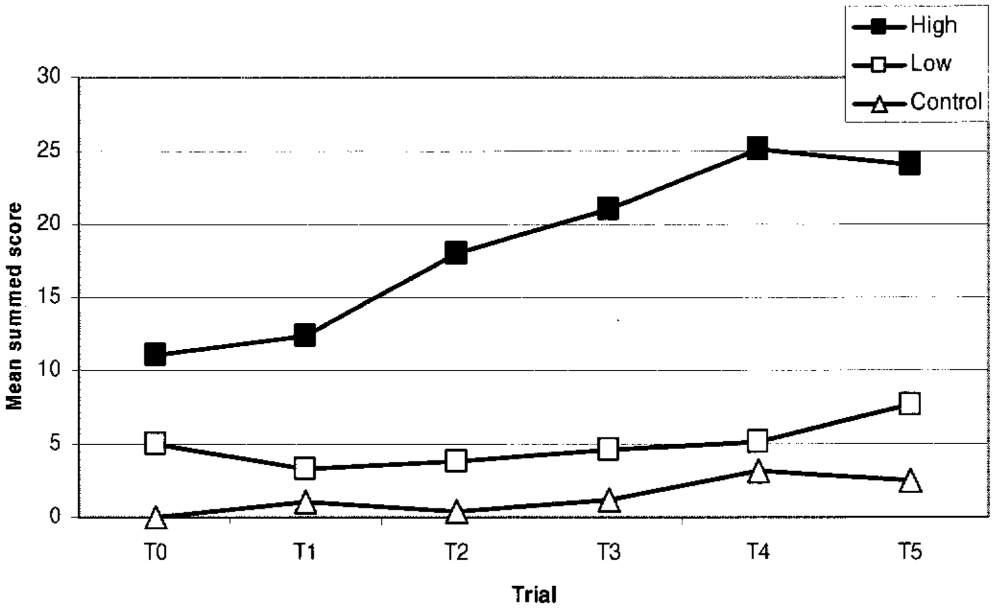


Fig. 4.5: Discomfort scores in High, Low and Control Groups

When the mean values of the 50th%APDF for the 8 muscles were divided into the High and Low groups, it was apparent that the major difference in muscle activities lay between the High and Low Groups. The Low Group had muscle activities more similar to the Control Group. For some muscles the Low Group had even lower muscle activities compared to the Control Group (See Fig.4. 6).

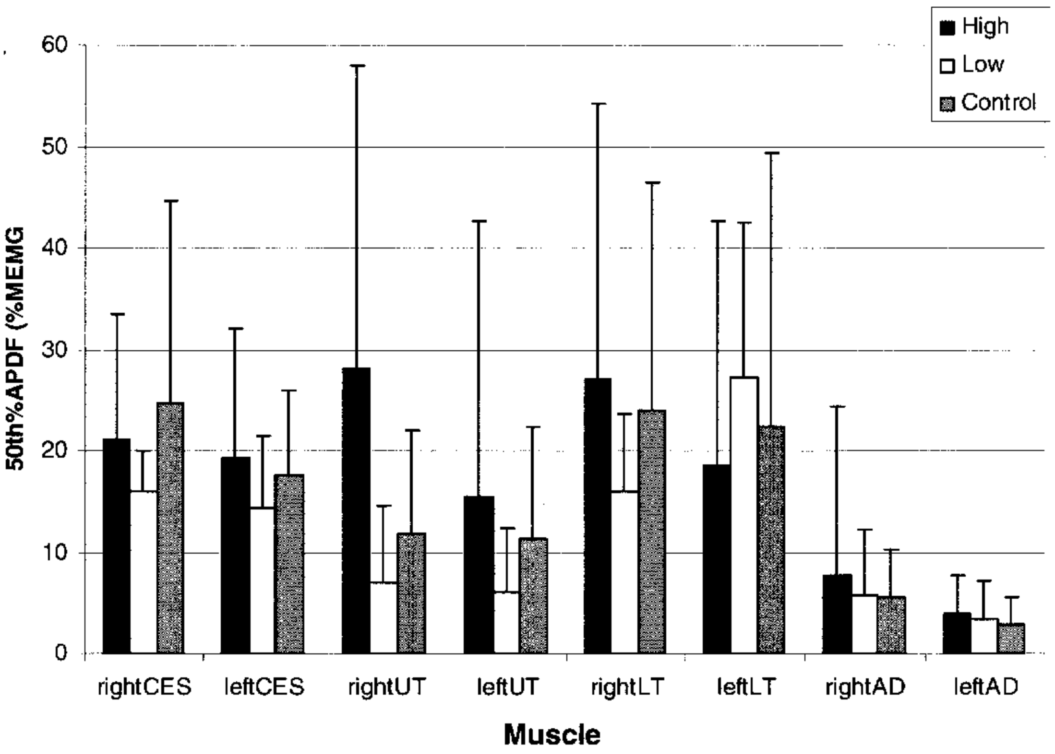


Fig. 4.6: Mean (±SD) 50^{th}%APDF of the 8 muscles comparing High, Low and Control Groups

The 50th% APDF of the CES and UT muscles were then compared using one-way ANOVA with 3 pairwise contrasts for the High, Low and Control Groups. Significant difference was found between groups only for the right UT 50th%APDF ($F_{2,40}$=4.32, *p*= .020), but not for the left UT or the bilateral CES muscles. In the pairwise contrasts, the right UT activity for the High Group was significantly higher than the Low Group (t_{40} =2.59, *p*= .019), and the contrast between High Group and Control Group was approaching significance (t_{40}=-2.03, *p*= .059). There was no significant difference in the right UT between Low Group and Control Group as expected (t_{40}=-1.38, *p*= .185). These results confirmed that the main difference in the UT muscle activity was in the

High Group which demonstrated significantly greater activity than both the Low Group and the Control Group, and this was not apparent in the previous statistical analysis between the Case and Control Groups.

4.3.4 Synergistic roles of CES and UT as stabilisers of cervical spine

As both the CES and UT are potential synergists acting on the cervical spine – they have a functional relationship during cervical postural tasks. Because of this, the relationship between these muscles was further investigated by calculating ratios to determine if a synergistic relationship between the muscles could be observed (Edgerton et al., 1996; O'Sullivan et al, 1997). The UT to CES ratios on both sides, the right to left UT muscle ratio as well as the right-left CES ratio were computed. The mean values of the muscle ratios are summarized in Table 4.3 which also contains all the statistical results of the one-way ANOVA. The pairwise contrasts of the right UT/CES ratio showed that the High Group was significantly higher than the Control Group (t_{40}=-2.15, *p*= .048), and the High Group significantly higher than the Low Group (t_{40}=2.37, *p*= .032). The other amplitude ratios comparing the left UT and CES, or the ratios between the two sides of the same muscles showed no significant difference between groups. These results suggested that there was a significantly higher UT with lower CES activities in the right side of the High Group; while the Low Group and the Control Group had the reversed pattern – with significantly lower UT and higher CES activities on the right side.

Table 4.3: Descriptive statistics and results of one-way ANOVA comparing muscle activities and amplitude ratios in High, Low and Control Groups

Measure	**Case: High (n=15)**	**Case: Low (n=8)**	**Control (n=20)**	**One-way ANOVA**		**Contrasts [t, sig.(2-tailed)]**		
	Mean (SD)	Mean (SD)	Mean (SD)	$F_{(2,40)}$	*p*	High vs Control	Low vs Control	High vs Low
Right CES 50th%APDF	20.99 (12.6)	16.04 (4.0)	24.67 (19.9)	0.89	.420	0.67, .510	-1.84, .079	1.40, .178
Left CES 50th%APDF	19.26 (12.8)	14.46 (7.0)	17.71 (8.3)	0.61	.548	-0.46, .649	-0.78, .439	1.10, .276
Right UT 50th%APDF	28.12 (6.9)	6.94 (7.6)	11.84 (10.1)	4.32	.020*	-2.03, .059	-1.38, .185	2.59, .019*
Left UT 50th%APDF	15.56 (6.2)	6.20 (6.2)	11.44 (10.9)	0.69	.507	-0.56, .583	-1.53, .139	1.24, .231
Right UT/CES ratio	2.27 (2.9)	0.43 (0.4)	0.61 (0.5)	4.48	.017*	-2.15, .048*	-0.97, .347	2.37, .032*
Left UT/CES ratio	0.81 (2.4)	0.45 (0.5)	0.64 (0.7)	1.30	.284	-1.65, .116	0.82, .437	-0.01, .998
Right/Left CES ratio	1.20 (0.5)	1.38 (0.9)	1.45 (1.1)	0.33	.724	0.80, .429	-0.18, .859	-.45, .653
Right/Left UT ratio	9.66 (19.8)	1.29 (0.8)	1.55 (1.6)	2.36	.107	-1.58, .136	-0.57, .575	1.63, .124

* significance level $p<0.05$

Post-hoc analysis was carried out to determine the relationship between UT activity and side of discomfort. It showed a positive correlation between increased activity in the right UT with right neck, left neck and right shoulder discomforts (r=0.630, 0.513, 0.483). Left UT was also correlated with right neck, left neck and right shoulder discomforts (r=0.448, 0.343, 0.406). All these correlation coefficients were statistically significant (*p*= .0001 - .024). The statistical results are presented in Appendix V (p.435).

4.4 DISCUSSION

4.4.1 Muscle recruitment patterns in Case and Control Groups

The present study has shown important differences in EMG amplitude levels among different muscles between the two subject groups as well as between the left and right sides. These results suggested that there were possibly different muscle activation strategies in different individuals for maintaining the static neck-shoulder posture in performing the sustained computer task.

The most important finding in terms of the group differences in this study lay with the levels of CES and the UT muscle activities on the right side. The Case subjects showed a trend for higher activity levels in the right UT muscle while the Control subjects showed higher activity in the right CES muscle. These results suggested that the symptomatic individuals in the Case Group tended to employ increased activity in the right UT muscle in maintaining the static neck-shoulder posture.

This trend became a statistically significant difference when the Case subjects were divided into the High and Low Groups. The High Group had significantly higher activity in the right UT muscle than the Low Group and Control Group; as well as significantly higher UT/CES amplitude ratio on the right. In contrast, the Low Group and the Control Group subjects tended to have higher activity of the right CES muscle for performing the same postural stabilizing task. It implied that it was mainly the subjects with the more severe discomfort scores that demonstrated a different muscle recruitment strategy, and those with less severe discomforts (the Low Group) seemed to have more similar muscle recruitment patterns to the Control Group, with a trend towards lower UT activities.

Past studies that compared Case and Control Groups in performing office work have reported conflicting results with some studies showing no difference in muscle activities between groups (Nordander et al., 2000; Roe et al., 2001; Vasseljen & Westgaard, 1995). It is possible that the lack of significant differences in these studies was due to the lack of differentiation between those with more severe discomforts and those with mild discomforts.

4.4.1.1 *Altered muscle recruitment patterns are related to the synergistic roles of neck-shoulder stabilizers*

The present results showing altered muscle recruitment patterns in the synergistic muscles of the cervical spine (UT and CES) have highlighted the importance of examining the anatomical functions of the different muscles involved in postural stabilisation. The CES muscles are mainly a cervical spine extensor with no action on the shoulder (Bernhardt et al., 1999; Kapandji, 1974). Their major anatomical function is to control the segmental movements of the cervical spine and they should be active to support the forward cervical/head posture (Janda, 1994; Johnson et al., 1994; Jull et al., 1999). The architecture of the trapezius muscle suggests it is not designed for the stabilization of the cervical vertebral segments (Janda, 1994; Johnson et al., 1994; Panjabi et al., 2001). The trapezius muscle is a primary stabiliser of the scapula, and its action is mainly to elevate and stabilise the acromion; and it is usually activated with shoulder flexion or abduction (Johnson et al., 1994; Keshner et al., 1989). Studies on biomechanical modeling in the cervical spine have also identified the lateral bending moment created by the asymetrical pulling of the UT muscle (Bernhardt et al., 1999; Panjabi et al., 2001; Patwardhan et al., 2000). On this basis the UT could be classified as a high load stabiliser of the cervical spine as it exerts compressive and side bending moments to the cervical spine without controlling individual segments (Bernhardt et al., 1999; Jull et al., 1999). The UT also attaches to the cranium – with resulting compressive forces exerted to the cervical spine via the head. It could be hypothesised that this sustained unbalanced compressive and side bending forces created by high UT activity could result in asymmetrical stresses in the cervical spinal articular and connective tissue structures resulting in tissue sensitisation and neck pain.

Many past studies have measured electrical activity in the upper trapezius alone, without studying the relationship of this muscle to other synergists (Bansevicius et al., 1999; Hagg & Astrom, 1999; Hermans & Spaepen, 1995; Jensen et al., 1993a; Roe et al., 2001). Kleine et al. (1999) reported considerably higher amplitudes in the UT muscles than the CES and AD muscles in office workers performing computer tasks, but did not compare the UT recruitment patterns to the other muscles studied. In the present study, we have demonstrated significantly higher amplitude ratios of UT /CES on the right side in the High Group compared to the Low Group. This result again confirmed the differences in muscle recruitment patterns between the two groups and provided evidence for the muscle substitution phenomenon in those individuals with high discomforts. To our knowledge, our study was the first to examine muscle activity ratios between UT and CES during the performance of occupational tasks. Ratios of EMG amplitudes between pairs of muscles have been used in clinical studies of low back pain patients to identify normal and abnormal muscle recruitment patterns between synergists (Edgerton et al., 1996; O'Sullivan et al., 1997). It is a useful way to examine the phenomenon of muscle substitution whereby synergistic muscles such as the CES and UT muscles may develop abnormally high or low activation patterns either as a result of pain / injury, or as a predisposing factor to pain disorder (Edgerton et al., 1996; O'Sullivan et al., 1997).

In contrast to CES and UT, the lower trapezii (LT) demonstrated fairly similar activity levels in both groups. When the LT activity was compared between the High and Low Groups, there was a trend for the High Group to have more right-sided activity compared to the left. This result suggested that the LT did not have lower activity in the symptomatic persons as predicted by the scapular stabilization theory. In physiotherapy practice the recent concept of "scapular stabilization" proposed that excessive scapular protraction was a pathological finding, and the importance of retraining lower trapezius is emphasized in order to maintain the scapula in a retracted position (Janda, 1994; Kibler, 1991). However, this concept has not been fully substantiated by research. Some studies have reported a positive relationship between scapular posture, muscle activity and pain (Culham & Peat, 1993; Griegel-Morris et al., 1992). Yet, there has been no agreement in the literature to support the effect of increasing activity in the middle or lower trapezius, on reducing pain or counteracting the hyperactivity problem in UT. The findings of this study do not support this theory.

The deltoid muscles were mainly acting as both stabilizers as well as dynamic movers of the upper arm in keyboard operation. It was observed that the EMG patterns occurred in bursts of large activities in addition to a steady background of static low-level activity.

4.4.1.2 *Side differences in muscle activity patterns*

The apparent side differences demonstrated in the present study is also an interesting finding. The side effect was strongest in the UT, CES and AD muscles. The side differences in the CES and UT muscles had different trends in the Case and Control Groups, and this was part of the group differences in muscle recruitment strategies.

Kleine et al. (1999) and Hermans and Spaepan (1995) also reported consistently higher activities in the right sided stabilizing muscles compared to the left, similar to our study. However, other studies have reported similar muscle activity levels in bilateral trapezii (Jensen et al., 1993a; Waersted, Bjorklund, & Westgaard, 1994).

The side differences in muscle activities may be related to the working habits of the subjects. Most of the subjects in both groups were right-hand dominant, thus the right side may be more used to performing a greater amount of computer work especially with the increasing emphasis in using the mouse for many of the computing functions. This may contribute towards an acquired habit of increased activity in the major stabilizing muscles on the right side, particularly when the workstation setting was often non-optimal in real life.

4.4.1.3 *Overall time trends in muscle activity patterns*

On the whole there were no significant changes in terms of time-at-task. The lack of major changes in amplitudes due to time suggested that these patterns of muscle recruitment were consistent across time. The right CES showed a significant *time x side* interaction and this was consistent with the apparently increasing trend across the trials in the Control Group, but only a slightly increasing trend in the Case Group. These differences were part of the group patterns between the Case and Control Groups, reflecting their different muscle activity responses to the sustained computer task. Past studies have reported some differences between subjects with and without discomforts in response to prolonged work tasks but the evidence was not strong (Hermans & Spaepan, 1995; Jensen et al, 1993a). This tends to suggest that the changes in recruitment are inherent in these subjects, instead of responses secondary to the onset or presence of discomfort.

In a recent study examining the effects of one-hour sustained isometric shoulder abduction on intramuscular trapezius activity, it was shown that low-threshold motor units (cindarella motor units) were active during the 60 minutes and there was evidence of motor unit substitution (Thorn et al., 2002). However, the subjects were again painfree individuals and it was not clear whether symptomatic persons would respond in the same way.

4.4.2 Discomfort patterns in Case and Control Groups

4.4.2.1 *Discomfort more widespread and severe in Case Group, and mainly in neck and shoulder areas*

The present results showed strong trends for more severe discomforts in more areas in the Case subjects and these discomforts increased significantly as the typing task was sustained. Characteristically the neck and shoulder regions were the most affected and these patterns were similar to those reported in previous research (Kamwendo et al., 1991a; Siu & Chan, 1998; Westgaard et al., 1993). During the one-hour typing task, the majority of Case subjects reported bilateral discomforts in their neck and shoulder regions, and the mean discomfort scores in both sides of the neck and shoulders were quite similar (left neck =3.0 ±2.9, right neck = 2.7 ± 2.9; left shoulder = 3.5 ± 3.0, right shoulder = 3.3 ± 2.4). On the other hand, the Control Group reported very minimal scores in discomforts and this trend did not change over the one-hour typing task. The significant group and time effects in the discomfort scores were consistent with those of previous studies which showed significantly higher discomfort scores due to prolonged work duration and repetitiveness of tasks (Jensen et al, 1993a; Takata et al., 1992; Westgaard et al., 2001).

4.4.2.2 *Discomfort differences in High and Low Groups*

When the Case subjects were divided into the High Group and the Low Group, distinctly different discomfort patterns emerged. From Fig.4.5, it was clear that mainly the High Group had the increasing trend for discomforts and the Low Group was basically similar to the Controls in terms of time trend for discomforts. However, the Low Group still had consistently higher discomfort scores than the Control Group across the one-hour typing trial, and this pattern did not change over time.

This finding suggested that there were different characteristics about these individuals in the High and Low Groups that may have contributed to their different responses in performing the same task. From the subjects' profiles, both the High and Low Groups had a similar history and experience of discomforts (all had over 3 months of discomforts), and they had similar patterns of computer usage in their jobs (see Table 4.1). Although their past durations of discomforts were similar, the High Group also reported higher discomfort scores in the past compared to the Low Group; and this pattern was compatible to that found in the experimental trials. This finding suggested that the High Group already had more severe discomforts in the past and this pattern continued to affect their performance or discomfort responses during the experimental task. Since the demographic and work profiles of the High and Low Groups were similar, the differences between them may involve intrinsic individual differences. It is possible that the High and Low Groups may have involved different etiology or different pathology in their musculoskeletal system, thus contributing to their different muscle recruitment patterns.

The intrinsic individual differences may be related to neurophysiological mechanisms linking motor control and pain perception. These mechanisms include central and/or peripheral sensitization of nociceptors which have been widely reported in studies that examined chronic somatic pain and experimental muscle pain (Arendt-Nielsen & Svensson, 2001; Coderre et al., 1993; Johansson & Sojka, 1991; Mense, 1993; Sheather-Reid & Cohen, 1998; Svensson et al., 1998). These neurophysiological processes may have a great influence on the perception and magnification of the pain/discomfort sensations.

Psychological profile and personal experiences have also been known to influence individuals' perception of pain or discomfort sensations as well as patterns of motor activity (Coderre et al., 1993; Linton, 2000; Mense, 1993; Waersted, 2000). Vasseljen and Westgaard (1995) reported that "perceived general tension" was the variable that was most strongly related to neck and shoulder pain at the workplace.

4.4.2.3 *Case Group also had more "task-induced discomforts" in addition to more "clinical discomforts"*

While the sustained typing task did provoke some of the discomforts that were already experienced by the subjects, which can be termed "*clinical discomforts*", there were also some new areas of discomforts reported by the subjects that were termed "*task-induced discomforts*". The most common area for task-induced discomfort was in the wrist-hand area, and these task-induced discomforts were more prevalent in the Case Group than the Control Group. This result implied that in addition to having the clinical pains, the Case subjects might also be under more strain in their other body regions and therefore experienced more widespread discomforts. This phenomenon may also be related to central or peripheral sensitization processes in pain perception.

This tendency in the symptomatic persons to have more severe and widespread discomforts has very important implications, suggesting that ergonomic interventions may need to consider the different or more sensitive responses of individuals with past history of discomforts. Many past studies have often focused on studying the responses of healthy painfree subjects to ergonomic interventions, and assumed that their responses would be representative of all individuals. However, human beings can demonstrate large individual variations, especially when their behaviours may be already modified by their past experiences.

4.4.2.4. *Age difference in subjects may be related to history of previous symptoms*

In examining the different subjects' profiles, a significant difference in the age distribution of the Case and Control Groups was noted, with the average age of the Control group being about 5 years younger than the Case group. This is in fact a difficult factor to control, as it was easier to recruit subjects that were older and had longer working histories; and the likelihood of experiencing work-related discomforts would also increase. Previous studies have shown a positive and strong correlation of past history of previous discomforts and present work-related discomforts (Westgaard et al., 1993). However, other epidemiological studies have reported no significant association of age with work-related musculoskeletal disorders (Bernard et al., 1994).

4.4.3 Potential mechanisms that may explain association between muscle activity patterns and discomfort

A large number of studies have produced different models and hypotheses attempting to find underlying causes and processes to explain musculoskeletal pain phenomena. There are likely to be more than one process or system involved and it is generally agreed that work-related musculoskeletal pain has a multifactorial etiology (Armstrong et al., 1993; Forde et al., 2002; Kumar, 2001; Moon & Sauter, 1996; Westgaard, 2000).

While these models attempt to identify the etiology of musculoskeletal problems, invariably they tend to have a specific focus or perspective. The "Multivariate Interaction Theory of Musculoskeletal Injury Precipitation" proposed by Kumar (2001) may be one of the most comprehensive or "global" models that takes into consideration the various systems of factors including physiological, morphological, genetic, biomechanical, psychosocial and environmental factors. Westgaard et al. (2001) also proposed that inter-subject differences in EMG activity patterns were more likely to be a feature of intrinsic, person-based differences rather than responses to work demands. These authors also advocated the need for more extensive research into the intrinsic physiological processes to explain the inter-individual differences in muscle activity patterns.

4.4.3.1 *Present results do not support muscle pain model, vicious cycle model or pain adaptation model*

The present results with the widespread area of symptoms in both the neck and shoulder areas bilaterally do not support the muscle-pain model. The location of discomforts and the rising time trend of discomforts were not consistent with the patterns of muscle activities which did not change with time. In addition, the muscle activities showed the greatest changes or highest concentration in the right UT in the symptomatic subjects, while the discomforts tended to be bilateral and more widespread, and this would suggest that the muscles were not the most likely source of the pain.

In the present study, the Case subjects demonstrated a steadily increasing discomfort score while the muscle activities did not show significant increases with time. This also did not support the "vicious cycle" model which predicted that muscle pain and muscle spasm develop in a self-perpetuating cycle (Travell & Simons, 1983; Johansson & Sojka, 1991). Thus this model would not be applicable to explain the increasing trend for the symptoms during the experimental task, but it might be appropriate with reference to the relationship between the habitual hyperactivity in the trapezius and the development of chronic pain in the subjects' past history.

The present results also did not support the "pain adaptation model" which proposed that muscle activity was inhibited as a result of pain (Arendt-Nielsen et al., 1996; Graven-Nielsen et al., 1997a; Svensson et al., 1998). The evidence for this model has mainly come from studies on experimentally-induced acute pain, but it was also thought to be applicable to explain work-related pain (Graven-Nielsen et al., 1997a). However, the responses of painfree subjects with acute experimental pain could not be taken as equivalent to those of workers with chronic work-related musculoskeletal pain. These pains usually involved a gradual onset over a considerable period of time, during which there may be physiological adaptations and motor control changes within the body. Morphological changes in muscle fibres of patients with "trapezius myalgia" have been reported by Larsson et al. (1999 & 2000). Other studies have also provided ample evidence for psychological and emotional adaptations to chronic pain in individuals (Jensen et al., 1993a; Linton, 2000; Zusman, 2002). All these changes would not be present in the subjects experiencing experimentally-induced pain, while they were more likely to occur in individuals with chronic and work-related pain.

4.4.3.2 *Results support an "Altered Motor Control" Model*

The present results appeared to support an "Altered Motor Control" Model. It can be hypothesised that the subjects with more severe discomforts had an altered motor control strategy compared to those with low or minimal discomforts, and this altered motor control would be activated whenever they performed their usual occupational tasks such as keyboard operation. It is not clear whether this motor control deviation may also operate when they perform other tasks.

The altered motor control patterns demonstrated in the High Group may have resulted in increased and chronic asymmetrical loading of cervical articular and connective tissue pain-sensitive structures, resulting in the widespread discomfort patterns observed in the symptomatic subjects. Furthermore the fact that the altered motor control patterns did not change with increasing symptoms over time, suggested that they did not occur secondary to pain, but rather may be an underlying cause of, or in association with the pain disorder.

It is possible that the hyperactivity in the UT muscle was due to inherent altered motor control in some individuals that gradually developed with daily work in using the keyboard and the mouse, and this pattern became programmed into the motor control patterns of the individuals. In contrast, the Control subjects demonstrated relatively lower and more symmetrical amplitude levels in their bilateral trapezii muscles, suggesting that they had the ability to keep the muscles in a relaxed state while working with the keyboard and the mouse in their daily work. From the outcome in terms of the discomfort scores, it would suggest that the Control Group has adopted a better coping strategy in the motor control of their muscles.

Bansevicius et al. (1997) also reported a positive correlation of the higher trapezius muscle activity with pain scores on the right side, but not the left. Jensen et al. (1993a) reported a significant but weak correlation of trapezius muscle activity and pain. In contrast, a number of studies reported no correlation between muscle activity and pain, but found pain to be more correlated with psychosocial factors (Roe et al., 2001; Sheather-Reid & Cohen, 1998; Vasseljen & Westgaard, 1995)

The altered motor control pattern observed in the symptomatic subjects could, on the one hand be an inherent difference within these individuals, or it could occur as a response to stress and psychosocial factors with resultant pain. On the other hand it could represent an adaptive response to a chronic pain disorder. Another possibility is that the muscle activity patterns in the Case subjects may be related to altered kinematics or posture, leading to an altered motor response (the kinematic data will be reported in Chapter 6). Further research is needed to thoroughly investigate these inter-relating factors.

4.4.3.3 *Neurophysiological mechanisms of sensitization*

It is not known how and why only some individuals would develop this altered muscle recruitment pattern and others do not. We would postulate that some individuals may have gradually developed this hyperactivity in the upper trapezius during their daily computer work, and the long-term constant afferent bombardment of the sustained hyperactivity may have triggered some physiological changes in either the peripheral nociceptors or central nociceptive processing pathways (Graven-Nielsen & Mense, 2001; Johansson & Sojka, 1991; Sheather-Reid & Cohen, 1998).

Neurophysiological processes of sensitization may have occurred in these nociceptive apparatus resulting in heightened responses (or lowered thresholds) in already symptomatic individuals. These mechanisms may have a crucial role in the etiology of work-related musculoskeletal disorders.

In addition, psychosocial studies have demonstrated that pain sensations are affected by the affective and psychological status of the individual (Linton, 2000; Waersted, 2000; Zusman, 2002). Other cognitive components such as attention and motivation may also have a role in the magnification and maintenance of clinical symptoms (Roe et al., 2001; Waersted, 2000; Zusman, 2002). Other individual factors such as age, past experience and past health may also be important influencing factors (Jensen et al., 1993a; Linton, 2000). The model proposed by Moon and Sauter (1996) highlighted the influences of the psychosocial and cognitive components on the physical responses of the individuals performing office work, resulting in musculoskeletal outcomes.

4.4.4 Limitations of study

4.4.4.1 *Low statistical power or lack of significant difference may not mean no difference*

Mathiassen et al. (2002) addressed the problem of low statistical power in EMG studies that examined APDF parameters in multiple muscles. They pointed out that many ergonomic intervention studies failed to produce statistically significant results, partly due to the large number of dependent variables and large variances inherent to EMG measurements, leading to low statistical power. From Fig. 4.2 it can be seen that there were large variances in the EMG amplitudes especially in the Case Group in the CES, UT and LT muscles; which are quite typical in surface EMG studies. Westgaard et al. (2001) also suggested that the negative findings in the field studies might be due to a low sensitivity in the recording and analysis of EMG recordings from the field measurements.

Some of our results especially in the group comparisons of muscle activities may have suffered from this problem of low statistical power; although our sample size of 23 Case subjects and 20 Control subjects is probably one of the largest case-control quasi-experimental studies conducted on computer workers or any light sedentary occupational groups. In order to detect a 20% difference in the group effect for the UT and CES 50^{th}%APDF, the necessary numbers of subjects would be 90 and 152 per group respectively ($p \leq .05$, power=0.8) (Borenstein et al., 1997). Similar numbers in sample sizes were also suggested by Mathiassen et al. (2002), in his paper addressing this issue of low statistical power in ergonomic EMG studies.

4.4.4.2 *Other potential EMG variables that can be examined*

The present paper has concentrated on the amplitude analysis of the EMG data. There may be fatigue mechanisms involved in the stabilizing muscles with prolonged activation but this would have to be examined through power spectrum analysis. Other measures such as exposure variance analysis (EVA) (Mathiassen & Winkel, 1991) and the study of EMG gaps (Veiersted et al., 1993) may also reveal important differences between the two subject groups.

4.5 CONCLUSION

The present results have demonstrated important differences in muscle recruitment patterns between symptomatic and asymptomatic female office workers. The CES muscle demonstrated a significant side effect and a significant time effect; while the UT muscle showed a significant side effect and a significant side by group interaction. Those with more severe symptoms (the High Group) had significantly increased activity in the right UT muscle as well as significantly increased UT/CES amplitude ratio on the right. The altered muscle activity patterns in the Case subjects suggested that altered motor control was an important mechanism associated with the development of WRNULD.

The present results with widespread area of discomforts and distinctly different muscle activity patterns in the Case Group subjects with high discomfort did not support the muscle-pain model or the vicious cycle model, and instead they support the Altered Motor Control Model. The results suggested that tissues other than muscles, such as the articular structures in the cervical spine, may also be a likely source of pain in the symptomatic subjects, due to the asymmetrical compressive forces resulting from high activities in the right UT. How these various intrinsic mechanisms operate, either peripherally or centrally, may be the key as to why certain individuals developed musculoskeletal discomforts and others did not. It is also possible that the different sub-groups (High and Low Groups) may have different etiology or pathological changes in their past experiences of musculoskeletal discomforts.

The Altered Motor Control Model may be a useful conceptual framework for explaining the etiology of WRNULD, and there may be multiple factors contributing to the altered motor control mechanisms. Future studies may aim at investigating the individual contributing factors, or designing interventions that can alter the muscle activation patterns in these symptomatic subjects and examine the effects on their work-related discomforts.

CHAPTER 5

STUDY 2 PAPER 2

EMG Median Frequency Changes In The Neck-Shoulder Stabilizers Of Symptomatic Office Workers Performing Monotonous Computer Work

This chapter is the second paper on Study 2 and it reports on the results of the EMG analysis in the frequency domain. Changes in the EMG median frequencies (MF) have been considered to be an indicator of muscle fatigue in past research. This paper reviews the relevant literature about EMG frequency studies and compares these findings with the present results.

The results did not show any significant decline in MF which was usually considered to indicate muscle fatigue. There were trends of up and down changes over time observed on the group mean graphs, suggesting that there were complex patterns of MF changes in the different muscles on both sides, and these patterns were different between groups. When the overall group means of MF were compared, the Case Group consistently showed a trend for higher MF than the Control Group. The physiological mechanisms that may be involved are discussed here in this chapter.

5. 1 INTRODUCTION

5.1.1 Work-related neck and upper limb disorders in computer users – the problem of prolonged static posture

Work-related neck and upper limb disorders (WRNULD) are common problems among office workers especially in relation to prolonged computer use (Bernard et al., 1994; Hagberg & Wegman, 1987; Siu & Chan, 1998; Tittiranonda et al., 1999). This problem is on a rising trend, and the neck and shoulder regions are the areas with the highest rates of discomforts. One of the major physical risk factors associated with WRNULD in computer users is thought to be the static posture held in the neck-shoulder region (Aaras et al., 1997; Bergqvist et al., 1995; Tittiranonda et al., 1999).

5.1.2 WRNULD in computer users associated with EMG changes

Static posture due to long hours of computer work has been associated with sustained low-level muscle activities in the neck-shoulder stabilizers (Hagg & Astrom, 1997; Kleine et al., 1999). The sustained muscle activities may put the muscles under considerable strain and this may be an important factor in the development of WRNULD.

EMG has been characterized by amplitude domain variables such as Amplitude Probability Distribution Function (APDF), and the temporal pattern of amplitude changes in terms of EMG gaps (Veiersted et al., 1993) or Exposure Variance Analysis

(EVA) (Mathiassen & Winkel, 1991). EMG changes in terms of increased amplitudes, decreased EMG gaps or decreased variances have been interpreted as signs of increased biomechanical and/or physiological loading resulting in increased risk for developing WRNULD (Hagg & Astrom, 1997; Kleine et al., 1999; Nordander et al., 2000).

In Chapter 4 we have reported the effects of performing a one-hour continuous typing task on the neck-shoulder muscle activity patterns, mainly in terms of the 50th% APDF which was an indicator of the median level of muscle activity. It was found that different subject groups had different muscle activity patterns and these were related to the discomforts experienced.

5.1.3 Differences demonstrated in EMG studies between symptomatic and asymptomatic persons

Many of the past studies have examined muscle activity changes in normal painfree subjects when they performed computer tasks at work (Aaras et al, 1997; Bansevicius et al, 1997; Kleine et al, 1999). Studying muscle activities in normal healthy subjects may not be the most appropriate way to examine the effects of different physical risk factors in causing WRNULD. Different persons may react differently to physical stressors. It is generally agreed that the etiology of WRNULD is multifactorial, and the interactions of intrinsic and extrinsic factors may simultaneously operate within each person (Kumar, 2001; Westgaard et al., 2001; Sjogaard et al., 2000). It may be the different interactions of these factors that caused symptomatic persons to have adverse reactions when exposed to certain physical stressors while asymptomatic persons were somehow able to cope.

In Chapter 4 we have compared the muscle activity patterns between symptomatic and asymptomatic office workers. It was found that the symptomatic subjects with a chronic and present history of neck-shoulder discomforts, tended to have higher activities in the upper trapezius (UT) muscle especially on the right side. In contrast, the asymptomatic subjects with no past or present discomforts, showed higher activities in the right cervical erector spinae (CES) muscles, while the other muscles (upper trapezius, lower trapezius and anterior deltoid) were more evenly loaded bilaterally.

Other studies that have reported symptomatic-asymptomatic muscle activity differences in computer workers, mainly examined changes in the EMG gaps and EVA (Hagg & Astrom, 1997; Jensen et al., 1993a; Nordander et al, 2000; Takala & Viikari-Juntura, 1991; Westgaard et al, 2001). Hagg and Astrom (1997) reported fewer EMG gaps and a more monotonous load pattern in a group of medical secretaries with complaints compared to a control group. Studies that have reported fewer EMG gaps in painful subjects interpreted this as a sign of the muscle's inability to relax (Hagg & Astrom, 1997; Westgaard et al., 2001).

Besides the associations with increased EMG amplitudes and decreased gaps, musculoskeletal pain has been linked with muscle fatigue which has often been explored in terms of frequency changes in EMG (Basmajian & De Luca, 1985; Westgaard et al., 1996). If fatigue is demonstrated in the stabilizing muscles during occupational tasks, it may imply that the muscles are under more strain thus resulting in pain or injury.

5.1.4 EMG changes in frequency domain – an indicator of muscle fatigue

5.1.4.1 *Definitions of frequency changes in power spectrum: mean power frequency vs median power frequency*

In EMG studies, shifts in the power spectrum are often taken as indications of muscle fatigue (Basmajian & De Luca, 1985). The surface EMG power spectrum represents the summary of all the firing frequencies of all the motor unit action potentials that are recorded at the EMG sensor (Hagg, 1992). Mean power frequency (MPF) and median frequency (MF) are two of the most commonly used single indexes of the power spectral alterations. The MPF is defined according to the standard definition of a mean in statistics, on the basis of a continuous distribution, in this case the power spectrum (Hagg & Kädefors, 1996). The MF is defined as the frequency that divides the power spectrum into two parts with equal areas. A third method is counting the number of zero crossings of the surface EMG signal per time unit (Hagg, 1992). These three indexes are often referred to as "muscle fatigue indexes".

Comparing the three indexes, MF is considered more sensitive to changes in the low-frequency band (20-40Hz) of the power spectrum, which is affected by synchronization and changes in firing patterns induced by muscle fatigue (Hagg, 1992; Stulen & De Luca, 1981). Given the typically negatively skewed nature of the power spectrum, MF may be a more appropriate measure of central tendency.

5.1.4.2 *Physiological phenomena that affect the fatigue indexes*

The frequency changes in surface EMG are affected by a number of physiological factors concerning the morphological and electrophysiological properties of the motor unit (Basmajian & De Luca, 1985; Enoka & Fuglevand, 2000; Hagg, 1992). These include the action potential conduction velocities, motor unit recruitment orders, fibre type distribution (type I and II), tissue temperature, the muscle length, and the nature/level/duration of muscle force produced (Enoka & Fuglevand, 2000; Hagg, 1992; Hagg & Kadefors, 1996; Larsson et al., 2000).

Whilst shifts of the muscle fatigue indexes to lower frequencies have been mainly attributed to a slowing of action potential conduction velocities and changes of firing patterns (from type II to type I fibres), a complex interaction of factors may occur (Edwards, 1988; Hagg, 1992).

5.1.4.3 *EMG frequency changes are related to morphological changes in pathological muscles*

Larsson and associates (1999 & 2000) conducted a series of studies investigating the morphological changes in the trapezius muscles with chronic myalgia and the correlations of these changes with EMG measures. They explored the morphological and metabolic changes in the muscles comparing symptomatic persons with control subjects in the same occupations – mainly female cleaners and teachers. They reported that a decrease in the cross-sectional area of type II fibres and the prevalence of ragged-red fibres were correlated with changes in mean frequencies (Larsson et al., 1999 & 2000). Ragged red fibres (type I fibres with damaged mitochondria) were found in pathological muscles and were considered a sign of insufficiency or depletion of energy supply (Larsson et al., 2000; Lindman et al., 1991).

5.1.5 Methods of measuring frequency changes

5.1.5.1 *Physiological research on muscle fatigue*

Laboratory research has examined EMG frequency changes in various upper and lower limb muscles during the performance of different types of contractions (*isometric /isokinetic*: Gerdle, Wretling, & Henriksson-Larsen, 1988; *static/dynamic*: Gerdle & Elert, 1994; Graven-Nielsen et al., 1997b), comparing different loads or contraction forces (Gerdle, Henriksson-Larsen, Lorentzon, & Wretling, 1991; Mannion & Dolan, 1996; Roy & De Luca, 1996), different number of repetitions (*endurance testing*: Gerdle & Elert, 1994; Gerdle & Fugl-Meyer, 1992), and effects of different joint positions (Hagberg, 1981; Herberts et al., 1979). These studies have provided useful information about the many physiological characteristics that influence the EMG power spectrum.

Unfortunately these studies have used different testing methods on different muscles with different fibre type compositions, which made synthesis of findings difficult. Some studies have examined the power spectral changes during reference contractions (usually maximally-resisted contractions) before and after performing certain fatiguing tasks (Christensen, 1986), while others have measured power spectrum during the actual task contractions (Gerdle & Fugl-Meyer, 1992; Gerdle & Elert, 1994; Hansson et al., 1992; Madeleine et al., 1999).

Only a few occupational studies have examined changes in muscle fatigue indexes during work tasks. The results have not been conclusive as there are large variations in methods of EMG measurement and normalization, as well as the method to record EMG in work tasks.

Herberts et al. (1979) and Hagberg (1981) studied the effects of elevated arm positions on localized muscle fatigue in the shoulder muscles in a number of different work environments, and reported downward shifts of power spectrum in more elevated arm positions. Christensen (1986) studied the changes in MPF in the upper trapezius, deltoid and infraspinatus muscles in seven manual workers across a whole working day. Power spectrum analyses were done on resisted isometric reference contractions of these muscles, and not during the work tasks. The author reported a shift (lowering) of the MPF in the trapezius from morning to afternoon, and this was interpreted as a sign of muscle fatigue.

Madeleine et al. (1999) studied the meat-cutting task in workers with clinical neck-shoulder pain, as well as during experimental pain induced by intramuscular injections of hypertonic saline into the trapezius muscle of control subjects. They reported significant differences in the MPF, both in subjects with clinical pain as well as those with experimental pain; but there was no downward shift of MPF with time. The authors suggested that the mechanism contributing to shifts towards higher frequencies may involve additional recruitment of motor units with higher conduction velocities. Hansson et al.(1992) reported no significant change in MPF of trapezius during an endurance test of isometric shoulder abduction at 90° in female industrial workers, and this finding was similar in a symptomatic group with "tension neck" compared to an asymptomatic group. Larsson et al. (1999) also reported no change in MPF in patients with chronic trapezius myalgia but the MPF were measured during a series of low-load repetitive shoulder elevation tasks. The approach of measuring fatigue index during the performance of repeated anatomical movements (such as shoulder elevation or abduction) may not produce the same responses in muscles as during the performance of actual occupational tasks. There may be more meaningful results if actual occupational tasks were examined in EMG studies on muscle fatigue.

The discrepant results produced in past studies have not shown consistent evidence to demonstrate clearly the physiological mechanisms affecting EMG frequencies that may be involved in musculoskeletal pain. Part of the confusion may be due to the different methods used, as well as the compound interactions of multiple factors affecting the power spectrum simultaneously.

5.1.5.2. *Fatigue studies in clinical research*

Clinical studies on low back pain (LBP) and other painful conditions have contributed to the body of knowledge on fatigue responses in muscles measured with surface EMG. Shifts in MF of muscles before and after fatiguing contractions have been used to differentiate LBP patients from control subjects (Biedermann et al., 1991; Roy et al., 1989). Shifts towards lower MF were found to be associated with increased amplitudes in EMG signals (Roy & De Luca, 1996). Studies have shown from MF measurements in back muscles that the responses of MF may vary between muscles and between different loads (De Luca, Roy, & Erim, 1993; Roy et al., 1989).

However, most of these studies on fatigue index changes have been performed on

LBP patients, and the findings may not be completely applicable to the neck-shoulder stabilizers; as different muscles have different fibre type compositions and different power spectral properties. The evidence on MF changes in the neck-shoulder region has mainly come from studies examining the performance of static or dynamic shoulder movements (Christensen, 1986; Hagberg, 1981; Herberts et al., 1979; Kuorinka, 1988) or from studies on "fibromyalgia" or "chronic trapezius myalgia" patients (Elert et al., 1992; Larsson et al., 1999 & 2000; Lindman et al., 1991). While there are some similarities of these types of muscular disorders with WRNULDs in terms of the cumulative and chronic nature of the discomforts, there are also some important differences between the different conditions. Hence the results may not be completely generalizable from these studies in terms of pathological changes in work-related musculoskeletal disorders.

5.1.6 Aim of study

Most of the previous studies have examined muscle fatigue through measuring power spectral changes during reference contractions which are usually anatomical movements (for example, during an isometric shoulder abduction against gravity, or performing active shoulder abduction through range repeatedly). In occupational studies, it becomes a dilemma – should the worker interrupt his work in order to perform such contractions for measuring muscle fatigue? The performance of these extra contractions may add to the workload of the subjects and possibly contribute to muscle fatigue. Furthermore, physiological movements in the pure anatomical planes cannot completely simulate the functional movements performed during work tasks. In addition, symptomatic persons may show different responses between the performance of reference (maximally resisted) contractions and the performance of work-task activities. Based on these considerations, it was more appropriate for our purposes to examine muscle fatigue indexes during work-task activities, since our focus was on comparing symptomatic-asymptomatic differences during these activities.

While Madelaine et al. (1999) reported EMG frequency differences between symptomatic and asymptomatic persons, the meat-cutting tasks they studied involved more dynamic arm motions with more force, and the tasks were only studied for less than 10 minutes in total. In contrast, computer tasks performed by office workers usually involved more static postures held for long durations (4-8 hours per day). It is not known whether muscle fatigue would be an important factor in performing such static contractions with low-force over long periods.

Thus the aim of the present study was to examine the EMG differences between symptomatic and asymptomatic office workers in performing a one-hour continuous typing task under similar circumstances. This particular paper will focus on the results of the EMG power spectral analysis, while EMG amplitude variables have been addressed in Chapter 4.

5. 2 METHOD

5.2.1 Research design

The present research employed a case-control quasi-experimental design where subjects were divided into Case and Control Groups based on their past and present discomfort profiles. Each subject worked for one hour at a standard screen-based typing task in an adjustable workstation, and muscle activity, discomfort and posture were assessed (reported in Chapter 4). The experimental procedures for each subject were completed in a single day. The study was approved by the Human Research Ethics Committee of Curtin University of Technology.

5.2.2 Subjects

The subjects were female office workers aged between 20-50, with a mean (SD) age of 33.8(±6.35). 23 subjects in the Case Group and 20 subjects in the Control Group successfully completed all the experimental procedures. The procedures for recruiting subjects and the assignment into Case and Control groups were described in Chapter 4. In brief, Case subjects were defined as those with current discomforts of more than 2/10 on a numerical scale of 0-10 as well as a past history of more than 3 months' discomforts in the neck and shoulder areas. Control subjects had no current discomfort in the last 7 days, and only minimal or no past discomforts in the same areas. Other than a significant difference in their mean age of about 5 years, the subjects were reasonably matched in terms of their physical build, their work background and their experiences with computers (see Table 5.1).

Table 5.1: Subject data of Case and Control Groups

Subject Data	Case Group n=23	Control Group n=20
Age (years): mean (SD; range)	36.0 (4.6; 29 – 46)	31.3 (7.2; 21 – 48)
Working Hours/Week: mean (SD; range)	42.5 (7.0; 20 – 60)	43.0 (4.1; 30 – 48)
Computer Use (hours/day): mode (range)	4-6 (2-4 - >8)	2-4; 4-6* (2-4 - >8)
Mouse-use (hours/day): mode (range)	2-4 (0-2 – 4-6)	0-2 (0-2 – 6-8)
Keyboard-use (hours/day): mode (range)	2-4 (2-4 – >8)	4-6 (0-2 – 6-8)

* 2 modes

5.2.3 Variables

The independent variables were *group* (Case versus Control), *side* (left versus right) and *time* (5 repeated trials during 1-hour typing task). The dependent variables were the MF in the muscle electrical activity power spectrum from eight muscles. The muscles studied were: the left and right cervical erector spinae (CES), upper trapezii (UT), lower trapezii (LT) and anterior deltoids (AD). Neck-shoulder kinematics was also recorded and is reported in Chapter 6.

5.2.4 Muscle electrical activity

The method of applying electrodes and recording procedures of muscle electrical activity were reported in Chapter 4. In brief, bipolar Ag-AgCl surface electrodes 15mm in diameter were placed on the eight muscles, with a 20mm inter-electrode distance (center to center). The skin was abraded, cleansed with 2% alcohol and shaved if necessary before placing the electrodes. The Noraxon Telemyo System (Noraxon, U.S.A. Inc., U.S.A.) was used to capture the EMG signals. EMG data were sampled at 1920Hz from the eight muscles for a 60-second period for each of the five trials (at the 5th, 20th, 35th, 50th and 60th minutes) during the 1-hour typing session. Immediately after each EMG (and posture) data capture, the subject was also asked to rate her subjective discomfort in the bilateral upper body regions (neck, upper back, shoulders, elbows, wrists/hands) on a scale of 0 to 10.

All the EMG signals were processed in a specially designed Labview (National Instruments^{TM}, Austin, U.S.A) program with a high-pass filter at 20Hz, a low pass filter at 200Hz and notch filters at 50Hz and 60Hz to reduce the noise levels. In some of the testing sessions, some non-biological interfering frequencies were also recorded, which showed up as second-wave harmonics in the power spectrum. These signals were discarded and replaced with data from adjacent recording trials.

5.2.5 Controlled variables

The same computer workstation with adjustable chair height and keyboard height was used by all the subjects. The arrangement of the workstation was standard with a height-adjustable chair and an adjustable keyboard tray. The subject was instructed to adjust the chair height, keyboard height and monitor height until she assumed a comfortable and reasonably erect posture. A standardized typing package, TypingMaster (Aquarian Technologies, Maldon, Australia) software was used to display children's stories on-screen for the subject to perform the copy-typing task.

5.2.6 Data analysis

The MF of the eight muscles during the 5 repeated trials of data collection in the one-hour typing task were compared between the two groups. A mixed model (between-subject *group* factor, within-subject *side* and *time* factors) MANOVA of the median frequencies of all the muscles was performed. Univariate analysis with the same factors for each muscle followed. The discomfort and EMG amplitude data were reported in Chapter 4 and kinematics data were reported in Chapter 6.

5.3 RESULTS

5.3.1 Median frequency results

Fig. 5.1 shows the overall means of the MF of the eight muscles in the Case and Control Groups. It can be observed from the graph that the Case Group appeared to have consistently higher MF values than the Control group, especially for CES, UT and LT. A group difference was not obvious for AD in both left and right sides. The mean values for MF in the Case Group ranged from 55.6 - 67.0Hz, and in the Control Group, 51.9 - 62.5Hz. Both groups showed large standard deviations for the mean MF of each muscle in 5 trials, ranging from 7.0 to 12.5. There was no observable difference between sides for CES, UT and LT in the group means, but there appeared to be a small difference between left and right AD, and this difference was apparent in both groups.

Fig. 5.2 shows the means of the MF over 5 trials in the one-hour typing task for the two subject groups. The trend for apparently higher MF in Cases was again evident. Also apparent was that left and right sides of CES, UT and LT were fairly similar for Controls but the MF for Cases appeared more asymmetrical. The left side appeared higher for CES and LT in Cases and the right side appeared higher for UT and AD. Side differences tended to decrease over time for CES and LT in Cases but increased over time for LT in Controls. UT appeared to show opposite trends between sides in both groups, but the gaps between sides appeared larger in Cases. The differences between sides also appeared larger in AD of Cases than Controls.

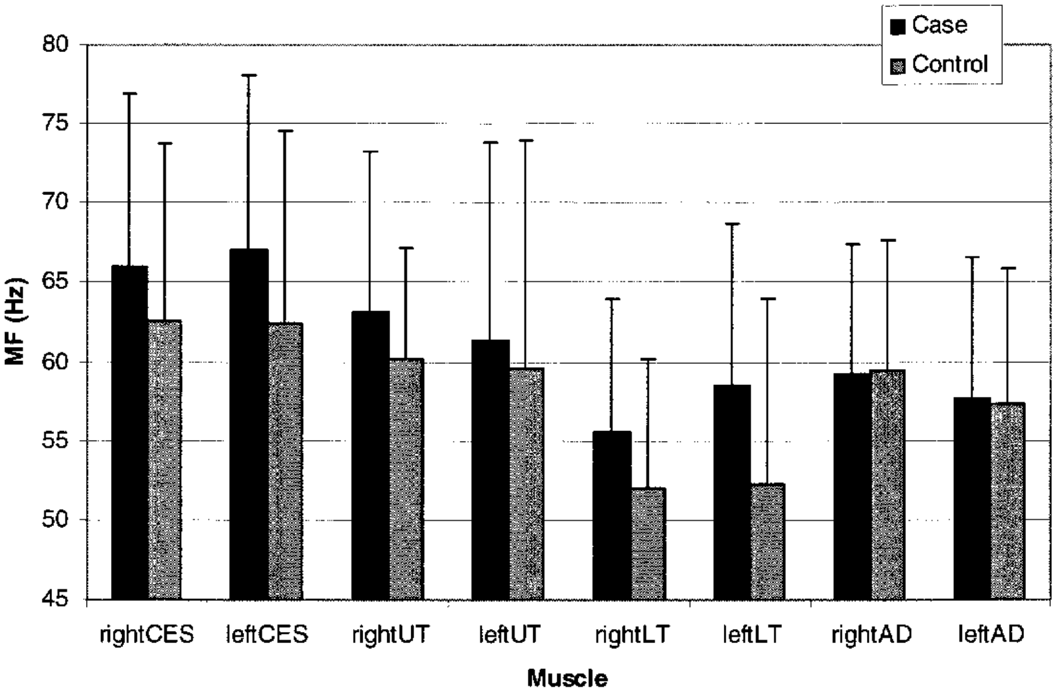


Fig. 5.1: Means (±SD) of median frequencies (MF) of 8 muscles comparing Case and Control Groups

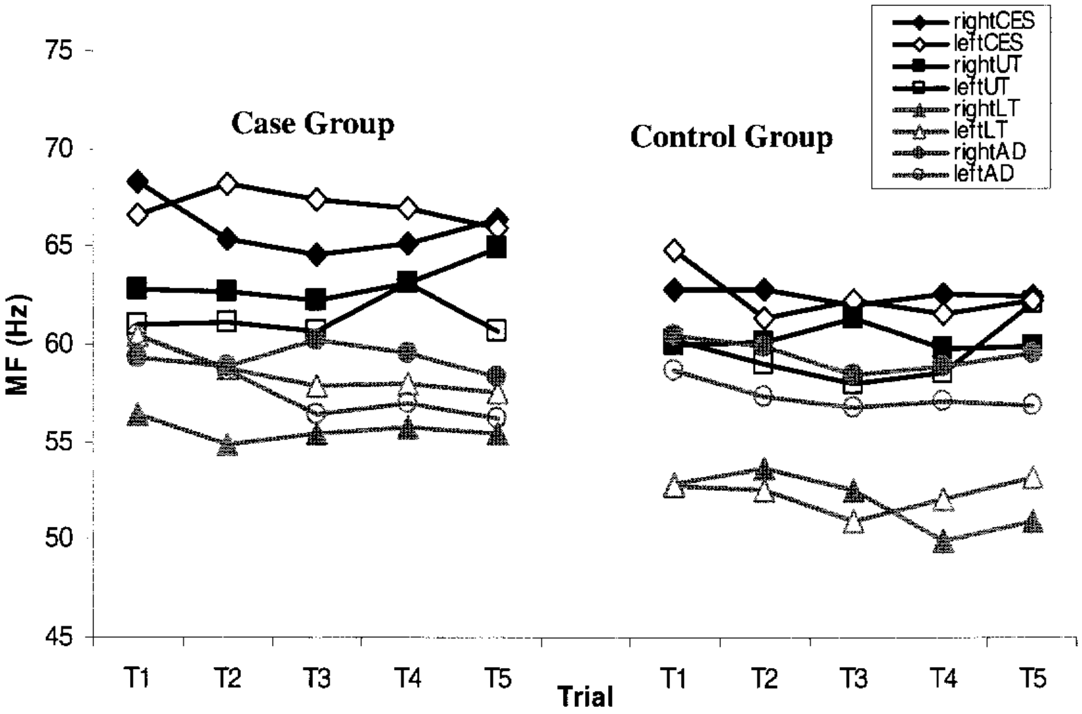


Fig. 5.2: Group means of MF for 5 trials in Case and Control Groups

A mixed model (between subjects *group* factor, within subjects *side* and *time* factors) MANOVA was performed on the MF variables of the four muscles. In the multivariate analysis, the main effect of *group* was approaching significance ($F_{4,38} = 2.27$, $p = .080$). The factor of *time* was even more close to reaching significance ($F_{16,26} = 2.03$, $p = .053$). The *side* factor was not significant as a main effect ($F_{4,38} = 1.73$, $p = .163$), and all the 2-way and 3-way interactions were also non-significant. These results suggested that there were trends for *time* differences in MF as a slight downward shift in some muscles as observable in Fig. 5.2 but these were not statistically significant. There were also trends for *group* differences apparent in Fig. 5.2 contributing to the main effect of *group* approaching statistical significance.

In the univariate analysis for the MF, the main effect of *group* was not significant for CES ($F_{1,41} = 0.33$, $p = .570$), UT ($F_{1,41} = 2.09$, $p = .156$) and AD ($F_{1,41} = 0.03$, $p = .863$), but it was significant for LT ($F_{1,41} = 8.47$, $p = .006$). The lack of significance for the *group* factor may be partly attributed to the large SD in the data. The *time* factor was not significant for all eight muscles ($F_{4,164} = 1.30\text{-}1.71$, $p = .150$ - $.274$). These results suggested that generally there was no demonstrable effect between the two groups except for the MF of LT; and there was no significant change in MF due to time-at-task. The *side* factor was not significant for CES ($F_{1,41} = 0.18$, $p = .674$), UT ($F_{1,41} = 2.86$, $p = .099$) and LT ($F_{1,41} = 0.09$, $p = .765$), but it was significant for AD ($F_{1,41} = 4.27$, $p = .045$). Again the 2-way interactions of *time* x *group*, *side* x *group* and *time* x *side* did not show statistical significance.

However, the 3-way interaction of *time* x *side* x *group* was significant for CES ($F_{4,164} = 2.54$, $p = .042$), UT ($F_{4,164} = 2.73$, $p = .031$) and LT ($F_{4,164} = 2.46$, $p = .048$), but not for AD ($F_{4,164} = 1.50$, $p = .203$). This confirms the apparent differences observed in Fig.

5.1 and 5.2, with the left side in Cases tending to be greater than the left side in Controls for CES and LT; and *side* differences decreased over *time* for Cases but not for Controls. In contrast, UT had greater *side* differences over *time* in Cases compared to Controls.

5.4 DISCUSSION

5.4.1 Time effects on MF

The present results have not demonstrated any trend for downward shifts of the MF with time that is the commonly accepted sign of muscle fatigue. Observing from Fig. 5.2, some of the muscles such as the right CES and the left AD muscles appeared to have a downward trend in the Case Group but only in the first half of the one-hour typing trial. Then the MF appeared to level off again towards the end of the typing trial. This may indicate that either the muscles did not experience any fatigue, or that the fatigue response was being affected by a number of factors causing no overall change in the fatigue index.

Increased recruitment of Type II fibres and the recruitment of additional Type I motor units with higher conduction velocities may counteract the downward shifting in the fatigue index (Hagg, 1992; Hagg & Kadefors, 1996). This was supported by the EMG amplitude results found in the present study (Chapter 4), with the right UT muscles sustaining moderately high amplitudes in the Case Group throughout the typing trial. This may possibly suggest additional recruitment of motor units at higher thresholds to maintain the muscle force levels. The complex interactions of various neural events may result in no or minimal change in the muscle fatigue indexes, despite demonstrable fatigue (Hagg & Kadefors, 1996).

5.4.2 Group, time and side interaction effects on MF

Although the 3-way interaction of *group*, *side* and *time* was not significant in the multivariate analysis, this interaction was significant in the univariate analysis for the CES, UT and LT muscles. This finding may provide evidence to support the complex interactions of various motor control processes affecting the power spectrum. It implied that these three muscles had different patterns of MF changes between left and right sides as the typing trial progressed with time, and these patterns were different between the two groups. The results supported the multifactorial relationship between the MF changes in muscle activities in response to the prolonged work duration, and the intrinsic motor control differences within individuals. The complex interactions of various motor control processes may have an important role to play in the development of musculoskeletal discomfort.

5.4.3 Trend for higher MF in Case Group

Although the statistical analysis did not show any significant main effect for the group factor, except for the LT muscle, there were trends for consistent differences observable in the group means graphs (Fig. 5.1 and 5.2). There were trends for consistently higher mean MF in all muscles in the Case Group compared to the Control Group on the graphs. Similar observations have been reported by Madelaine et al. (1999) and Larsson et al. (2000).

Madelaine et al. (1999) reported significantly higher MPF of the upper trapezius and the infraspinatus muscles in the clinical pain group compared to controls. This was also the case in the experimental pain subjects both before and after the onset of pain.

Larsson et al. (2000) reported significantly higher EMG amplitudes in terms of the signal-amplitude ratio in the painful subjects, and this was interpreted as an indication of increased recruitment of type I muscle fibres. Their study also found higher initial values of MPF in the same muscles. The results of these two studies were similar to our results.

In another study, Larsson et al. (1999) reported that significantly *lower* MPF in the patient group compared to the control group. However, in that study MPF was measured during physiological arm movements in various degrees of shoulder abduction while lifting small weights. Many of the painful subjects in that study had either serious cervical trauma, or had received disability compensations. The Case subjects in our present study were all full-time workers and their conditions were less severe. The differences in research design and the subject characteristics may have accounted for the differences in results between studies. Nevertheless, both studies have revealed interesting responses of symptomatic individuals, when their symptoms were of different natures and severities.

Other studies have also reported that muscles with high percentages of type II fibres had a correspondingly higher initial value and rate of decrease of MF, compared to muscles with relatively lower percentages of type II fibres (Gerdle et al., 1991; Hakkinen & Komi, 1986; Kupa, Roy, Kandarian, & De Luca, 1995). In the present study, the higher mean values of MF in the Case Group was likely to reflect a higher initial value of MF, and since the decline in MF across the typing trial was not marked, this difference was maintained in the overall means.

Ergonomic studies have compared spectral changes in EMG on a within-subject basis, but mostly on healthy painfree subjects and on industrial workers (Christiansen, 1986). Very few occupational studies have compared muscle fatigue indexes in a case-control comparison (Hansson et al., 1992; Madeleine et al., 1999). Our study therefore provides unique information on frequency differences between symptomatic and asymptomatic persons during the sustained contractions in performing computer tasks. Such a study can examine intrinsic differences between the two groups of individuals, when the extrinsic physical conditions and tasks are standardized.

5.4.4 Differences in MF of the 4 muscles

The complex interactions of various intrinsic factors may be the cause of different responses in different muscles, as reflected in the group means graphs. The present results with MF of various muscles going in different upward and downward trends may suggest that the muscles were changing their motor unit recruitment patterns and action potential conduction velocities, in order to cope with the sustained typing task.

The four muscles studied have different roles in postural stabilization, and this may have been reflected in their muscle activity patterns and their power spectra. The CES, UT and LT muscles had a more static type of muscle activities, while the anterior deltoid (AD) acted both as a static stabilizer and a dynamic mover of the shoulder joint into forward flexion in the typing motion. From the EMG recordings, it was observed that the AD typically had a more burst-like activity in addition to a background of static level of EMG.

It is likely that these muscles have different fibre type compositions with different fatiguability (Hagg, 1992; Lindman et al., 1991). Postural muscles like the UT muscle have been shown to have a particularly high proportion of type I fibres, especially in female patients with chronic trapezius myalgia (Larsson et al., 2000; Lindman et al., 1991). A high proportion of type I fibres was found to be associated with lower shifts of MF and low perception of fatigue (Lundblad, Elert, & Gerdle, 1998). Although the precise proportions of type I and II fibres in the different muscles are not clearly understood yet, it is expected that they would be different among different muscles; and there may also be differences between individuals, affecting their responses in terms of muscle activity patterns and fatiguability.

5.4.5 MF and discomforts in Case and Control Groups

Although the one-hour typing task did not produce significant fatigue responses in the muscles, it was sufficient to produce significant increase in symptoms in the Case Group. As the subjects did experience pain (located beyond the muscles examined) – it appeared that muscle fatigue as determined by MF, was not part of the mechanism for pain. If muscle fatigue was the basis to their pain then it is expected that fatigue would be present and it should increase with time similar to the response of pain.

5.4.5.1 *Comparison of MF in High and Low Groups*

The overall analysis of discomfort scores in the upper body areas (neck, shoulders, upper back, elbows, wrist/hands) showed statistically significant differences between the Case and Control Groups with respect to *group* and *time*. The Case Group had a steadily increasing trend of discomfort scores in the one-hour typing trial, while the Control Group had a very low score (mean<1.0) that did not show much change.

On further analysis, the subjective discomfort scores of the Case Group revealed significant differences between two sub-groups: a "High" Group (n=15) and a "Low" Group (n=8). The groups were identified based on the means of the summed discomfort scores from each of the five trials. The "High" Group was defined by a mean discomfort score >12 (from all areas). In Chapter 4, we reported that there were significant differences in EMG amplitudes between these two sub-groups, mainly in the right UT mean 50th%APDF, as well as the right UT/CES amplitude ratios.

However, for the MF analysis, sub-dividing the Case Group into the High and Low Groups showed no significant differences between the High Group and the Low Group for any of the MF of the 8 muscles. This finding further confirmed that the discomforts of the subjects were more correlated with the EMG amplitudes, rather than the frequency variables.

5.4.6 Physiological mechanisms responsible for symptomatic/asymptomatic differences

5.4.6.1 *Higher MF in Case subjects – suggest increased recruitment of Type II fibres*

The observed trend for higher MF in symptomatic persons may suggest increased recruitment of type II fibres in addition to recruiting type I fibres for this sustained occupational task (Arendt-Nielsen, Mills, & Forster, 1989; Hagg & Kadefors, 1996; Madelaine et al., 1999). In contrast to the asymptomatic persons, it is possible that symptomatic persons may also need to recruit more type II fibres to help out in sharing the load of the postural stabilization task. Type II fibres are more prone to fatigue, and this factor may be related to the development of, or response to, pain in the symptomatic subjects. In terms of histochemical changes, recruitment of type II muscle fibres has been associated with accumulation of acidic by-products such as lactate, potassium and H+ (Basmajian & De Luca, 1985). The accumulation of these substances in the exercised muscle has also been suggested to be related to pain but the research evidence is not clear (Gerdle & Fugl-Meyer, 1992). Further research involving intramuscular EMG is required to clarify this issue.

In the present study, we have also demonstrated that the Case Group had trends for higher amplitudes in the right upper trapezius muscle, suggesting possibly recruitment of both low-threshold and high-threshold Type I motor units in carrying the sustained postural load. However, we cannot determine the exact physiological mechanisms from our study, and more precise evidence needs to come from intramuscular investigations. In the past, most of the motor unit recruitment research related to WRNULD has mainly focused on type I motor unit activities in normal healthy persons (Kadefors et al., 1999; Westgaard & De Luca, 1999). It is possible that in the symptomatic persons, type II motor units are also activated in order to share the load (Kadi et al., 1998). Yet there is a lack of research evidence about type II motor unit activities during computing tasks from intramuscular electrode studies. Further research should pursue the comparison of motor unit activity in symptomatic and asymptomatic persons while performing occupational tasks.

5.4.6.2 *Pain Models*

EMG studies on low back pain patients have proposed that muscle fatigue can be the cause of pain, based on the finding of decline in MF in these patients. In the present study we have found no significant decline in MF in the symptomatic subjects yet their discomfort scores increased significantly with time. This finding would not support the muscle fatigue model as a major factor contributing to the work-related discomforts associated with sustained computer work.

In Chapter 4, we have proposed that an "Altered Motor Control Model" as a potentially useful conceptual framework contributing to the discomforts experienced by the Case subjects, as the symptomatic subjects seemed to have an altered muscle recruitment pattern compared to the asymptomatic controls. The evidence became more apparent comparing the EMG amplitude patterns and the discomfort patterns of the High and Low sub-groups in the Case Group. In view of the bilateral and widespread discomfort patterns and the significant time trend of these discomforts, it appeared likely that there was more than one source of pain. We have proposed that articular structures such as the facet joints in the cervical spine may also be a source of pain due to compressive loading imposed on these structures by the high activity levels in the UT muscle. These findings would also fit in well with the present finding demonstrating no evidence of muscle fatigue in the stabilizing muscles in Case or Control subjects.

5.4.7 Limitations and directions for future studies

This study has mainly examined the frequency changes during the typing task and no significant downward shifts have been found. The lack of change is possibly due to the light nature of the typing task and subjects who were well familiar with this type of work. If the task was sustained for longer periods, there may have been more noticeable changes in muscle fatigue. One possible study would be to ask the subjects to continue typing for indefinite periods until they report subjective perceptions of fatigue, it would be interesting to compare this perception with the physiological signs of local muscle fatigue. However this is unlikely to change the trends for group differences as Case subjects in the current study did experience significant increases in discomfort.

Shifts in fatigue indexes may be more easily detected in the performance of maximal contractions as all motor units would be activated. Thus it may be interesting to compare the power spectral changes in maximal contractions before and after performing a prolonged typing task. We chose to evaluate the EMG of actual working tasks as we considered this more occupationally relevant, however the standardized contraction approach may provide interesting information.

The observed power in the statistical analysis for the main effect of *group* ranged from 0.05 for AD, 0.09 for CES, 0.29 for UT, to 0.81 for LT (LT had a statistically significant *group* effect). The statistical power may possibly be increased by recruiting larger sample sizes; however, due to the large number of variables the sample size would have to be 3-4 times more than the present number (Mathiassen et al., 2002). The present sample size of 23 Cases and 20 Controls is already one of the largest Case-Control studies in related research.

5.5 CONCLUSION

The present study has shown a trend for consistently higher median frequencies of the three stabilizing muscles in the Case Group compared to the Control Group. The results suggested possible complex interactions of the three main factors of *group*, *time* and *side*. Together with the results of higher amplitudes in the right UT muscles of the Case Group (Chapter 4), the evidence from the present study supported the important role of intrinsic mechanisms in terms of altered muscle activation patterns in symptomatic persons compared to asymptomatic controls. The responses observed in symptomatic persons are likely to be both pathogenic as well as adaptive processes associated with the development of WRNULD, and more research is needed to fully understand these intrinsic mechanisms within the individual.

CHAPTER 6

STUDY 2 PAPER 3

A Comparison Of Neck And Shoulder Postures And Movements In Symptomatic And Asymptomatic Office Workers Performing Monotonous Keyboard Work

This chapter is the third paper on Study 2 and it contains the results of the kinematics analysis comparing the Case and Control Groups, when the subjects worked on the one-hour standardized typing task.

The present 3D kinematics analysis showed similar findings to those of the 2D analysis in Study 1. Case Group displayed trends for increased neck flexion angles and greater ranges of movements than the Control Group. There were also subtle differences in the side flexion and rotation angles of the head-neck region between groups. The scapular segment showed no group differences in postures, while the right shoulder had a trend for greater flexion angle in the Case Group.

This chapter links together all the results of Study 2 in terms of kinematics, muscle activity patterns and discomforts. The findings suggest that the Case Group subjects had different kinematics and muscle activity patterns from the Control Group. These alterations in motor control strategies are likely to involve centrally programmed changes and they may have important contributions to the development of WRNULD.

6.1 INTRODUCTION

6.1.1 Prolonged static posture is a risk factor for WRNULD

Work-related neck and upper limb disorders (WRNULD) has been associated with increasing usage of computers, and the long durations of computer work are associated with prolonged periods of holding a static posture (Ariens et al., 2001; Bernard et al., 1994; Tittiranonda et al., 1999). For office workers, the static posture is most pronounced in the neck and shoulder region, resulting in increased forward neck flexion and increased static muscle tension in the region (Ariens et al., 2001; Schuldt et al., 1986; Villanueva et al., 1996). In the field investigation in Study 1, we demonstrated that office workers working with computers had increased forward neck flexion compared to their relaxed sitting postures, and this forward flexion was more pronounced in symptomatic persons (about 13% more neck flexion). The consequence of increased forward neck flexion may imply increased tension in the stabilizing muscles as well as increased compressive forces in the articulations of the cervical spine resulting in higher risk of WRNULD.

Many ergonomic studies have focused on the postural effects of changing parts of the computer workstation such as the display screen height and/or the keyboard height (Aaras et al., 1997; Burgess-Limerick et al., 1999; Liao & Drury, 2000; Villanueva et al., 1996). Most of these studies have been conducted on normal healthy persons without work-related musculoskeletal problems. Posture is often studied together with EMG changes to examine musculoskeletal loading in performing occupational tasks (Aaras et al., 1997; Madeleine et al., 1999; Saito, Miyao, Kondo, Sakakibara, & Toyoshima, 1997).

6.1.2 Methods and instruments used to study computer working postures and movements

Body posture in performing computer work has been commonly studied in the sagittal plane as two-dimensional (2D) static posture or movements. One of the most common methods is by taking photographs of the sagittal profile, sometimes with reflective markers on major bony landmarks (Raine & Twomey, 1997; Straker, Jones, & Miller, 1997). The aim is usually to measure the angles formed by the body segments while the subject is in a working posture. In the upper body, most commonly studied segments are the head-neck, trunk (thorax), arm, forearm and hand segments. Other studies have used video cameras to capture the sagittal profile and digitize reflective marker locations frame by frame (Braun, 1991; Szeto et al., 2002; Villanueva et al., 1996). This method has been used to provide information about the extent and frequency of movements in addition to static posture (Liao & Drury, 2000; Szeto et al., 2002).

Manual goniometers and electrogoniometers have also been used in ergonomic research for studying smaller joints such as the elbow and wrist joints during keyboard use (Ortiz, Marcus, Gerr, Jones, & Cohen, 1997; Smutz, Serina, & Rampel, 1994). For studying the postures in the spine these tools may not be very accurate and tend to be quite intrusive.

More recently three-dimensional (3D) motion analysis systems have been used to analyse motions of body segments in three planes. The advantages and disadvantages of using the different motion analysis systems in ergonomic research have been reviewed by Chaffin et al. (1999) and Li and Buckle (1999). In brief, the advantages of these 3D systems are that they can track the movements of multiple body segments and it can be done simultaneously with EMG capture. In recent years there has been a rising interest to use these systems to examine the biomechanics of upper limb motions during functional and occupational activities (Anglin & Wyss, 2000; Rau et al., 2000).

6.1.3 Evidence for different postures in symptomatic office workers

6.1.3.1 Case-Control studies in office workers

Past studies have mainly compared within subject changes in posture in response to workstation changes. However there is a lack of evidence whether symptomatic and asymptomatic persons have different postures when working with the same workstation setting. In the field investigation in Study 1, we have found consistent differences in the neck and shoulder posture between symptomatic and asymptomatic office workers; but these were based on workers in their own workstations, which can be quite varied. Symptomatic persons were found to have increased forward neck flexion and head tilt angles and greater extents of forward neck movements. These patterns were consistent on repeated measures throughout the day, and were thought to reflect more the subjects' personal habitual movements and postures rather than the influence of their workstations.

Vasseljen and Westgaard (1995 & 1997) compared the postures and muscle activities in 24 matched pairs of office workers in a case-control study using the Physiometer system. Only the upper back and arm postures were reported and there were no significant differences between groups during a 30-min work period. The authors discussed the important correlations of arm elevation postures and upper trapezii activities but the head-neck postures were not studied. While their study provided useful information about symptomatic office workers, the postural and muscle activity analysis may not have covered all the major stabilizing structures in the neck-shoulder region. In addition, there was no clear report of any current discomfort experienced by the subjects during the work posture analysis. These authors have also focused more on the influence of psychosocial and personality variables on muscle activities of the same subject groups (Vasseljen & Westgaard, 1995).

In contrast, Hermans et al. (1998) reported on a small sample of case and control subjects (5 each) in comparing the viewing angle and neck angle together with electrical activities of 4 muscles. Results showed increased neck angles and muscle activities in case subjects performing computer work measured periodically across a working day. If such differences are important in explaining the development of WRNULD, then there is a need to establish these differences much more clearly with symptomatic and asymptomatic office workers performing the same task under the same circumstances.

Other studies that have compared symptomatic and asymptomatic office workers have mainly concentrated on muscle electrical activity (Hagg & Astrom, 1997; Jensen et al., 1993a; Nordander et al., 2000; Roe et al., 2001). Conflicting results have been reported with some studies showing increased amplitudes and decreased EMG gaps in symptomatic groups (Hagg & Astrom, 1997), while others reported no difference in muscle activity levels between groups (Jensen et al., 1993a; Nordander et al.; 2000; Roe et al., 2001). All these studies were cross-sectional in design (except Roe et al., 2001), and it is not known whether there were any group differences in the postures assumed.

6.1.3.2 *Case-Control studies in other occupations*

Madeleine et al. (1999) was one of the few occupational studies that examined working postures and movements in addition to muscle activities comparing between symptomatic and asymptomatic persons. They reported on three-dimensional trunk and upper arm posture and movements, comparing a clinical pain group and a control group, as well as before and after experimental pain, in studying a meat-cutting task. Trends for increased amplitudes of postures and movements in the trunk were reported but head-neck postures were not studied, and the postural differences were not statistically significant. Muscle activities in the major postural stabilizers of the neck and thoracic regions were also increased in the pain groups.

6.1.3.3 *Clinical research – symptomatic-asymptomatic differences noted but not confirmed*

In clinical research, studies have reported significant differences in relaxed or resting head/neck postures (commonly known as the forward head posture) between symptomatic patients and asymptomatic persons (Braun, 1991; Griegel-Morris et al., 1992). However, large variations in posture exist among individuals, and age and gender are important factors to consider (Kebaetse, McClure, & Pratt, 1999; Raine & Twomey, 1997). Greenfield et al. (1995) reported that patients with shoulder overuse injuries had significantly increased forward head posture as well as less scapular abduction (or protraction) than the healthy controls. In Chapter 3, we have also found a strong trend for consistent differences in resting head-neck posture between Case and Control subjects when they were seated at their computer workstations. However, it is not clear whether these postural differences would be maintained during the performance of a sustained computer task.

6.1.4 Researchers question –postures and movements - is it trait or response? Relationship with muscle activities and the role in WRNULD

Researchers have questioned whether posture is an innate characteristic, or is it purely a response to the physical environment (Westgaard, 2000). If it is purely a response to the physical environment, then all persons would have more or less the same posture if working with the same workstation. Our previous field investigation has shown a consistent difference in both the resting and the working posture in the head-neck region between symptomatic and asymptomatic office workers (Chapter 3). These results seemed to suggest that observed differences in individuals' postures may be a "*trait*" rather than a response.

In the present research study we have measured both posture and muscle electrical activity in the neck and shoulder region in symptomatic and asymptomatic office workers in a standardized working environment. Our current study has shown important between-group differences in the muscle activity patterns of the neck and shoulder stabilizers in performing a one-hour non-stop typing task (Chapter 4 and 5). It was found that the Case subjects with a chronic and current history of neck-shoulder discomforts, recorded higher activities in the UT muscle especially on the right side.

In contrast, the Control subjects with no history or present discomforts, showed higher activities in the right CES muscles, while the other muscles (UT, LT and AD) were more evenly loaded.

Our EMG results suggested that there may be motor control differences involving altered muscle recruitment patterns in the symptomatic persons. It was not clear whether these motor control differences in muscle recruitment were related to intrinsic differences in the joint movements and static postures in the neck-shoulder region. EMG measurements can only provide part of the picture of musculoskeletal loading; an evaluation of posture is also needed, as this gives a better idea of stresses on passive connective tissues in the joints.

This paper compares the kinematics in the neck-shoulder region between the symptomatic and asymptomatic groups, in response to the prolonged static posture in performing a one-hour typing task. The relationships between the kinematics of the neck and shoulder segments and the muscle activities in the same region will also be examined.

6.2 METHOD

6.2.1 Research design

The present research employed a Case-Control quasi-experimental design where subjects were divided into Case and Control Groups based on their past and present discomfort profiles. Each subject performed a 1-hour typing task at the same adjustable workstation. Besides the kinematics data, muscle electrical activity and discomfort were assessed and those results were reported in Chapters 4 and 5.

6.2.2 Subjects

Female office workers were recruited in the study and assigned into Case and Control groups. Those subjects with current complaints and a past history of neck and shoulder discomforts of more than 3 out of the past 12 months were assigned into the Case Group (n=23). Other subjects without any current discomfort or past history were grouped as Controls (n=20). Other than a significant difference in their mean age of about 5 years, the subjects were reasonably matched in terms of their physical build, their work background and their experiences with computers. All subjects were experienced touch-typists but they came from a variety of different companies as they were sampled by convenience.

Whilst 23 Case subjects and 20 Control subjects were measured for both EMG and kinematics data during the 1 –hour typing task, due to technical problems with missing markers, kinematic data were only successfully analysed for 21 Case subjects and 17 Control subjects.

6.2.3 Variables

The independent variables were *group* (Case versus Control), and *time* (5 repeated trials during 1-hour typing task). *Side* differences were only assessed for the shoulder joint and scapular segment. The dependent variables consisted of:

1. Head* X (flexion/extension)[a], Head Y (bilateral side flexion)[b] and Head Z (bilateral rotation)[c]
2. Thorax X (flexion/extension)[a], and Thorax Y (bilateral side flexion)[b]
3. Left and right Shoulder X (flexion/extension)[a], and Shoulder Y (abduction/adduction)[d]
4. Left and right Scapula X (flexion/extension)[a], Scapula Y (abduction/adduction)[d], and Scapula Z (medial/lateral rotation)[e]

*In the Vicon biomechanical model, the Head and Neck is considered as one segment.

[a] positive(+ve)=flexion, negative(-ve)=extension, [b]-ve=left side flexion, [c] -ve=right rotation, [d]+ve=abduction, [e] +ve=medial rotation

Movements of the scapula segments were measured in three planes of X, Y and Z with reference to the thorax segment. The X, Y and Z planes represented the anatomical movements of flexion/extension (or elevation/depression), abduction/adduction, and medial/lateral rotation respectively. This is a simplified way to record movements of the scapula which in fact have many subtle axes of rotations.

6.2.4 Procedures for recording kinematics data

The Vicon 370, Version 3.1 (Oxford Metrics, UK), 3-dimensional motion measurement and analysis system was used to record the upper body posture and movements during the one-hour typing task. Six infra-red cameras were used to perform the video capture at a sampling frequency of 60 Hz.

6.2.4.1 *Calibration procedures*

Before the start of the video capture, the Vicon system was calibrated to determine the exact positions and orientation of the cameras with respect to the laboratory ("global coordinate system"). Static and dynamic calibration procedures (using Vicon calibration frame and wand respectively) were carried out to ensure that the "Calibration Residual" values were below 0.1% of the reconstruction volume (Vicon 370 Users' Manual).

6.2.4.2 *Marker placement and body segment definitions*

Reflective markers were placed on the following bony landmarks to define the body segments. Altogether 4 body segments were defined by at least 3 markers in each segment:

1. Head-neck segment - defined by 2 markers at two sides of the forehead (lateral to outer canthus of the eye) and 2 markers at the bilateral mastoid processes,
2. Thorax segment – defined by marker at the top of the sternum just below the suprasternal notch, and markers at the C7 and T8 spinous processes,

3. Upper arm segment – defined by markers at the acromioclavicular joint, at the lateral humeral epicondyle and at the midpoint of the posterior shaft of the humerus between lesser tuberosity and olecranon process,
4. Scapula segment – defined by markers at the acromioclavicular joint, medial end of the spine of scapula, and the area just above the inferior angle of scapula on the posterior scapular fossa.

6.2.4.3 *Video capture during typing trials*

Before the typing task started, a static trial with the subject seated at the adjustable workstation was captured. The subject was instructed to place her hands in the ready-to-type position with the fingers resting lightly on the keyboard. This static trial was used by the Vicon system to construct a reference frame for the kinematics modeling of the upper body and determining the starting 3-D coordinates of the defined body segments. When this was completed, the subject was instructed to start the typing task and synchronized kinematics and EMG signals were captured at the 5th, 20th, 35th, 50th and 60th minutes of the typing task. Each data capture was for a 60-second duration. The subject was asked to rate the discomfort in ten upper body regions (bilateral neck, shoulder, upper back, elbow and wrist/hand) on a scale of 0-10 immediately after each kinematics and EMG data capture.

6.2.5 Controlled variables

The same computer workstation with adjustable chair height and keyboard height was used by all the subjects. The arrangement of the workstation was described in Chapter

4 and depicted in Fig. 4.1. Basically the subject was instructed to adjust the chair height, screen height and keyboard height, until a reasonably erect and comfortable posture was achieved. Arm support was provided by the rounded edge of the adjustable keyboard tray for about 4 cm at the region just proximal to the wrists. A standardized typing package, TypingMaster (Aquarian Technologies, Maldon, Australia) software was used to display children's stories on-screen for the subject to perform copy-typing. The subject was instructed to perform the typing task continuously for one hour.

6.2.6 Data analysis

For each data capture trial, the marker trajectories were reconstructed and processed using the Vicon Bodybuilder (Oxford Metrics, UK) to produce Euler's angles (x,y,z) for the 4 body segments: head-neck, thorax, arm and scapula. The dynamic movement data during the typing trials were referenced to the initial global coordinates in the static trial. The data were exported to a Labview program where angle corrections were computed to produce anatomical angles of the body segments with reference to the vertical. The 10th%, 50th% and 90th% of the amplitude probability distribution function (APDF) were then computed using the corrected angles. The 50th%APDF was used as an indicator of the median angle of each movement in all the analyses. The "range" of movement of the segment was calculated as the difference between the 90th% value and the 10th% value in the APDF data.

A mixed model (between subjects *group* factor, within subjects *time* factor, and for some measures, within subjects *side* factor) MANOVA was performed for the 3 APDF levels of each joint angle of the four body segments as well as the range of each movement. The kinematics variables for the four body segments (head, thorax, upper arm and scapula) were analysed in separate MANOVA's.

6.3 RESULTS

6.3.1 Head/neck postures and movements

From Fig. 6.1 showing the head-neck flexion/extension, side flexion and rotation median angles (postures), it can be seen that the Case Group had apparently greater median angles (50^{th} % APDF) in head flexion and slightly greater ranges of movements in all 3 planes compared to the Control Group. Median angles in side flexion and rotation appeared greater in the Control Group, although the group differences were very small.

All head angles were referenced to the vertical. For comparison, looking straight ahead would be equivalent to about 55 ± 5^0. For head side flexion, positive angles were for left side flexion, while negative angles represented right side flexion. For head rotation, positive angles were right rotation and negative angles were left rotation. Thus the median angles of the two groups from Fig. 6.1 suggested that the Case subjects had a trend to hold their heads in more forward flexion, but the Control subjects showed a trend to hold their heads in slightly more right side flexion and right rotation. Fig. 6.2 shows the means of head flexion angles over 5 trials in the Case and Control Group. This graph demonstrated the group differences that persisted throughout the 5 trials in the typing task.

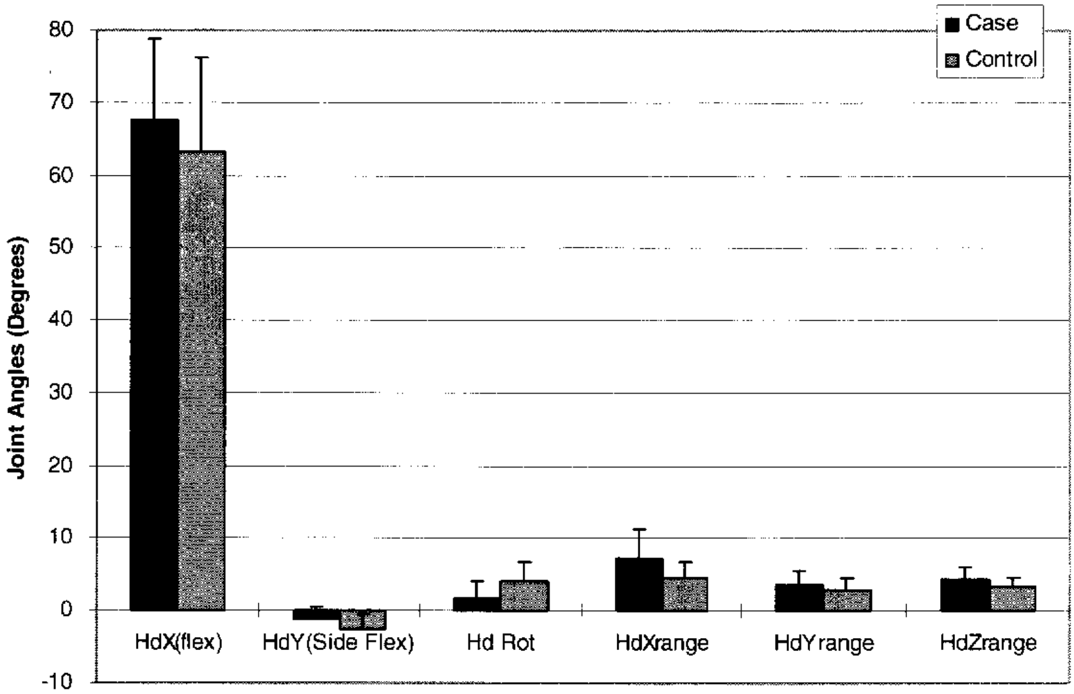


Fig. 6.1: Head median angles (postures) and ranges (± SD) in X,Y,Z planes in Case and Control Groups

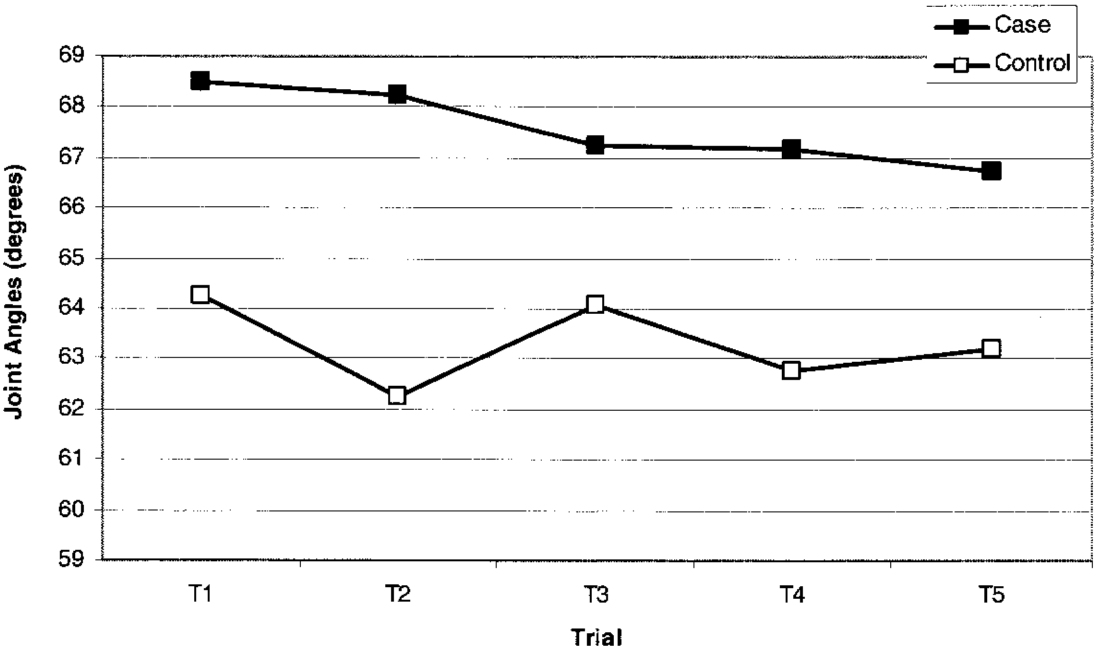


Fig. 6.2: Head flexion angles in 5 trials in Case and Control Groups

A mixed model MANOVA (between subjects *group* factor, within subjects *time* factor) of the joint angle of the Head X,Y, Z, was performed for the 10th%, 50th% and 90th% APDF of each variable as well as the range of each movement. For the median angle (50th%) data, the results of the multivariate analysis showed a significant difference between *groups* ($F_{9,28}$ = 2.62, *p*= .025). The *time* factor was not significant ($F_{36,556}$ = 0.97, *p*= .518), and neither was the *time* x *group* interaction ($F_{36,556}$ = 0.75, *p* = .859).

In the univariate analysis, there was a significant *group* effect for the Head X range ($F_{1,36}$ = 4.74, *p* = .036) as well as for the Head Y and Z median angles (Head Y: $F_{1,36}$ = 5.56, *p*= .024; Head Z: $F_{1,36}$ = 9.47, *p*= .004). There was no significant *group* effect for Head X angles ($F_{1,36}$ = 1.00, *p*= .325).

The results suggested that there were trends for the Case Group to have greater median flexion angle of the head than the Control Group but this difference was not statistically significant. On the other hand, the Case Group also had significantly increased median angles of side flexion and rotation compared to the Control Group, although the difference was only small in absolute numbers. Together these results suggested that there were differences in the 3D orientation of the head-neck region between the Case and Control Groups. The median angles and ranges of head movements were consistent over 5 repeated trials, as demonstrated in Fig. 6.2.

6.3.1.1 *Comparison of head angles between High-Low sub-groups in Case subjects*

When the Case Group subjects were sub-divided into 2 groups according to their discomfort scores (the High Group was defined by a mean discomfort score per trial ≥ 12), there appeared to be a trend for differences in the head flexion angles between the two sub-groups. The mean of the head flexion angles of the High Group showed a difference of about 8° compared to the Low Group, and a 6° difference compared to the Control Group. This difference was also observable on the group mean graph (Fig. 6.1). There were also some differences in side flexion and rotation angles but these were of very small absolute angles.

One-way ANOVA was carried out to compare the differences in head angles among the three groups (High Group, Low Group and Control Group). However, no statistically significant difference was found in the head flexion angle in the pairwise comparisons among the three Groups. Interestingly there was a strongly significant difference in the head rotation angle between the High Group and the Control Group, as well as in the head side flexion angle and the rotation range. Since the main differences seemed to lie with the comparison between the High Group and the Control Group, together these results may indicate that there was a different 3D orientation of the head angle between these two groups.

6.3.2 Thorax posture and movements

The mean angles and ranges of the Thorax X and Y movements are presented in Fig. 6.3. There was generally no significant difference in the Thorax X (flexion/extension) and Thorax Y (side flexion) median angles in the multivariate analysis, in terms of the *group* effect ($F_{6,31}$=0.81, *p*= .569) or the *time* effect ($F_{24,13}$=0.99, *p*= .525). There was also no significant *time* x *group* interaction ($F_{24,13}$=0.86, *p*=0.641).

These results suggested that two groups of subjects had very similar postures in their thorax segments and there were also very little movements in these regions during the sustained typing task.

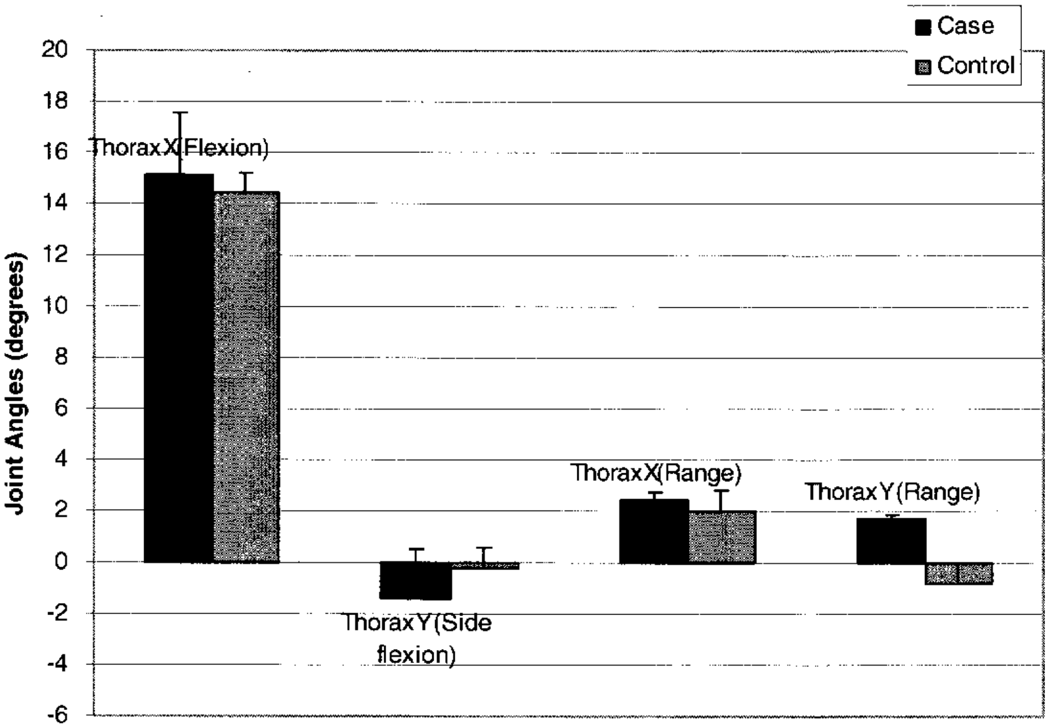


Fig. 6.3: Thorax X (Flexion) and Thorax Y (Side Flexion) mean angles and ranges in Case and Control Groups

6.3.3 Bilateral shoulder postures and movements

Fig. 6.4 shows the shoulder mean angles and ranges for the two sides for the shoulder flexion (Shoulder X) and shoulder abduction (Shoulder Y) movements. The Case Group appeared to be in slightly greater flexion in the right shoulder, while the Control Group seemed to have slightly greater shoulder abduction on both left and right sides. These differences in shoulder angles may have some relationship or influence on the muscle activities. The descriptive statistics of the Shoulder X and Shoulder Y angles and ranges are presented in Table 6.1, which also contain the mean angles and ranges of the four body segments studied.

The left and right Shoulder X and Shoulder Y angles were analysed for any *group* effect (x2 levels), *time* effect (x5 levels) and *side* effect (x2 levels) in the mixed model MANOVA. In the multivariate analysis, there was a significant *group* effect ($F_{6,31}=2.58$, $p= .038$) and a very strong *side* effect ($F_{6,31}=5.35$, $p= .001$). The *time* effect was not significant ($F_{24,13}=1.23$, $p= .356$) and neither were the 2-way and 3-way interactions.

In the univariate analysis, there was no significant main effect for the *group* factor nor the *time* factor for all variables. *Side* effect was significant for Shoulder X (flexion) mean angle ($F_{1,36}=4.30$, $p= .045$) and Shoulder X range ($F_{1,36}=25.99$, $p<0.001$), as well as the Shoulder Y range ($F_{1,36}=7.55$, $p= .009$). The *time* x *side* interaction was significant for the Shoulder Y range ($F_{4,144}=4.18$, $p= .003$), but all the other 2-way and 3-way interactions were not significant.

6.3.3.1 *High-Low Group comparison of shoulder angles*

When the Case subjects were sub-divided into the High and Low Groups, the High Group appeared to have greater shoulder flexion angle than the Low and Control Groups but this difference was still small in absolute terms (Fig. 6.4a). In the right shoulder abduction, left shoulder flexion and abduction, the Low Group appeared to have different angles from both the High Group and the Control Group. As there appeared to be no clear trend of group differences, no further statistical analysis was carried out on these shoulder angles.

In summary, the results on the shoulder kinematics suggested that there was a strong *side* effect with the right side greater than the left in both shoulder flexion and abduction mean angles and ranges. The *group* factor showed no significant difference as a main effect but there were apparent trends for the Control Group to have greater shoulder abduction angle than the Case Group on both sides. And there also appeared to be slightly greater shoulder flexion angle in the Case Group on the right. Examining the Case sub-groups did not reveal any clear pattern of differences among the three groups in various shoulder movements.

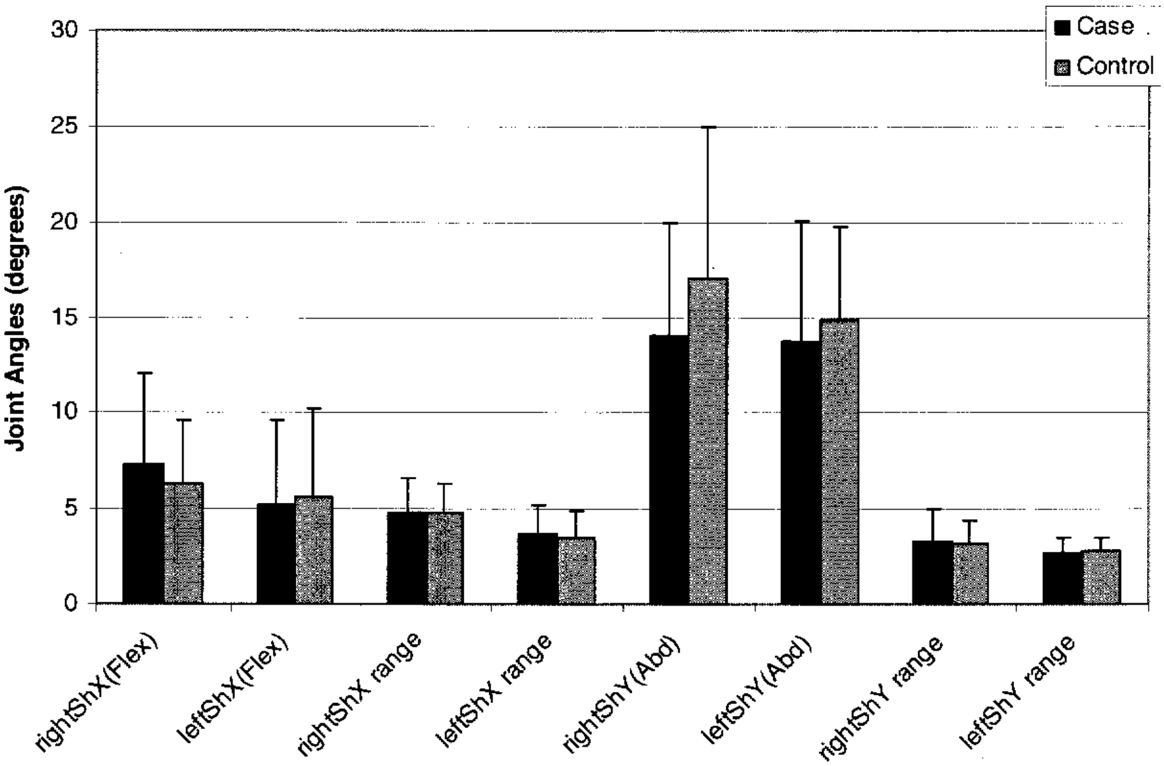


Fig. 6.4a: Shoulder X (flexion) and Shoulder Y (Abduction) mean angles and ranges on both sides in Case and Control Groups

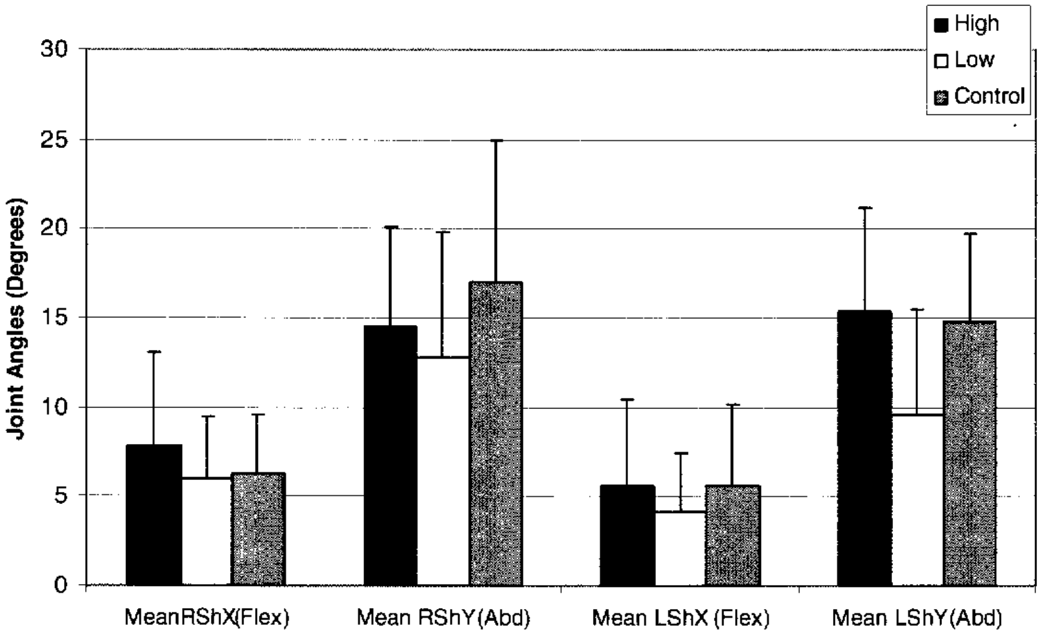


Fig. 6.4b: Shoulder X (flexion) and Shoulder Y (Abduction) mean angles in High, Low and Control Groups

6.3.4 Bilateral scapular postures and movements

From the results it can be seen that the bilateral scapulae were basically held in rather static positions during the 5 trials (see Fig. 6.5). The three planes of movements in the scapular segment were referenced to the thorax segment, and represented movements in the three anatomical planes; thus Scapula X represented flexion/extension, Scapula Y abduction/adduction, and Scapula Z medial/lateral rotation. No obvious difference was observed between groups and between sides in the Scapula X and Y mean angles, although there appeared to be a slightly greater medial rotation (Scapula Z) mean angle in the Case Group compared to the Control Group on both sides (difference of about 3° in the mean). As expected the statistical analysis yielded no significant difference for the effects of *group*, *time* and *side* factors of the mean angles of the scapular movements in the X, Y and Z planes. The ranges of movements were all very small in the three planes ($1\text{-}2^{0}$ on the average).

These results showed that the left and right scapula segments were maintained in very static positions throughout the typing task, and these positions were very similar in both Case and Control Groups.

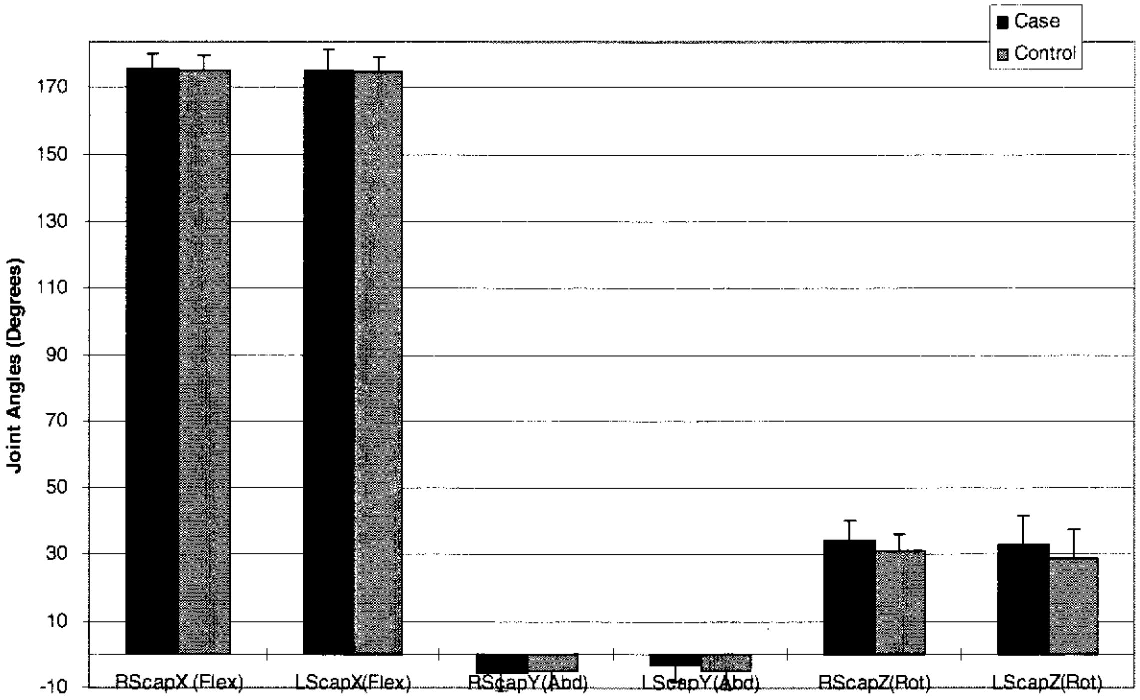


Fig. 6.5: The Scapula X, Y, Z angles and ranges in Case and Control Groups

Table 6.1: Descriptive statistics of mean angles and ranges of the 4 body segments (SD) comparing Case and Control Groups

Head and Thorax Movements	Case: Mean Angle (SD)	Control: Mean Angle (SD)	Case: Range (SD)	Control: Range (SD)
HeadX (Flex/Ext)[a]	67.59 (10.8)	63.74 (12.9)	6.77 (3.8)	4.53 (2.1)
HeadY (L/R Side Flex)[b]	-1.14 (1.8)	-2.67 (2.2)	3.56 (2.1)	2.99 (1.5)
HeadZ (L/R Rot)[c]	1.78 (2.4)	4.23 (2.5)	4.38 (1.6)	3.41 (1.3)
ThxX (Flex/Ext)[a]	15.09 (6.8)	14.41 (6.2)	2.43 (0.3)	1.98 (0.2)
ThxY (L/R Side Flex)[b]	-1.43 (3.1)	-0.24 (2.9)	1.67 (0.1)	0.81 (0.1)

Shoulder and Scapular Movements	Case Right (angle)	Control Right (angle)	Case Left (angle)	Control Left (angle)	Case Right (range)	Control Right (range)	Case Left (range)	Control Left (range)
ShX (Flex/Ext)[a]	7.32 (4.8)	6.32 (3.3)	5.20 (4.4)	5.64 (4.5)	4.82 (1.8)	4.77 (1.6)	3.74 (1.5)	3.52 (1.4)
ShY (Abd/Add)[d]	14.03 (5.9)	17.02 (7.9)	13.72 (6.3)	14.85 (4.9)	3.31 (1.7)	3.22 (1.2)	2.76 (0.8)	2.76 (0.8)
ScapX (Flex/Ext)[a]	175.58 (4.7)	175.37 (4.3)	175.29 (5.2)	174.71 (5.9)	1.48 (0.9)	1.33 (0.7)	1.64 (1.2)	1.50 (1.2)
ScapY (Abd/Add)[d]	-5.23 (6.4)	-4.88 (4.5)	-3.13 (5.9)	-4.70 (5.3)	2.01 (1.7)	1.69 (0.9)	1.45 (0.6)	1.48 (0.6)
ScapZ (Med/Lat Rotation)[e]	34.31 (5.6)	31.14 (7.1)	33.18 (8.8)	29.02 (8.7)	1.64 (0.7)	1.82 (0.7)	1.56 (0.9)	1.48 (0.6)

[a] positive(+ve)=flexion, negative(-ve)=extension, [b]-ve=left side flexion, [c] -ve=R Rot, [d]+ve=abduction, [e] +ve=medial rotation

6.4 DISCUSSION

6.4.1 Group differences in postures and movements

6.4.1.1 *Postural differences in the head-neck segment*

The results of the kinematics analysis in the head-neck segment suggested that the head flexion posture showed trends for consistently greater degrees of flexion in Case subjects compared to the Controls (Fig.6.1), and this apparent difference was maintained throughout the five trials of data capture. However, this group difference was not statistically significant, which may be due to the large standard deviations reflecting large inter-individual variations of the head flexion angles.

The present trends for increased forward head flexion in the Case subjects were compatible with our findings in the field investigation in Study 1 (Chapter 3). In Study 1, we showed that Case subjects had a tendency to keep their necks in more forward flexion (about 7^{o}) than the Control subjects (a difference of about 13%). In the present study, the overall means of head flexion angles had a smaller group difference of only about 4^{o}, but this difference was more apparent when the Case Group was sub-divided into the High and Low Groups according to their discomfort scores. Then the difference in head flexion angle between the High Group and the Control Group in the present study was about 8^{o}, very similar to those found in the field study (see Table 6.2). These results lend support to the hypothesis that symptomatic (with more severe discomforts) and asymptomatic individuals had consistent differences in terms of their forward head-neck flexion angles when they performed computer tasks. It has been reported that a difference of about 5^{o} in the neck flexion angle can have a considerable impact on the neck extensor moment and therefore the muscle force required from the neck extensors to support the weight of the head (Chaffin et al., 1999). Thus the present finding of a group mean difference of about 7-8^0 in head flexion posture may have an important relationship with the muscle activities required to sustain this posture, and it may also be related to the discomforts experienced by the High Group subjects.

Table 6.2: Comparison of Head-Neck angles (means and SD) in previous field study (Study 1) and the present study (Study 2)

Head-neck angles and ranges		**Case**	**Control**	**Difference between Groups**
Field Study	Head Tilt mean angle	60.6^0 (6.1)	57.1^0 (6.2)	3.1^0
	Neck Flexion mean angle	59.3^0 (10.0)	52.5^0 (7.1)	6.8^0
	Head Tilt range	15.3^0 (5.7)	12.3^0 (5.9)	3^0
	Neck Flexion range	7.7^0 (2.5)	6.1^0 (2.0)	1.6^0
Present Study	Head X (composite head-neck flexion)	67.6^0 (10.8) High=69.9^0(10.1) Low=61.7^0(11.6)	63.7^0 (12.9)	3.9^0 (Case-Control) 8.2^0 (High-Low)
	Head X range	6.8^0 (3.8) High=6.7^0 (4.2) Low=6.9^0 (3.0)	4.5^0 (2.1)	2.3^0 (Case-Control) 0.2^0 (High-Low)

In comparing the results of the two studies, a number of factors must be considered. In the field study the working environment was not controlled whereas the workstation was standardized in the present study. In the field study, the Peak (2D) system was used and the sagittal head tilt and neck flexion components were differentiated as two different joint angles. In the present study, the Vicon system with its associated biomechanical model did not allow this differentiation and the head-neck region was defined as one segment. Thus the results of the present "Head X" angle was the composite angle of head tilt and neck flexion. Nonetheless, similar trends or patterns are found in both studies – that Case subjects tended to have increased forward flexion in the head-neck region compared to the Control Group, and this pattern was consistent both in terms of the mean posture as well as the range of motion.

The present 3D analysis was also able to demonstrate significant differences in the mean angles of head side flexion and head rotation between groups. This finding suggested that there may be differences in the 3D orientation of the head-neck region between the Case and Control Groups. Although these differences were small in terms of absolute joint angles, yet they may represent subtle adjustments in the cervical spine posture in response to the increased tension in the right UT muscle. These differences in the 3D head-neck posture may imply different biomechanical strain on the passive connective tissues or impose differential strains on the stabilizing muscles (Chaffin et al., 1999; Harms-Ringdahl et al., 1986).

6.4.1.2 Group differences in head flexion range

The results also showed that the Case subjects had a significant difference in the "range" of head flexion movement and this may be clinically relevant. This suggested that the Case subjects had a tendency to move their necks to a greater extent than the Controls. In Study 1, we also found trends for greater range of head tilt and neck flexion in the Case subjects, suggesting that they tended to move their head-neck segments in greater extents compared to the Controls.

The significantly greater head flexion range in the present study may be linked to the muscle activities of the major stabilizers in the region, or a lack of control from segmental stabilizers. From the EMG analysis, we have reported increased UT activity coupled with decreased CES activity on the right side in the Case Group compared to the Control Group, suggesting altered muscle recruitment patterns in the symptomatic individuals (Chapter 4). The UT muscle is a long lever muscle designed more for scapular elevation rather than fine motor control of the segmental movements in the cervical spine (Johnson et al., 1994; Keshner et al., 1989). In contrast, the CES muscles are more designed for fine regional control of the cervical spine and this muscle was more active in the Control Group performing the same task. As a result, high amplitudes of UT coupled with reduced CES working as a cervical stabilizer may reflect in larger magnitudes of head-neck movements in the Case Group, due to a deficit in fine motor control of the cervical spine.

The other possible explanation for the significant difference in head flexion range was the result of increased discomfort causing the subject to "fidget" or move more. Such postural shifts that are related to discomfort would likely involve large movements of multiple body segments (Liao & Drury, 2000), and our significant group differences involved only the head flexion range. The ranges of other movements either in the head-neck, shoulder or thoracic regions were all very small in numbers and similar between two groups, suggesting that there were very little bodily movements. In addition, the present results showed no time trend for any of the postural parameters while the discomforts had significant increases with time in the Case Group. Thus the results would not support the "discomfort - fidget" hypothesis.

There is debate as to the influence that forward head posture has on the muscles and articulations in the neck. While it has been suggested that even a small change in the neck flexion angle of 5-10^{0} would significantly affect the neck extensor load moment (Chaffin et al., 1999; De Wall, van Riel, & Snijders, 1991); yet other studies argued that muscle activities were not significantly affected despite increased neck flexion angles associated with lower display screen heights (Aaras et al., 1997; Burgess-Limerick et al., 1999). These authors argued that the passive muscle and ligament lengthening was sufficient to counterbalance the forward turning movement of the head. Yet other studies examining different screen angles reported increased muscle activities with increased neck angles in viewing lower display screens (Hermans et al., 1998; Turville et al., 1998). Hence it does not appear that there is a direct relationship between neck posture and muscle activity patterns, as they may be greatly influenced by individual variations in motor control, as well as the physical conditions of task demands and environmental factors.

Muscle activation is closely related to control of joint movements and postures and it is difficult to separate the influence of the two components. On one hand it is possible that altered patterns of muscle recruitment may have preceded the altered kinematics, as uneven muscle tensions would result in an asymmetrical head posture and increased head flexion movement range. On the other hand, altered kinematics may also be the cause of altered muscle recruitment, and the cause-effect relationship of the two cannot be clearly established. Nevertheless, both altered muscle recruitment patterns and altered kinematics could have contributed to increased loading in the cervical spine, affecting the articular structures such as the zygapophyseal joints, connective tissues and neural tissues which are all peripheral generators of referred pain (Bogduk, 1995).

In the present study the High Group predominantly reported bilateral neck discomforts with either right shoulder or bilateral shoulder discomforts. This pattern of bilateral neck and shoulder discomfort while muscle activities were more concentrated in the right UT suggested that the source of pain was not only located in the right UT area. It is likely that the large compressive loading in the cervical spine created by the asymmetrical bending and compression moment caused by high activity in the right UT, may have caused referred pain due to stimulation of the nociceptors in the articular structures of the cervical spine (Bernhardt et al., 1999; Panjabi et al., 2001; Patwardhan et al., 2000).

6.4.1.3 *Comparison with other Case-Control studies on office workers*

Previous Case-Control studies on office workers have not provided similar information about the head-neck postures and movements. Vasseljen and Westgaard (1997) and Waersted and Westgaard (1997) only measured trunk angles and arm elevation angles. As it is commonly accepted that the trapezius muscle has an important role as a major stabilizer of the head-neck posture, as well as shoulder posture, it is important to examine both neck and shoulder joints as well as muscle activities in these regions. In addition, previous studies have tended to focus on the physical ergonomics of work-related musculoskeletal problems, and often the anatomical and functional aspects of various musculoskeletal structures were ignored.

Our present study compared postures and muscle activities between two groups of symptomatic and asymptomatic subjects when they performed the same task using the same workstation. The present results have not shown any major changes in postures and movements as a result of time-at-task. These results agreed with our previous finding in the field study, that there were no major changes of postures due to time-at-task.

6.4.1.4 *Differences in shoulder kinematics*

The results of the shoulder posture analysis showed a strong *side* effect with statistical significance in the shoulder flexion (Shoulder X) mean angles, as well as the ranges of shoulder flexion and abduction. From Fig. 6.4 we can also observe that generally there was a trend for greater angles in both shoulder flexion and abduction on the right side than the left. However, the difference in left-right shoulder flexion appeared to be greater in the Case Group, while the left-right difference in shoulder abduction appeared to be greater in the Control Group.

Although the shoulder angle differences between groups were not significant, they may still have important implications considering their associations with observed muscle activity differences between the two groups. The trend for greater shoulder flexion angle in the Case Group may have some relationship with the muscle activity patterns of the anterior deltoid (AD) muscle as well as the UT muscle. The AD muscle is a prime mover of the glenohumeral joint in forward flexion, and it should be active in the movements of the upper arm in the keyboarding actions (Jensen et al., 1999). In the present study, the median levels of activities for the right AD muscles were 7.14 (± 13.5)%MEMG for the Case Group and 5.63 (± 4.0)%MEMG for the Control Group. In comparison, the right UT muscle showed much higher muscle activities for the two groups (Case = 20.76 ± 28.3%MEMG; Control = 11.83 ± 10.7%MEMG), while the left UT activities were very similar between the two groups (11-13%MEMG). These results showed that the UT muscles were highly active during the arm movements of typing, and possibly more so than the AD muscles that were the prime movers. Although anatomically the UT muscle is more designed for the dynamic action of scapular elevation, it is also an important stabilizer of the shoulder girdle (from scapula to the clavicle) whenever the arm is involved in functional activities (Johnson et al., 1994; Kapandji, 1974; Winkel & Westgaard, 1992). It has been shown in several studies that the UT muscle is active in a number of arm positions in different degrees of flexion and abduction of the glenohumeral joint (Hagberg, 1981; Herberts et al., 1979; Mathiassen & Winkel, 1990).

In the present study, the subjects' forearms were partially supported by the rounded edge of the keyboard tray, and this should off-load some of the demand on the trapezius in stabilizing the shoulder joint. Previous studies have also reported significant reductions of the trapezius load as a result of forearm support during keyboarding but these were mainly investigated in healthy painfree subjects (Aaras et al., 1997; Cook et al., 2002; Erdelyi et al., 1988). Our EMG results showed that the Control Group had significantly lower and more symmetrical activities of bilateral UT muscles, while the High Group subjects maintained high levels of UT activities on the right despite the forearm support. The high level of UT activity appeared to be associated with a trend for increased head-neck flexion as well as increased shoulder flexion on the right. These changes may indicate alterations in the muscle recruitment and postural control strategies that have become programmed intrinsically in the symptomatic individuals.

6.4.1.5 *The scapulae – also mostly static and no difference between groups*

It was expected that the postures and movements of the scapulae would show differences between the Case and Control subjects, as the position of the scapula is related to the functions of the upper and lower trapezii. However, the present study has shown no significant difference of scapular mean angles in all three planes between the two groups, as well as between the two sides.

In clinical practice the recent concept of "scapular stabilization" proposed that excessive scapular protraction is a pathological finding, and the importance of retraining lower trapezius is emphasized in order to maintain the scapula in a retracted position (Janda, 1994; Kibler, 1991). However, this concept has not fully been substantiated by research. Some studies have reported a positive relationship between scapular posture, muscle activity and pain (Culham & Peat, 1993; Griegel-Morris et al., 1992). Other studies have reported either no relationship between scapular posture and middle trapezius muscle force (DiVeta et al., 1990) or no significant difference in scapular postures comparing patients and controls (Greenfield et al., 1995). Most of these studies have measured the static position of the scapula in relaxed standing or sitting. Our study is one of the few projects that have examined the scapular posture or movements during the performance of occupational tasks. Our results have shown no apparent difference in scapular positions between symptomatic and asymptomatic persons, and the major differences seemed to lie with their neck and shoulder postures, and these were closely related to the muscle activity of the upper trapezius in a postural stabilizing role.

There was a mean difference of about 3° in the medial/lateral rotation (Scapula Z) movement comparing the Case and Control mean angles, but when split into the High-Low sub-groups, this difference was not apparent. If this increased medial rotation of scapula was real, it would fit with the UT action on the lateral end of clavicle causing increased protraction and therefore the upper arm would also naturally move forward into more flexion. In the field investigation of Study 1, we have also found increased acromion protraction in the Case subjects (Chapter 3).

The measurement of scapular movements had two major technical problems. One is the large amount of skin movement in the scapular region especially between the borders of scapula and the underlying tissues. In our study, this problem was partly compensated by the static nature of the task and the placement of skin markers on the inside border of the scapula which helped to reduce the amount of skin movement. Another issue is that scapular kinematics are very complicated as these movements occur simultaneously in several planes and axes around the scapulothoracic and claviculoscapular articulations (Zatsiorsky, 1998). The present approach represented a simplified method to study the scapular postures during typing, and the three directions of movements were mainly referenced to the scapulothoracic articulation.

6.4.1.6 *Thorax was mostly static – may be related to subjects sitting with their backs supported*

The thorax was held in fairly static positions in both the Case and Control subjects. This was expected as the subjects were mostly sitting in a rather static posture during the typing task. Most of them had their backs resting against the seatbacks in an erect manner, partly as a result of the investigator's instructions for not performing large movements due to the many markers and electrodes placed on the subject. Both groups of subjects received the same instructions, so that any differences found could be contributed to the individuals' postural habits.

The lack of movements in the thorax confirmed that most of the postural changes were occurring in the head-neck region, especially in the Case subjects. Aaras et al. (1997) and Schuldt et al. (1986) have emphasized the importance of the thoracic posture in affecting the loading in the head-neck region. A more backward reclining thoracic spine was thought to balance out the forward flexion of the cervical spine, and thus requiring very little muscle effort to maintain the posture (Aaras et al., 1997). In the present study, as the subjects were mainly sitting with an erect thoracic spine, most of the stress or biomechanical loading would concentrate in the cervical spine. Still, the most important comparison is the difference between the two groups, showing the symptomatic subjects with more exaggerated movements and postures in the head-neck region, while thoracic spine angles were similar in both groups.

6.4.2 Associations between posture, muscle activity and discomfort

The present results showed that mean postures and movements showed only small differences between the two subject groups while their muscle recruitment patterns showed much greater differences. The link between altered kinematics and altered muscle recruitment may have an important relationship to the discomforts experienced by the subjects. On the other hand, they could also be the outcome of the long-term discomforts resulting in compensatory changes in muscle activities and posture.

In the head-neck region, the consistent differences in head flexion postures and ranges in Studies 1 and 2 would suggest that these postural changes were intrinsic differences between the Case subjects with high discomforts compared to those with low or no discomforts. This difference could have an important influence on the load moment of the cervical spine (Chaffin et al., 1999).

It is possible that the symptomatic subjects may have developed changes in their postures and movements first which then resulted in changes in muscle activities. For example, the "poking chin" posture is very common even among the general population (Braun, 1991; Raine & Twomey, 1997), and it is commonly observed that office workers may poke their chins even more forward when they are concentrating on viewing the computer display. And we have provided objective evidence to support this phenomenon from our field study (Chapter 3). This forward head movement may gradually develop into a fixed postural habit whenever they work with computers, resulting in increased compressive loading in the cervical spine. This increased compressive loading in the spine may be sufficient to stimulate the nociceptors in the spinal articular structures; or these individuals may also develop increased muscle activities to maintain these altered postural habits.

The habit of maintaining high activities in the right UT muscle may be related to the increasing trend of intensive use of the mouse with the right hand, which may also contribute to increasing trend for right arm movements, as reflected in the trend for increased right shoulder flexion in the Case Group.

Based on the present results, it appeared that the UT muscle was assuming a dual role as a cervical stabilizer as well as a shoulder stabilizer in the High Group subjects. This appears to be a mal-adaptive pattern to control the head-neck and shoulder posture. Although the differences in the head-neck and shoulder kinematics only involved a few degrees in various directions, if sustained for a prolonged period these small changes may add up to considerable loading in the articular structures (Chaffin et al., 1999; Harms-Ringdahl et al, 1986). Activation of nociceptors in the articular structures of the cervical spine would be compatible with the widespread and bilateral distribution of discomforts reported by the High Group subjects (Bogduk, 1995).

In contrast, the Control subjects had greater loading of the right CES muscle which was a more effective regional stabilizer of the cervical spine, as well as a more even distribution of UT and other muscle activities between left and right sides. This was accompanied by a more erect head-neck posture with relatively reduced head-neck flexion and possibly less shoulder flexion throughout the typing trial. These results suggested that the Control Group may have adopted a more efficient motor control strategy, effectively reducing the biomechanical strains on the musculoskeletal structures.

6.4.2.1 The Altered Motor Control Model

The present results suggested that the between-subject differences in posture and muscle recruitment were likely due to intrinsic differences, rather than simply responses to the ergonomic or environmental conditions in performing computer tasks. The results would support that altered kinematics is an important mechanism related to the development of WRNULD. Kumar (2001) highlighted the multivariate interactions of differential and cumulative muscle and joint loading and fatigue responses, contributing to occupational musculoskeletal injuries. Winkel and Westgaard (1992) have also presented a conceptual model emphasizing the roles of internal exposure factors but the kinematic and muscle loading influences were not clearly differentiated.

In Chapter 4 we have presented an "Altered Motor Control" Model based on the results of the muscle recruitment patterns. The present findings of altered kinematics can be incorporated into this model, as the control of joint movements and muscle activities are intricately related. It is likely that altered kinematics and altered muscle recruitment were concurrent processes but occurring to different extents in different individuals. However, the cause-effect relationships of these two components cannot be established from the present research. Longitudinal studies may be able to provide more insight on this relationship.

The present results suggested that the altered kinematics mainly occurred in the High Group individuals, although some of the observed trends such as increased shoulder flexion were observed in the Case Group in general. The differences between the High Group and Low Group individuals mainly lay with their discomfort responses during the experimental trials. Both groups had similar durations of discomfort in the last 12 months, but the High Group reported higher discomfort scores in the past. It may possibly suggest that the High Group individuals had more severe discomforts in the past, thus contributing to their significantly higher discomfort scores in the experimental trials. There may also be other individual differences between these two groups such as different psychosocial profiles and psychological stress that have been the underlying or predisposing factors. It has been well established in the literature that non-physical factors such as personality types, perceived tension, psychosocial and motivational factors can significantly affect the perception of musculoskeletal discomforts (Jensen et al, 1993a; Linton, 2000; Vasseljen & Westgaard, 1995; Waested, 2000; Zusman, 2002). Further research is needed to explore the differences in the sub-groups among symptomatic individuals that contribute to their differences in response to physical stressors.

6.4.3 Limitations of study and directions for future research

The present system utilized the Vicon system which has not been used in other similar studies, and thus results cannot be easily compared with other studies using other motion analysis systems. In addition, the upper body joints such as the cervical spine and the scapula involve very complex biomechanical modeling. What is presented here is only very basic kinematics data in a very simplified form. More detailed studies are needed to provide a better understanding of more complex kinematics modeling in the upper and lower cervical spine, as well as in the scapular articulations with the thorax, the acromioclavicular joint and the glenohumeral joint.

In the present study, we have evaluated the differences in symptomatic and asymptomatic persons in response to performing a monotonous computer task for a prolonged period. While the working conditions have been standardized, it is not known whether these individual differences would be maintained if the working conditions were varied. Beside static posture, the speed and force components of performing work tasks have also been commonly identified as major physical risk factors in occupational diseases. Changing the speed and force components of computer work may also produce different responses in symptomatic and asymptomatic individuals. Further research may involve examining the effects of physical stressors such as the speed and force factors in keyboard operation in affecting the development of WRNULD.

6.5 CONCLUSION

The present study has shown trends for increased forward head-neck flexion posture and greater range of movement in the Case Group compared to the Control Group during the performance of a one-hour continuous typing task. There were also significant differences in head side flexion and rotation postures but these differences were only small in absolute numbers. When further examined in the High-Low sub-groups among the Case subjects, the head-neck flexion angles showed similar differences to those reported in our previous field investigation, thus further supporting the intrinsic differences in head-neck postural control between symptomatic and asymptomatic persons. Both the head-neck flexion changes and the trend for increased forward flexion of the right shoulder in the Case Group could be related to concurrent findings of increased activation of right UT in the Case subjects, especially in those with high discomfort scores.

Together the results suggested that the symptomatic persons, especially those with more severe discomforts, had different muscle activation patterns and different kinematics associated with a widespread bilateral discomfort response. Both the altered kinematics and altered muscle recruitment would contribute to the Altered Motor Control Model, which may be an important concept in understanding why WRNULD would develop in some individuals and yet not others performing similar work tasks.

CHAPTER 7

STUDY 3 PAPER 1

The Effects of Increased Typing Speed and Force on Neck-Shoulder Muscle Activities in Symptomatic and Asymptomatic Office Workers

This chapter is the first of 2 papers on Study 3, focusing on the EMG changes and discomforts in the Case and Control Groups when they were challenged by the physical stressors of increased typing speed and increased typing force.

In this study, each subject had to perform 20 minutes of typing under 3 conditions: Normal, Faster and Harder. The Case Group showed trends for higher muscle activities in all three conditions in both the UT and CES muscles. On the whole, there were greater increases in muscle activities in both groups under the Faster condition, implying that increasing the typing speed was a more difficult demand. When the Case subjects were sub-divided into High-Low Groups, greater differences in muscle activities were revealed. It was mainly the High Group that showed the greatest changes in terms of muscle activities and discomforts. The Low Group showed moderate increases in discomforts and muscle activities, while the Control Group showed minimal changes in both.

The results confirmed our proposed model of "Altered Motor Control"(Chapter 4) in the symptomatic individuals who may also have developed a "heightened sensitivity" to physical stressors due to their prolonged history of discomforts in the past. These proposed mechanisms will be discussed in this chapter.

7. 1 INTRODUCTION

Work-related neck and upper limb disorders (WRNULD) are common problems among office workers, especially among those who are intensive computer users (Bergqvist, 1993; Bernard et al., 1994; Hagberg & Wegman, 1987; Kamwendo et al., 1991a & b; Tittiranonda et al., 1999). The long working hours and the static posture associated with computer use have been commonly identified as major risk factors for computer users (Aaras et al., 1997; Bergqvist et al., 1995; Faucett & Rempel, 1994). In Study 2 we have demonstrated differences in muscle recruitment patterns and kinematics comparing symptomatic and asymptomatic office workers in performing a one-hour typing task (Chapter 4, 5, & 6). These results suggested that different individuals may respond differently even when exposed to the same physical stressor, in this case, the stressor being the maintenance of a prolonged static posture.

7.1.1 Speed and force factors in keyboard operation

Besides sustaining a static posture for long hours, the repetitiveness or speed of keyboard operation as well as the force of keyboard operation may also be important risk factors for office workers (Feuerstein et al., 1997; Laursen et al., 1998a & b; Sommerich et al., 1996a & b). Increased risk for arm, elbow and hand pain has been reported for repetitive keying reported at 8,000-12,000 strokes per hour (Maeda, Hunting, & Grandjean, 1980). Thatcher and Brophy (1999) reported a doubling of the incidence of neck-shoulder pain among data-entry clerks working at >11,000 strokes per hour.

The task of keyboard operation characteristically involves small forces generated in the distal upper limb muscles while sustained activities may be required in the proximal stabilizing muscles. Prolonged periods of static activities in the proximal stabilising muscles may be an important factor leading to discomfort in the neck-shoulder region. Previous studies have demonstrated that when the shoulders were sustained in slightly abducted or elevated positions for a period of time, there were significant increases in muscle activity of the upper trapezius muscles (Aaras, 1994; Hagberg, 1981).

The speed and force elements are two fundamental characteristics of any motor task, and these factors are important considerations in examining the keystroke action. Furthermore, speed and force of hand movements in computer work have been directly linked to the muscular activity of the neck and shoulder region in occupational studies (Birch et al., 2000; Gerard et al., 1999 & 2002). Birch et al. (2000) studied the muscle activities in upper trapezius and mid-deltoid in CAD operators during mouse tasks of different combinations of precision, speed and mental demands. The muscle activities did not show significant changes as expected, possibly due to the interactions of too many variables such as speed, mental demand and productivity. Gerard et al. (1999 & 2002) compared the effects of typing with different keying paces and keying forces, but their aims were to compare the effects of using different keyboards with different key designs and stiffness. They also measured finger flexor and extensor tendon activities and subjective discomforts in healthy office workers, and found that faster typists had reduced finger extensor activity and no difference in discomforts compared to the slower typists. The authors suggested that as the typists increased their speeds and their skills, they may use their muscles more efficiently to perform the typing and therefore may be less likely to develop musculoskeletal problems.

Past studies on repetitive manual tasks have also reported on the effects of speed and force on muscle activities. Westgaard and Bjorklund (1987) studied the EMG of upper trapezius and rhomboids with subjects performing repetitive manual tasks. Their results showed a two- to three-fold increase in EMG activity due to the demand of increasing speed. Laursen et al. (1998a) measured the muscle activities in 13 shoulder muscles during a pen-and-paper task with various combinations of precision and speed demands. They reported that both the speed and precision demands caused increased muscles activities and the effects of speed demands were stronger than precision demands.

The physical stressors of speed and force demands are likely to affect the workload associated with keyboard operation, which is the main activity performed by the majority of office workers daily (Birch et al., 2000; Laursen et al., 1998a & b; Gerard et al., 1999; Pascarelli & Kella, 1993; Sommerich et al., 1996a & b). However, most of the studies to date have not explored whether symptomatic and asymptomatic persons may respond in the same way to different speed demands (Birch et al., 2000; Laursen et al., 1998a & b; Sommerich et al., 1996b) or different force demands (Gerard et al., 1999; Sommerich et al., 1996a) in performing manual tasks or computer work. The static muscle load in the proximal stabilising muscles may be affected greatly by these different physical demands, contributing to discomforts in the neck and upper limb region.

7.1.2 Past studies on keystroke force characteristics

A number of studies have examined the kinetics of keystroke operation, in terms of the activation forces and/or the muscle activities involved (Armstrong et al., 1994; Dennerlein et al., 1998; Feuerstein et al., 1997; Martin et al., 1996; Radwin & Jeng, 1997; Rempel et al., 1997). Most of these have been conducted on normal healthy subjects and the sample sizes were usually very small (<10). These studies have mainly focused on the biomechanical factors occurring at the finger or wrist joints, or the muscle activities in the forearm region (Gerard et al., 1999; Martin et al., 1996; Radwin & Jeng, 1997; Rempel et al., 1997). These studies on forearm and hand biomechanics have mainly focused on comparing different keyboard designs or keystroke characteristics. Few studies have looked at muscle activities in the proximal stabilising muscles while examining keystroke biomechanics.

Pascarelli and Keller (1993) identified a number of typing styles including "clackers" who were persons who hit the keys with excessive forces and reported a high prevalence of forearm symptoms and DeQuervain's syndrome among these, but there were no objective measurements of keystroke forces.

Feuerstein et al. (1997) was one of the few studies that examined discomfort symptoms, keyboard forces and keying rate between case and control groups. "Cases" (symptomatic subjects) were found to generate significantly higher force levels in the keyboard task, and the results supported a strong association between keystroke forces and upper limb symptoms; however, there was no measurement of muscle activity. The muscle effort required in stabilising the upper limb while different keystroke forces are produced may be an important link to the development of work-related symptoms.

7.1.3 Past studies have focused on normal healthy subjects and symptomatic-asymptomatic differences are not researched

In the past, ergonomic studies that have analysed postural or muscle loading at work tended to mainly focus on the "normal" healthy workers, that is, those without work-related musculoskeletal problems. This type of research would not reveal individual differences between symptomatic and asymptomatic persons in their intrinsic responses (internal exposures) that may have contributed towards the development of pain and discomfort in some workers and not others.

In Study 2 we have demonstrated symptomatic-asymptomatic differences in muscle activities while subjects performed a one-hour typing task at their normal work pace (Chapters 4-6); and these differences were thought to be attributed to intrinsic variations in motor control strategies. Feuerstien et al. (1997) also reported symptomatic-asymptomatic differences in keystroke performance. However, it is not clear from their study whether the increased upper limb discomforts were due to increased muscle activities in the stabilizing muscles or other factors, when the Case subjects were keying with greater forces.

7.1.4 Case-Control studies on office workers have mainly studied EMG during normal computer tasks with no control of speed and force

Several case-control or cross-sectional studies have reported on neck-shoulder muscle activities in office workers (Jensen et al, 1993a; Hagg & Astrom, 1997; Nordander et al., 2000; Vasseljen & Westgaard, 1997). These studies have mostly examined the muscle activities in the upper trapezius, deltoid and infraspinatus during the performance of "normal" office work. There was usually no control of work tasks, and the relationship between the tasks performed (such as word-processing or data entry) and muscle activities were not examined.

A number of studies have reported that psychosocial factors and mental demands can affect muscle activities (Bansevicius et al., 1997; Vasseljen & Westgaard, 1995; Waersted & Westgaard, 1997). These stress factors may be related to or be manifested as speed and force changes in keyboard tasks. For example, a worker who is working under high pressures to meet a deadline, may either type with increased speed (in trying to finish the work more quickly) or with increased force (due to frustration or anxiety), or a combination of both. Such changes in the motor performance may affect the muscle loading in the proximal stabilizing muscles and the spinal articular structures which may in turn affect work-related discomforts.

It is generally agreed that the etiology of WRNULD is multifactorial, and the interactions of intrinsic and extrinsic factors may simultaneously operate within each person (Kumar, 2001; Westgaard et al., 2001). A better understanding of how different individuals respond to different keying stresses may improve our understanding of why some persons develop WRNULDs and others do not, even though they may perform the same work tasks.

7.1.5 Aim of Study

The aim of the present study was to examine the muscle activity in the neck and shoulder regions in symptomatic and asymptomatic office workers when they performed standardized keyboard tasks under the three conditions of:

1. typing at normal speed and force
2. typing with increased speed
3. typing with increased force

The effects of these typing conditions on the muscle activities of the major neck-shoulder stabilizers and the subjective discomforts in the upper body were evaluated. The results could provide better understanding of differences in motor control strategies between symptomatic and asymptomatic persons, in reacting to the physical stressors of speed and force of keyboard operation.

7.2 METHOD

7.2.1 Subjects

This study employed a Case-Control quasi-experimental design, with female office workers recruited through convenience sampling mainly from health promotion activities and from staff at the local university. The inclusion criteria were that the subjects had to perform a minimum of 4 hours of computer work daily, and only those who performed clerical and/or administrative duties (mainly word-processing) were included. Prior to participating, the subjects were asked a series of questions to gather information about their history of computer work as well as any previous history in the past 12 months or current complaints of neck and upper limb discomfort. Those with past traumatic injuries or surgical interventions in their neck and upper limb regions were excluded. The information on the past history of discomfort was obtained based on questions adopted from the Standardised Nordic Questionaire (Kuorinka et al., 1987).

For the present study, 21 Case subjects and 20 Control subjects were successfully recruited and they completed all experimental procedures. Subjects were assigned into the Case Group if they indicated that their past/present discomfort was related to computer use, that their discomforts lasted more than 3 months in the past year, that they had discomfort in the past 7 days and they had discomfort on the day of testing. The presence of "current complaint" was defined by a score of > 2/10 on the discomfort scale reported by the Case subjects on the day of testing. Control subjects must have had no or minimal discomfort on the day of testing, and had no discomfort in the past 7 days. If they had reported discomfort in the past 12 months, it had to be of a short duration (<3 months) and the condition has resolved.

The Case and Control subjects were reasonably matched in terms of their physical build, handedness and job profile. Age was significantly different by a mean of about 9 years (see Table 7.1). Prior to commencing the data collection, all subjects were asked to sign the Informed Consent Form, after the Principal Investigator explained the detailed procedures to them. The study was approved by the Curtin University Human Research Ethics Committee.

Table 7.1: Subject profiles for the Case and Control Groups in Study 3

		Case Group (n = 21)	Control Group (n = 20)	Group Difference Statistics
Subjects' Background	Age [mean (sd; range)]	$\bar{x}$ = 39.0 (7.4; 24 – 52)	$\bar{x}$ = 30.4 (5.9; 22 – 42)	$t = 4.13$ $p < .000^{**}$
	Body Height (cm) [mean (sd; range)]	$\bar{x}$ = 157.9 (6.9; 143.0 – 164.0)	$\bar{x}$ = 157.6 (5.7; 148.0 – 167.5)	$t = 0.10$ $p = .922$
	Body Weight (kg) [mean (sd; range)]	$\bar{x}$ = 49.8 (7.7; 38.2 – 68.0)	$\bar{x}$ = 50.4 (5.4; 41.8 – 60.0)	$t = -0.18$ $p = .857$
	Hand Dominancy [count (expected count)]	Left = 0 (.5) Right = 21 (20.5)	Left = 1 (.5) Right = 19 (19.5)	$^{a}\chi^2 = 1.46$ $^{a}p = .227$
	Work Experience [mode (range)]	mode = > 3 yr (1-2 yr - >3 yr)	mode = > 3 yr (0-6 mon - >3 yr)	$Z = -1.59$ $p = .111$
	Working Hours per week [mean (sd; range)]	$\bar{x}$ = 45.3 (5.6; 37.5 – 65.0)	$\bar{x}$ = 42.2 (4.6; 30.0 – 50.0)	$t = 1.95$ $p = .058$
	Computer Usage in Hours/Day [mode (range)]	mode = 4 – 6 hrs (2-4 hrs - > 8 hrs)	mode = 4 – 6 hrs (2-4 hrs - > 8 hrs)	$Z = -2.40$ $p = .016^{*}$
	Keyboard Usage in Hours/Day [mode (range)]	mode = 4 – 6 hrs (2-4 hrs - > 8 hrs)	mode = 2 – 4 hrs (2-4 hrs - > 8 hrs)	$Z = -1.63$ $p = .103$
	Mouse Usage in Hours/Day [mode (range)]	mode = 0 – 2 hrs (0-2 hrs – 6-8 hrs)	mode = 0 – 2 hrs (0-2 hrs - >8 hrs)	$Z = -0.24$ $p = .811$
	Previous Typing Training [count (expected count)]	Yes = 14 (14.3) No = 7 (6.7)	Yes = 14 (13.7) No = 6 (6.3)	$\chi^2 = .05$ $p = .819$
	Typing Method Adopted [count (expected count)]	Touch-type = 18 (19.0) Increased Force = 2 (1.0) Used Certain Finger = 1 (1.0)	Touch-type = 19 (18.0) Increased Force = 0 (1.0) Used Certain Finger = 1 (1.0)	$^{a}\chi^2 = 2.77$ $^{a}p = .250$
Past Discomfort	Duration of Discomfort in Past 12 months [mode (range)]	mode = > 6 months (8-30 days - > 6 months)	mode = 0 day (0 day - > 6 months)	$Z = -4.17$ $p < .000^{**}$
	Prevalance of Discomfort in Past 7 Days [count (expected count)]	Yes = 20 (12.3) No = 1 (8.7)	Yes = 4 (11.7) No = 16 (8.3)	$\chi^2 = 23.89$ $p < .000^{**}$

** *p value significant at* $\alpha = 0.01$ *level*

* *p value significant at* $\alpha = 0.05$ *level*

[a] 1 cell or more have expected count < 5. Likelihood ratio is used.

7.2.2 Variables

The independent variables were *group* (Case versus Control), *condition* (Normal, Faster and Harder), *side* (left versus right) and *time* (5 repeated trials during each condition). The dependent variables were muscle electrical activity and discomfort. Keyboarding performance in terms of speeds and forces were also measured and are reported in Chapter 8.

7.2.3 Muscle electrical activity

The eight muscles being studied were the bilateral cervical erector spinae (CES), upper trapezii (UT), lower trapezii (LT) and anterior deltoids (AD). These muscles were selected as they are the major stabilising muscles of the neck and shoulder region, and they would be subjected to biomechanical strain in performing computer tasks.

For EMG measurement, eight pairs of bipolar Ag-AgCl surface electrodes ($3M^{TM}$ Infant Red Dot^{TM} electrodes, 15mm in diameter, 3M Hong Kong Limited, Hong Kong) were placed on the skin of the eight muscles examined. The inter-electrode distance was fixed at 20mm. The locations of the electrodes and the skin cleansing procedures were described in detail in Chapter 4.

The Noraxon Telemyo System (Noraxon, U.S.A. Inc., U.S.A.) was used to capture EMG signals (intrinsic frequency of 1000Hz and a bandwidth of 10-500Hz). The eight channels of EMG signals were pre-amplified close to the electrodes before they were transmitted to the Vicon 370 system (Oxford Metrics Ltd., U.K.) with a sampling frequency of 1920Hz. All the EMG signals were processed in a specially designed Labview (National Instruments^{TM}, Austin, U.S.A) program with a high-pass filter at 20Hz, a low pass filter at 200Hz and notch filters at 50Hz and 60Hz to reduce the noise levels. Then the signals were down-sampled to 10Hz root mean square (RMS) values.

Prior to the typing trials, EMG normalisation procedures were carried out by having the subject perform 3 trials of resisted maximum voluntary isometric contractions (MVC) and 1 trial of sub-maximal "ramp" contraction from 0-30%MVC for each muscle. EMG signals recorded during the typing trials were expressed as percentages of the EMG activity during MVC (%MEMG). (The normalization procedures were described in detail in Chapter 4).

7.2.4 Discomfort ratings

At the start of the testing session, the subject was asked to rate her discomfort in ten upper body areas (left and right neck, upper back, shoulders, elbows, wrists/hands). The discomfort rating was asked again at the 10th min and the 20th min in each typing condition. A numerical scale of 0 to 10 (with 0 = no discomfort, 1=minimal discomfort and 10 = extreme/intolerable discomfort) was used. For statistical analysis the discomfort data were analysed in terms of the summed score (total score of all discomfort areas reported at each data collection point), in the comparison between groups and among the three typing conditions.

7.2.5 Keyboard speed and force measurements

Four piezoelectric load cells (Piezotron® load cells, Kistler Instrument Corporation, Amherst USA) were fixed under the four corners of a platform supporting a standard QWERTY keyboard. The load cells were used to measure the speed and force data during the typing trials. The keystroke force data were also collected through the Vicon 370 system (Oxford Metrics Ltd., U.K) as separate analogue channels from the EMG channels. An oscilloscope was connected to one of the load cells to display the real time signals in order to monitor the actual keystroke force values during the typing trials. The readings from the oscilloscope were used to establish the baseline values of keystroke forces in the "Normal" condition which were used to compute the expected increases for the Harder condition. The baseline keystroke speed data were obtained from the instantaneous display of speed (in words per min) from the FasType program, for computing the expected increases in the Faster condition.

7.2.6 Experimental procedures

Each subject was required to perform 3 trials (of 20 minutes) of screen-based typing. The order of testing was:

1. the "Normal" condition - typing at "normal" speed and force x 20 minutes, followed by either,
2. the "Faster" condition - typing with increased speed (20%>Normal) x 20 minutes,

   or,
3. the "Harder" condition - typing with increased force (20%>Normal) x 20 minutes.

In order to control the order effect of the "Faster" and "Harder" conditions, the subjects in each group were alternated to perform the "Faster" condition in the second trial followed by the "Harder" condition in the third trial, or vice versa. There was a short break of 5 minutes between consecutive trials, followed by a 2-3 minutes' practice with the Faster or Harder task until the required speed or force level was reached.

During each of the 20 minute typing tasks, the EMG data were recorded at the 1st, 5th, 10th, 15th and the 20th minutes. Each data collection period lasted 40 seconds. The subject was asked to indicate and rate the discomfort after the 1st, 10th and 20th minutes, following the EMG data collection.

The baseline speed and force values for each subject were established from the keyboard data collected in the "Normal" condition. From this data, the expected speed and force levels at 20% above the normal values were computed.

In the "Faster" condition, the subject was expected to maintain the typing speed at a level equivalent to or more than the 20% above the "Normal" level while the force exerted was not controlled. The investigator monitored the keystroke rate continuously on the FasType program and provided gentle reminders to the subject if the speed went below the pre-set level by a margin of 20%. The same approach was used for the "Harder" condition, i.e., the subject was expected to type at the higher force level (20% above Normal or more) while the speed component was not controlled.

7.2.7 Controlled variables

7.2.7.1 *Computer workstation*

The computer workstation included a standard table for placing the monitor, a fixed-height wooden frame for the keyboard with the load cell platform, a wooden bench for forearm support, and an adjustable height swivel chair with no arm rests (Fig. 7.1).

The subject was instructed to adjust the chair height to a level that allowed the forearms to be supported comfortably on the wooden bench with the elbows at approximately 90°. Then the other aspects such as the monitor height, keyboard position and footrest (optional) were adjusted accordingly. The aim was for the subject to achieve a comfortable typing position with back and forearms supported, while only the fingers would be in contact with the keyboard on the load cell platform. The forearm support bench was padded and provided about 15 cm support to the forearms. The display screen height was adjusted so that the subject maintained an erect head posture.

Fig. 7.1: Photograph showing the subject in the ready to type position. Her forearms are resting on the padded bench in front of the wooden frame supporting the force platform and keyboard.

7.2.7.2 Computer task

Each subject performed a standardised task of copy-typing. The typing program called FasType® (Trendtech Corporation, Scottsdale USA) was used for the study, as it was able to provide an instantaneous display of the raw typing speed. The typing program provided long passages of texts containing commonly used words. This made the typing task more realistic and allowed the subjects to use all the keys of the 26 letters.

During the typing tasks, the subject was instructed to correct any typing errors by striking the backspace key. The FasType program would accept occasional mistakes but the program would stop if there were too many mistakes. This was the program's requirement to ensure a certain level of accuracy (<10% typing errors).

7.2.8 Data processing and analysis

Muscle electrical activity was analysed in terms of normalized %MEMG expressed as 3 levels of the Amplitude Probability Distribution Function (APDF) (10th%, 50th%, 90th%). Median Frequency (MF) of the power spectrum was also computed for each EMG data trial. EMG data and discomfort ratings were compared within each subject as well as between the two subject groups. A mixed model MANOVA was used to examine the effects of *group* (between-subjects factor), *condition, side* and *time* (within-subjects factors). The critical alpha level of 0.05 was used throughout and no family-wise error adjustment of critical level was made in order to balance type I and type II errors.

7. 3 RESULTS

7.3.1 EMG amplitude analysis

7.3.1.1 *Graphs and trends*

Fig. 7.2a,b,c,d show the mean values of the 50th%APDF of the four muscles comparing the three conditions of "Normal", "Faster" and "Harder". Each part of Fig. 7.2 represents the comparison between *groups* and between *sides* for each of the four muscles. On the whole, the right CES, UT and LT showed the most apparent Case-Control differences, and generally there appeared to be greater increases in muscle activities in the Faster condition than the Harder condition.

In Fig. 7.2a, the right CES muscle displayed an apparent trend for proportionally the greatest Case-Control difference among all the muscles in all three typing conditions, while the two groups were at fairly similar levels on the left. The Control Group showed very little change in amplitudes on the right but there were more apparent increases in the left in the Faster and Harder conditions. In Fig. 7.2b, the UT muscle showed fairly similar trends to those in Fig. 7.2a. The Case-Control difference in the right UT appeared to be proportionally less than that in the right CES, and the Case Group had consistently higher activities on the right than the left in all 3 conditions. The Control Group showed symmetrical increases in activities in both left and right UT. Both groups showed higher increases in UT activities in the Faster condition than the Harder condition.

In the LT muscle (Fig. 7.2c) the right side was generally at higher activities than the left, and the trend was for greater activities in the Case Group than the Control Group. Again, the Faster condition appeared to produce the greatest increase in the right LT. The AD muscles (Fig. 7.2d) also had greater increase in activities in the Faster condition than the Harder condition, but the Control Group showed a trend for higher increase in activity compared to the Case Group in the Faster condition.

On the whole there was a trend for the Case Group to show higher activities than the Control Group in most situations, especially on the right side. The Case Group showed consistently higher activities on the right compared to the left, but the Control Group had apparently higher activities on the left in the CES muscle, and fairly similar activities on both sides for UT. Both groups showed trends for greater activities on the right side than the left, as well as higher increases in the Faster condition compared to the Harder condition and the Normal condition.

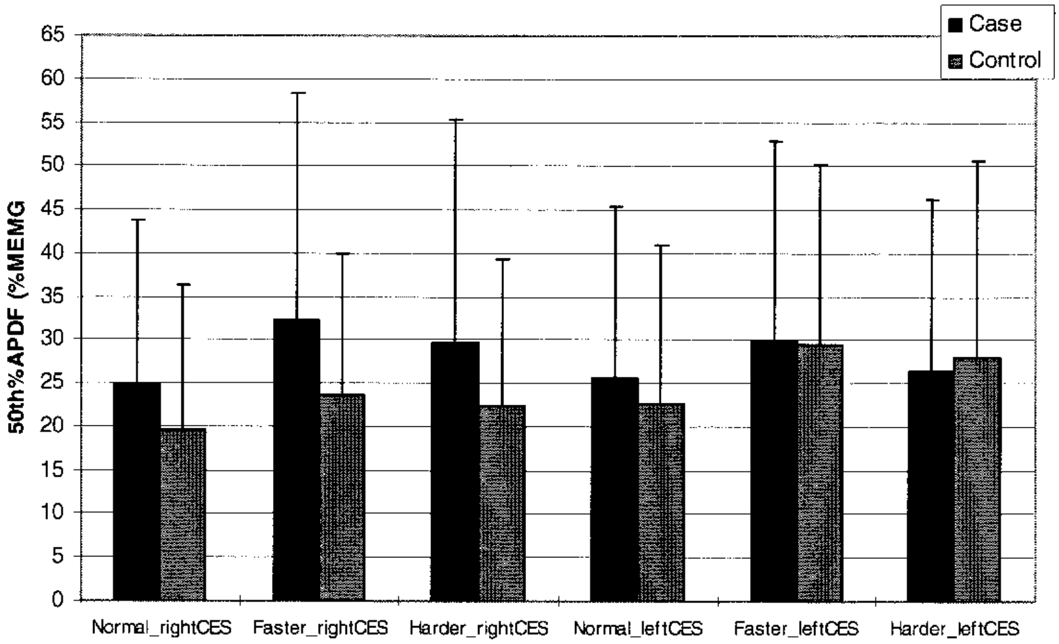


Fig. 7.2a: Mean 50th%APDF of CES muscles in the three typing conditions of Normal, Faster and Harder

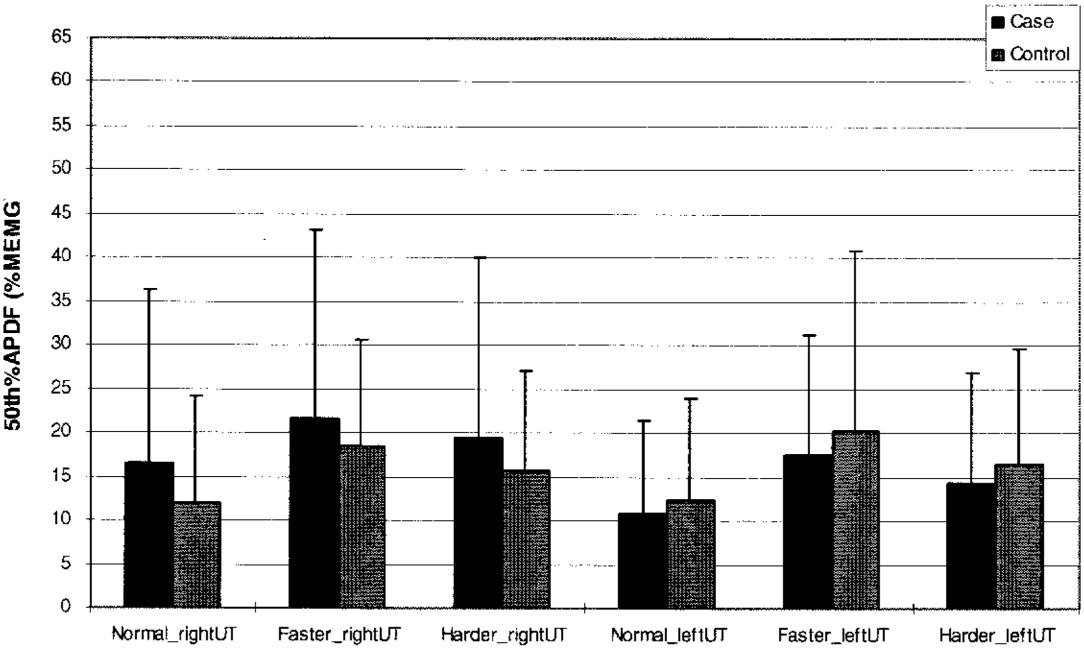


Fig. 7.2b: Mean 50th%APDF of UT muscles in the three typing conditions

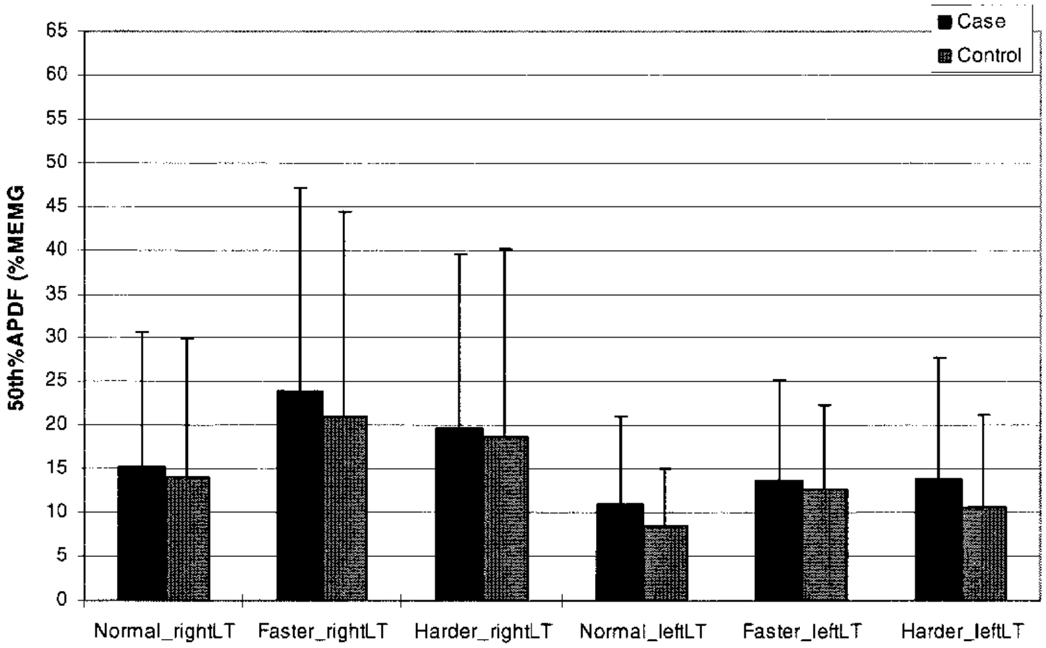


Fig. 7.2c: Mean 50th%APDF of LT muscles in the three typing conditions

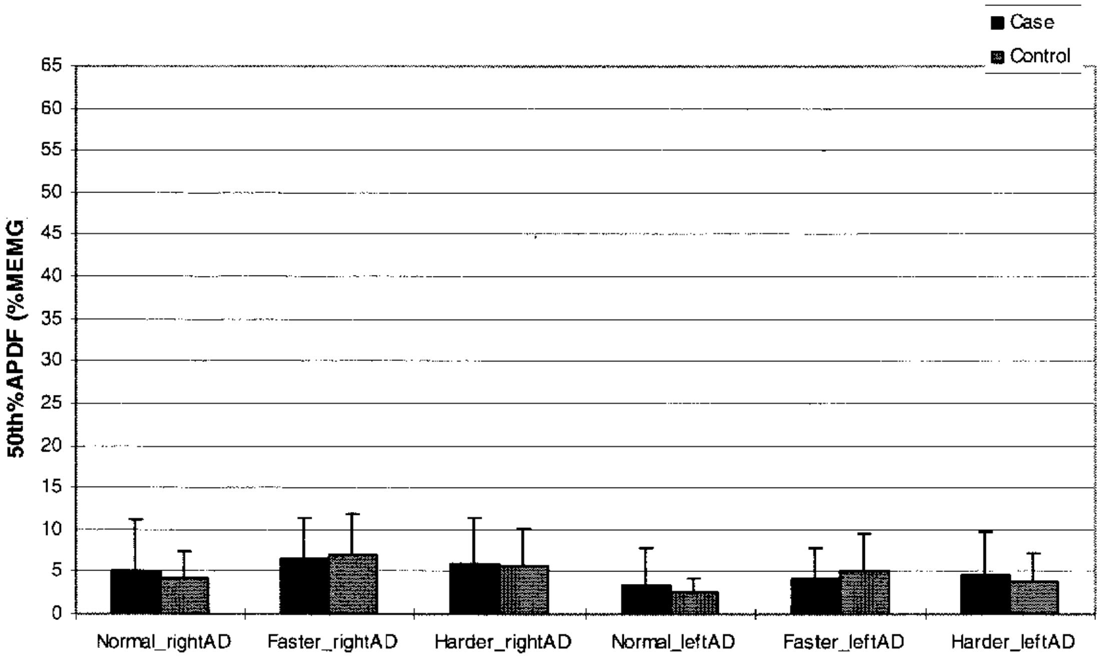


Fig. 7.2d: Mean 50th%APDF of AD muscles in the three typing conditions

7.3.1.2 *Results of MANOVA on 50th%APDF of 8 muscles*

A mixed model (between subjects *group* factor, within subjects *condition*, *side* and *time* factors) MANOVA was performed on the muscle activities (APDF) of all four muscles. All the 50th% APDF data of the four muscles were analysed in one analysis. From the multivariate analysis, the main findings were the significant *condition* effect ($F_{8,32}=5.60, p < .001$) and the significant *side* effect ($F_{4,36} = 8.81, p < .001$). There was also a significant 3-way interaction of *time* x *side* x *group* ($F_{16,24} = 2.92, p = .009$). The *group* factor ($F_{4,36} = 0.20, p = .937$) and the *time* factor ($F_{16,24} = 1.43, p = .209$) showed no significant main effect and the rest of the 2-way and 3-way interactions were also not statistically significant.

In the univariate analysis on the 50th%APDF, the *condition* factor showed a strong statistical significance as a main effect for all 4 muscles (CES: $F_{2,78}=17.05, p < .001$; UT: $F_{2,78}=20.35, p < .001$; LT: $F_{2,78}=10.27, p < .001$; AD: $F_{2,78}=6.82, p < .001$). There was no significant main effect for the *group* factor ($F_{1,39}=0.00\text{-}0.43, p =.516\text{-}.950$). The *time* factor showed a marginally significant difference for CES ($F_{2.2,86.1}=2.84, p=.059$) and LT ($F_{2.7,106}=2.61, p=.060$); but not significant for UT ($F_{3,117.9}=0.77, p=.513$) and AD ($F_{2.4,92.4}=1.91, p=.146$). The *side* factor was significant for LT ($F_{1,39}=7.42, p= .010$) and AD ($F_{1,39}=25.15, p< .001$). Among all the 2-way and 3-way interactions, CES had a significant *condition* x *side* x *group* interaction ($F_{2,78}=4.12, p=.020$), and LT had a significant *condition* x *side* interaction ($F_{2,78}=3.77, p=.027$). UT showed a marginal significance for the *condition* x *time* interaction ($F_{4.9,189.7}=2.23, p=.055$). The rest of the interactions were not statistically significant.

Fig. 7.3 illustrates the 3-way interaction for CES showing higher activity for the Case Group than the Control Group. There were also higher activities in the Faster condition more than Harder and then Normal conditions. There also appeared to be much higher activities on the left side in the Control Group compared to the Case Group.

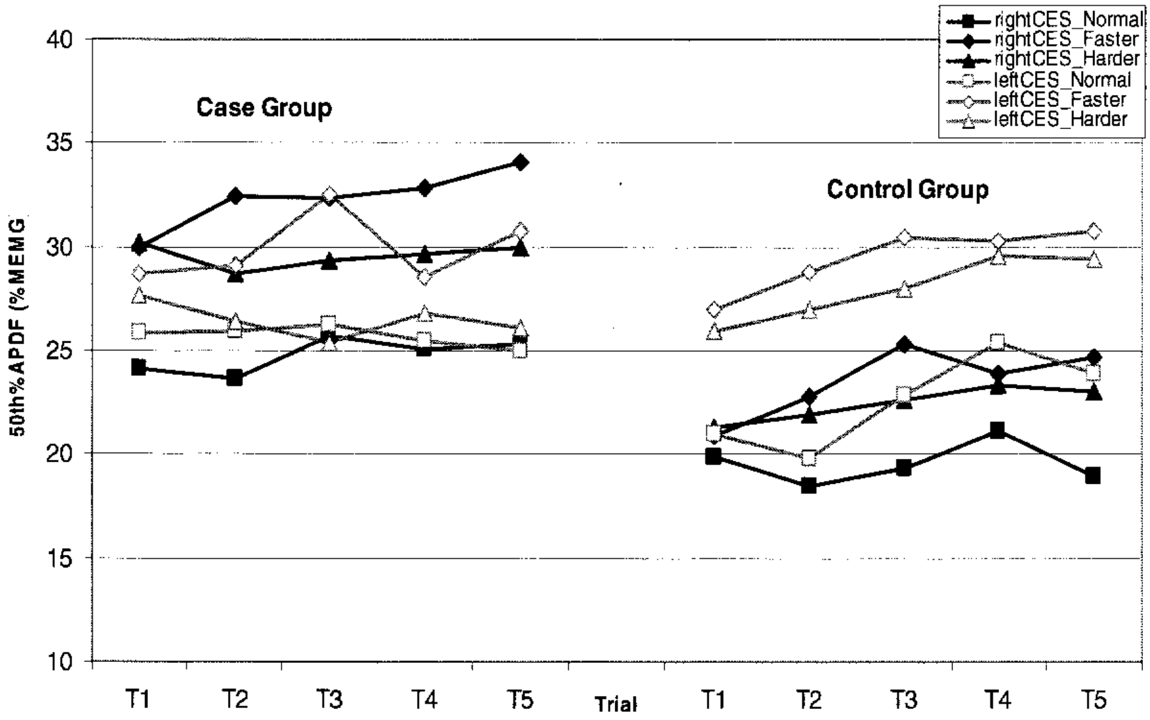


Fig. 7.3: Comparison of CES activities on both sides in the Case and Control Groups throughout the 5 trials in the 3 conditions

7.3.1.3 *Summary of APDF results*

On the whole, all four muscles responded differently to the three conditions of changing speed and force. There were trends for the Case Group showing greater increases in muscle activities in the Faster and Harder Conditions than the Control Group on the right side in the CES, UT and LT muscles. The Control Group showed trends for proportionally higher increases in muscle activities in the left CES and UT muscles. Generally the Faster condition seemed to elicit greater increases in muscle activities than the Harder condition.

7.3.2 EMG median frequency (MF) analysis

7.3.2.1 *Graphs and trends*

The EMG results were also analysed to examine changes in the power spectrum. In Fig. 7.4 a,b,c,d comparing the means of MF for the three conditions, it can be observed that the Case Group had a trend for consistently higher MF values than the Control Group, especially for the CES, UT and LT muscles. The most apparent Case-Control differences were in the right CES, right UT and bilateral LT muscles. In Fig. 7.4a, there appeared to be a trend for greater difference in the right CES as well as a decline of MF in the Faster and Harder conditions compared to the Normal. In Fig.7.4a, the Case Group seemed to show a decline in MF in the right CES muscle in the Faster and Harder conditions. In Fig. 7.4b, there was a marked Case-Control difference for all 3 conditions in the right UT and the MF were similar among the three conditions. The left UT showed a trend for higher MF in the Faster condition and the two groups had similar levels in MF. In Fig. 7.4c, both sides of LT had large Case-Control differences, and the Faster condition showed higher MF than the other two conditions. In Fig. 7.4c, there appeared to be a decrease in MF in the Faster condition compared to the other two conditions, and there appeared to be very similar MF between the Case and Control Groups. In summary, the most apparent Case-Control differences in MF appeared to be in the right CES, right UT and bilateral LT muscles. The UT and LT muscles showed trends for higher MF in the Faster condition, while CES and AD muscles showed similar or slightly declining MF in the Faster and Harder conditions.

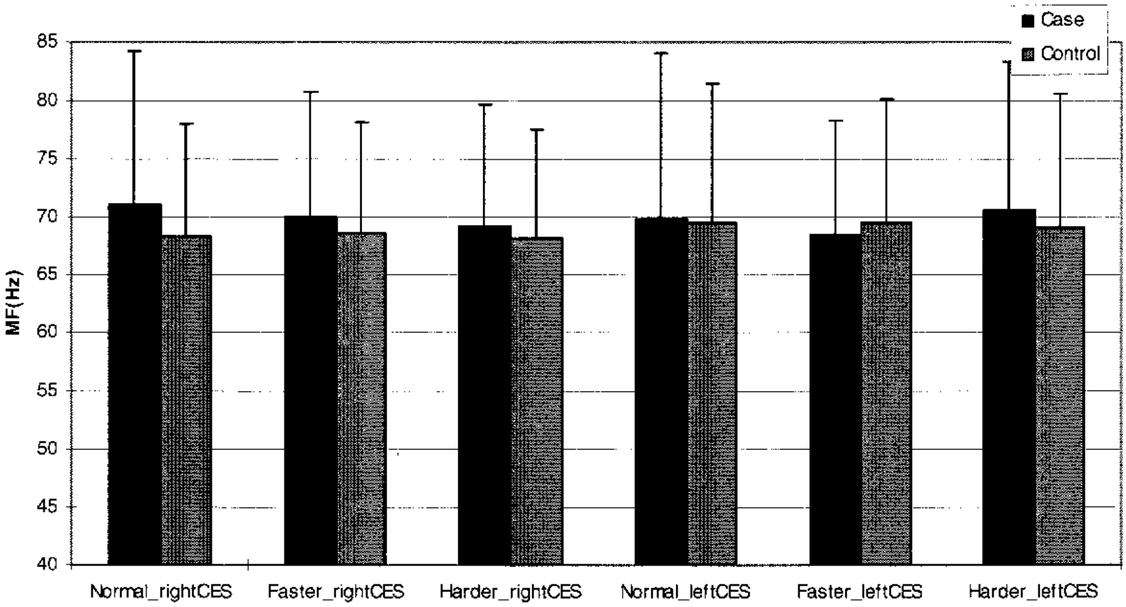


Fig. 7.4a: MF of CES muscles during the three typing conditions of Normal, Faster and Harder

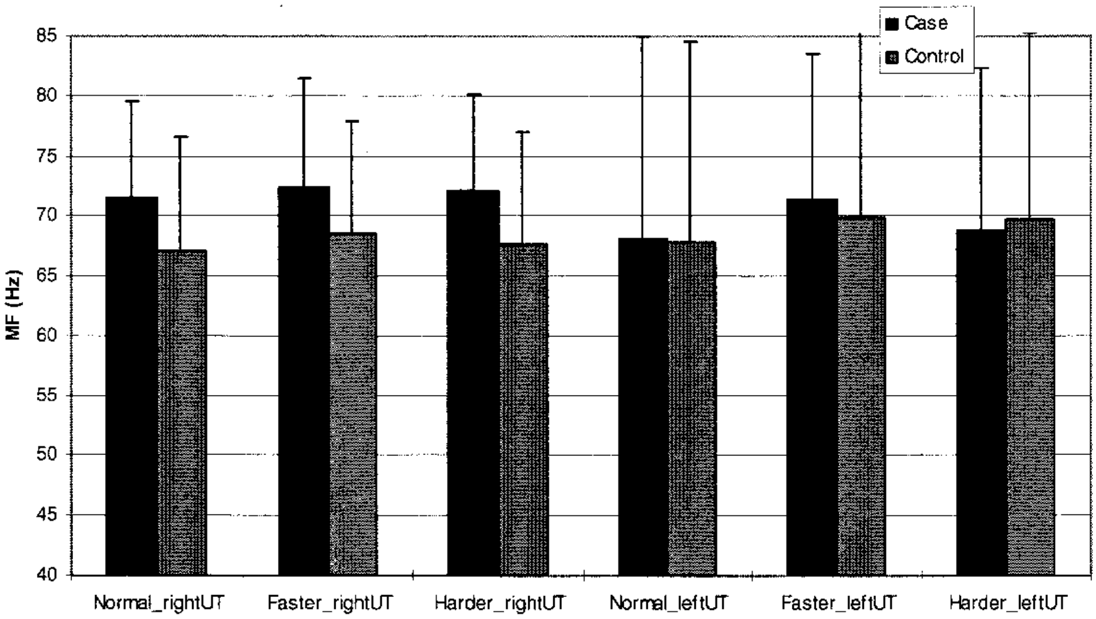


Fig. 7.4b: MF of UT muscles during the three conditions of Normal, Faster and Harder

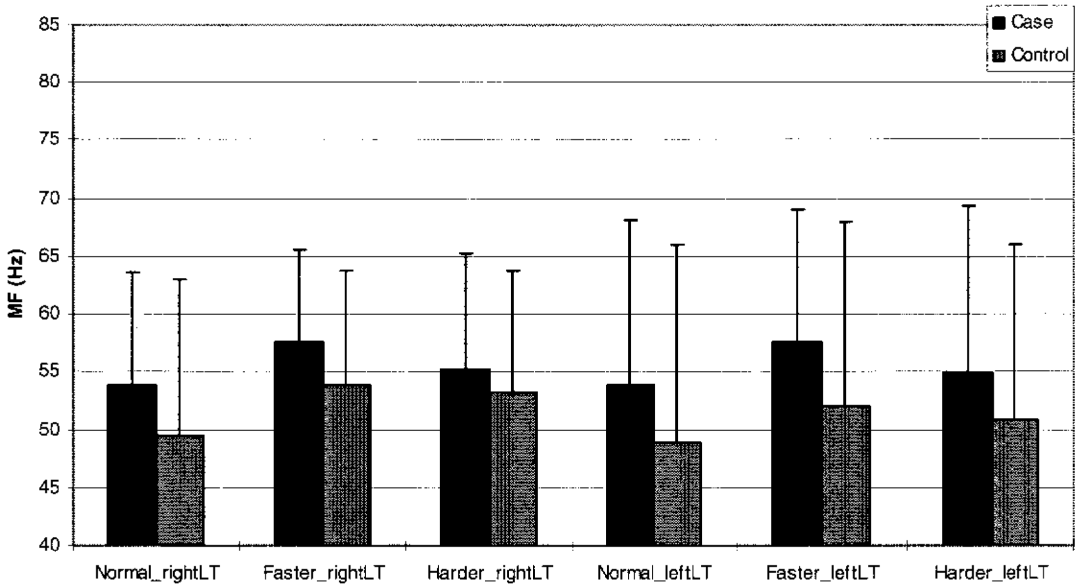


Fig. 7.4c: MF of LT muscles during the three typing conditions of Normal, Faster and Harder

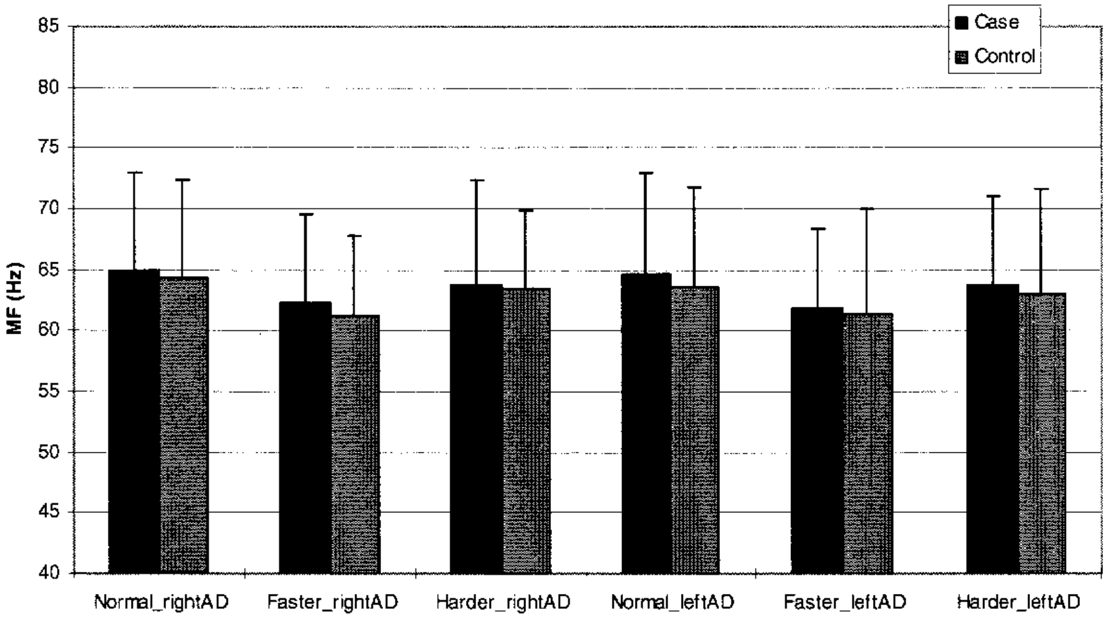


Fig. 7.4d: MF of AD muscles during the three typing conditions of Normal, Faster and Harder

7.3.2.2 *Results of MANOVA on MF*

In a mixed model MANOVA for the effects of *condition*, *time*, *side* and *group*, all the 4 muscles were examined in one analysis. Similar to the APDF results, the MF showed a very strong *condition* effect in the multivariate analysis ($F_{8,32} = 4.39$, $p=.001$). The *time* factor was also statistically significant ($F_{16,24}=2.28$, $p=.032$). The *group* factor ($F_{4,36} = 0.64$, $p=.634$) and the *side* factor ($F_{4,36} = 0.03$, $p=.999$) were not significant, and all the 2-way and 3-way interactions were also non-significant.

In the univariate analysis for the MF, the UT, LT and AD muscles had significant *condition* effects (UT: $F_{2,78} = 3.84$, $p=.026$; LT: $F_{2,78} = 6.15$, $p=.003$; AD: $F_{2,78} = 3.84$, $p<.001$), but not for the CES muscle ($F_{2,78} = 0.23$, $p=.793$). The *time* factor was significant for UT ($F_{4,156} = 2.50$, $p=.044$) and close to significance for AD ($F_{4,156} = 2.22$, $p=.069$), but not significant for CES ($F_{4,156} = 0.96$, $p=.434$) and LT ($F_{4,156} = 0.90$, $p=.466$). The *group* factor and the *side* factor were not significant for all 4 muscles (*group*: $F_{1,39} = 0.15\text{-}1.82$, $p=.185$ -.490; *side*: $F_{2,78} = 0.00\text{-}0.07$, $p=.569$ - .969). Among all the 2-way and 3-way interactions, AD showed a significant *condition* x *time* x *side* interaction ($F_{8,312} = 2.28$, $p=.022$). The *condition x time x side* interaction for UT was approaching significance ($F_{5,196.8} = 2.13$, $p= .062$), and so was the *condition x time x side x group* interaction ($F_{5,196.8} = 2.02$, $p= .076$).

7.3.2.3 *Summary of MF results*

In summary, the results suggested that the MF of the four muscles showed significant changes in response to the Faster and Harder conditions and these changes were not the same on both sides. The *condition* effect was significant for

UT, LT and AD muscles but not for CES, as the overall change in MF was relatively small in CES on the whole. From the graphs we could see that the MF increased to a greater extent in the Faster condition for UT and LT than in the Harder condition, and in AD there was a decline in MF in the Faster condition. The significant 3-way interactions for UT and AD in the univariate analysis suggested that these muscles had different changes on both sides in response to *time* and *condition.*

7.3.3 Discomfort results

7.3.3.1 *Graphs and trends*

In the three experimental conditions, the subject was asked to rate her discomfort at the first minute, the 10th minute and the 20th minute of each typing trial. Fig. 7.5a shows the summed discomfort scores for Case and Control in the 3 conditions. It can be seen that the Case Group had much higher discomfort scores compared to the Control Group in all trials; and the mean discomfort scores in the Case Group increased steadily from the start of the typing trial (0min) to the end (20min). The progressive increase in discomfort scores in the Case Group were higher in the Faster condition compared to the Harder condition.

7.3.3.2 *Statistical analysis on discomfort scores*

The summed discomfort score for each trial was analysed using repeated measures ANOVA with *condition (*x3 levels) and *time* (x 3 levels) as within subjects factors, and *group* as between subjects factor. In the multivariate analysis of the summed scores, there were significant differences due to *condition* ($F_{2,38}$=20.17, p<.001) and *time* ($F_{2,38}$=15.42, p<.001). There was also a significant *condition x group* interaction ($F_{2,38}$=16.59, p<.001) and *time x group* interaction ($F_{2,38}$=8.77, p=.001), suggesting that there were significant differences in discomfort across the 20-minute typing trials, and these changes were not the same for both groups.

In the univariate analysis for the summed discomfort scores, the *group* factor had a very strong significance as a main effect ($F_{1,39}$=62.64, p<.001). The *condition* factor and the *time* factor were also statistically significant (*condition*: $F_{2,78}$=16.02, p<.001; *time*: $F_{1.3,52.1}$=26.93, p<.001). Again the *condition x group* interaction ($F_{2,78}$=13.15, p<.001) and the *time x group* interaction ($F_{1.3,52.1}$=14.28, p=.001) were statistically significant.

7.3.3.3 *Dividing Case Group into a High Group and a Low Group*

When the discomfort scores of the Case Group were examined further, two sub-groups could be identified. The "High" Group (n=8) was defined by a mean score of 15.0 or over in the Normal condition, and the "Low" Group (n=13) had mean scores lower than 15.0. When the mean scores were compared using one-way ANOVA with pairwise contrasts, significant differences were found in all the pairwise comparisons between the High Group, Low Group, and Control Group (t_{38} =2.24-10.61, p <.001). Only in the initial part of the Normal Condition did the Low Group had similar discomfort scores to the Control Group (t_{38} =1.26, p=.215). The Low Group also showed significant increases in discomfort scores across time in all 3 conditions, but their patterns of discomforts were significantly lower than the High Group in all three conditions (see Fig. 7.5b).

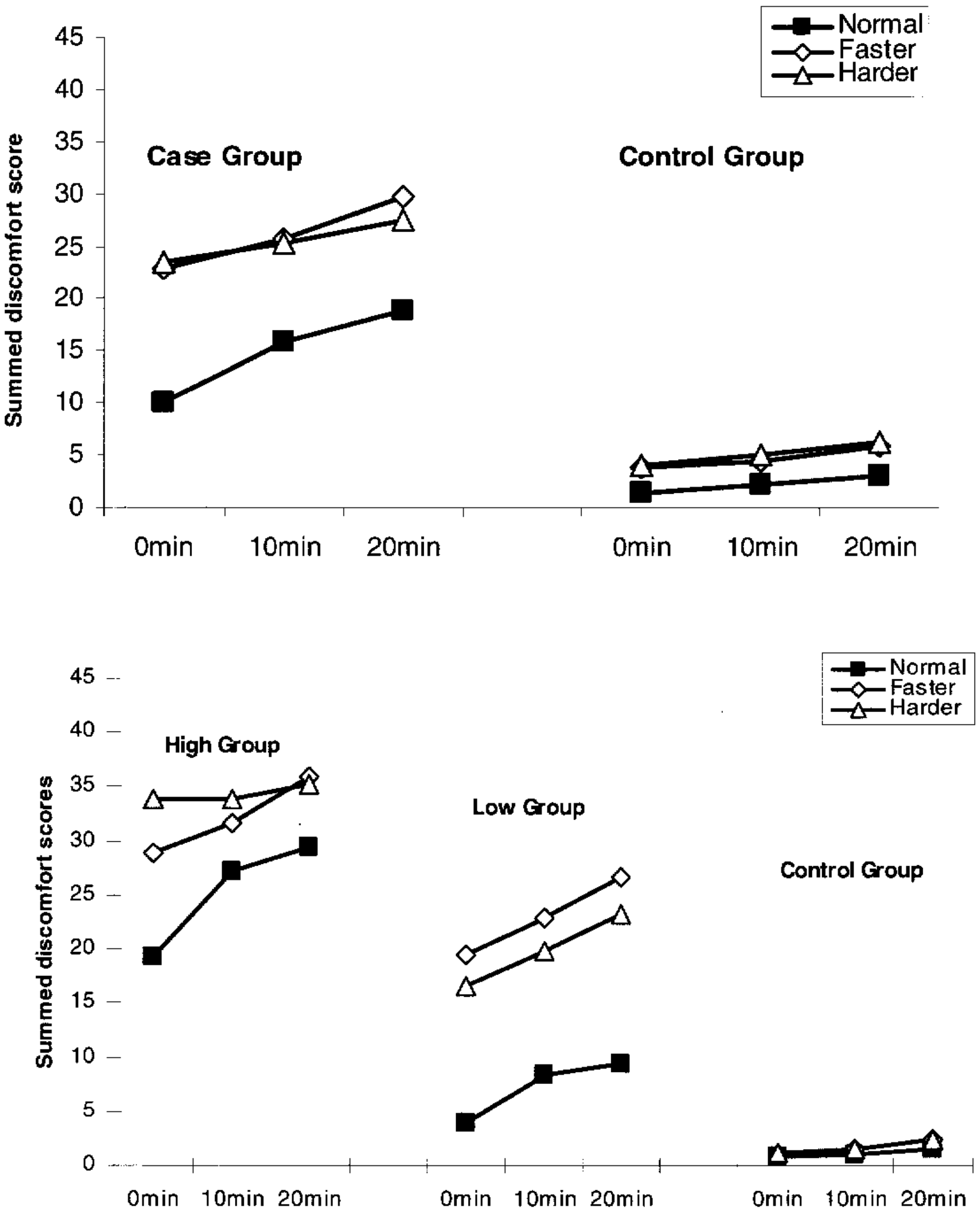


Fig. 7.5a&b: Comparison of discomfort scores (a) in Case and Control Groups in the 3 conditions; (b) in High, Low and Control Groups in the 3 conditions

7.3.3.4 *Comparing muscle activities in High-Low Groups*

Fig. 7.6a,b show the mean values of the 50^{th}% muscle activities of the CES and UT muscles compared among the High, Low and Control Groups. It can be observed that the High Group generally showed more apparent differences to the Low Group and the Control Group in bilateral CES activities as well as the right UT activity (See Fig 7.6 a&b). On the whole, there were trends for much higher increases in the High Group in the Faster condition compared to the Harder condition. In comparison to Fig 7.2 a&b, the increase in muscle activities in CES and UT muscles were mainly in the High Group subjects and the Low Group showed smaller extents of change in both muscles bilaterally. In particular the bilateral CES muscle and the right UT muscle showed trends for apparently much higher increases in the High Group in the Faster and Harder conditions, than the Low Group and the Control Group. The left UT muscle showed trends for higher or similar activities in the Low and Control Groups compared to the High Group.

The 50^{th}% muscle activities of the CES and UT muscles were also compared statistically among the High, Low and Control Groups using one-way ANOVA with pairwise contrasts. Generally, the comparisons between the High and the Low Groups were not statistically significant, which may be due to the sample size difference. The difference between the High and Low Groups in the right UT for the Faster condition was approaching statistical significance (t_{38}= 1.95, p=.059).

The CES and UT muscle activities were also compared in terms of amplitude ratios and four ratios were computed. Ratios of EMG amplitudes between pairs of muscles have been used in clinical studies of low back pain patients to identify normal and abnormal muscle recruitment patterns between synergists (Edgerton et al., 1996; O'Sullivan et al., 1997). In our previous study we have also reported significant group differences in UT/CES amplitude ratios when High, Low and Control Groups were compared in a prolonged typing task (Chapter 4).

Ratios were computed between the UT and the CES amplitudes on the right side, likewise on the left side; between the UT muscle on the right and left sides, and likewise for the CES muscle. The present results showed no significant difference in the UT/CES ratios on either side. There was a significant difference in the right/left ratio of the UT amplitude in the Normal condition ($F_{2,38}$= 1.20, *p*=.003) due to the significant difference between High and Control (t_{38}=3.48, *p*=.001), and the difference between High and Low (t_{38}=3.08, *p*=.004). In the Harder condition, the right/left UT ratio was also different in the High - Control contrast (t_{38}=2.25, *p*=.030). The right/left CES ratio was also significantly different in the Faster condition (t_{38}= 2.05, *p*=.048). These results suggested that the High Group subjects showed greater increases in UT and CES activities on the right compared to the left in response to the Faster and Harder conditions; whereas the Low Group and the Control Group showed comparatively lesser extents of change in muscle activities in these conditions.

Interestingly in the LT muscle activities for the three conditions, the Low Group showed the consistent trends for highest increases on both sides compared to the High Group and the Control Group. This may suggest that they recruited their LT muscles more than the other two groups but the idea needs to be confirmed with more studies. The AD muscles did not show very obvious group differences except a slightly greater activity in the High Group in the Faster and Harder conditions.

7.3.3.5 *Comparing discomforts scores and muscle activities in High-Low Groups*

The discomfort responses showed significant *group* effects, *time* effects and *condition* effects. In particular the Case Group showed two sub-groups with distinctly different patterns of discomfort responses to the three typing conditions. The Control Group responded with minimal changes in discomfort scores across all three typing conditions. When the Case Group was divided into a High and a Low Group, distinctly different patterns of discomforts emerged for each group. The High Group had high discomfort scores initially in the Normal condition and the scores increased to even higher levels with the Faster and Harder conditions. The Low Group had only low discomfort scores in the Normal condition, but their discomforts increased markedly for both Faster and Harder conditions.

When the muscle activities of the Case subjects were examined in the two sub-groups, the High Group showed more apparent increases in activities in both CES and UT to the demanding conditions of typing faster and harder. The High Group showed trends for proportionally greater activities in the CES muscles than both the Low and Control Groups in all 3 conditions. The UT muscle also showed a trend for much higher activities in the High Group compared to the Low and Control Group on the right side. The differences between groups in right UT activity were much more apparent in the High-Low comparisons than when the Case Group was considered as a whole as in Fig. 7.2b.

The Low Group also showed increased activities but to lesser extents in the Faster and Harder conditions. The Control Group showed more apparent increase in the left CES activity in the Faster and Harder conditions, while the right CES and bilateral UT muscle activities showed very similar changes in the Faster and Harder conditions between sides. These results for the Low Group and the Control Group may suggest that they had more even distribution of muscle loads between two sides in meeting the higher physical demands of the Faster and Harder conditions.

Table 7.2: Summary of statistical analysis comparing High, Low and Control Groups in muscle activities (UT and CES)

50^{th}% APDF	**Experimental cond**	**Case: High (n=8)**	**Case: Low (n=13)**	**Control (n=20)**	**One-way ANOVA**		**Contrasts [t_{38}, sig.(2-tailed)]**		
		Mean (SD)	**Mean (SD)**	**Mean (SD)**	**F (2,38)**	***p***	**High vs Control**	**Low vs Control**	**High vs Low**
Right CES	Normal	28.6 (13.7)	23.9 (19.9)	20.2 (16.6)	0.75	.479	-0.65, .238	0.64, .526	0.61, .546
	Faster	40.5 (25.3)	28.6 (26.2)	24.0 (15.9)	1.68	.200	1.83, .075	0.61, .547	1.22, .228
	Harder	35.7 (25.1)	26.7 (25.7)	22.9 (16.8)	0.99	.382	1.41, .168	0.48, .634	0.93, .359
Left CES	Normal	30.5 (23.2)	22.0 (16.6)	31.5 (23.2)	0.63	.538	1.02, .314	-0.10, .921	1.03, .310
	Faster	37.2 (27.2)	24.5 (17.7)	29.4 (20.1)	0.90	.414	0.89, .380	-0.65, .519	1.34, .187
	Harder	31.5 (23.2)	22.7 (15.9)	28.0 (22.2)	0.49	.613	0.40, .692	-0.73, .473	0.95, .349
Right UT	Normal	24.2 (28.0)	11.7 (8.9)	13.1 (12.4)	1.80	.178	1.69, .099	-0.24, .808	1.77, .085
	Faster	30.6 (30.4)	16.1 (10.3)	19.2 (12.0)	2.01	.148	1.64, .108	-0.53, .601	1.95, .059
	Harder	27.5 (28.2)	14.5 (9.9)	16.5 (11.2)	1.91	.162	1.69, .100	-0.36, .719	1.86, .071
Left UT	Normal	8.6 (4.8)	12.9 (11.9)	13.0 (11.1)	0.54	.585	-0.99, .328	-0.03, .978	-0.90, .373
	Faster	18.4 (8.9)	17.5 (14.5)	20.8 (19.5)	0.17	.841	-0.35, .730	-0.56, .576	0.12, .901
	Harder	12.8 (6.9)	15.6 (13.5)	17.2 (12.2)	0.39	.675	-0.89, .380	-0.37, .710	-0.53, .600
Right UT / right CES	Normal	0.97	0.66	0.73	0.53	.593	0.85, .400	-0.26, .796	0.99, .324
	Faster	0.78	0.74	0.88	0.33	.723	-0.46, .645	-0.78, .441	0.18, .854
	Harder	0.86	0.75	0.83	0.09	.913	0.09, .932	-0.36, .717	0.37, .713
Left UT / left CES	Normal	0.40	0.66	0.61	0.84	.441	-1.09, .280	0.28, .783	-1.24, .222
	Faster	0.62	0.80	0.73	0.29	.746	-0.47, .642	0.42, .679	-0.77, .448
	Harder	0.49	0.76	0.67	0.77	.470	-0.88, .383	0.53, .602	-1.24, .223
Right UT / left UT	Normal	4.44	1.41	1.25	1.20	**.003** *	3.48, **.001** *	0.20, .840	3.08, **.004** *
	Faster	2.05	1.26	1.26	2.95	.242	1.61, .115	-0.02, .987	1.51, .138
	Harder	2.65	1.51	1.16	1.91	.091	2.25, **.030** *	0.63, .532	1.60, .118
Right CES / left CES	Normal	1.17	1.19	0.94	6.59	.311	1.10, .279	1.40, .169	-0.09, .929
	Faster	1.26	1.23	0.88	1.47	.065	1.92, .063	2.05, **.048***	0.16, .872
	Harder	1.27	1.18	0.92	2.55	.162	1.70, .098	1.48, .146	0.40, .689

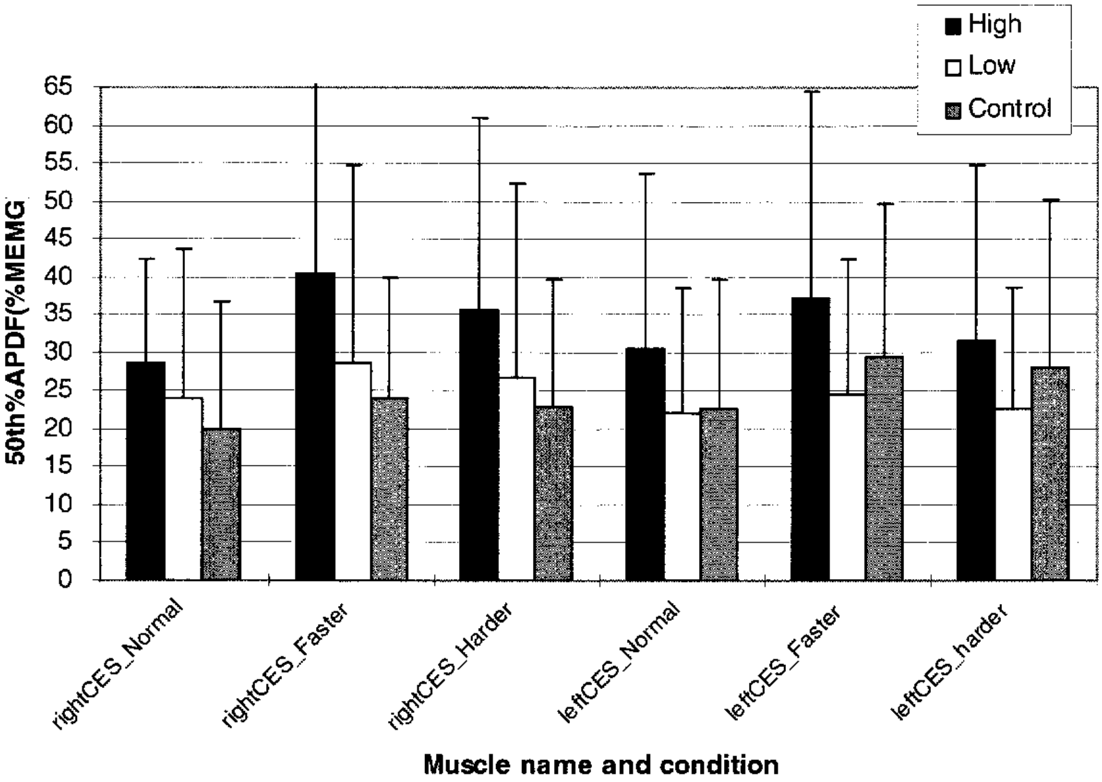


Fig. 7.6a: Comparison of 50th %APDF of CES muscle in High, Low and Control Groups in the 3 conditions

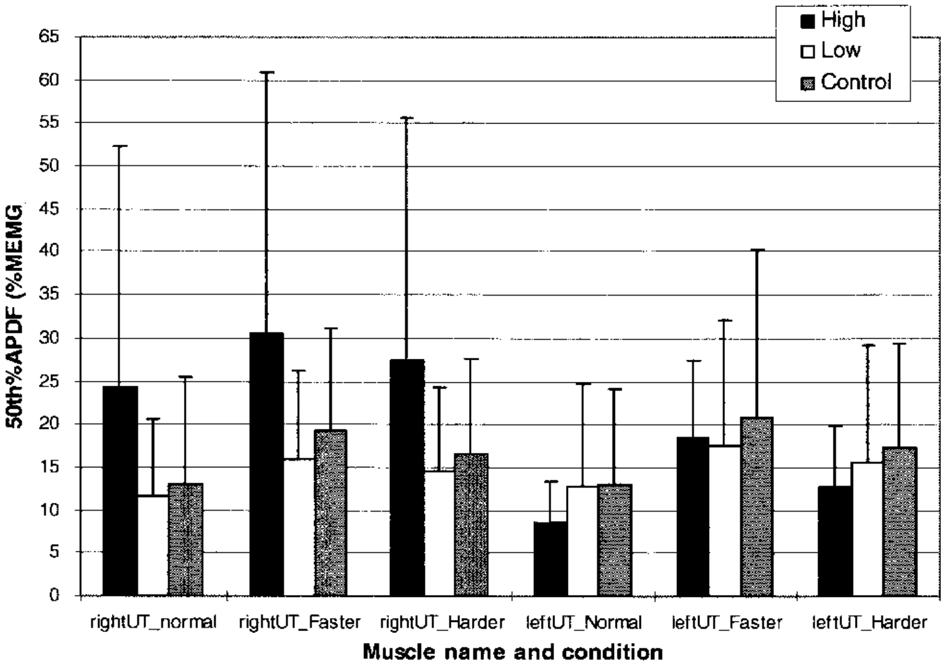


Fig.7.6b: Comparison of 50th %APDF of UT muscle in High, Low and Control Groups in the 3 conditions

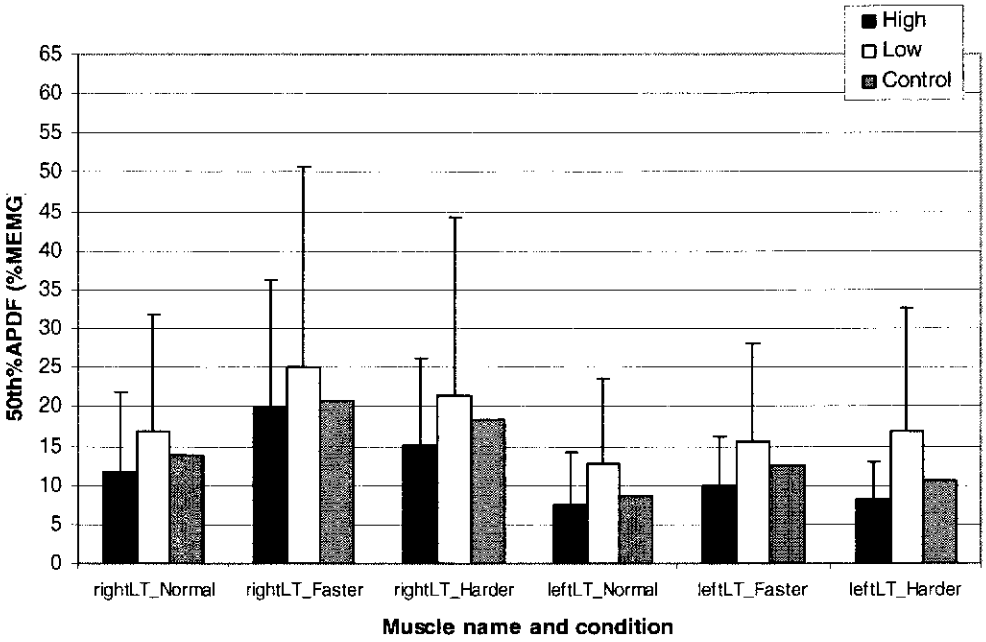


Fig.7.6c: Comparison of 50th%APDF of LT muscle in High, Low and Control Groups in the 3 conditions

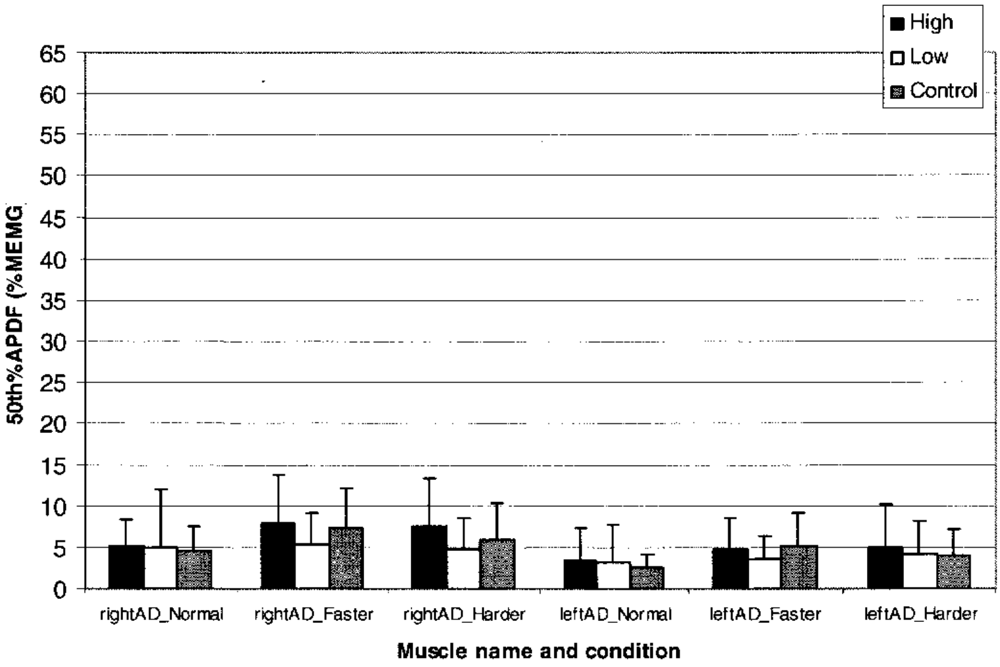


Fig.7.6d: Comparison of 50th%APDF of AD muscle in High, Low and Control Groups in the 3 conditions

7.4 DISCUSSION

7.4.1 Group differences in muscle activities in response to 3 typing conditions

The present study has demonstrated important group differences in the neck-shoulder muscle activities in response to the different demands of speed and force in keyboard operation. Examining the EMG amplitude changes, the *condition* factor produced the most significant change in the activities of all four muscles. These results suggested that all the major muscles had to work with higher muscle activities in performing the keyboard task with increased speed or increased force. We will discuss the effects of increased speed and increased force of keyboard operation separately in the following sections.

7.4.1.1 *Group differences in EMG amplitudes in response to the Faster condition*

The present results showed that the Faster condition produced trends for greater increases mainly in muscle activities in the right CES, UT and LT muscles than the Harder condition. This result suggested that working with increased speed may cause greater strain in the proximal (neck-shoulder) stabilizing muscles, particularly in the right sided stabilizers as the right arm was the dominant arm. The Case-Control group difference appeared to be most obvious in the right CES muscle in the Faster condition, while the right UT and LT muscles showed proportionally smaller differences between Case and Control Groups. This result may suggest that the CES muscle was more reactive than the UT and LT to the demand of increased speed in the Faster condition. The Case Group showed trends for slightly higher increases in the right side of the CES and UT muscle activities in the Faster condition while the Control Group showed higher increases in both the left CES and UT activities in the Faster condition. These results suggested that in the stressful situation of having to type at a faster speed while maintaining a good level of accuracy, the Case subjects utilized their right sided stabilizers to even greater extents than the left, while the Control Group seemed to spread the load more evenly between the left and right sides. By distributing the loads more evenly between the two sides, the Control Group may have a better motor control strategy than the Case Group, and this may have an important association with their large disparities in discomforts.

The LT and the AD muscle showed no obvious difference between the two groups in both left and right sides, which suggested that these muscles did not demonstrate such discrepancies in motor control between Case and Control Groups under the demands of the Faster condition.

The present results are consistent with those of previous studies showing substantial increases in muscle activities when subjects had to perform computer or manual tasks with increased speed (Birch et al., 2000; Laursen et al., 1998a & b; Westgaard & Bjorkland, 1987). These authors attributed the increase in stabilizing muscle activities to the higher level of agonist-antagonist co-contraction of muscles involved in performing faster and/or more precise movements. Birch et al. (2000) reported that the highest increase in UT muscle activities was recorded in the condition combining high time pressure with low precision and mental demand. This situation would be similar to the Faster condition in our study, when the subjects focused on increasing their working speed and not the force or accuracy of their typing. The results suggested that the same individuals may adopt different muscle recruitment strategies in order to perform motor tasks at different speeds. However, there was no inter-individual comparison in the past studies, and the influence from or effect on discomfort was unclear.

Our present results represented one of the first studies to examine inter-individual differences in motor control when the subjects had to perform with increased speed in computer tasks. The major difference between the two groups of subjects was their past history and their present experience of discomforts; and they were being exposed to the same physical demand of increasing their typing speed to 120% of their baseline performance. The environmental factors were also controlled by having the subjects performed the same typing task using the same workstation and equipment, and their postures were adjusted to be similar erect postures. The results were able to demonstrate intrinsic differences in muscle recruitment strategies in different individuals, mainly between those with more severe symptoms and those without.

Gerard et al. (2002) reported that faster typists used different muscle recruitment patterns that were more efficient than the slower typists but these were in the forearm muscles. Our study has shown altered muscle activity patterns in the proximal stabilizers of symptomatic subjects due to increased typing speed and these would have direct implications on the development of WRNULD in these individuals.

Tasks requiring higher speeds may or may not involve higher cognitive and mental demands, and the complex interactions of many internal and external factors affecting human performance must be recognized (Sommerich et al., 1996b). Past research has identified the "speed-accuracy trade-off", which predicted that when motor tasks were performed with higher speed, there may be a loss of accuracy of performance (Gentner, 1983). In our present experiment we required the subjects to maintain a reasonably high level of accuracy (>90% correct in text typed), while increasing their typing speed by a mean of 20% above their baseline. This requirement would certainly create a high demand on the coordination of the hand actions as well as the entire motor control system from higher cerebral centres down to the peripheral motor apparatus. This factor may involve both increased physical and psychological strain on the subjects. However, it appeared that subjects in the Control Group could cope with these stress factors more efficiently than those in the Case Group.

The experimental situation may be a close simulation of practical working situations, where workers may be required to work at a faster pace in order to meet a deadline, while the performance needs to maintain a high standard. Past studies have also reported a higher odds ratio for neck pain as well as wrist-hand pain due to the number of hours spent under a deadline (Bernard et al., 1994). The present results implied that if workers perform keyboard tasks at very high speeds, they may be subjecting their muscles to greater strains resulting in greater discomforts. This problem may be even more exaggerated if the individuals already have a history of past and present discomforts.

The present results implied that the task demand of increased keystroke speed did not produce the same responses in all individuals. The Control Group seemed to be able to cope with such demands and there were relatively small increases in muscle activities and discomfort. In contrast the Case Group subjects produced trends for higher increases in muscle activities and significantly increased discomforts in meeting the same task demands, especially in the High Group individuals.

7.4.1.2 *Group differences in the Harder condition*

Interestingly the Harder condition showed trends for relatively smaller increases in muscle activities compared to the Faster condition and this trend was observed in all four muscles. These findings may imply that increasing the force demand in performing keystroke actions did not require large increases in muscle effort as in the Faster condition. It is possible and likely that there may have been greater muscle effort required in the distal muscles such as the wrist and finger flexors and extensors. Further research could be conducted in order to investigate this.

Interestingly, the Case-Control differences in the activities of respective muscles were maintained at very consistent levels in all the Normal, Faster and Harder conditions (see Fig 7.2a,b,c,d). In examining the Case Group muscle activities, it can be seen that the right sided muscles were consistently higher than the left side in all conditions. Yet the Control Group had very similar levels of muscle activities in the UT muscle, even higher activities in the left CES than the right, and trends for slightly higher LT and AD activities on the right. Again similar to the Faster condition, the Control Group seemed to have more even distribution of muscle activities than the Case Group. The AD muscle is a dynamic mover of the shoulder joint and it was expected that this muscle would show greater changes in activities in performing the typing actions with greater force. However, the results showed very little increase in the AD muscle activities on both sides, and this was the same in both Case and Control Groups. These results may suggest that only certain muscles (namely the CES and UT muscles) were more affected in symptomatic persons than in asymptomatic persons.

Previous studies examining typing force and muscle activities have reported increases in forearm muscle activities that were positively correlated to the typing force, but these studies have focused more on comparing different features in keyboard designs (Armstrong et al., 1994; Gerard et al., 1999; Rempel et al., 1997; Sommerich et al., 1996a). These studies have reported on the effects of different keyswitch make force (for activating the keys) and actual applied forces, and muscle activities in the forearm muscles. Gerard et al. (2001) measured the typing forces and the resultant finger muscle activities when typists worked with different typing speeds, but they did not examine the effects of controlling the typing forces. Feuerstein et al. (1997) compared the typing forces of symptomatic and asymptomatic subjects but there was no measurement of muscle activities. To our knowledge, no prior study had examined the effects of changing the keystroke forces on the muscle activities of the proximal stabilizers such as the UT and the CES muscles, especially in a Case-Control design.

7.4.2 Group differences in MF comparing 3 conditions

The present results have demonstrated trends for group differences in MF when the subjects worked in the three conditions. The difference between Case and Control Groups was more apparent in the right UT and in the bilateral LT muscles, with Cases having higher MF than Controls. The CES and AD muscles did not demonstrate much apparent group difference in MF on either side. The MF of the 4 muscles did not seem to be affected by the demands of the three typing conditions.

In our previous study on the effects of static posture (Chapter 5), there was also a consistent trend for higher MF in the same muscles of the Case subjects compared to the Controls. Thus the results of the present study add to the evidence confirming that symptomatic persons tended to have higher MF in their muscles compared to asymptomatic persons.

Higher MF has been suggested to indicate an increased recruitment of type II muscle fibres which are more prone to fatigue (Hagg, 1992; Madeleine et al., 1999). It is generally agreed that postural stabilising muscles such as the UT and CES are mostly responsible for generating low-force endurance type contractions, recruiting mainly type I motor units which are more resistant to fatigue (Hagg, 1992). However, in symptomatic persons, there may have been an alteration in motor control strategy resulting in increased recruitment of type II fibres in addition to type I fibres. These muscles may be more prone to fatigue and this may be linked to the development of pain and discomfort. Further studies such as motor unit investigations and/or muscle biopsy studies may be useful to provide more insight into this phenomenon.

7.4.3 Increase in discomforts significantly greater in Case than Control Group

The discomfort scores reported by the Case subjects were significantly increased in both the Faster and the Harder conditions. In contrast, the Control subjects reported only minimal increase in discomforts throughout the three typing conditions. Given that their work experiences were very similar, the large discrepancies in their discomfort scores suggested that the Control subjects were able to cope with the physical stressors of speed and force much more comfortably than the Case subjects. The Case subjects seemed to be much more reactive to new stresses, and this trend is also reflected in their muscle activity patterns as well as their keystroke performance.

7.4.3.1 *Comparing the High-Low Groups in discomforts and muscle activities*

In Study 2 (Chapter 4) that examined muscle activities in Case and Control subjects while performing a one-hour continuous typing task, we found that the High and Low sub-groups from the Case Group demonstrated significant differences in the discomfort scores as well as EMG amplitude ratios of right UT and right CES muscles (right UT/CES). The Low Group showed very similar patterns to the Control Group, both in terms of discomfort scores and muscle activity patterns.

In the present study, we also divided the Case Group into a "High" Group and "Low" Group based on their discomfort scores in the Normal Condition. Interestingly we found that the Low Group displayed a distinctly different pattern of discomfort responses from both the High Group and the Control Group (see Fig. 7.5b). Although their discomfort scores were low in the Normal condition, their discomforts rose to levels that were close to those of the High Group in the Faster and Harder conditions. This result is most interesting, as it suggests that the Low Group subjects may have a potential to behave like the subjects in the High Group, when they are exposed to high stress levels. More in-depth study of the characteristics of this group of individuals is certainly warranted. This increase in discomfort could result from increased loading of previously sensitised tissues, such as the neck-shoulder muscles or the articular structures in the cervical spine.

When the EMG amplitudes of the CES and UT muscles were compared between the High and Low Groups of the Case subjects, it has revealed a totally different picture about the muscle activity changes in response to the Faster and Harder conditions. It was apparent that the greatest increases in amplitudes were mainly in the High Group for both left and right CES, as well as the right UT. However, the differences in muscle activities between High and Low Groups were not statistically significant, which may be attributable to the small sample size (High=8, Low=13). When activities of 4 muscles in High and Low Groups were compared in a MANOVA with *condition* x 3 levels, *side* x 2 levels and *group* as between factor (2 levels), $F_{1,19} = 0.54 - 1.05$, $p = .292 - .470$, and the observed power = .108 - .178]. With the large number of dependent variables and the independent variables involved comparing among 3 conditions, between sides and between groups, it is indeed difficult to show statistically significant differences.

The right UT muscle has been shown to be a high load-carrier for the postural stabilization during a prolonged typing task as shown in Study 2 (Chapters 4-6). In the present study it seemed that the High Group subjects needed to recruit the bilateral CES muscles in addition to the right UT muscle for the postural stabilization in the Faster and Harder conditions. Thus the results suggested that when the physical demands were greater, the more symptomatic subjects recruited more muscles to assist in sharing the muscle load.

Similar to Study 2, the Low Group subjects in the present study had more similar muscle activity patterns to the Control Group (Chapter 4). These results suggested that muscle activity patterns may be more correlated with discomforts in certain individuals such as the subjects in the High Group, while in other individuals such as those in the Low Group, other factors may have greater influences or correlations with discomforts induced by the physical stressors. These "other" factors may be psychological in nature, and further research is required to explore the intrinsic differences between the High – Low Groups.

7.4.4 Potential models explaining inter-individual differences in response to different physical stressors

7.4.4.1 *Present results support the Altered Motor Control Model*

In Study 2 we have found altered muscle recruitment patterns and altered kinematics between Case and Control Groups, and these differences were even more apparent when Case Group was sub-divided into High and Low Groups (Chapters 4-6). These group differences have been attributed to possible motor control changes in the symptomatic individuals associated with their past history of WRNULD (Chapter 6).

Based on our findings, we postulated that symptomatic persons may have become habituated to a concentrated upper trapezius recruitment strategy. The UT muscle is thought to be a "global stabilizer" for sustaining the static cervical posture and upper limb flexion during functional upper limb tasks. We have also proposed that this muscle may have a dual role in stabilizing the cervical spine as well as the shoulder joint, and this appeared to be a selective motor control strategy in those individuals with more severe discomforts only.

In the present study, the Case subjects seemed to have trends for higher activities in both the CES and UT muscles, rather than in the UT alone. This result was most likely due to the different task demands as well as the different computer workstation setup in the two studies. In the present study, the subjects were required to rest their forearms on a wooden bench in order to avoid unnecessary contact with the keyboard and force platform. This should have relieved some of the demand on the neck-shoulder muscles to support the weight of the arms during typing. Yet in the High Group subjects, both the CES and UT muscles showed trends for high increases in muscle activities in the Faster and Harder conditions. This would imply that in spite of the forearm support, the stressful demands of increasing typing speed and force have elicited a strong response from the neck-shoulder stabilizing muscles of High Group individuals. These results would support the Altered Motor Control Model as proposed in Chapters 4 and 6, and in addition, the results demonstrated that this altered motor control strategy may be elicited by different physical stressors.

In contrast, the Low Group and the Control Group showed proportionally lower activities and much more even distribution of muscle load between the CES and UT on both sides, which would be a more efficient motor control strategy in dealing with the physical stressors. These results demonstrated that the distribution of muscle load was affected by both external and internal factors, and these symptomatic-asymptomatic differences would confirm the intrinsic nature of the group responses that are likely to persist in different situations.

Under "normal" circumstances, it is expected that the motor control of the proximal stabilizers should be executed independently from the control of the distal dynamic movers, although they are likely to be related (Gentner, 1987). When a new physical stressor such as increased typing force is introduced, an individual with a good motor control strategy may learn to adapt to the new stressor and no large increase in muscle effort should be required. This appears to be evident in the Control Group subjects, who maintained similar levels of proximal muscle activity under the Faster and the Harder conditions. On the other hand, the Case subjects, especially those in the High Group, demonstrated trends for greater increases in bilateral CES and right UT muscle activities, in both the Faster and the Harder conditions; implying that they required greater muscle efforts to cope with the increased physical demands. However it must be acknowledged that these group differences did not reach statistical significance.

Subjects in the Low Group also demonstrated a susceptibility to increased discomforts with different patterns of change in muscle efforts, when they are subjected to high levels of physical stress. The Low Group demonstrated proportionally less increases in CES and UT activities and showed more apparent increase in LT activities, and this would also imply a more balanced muscle recruitment pattern. These results suggested that the physical stressors in the present study were able to elicit stronger reactions from this group of individuals, than the demands in Study 2.

In Chapter 4 we have proposed that the high concentration of muscle activities in the right UT muscle may have resulted in an asymmetrical loading of cervical articular structures which contain abundant nociceptors for generating a widespread pattern of pain. In the present study these mechanisms were also likely to occur but possibly to different extents as there were also high levels of CES activities beside the high UT activities.

The altered motor control is likely to involve changes that developed over a long period of time within certain individuals, and we have proposed that the long durations of daily computer work and increasing reliance on the mouse as input device may be important factors that may be related to these changes. However, there are likely to be more than purely the physical workload that has led to changes in internal motor control strategies, since other individuals such as those in the Low and Control Groups were not affected in a similar way. The ability to handle mental stress, past health status, personality characteristics and personal work or postural habits may be important factors causing the High Group individuals to develop such changes (Jensen et al, 1993a; Linton, 2000; Westgaard, 1999).

7.4.4.2 *Heightened Sensitivity Model*

The present results have demonstrated that different individuals have different levels of responsiveness to the demands of the physical stressors. The High Group subjects exhibited much greater responses in their muscle activity patterns to the stressful demands in the Faster and Harder conditions. In the High Group the most apparent changes were in the bilateral CES and the right UT muscles. The Low Group showed comparatively lesser extents of change in these muscles but they showed greater increases in the LT muscles bilaterally. These results suggested that heightened sensitivity may be an important mechanism affecting the different reactivities of the different individuals to the same physical demands.

Studies on the pathomechanics of musculoskeletal pain have produced evidence to support central sensitization of nociceptive processing (Sheather-Reid & Cohen, 1998) as well as peripheral sensitization of muscle nociceptors (Graven-Nielsen & Mense, 2001). While researchers argued about the relative importance of central versus peripheral processes, most tended to support the theory that the nociceptors could be sensitized as a result of continual or repetitive exposure to mechanical and/or chemical stimuli, which would be produced by the various physical stressors; and the outcome involved lowered excitation thresholds of these nociceptors at various levels (Graven-Nielsen & Mense, 2001; Mense, 1993; Sheather-Reid & Cohen, 1998). These mechanisms could possibly explain the heightened responses in terms of subjective discomfort scores and increased muscle activities in the Case subjects, especially those with high discomforts.

The higher reactivities in the Low Group in the present study compared to those in Study 2 would also add support to the Heightened Sensitivity Model. In addition, the results of Studies 2 and 3 confirm that the Low Group consistently had lower sensitivity levels than the High Group subjects. This group of subjects may represent those individuals with more subtle changes in their motor control strategies that required greater stimulation levels before these programmed changes would surface.

The mechanisms of why and how different individuals would develop different sensitivities still require further investigations. There may be a number of underlying factors which included personality traits influencing different motor responses to stress and inherent motor control programming (Linton, 2000; Zusman, 2002). Westgaard (1999) also developed a conceptual model depicting the relationships between physical workload, mental stress and individual sensitivity. The factors that would affect individual sensitivity included past history of disorders, tendency of sustained motor unit activation and excessive use of force (Westgaard, 1999).

Some of the factors mentioned by Westgaard (1999) have been investigated in our present study. Based on the results of the present study, symptomatic persons may be more susceptible to changes in the physical demands of their work tasks and have more exaggerated responses. These exaggerated responses may be manifested as increased muscle activities, or perceptions of increased tension, or perception of increased pain. Individual factors such as psychosocial and cognitive factors may have contributed to inter-individual differences in musculoskeletal responses when they are exposed to the same physical task demands. Moon and Sauter (1996) highlighted the influences of the psychosocial and cognitive components on the physical responses of the individuals performing office work, resulting in musculoskeletal outcomes. Further research is required to explore both the physical and non-physical characteristics of different individuals, in order to understand why some could cope better than others when they are exposed to the same physical stressors.

7.4.5 Limitations of study

7.4.5.1 *Lack of statistical significance in EMG results*

While the present results have demonstrated important trends of muscle activity changes in the subject groups, a larger sample size may be required to demonstrate the group differences statistically. The differentiation into High-Low sub-groups has led to more apparent trends of group differences in muscle activities but there was no significant difference demonstrable for the various muscles. It may be due to the uneven and small numbers in the High and Low Groups (8 and 13). However, due to the large number of variables that can affect muscle electrical activities, it is often not easy to get sample sizes large enough to achieve statistical significance. This issue has been addressed by Mathiassen et al. (2002), who highlighted the problem of low statistical power in EMG studies with large numbers of variables. Mathiassen et al. worked out that in order to achieve a 20% difference in amplitude variables like the APDF, it would require sample sizes around 100 per group, which was not generally practical.

7.4.5.2 *EMG analysis may involve more than APDF and MF*

Past studies on EMG in office workers have suggested that analyzing APDF alone may not reveal the whole picture of muscle loading patterns in these static activities. EMG gaps and EVA have been used successfully to demonstrate differences between symptomatic and asymptomatic persons (Hagg & Astrom, 1997; Nordander et al., 2000). These additional EMG tools may be pursued in further studies. However, the present results have already demonstrated some interesting differences between symptomatic and asymptomatic persons that provides insight into the basis of these disorders.

7.4.5.3 *Possible intervening factors*

The age difference between the two subject groups was another factor to be acknowledged. Previous studies have shown a relationship between age, previous history of pain and the current prevalence of work-related discomforts (Jensen et al, 1993a). However, when age was used as a covariate to compare discomfort scores and EMG data, no significant difference in analysis was found.

It was also noted that the order of testing had a considerable influence on the discomfort scores, with the Case subjects (both High and Low Groups) generally reporting increased discomfort scores in the third (last) 20-minute typing trial compared to the first and second trials suggesting an accumulation of discomfort. However, the order factor did not seem to have the same influence on the muscle activities comparing the three conditions, when it was used as a covariate in the statistical analysis.

7.5 CONCLUSION

The present study has demonstrated important differences between symptomatic and asymptomatic individuals in their motor control when exposed to the physical stressors of increased typing speed and increased typing force. The Case Group generally showed greater increases in muscle activities compared to the Control Group in both the Faster and Harder conditions. On the whole, the muscle activities showed consistently greater responses to the demand of increased speed compared to increased force.

The Case subjects with more severe and widespread discomforts in the High Group showed trends for greater increases in muscle activities. However, those in the Low Group also reported increased discomforts over time yet without the marked increase in muscle activities in response to the physically stressful situations. These results were compatible with Study 2 showing consistent differences in the muscle activity patterns between symptomatic and asymptomatic persons. Together the results suggest that symptomatic persons may be more responsive to the physical stressors of sustained posture, increased speed and increased force of keyboard operation. Their heightened responses may present as increased muscle activities and increased discomfort sensations. This phenomenon may have important implications in understanding the etiology of WRNULD. However, further investigations are required to understand the cause-effect relationship between these physical stressors and WRNULD.

CHAPTER 8

STUDY 3 PAPER 2

The Effects of Increased Typing Speed and Force Demands on Keyboard Dynamics in Symptomatic and Asymptomatic Office Workers

This chapter is the second paper on Study 3 and it examines the keystroke performance of the subjects when they were challenged by the three typing conditions of Normal, Faster and Harder. The speed and force performance in the keystroke actions were important elements in the motor control strategies that may be influenced by the presence or absence of musculoskeletal symptoms.

The results showed that both groups performed with similar levels of Mean Speed and Mean Peak Force in the Normal condition. In the Faster condition, the Case Group showed trends for greater Speed and Force Variability. In the Harder condition, the Case Group showed more associated increase in Mean Speed while achieving a lower increase in Mean Force. These group differences were even more apparent when the Case Group was sub-divided into the High-Low sub-groups. The results suggest a more erratic motor control of the keystroke actions in the Case subjects especially in the High Group. Combined with the results on muscle activities, the High Group individuals seemed to be more reactive to the demands of the physical stressors. The potential mechanisms associated with the "Heightened Sensitivity Model" are discussed in this chapter.

8.1 INTRODUCTION

8.1.1 Work-related neck and upper limb disorders (WRNULD) in computer users are related to muscle activities in neck-shoulder stabilisers

In Study 2, we have reported important differences in muscle activities of the neck-shoulder stabilizers between symptomatic and asymptomatic persons in performing sustained computer tasks. Consistent differences in muscle activation patterns were found comparing symptomatic and asymptomatic persons in performing a computer task involving sustained posture for one hour. We have also demonstrated differences in neck-shoulder postural angles as well as subjective discomfort scores between symptomatic and asymptomatic persons in the sustained computer task.

In Study 3, we have demonstrated differences in muscle activities comparing symptomatic and asymptomatic persons in response to typing with different speeds and forces (Chapter 7). In particular, muscle activity changes had different trends between the two subject groups in response to the different demands of increased speed and increased force of typing.

Previous studies have reported symptomatic-asymptomatic differences in terms of increased monotony in muscle load pattern or increased EMG gaps in office workers with pain, compared to those without (Hagg & Astrom, 1997; Hermans & Spaepen, 1995; Jensen et al, 1993a). However, other studies have reported no difference in EMG activity or EMG gaps between symptomatic and asymptomatic office workers (Nordander et al., 2000; Vasseljen & Westgaard, 1995).

Gerard et al. (1999) examined the effects of different typing speeds on muscle activities, perceived discomfort and exertion among 18 subjects; but their comparison was between faster and slower typists. Birch et al. (2000) demonstrated increased muscle activities in major upper limb muscles when subjects had to perform mouse tasks under high speed demands. Sommerich et al. (1996a) examined the wrist joint dynamics and forearm tendon travel and their relationships to keystroke forces. Other studies have shown evidence of increased muscle activities from the effects of pen-and-paper tasks demanding different speeds (Laursen et al., 1998a & b; Westgaard & Bjorklund, 1987). However, conflicting results have also been reported showing no major difference in EMG activities in performing mouse tasks of different speeds and complexities (Jensen et al., 1999a). These studies were mainly done on healthy pain-free subjects and we do not know whether symptomatic persons would respond the same way.

8.1.2 Case-Control differences may also be present in keystroke performance variables

Speed and force are two fundamental aspects of physical exposure in the performance of work tasks. In office workers who perform intensive keyboard work daily, these two characteristics of keyboard operation may have an important influence on the muscle efforts required from the proximal stabilizers as well as a possible direct impact on the development of work-related musculoskeletal disorders. Therefore it is important to have a better understanding of these physical characteristics of the keystroke actions.

From studies on office workers, high keystroke rates at 8,000-12,000 strokes per hour have been linked with increased rates of upper limb discomforts (Bernard et al., 1994; Maeda et al., 1980; Thatcher & Brophy, 1999). Long typing hours and high repetitive rates of keyboard work have also been linked with increased muscle activities which may be an important factor leading to development of musculoskeletal pain (Bernard et al.., 1994; Tittironanda et al., 1999). It has been suggested that increase in typing speed may be associated with increased muscle effort (Gerard et al., 1999 & 2002; Laursen et al., 1998a & b; Sommerich et al., 1996a).

Different typing styles have been studied by Pascarelli and Kella (1993) who proposed that typists who hit the keys with excessive vigor creating a loud clacking noise (the “Clackers”), had higher rates of upper limb disorders due to the increased biomechanical stress in the typing action. Sommerich et al. (1996a & b) studied different force exertions when subjects performed word-processing and data-entry tasks, and reported that some subjects were typing harder than necessary when the force data were correlated with the tendon travel velocities. Sommerich et al. (1996b) reported that when subjects were typing at their own preferred speed, there appeared to be no relationship between typing speed and force; but the two factors became more related when they were required to change their typing speeds. Gerard et al. (2002) also reported that as typists typed faster, their typing force and finger muscle activities would increase. However, most of these data were collected from normal pain-free subjects and it is not known if there are similar responses in individuals with chronic discomforts.

Feuerstein et al. (1997) reported one of the few case-control comparisons by examining keystroke rates and forces, in relation to symptom scores, range and strength (wrist and forearm), perceived exertion, and psychological stress. Each subject performed a 15 minutes' keyboard task, and keying forces were measured by 2 strain gauges under opposite ends of the keyboard. They reported that the Case group consistently typed with greater forces, but there was no significant correlation between keying rate and force. Their results suggested a relationship between the keystroke force and the development of work-related musculoskeletal discomforts, but further research is required to investigate this link.

8.1.3 Biomechanical research on keystroke characteristics

A number of studies have examined the physical characteristics of the keystroke actions and force-displacement properties either in typing tasks or finger tapping (Aoki & Kinoshita, 2001; Armstrong et al., 1994; Dennerlein et al., 1998; Feuerstein et al., 1997; Gerard et al., 1999 & 2002; Martin et al., 1996; Radwin & Jeng, 1997; Rempel et al., 1994 & 1997). Rempel and associates (1994 & 1997) have analyzed the detailed fingertip actions and activations forces measured with the fingers hitting single keys of "e" or "j". Their approach involved placing a piezoelectric load cell directly under the keycap, and the "keyswitch make force" has been reported to be in the range of 0.3-1.1N. These studies have mainly focused on comparing different keyboard designs and the detailed finger and wrist joint kinematics and kinetics in using various types of keyboards (Aoki & Kinoshita, 2001; Armstrong et al., 1994; Dennerlein et al., 1998; Gerard et al., 1999 & 2002; Martin et al., 1996; Radwin & Jeng, 1997; Rempel et al., 1994 & 1997).

Armstrong et al. (1994) studied the peak and average forces for striking the "e" key in typing long sentences containing all 26 letters, and reported keying rates at 98 – 383 keys per min (mean = 267) from 10 healthy subjects and observed that peak forces tended to decrease with increasing pace. In the case-control study by Feuerstein et al. (1997), the mean keying forces of 2-4 N were reported in the case and control groups, in performing 15 minutes of typing. Martin et al. (1996) studied the peak reaction forces for each finger during typing, and they ranged from 3.33N in the thumb, to 1.84N in the little finger, with an overall mean of 2.54N.

Aoki and Kinoshita (2001) compared the fingertip forces generated in performing single-finger tapping, double-finger tapping and tapping with the whole hand. They reported that the whole-hand mode had a significantly faster tapping frequency with greater peak forces compared to the single- and double-finger modes. The mean peak force in the whole-hand mode was 2.19N which was twice that in the single-finger mode. Hermsdorfer, Marquardt, Wack and Mai (1999) also reported faster tapping frequencies with the whole hand compared with the index finger alone.

The amount of force exerted in typing is directly affected by the speed or acceleration of the finger actions, and typing is a coordinated sequence of finger motions (Gentner, 1987). In normal word-processing (or text-typing) tasks performed by office workers, the fingers need to move over the whole keyboard to strike the right keys. The study of single key-tapping actions may not reflect the true forces exerted by the different fingers in a realistic typing task performed by office workers. There are likely to be differences in motor control strategies in coordinating the dynamic actions of all the fingers in performing text-typing tasks, compared to the laboratory task of tapping on fixed force transducers with either one or two fingers. The results of Aoki and Kinoshita (2001) and Hermsdorfer et al. (1999) have raised questions about the validity of measuring forces in single finger tapping or under single keycaps as indicators of typical forces in performing keyboard tasks.

In addition there may be differences in performance between the two hands, which would be interesting to study; especially relating the motor performance to the location of pain. These reasons support the approach of measuring all keystroke forces in the entire keyboard in studying text-typing tasks, rather than measuring forces from one or two keys only.

8.1.4 Motor control for typing skills

Typing skills are affected by a number of factors involving central and peripheral control mechanisms (Gentner, 1983 & 1987). Gentner (1983) reported that as typing skill improves and speed increases, cognitive constraints become less important, and the interstroke intervals are more limited by peripheral constraints – the speed of finger movements and the keyboard layout. As speed increases, the finger movements also become less sequential and more overlapping occurs. Variability in typing performance usually decreases in expert typists and as fluency increases (Gentner, 1983; Life & Pheasant, 1984).

With skill acquisition, it is also found that there is gradual refinement of force dynamics and control resulting in more coordinated and efficient force exertions with decreased variability (Gentile, 1998). The fine control of force application is especially critical in using modern-day touch-activated keyboards. The control strategies for finger movements during touch-typing involve sequential bursts of finger extensor and flexor activities (Dennerlein et al., 1998).

These findings on the motor control of typing skills were based on observations in healthy pain-free typists and it is not clear how discomforts or pain may affect motor performance in symptomatic individuals. The relationship of keystroke forces and muscle load may be an important link to the development of work-related symptoms but this area has not been fully explored. Most of the studies on the keystroke mechanics have been conducted on normal healthy subjects and the sample sizes were usually very small (<10) (Armstrong et al., 1994; Martin et al., 1996; Radwin & Jeng, 1997; Rempel et al., 1997). These studies have mainly focused on the biomechanical factors occurring at the finger or wrist joints, or the muscle activities in the forearm region (Martin et al., 1996; Radwin & Jeng, 1997; Rempel et al., 1997; Sommerich et al., 1996a). Kitahara et al. (2000) studied the motor unit activity in the trapezius muscle comparing the actions of fast finger tapping and inputting data in 6 healthy subjects. The results have provided some evidence to support that trapezius motor unit activity was affected by the different tasks, but the results may be different if measured in symptomatic persons.

Feuerstein et al. (1997) was one of the few studies that reported on symptomatic and asymptomatic differences in keystroke forces. In our series of studies we have demonstrated symptomatic – asymptomatic differences in the muscle activity patterns, posture and subjective discomfort in performing keyboard tasks. The results suggested that differences in motor control strategies may be the key factor contributing to the symptomatic – asymptomatic differences. Whether these symptomatic – asymptomatic differences may also affect the performance parameters of motor tasks such as keyboard operation is not clear.

8.1.5 Aim of study

The aim of the present study was to examine the changes in keystroke speed and force in symptomatic and asymptomatic office workers when they performed a standardized keyboard task under the three conditions of :

1. typing at normal speed and force,
2. typing with increased speed,
3. typing with increased force

The keystroke speed and force are integral parts of the motor control in keyboard operation which is an essential component of computer work carried out daily by office workers. It is postulated that symptomatic individuals may have developed changes in their motor control either as an etiological process or an outcome related to WRNULD. These results will be linked with the findings on the muscle activities and discomforts measured from the same subjects in the present study. The results will provide a better understanding of differences in motor control strategies between symptomatic and asymptomatic persons, in reacting to the physical stressors of speed and force of keyboard operation.

8.2 METHOD

8.2.1 Subjects

Study 3 employed a Case-Control quasi-experimental design. Forty-one female office workers were recruited through convenience sampling, mainly from health promotion activities and from staff at the local university. The inclusion criteria were that the subjects had to perform a minimum of 4 hours of computer work daily, and only those who performed clerical and/or administrative duties (mainly word-processing) were included. Those with past traumatic injuries or surgical interventions in their neck and upper limb regions were excluded. Most of the subjects performed 4-6 hours of computer work daily and their computer tasks typically consisted of word-processing, editing documents, data entry and emailing. All subjects were experienced touch-typists and there was no significant difference in their time spent on different computer tasks.

Subjects were assigned into the Case Group or the Control Group based on information from an interview, modified from the Standardised Nordic Questionaire (Kuorinka et al., 1987). Case subjects were defined as those with past discomforts lasting more than 3 months in the past year, discomfort in the past 7 days and discomfort on the day of testing. The presence of "current complaint" was defined by a score of > 2/10 on the discomfort scale reported by the Case subjects on the day of data collection. Control subjects must have had no or minimal discomfort on the day of testing, and had no discomfort in the past 7 days. If they had reported discomfort in the past 12 months, it was less than 3 months' duration and they had no discomfort in the last 6 months. 21

Case subjects and 20 Control subjects were successfully recruited and completed all the experimental procedures.

The subjects were well matched in terms of their physical build, handedness and job profile but not age. The mean age of the Case Group was 39.0±7.4 and the mean age of the Control Group was 30.4±5.9. Full details of the subjects were reported in Chapter 7. Prior to commencing data collection, all subjects were asked to sign the Informed Consent Form, after the Principal Investigator explained the detailed procedures to them. The study was approved by the Curtin University Human Research Ethics Committee.

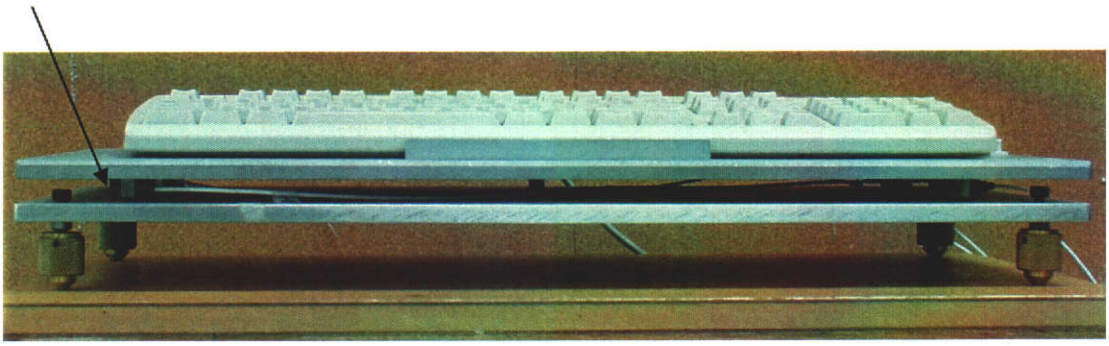
8.2.2 Variables

The independent variables were *group* (Case versus Control) and *condition* (normal, "Faster" and "Harder"). The dependent variables were in terms of keystroke performance defined as follows:

1. Mean Speed (number of keystrokes per min)
2. Speed Variability (mean of within-subject SD in speed)
3. Mean Peak Force (Newtons)
4. Force Variability (mean of within-subject SD in peak force)

Muscle electrical activity and discomfort scores were also been measured concurrently, and these results have been reported in Chapter 7.

Four Piezotron® load cells (Model 9712B5, Kistler Instrument Corporation, Amherst USA) were fixed under the keyboard to measure the speed and force of keystrokes. A specially designed platform was fabricated to fixate the 4 load cells in position under the 4 corners of the keyboard (Fig. 8.1). The 4 load cells were coupled to the Vicon 370 system (Oxford Metrics Ltd., U.K) which was used to capture all the analog data. The coupler (Model 5134A, Kistler Instrument Corporation, Amherst USA) was a four-channel signal conditioner for low impedance piezoelectric transducers. The A-D conversion took place in the Vicon system at a sampling rate of 1920 Hz for the analogue channels including the 4 keyboard load cell channels.



a load cell

Fig. 8.1: Design of the force platform to fixate the 4 load cells under the 4 corners of the keyboard

An oscilloscope was set up to display the instantaneous force (voltage) readings from one of the load cell channels. This was used to establish the baseline force value during the Normal condition which was used to compute the 20% increase in the Harder condition. The real-time keystroke speed was monitored by the instantaneous display of keystroke speed from the FasType program, and this was used to establish the baseline condition. The real-time keystroke speed was monitored by the instantaneous display of keystroke speed from the FasType program, and this was used to establish the baseline speed for computing the 20% increase in speed. During all the typing trials, the force and speed readings were monitored continuously by the investigator in order to provide verbal feedback to the subject so that the required speed and/or force levels could be maintained.

8.2.4 Experimental procedures

The keystroke performance was measured in 3 trials (of 20 minutes) of screen-based typing, with a 5 minute rest period in between trials. Each subject had to perform the three typing trials in the following manner:

1. the "Normal" condition - typing at "normal" speed and force,
   followed by either,
2. the "Faster" condition - typing with increased speed (20%>Normal),
   or,
3. the "Harder" condition - typing with increased force (20%>Normal).

In the Normal condition, the subject was instructed to type at her usual preferred speed and force for 20 mins. In the Faster condition, the subject was expected to maintain the typing speed at a level equivalent to or more than 20% above the "Normal" level while the force exerted was not controlled. In the Harder condition, the subject was expected to type at the higher force level (20% above Normal or more) while the speed component was not controlled.

Before the Faster and Harder trials, the subject was given 2-3 minutes to practise the task until the required speed or force level was reached. In order to minimize the bias from the ordering effect of the Faster and Harder conditions, half of the subjects in each group performed the Faster condition in the second trial followed by the Harder condition in the third trial, and the other half did it in the reversed order.

During each of the 20 minute typing tasks, the keyboard load cell data (and the EMG data) were recorded at the 1st, 5th, 10th, 15th and the 20th minutes. Each data collection period lasted 40 seconds. The subject was asked to indicate and rate the discomfort on three occasions, at the 1st, 10th and 20th minutes, following the keyboard data collection.

8.2.5 Controlled variables

8.2.5.1 *Computer workstation*

The same computer workstation was used for all subjects. The display screen and the computer unit were placed on a separate table from the keyboard and force platform. As the load cells were very sensitive to any vibration or forceful movements in the adjacent area, the keyboard and force platform was placed on a stand-alone wooden frame. A padded wooden bench for supporting the forearms was placed between the subject and the frame supporting the keyboard. This was to ensure no contact of body parts other than the fingers with the keyboard.

The subject sat on a standard swivel chair with adjustable height and no arm rests. The subject was instructed to adjust the chair height in order to assume a position of comfort in a reasonably erect posture, with hips, knees, and elbow joints at approximately 90 degrees. The monitor height, distance and angle were adjusted to a comfortable level for the subject (top of monitor at approximately their horizontal eye height), so that the head-neck region was in a reasonably erect position. After the adjustments the subject was asked if she felt she could be comfortable for the duration of the typing task, and whether this posture simulated her workstation setting at work. The adjustments were only considered adequate when the subjects indicated positive answers to these questions.

8.2.5.2 *Computer task*

The typing program called FasType® (Trendtech Corporation, Scottsdale USA) was used as it provided an instantaneous display of the raw typing speed on-screen. Each subject performed the same standardised task of copy-typing in 3 periods of 20 minutes each, typing long paragraphs of well known stories utilizing all the alphabetical keys on the keyboard. The subject was instructed to correct any typing errors during typing by striking the backspace key. The FasType program would accept occasional errors but the program would stop if there were too many mistakes. This was the program's requirement to ensure a certain level of accuracy (>90%) was achieved.

8.2.6 Data processing and analysis

The keyboard data collected in the Vicon system were imported into a specially designed Labview^{TM} program for further processing. The analog data from the 4 load cells were batch-processed and reduced at a sampling rate of 96 Hz by using a window size of 20. The down-sampled data from the 4 load cells were summed, scaled, half-wave rectified and smoothed using a 3-point moving average. The summed data were automatically analysed to identify the keystroke peaks. The start of each keystroke was identified as being where the smoothed data rose one half of a standard deviation (of the un-smoothed data) above zero (see Fig. 8.2). A keystroke ended at the last sample before the next keystroke "start" point. The keystroke peak was determined as the highest value in each keystroke. A typical graph showing the keystroke peaks matched to the summed forces of the load cells is presented in Fig. 8.2.

From the keystroke peaks, the keystroke speed and force variables were computed. The mean keystroke speed was computed as the number of keystrokes per minute, which was calculated from the peak-to-peak intervals in ms. The mean force was computed as the mean value of the peak forces in each trial in Newtons (N). The within-subject variability in keystroke speed and force were also recorded in terms of the standard deviations of the speed and force data for each trial, and these were also analysed statistically.

All the above variables were compared within each subject as well as between the two subject groups. A mixed model MANOVA was used to examine the effects of *group* as between subjects factor and *condition* as within subjects factor on the keystroke speed and force variables. An initial analysis had shown no change with time so the mean of the five data collection trials was used to represent the mean of each typing condition and this value was used in further analysis.

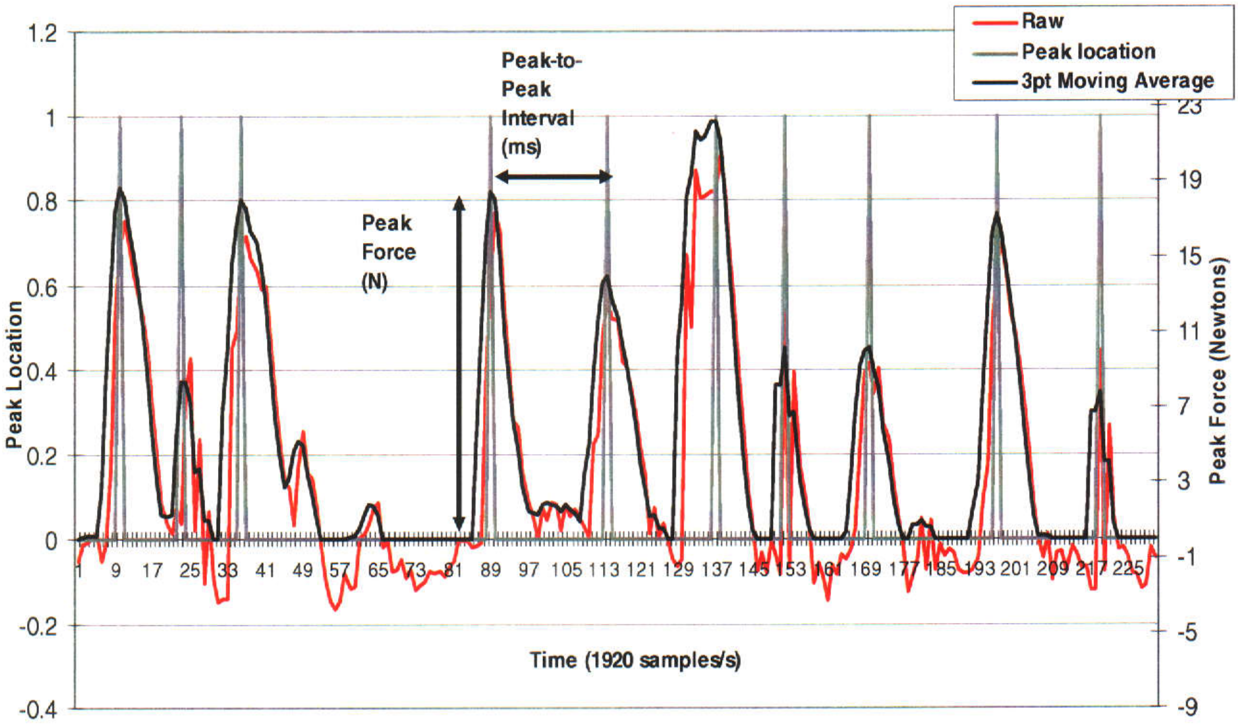


Fig. 8.2: The identification of individual keystroke "peaks" and the definition of peak force and peak-to-peak interval

8.3 RESULTS

8.3.1 Group differences in keystroke Mean Speed and Speed Variability

Fig. 8.3 shows the group mean values of the keystroke Mean Speed in terms of number of keystrokes per minute. The Mean Speed was compared between the two groups and among the three typing conditions. From Fig. 8.3, in the Normal condition the two groups appeared to have very similar Mean Speeds. When the subjects were required to increase their speed in the Faster condition, both groups achieved similar increases in number of keystrokes per minute. In the Harder condition, the Case Group recorded a high level of speed which was almost the same as that in the Faster condition. The Control Group also showed a concomitant increase in speed in the Harder condition, but it did not reach such a high level as the Case Group.

The standard deviations (SD) of the peak-to-peak intervals were also computed for each trial in each subject and all the SD data were compared in a similar way as the Mean Speed. This measure was an indicator of the inconsistency or variability of the speed performance at the within-subjects level. Fig. 8.4 shows the group mean values of Speed Variability comparing the Case and Control Groups. The graph shows that in the Normal condition there was a trend for slightly higher Speed Variability in the Control Group. But in the Faster condition, the Case Group showed a trend for higher variability, while the two groups were at very similar levels in the Harder condition. This finding may suggest that the Case Group had less consistent performance in their keystroke speed in the Faster condition, even though both groups were able to reach the targeted increase in speed required. The Case Group also demonstrated a trend for higher increase in Mean Speed during the Harder condition although the Speed Variability were similar in both groups.

In the statistical analysis, the dependent variables of Mean Speed and Speed Variability were examined for any *group* effects and *condition* effects in the mixed model MANOVA.

In the multivariate analysis on Mean Speed and Speed Variability, there was a significant *condition* effect ($F_{14,25}$=18.69, p<.001) but there was no significant *group* effect ($F_{7,32}$=1.12, p=.376) nor *condition* x *group* interaction ($F_{14,25}$=0.88, p=.588).

In the univariate analysis on the Mean Speed, the *condition* effect was again significant ($F_{2,76}$=38.76, p<.001). There was no significant *group* effect ($F_{1,38}$ =0.23, p= .631) or *condition* x *group* interaction ($F_{2,76}$=1.67, p=.195). In the post-hoc contrast comparing the Faster and Harder conditions, there was a significant difference ($F_{1,38}$ =5.52, p=.024). The contrast for Faster vs Normal showed a strong statistical significance ($F_{1,38}$ =84.45, p<.001) and similarly in the contrast between Harder and Normal conditions ($F_{1,38}$ =33.37, p<.001). This result would suggest that while both Faster and Harder conditions produced significantly higher Mean Speed than the Normal condition, the Mean Speed in the Faster condition was also significantly higher than that in the Harder condition. These results have demonstrated that the subjects in both groups had significant changes in Mean Speed in response to the three typing conditions, and the directions for change were similar in both groups.

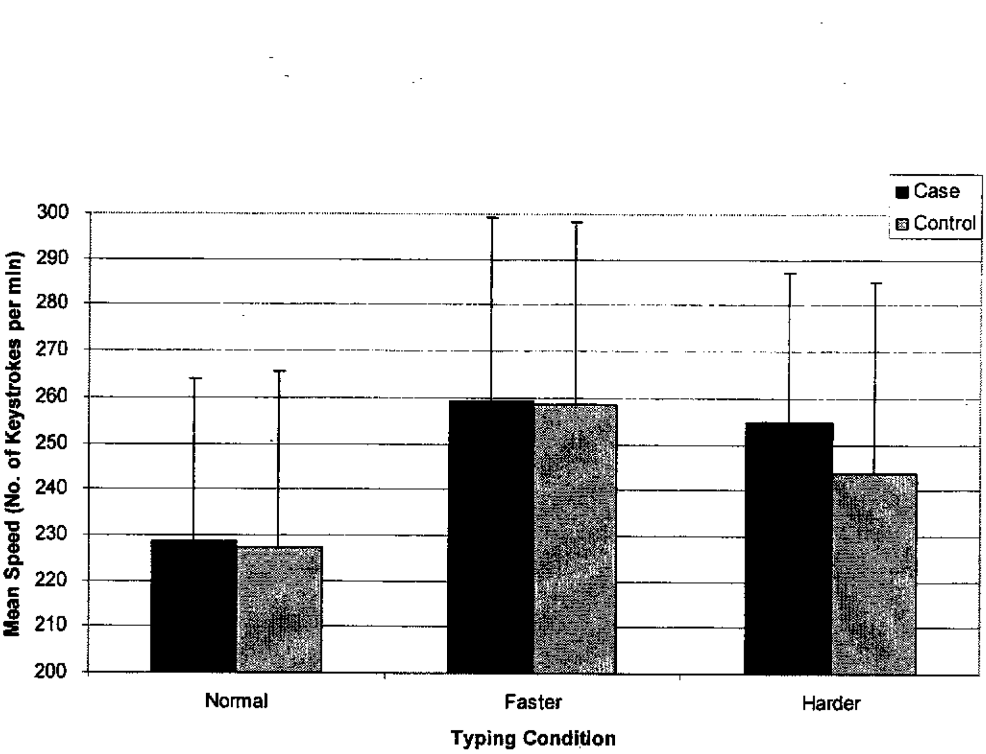


Fig. 8.3: Keystroke Mean Speed of the Case and Control Groups in three typing conditions

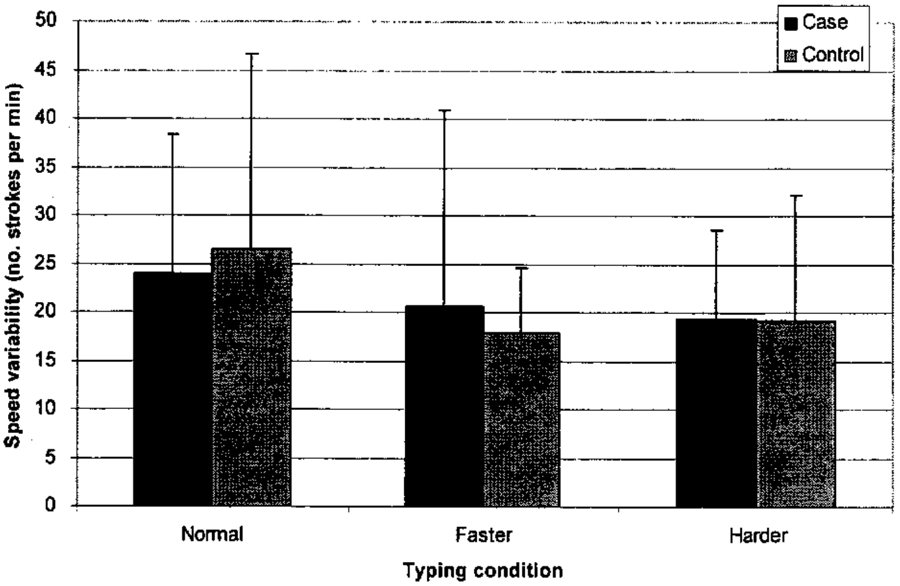


Fig. 8.4: Speed Variability of the Case and Control Groups in the three typing conditions

In the univariate analysis for Speed Variability, the *condition* factor was approaching statistical significance ($F_{2,76}$=2.74, p=.071). There was no significant *group* effect ($F_{1,38}$ =0.01, p=.973) or *condition* x *group* interaction ($F_{2,76}$=0.39, p=.675). In post-hoc contrasts, there was no significant difference in Speed Variability comparing the Faster and Harder conditions directly ($F_{1,38}$ =0.00, p=.988). But the contrasts were approaching significance when compared against the Normal condition (Faster vs Normal: $F_{1,38}$ =3.74, p=.061; Harder vs Normal: $F_{1,38}$ =3.57, p=.066). These results suggested that the Speed Variability were similar in the Faster and Harder conditions, but both conditions had trends for lower variabilities than the Normal condition.

On the group mean graph however, there was a trend for greater Speed Variability in the Case Group in the Faster condition although this was not statistically significant. In summary, the significance of the *condition* factor confirmed that Mean Speed was significantly higher in the Faster condition, than the Harder condition, followed by the Normal condition. Both groups achieved similar Mean Speeds in the Faster and Normal conditions, while in the Harder condition, the Case Group had a trend for higher Mean Speed but this was not statistically significant. In terms of Speed Variability, both groups demonstrated lower values of this variable in the Faster and Harder conditions, and notably the Case Group demonstrated a trend for higher Speed Variability in the Faster condition than the Control Group.

8.3.2 Group differences in Mean Peak Force and Force Variability

Fig. 8.5 shows the mean values of the Mean Peak Forces in the three typing conditions for the two groups. There appeared to be a negligible difference in this variable between the 2 groups in the Normal condition. In the Faster condition where the subjects were required to type with increased speed, both groups showed similar increases in Mean Peak Force, whereas in the Harder condition, the Case subjects produced an apparently smaller increase in Mean Peak Force compared to the Control Group.

The SDs of peak forces of all keystrokes were examined for within-subject variability in peak forces of the various typing trials. Fig. 8 6 shows the group means comparing the Force Variability in the two groups. In the Normal condition, the Case and Control Groups had very similar levels of variability. In the Faster condition, the Case Group had apparently a much higher level of Force Variability, suggesting that they varied their forces considerably when typing with increased speed. In contrast, the Control Group showed an even lower level of variability in the Faster condition compared to the Normal condition. This result suggested that the Control subjects had much more consistent control of their peak forces during the Faster condition. The trend for high within-subject variability in peak force of the Case subjects in the Faster condition suggested that these subjects had less consistent control of their force exertions under increased speed demand. In the Harder condition, both groups had similar Force Variabilities suggesting that both groups were able to produce consistent force exertions in this task.

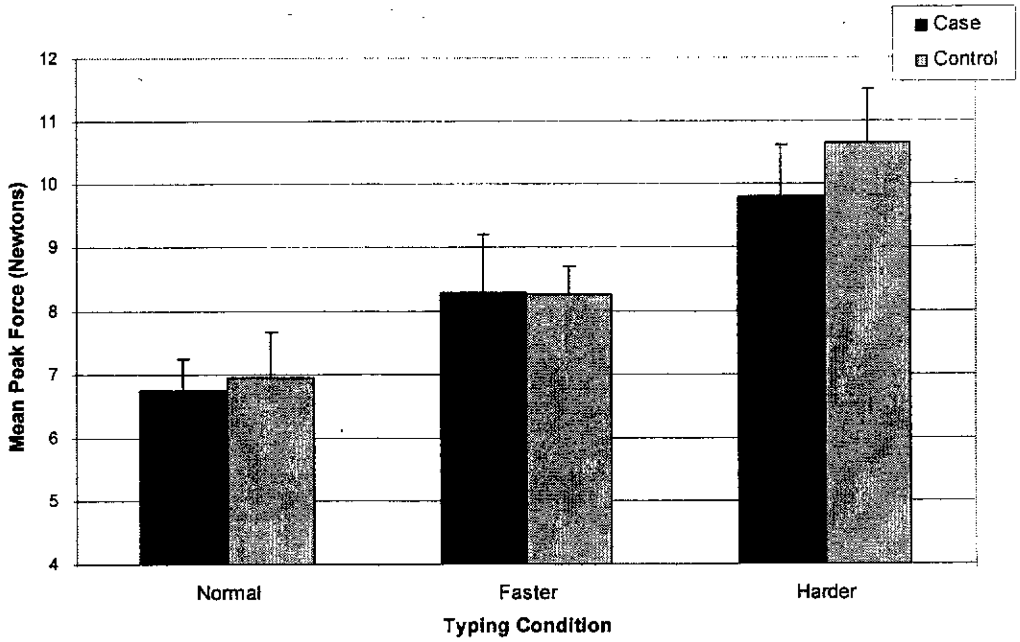


Fig. 8.5: Peak keystroke forces comparing Case and Control Groups in the 3 conditions

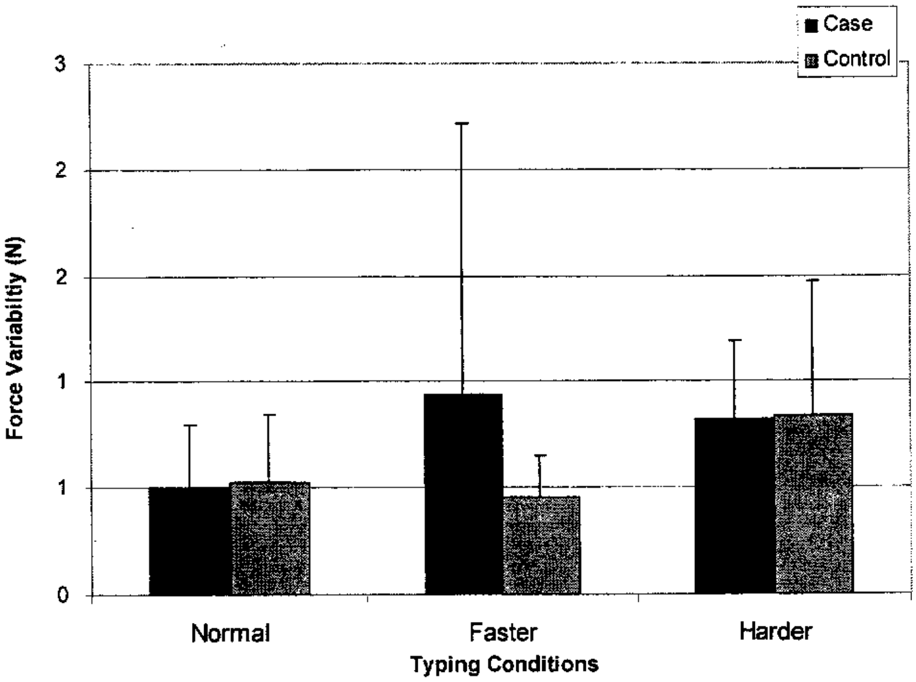


Fig. 8.6: Force Variability in the Case and Control Groups comparing the 3 conditions

The force variables were analysed in the same MANOVA analysis as the keystroke speed variables which found a significant effect of *condition* ($F_{14,25}$=18.69, *p*<.001) but the *group* effect was not significant ($F_{7,32}$=1.12, *p*=.376), and neither was the *condition* x *group* interaction ($F_{14,25}$=0.88, *p*=.588), in the multivariate analysis.

In the univariate analysis for Mean Peak Force, there was a significant *condition* effect ($F_{2,76}$=100.15, *p*<.0001) but there was no significant *group* effect ($F_{1,38}$=0.25, *p*=.623), nor *condition* x *group* interaction ($F_{2,76}$=1.74, *p*=1.183). In the post-hoc contrasts, there were significant differences in all the pairwise comparisons between Normal, Faster and Harder conditions ($F_{1,38}$=48.29 – 177.29, *p*<.0001), These results confirmed the observations in Fig.8.6 showing that the Mean Peak Force was significantly greatest in the Harder condition, followed by the Faster condition which was significantly greater than the Normal condition.

In the univariate analysis for Force Variability, there was no significant *condition* effect ($F_{2,76}$=0.99, *p*=.376), nor any significiant *group* effect ($F_{1,38}$=0.33, *p*=.571) or the *condition* x *group* interaction ($F_{2,76}$=2.61, *p*=.080). The statistical analysis did not show any difference in Force Variability despite the apparent Case-Control difference in the Faster condition. This may be due to the large SD of the Force Variability in the Case Group. However, this finding may still have important implication although no statistical significance was found.

8.3.3 Comparing the speed and force variables in the High-Low sub-groups of the Case subjects

When the Case subjects were sub-divided into a High Group (n=8) and a Low Group (n=13) according to their discomfort scores in the Normal condition, more apparent trends were observed in their Mean Speed and Speed Variability (Fig. 8.7a,b), as well as the Mean Peak Force and Force Variability (Fig. 8.8a,b).

In Fig. 8.7a, the High-Low sub-groups did not show apparent differences in Mean Speed in both the Normal and Faster conditions. The High and Low Groups also achieved similar Mean Speed in the Harder condition but these were both higher than the Control Group. Fig. 8.7b showed the Speed Variabilities and the most apparent trend was the higher Speed Variability in the High Group in the Faster condition. This is an important finding as previously in the Case – Control comparison (Fig. 8.5) the difference in Speed Variability between groups was much smaller. One-way ANOVA analysis with pairwise contrasts was performed to compare the differences in Mean Speed and Speed Variability within each typing condition. There was generally no significant difference in all the pairwise contrasts, possibly due to the large SD in the means, especially in the High Group. Considering the large apparent difference in Speed Variability in the High Group compared to the Low Group and the Control Group, there was still no significant difference (t_{37} = -.29 – 1.65, p=.107 - .777).

In Fig. 8.8a, the Mean Peak Forces were quite similar in all the High, Low and Control Groups in the Normal condition. In the Faster condition, there was a trend for higher Mean Peak Force in the High Group, while the Low Group was more similar to the

Control Group. In the Harder condition, the Low Group actually showed a lower Mean Peak Force compared to the High and Control Groups. In terms of Force Variability, again the High Group showed an apparent trend for higher Force Variability compared to the Low Group which was also higher than the Control Group (Fig. 8.8b). The Force Variability in the High Group was more than twice that of in the Control Group. However, in the one-way ANOVA with pairwise contrasts, there was still no significant difference demonstrated, which again may be due to the large SD's. In the High-Control contrast of Force Variability, the *p* value was approaching significance ($t_{37} = 1.69$, p=.099).

8.3.4 Summary of keystroke performance results

On the whole, both groups were able to meet the required demands of increasing their keystroke speed and force in the Faster and Harder conditions. The most apparent differences in keystroke performance were in response to the *condition* factor that was statistically significant for most of the speed and force variables. The Case-Control differences were initially not so apparent in the speed variables but the Force Variability showed a trend for a large apparent difference. When the Case Group was sub-divided into the High and Low Groups, greater differences were revealed. In both the Speed and the Force Variabilities, the High Group showed a large gap from the Low and the Control Groups but these differences were not statistically significant. The High and Low Groups also showed trends for greater Speed Variabilities than the Control Group in the Harder condition.

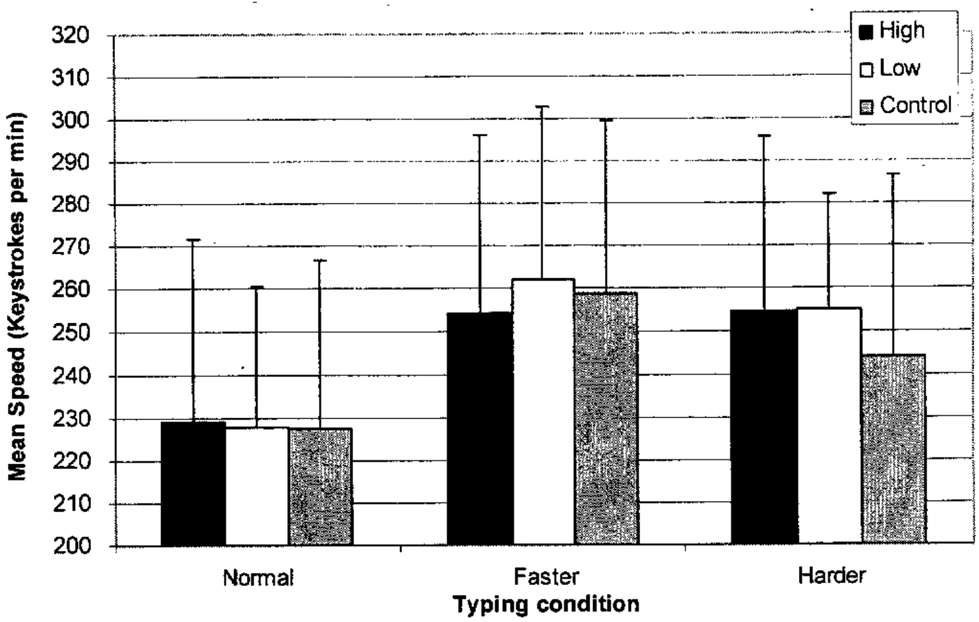


Fig. 8.7a: Comparison of Mean Speed of the High, Low and Control Groups in the three typing conditions

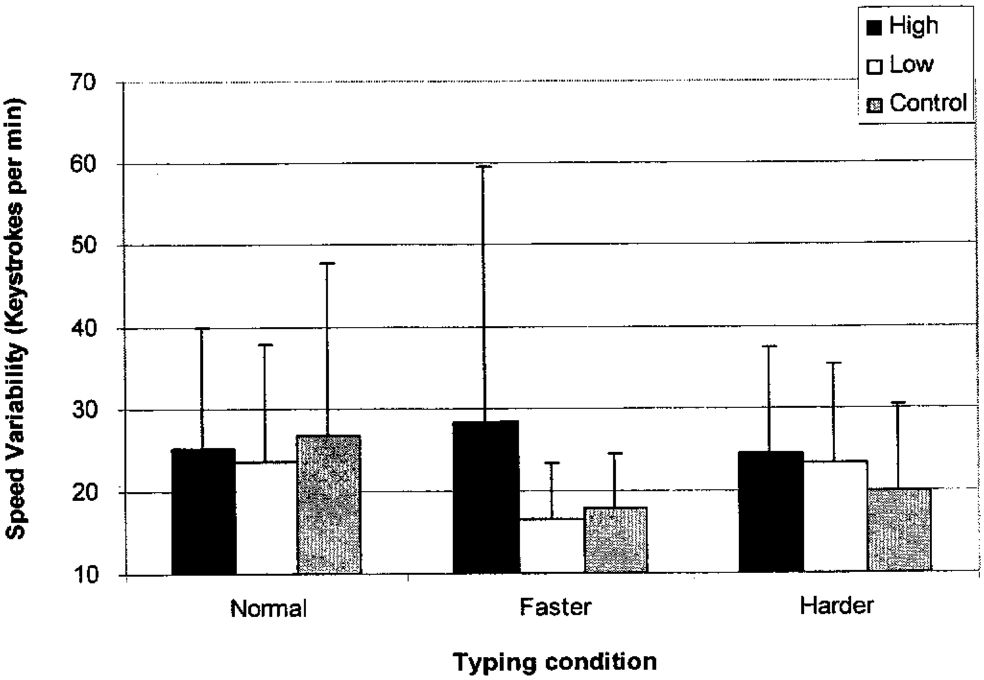


Fig.8.7b: Comparison of Speed Variability of the High, Low and Control Groups in the three typing conditions

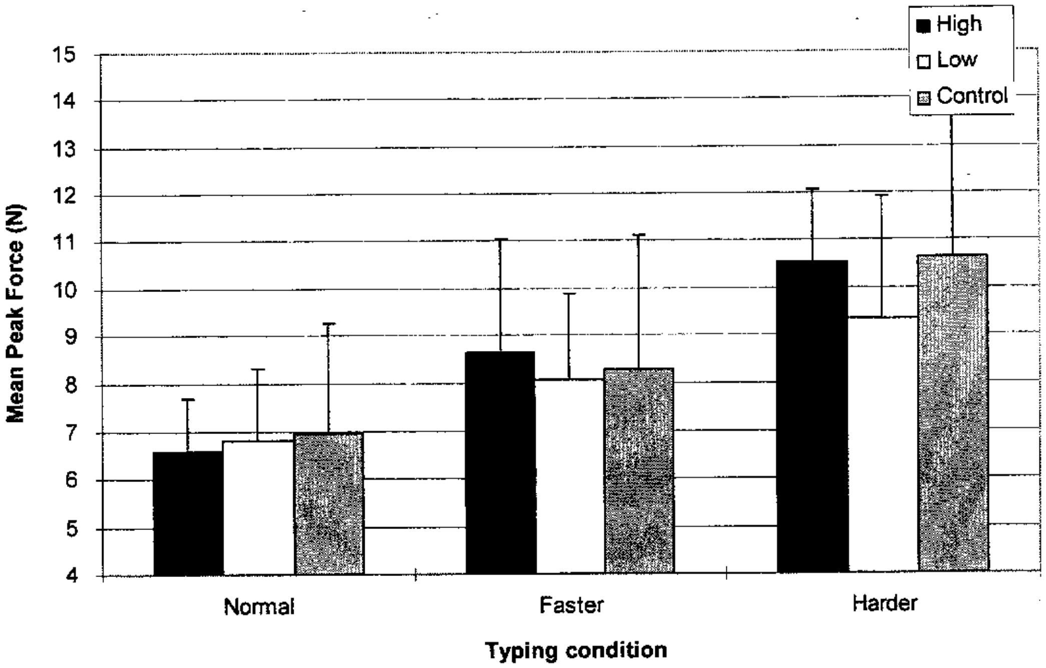


Fig. 8.8a: Comparison of Mean Peak Force of the High, Low and Control Groups in the three typing conditions

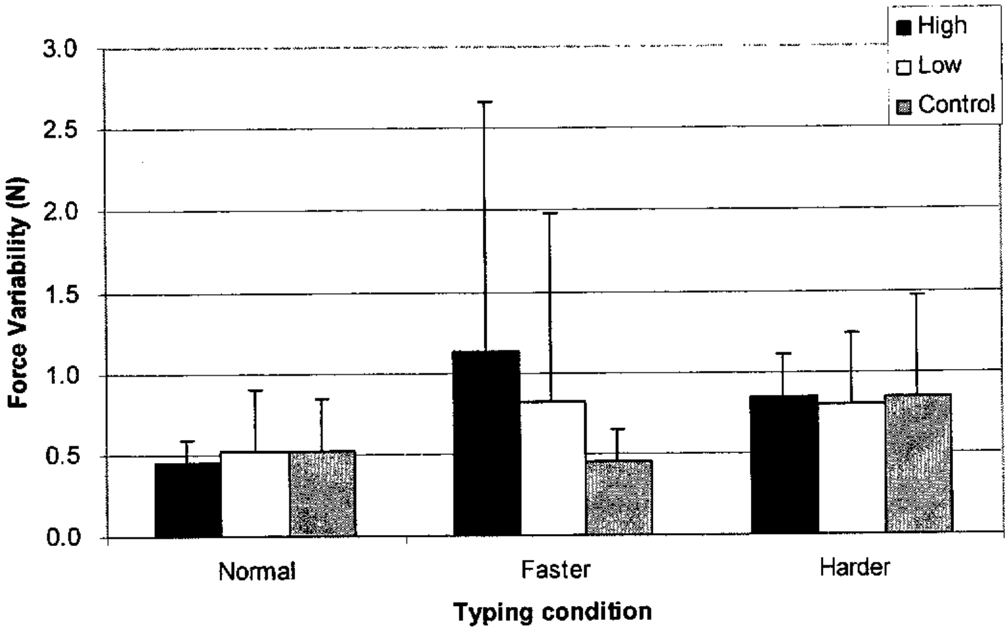


Fig. 8.8b: Comparison of Force Variability of the High, Low and Control Groups in the three typing conditions

8.4 DISCUSSION

8.4.1 Group differences in keystroke speed and force performance in response to 3 conditions

The present study has demonstrated important differences in the subjects' motor performance in terms of keystroke speed and force variables under the demands of the Faster and Harder conditions. In the Normal condition, both groups showed similar performance in speed and force; but different patterns of change were observed in their performance during the Faster and Harder conditions.

8.4.1.1 *Group differences in keystroke performance in the Faster condition*

In the Faster condition, the subjects were expected to increase their typing speed to at least 20% above their baseline performance. The aim of imposing this condition was to examine how the Case and Control subjects would cope with such a stressful demand. The results showed that both groups were able to achieve similar increases in keystroke speed as evident in Fig. 8.3. When the Case subjects were sub-divided into the High and Low Groups, a different picture emerged. The Low Group and Control Group actually achieved higher Mean Speed than the High Group, although this difference was less than 10 strokes per min.

In the Faster condition the keystroke force was not controlled and both groups showed some associated increase in force levels. The associated increase in mean force in the Faster condition indicated that the force and speed control in the keystroke actions were closely related, and it is difficult to increase one component without some effects on the other. This association between speed and force appeared to be much stronger in the Case Group, implying that these subjects had more difficulty separating the motor control of these two components. The Case subjects also demonstrated a trend for notably higher within-subject variability in both speed and force in the Faster condition. This was even more apparent when the Case Group was sub-divided into the High and Low Groups. The physical demand of increasing the keystroke speed would create increased demand on the motor control to produce more rapid accelerations and decelerations of finger motions. These results would suggest that the Case subjects especially the High Group individuals had more erratic motor control strategies for the keystroke actions than that of the Control subjects.

Past studies analysing the motor control of typing skills have reported that as novice typists improved their skills, they increased their speed by decreasing the interstroke intervals, and the finger movements become less sequential and more overlapping (Gentner, 1983). The performance constraints would become shifted from cognitive constraints in students to being limited by peripheral and physical constraints (the finger actions) in experts (Gentner, 1983). Refinement of force control involving co-contraction of opposing muscles is an important process in skill acquisition (Gentile, 1998).

Sommerich et al. (1996b) studied the relationship of speed and force by asking the subjects to type with a variety of faster and slower than "preferred" speeds, and reported a strong positive association between speed and force especially in the fast typing condition. Previous studies that have measured keying speeds have tended to use this factor of increasing typing speed as an independent variable to study the effects on muscle activities (Birch et al., 2000; Gerard et al., 2002; Kitahara et al., 2000), joint movements (Aoki & Kinoshita, 2001; Dennerlein et al., 1998; Sommerich et al., 1996a) or to compare different keyboard designs (Armstrong et al., 1994; Gerard et al., 1999; Radwin & Jeng, 1997). In our study we have imposed a speed requirement on the subjects while also recording their speed as an outcome measure, the results were able to demonstrate differences in the speed and force control between symptomatic and asymptomatic subjects.

8.4.1.2 *Group differences in keystroke performance during the Harder condition*

In the Harder condition the subjects were required to increase their keystroke peak force to at least 20% above their baseline levels. The results showed that the Control Group achieved a greater increase in peak force in the Harder condition compared to that in the Case Group; but this difference was not statistically significant. In fact the mean increases in peak force in both groups were well above the 20% requirement, reaching close to 60% for the High and Control Groups while the Low Group had about 30% increase from the baseline force level. These figures would suggest that the subjects had no difficulty in meeting the physical demand of this condition. The Force Variabilities were very similar in all three groups in the Harder condition, as this increased physical demand may be more controlled by the distal forearm muscles, that can handle such changes in force exertions.

However, the Case Group demonstrated a concomitant increase in the keystroke speed during the Harder condition when the requirement was only to increase the typing force;

and this increase in speed by the Case subjects was almost as high as that achieved in the Faster condition. This result could not be explained by any "order" effect as half the subjects performed the Harder condition first. The Case Group subjects, both the High and Low Groups, also showed a trend for higher variability in speed compared to the Control Group. In contrast, the Control subjects showed a comparatively smaller increase in keystroke speed in the Harder condition, while achieving a higher level of increase in peak force.

Together, the results indicated the Case subjects were less able to separate the two components of speed and force control when they were placed in a stressful situation, and tended to have high levels of association between speed and force. The higher levels of Speed Variability in the High Group for both the Faster and Harder conditions would confirm that these individuals had more erratic motor control strategies, while the Control Group demonstrated low levels of variabilities in both Faster and Harder conditions. Sommerich et al. (1996b) also reported strong positive associations in speed and force when subjects were demanded to perform tasks other than their own preferred typing speed, especially in faster typing tasks.

Feuerstein et al. (1997) reported significantly higher peak forces in symptomatic subjects compared to asymptomatic controls, in a 15 minutes' typing task at normal pace. Their results may be more a reflection of the subjects' "normal" performance without being challenged. However, our study has shown similar peak force levels in the Normal condition between the Case and Control Groups. In our study, the symptomatic-asymptomatic differences in keystroke forces were mainly produced when the subjects were physically challenged in the Faster and Harder conditions.

The present results showed that both the Case and Control subjects were able to increase their forces to higher levels, but the High Group, showed other associated changes with higher Mean Speed and Speed Variability than the Control Group. This is likely to reflect the higher capacity of the Controls to cope with the physical challenges and they had more efficient and consistent motor performance, while the symptomatic subjects especially the High Group were less able to separate the speed and force control and therefore had less efficient motor performance. To our knowledge there has been no other similar study reporting on symptomatic- asymptomatic comparisons in keystroke variabilities and our results may have important implications in understanding the differences in motor control between different individuals.

8.4.2 Relationship of keystroke performance, muscle activities and discomforts

The present results have demonstrated important differences in keystroke speeds and forces when subjects were physically challenged in the Faster and Harder conditions. Concurrently there were also changes in their muscle activity levels as well as changing discomfort scores reported under the demands of increased speed and force. These changes in muscle activities and discomforts were more evident in the Case Group compared to the Control Group, and these results were reported in Chapter 7. The results on the keystroke dynamics, muscle activity and discomfort results will be linked together in the following section.

8.4.2.1 *Combined results in the Normal condition*

In the Normal condition, when both groups performed keyboard operation at their normal speed and force levels, similar keystroke speed and force measures were recorded in both groups. However, there were already trends for the Case Group to have higher levels of muscle activities in the Normal condition especially in the muscles on the right side. These between-group differences in muscle activities were more obvious (about 5%MVC) in the right cervical erector spinae (CES) and upper trapezius (UT) muscles, and were only very small in the lower trapezius (LT) and the anterior deltoid (AD) muscles. On the left side, the CES, LT and AD activities were also slightly higher in the Case Group compared to the Control Group.

There were also significant differences in the mean discomfort scores between the two groups in the Normal condition (Case=14.16±12.0; Control=1.08±1.7). This result suggested that when the subjects were typing at their own normal speed and force (ie under minimal pressure), there were already some trends for higher muscle activities and discomfort in the Case Group compared to the Control Group, while their keystroke performance were similar.

8.4.2.2 *Combined results in the Faster condition*

In the Faster condition where the subjects had to increase their typing speed, both groups were able to reach similar levels in keystroke speeds and peak forces, but the High Group showed consistently higher within-subject variability in both speed and force performance, suggesting more erratic motor control. The Low Group showed a low Speed Variability but higher Force Variability than the Control Group in the Faster condition, suggesting that their motor control "efficiency" may be somewhere in between that of the High Group and the Control Group. In terms of muscle activities, the Case Group showed trends for much greater increase in muscle activities especially in the CES, UT and LT muscles than the Controls; and these differences became much more apparent when the High Group was compared to the Low and Control Groups. The High Group also showed significantly increased discomfort scores in the Faster Condition compared to the Control Group and this increase was also significant over time.

The combined results suggested that in response to the demand of typing with increased speed, the symptomatic subjects showed greater changes in terms of muscle activities, discomfort scores, and greater Speed and Force Variabilities. In particular the High Group subjects who had significantly higher discomfort scores, showed trends for much higher increases in muscle activities of the major stabilizers – the CES, UT and LT muscles on the right. These results suggested that the highly symptomatic subjects were more reactive in the Faster condition, requiring greater muscle efforts and experiencing greater discomforts in order to maintain their motor performance at the higher typing speeds demanded. In doing so, these subjects also demonstrated higher variability in speed and force, suggesting less efficient or more erratic motor control strategies. Interestingly the Low Group subjects also responded with moderate to high increases in discomfort scores in both the Faster and Harder conditions but without great increases in muscle activities. They showed some increase in Speed and Force Variabilities that were about mid-way between the changes in the High Group and the Control Group. This result suggested that these individuals may have the potential to develop changes like the High Group subjects, or that they had higher "threshold" in reacting to the physical stressors than the High Group. An alternative explanation would be that this group of individuals may be more influenced by other factors which were non-physical in nature, rather than purely responding to the physical demand of the task.

The Control Group, on the other hand, had smaller (or minimal) increase in muscle activity and they experienced very little discomfort in producing similar keystroke performance under the same circumstances. These results suggested that the Control subjects may have better motor control strategies and were able to cope with the increased physical demand without great increases in effort.

The present results are consistent with those of previous studies showing substantial increases in muscle activities when subjects had to perform computer tasks with increased speed (Birch et al., 2000; Laursen et al., 1998a & b; Westgaard & Bjorklund, 1987). They attributed the increase in stabilizing muscle activities to the higher level of agonist-antagonist co-contraction of muscles involved in performing faster and/or more precise movements. However, our results have produced detailed comparisons of the responses between symptomatic and asymptomatic persons, which have not been clearly shown in past studies.

In practical working situations, workers may be required to work at a faster pace if they have a deadline to meet. This may cause them to work at a faster speed than they would normally. The present results implied that if workers perform keyboard task at very high speeds, they may be subjecting their muscles to greater strain resulting in greater discomforts; and those individuals with considerable past and present symptoms, such as the High Group subjects, would be more susceptible to such problems.

8.4.2.3 *Combined results in the Harder condition*

In the Harder Condition, both the High Group and the Control subjects showed similar increases in peak force levels while the Low Group showed a somewhat lower increase; but all three groups had increased their force levels well above the 20% requirement and their force variabilities were very similar. However, both the High and Low Groups showed higher increase in mean speed and speed variabilities in the Harder condition, and this implied that they were less able to separate the speed and force control.

In the Harder condition, there were also concurrent trends for greater increases in muscle activities in the right CES and UT in the Case Group, and this increase was most apparent in the High Group subjects. The Case subjects also showed significantly increased discomforts in the Harder condition, though the discomfort scores were generally lower than those in the Faster condition. The High Group subjects showed significantly higher increase in discomforts than the Low Group in all conditions, which was also significantly higher than the Control Group. However, the Low Group showed muscle activities that were more similar to those in the Control Group in both the Faster and Harder conditions. This result indicated that the discomforts in the Low Group subjects may be affected by factors other than the muscle efforts required in the tasks.

Together these results confirmed that the symptomatic subjects showed greater physical changes in response to the physically demanding task of typing with increased force, and experienced greater discomforts in the process. Conversely, the Control subjects were able to meet the demand for increasing keystroke force without much increase in muscle effort or discomfort.

Interestingly the Harder condition produced relatively smaller increases in muscle activities on the whole when compared to the Faster condition. This phenomenon was observed in all four muscles, and it may suggest that the increase in proximal muscle effort in performing faster keystrokes was greater than that demanded in typing with harder keystrokes. It may be due to the greater demand on the coordination of muscle activities that are required in performing faster keystrokes, and it would also mean increased number of movements performed in the same period of time. It would appear that such demand on the fine motor control is more difficult for the Case subjects compared to the Controls, particularly the High Group subjects. This may reflect a more generalized and widespread motor control disorder in these individuals.

Table 8.1: Summary of results on keystroke performance, muscle activities and discomforts in both the Case-Control comparison and the High-Low-Control comparison

	Normal Condition	**Faster Condition**	**Harder Condition**
Mean Speed	Case = Control *High=Low=Control*	Case = Control *Low > Control > High*	Case > Control *High, Low > Control*
Mean Peak Force	Case = Control *High=Low=Control*	Case = Control *High > Low, Control*	Control > Case *High, Control > Low*
Speed Variability	Control > Case *High=Low=Control*	Case > Control *High > Low, Control (100%)*	Case = Control *High, Low > Control*
Force Variability	Control > Case *High=Low=Control*	Case > Control *High > Low > Control*	Case = Control *High=Low=Control*
Muscle activity	Case > Control in right CES, UT, LT *High > Low, Control* Bilat LT: *Low > High, Control*	Case > Control in right CES, UT, LT *High > Low, Control* Bilat LT: *Low > High, Control*	Case > Control in right CES, UT, LT *High > Low, Control* Bilat LT: *Low > High, Control*
Discomfort	Case > Control (sig.) *High > Low> Control*	Case > Control (sig.) *High > Low> Control*	Case > Control (sig.) *High > Low> Control*

8.4.3 Symptomatic-asymptomatic differences in motor control

The present results of the keystroke performance, muscle activities and discomfort confirmed the presence of intrinsic differences between Case and Control subjects. The Case subjects seemed to be much more reactive to the introduction of new stresses, and this tendency is reflected in their muscle activity patterns, discomfort scores as well as their keystroke performance. In contrast, the Control subjects were more able to cope with the physical stressors of increased speed and force demands, reflected by the relatively smaller changes in muscle activities, discomforts and keyboard performance.

Comparing the two different physical stressors of speed and force of keyboard work, the speed demand seemed to have imposed greater strains on the Case subjects, reflected in the increased keystroke variability, higher muscle activities, as well as significantly greater increase in discomforts. In contrast, the increased force demand in the Harder condition did not seem to induce such apparent responses. In addition, the Faster condition produced a trend for much greater Speed and Force Variability in the High Group subjects, again confirming that they had more erratic or less efficient motor control strategies. At the same time, the increase in subjective discomforts also appeared to be higher in the Faster condition compared to the Harder condition for the Case Group, and this pattern was consistent in both the High and Low sub-goups. This may also confirm that the Faster condition was a physically more demanding task for the Case Group, while the Control Group was able to cope with both types of physical stressors with relative ease.

The symptomatic-asymptomatic differences in the various measures of muscle activity and keystroke performance may have involved intrinsic changes in motor control strategies in those individuals with a long history of WRNULD. It is also possible that the psychological stress created by these physically demanding tasks, may have been the underlying factor contributing to the resultant changes in the symptomatic persons. Past studies have reported changes in subjective perception of general tension, muscle fatigue and discomfort without any observable change in muscle activity (Roe et al., 2001; Vasseljen & Westgaard, 1995). There may possibly be interactions between physical and non-physical factors contributing towards the development of WRNULD.

8.4.3.1 *Altered Motor Control Model*

The present results are consistent with our previously proposed "Altered Motor Control" Model, which was based on the observations of altered muscle recruitment and kinematics patterns in symptomatic and asymptomatic subjects, when they were exposed to the same physical stressors (Chapter 4). In both the field and the laboratory studies, we have reported consistently increased forward flexion of the neck and the shoulder joint in symptomatic subjects compared to asymptomatic controls (Chapters 3 and 6). The differences in their muscle recruitment patterns, joint kinematics, discomfort responses as well as keystroke performance could be attributed to changes in motor control strategies which may have developed intrinsically within the individuals during their working lives. Both physical and non-physical characteristics that are intrinsic to different individuals may be involved in contributing to the different patterns of physical responses observed. However, we cannot draw any conclusion about the cause-effect relationships of the motor control changes and work-related discomforts due to the case-control research design.

Future studies could usefully examine the effects of changing some aspects of the motor control strategies of symptomatic persons such as reducing the speed and/or force of keyboard operation, to see whether other responses such as muscle activities or discomfort sensations may be affected also.

8.4.3.2 *Heightened Sensitivity Model*

In Chapter 7 reporting on the EMG and discomfort results in this study, we have proposed a "Heightened Sensitivity Model" to explain the different levels of reactivity in the High, Low and Control Groups in the Faster and Harder conditions. Both the High and Low Group subjects had similar past histories of discomforts affecting the same body areas and they had similar work profiles. The main difference between the two groups would be the severity of the discomforts both in the past and in the present during the experimental tasks. When challenged by the demands of the Faster and Harder conditions, the High Group consistently demonstrated greater increases in muscle activities in the major neck-shoulder stabilisers as well as increased variabilities in speed and force performance. Although these findings were not statistically significant, they had very consistent trends in the different situations, and all the keystroke variables, muscle activity and discomfort results were compatible with each other.

Past research has reported that nociceptors may develop peripheral or central sensitization phenomena due to repetitive or prolonged exposures to mechanical and/or chemical stimuli (Graven-Nielsen & Mense, 2001; Mense, 1993; Sheather-Reid & Cohen, 1998). These processes are likely to operate in symptomatic individuals during their past history in relation to the development of chronic work-related musculoskeletal disorders. The sensitization phenomena may have resulted in heightened sensitivity of the symptomatic persons making them more reactive when exposed to new physical demands. Our present finding has demonstrated greater reactivity in the High Group subjects when they were challenged by the physical stressors of increased speed and increased force, whereas the Control Group showed only minimal changes in muscle activities as well as more efficient motor performance in keystroke dynamics. These findings would support the Heightened Sensitivity Model.

The responses of the Low Group subjects would also fit in with the Heightened Sensitivity Model. These individuals seemed to be less sensitive to the physical stressors than the High Group but their responses were still greater than the Control Group in various aspects. In terms of discomfort scores, they showed significant increases in both the Faster and Harder conditions that were about half-way between the scores of the High Group and the Control Group. They also displayed trends for higher increases in the right CES and bilateral LT muscle activities than the Control Group; as well as higher Force Variability in the Faster condition and higher Speed Variability in the Harder condition than the Control Group. Consistently the changes in their muscle activities and keystroke performance were lower than those in the High Group. Thus the results implied that the Low Group had a lower sensitivity to physical stressors than the High Group, and this could be related to their less severe musculoskeletal problems in the past as well as the present.

It is possible that these different sensitivities of different individuals developed as a result of their past discomforts which may have involved either neurophysiological sensitization or pathological changes in the muscle or articular structures due to prolonged or repetitive biomechanical loading (Kumar, 2001; Westgaard, 2000). On the other hand, the discomforts may have preceded the development of sensitization processes. Longitudinal studies would be required in order to provide more insight on the cause-effect relationships of these processes.

The present results suggested that the symptomatic subjects may possibly have heightened responses when exposed to induced physiological stresses created by the demands of increased speed and force of keying. It is possible that they may have similar reactions to other kinds of stressors, either physical or psychological. It is also not known if such sensitization phenomena would only apply to certain work tasks or they may become generalised to all other physical tasks performed.

Alternatively, it can be postulated that those individuals with chronic symptoms may develop reduced capacity or reduced flexibility to cope with new stresses, and therefore greater muscle efforts or more erratic motor performance were produced. Prolonged static loading could render the musculoskeletal tissues more vulnerable or susceptible to injury (Kumar, 2001), and therefore comparatively greater increases in efforts would be required when new physical stressors were introduced. In both Studies 2 and 3, we have shown that certain muscles, namely the UT and CES, were more reactive to the physical stressors than the other muscles. Symptomatic individuals could also have developed reduced flexibility in their altered motor control strategies to cope with new stimuli as these were fixed in their centrally programmed patterns. All these intrinsic processes could be operating to different extents simultaneously within the body and our present research can only postulate on these but we cannot provide any objective evidence to support them. However, the heightened sensitivity model seems to be the most logical scenario, and other physical and non-physical influences should also be acknowledged. Future research should explore these physical and non-physical factors in greater depth.

8.4.4 Method issues

8.4.4.1 *Comparison of keystroke speed and force data with previous studies*

The present results showed that our method of measuring keystroke speed has produced valid measures which were comparable to those of previous studies that have reported keystroke durations in the range of about 130 – 280 ms (±30-70) (Dennerlein et al., 1998; Rempel et al., 1997). Our present results in terms of number of keystrokes per minute were in the range of 227 in the Normal condition, to about 260 in the Faster condition, which would be equivalent to over 13, 000 keystrokes per hour. Thatcher and Brophy (1999) reported that typists who worked at greater than 11,000 strokes per hour had higher risks of developing upper limb pain. Speed measurements recorded in our study may explain why some individuals may develop these problems due to deviations in motor control strategies in performing keyboard tasks.

In our results, the mean peak forces were in the range of 6-7N in the Normal condition and increased to 10-11N in the "Harder" condition. The present results were somewhat higher in values compared with keyboard forces reported in previous studies. Previous studies which measured keystroke or tapping forces have reported force values in the range of 1-4N (Armstrong et al., 1994; Feuerstein et al., 1997; Martin et al., 1996; Rempel et al., 1997). Sommerich et al. (1996a) reported average keystroke forces in the range of 0.6 - 4.4N, with some of the "peaks" reaching up to 7N, and these values were more similar to our data in the Normal trials. The discrepancies in the results between previous studies and our results may possibly be due to the different sensitivity of equipment used, and the difference in sampling frequency used in the present study

(1920Hz) compared to those in previous studies, which have been mainly in the 200-500Hz range.

Our study is one of the first to use 4 load cells under 4 corners of the keyboard, creating a force platform which collected keystroke data generated on the entire keyboard. The difference in the measuring instrument may have accounted for some of the differences in the force data generated in our study compared to previous ones. Armstrong et al. (1994) used 2 strain gauge force transducers under the two ends of the keyboard and measured finger forces on all keys comparing three different keyboards. Sommerich et al. (1996a) used the same type of piezoelectric load cells as we have used, but they had two load cells under the keyboard instead of four. In our opinion, our present approach with 4 load cells under the 4 corners of the keyboard and measuring all keystroke forces during text typing, would generate data from a more realistic simulation of the task of word-processing performed by office workers.

8.4.4.2 *Keystroke peaks identified without locating which keys or which fingers*

The present method of studying keystroke speed and force has been shown to produce reliable and consistent results; as the Labview program for the keystroke peak identification was able to accurately identify over 90% of all keystrokes during typing. However, presently the keystroke peaks were identified without matching the exact keys being typed and the specific fingers involved in the actions. In future, this method could be further developed in order to differentiate the different speeds and forces that are generated by different fingers in the performance of actual typing tasks. This may be useful in studying the force dynamics of affected and non-affected hands or finger joints in symptomatic persons suffering from work-related problems such as carpal tunnel syndromes.

8.5 CONCLUSION

The present study has examined the keystroke performance in terms of speeds and forces generated by symptomatic and asymptomatic subjects under different typing conditions of normal, increased speed and increased force demands. The Case Group, particularly the High Group demonstrated trends for both higher speed and force variabilities during the Faster condition, and a high increase in speed associated with increased force in the Harder condition. The results seemed to suggest that the Case subjects may have developed impaired or altered motor control strategies when placed under stressful situations, and were less able to separate the speed and force components in the coordinated task of text-typing. The Case subjects also demonstrated greater increases in muscle activities in the major neck-shoulder stabilisers and reported much higher discomfort scores in performing the physically demanding tasks (Chapter 7). In contrast, the Control subjects appeared to have better ability to separate the control of speed and force in their typing tasks; and did not show great increase in muscle activities or discomfort, under similar demands of physically stressful conditions.

The heightened responses in symptomatic persons add further support to our proposed "Altered Motor Control" Model, as well as the "Heightened Sensitivity Model", on a multi-faceted etiological basis, to explain the symptomatic – asymptomatic differences in response to physical stressors. These models may have important implications towards the understanding of the etiology of WRNULD. More research is required to gain deeper understanding about these motor control mechanisms in different individuals. Future ergonomic research should further explore the precise biomechanical stresses that occur in symptomatic persons as opposed to painfree control subjects, as symptomatic persons may have different responses to physical stresses in performing occupational tasks.

CHAPTER 9

DISCUSSION

The results of the studies in the present thesis point to consistent patterns of differences in terms of internal exposure variables between symptomatic and asymptomatic persons. The 3 studies have been reported and discussed separately at some length in previous chapters. This chapter will attempt to link together the findings of the studies in terms of kinematics, muscle activities, keystroke performance and discomfort differences between the Case and Control Groups, as well as between the High-Low sub-groups.

The results of the three studies have produced evidence for some important physiological control mechanisms for muscle activity and joint movements, and these appeared to be closely related to the development of musculoskeletal discomforts. Synthesis of the present findings forms the basis for constructing conceptual models linking the individual differences in response to physical stressors to the development of WRNULD. These models will be discussed in detail in this chapter and the implications for ergonomic research will be addressed.

9.1 CONSISTENT CASE-CONTROL GROUP DIFFERENCES IN KINEMATICS, EMG AND KEYSTROKE PERFORMANCE IN 3 STUDIES

The present results have shown consistent Case-Control group differences in terms of kinematics, EMG as well as keystroke performance variables in all 3 studies. In Study 1 we have demonstrated some consistent trends for postural differences between the symptomatic and asymptomatic office workers, when they performed computer work at their own workstations. The differences were mainly in their forward head tilt and neck flexion angles, and there were trends of increased acromion protraction in the Case subjects. In Study 2 we standardized the physical workstation and the work task, and found similar trends of Case-Control differences in the head-neck angles to those of Study 1. In Study 2 we also found a trend of increased right shoulder flexion in the Case subjects, which was compatible with the trend for increased acromion protraction in Case subjects in Study 1.

Muscle activities were measured in Studies 2 and 3, and the Case Group consistently had greater activities in the UT muscle especially on the right side. CES muscles showed different activity patterns in Studies 2 and 3 and this may be related to the different tasks performed and the different workstation settings. The LT and AD activities were very similar in both studies and between groups. Consistently the Control Group showed a more even distribution of muscle activities on both sides, and they also had smaller extents of changes in different experimental conditions compared to the Case Group.

In addition, the MF of all four muscles on both sides tended to be higher in the Case Group than the Control Group in Studies 2 and 3, although these differences were not statistically significant. The MF results in both studies did not show any significant decline over time-at-task possibly suggesting that no muscle fatigue was experienced by the subjects.

Keystroke performance in terms of the speed and force variables also demonstrated trends for Case-Control differences in Study 3, and these were thought to be part of the motor control changes in the symptomatic individuals.

In terms of subjective discomforts, all three studies demonstrated significantly higher discomfort scores in the Case Group compared to the Control Group, who generally had minimal or no discomforts in all body areas. The Case subjects commonly complained of bilateral neck and shoulder discomforts, followed by the wrist/hand and elbow symptoms. Study 1 showed that there was no significant increase in discomfort across a working day; but both Studies 2 and 3 showed a significant increase in discomforts with time-at-task in the Case Group. By differentiating the Case subjects into the High and Low Groups, more important differences in terms of the motor responses were revealed. Discomfort patterns demonstrated a tendency for bilateral and more widespread distribution than what the EMG amplitude differences demonstrated in the underlying muscles. The following sections will discuss the major findings produced by the present research, in comparing the different subject groups.

9.1.1 Differences between symptomatic and asymptomatic persons were more apparent when Case subjects were sub-divided into High and Low Groups

While consistent differences were observed in comparing the dependent variables between the Case and Control Groups, these differences became much more apparent when the Case Group was divided into the High-Low Groups. In Study 1, due to the small sample size of only 8 subjects in each group, we have not differentiated the Case subjects into High-Low Groups. In Study 2, when the Case subjects were divided into the High-Low Groups, the head-neck angles showed greater differences; as much as 8° in the mean flexion angle between the High and the Low Groups, and about 6° difference between High and Control Groups (High Group mean = 69.9° ±10.1; Low Group mean = 61.7 ° ±11.5; Control Group mean = 63.7 ° ±12.7). In Study 1, the Case-Control difference was about 7 ° in the neck flexion angle. This difference may be sufficient to cause an important change in the neck extensor moment as reported in previous biomechanical research (Chaffin et al., 1999).

However, not all kinematics variables showed such apparent differences in the division of High and Low Groups. The shoulder angles were one example that did not show further differences between the High and Low Groups. This may suggest that the head-neck angles were more affected by or closely related to the discomforts of the subjects than the other joint angles.

The altered kinematics findings in the neck-shoulder region appeared to be closely related with the altered muscle activity patterns in the Case subjects. In the EMG results of both Study 2 and Study 3 greater differences were demonstrated when Case subjects were examined in the High-Low Groups. In Study 2, the differences in the right CES and UT median amplitudes (50th% APDF) became statistically significant in the High-Low comparisons. The High Group subjects showed a significantly higher 50th%APDF of the right UT muscle, as well as a significantly different CES/UT amplitude ratio on the right, compared to the Low Group and to the Control Group. The significant CES/UT ratio indicated that the High Group had proportionally higher UT activity and lower CES activity compared to the Low Group and the Control Group. These results implied that the subjects with more severe discomforts were utilizing their UT muscles more than the other cervical stabilizers in maintaining a more asymmetrical head-neck and shoulder posture. This was an important contrast against those with mild or minimal symptoms (Low and Control Groups) that relied more on their CES muscles to share the major load in controlling the head-neck posture. The results in Study 2 have demonstrated that within the Case Group, not all individuals would show the same motor responses; and the Low Group individuals behaved more similarly to those in the Control Group although the Low Group had slightly more discomforts in general.

In Study 3, again greater muscle activity differences were revealed when the High, Low and Control Groups were compared. However, in this study both the UT and the CES muscles showed much higher activities in the High Group compared to the Low Group and the Control Group. The increased complexity of the task demands and the different workstation setup in this study were important factors that were likely to account for this different pattern of muscle recruitment in the High Group.

While the UT muscle activities in the High Group showed consistently high levels in both Study 2 and Study 3, the High Group subjects also seemed to have recruited more CES activity to help in sharing the muscle load in Study 3. Waersted (2000) has pointed out that in performing computer or manual tasks with greater complexity, there is a need for increased stabilizing muscle activities. Our results have demonstrated that this phenomenon was more pronounced in symptomatic persons, such as those in the High Group and to a lesser extent, the Low Group also. In contrast, the Control Group subjects showed that they were able to cope with the same task demands without such large increases in stabilizing muscle activities in both Study 2 and Study 3.

In Study 3 we have also found trends for greater differences in the keystroke performance variables comparing the High, Low and Control Groups. Although these variables did not show significant differences, the patterns were similar to those of the muscle activities, with the High Group showing the most apparent changes. The trends for higher Speed and Force Variabilities in the High Group subjects possibly reflected a more erratic motor control of the keystroke actions, and this has been reported as a loss of "fluency" in typing skills in past research (Gentner, 1983). Together the poorer motor control in keystroke actions and the higher muscle activities in the stabilizing muscles in the High Group subjects, confirmed their heightened reactivity to physical stressors. In contrast, the Control Group subjects demonstrated a more efficient motor control of their keystroke performance as well as maintained lower muscle activities in the neck-shoulder stabilizers, thus indicating their better abilities to cope with the physical stressors. The Low Group demonstrated more similar responses to the Control Group in Study 2, and proportionally greater responses in Study 3 that were in between the High Group and the Control Group.

Together these results demonstrated that among the symptomatic individuals, there may be different patterns of intrinsic motor control changes that may have developed in relation to their past and present discomforts. These results have not been clearly demonstrated in past research, which often failed to examine different sub-groups within symptomatic subjects (Hagg & Astrom, 1997; Nordander et al., 2000; Sandsjo, Melin, Rissen, Dohns, & Lundberg, 2000; Takala & Viikari-Juntura, 1991; Westgaard et al., 2001)

9.1.2 Kinematics differences between symptomatic and asymptomatic appeared to be related to muscle activity differences

The kinematic analysis in both Studies 1 and 2 showed trends for increased mean angles and ranges of movements for head-neck flexion, and there was also a significant difference in side flexion and rotation angle of the neck in Study 2. These findings suggested that symptomatic persons held their necks in more forward flexion and moved their head-neck segments in greater extents of flexion/extension. In addition, they may also have more asymmetrical head postures that were different from those of the asymptomatic controls. Together these results showing trends for increased forward neck flexion and significant differences in head side flexion / rotation, may indicate that there were increased or asymmetrical compressive forces acting on the articular structures in the cervical spine.

While these differences in kinematics may involve only subtle changes of a few degrees in the mean angles, the trends were consistent in both the field study as well as the laboratory study, thus making this evidence stronger. If sustained for a long period, these subtle differences in joint postures may have an important impact on the compressive loading in the joints. There may also be implications for sustained muscle activities required to maintain these static joint postures.

Our results have demonstrated the close relationship between muscle activity and joint loading. In particular, the UT muscle consistently showed a high level of activity especially among those with high discomfort scores in the High Group. In both Studies 2 and 3, the right UT muscle seemed to the primary stabilizing muscle in the High Group, throughout the challenges of the various physical stressors. In Study 3, the High Group subjects seemed to have recruited high levels of both UT and CES muscles to share in the stabilizing role.

In Chapter 6, we have discussed the different possible relationships between altered kinematics and altered muscle recruitment. The right UT activity was closely related to both increased neck flexion angle as well as increased right shoulder flexion angle in the Case subjects, particularly the High Group individuals. Thus it appeared that the UT muscle in the High Group subjects, had a dual role as a primary cervical stabilizer as well as a shoulder stabilizer. It is possible that the habitual forward head posture may have preceded the altered muscle activation patterns, and the resultant high activity in the UT was a response to the compressive loading in the cervical spine causing a painful reaction of heightened UT activity. On the other hand, it is also possible that the individual may have developed high UT activity first which resulted in an asymmetrical head-neck posture.

Studies have identified UT as a major "global" stabiliser, acting on multiple segments of the spine; while CES is considered a more effective inter-segmental stabiliser of the cervical spine (Bergmark, 1989; Comerford & Mottram, 2001). However, there has been very little direct evidence to clearly demonstrate the compressive and side bending moments of the trapezius muscle *in vivo,* and this concept is relatively new. Most of the studies on biomechanical modeling of the cervical spine have used cadaveric specimens generating only *in vitro* information. This type of muscle force simulation would only generate passive tension forces in muscles during various movements of the head-neck segments, but *in vivo* forces cannot be known (Bernhardt et al., 1999; Miura et al., 2002). Johnson et al. (1994) identified the functions of the various parts of the trapezius muscle, and proposed that the upper trapezius exerted more compressive forces on the acromioclavicular joint than the cervical spine, but this work was also done on cadaveric specimens. It is not known whether the muscle actions would be the same in the living human beings working in an erect position, performing functional tasks. Comparatively, EMG is still a better method to study the dynamic muscle activities during occupational tasks in different workers.

The present research has generated important information about the relationship of kinematics and muscle activities in different individuals. Although it is hard to establish the cause-effect relationship of the altered muscle activities and altered kinematics, the present results have demonstrated that they may both be potentially important mechanisms in the development of work-related musculoskeletal problems.

9.1.3 Some muscles (CES and UT) were more reactive than others (LT and AD)

The present findings have highlighted the important roles of the CES and UT muscles in postural stabilization during computer tasks, and their muscle activities were closely related to the discomforts in the experimental conditions. Consistently in Study 2 and Study 3, the CES and UT muscles demonstrated the greatest changes in response to the demands of the physical stressors. Comparatively the LT and AD muscles appeared to have smaller extents of change in their muscle activities in the same experimental conditions. The differences in muscle responses were most evident in the High Group subjects who had more severe discomforts, and these findings were consistent in both studies.

The results in Study 2 showing the tendency to use the CES muscles more than the UT muscles in a cervical-stabilising role in the Low Group and Control Group, suggest that this may be a better motor control strategy, resulting in the low level of discomforts in these subjects. The High Group subjects, on the other hand, demonstrated a high reliance on the UT muscle, and this may be a less efficient motor control strategy. The High Group subjects also demonstrated a significantly greater extent (range) of flexion movements in the head-neck segment, which again could be tied to the less efficient role of the UT in controlling the fine segmental movements of the cervical spine.

In Study 3 the High Group subjects maintained trends for higher muscle activities in both the CES and UT muscles in all three typing conditions. The high UT activities also displayed the largest increases during the challenges of the Faster and Harder conditions. These results confirmed the reliance on this muscle as a main stabilizer in the highly symptomatic individuals. This increased EMG has occurred despite the added support to the forearms to off-load some of the demands on the UT muscles. The increased activities in both the UT and CES muscles in the High Group during the Faster and Harder conditions may be due to the more complex motor control required in meeting the demands of these physical stressors. It is indeed difficult to separate the influences of workstation factors from the work task factors, and the muscle activity changes are likely to be the results of a mixture of these various factors.

The anatomical differences of the CES and UT muscles contributing to their different functional roles, and their selective recruitment strategies by symptomatic and asymptomatic individuals have important implications for the understanding of WRNULD. To our knowledge, past studies on occupational EMG activities comparing Case and Control subjects have not examined the synergistic roles of these muscles in such detail. Most of the occupational studies have focused on the UT muscle activities, while the important aspect of how the various major stabilising muscles work together during occupational tasks has not been fully addressed (Birch et al., 2000; Hagg & Astrom, 1997; Nordander et al., 2000; Turville et al., 1998). In addition, muscle activity patterns during occupational tasks have seldom been examined in relation to the anatomical functions of the muscles (Birch et al., 2000; Feng, Grooten, Wretenberg, & Arborelius, 1997; Madeleine et al., 1999). Edgerton et al. (1996 & 1997) examined the synergistic actions of all the major stabilising muscle groups in various static positions but these would be very different from muscle activities and movements during occupational tasks, and their subject groups were mainly patients with traumatic injuries such as whiplash.

In contrast to the CES and UT muscles, the LT and AD did not show such apparent changes when exposed to the same physical stressors. Consistently these muscles were less reactive and showed similar responses in both Study 2 and 3, indicating that they were not affected by the physical stressors to the same extent as the CES and UT muscles. When the Case Group was sub-divided into the High and Low Groups, the AD muscle still showed no apparent difference among the groups in both Studies 2 and 3; and generally their mean 50th%APDF activities were about 5%MVC. This may suggest that the AD muscle activities were not greatly affected by the different tasks performed and that they may not have an important role in relation to the discomforts experienced.

The clinical concept of "scapular stabilization" proposed that the LT muscle should assume a more active role in stabilization of the scapula in order to counterbalance the strong tension in the UT muscle which is often considered 'pathologically hyperactive' in patients with neck and shoulder pain (Comerford & Mottram, 2001; Forde et al., 2002; Janda, 1994; Jull et al., 1999). However, our results have not shown any clear patterns of group differences in LT activities except in Study 3. The Low Group demonstrated a trend for higher activities in LT muscles bilaterally than the High and Control Groups in Study 3, while in Study 2, only the left LT showed such a trend in the Low Group. If these trends were real, it may possibly suggest that the Low Group subjects recruited their LT muscles to assume a more substantial role in postural stabilization, and this may have some relationship with their lower discomfort scores than the High Group. Otherwise, all the most apparent differences between groups have been in the CES and UT muscles in both studies 2 and 3, suggesting these two muscles were more reactive to different physical stressors.

Alternatively these two muscles could be considered being more reactive to either the discomforts in the past or possibly more reactive to the discomforts during the experimental conditions.

In examining the LT muscle activities, the interference from Electrocardiogram (ECG) signals must be acknowledged. Although we have implemented several high-pass and low-pass filters to minimise unwanted signals in the EMG, the ECG signals cannot be completely eliminated and these signals may have contributed to certain proportion of the LT amplitude results. In the present analysis, we have assumed that any difference between individuals would be due to the differences in actual muscle activities, as each individual should be equally affected by this factor across conditions. Certainly the EMG methods still need to be improved in studying muscles in the thorax region. More research is also needed to examine the activities of the different parts of the trapezius muscle, as well as other major stabilizers of the scapula during occupational tasks.

9.1.4 The right sided muscles showed greater changes in response to 3 physical stressors than the same muscles on the left

Another interesting finding from the studies is that most of the apparent changes in muscle activities seemed to be concentrated in the right sides of the muscles. In both Studies 2 and 3 the Case-Control differences were most apparent in the right side of the CES and UT muscles. Consistently the LT and AD muscles also exhibited slightly higher amplitudes of muscle activities on the right side than the left; but the extents of these left-right differences were not as great as those in CES and UT muscles in absolute terms.

This phenomenon may be related to the working habits of the subjects, showing greater dominance in using the right upper limb in performing computer work. The present subjects were mostly right-hand dominant, with only 1 subject from Study 2 being left-hand dominant. In Chapter 4, we have addressed the issue of increasing popularity of using the mouse as an input device, and this has been reported to result in significant increases in muscle activity of the right UT muscle (Harvey & Peper, 1997; Jensen et al., 1998; Karlqvist et al., 1998). However, this trend of increasing mouse use seemed to affect some individuals more than others. These findings suggested that while both groups of subjects may perform similar kinds of work, only the High Group subjects gradually developed the habits of sustaining higher muscle activities in the right UT, while the Low Group and Control Group subjects did not seem to demonstrate such phenomena.

9.1.5 Generally, there were no apparent changes in posture and muscle activity as a result of time-at-task

EMG amplitudes, MF and kinematics measurements in Studies 1, 2 and 3 have not demonstrated consistent trends for change with time-at-task. These findings suggested that the observed movement and muscle activity patterns reflected the usual postural habits of the subjects as in their normal daily work routines. Previous research have also produced similar results with no change in muscle activities nor movement patterns over time-at-task (Hermans & Spaepan, 1995; Turville et al., 1998) as discussed in Chapters 6.

The lack of change with time-at-task was not actually what we predicted at the onset of the research, when we expected to see deterioration in postures and increased muscle amplitudes and downward shifts in MF, as the subjects may experience fatigue in sustaining the physical loads during the experimental tasks.

However, in some of the Case subjects with more severe symptoms, we did observe some shifting of the muscle activities towards higher amplitudes especially in the UT and CES muscles, as the experimental task proceeded. On a group basis, in Study 2 the CES muscles demonstrated a statistically significant side effect as well as a significant time effect, indicating that this muscle showed different responses to time on both sides, and the patterns of change were also different in the Case and Control Group (see Fig. 4.3, Chapter 4). Although the muscle activity patterns did not demonstrate any clear-cut trends of increase or decrease over time, their patterns of change may be affected by a number of factors. The various muscles displaying the different up and down trends may suggest that the subjects were actually changing or re-distributing their loads as time-at-task progressed (Fig. 4.3 and Fig. 7.3). This may be an important factor to consider. The lack of significant time effect for any one muscle does not necessarily mean that there is no increase in overall muscle load with time-at-task. Different individuals may employ different strategies of recruiting more of another muscle on the same side, or increase the activity of the same muscle on the opposite side to share the workload as time progressed. This factor may account for the up and down trends of the different muscles across the experimental trials.

For example, in Fig. 4.3 the right UT muscle in the Case Group seemed to have a downward trend towards T5 (the end of the 1-hour typing task) while the left UT was unchanged throughout. In contrast, the right CES muscle in the Control Group seemed to have an upward trend from T3-5 while the left CES was relatively unchanged. In addition, there may be individual variations in their different strategies of muscle recruitment. What we have identified so far, may only be the overall distribution of muscle loads for the four muscles studied on a group basis.

While we acknowledge that no significant time effect was found statistically in the present results, nonetheless, the complex and variable time patterns demonstrated by the different kinematics and muscle activities in Studies 2 and 3 implied that there may be subtle inter-individual variations in motor control strategies, and these mechanisms are likely to have an important contribution towards WRNULD.

9.1.6 Discomfort patterns demonstrated a tendency for bilateral and more widespread distribution than what the EMG amplitude patterns suggested

In Study 1, there were no significant changes in discomfort across the working day in both Case and Control Groups; but the mean discomfort scores were significantly different between groups. In Study 2 and Study 3, the discomfort scores showed a significant group effect as well as a significant time effect. The results confirmed that the physical stressors were sufficient to produce significant discomforts in the Case subjects and these discomforts increased significantly with time-at-task, while the Control subjects did not experience such unpleasant or distressful sensations. The combined results of the three studies may also suggest that the controlled physical exposures in the experimental tasks of Study 2 and Study 3 were imposing greater stresses on the symptomatic persons, possibly more than their daily work routines as in the situation of Study 1.

Within the Case Group, the High Group had significantly higher discomforts compared to the Low Group in both Studies 2 and 3. The Low Group had only slightly more discomforts than the Control Group in Study 2, but significantly higher discomforts than the Control Group in Study 3. These results confirmed that the physical stressors in Study 3 were exerting greater strains on the subjects than in Study 2.

In Study 2 and Study 3, the Case Group subjects exhibited discomfort patterns that were more widespread and they did not match with the locations of high muscle activities. In previous sections, we have discussed the relationships of discomfort locations to the neurophysiological mechanisms of pain control. It is possible that the discomfort areas may not be the actual locations of the source of nociceptive signals, but rather may reflect distal pain referral sites. The significant increase of discomforts with time and the widespread location of discomforts may also imply that factors other than muscle activity patterns or altered kinematics may be influencing the discomfort sensations (or maybe be active in combination with these factors). In the following section (9.2), we will examine the individual characteristics of the subjects which may contribute towards the group differences in the various physiological responses.

9.2 EXAMINING DISCOMFORT AND INDIVIDUAL CHARACTERISTICS IN THE SUBJECTS

The assessment of subjective discomfort scores in the present studies has produced significant differences between the Case and Control Groups in terms of group effects and time effects. These significant differences in discomfort scores were reported in all three studies, indicating that Case subjects had increased discomforts in their actual workplace across a typical working day (Study 1), as well as in response to different physical stressors in a laboratory setting (Studies 2 and 3).

Perhaps the most interesting findings were when the Case subjects were sub-divided into a High Group and a Low Group based on their mean discomfort scores in Study 2 and 3, as it revealed much greater differences in terms of kinematics and muscle activities between these two sub-groups. Consistently in Study 2 and Study 3, the Low Group subjects displayed more similar responses to the Control Group, rather than the High Group.

However, the exact underlying mechanisms resulting in their different reactivities are not clearly understood, and this is a difficult issue to resolve. The information we have gathered about the individual characteristics of the subjects, mainly involved their demographic profiles, work nature and work habits, as well as their past discomfort histories. In the following section, we will examine these individual characteristics in order to explore the possible links between these factors and how they affect the individuals' responses to the physical stressors.

9.2.1 Differences in past discomfort profiles comparing the High, Low and Control Groups

Examining the past discomfort profiles of the Case subjects, both the High and Low Group subjects had similar histories of past discomforts in terms of duration of discomforts and the body areas affected, but the Low Group subjects reported generally lower discomfort scores in the past. This would suggest that the High Group consisted of subjects with a more severe discomfort in the past, and they were also suffering from a considerable amount of discomfort at the start of the experimental task in Studies 2 and 3. The presence of already existing discomforts would have affected their responses in the experimental conditions. Their discomfort scores during the experimental tasks in Study 2 appeared to be similar in magnitude to their past scores, especially in the neck and shoulder areas.

The Low Group, on the other hand, consisted of individuals who experienced less severe discomforts in the past but these were of similar duration as the High Group; and their responses to the physical stressors were different. Interestingly their discomforts were much lower in the neck and shoulder region during the experimental tasks in Study 2 compared to their past scores.

The Low Group individuals may have more subtle motor control changes that required higher levels of physical and/or mental stimuli before they were elicited. This idea would fit with the results of Study 3 that involved more demanding tasks and therefore the Low Group subjects had more discomforts and greater increases in some muscle activities, compared to their responses in Study 2. The differences in motor control between the High Group and the Low Group may possibly be an important etiological mechanism contributing towards the development of WRNULD. On the other hand, we cannot rule out the possibility that the differences in response were a result of the presence of discomforts.

When the discomfort pattern of the subjects for the 12 months prior to testing were compared with the discomfort ratings during the 1 hour typing trial in Study 2, the Case Group subjects were found to have additional areas of discomforts induced by the physical stressors in Study 2 and Study 3 that were not present in their past histories. We have identified these as "*task-induced discomforts*", as opposed to "*clinical discomforts*" which were the subject's original painful areas. The most common task-induced discomforts were in the wrist-hand area and these were more prevalent in the Case Group than the Control Group. This result implied that in addition to having the clinical discomforts, the Case subjects might also be under more strain in their other body regions and therefore experienced more widespread discomforts.

Another mechanism associated with prolonged musculoskeletal discomforts is that the symptomatic persons may have become more "sensitized" due to previous experience of symptoms (Coderre et al., 1993; Mense, 1993; Westgaard, 1999). There may be mechanisms of both peripheral and central sensitization of musculoskeletal pain which appeared to have greater influence on the High Group subjects compared to the Low Group (Arendt-Nielsen & Svensson, 2001; Graven-Nielsen et al., 1997a; Mense, 1993). There may also be a psychological component involved in the subjective complaint of task-induced discomforts, that the other body areas were "perceived" to be under more strain, and therefore more discomforts were reported.

9.2.2 Other individual characteristics – effects of age difference and work experience

In Studies 2 and 3 we have reported on the information collected from the subjects and there were no significant differences in their physical build, work experience, work nature and patterns of computer usage (Chapters 4 and 7). The only personal factor that was significantly different was the mean age of the subjects, with the Case Group being about 5 years older than the Control Group in Study 2, and about 9 years difference in Study 3. This factor was difficult to control as there was a higher chance of recruiting subjects who were older and have had past discomforts. When age was used as a covariate to compare discomfort scores and EMG amplitude data in Studies 2 and 3 comparing the High, Low and Control Groups, there was no significant effect of age on the dependent variables and there was no change to the analysis patterns. Since there was no significant difference in the mean age between the High and Low Groups, and yet these two groups responded very differently in Study 2 and 3; this would support our interpretation that the results were more due to the individual intrinsic motor control differences, rather than their age differences.

Past studies have reported variable results regarding the influence of age on work-related musculoskeletal disorders (NIOSH, 1997). Bernard et al. (1994) found no association between age and work-related musculoskeletal disorders in their study on newspaper employees. Age may be more a risk factor in occupations involving manual handling and physical labour, in which case there may be a phenomenon of "survivor bias" (NIOSH, 1997). "Survivor bias" predicted that workers whose health has not been adversely affected by their jobs would stay longer than those who had work-related health problems causing them to leave the jobs. In the case of office workers, our experience showed the opposite trend to survivor bias. We found that there was an increased chance of recruiting older subjects for the Case Group, as there may be more opportunity for them to experience musculoskeletal discomforts related to their work while they can still continue to survive in their jobs. This factor would account for the age difference between the Case and Control Groups. However, this factor has not adversely affected the performance of the subjects as demonstrated by the lack of statistical significance in all the dependent variables with age as a covariate. It is also possible that people with the worst musculoskeletal problems would have already dropped out of office work early in their careers.

Besides age, other individual characteristics that we have gathered information on, included the subjects' work experience and work nature related to computer use. The results showed that all subjects were experienced office workers with fairly similar characteristics in their job duties, and that they had all used computers for more than 3 years. We have purposely selected subjects who had a more clerical nature of work so that they were well familiar with text typing. In other words, these subjects were equally skilled in typing so that this factor would not become an intervening variable in the studies.

In our study all subjects reported a similar number of hours in keyboard use and mouse use per day, thus group differences in their performance or physiological responses during the experimental tasks should not be affected by their similar daily exposures to computer use. Previous studies have reported higher risk for developing WRNULD related to the number of keyboard hours (Bernard et al., 1994; Faucett & Rempel, 1994; Green & Briggs, 1990). Recently there has also been a rising trend for intensive use of the mouse and this has also been shown to be associated with higher risks for WRNULD (Harvey & Peper, 1997; Jensen et al., 1999a).

In general, the various individual factors such as age or work experience factors did not appear to be important intervening variables contributing towards the group differences among the High, Low and Control Groups.

Table 9.1: Comparison of personal profiles of High, Low and Control Groups in Studies 2 and 3

	Study 2			*Study 3*		
	High Group	**Low Group**	**Control Group**	**High Group**	**Low Group**	**Control Group**
Age	36.0±4.5	36.0±5.2	31.3±7.2	39.8±9.4	38.2±6.0	30.5±5.9
Past history of discomforts (mode)	>6 months	>6 months	0-8 days	>6 months	>6 months	0-8 days
Working hours / week (mean±sd)	41.0±7.1	45.3±6.1	43.0±4.1	44.3±2.2	46.0±7.0	42.2±4.6
VDU work/day (mode)	4-6 hours	6-8 hours	4-6 hours	6-8 hours	4-6 hours	4-6 hours
Keyboard work/day (mode)	2-4 hours	2-4 hours	4-6 hours	4-6 hours	4-6 hours	2-4hours

9.2.3 Possible influence of other non-physical factors

We need to acknowledge the possible influence of other non-physical factors such as the psychosocial profiles, cognitive and emotional processes within the individual, affecting their motor behaviour and their perceptions of pain or discomfort. There has been ample research evidence to support the important influence of these psychological factors that can affect the perception of pain or discomfort (Linton, 2000; Waersted, 2000; Westgaard et al., 1993; Zusman, 2002). Linton (2000) described the different psychological factors that can affect the onset and/or development of neck and back pain. These included a cognitive component, an emotional dimension as well as a social aspect. Waersted (2000) proposed that biomechanical muscle activities related to postural demands should be differentiated from "non-biomechanical" or "psychogenic" muscle activities which are arising more from mental tension or stress. All these components may interact and together affect the behavioural patterns manifesting as pain or discomfort, as well as other physiological responses such as muscle activity changes (Linton, 2000). Indeed the psychological or emotional processes are an important component of the individual differences that may directly or indirectly influence muscle activities especially in the neck-shoulder musculature (Vasseljen & Westgaard, 1995; Waersted, 2000).

As the present subjects were recruited from a large variety of different businesses and they came with various job titles on a voluntary basis; they could be considered to be a heterogeneous group. When assigning into Case and Control Groups, the subjects were not differentiated in terms of their psychological status or psychosocial profiles; and this approach was used in all 3 studies. Since the subjects participated on a voluntary basis outside their work settings and working hours, the subjects should not have felt any undue stress that they may be otherwise exposed to in their actual work situations. Yet each person has his or her own unique personality and/or psychological composition that may have an important influence on their physical / physiological performances. These factors are likely to play an important role to affect the physical processes of motor control and postural habits of individuals. However, the present research is focused on studying the physical responses to the various physical stressors, and further research is needed to examine the effects of these other non-physical factors. The present research design with the case-control comparison may be useful if the non-physical factors could also be manipulated and studied individually in terms of their influence on the motor control mechanisms and discomfort responses in subjects with and without WRNULD.

9.3 COMPARING THE EFFECTS OF THE THREE PHYSICAL STRESSORS

Comparing the responses of the two subject groups in Studies 2 and 3, some differences in the degree of "stress" elicited by the different physical stressors can be observed.

In Study 2, the main physical stressor was the duration of the task (one hour continuous typing), while the subjects were allowed to type at their normal pace and style. This physical requirement may not be so difficult for the subjects who are quite accumstomed to this sort of task demand in their daily work. Yet the task was sufficient to produce significant increase of discomforts in the High Group among the Case subjects, which implied that these subjects were sufficiently "stressed". Thus the observed muscle activity patterns and their kinematics may be a good reflection of their typical responses to the physical stressor of maintaining a static posture for one hour. It is possible that even greater changes may be provoked if the duration of the static posture was extended to even longer periods, and further research could be pursued to examine this relationship.

In Study 3, the physical stressors of increasing the speed and the force of keyboard operation were assessed. The other conditions such as the typing content and the workstation were standardized. The demands of increasing the typing speed and typing force by 20% may have introduced greater physical stresses for the subjects, as compared to the physical demands in Study 2. Sustaining a faster typing speed or stronger typing force for a period of 20 minutes would have demanded physical performance involving complex motor control mechanisms. The subjects may not be frequently exposed to such stringent demands on their speed and force control in their daily working situations, although they may be required to work at a faster pace on occasions when there is a deadline to meet. Past studies have reported a significant association between meeting deadlines and musculoskeletal discomforts (Bernard et al., 1994; Faucett & Rempel, 1994).

In comparing the responses to the two physical stressors of increasing speed and increasing force, the results showed that the Faster condition produced generally greater responses from the subjects than the Harder condition, in terms of significantly greater increases in muscle activities, and greater increases in Speed and Force Variabilities. There were also significantly greater increases in discomfort scores for both the High and Low Groups in the Faster condition, compared to the

Harder condition and the Normal condition. These results may have reflected the more difficult task demand of coordinating all the muscle activities and joint motions in performing the more rapid hand actions. In comparison, the demand of increasing the force while the speed component was not increased may not be as difficult in terms of motor coordination. The main difficulty in meeting the force may be the tendency to overshoot the expected force level resulting in high variabilities in force performance.

The present research has demonstrated intrinsic motor control differences between individuals in response to three commonly encountered physical stressors. Static posture as well as the speed and force of movements are among the most commonly identified occupational risk factors for all kinds of occupation. The present approach using similar internal exposure measures to compare the influences of these three physical stressors has enhanced the understanding of inter-individual differences to these physical challenges. Based on these results, conceptual models can be developed to examine the relationship between individual differences in response to these physical stressors, and the development of WRNULD.

9.4 MODELS TO EXPLAIN SYMPTOMATIC-ASYMPTOMATIC DIFFERENCES

The present research has demonstrated evidence of altered muscle recruitment and altered kinematics in the neck-shoulder region in subjects with more severe discomforts. The consistent patterns of internal exposure differences of the Case and Control Groups across the three studies formed the basis for constructing conceptual models to illustrate the relationships between (1) the three physical stressors, (2) the group patterns of internal exposure responses, and (3) the discomforts experienced by the individuals.

In Chapter 1, we have raised the issue of whether past established models have adequately addressed the relationship between external and internal factors that may influence the etiology of WRNULD. Established models such as those proposed by Armstrong et al. (1993), Kumar (2001), and Winkel and Westgaard (1992) may have addressed this relationship between external exposure factors and internal exposure factors on a within-individual basis. Our present models have directed the focus towards the inter-individual differences and these aspects have not been clearly illustrated in past models. Although the present models specifically address the intrinsic responses of office workers induced by the three physical stressors that were studied, it is possible that these models may have wider applications in describing the relationships of other internal exposure responses and different types of physical stressors generally.

With regard to the etiology of musculoskeletal discomforts or pain, the present results do not support past models such as the "vicious cycle" model (Travell & Simons, 1983) or the "pain adaptation" model (Lund et al., 1991) in explaining the phenomenon of WRNULD. The vicious cycle theory predicted that muscle activity would increase as discomfort increased, which suggested both should increase with time-at-task. Yet our present results showed that discomforts increased significantly with time while muscle activities did not. The pain adaptation model predicted the opposite relationship, that pain would cause inhibition of muscle activity, and this was not found in our present results also.

Instead, the present findings lend support to the Altered Motor Control Model as an important potential mechanism associated with WRNULD. In addition, the present results have demonstrated that there may be a phenomenon of "heightened sensitivity" in symptomatic persons with a chronic history of discomforts. These models have important implications for future ergonomic research and will be discussed in more detail in the following sections.

9.4.1 Altered Motor Control Model

The results of the three studies have demonstrated consistent patterns of altered muscle recruitment and altered kinematics in the Case Group, particularly the High Group subjects. In Chapter 4, we have proposed the Altered Motor Control Model based on the results of the altered muscle activity patterns in the symptomatic subjects, and in Chapter 6 we have reported on the altered kinematics in the Case subjects. Although we have reported these results separately before, the control of muscle activities and joint movements are intricately related. Together the altered muscle recruitment patterns and the altered kinematics constitute two integral parts of the Altered Motor Control Model.

The altered kinematics findings in Studies 1 and 2 with increased forward flexion of the neck in the mean posture as well as increased extent (range) of movement, were closely related to the patterns of increased activities in the UT muscles. We have previously discussed the anatomical architecture of the UT muscle being a global stabilizer not designed for fine segmental control of the cervical spine. In both Studies 2 and 3 we have found different recruitment of the UT and CES muscles on both sides in the High Group, and these uneven muscle activities would result in altered joint positions and abnormal joint movements. Abnormal and uneven loading of the articular joints could lead to altered loading of pain sensitive structures such as the zygapophyseal joints. On the other hand, there could be abnormal postural patterns resulting in changes in muscle activity patterns, and over a period of time these become programmed centrally as altered motor control strategies. Hence the altered muscle recruitment patterns and altered kinematics are two integral parts of the Altered Motor Control Model, and their relationships are presented in a schematic form in Fig. 9.1.

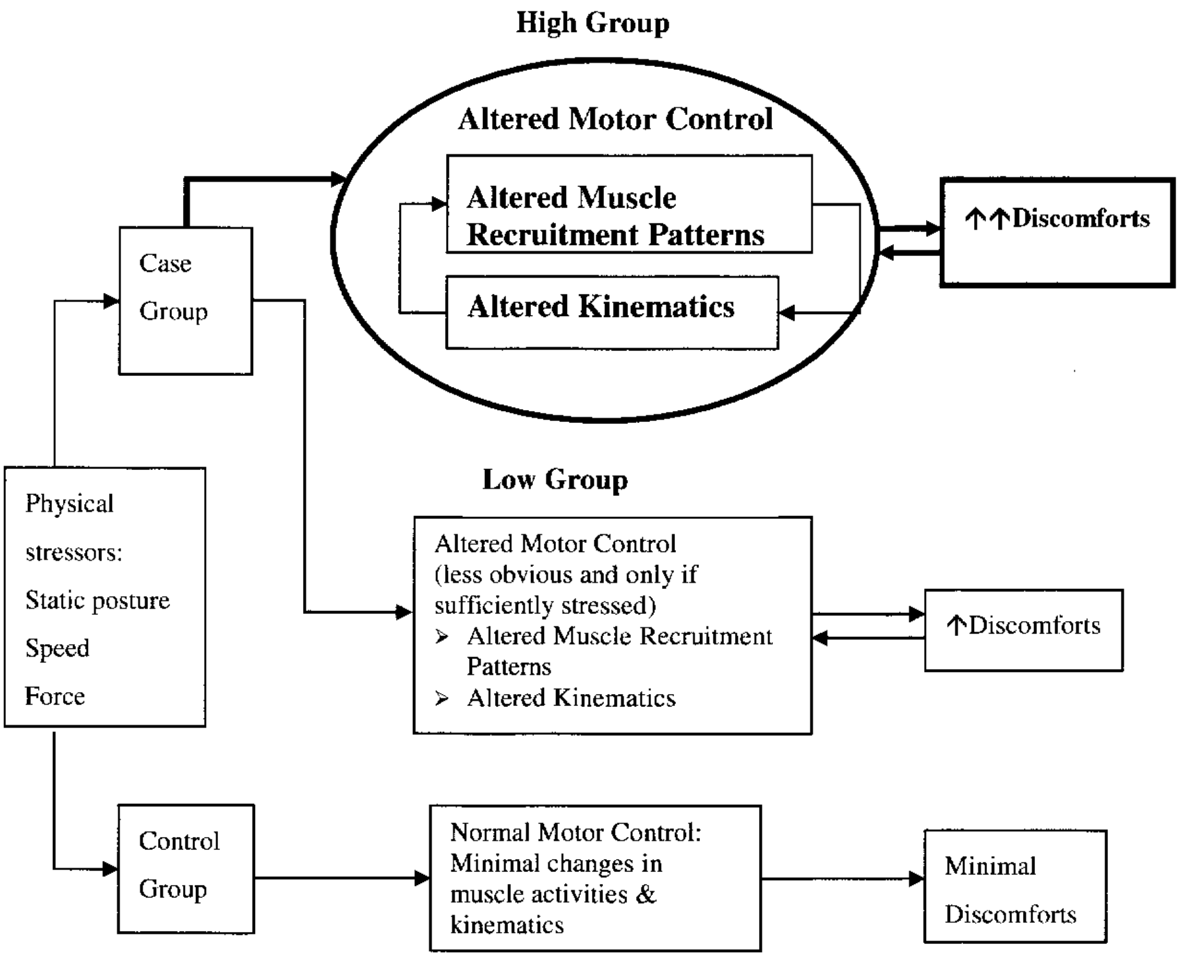


Fig. 9.1: The Altered Motor Control Model based on the results of altered muscle recruitment patterns and altered kinematics in the 3 Studies

The consistency of the observed differences in muscle activities and kinematics in the symptomatic individuals of the High Group would support that central changes in motor control were involved. The group differences in the motor control of keystroke actions also added to the evidence. These programmed changes in motor control strategies would have taken some time to develop, and this was likely to be closely related to the individuals' past history of WRNULD. These changes may either be a contributor or a response to the pain or discomfort experienced. The neurophysiological processes of motor control and nociceptive pathways are intricately related and it is beyond the scope of this research work to explore the fine details of these neural network pathomechanics.

On the other hand, the abnormal postural habits or altered muscle recruitment patterns may be inherent to the individuals that predispose them to developing musculoskeletal problems. Past research on comparing postural alignment between symptomatic and asymptomatic persons has not been able to establish any causal relationship between posture and pain (Braun, 1991; Griegel-Morris et al, 1992; Raine & Twomey, 1997). To confirm this hypothesis would require longitudinal studies that examine individuals' postural or musculoskeletal loading patterns before they develop symptoms. Another possibility is to investigate whether correcting their postural or muscle activity patterns would change their pains or discomforts.

9.4.1.1 *Altered kinematics*

The findings on altered kinematics encompass two aspects. One aspect is the motor control of the joints' static positions and the extents of movements, which is largely executed by muscle actions. Tensions and loading in other connective tissues such as ligaments and tendons also have important contributions in this process.

The other important aspect of altered kinematics refers to the biomechanical loading of the joints, which may trigger off activation of pain-sensitive structures. Abnormal or asymmetrical joint movements in the neck-shoulder region may result in asymmetrical compressive loading of the articular structures in the cervical spine and shoulder joints, resulting in activation of nociceptors in these structures. The high activity in the unilateral UT muscle may also be a contributing factor to the asymmetrical compressive loading in the cervical spine. The strongest evidence to support this idea came from the bilateral and widespread location of the discomfort areas which did not completely match with the areas of high muscle activities.

This idea supports that the origin of the discomforts may be a form of somatic referred pain, which has been known to be generated from structures such as the zygapophyseal joints and intervertebral discs (Bogduk & Aprill, 1993; Bogduk & Marsland, 1988). Previous studies reporting on referred pain patterns originated from muscles seldom describe a contralateral distribution (Travell & Simons, 1983). Referred pain from muscle would usually involve areas that are proximal or distal to the muscle but on the same side (Graven-Nielsen et al., 1997a; Graven-Nielsen & Mense, 2001).

Past research studies have often assumed that work-related discomforts in the neck and shoulder areas had a muscle origin. It is often assumed that if the pain is located over the shoulder area, it is coming from the trapezius. "Trapezius myalgia" is often used in research studies to indicate pain in the shoulder areas, but there is usually very little description as to how it is defined (Elert et al., 1992; Kadi et al., 1998; Larsson et al., 1999, 2000 & 2001; Roe et al., 2001; Veiersted et al., 1993; Westgaard, 1999; Westgaard et al., 2001).

Our present results suggest that there may be more than one possible source of pain in symptomatic persons experiencing discomforts when they are exposed to different physical stressors. However, while the present results may support the possibility of neural tissues, zygapophyseal joints and intervertebral discs as potential sources of neck and shoulder pain, this concept certainly needs to be substantiated by further research. It also does not exclude the muscles from being a source of pain. It may well be that both the neural, articular and muscular structures are concurrent sources of pain, due to widespread tissue sensitisation.

9.4.1.2 *Altered muscle recruitment patterns*

The evidence for altered muscle recruitment patterns was consistent in Studies 2 and 3, with the High Group subjects selectively recruiting higher activities in the right UT and CES muscles. In Study 2, when the physical stressor was the static posture, the right UT muscle appeared to be the main selected stabilizer in the High Group. In Study 3, with the physical stressors of speed and force, both UT and CES muscles were actively recruited. These results suggested that with higher "stress" levels requiring increased speed or increased force, there may be sequential changes in the altered motor control strategies that could be elicited from these individuals. Alternatively, it can be considered that the altered motor control changes are also influenced by the physical factors such as differences in workstation setting, or the differences in task demands (as suggested by the results in Study 3).

The EMG results with different patterns of change involving the group, time and side factors in Studies 2 and 3 also confirmed that there were different coping strategies adopted by different individuals to deal with the physical demands. We have observed that some individuals may recruit more of the same muscles on the other side, or more of another muscle from the same side, in response to different task demands in Studies 2 and 3. The differences in muscle recruitment order may be an important component in the altered motor control schema, and further research is required to bring more insight into this area.

To confirm whether these muscle recruitment changes are real and consistent in all symptomatic persons, there needs to be more research comparing symptomatic-asymptomatic differences in muscle activation under a variety of different circumstances. The experimental conditions can explore the effects of other physical stressors, or non-physical stressors (e.g. psychological stress), as well as other occupational tasks.

The mechanisms of altered muscle recruitment may also involve physiological processes at different levels. At the cellular level, there may be pathological changes in muscle fibres demonstrated in muscle biopsy samples taken from patients with fibromyalgia and work-related "trapezius myalgia" (Kadi et al., 1998; Larsson et al., 1999 & 2001; Lindman et al., 1991). At the motor unit level, the continuous or prolonged recruitment of "cindarella" motor units and the phenomenon of "motor unit substitution" have been proposed as possible mechanisms involved in WRNULD (Forde et al., 2002; Kadefors et al., 1999; Kitahara et al., 2000; Westgaard & De Luca, 1999). However, single motor unit studies have mainly been studied on asymptomatic subjects in the past. Intramuscular EMG studies on symptomatic subjects are needed to gain understanding of how the altered motor control strategies affect the motor unit functions during the execution of occupational tasks.

In the neural control of pain sensations, peripheral and central sensitization, as well as convergence of nociceptive input are important processes that are likely to influence the subjective experience of pain or discomfort sensations within different individuals (Graven-Nielsen et al., 1997a; Mense, 1993). All these mechanisms may contribute towards the pain or discomfort sensations experienced by the symptomatic subjects. Widespread tissue sensitisation may develop in individuals with chronic pain and it becomes even more difficult to isolate the original source of pain.

9.4.2 Heightened Sensitivity Model

The Heightened Sensitivity Model was developed based on the combined results of Studies 2 and 3, demonstrating increased reactivity of the highly symptomatic subjects (the High Group), in all the internal exposure measures (kinematics, muscle activities and keystroke performance); and these were closely related to discomforts experienced. In contrast, the Control Group subjects showed only minimal changes in all the dependent variables when exposed to the physical stressors. The Low Group subjects also showed minimal responses in Study 2 but they displayed more apparent changes in muscle activities and discomforts when challenged by the more demanding Faster and Harder conditions in Study 3. These results indicated that the different groups of individuals had different levels of sensitivities in responding to the physical stressors.

The present results have demonstrated that given the same set of working conditions and the same task demands, there were individual differences in physiological reactivities. When new stresses were introduced or when there were changes in the working conditions, the highly symptomatic individuals were more sensitive to such changes and required greater muscle efforts to cope with such changes, resulting in greater discomforts.

Kumar (1990) has identified a “threshold level of cumulative exposure” for occupational low-back injury, and this concept may also apply in the present situation. Our results have demonstrated that different individuals may have different “threshold” levels which would have developed in association with their past work histories and past discomfort experiences. Kumar (2001, p.19) also pointed out that there may be a “progressive reduction in stress tolerance capacity due to steadily increasing residual strain”. This is supported by the responses of the High Group subjects, who may have gradually accumulated more “residual” biomechanical strains and developed higher sensitivities to physical stimuli in the work demands.

The responses of the Low Group subjects present another very important and interesting finding in this research. Their motor control changes seemed to be more subtle or less extensive than those of the High Group. Alternatively, the Low Group subjects may not be as reactive as the High Group but are predisposed to motor control changes when they are sufficiently stressed. This hypothesis is based on the Low Group's responses in Study 3 that involved more demanding tasks, resulting in greater changes in muscle activities and increased discomforts. This would imply that they may have moderately heightened sensitivity that were in between those of the High Group and the Control Group.

The Heightened Sensitivity Model is also supported by well established neurophysiological phenomena including the central and peripheral sensitization processes (Arendt-Nielsen & Svensson, 2001; Mense, 1993). There may also be other non-physical factors such as psychological stress and personality type, that may have substantial influence on these symptomatic individuals contributing to their "heightened responses" compared to those of the Low Group and the Control Group.

Although this may appear logical, however, there was previously little objective evidence to support these assumptions. In addition, this model may have important implications for ergonomic research. The different sensitivities of different individuals may imply that when changes in work demands or new ergonomic interventions are introduced, the different "sensitivity" levels of individuals must be considered. In other words, symptomatic individuals may have greater reactivity to new changes or increased physical demand at work and may suffer an exacerbation of symptoms. Thus changes may need to be introduced more gradually or in smaller doses in dealing with symptomatic persons.

The precise mechanisms or processes that are involved in the altered motor control changes or the development of heightened sensitivity still need to be further explored. In addition, the individual characteristics that lead to certain individuals developing such changes or having such reactions are still not clear. Further research is required to explore the various individual characteristics that may contribute towards the different response patterns of the High, Low and Control Groups. A schematic drawing depicting the different responses of the three groups of individuals due to different sensitivities is presented in Fig. 9.2.

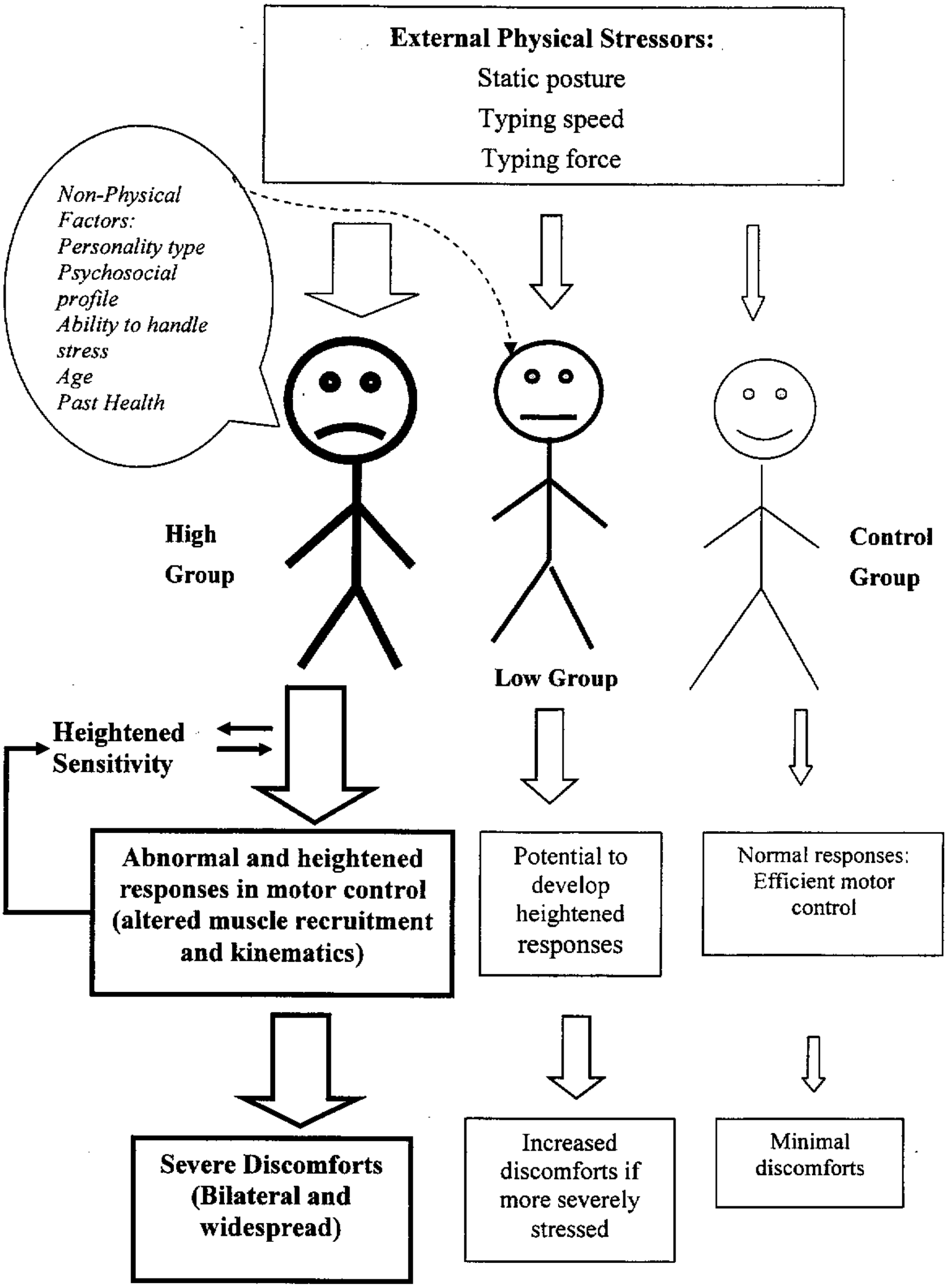


Fig. 9.2: Heightened Sensitivity Model depicting the different sensitivities resulting in different responses of the 3 groups of individuals to the physical stressors

9.4.3 Combined Model

This body of research work has generated two potential models in relation to the physical demands of computer work and the phenomenon of WRNULD. Our models are not in opposition to the conceptual models proposed by Armstrong et al. (1993), Winkel and Westgaard (1992), or Kumar (2001). These well established models tended to focus on the influence of physical exposure factors on a within-person basis while our models have focused on the inter-individual differences. It is possible that the model can be extended to examine the relationships of other physical stressors and work-related musculoskeletal discomforts.

The Altered Motor Control Model links together the centrally programmed changes in the control of muscle activities and joint movements, and their relationships with discomforts. The Heightened Sensitivity Model takes into consideration all the various responses in the three studies, and identifies a consistent pattern of increased reactivity in the highly symptomatic individuals (the High Group) when exposed to various physical stressors. The combined results also suggested that in the highly symptomatic persons, there may be a more widespread and diffused motor control disorder affecting their motor functions generally. Hence heightened sensitivity may act as an effect-modifier to altered motor control.

The proposed models are likely to work simultaneously but to different extents in different individuals. Thus there may be different extents of altered motor control involving altered kinematics and altered muscle recruitment operating at different sensitivity levels in different persons, and these processes may also be interactive with each other.

The proposed combined model based on the findings of the present research work is presented graphically in Fig. 9.3. This model highlights the relationship between heightened sensitivity affecting both the altered motor control and the development of WRNULD. An important feature to note in this model is the potential two-way interactions between each of the major components. Heightened sensitivity would feed into the altered motor control mechanisms which may result in even greater sensitivity, and similarly discomforts and altered motor control can reinforce each other. In some ways, these mutual feedback mechanisms may be a form of vicious cycle. The chain of events depicted in the model in Fig. 9.3 would apply in the situation of the High Group individuals, whereas individuals that are typical of the Control Group may be able to cope with the physical stressors without following these pathways in the model. The Low Group individuals may be somewhere in between the High Group and the Control Group. They are likely to have lower sensitivities and require greater stimulation from the physical stressors before their altered motor control patterns could be activated. Further research should continue to explore the individual characteristics that make these individuals respond differently from the other groups, and to understand the internal physiological processes within the symptomatic persons.

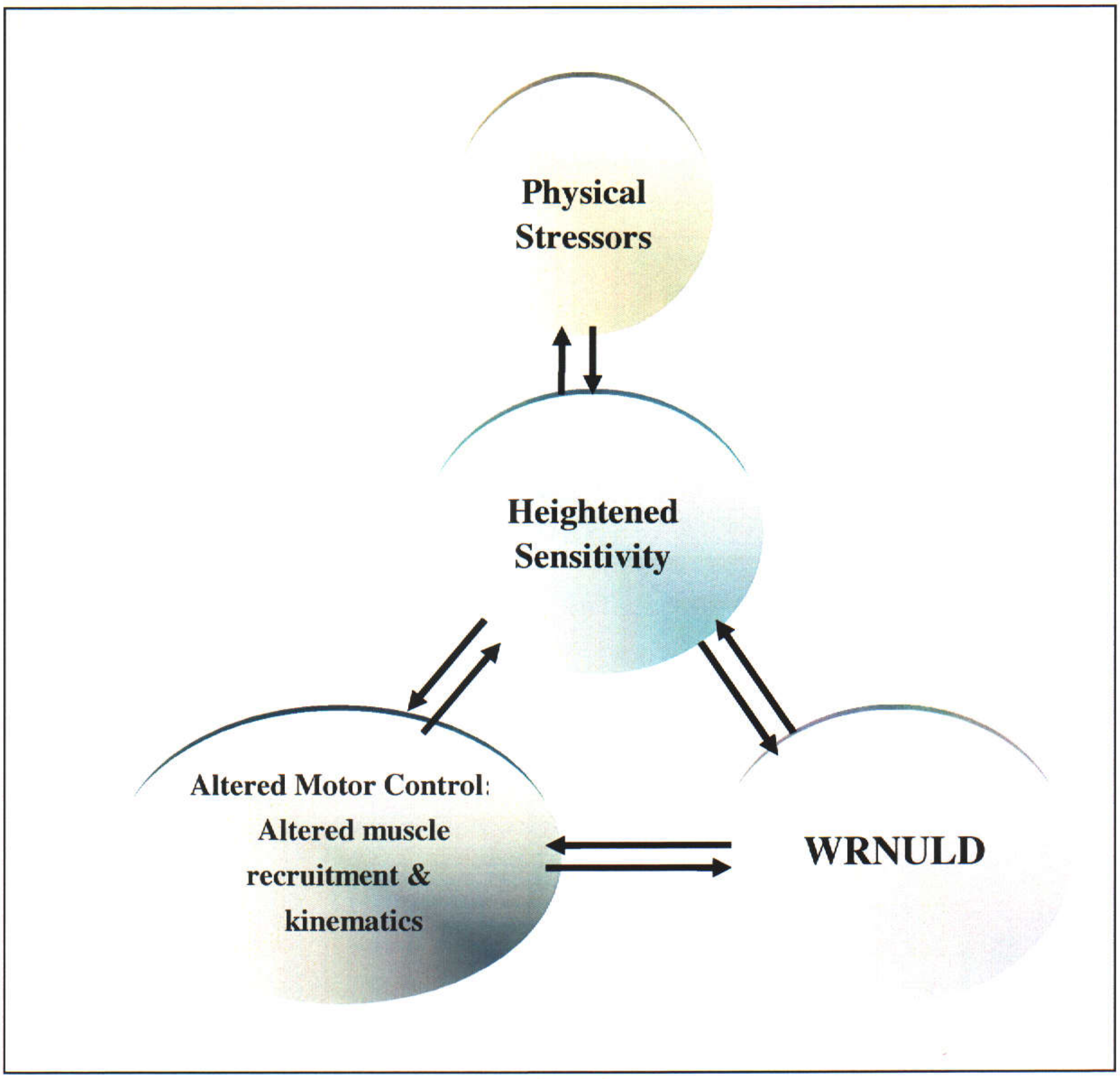


Fig. 9.3: Model describing the relationship between WRNULD and the major mechanisms operating within the High Group individuals (altered motor control and heightened sensitivity) that can be elicited by the physical stressors

9.5 IMPLICATIONS FOR ERGONOMICS RESEARCH

The present research has important implications for future ergonomics research. Previously many ergonomics studies have based their research on the assumption that if the intervention did not cause any major change in a "normal" healthy painfree sample, this intervention can be safely applied to the general population. For example, in the research regarding a suitable display screen height for computer users, if the screen height did not cause major changes in muscle activities measured for short periods in "normal" subjects, it was concluded that this screen height would be suitable for all users. Given the high prevalence rates of WRNULD among office workers and our present findings showing different sensitivities of different individuals, there needs to be a re-thinking about this assumption. We would recommend that future ergonomics interventions need to be tested on both symptomatic as well as asymptomatic workers, and their differences must be recognised.

Furthermore, the present findings demonstrated that symptomatic persons are more sensitive to new physical stressors resulting in more exaggerated physiological responses and increased discomforts. If new interventions are introduced to their workstations or their work organization, symptomatic persons may take a longer time to adapt or they may be more reactive to changes, and consequently they may suffer from a period of symptom exacerbation. This implies that ergonomists need to consider introducing changes more gradually or in small doses when they are dealing with symptomatic persons, especially those with more severe symptoms.

In addition, the lack of significant differences in internal exposure responses in previous Case-Control research, may have been partly due to a lack of differentiation into possible sub-groups within the symptomatic samples. Our present findings have been based on an arbitrary sub-division of the discomfort scores of the Case subjects, and we were able to delineate clearly different patterns of motor responses in the High and Low sub-groups. There may possibly be more different types of sub-groups based on other differentiating factors such as psychosocial profiles (Linton, 2000; Marras et al., 2000). Future research should explore further the different personal characteristics of different symptomatic individuals, and these characteristics may involve physiological, morphological and/or psychological aspects. More in-depth understanding of inter-individual differences is needed in order to construct a more wholistic and comprehensive model for the etiology of WRNULD.

CHAPTER 10: CONCLUSION

The present research has examined the responses of symptomatic and asymptomatic office workers in terms of kinematics, muscle activities, keystroke performance, and discomforts when they were exposed to three physical stressors of sustained static posture, increased typing speed and increased typing force. The results have demonstrated that symptomatic persons, especially those with more severe discomforts, had consistent patterns of altered kinematics, altered muscle activity patterns as well as altered keystroke performance, in response to the challenges of the three physical stressors. Furthermore, these physiological responses were closely related to the significantly higher discomfort scores reported by the highly symptomatic individuals.

The results also showed that there were different degrees of reactivities in different muscles, with the CES and UT muscles producing the greatest EMG changes in response to the various physical stressors; and the head-neck angles and extents of movements being most responsive postural elements.

It was found that the right sided muscles and joints were more responsive than the left in the Case subjects, especially the High Group, while the Low Group and Control Group appeared to have a better coping strategy with more even distribution of load on both left and right sides.

The results also suggested that the source of discomfort may include structures other than muscles. Articular structures such as the zygopophyseal joints in the cervical spine may be asymmetrically loaded due to the altered kinematics, and these structures as well as sensitised neural tissue structures may also be a potential source of pain.

One of the most important findings of the present research is that not all "symptomatic" persons demonstrated the same responses when placed under the same physical demands. The Case-Control comparisons have shown some interesting findings but more profound differences between groups were revealed when the Case Group was sub-divided into the High and Low Groups based on their mean discomfort scores. This sub-division has clearly demonstrated that it was mainly the High Group subjects who consistently had the greatest responses in terms of altered kinematics and altered muscle recruitment. Examining the individual characteristics and past discomfort profiles of the High and Low Groups have shown no major difference between these individuals except that the High Group also had more severe discomforts in their past compared to the Low Group, while the discomfort durations and body areas involved were very similar. Other possible factors that may contribute towards these High-Low group differences have been discussed but it will require further research to substantiate their effects.

Based on the results of the three studies, we have developed conceptual models in an attempt to construct the potential relationships between the different individuals' responses and the development of WRNULD. The Altered Motor Control Model was developed from the different group responses of altered kinematics and altered muscle recruitment patterns observed in Studies 1, 2 and 3. It is proposed that different groups of individuals may have developed centrally programmed changes in the control mechanisms of muscle activities and joint movements, and these changes are closely related to their musculoskeletal discomforts. The Heightened

Sensitivity Model was developed based on the group responses in terms of all the dependent variables comparing the High, Low and Control Groups in the three studies. This model predicts that individuals with more severe pre-existing discomforts, may also be more reactive to physical stressors such as static posture, speed and force demands of computer tasks. This heightened sensitivity is also likely to be a centrally programmed change as an integral part of the long-term changes that have developed during the course of WRNULD.

Due to the research design, the present results have mainly demonstrated associations between various factors and WRNULD. We must acknowledge that we cannot establish any cause-effect relationships between the various physiological measures of kinematics and muscle activities, nor between these measures and the development of WRNULD in office workers.

The present results have important implications for future ergonomics research, as they have clearly demonstrated that not all individuals would show similar responses to external physical work demands and variations in internal physiological and motor control processes must be taken into consideration. Thus research findings on ergonomics interventions tested on healthy painfree subjects cannot be generalized to the entire working population, as a high percentage of individuals may have developed alterations in motor control strategies in relation to their past history of work-related discomforts. The implications of the present results are that the responses of symptomatic individuals need to be considered separately when ergonomic interventions are introduced. There is a need to further explore these intrinsic motor control mechanisms and other individual factors that contribute to the etiology and the development of WRNULD.

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Appendix I

Subject Interview Questionnaire

QUESTIONAIRE ON BODY DISCOMFORT IN OFFICE WORKERS

The following questions are designed to find out information about your personal characteristics, your work situation and to identify certain work-related symptoms that you may be suffering. The information will be used in a research project which analyses certain factors about work-related health problems in keyboard operators. The information will be kept confidential and will only be available to the researcher of this project.

1. Date of Interview: ________/________/________ (day / month / year)	Intdd Intmm Intyy	☐ ☐ ☐
2. Name: ______________________	Name	______
3. Sex: M / F	Q3	☐
4. Age: ______________	Q4	☐
5. Post: ______________	Q5	☐
6. Are you left-handed or right-handed? 1= Left 2= Right	Q6	☐

Here are some questions about your work with computers:

7. How long have you been doing your present type of work? 1= 0-6 months 2= 6-12 months 3= 1-2 years 4= 2-3 years 5= > 3 years	Q7	☐
8. On average, how many hours a week do you work?	Q8	☐
9. Does your present job require the use of a computer? 1= No 2= Yes	Q9	☐
10. How long have you been using a computer? 1= 0-6 months 2= 6-12 months 3= 1-2 years 4= 2-3 years 5= > 3 years	Q10	☐
11. On average, how many hours a day do you spend working with a computer? 1= 0-2 Hrs 2= 2-4 Hrs 3= 4-6 Hrs 4= 6-8 Hrs 5= over 8 Hrs : _____ Hrs (specify if you can)	Q11	☐
12. On average, what is the estimated amount of time you would spend in a day Using the keyboard when working with the computer ? 1= 0-2 Hrs 2= 2-4 Hrs 3 = 4-6 Hrs 4= 6-8 Hrs 5= over 8 Hrs : _____ Hrs (specify if you can)	Q12	☐

13. On average, what is the estimated amount of time you would spend in a day Using the <u>mouse</u> when working with the computer? Q13 ☐
 1= 0-2 Hrs
 2= 2-4 Hrs
 3= 4-6 Hrs
 4= 6-8 Hrs
 5= over 8 Hrs : _____ Hrs (specify if you can)

14. Have you ever received any training in typing skills or keyboard operation? Q14 ☐
 1= No 2= Yes, Please specify ________________________________

15. How would you describe your current method of keyboard operation? Q15 ☐
 1= proper touch-typing method using all 5 fingers of each hand
 2= traditional type-writer method using all 5 fingers of each hand but with More force than touch-typing
 3= using only certain fingers from each hand
 4= others, please specify ________________________________

Here are some questions about your computer workstation:

16. Your computer is placed on a: Q16 ☐
 1= standard table
 2= standard desk
 3= computer table

17. Your keyboard is placed on a: Q17 ☐
 1= slide-out tray under the table
 2= same surface as the computer
 3= others, please specify ______________

18. Your computer screen is at: Q18 ☐
 1= approximately eye level
 2= below eye level
 3= above eye level

19. Is there adequate leg room under the table? 1= No 2= Yes Q19 ☐

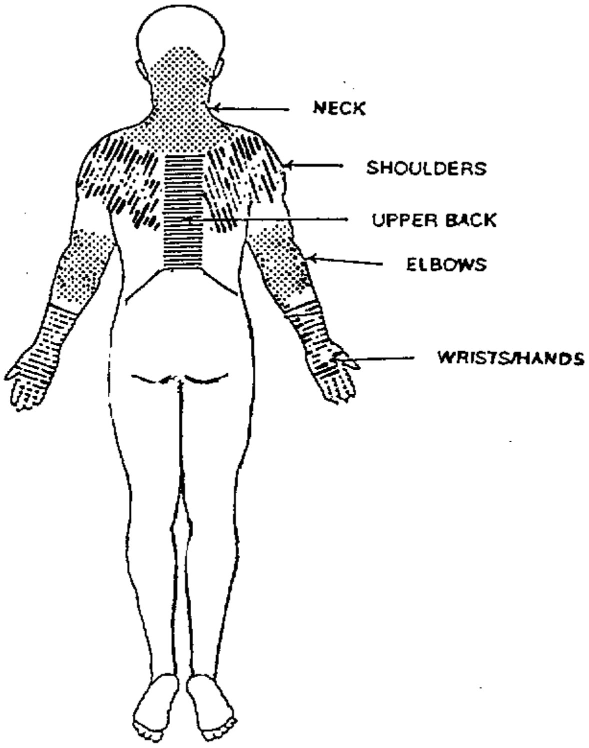
20. a. Is your chair adjustable in height? 1= No 2= Yes Q20a ☐
 b. If "yes", then: Is the adjustment device pneumatic or manual? Q20b ☐
 1=pneumatic 2=manual

21. Other chair features:
 a. Are there armrests? 1= Full arms 2= Half arms 3= None Q21a ☐
 b. Does your chair give you comfortable low back support? 1= No 2= Yes Q21b ☐
 c. Is the low back support adjustable - in tension ? 1= No 2= Yes Q21c ☐
 d. - in angle of recline ? 1= No 2= Yes Q21d ☐
 e. Are there casters (wheels) on chair: 1= No 2= Yes Q21e ☐
 f. If yes, how many? 1= 3 wheels, 2= 4 wheels, 3= 5 wheels Q21f ☐

22. Do you use additional supporting devices with your computer workstation?
 1= No 2= Yes
 a. foot rest Q22a ☐
 b. back support Q22b ☐
 c. document holder Q22c ☐
 d. wrist padding Q22d ☐
 e. others Please specify: ________________________________ Q22e ☐

Here are some questions regarding your health:

In the following diagram you can see the approximate positions of the regions of the body referred to in the subsequent questions (Part A & B). Limits are not sharply defined and certain regions may overlap. Please refer to the diagram, when you answer Part (A) on the next page.



*For "Discomfort Level", estimate the <u>average</u> level of discomfort you have experienced during the last 12 months by selecting a number from the Discomfort Scale (1-10) below.

<u>Discomfort Scale</u>

0	No Discomfort
1	Minimal Discomfort
2	
3	
4	
5	
6	
7	
8	
9	
10	Extreme/Intolerable Discomfort

Part A:

Based on the diagram on Page 4, can you identify the region that you have experienced discomfort during the last 12 months?

Q.23.Region of Discomfort:

a.	Neck	☐	Left	☐	Right	☐	Both	☐	Q23a	☐	*Discomfort level	☐
b.	Shoulder	☐	Left	☐	Right	☐	Both	☐	Q23b	☐	*Discomfort level	☐
c.	Upper Back	☐	Left	☐	Right	☐	Both	☐	Q23c	☐	*Discomfort level	☐
d.	Elbow	☐	Left	☐	Right	☐	Both	☐	Q23d	☐	*Discomfort level	☐
e.	Wrist/Hand	☐	Left	☐	Right	☐	Both	☐	Q23e	☐	*Discomfort level	☐

Q.24. How many regions have you identified ? Q24 ☐
1=one region 2=more than one region
If there is only one region, please go to Q30

Q.25 If you have indicated more than one region of discomfort, Q25 ☐
do you feel that they are related? 1= No 2= Yes
If yes, please specify which regions are related: ______________

If you feel that the regions you have selected are not related at all and are distinctly different areas of discomfort, you need to answer Part B for each region separately.

If you feel that the regions you have selected are highly related and can be considered as one overlapping area of pain, you will only need to answer Part B once.

(Please concentrate on each region you have selected and ignore any discomfort you may have in adjacent parts of the body, for example pain in the lower back.)

Part B:

Q.26.Region of Discomfort:

a.	Neck	☐	Left	☐	Right	☐	Both	☐	Q26a	☐	*Discomfort level	☐
b.	Shoulder	☐	Left	☐	Right	☐	Both	☐	Q26b	☐	*Discomfort level	☐
c.	Upper Back	☐	Left	☐	Right	☐	Both	☐	Q26c	☐	*Discomfort level	☐
d.	Elbow	☐	Left	☐	Right	☐	Both	☐	Q26d	☐	*Discomfort level	☐
e.	Wrist/Hand	☐	Left	☐	Right	☐	Both	☐	Q26e	☐	*Discomfort level	☐

f. Combined, specify______________________________

The following questions refer to the region you have indicated above

in question Q.26.

Q.27. Have you ever injured this region in an accident? Q27 ☐
1=No 2= Yes, please specify______________________________

Q.28. Have you ever had to change jobs or duties because of this discomfort? Q28 ☐
1= No 2= Yes, please specify ______________________________

Q.29. What is the total length of time that you have had this discomfort During the last 12 month? Q29 ☐
1= 0 days
2= 1-7 days
3= 8 - 30 days
4= More than 30 days, but not every day
5= 1-3 months
6= 3-6 months
7= more than 6 months

Q30. Has this discomfort caused you to reduce your activity During the last 12 months?
a. Work activity (at home or away from home): 1=No 2= Yes Q30a ☐
b. Leisure activity: 1= No 2= Yes Q30b ☐

Q.31. What is the total length of time that this discomfort has prevented you From doing your normal work (at home or away from home) during The last 12 months? Q31 ☐
1= 0 days
2= 1-7 days
3= 8 - 30 days
4= More than 30 days, but not every day
5= 1-3 months
6= 3-6 months
7= more than 6 months

Q.32a. Have you ever been seen by a doctor, physiotherapist, chiropractor or Other such person because of this discomfort during the last 12 months? Q32a ☐
1= No 2= Yes If No, go to Q.37
32b. If Yes, Please Specify a. Doctor Q32ba ☐
b. Physiotherapist Q32bb ☐
c. Chiropractor Q32bc ☐
d. Others, please specify ____________________ Q32bd ☐

Q.33. If you have seen a medical doctor regarding this region of discomfort, What is the specific diagnosis?______________________________ Q33 ☐

Q.34a. Have you ever had to take medication for this discomfort? Q34a ☐

1= No 2= Yes If yes, please specify ____________________________

34b. Are you taking medication for this discomfort at present? Q34b ☐

1= No 2= Yes If yes, please specify____________________________

Q.35a. Have you ever had any x-rays taken of your spine or upper limb region ? Q35a ☐

1= No 2= Yes. If yes, when were they taken? ____________________

35b. Do you know the results of the x-rays? Q35b ☐

1= No 2= Yes If yes, please specify ____________________________

Q.36. Have you felt this discomfort at any time during the last 7 days? Q36 ☐

1= No 2= Yes

Q.37. Do you feel this discomfort is related to or is aggravated by your work with the computer everyday? Q37 ☐

1= No 2= Yes

Q38. Do you find increased discomfort usually at the end of the working day? Q38 ☐

1= No 2= Yes

Q.39. Do you find increased discomfort in the morning when you wake up? Q39 ☐

1= No 2= Yes

**Please remember to complete Part B for each <u>unrelated</u> region of discomfort.

Thank you for your co-operation.

----------------------------------The End-----------------------

Appendix II

Consent Form

STATEMENT OF INFORMED CONSENT

I (Name)____________________________________ agree to participate as a subject in the research project:

An analysis of posture, muscle activity and keyboard dynamics in computer users with and without work-related neck and upper limb disorders

being undertaken by:

Ms Grace Szeto, Assistant Professor, Dept. of Rehabilitation Sciences, Hong Kong Polytechnic University.

I understand that I will be required to provide information on my personal data, work details and health history to the investigator. I understand that I may be asked to participate on more than one occasion. The procedures have been fully and clearly described to me and I understand the possible benefits and hazards.

I understand that the research procedure involves an evaluation of my posture and my muscle activities, when performing a keyboard task. I also understand that I can withdraw from the research at any time without prejudice.

I am aware of no medical reasons for me not to participate.

Signed .... Date: ....

Researcher's signature ....

Supervisor's signature ....

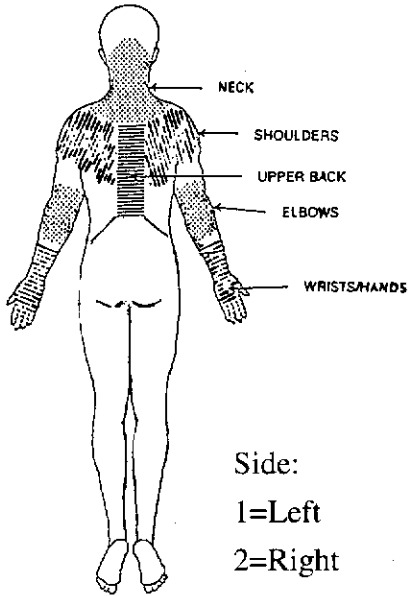
Appendix III

Discomfort Assessment Forms For Studies 1,2,3

Study 1 and Study 2
Body Discomfort Assessment Form

Discomfort Scale

0	No Discomfort
1	Minimal Discomfort
2	
3	
4	
5	
6	
7	
8	
9	
10	Extreme/Intolerable Discomfort



Side:
1=Left
2=Right
3=Both

Name: _________________________Date: _____________________

Trial __Time: _______ Area ________ Side: L / R /Both Discomfort Score _______
Trial __Time: _______ Area ________ Side: L / R /Both Discomfort Score _______
Trial __Time: _______ Area ________ Side: L / R /Both Discomfort Score _______
Trial __Time: _______ Area ________ Side: L / R /Both Discomfort Score _______
Trial __Time: _______ Area ________ Side: L / R /Both Discomfort Score _______
Trial __Time: _______ Area ________ Side: L / R /Both Discomfort Score _______
Trial __Time: _______ Area ________ Side: L / R /Both Discomfort Score _______

VDU Workstation measurements during testing

1. Chair height ________________
2. Screen height _______________

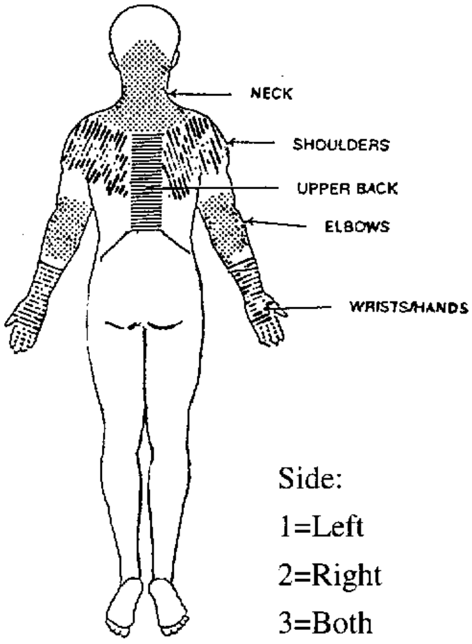
Subject's measurements

1. Standing height _________________
2. Weight _______________________

Study 3
Body Discomfort Assessment Form

Discomfort Scale

0 No Discomfort
1 Minimal Discomfort
2
3
4
5
6
7
8
9
10 Extreme/Intolerable Discomfort



Side:
1=Left
2=Right
3=Both

Name: ____

Date: ________________ Group: ________________

Trial	Time	Area	Side	Score

Appendix IV

Labview Programs for Processing EMG data

Procedure for Normalising EMG Data

Overview

The program has been updated to allow the normalisation of all 8 EMG channels in each EMG trial at once, after the 8 MVC and 8 30% Ramp trials have been processed.

1. 100% Maximum Voluntary Contraction Trial
2. 30% Ramp Trial
3. Saving/Loading Normalisation Data
4. Normalisation of EMG trials
5. Analysis of EMG trials
    i. Median Power Frequency
    ii. Amplitude Probability Distribution Function (APDF)
    iii. Exposure-level Variance Analysis (EVA)

A. GraceC3D Main Dialog
B. C3D Reader Dialog
C. Choose C3D Channels Dialog
D. Channel Label Descriptions
E. Pre-Resampling Dialog
F. Post-Resampling Dialog
G. Scale Data Dialog
H. Slice Data Dialog

Procedure

100% Maximum Voluntary Contraction Trial

1. The first step is to run the program on each of the (8) MVC C3D files. (Overview)
    a. Check the "**SLICE DATA**" and "**MAXIMUM (100%) ..**" checkboxes.
    b. If the C3D file does not contain the approprate analog (EMG, Force) scaling factors or if the Force data is inverted, then check the "**SCALE ANALOG**" checkbox.
    c. Select the correct EMG channel (REMG1-REMG8) from the "**EMG Channel**" drop-down list box. (Descriptions of EMG channels).
    d. If this procedure has previously been run on this C3D file, and the "trialname_ANALOG.txt" file exists, then:
        i. Uncheck the "**C3D TO ASCII**" checkbox.
        ii. Ensure that the toggle switch is set to "_ANALOG" (not "_NORM").
        iii. Click the "**RUN**" button.
        iv. An open file dialog box will appear, with the title "**Please choose the _ANALOG.txt file**". Choose the file with the name "trialname_ANALOG.txt".
        v. Skip to Step g.

    Otherwise, go on to Step e.

    e. Click the "**RUN**" button. This brings up the C3D Reader dialog box. Click this "**RUN**" button too.
    f. The next dialog box (Choose C3D Channels Dialog) to appear will ask you to choose the channels of the C3D file that you want to read. Only Analogue channels are needed, so ignore the lower 3D section. You need to choose the correct Force channel (usually acc1) and the correct EMG channel (the same as was chosen in Step c). When you have chosen the two channels, click "**DONE**". The C3D Reader will then read the C3D file and output the 2 channels (together with frame numbers) into a file with the name "trialname_ANALOG.txt". This will take a few minutes. When the C3D Reader has finished (as indicated by the green light) the C3D Reader closes.
    g. The "PreResampling" dialog box will appear to display the raw data prior to down-sampling to 10Hz. Just click "**DONE**" (or click the "**Cancel**" button to abort this run of the program and return to the starting screen).
    h. Next, a "PostResampling" dialog box will appear to display the raw data after down-sampling to 10 Hz. Just click "**DONE**" (or click the "**Cancel**" button to abort this run of the program and return to the starting screen).
    i. The "Scale Data" dialog will now appear if "**SCALE ANALOG**" was checked. Follow the instructions in the dialog. Click "**DONE**".
    j. The "Slice Data" dialog will now appear. Since the current file is an MVC trial, slice off all data that you don't want to use to determine the values of mean 100% EMG and mean 100% Force. Ensure that you click "**SLICE**" before you click "**DONE**" (or click the "**Cancel**" button to abort this run of the program and return to the starting screen). You can slice the data more than once to enable you to slice the data more precisely (or click "**RESET**" if you make a mistake). This completes the MVC processing. The mean values of 100% EMG and 100% Force should now appear in the appropriate boxes.
    k. There will be a file named "trialname_NORM.txt" in the same directory as the other files. This file contains the sliced, scaled EMG and Force channel data.

30% Ramp Trial

2. The second step is to run the program on each of the the (8) 30% Ramp C3D files. (Overview)
    a. Check the "**SLICE DATA**" and "**LINEAR REGRESSION FOR 30% RAMP-UP TRIALS**" checkboxes.

b. If the C3D file does not contain the approprate analog (EMG, Force) scaling factors or if the Force data is inverted, then check the "**SCALE ANALOG**" checkbox.

c. Select the correct EMG channel (REMG1-REMG8) from the "**EMG Channel**" drop-down list box. (Descriptions of EMG channels).

d. If this procedure has previously been run on this C3D file, and the "trialname_ANALOG.txt" and/or "trialname_NORM.txt" file exists, then:

    i. Uncheck the "**C3D TO ASCII**" checkbox.
    ii. If you wish to perform the slicing again, set the toggle swtich to "_ANALOG" and skip to Step v.
    Alternatively, if you simply want to view the linear-regression plot again, set the toggle switch to "_NORM".
    iii. Click the "**RUN**" button.
    iv. An open file dialog box will appear, with the title "**Please choose the _NORM.txt file**". Choose the file with the name "trialname_NORM.txt", and skip to Step k.
    v. Click the "**RUN**" button.
    vi. An open file dialog box will appear, with the title "**Please choose the _ANALOG.txt file**". Choose the file with the name "trialname_ANALOG.txt".
    vii. Skip to Step g.

Otherwise, go on to Step e.

e. Click the "**RUN**" button. This brings up the C3D Reader dialog box. Click this "**RUN**" button too.

f. The next dialog box (Choose C3D Channels Dialog) to appear will ask you to choose the channels of the C3D file that you want to read. Only Analogue channels are needed, so ignore the lower 3D section. You need to choose the correct Force channel (usually acc1) and the correct EMG channel (usually one of REMG1 - REMG8). When you have chosen the two channels, click "**DONE**". The C3D Reader will then read the C3D file and output the 2 channels (together with frame numbers) into a file with the name "trialname_ANALOG.txt". This will take a few minutes. When the C3D Reader has finished (as indicated by the green light) the C3D Reader closes.

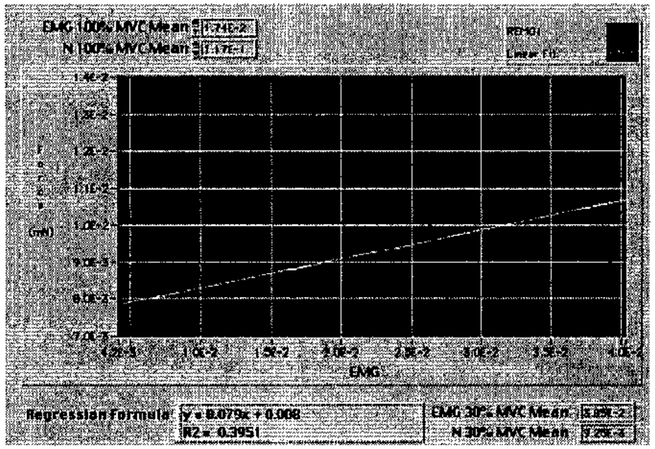
g. A "PreResampling" dialog box will appear to display the raw data prior to down-sampling to 10Hz. Just click "**DONE**" (or click the "**Cancel**" button to abort this run of the program and return to the starting screen).

h. Next, a "PostResampling" dialog box will appear to display the raw data after down-sampling to 10 Hz. Just click "**DONE**" (or click the "**Cancel**" button to abort this run of the program and return to the starting screen).

i. The "Scale Data" dialog will now appear if "**SCALE ANALOG**" was checked. Follow the instructions in the dialog. Click "**DONE**".

j. The "Slice Data" dialog will now appear. Since the current file is a 30% Ramp trial, slice off all data that you don't want to use to determine the values of mean 30% EMG, mean 30% Force, and the linear regression coefficients between EMG and Force. Ensure that you click "**SLICE**" before you click "**DONE**"(or click the "**Cancel**" button to abort this run of the program and return to the starting screen). You can slice the data more than once to enable you to slice the data more precisely (or click "**RESET**" if you make a mistake).

k. The final dialog box to appear is just an informative one.



EMG 100% MVC Mean 1.74E-2
N 100% MVC Mean 1.17E-1
Regression Formula y = 0.079x + 0.008
R2 = 0.3951
EMG 30% MVC Mean [illegible]
N 30% MVC Mean [illegible]

It shows you the Force vs. EMG scatterplot, and the corresponding linear regression equation. Just click the "**DONE**" button (or click the "**Cancel**" button to abort this run of the program and return to the starting screen). This completes the 30% Ramp trial processing. The mean values of 30% EMG and 30% Force, and the linear regression coefficients, should now appear in the appropriate boxes.

l. There will be a file named "trialname_NORM.txt" in the same directory as the other files. This file contains the sliced, scaled EMG and Force channel data.

Saving/Loading Normalisation Data

3. The "initialisation" process is now complete for this subject and EMG channel (muscle). (Overview)

a. You can save the normalisation constants to a datafile by clicking the "**SAVE**" button. This allows you to use the current normalisation constants at a later time
b. You can load a previous set of normalisation constants by clicking the "**LOAD**" button and choosing the datafile to which the constants were saved.

Normalisation of EMG trials

4. You can now process and normalise the trials. You can also perform the Analysis of the EMG trials at this time by checking the appropriate checkboxes, or, alternatively, you can perform this analysis in a separate step. (Overview)
    a. Check the "**EMG Normalsation**" checkbox.
    b. If the C3D file does not contain the approprate analog (EMG) scaling factors, then check the "**SCALE ANALOG** " checkbox.
    c. If this procedure has previously been run on this C3D file, and the "trialname_ANALOG.txt" file exists, then:
        i. uncheck the "**C3D TO ASCII**" checkbox.
        ii. Click the "**RUN**" button.
        iii. An open file dialog box will appear, with the title "**Please choose the _ANALOG.txt file**". Choose the file with the name "trialname_ANALOG.txt".
        iv. Skip to Step f.

    Otherwise, go on to Step d.

    d. Click the "**RUN**" button. This brings up the C3D Reader dialog box. Click this "**RUN**" button too.
    e. The next dialog box to appear will ask you to choose the channels of the C3D file that you want to read. Only Analogue channels are needed, so ignore the lower 3D section. You need to choose the correct 8 EMG channels (usually all of REMG1 - REMG8). When you have chosen the 8 channels, click "**DONE**". The C3D Reader will then read the C3D file and output the 8 channels (together with frame numbers) into a file with the name "trialname_ANALOG.txt". This will take a few minutes. When the C3D Reader has finished (as indicated by the green light) the C3D Reader closes.
    f. A "PreResampling" dialog box will appear to display the raw data prior to down-sampling to 10Hz. Just click "**DONE**" (or click the "**Cancel**" button to abort this run of the program and return to the starting screen).
    g. Next, a "PostResampling" dialog box will appear to display the raw data after down-sampling to 10 Hz. Just click "**DONE**" (or click the "**Cancel**" button to abort this run of the program and return to the starting screen).
    h. The "Scale Data" dialog will now appear if "**SCALE ANALOG**" was checked. Follow the instructions in the dialog. Click "**DONE**".
    i. This completes the EMG Normalisation.
    j. There will be a file named "trialname_NORM.txt" in the same directory as the other files. This file will contain the 8 channels of sliced, scaled EMG data, followed by (in sets of 3 columns) the normalised data of each EMG channel (8). For each EMG channel there will be:

%MVC_trialname	%MEMG_trialname	%Max_trialname

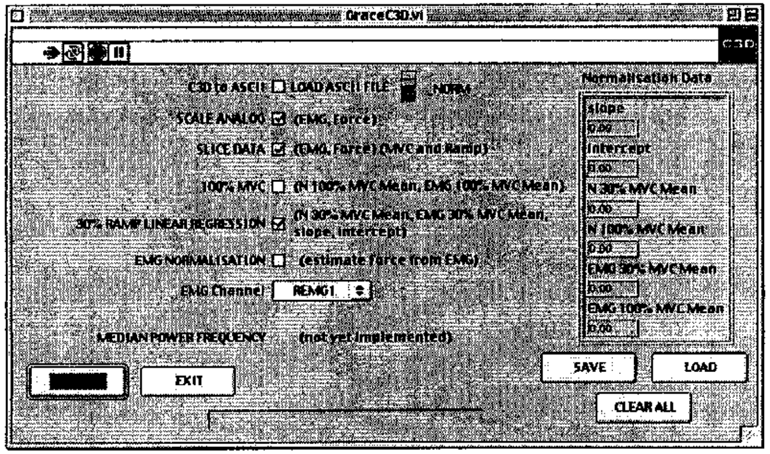
Analysis of EMG trials

5. This step can be performed together with Step 4 - Normalisation of EMG trials, or as a separate step after Normalisation has been performed.
    a. Check the **MEDIAN POWER FREQUENCY**, **APDF** and **EVA** checkboxes as desired.
    b. Uncheck the "**C3D TO ASCII**" checkbox.
    c. Set the toggle switch to "_NORM".
    d. Click the "**RUN**" button.
    e. Note that this step actually uses the raw "_ANALOG.txt" data because it requires the full frequency of the data (which is lost upon normalisation). This means that it will take a while to load in all the data - please be patient and wait until you see the graph data appear.
    f. An open file dialog box will appear, with the title "**Please choose the _NORM.txt file**". Choose the file with the name "trialname_NORM.txt".
    g. If the **MEDIAN POWER FREQUENCY** checkbox was checked, the "C3D Median Freq" dialog will now appear, which displays the Power Spectrum of one channel of EMG at a time. You can change the channel being displayed by using the **Channel** selector. The Median Frequency is highlighted by the yellow cursor line, and the exact value (with the associated amplitude) is displayed at the lower left of the below the graph. A pair of these values will be written to the file "trialname_DESC.txt". Click "**DONE**".
    h. If the **APDF** checkbox was checked, the "APDF" dialog will now appear, which displays the Amplitude Probability Distribution of all 8 channels of EMG at a time. You can change the Mode (Normalisation type) being displayed by using the **Mode** selector. Note that it does not matter which mode is selected because the scale is relative - 0 to 1. Click "**DONE**". The 10th, 50th and 90th percentiles of each channel (and each mode) will be determined/estimated and written to the file "trialname_DESC.txt".
    i. Lastly, if the **EVA** checkbox was checked, the "EVA" dialog will now appear, which displays the EVA plot of one channel of EMG at a time as an intensity plot (colour indicates the "height"). The "bins" on the **Exposure Level** and

Time Period Length axes are logarithmic - please refer to the adjacent Conversion Tables for the values they represent. You can change the channel and Normalisation Mode being displayed by using the **Channel** and **Mode** selectors respectively. Click "**DONE**". According to the **Mode** selected, 8 files (one for each channel) with names "trialnameNormMode_channelname_EVA.txt", e.g. "katvp60r%MVC_REMG1_EVA.txt". These files contain the EVA data for the respective channel, and can be opened in Excel to create spiffy 3D column graphs.

Dialogs

A. GraceC3D Main Dialog

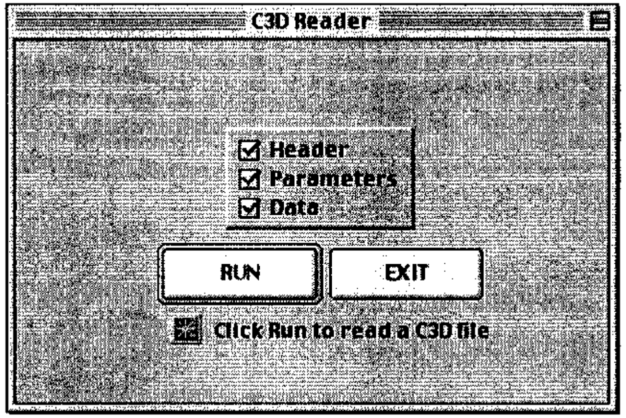


C3D to ASCII ☐ LOAD ASCII FILE
SCALE ANALOG ☑ (EMG, Force)
SLICE DATA ☑ (EMG, Force) (MVC and Ramp)
100% MVC ☐ (N 100% MVC Mean, EMG 100% MVC Mean)
30% RAMP LINEAR REGRESSION ☑ (N 30% MVC Mean, EMG 30% MVC Mean, slope, intercept)
EMG NORMALISATION ☐ (estimate force from EMG)
EMG Channel REMG1
MEDIAN POWER FREQUENCY (not yet implemented)

slope 0.00
intercept 0.00
N 30% MVC Mean 0.00
N 100% MVC Mean 0.00
EMG 30% MVC Mean 0.00
EMG 100% MVC Mean 0.00

The main dialog of the program. The checkboxes determine what is done with the data, and need to be checked according to the instructions. To the right is the display of the Normalisation Data that is used (after it has been calculated from Steps 1 and 2, or Step 3) to Normalise the EMG (Step 4). Clicking "**EXIT**" exits the entire program (including Labview itself).

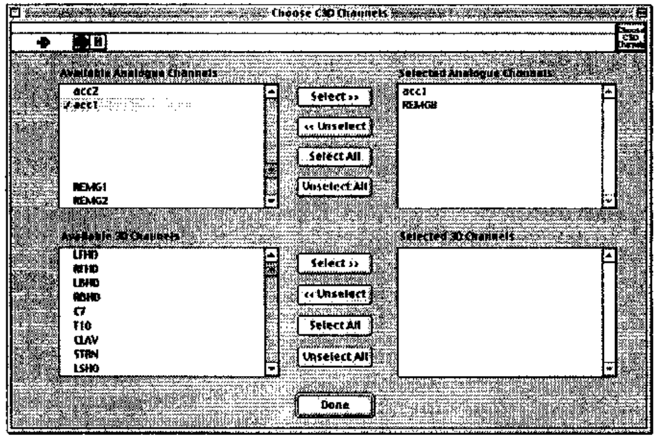
B. C3D Reader Dialog



☑ Header
☑ Parameters
☑ Data
Click Run to read a C3D file

The dialog of the C3D Reader. Simply clikcing "**RUN**" will start the reading of a C3D file that you choose, or clicking "EXIT" will close the C3D Reader and you return to the GraceC3D Main Dialog. This program can also be run on it's own to dump C3D files as ASCII.

C. Choose C3D Channels



Available Analogue Channels
acc2
✓acc1
REMG1
REMG2

Selected Analogue Channels
acc1
REMGB

Available 3D Channels
LFHD
RFHD
LBHD
RBHD
C7
T10
CLAV
STRN
LSHO

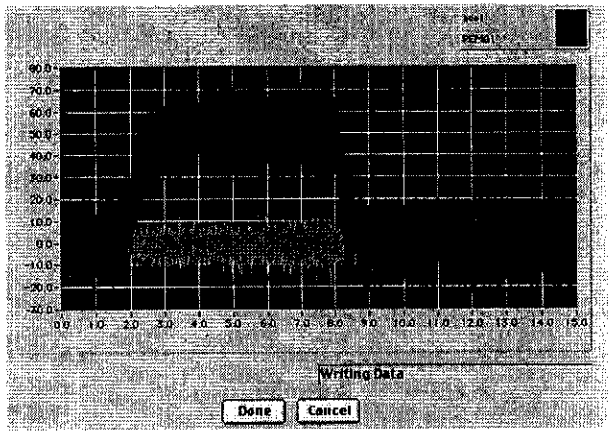
Selected 3D Channels

The "Choose C3D Channels" Dialog box is used to allow the user to specify which channel(s) are to be used in the normalisation. The 3D data channels are offered for the sake of completion, and although they will be output in ASCII, they are not used in the normalisation. The relative order of the channels is determined by their order in the C3D file, and it is assumed throughout the program that the Force channel is before (but not necessarily immediately before) the EMG channels.

D. Descriptions of Channel Labels

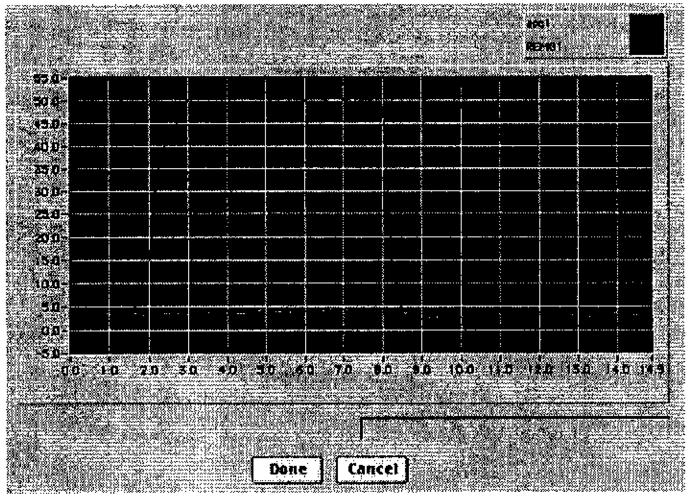
D. Descriptions of Channel Labels **Channel Label**	**Description**
accl	accelerometer 1 (Force)
REMG1	RCES
REMG2	LCES
REMG3	RUT
REMG4	LUT
REMG5	RLT
REMG6	LLT
REMG7	RDEL
REMG8	LDEL

E. Pre-Resampling Dialog



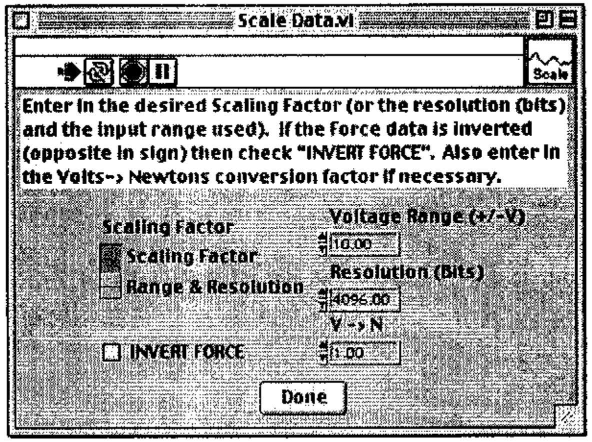
The "Pre-Resampling" dialog box displays the data before it is down-sampled to 10Hz.

F. Post-Resampling Dialog



The "Post-Resampling" dialog box displays the data after it has been down-sampled to 10Hz.

G. Scale Data Dialog



Enter in the desired Scaling Factor (or the resolution (bits) and the input range used). If the Force data is inverted (opposite in sign) then check "INVERT FORCE". Also enter in the Volts-> Newtons conversion factor if necessary.

Scaling Factor

▨ Scaling Factor

☐ Range & Resolution

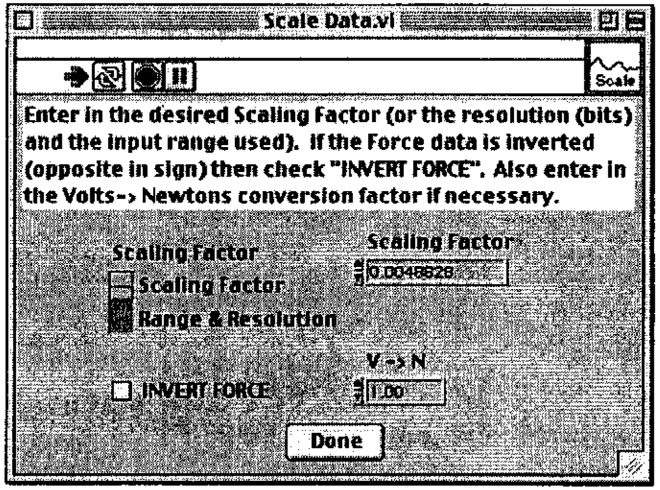
☐ INVERT FORCE

Voltage Range (+/-V): 10.00

Resolution (Bits): 4096.00

V -> N: 1.00

The "Scale Data" dialog box as it would appear if the user wanted to specify the Voltage Range and Resolution used to capture the data. Note that "**INVERT FORCE**" and "V -> N" would not be visible if EMG Normalisation was being performed (Step 4).

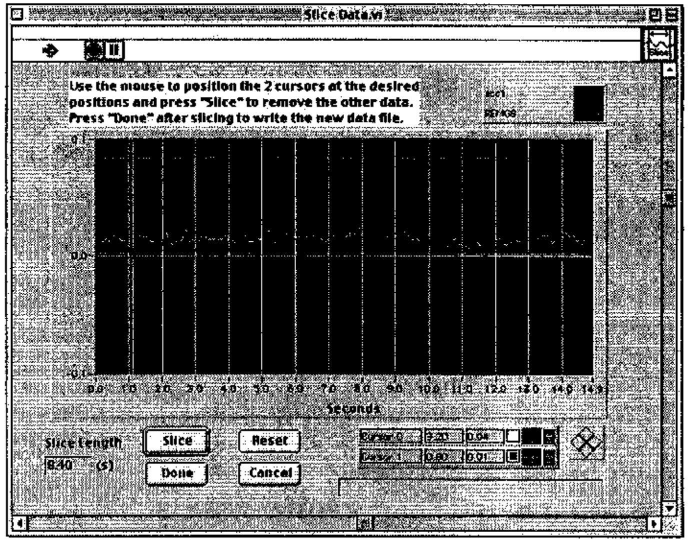

Enter in the desired Scaling Factor (or the resolution (bits) and the input range used). If the Force data is inverted (opposite in sign) then check "INVERT FORCE". Also enter in the Volts-> Newtons conversion factor if necessary.

Scaling Factor: 0.0048828

V -> N: 1.00

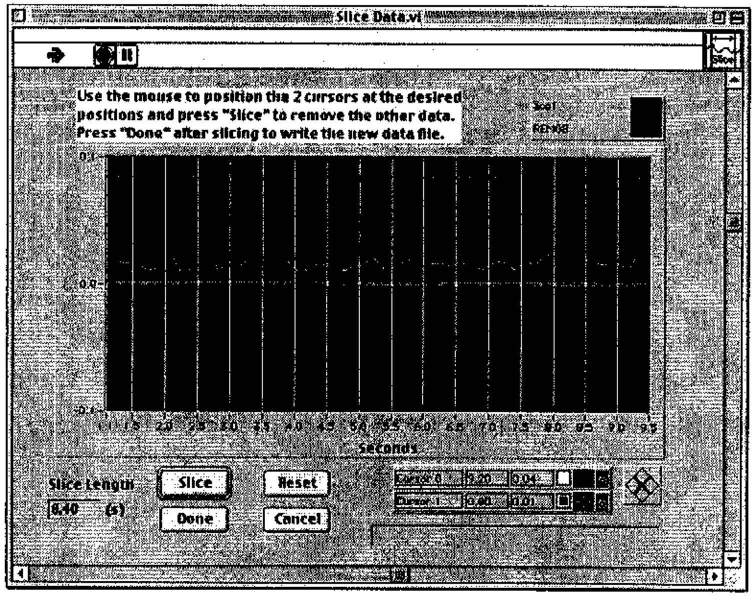
The "Scale Data" dialog box as it would appear if the user wanted to specify the Scaling Factor itself. Note that "INVERT FORCE" and "V -> N" would not be visible if EMG Normalisation was being performed (Step 4).

H. Slice Data Dialog


Use the mouse to position the 2 cursors at the desired positions and press "Slice" to remove the other data. Press "Done" after slicing to write the new data file.

Slice Length: 8.40 (s)

Slicing Step 1. The "Slice Data" dialog box as it would first appear with a typical Ramp file prior to any slicing. The user positions the 2 cursors (blue and yellow) at the (approximate) slicing boundaries. The slice-length in seconds is displayed in the lower left box. The user then clicks the "**Slice**" button to slice the data at the cursor positions.


Use the mouse to position the 2 cursors at the desired positions and press "Slice" to remove the other data. Press "Done" after slicing to write the new data file.

Slice Length: 8.40 (s)

Slicing Step 2. The "Slice Data" dialog box as it would appear with the same Ramp file after slicing in Slicing Step 1. The data can now be sliced more precisely if necessary by repeating Slicing Step 1, or the slicing can be reset by clicking the "**Reset**" button. When the desired slice has been defined (and the "**Slice**" button has been clicked), the "**Done**" button is clicked to complete the slicing.

Appendix V

Summary tables for statistical analyses in Studies 2 and 3

Chapter 4 (Study 2): Summary of statistical analysis results on muscle activities

(APDF - 4 muscles in 4 separate MANOVA)

4.3.1.1 CES : APDF analysis (p. 138)

Multivariate

Factor	F	df	*p*
Group	3.34	3,39	0.027*
Time	2.76	12,30	0.012*
Side	2.43	3,39	0.079
Time x group	1.27	12,30	0.287
Side x group	1.18	3,39	0.329
Time x side	.908	12,30	0.550
Time x side x group	1.38	12,30	0.230

Univariate

Factor	**10th%APDF**		**50th%APDF**		**90th%APDF**	
	F (df)	*p*	**F (df)**	*p*	**F (df)**	*p*
Group	.946 (1,41)	.336	.649 (1, 41)	.425	.163 (1, 41)	.689
Time	2.386 (1.7, 69.4)	.108	3.26(2.2, 90.1)	.039*	4.64(2.6,106.4)	.006*
Side	2.517(1,41)	.120	3.259 (1,41)	.044*	4.643(1,41)	.029*
Time x group	1.266 (1.7, 69.4)	.284	1.4 (2.2, 90.1)	.252	1.101 (2.6, 106.4)	.347
Side x group	1.972 (1,41)	.168	1.609 (1,41)	.212	.972 (1,41)	.330
Time x side	2.657 (1.6, 64.9)	.090	3.552 (1.6,64.0)	.045*	4.162 (2.0, 83.4)	.018*
Time x side x group	.289 (1.6,64.9)	.698	1.033 (1.6, 64.0)	.346	.527 (2.0, 83.4)	.595

4.3.1.2 UT: APDF (p. 138)

Multivariate

Factor	**F (df)**	*p*
Group	1.027 (3,39)	.391
Time	1.27 (12, 30)	.280
Side	1.912 (3,39)	.144
Time x group	1.345 (12,30)	.246
Side x group	2.427 (3,39)	.080
Time x side	1.224 (12, 30)	.312
Time x side x group	1.013 (12, 30)	.462

Univariate

Factor	**10th%APDF**		**50th%APDF**		**90th%APDF**	
	F(df)	*p*	**F(df)**	*p*	**F(df)**	*p*
Group	1.093 (1,41)	.302	.761 (1,41)	.308	.433 (1,41)	.514
Time	.976 (2.0, 83.3)	.382	1.272 (2.1, 86.9)	.287	1.602 (2.1, 83.9)	.207
Side	5.504 (1,41)	.024*	6.016 (1,41)	.019*	5.246 (1,41)	.027*
Time x group	1.609 (2.0,83.3)	.206	1.129 (2.1, 86.9)	.330	.843 (2.1, 83.9)	.436
Side x group	4.681 (1,41)	.036*	4.991 (1,41)	.031*	4.996 (1,41)	.031*
Time x side	.432 (1.8, 72.5)	.626	.606 (1.6, 64.9)	.511	.570 (1.6, 65.1)	.529
Time x side x group	.388 (1.8, 72.5)	.654	.559 (1.6, 64.9)	.535	.648 (1.6, 65.1)	.492

4.3.1.3 LT: APDF (p. 139)

Multivariate

Factor	**F(df)**	*p*
Group	.252(3, 39)	.859
Time	1.053 (12, 30)	.430
Side	0.197 (3, 39)	.898
Time x group	1.037 (12, 30)	.447
Side x group	0.252 (3, 39)	.859
Time x side	1.363 (12,30)	.237
Time x side x group	1.404 (12,30)	.228

Univariate

Factor	**10th%APDF**		**50th%APDF**		**90th%APDF**	
	F (df)	*p*	**F (df)**	*p*	**F (df)**	*p*
Group	0.100 (1,41)	.754	0.017 (1,41)	.896	.003 (1,41)	.956
Time	0.866 (2.9, 118.4)	.457	1.21(3.4, 139.3)	.308	.996 (3.1, 125.9)	.392
Side	0.060 (1,41)	.808	0.255 (1, 41)	.616	0.295 (1, 41)	.590
Time x group	1.488 (2.9, 118.4)	.323	1.106 (3.4, 139.3)	.352	1.831 (3.1, 125.9)	.143
Side x group	0.042 (1,41)*	.839	0.000 (1,41)	.992	0.149 (1, 41)	.702
Time x side	1.465 (2.9, 119.3)	.228	2.035 (3.5, 145.7)	.100	0.852 (2.9, 118.3)	.465
Time x side x group	1.240 (2.9, 119.3)	.298	1.153 (3.5, 145.7)	.333	1.733 (2.9, 118.3)	.166

4.3.1.4 AD: APDF (p. 140)

Multivariate

Factor	**F(df)**	*p*
Group	1.404 (3,39)	.256
Time	0.576 (12,30)	.844
Side	2.349 (3,39)	.087
Time x group	1.082 (12,30)	.409
Side x group	0.041 (3,39)	.989
Time x side	0.546 (12,30)	.857
Time x side x group	0.900 (12,30)	.557

Univariate

Factor	**10th%APDF**		**50th%APDF**		**90th%APDF**	
	F(df)	*p*	**F(df)**	*P*	**F(df)**	*p*
Group	0.121 (1,41)	.730	0.404 (1,41)	.528	0.770 (1,41)	.385
Time	0.481 (1.7,69.1)	.588	1.244(3.3,133.9)	.296	1.537(4,136.4)	.204
Side	5.114 (1,41)	.029*	4.144 (1,41)	.048*	4.380 (1,41)	.043*
Time x group	1.573(1.7,69.1)	.217	0.444(3.3,133.9)	.738	0.580(3.3,136.4)	.647
Side x group	0.053 (1,41)	.819	0.048 (1,41)	.827	0.064 (1,41)	.801
Time x side	0.302 (1.4, 55.5)	.654	0.469 (2.6,107.3)	.678	0.563 (2.6, 105.1)	.613
Time x side x group	0.857 (1.3, 55.5)	.391	0.608 (2.6, 107.3)	.590	0.911 (2.6, 105.1)	.426

4.3.4: Post-hoc Correlations between Body Area Discomfort Scores and 50th%APDF (p. 146)

		Right CES	Left CES	Right UT	Left UT	Right LT	Left LT	Right AD	Left AD
Right Neck	r_p	.187	.336*	.630**	.448**				
	p	.229	.028	.000	.003				
Left Neck	r_p	.087	.145	.513**	.343*				
	p	.579	.354	.000	.024				
Right Shoulder	r_p	.066	.122	.483**	.406**	.024	.047	.146	.109
	p	.672	.435	.001	.007	.876	.763	.351	.488
Left Shoulder	r_p	-.128	-.130	.244	.031	-.253	-.232	-.186	-.080
	p	.415	.404	.115	.845	.102	.135	.233	.610
Right Upper Back	r_p					.106	.055		
	p					.500	.725		
Left Upper Back	r_p					-.172	-.167		
	p					.271	.286		

** Correlation is significant at the 0.001 level (2-tailed).

* Correlation is significant at the 0.01 level (2-tailed).

Chapter 5 (Study 2): Summary of multivariate and univariate statistical analysis for MF of 4 muscles

5.3.1: Median frequency results (p. 181-182)

Multivariate

Factor	**F (df)**	***P***
Group	2.27 (4,38)	.080
Time	2.03 (16,26)	.053
Side	1.73 (4,38)	.163
Time x group	0.36 (16,26)	.983
Side x group	0.87 (4,38)	.491
Time x side	0.52 (16,26)	.916
Time x side x group	1.40 (16,26)	.215

Univariate

Factor	**CES_MF**		**UT_MF**		**LT_MF**		**AD_MF**	
	F (df)	**p**	**F (df)**	**p**	**F (df)**	**P**	**F (df)**	**p**
Group	0.33 (1,41)	.570	2.09 (1,41)	.156	8.47 (1,41)	.006*	0.03 (1,41)	.863
Time	1.46 (4,164)	.216	1.30 (4,164)	.274	1.71 (4,164)	.150	1.63 (4,164)	.168
Side	0.18 (1,41)	.674	2.86 (1,41)	.099	0.09 (1,41)	.765	4.27 (1,41)	.045*
Time x group	0.20 (4,164)	.936	0.50 (4,164)	.738	1.06 (4,164)	.380	0.52 (4,164)	.724
Side x group	0.16 (1,41)	.688	0.53 (1,41)	.471	2.84 (1,41)	.099	0.72 (1,41)	.400
Time x side	0.56 (4,164)	.692	0.50 (4,164)	.739	0.88 (4,164)	.477	1.19 (4,164)	.318
Time x side x group	2.54 (4,164)	.042*	2.73 (4,164)	.031*	2.46 (4,164)	.048*	1.50 (4,164)	.203

Chapter 6 (Study2): Summary of statistical analysis results on the kinematics data

6.3.1: Head/neck postures and movements (p. 208)

Multivariate

Factor	F	df	*p*
Group	2.62	9,28	0.025*
Time	0.97	36,556	0.518
Time x group	0.75	36,556	0.859

Univariate

	Time		**Group**		**Time x Group**	
	F(df)	***p***	**F(df)**	***P***	**F(df)**	***p***
HeadX (10th%)	2.60 (4,144)	.038*	0.74 (1,36)	.397	0.34 (4,144)	.851
HeadX (50th%)	2.16 (4,144)	.077	1.00 (1,36)	.325	0.29 (4,144)	.885
HeadX (90th%)	2.26 (4,144)	.066	2.34 (1,36)	.135	0.45 (4,144)	.771
HeadX range	0.95 (4,144)	.437	4.74 (1,36)	.036*	0.90 (4,144)	.468
HeadY (10th%)	1.38 (4,144)	.244	1.91 (1,36)	.175	0.08 (4,144)	.958
HeadY (50th%)	1.29 (4,144)	.279	5.56 (1,36)	.024*	0.48 (4,144)	.722
HeadY (90th%)	0.83 (4,144)	.507	6.74 (1,36)	.014*	0.70 (4,144)	.571
HeadZ (10th%)	0.80 (2.3,84.9)	.471	11.16 (1,36)	.002*	0.45 (2.3,84.9)	.673
HeadZ (50th%)	0.76 (2.4,88.1)	.493	9.47 (1,36)	.004*	0.42 (2.4,88.1)	.698
HeadZ (90th%)	0.97 (2.5,90.5)	.398	5.58 (1,36)	.024*	0.48 (2.5,90.5)	.662

6.3.1.1: Summary of descriptive statistics and one-way ANOVA results comparing head angles and ranges in the High, Low and Control Groups (p. 209)

	High Group	**Low Group**	**Control Group**	**One-way ANOVA**		**Contrasts [t, sig.(2-tailed)]**		
	Mean (sd)	**Mean (sd)**	**Mean (sd)**	**F (2,35)**	***p***	**High vs Control**	**Low vs Control**	**High vs Low**
Flexion (HdX) mean angle	69.93 (10.10)	61.73 (11.56)	63.74 (12.69)	1.58	.220	-.50, .142	.36, .718	1.46, .153
Side Flexion (HdY) mean angle	-1.12 (1.76)	-1.20 (1.93)	-2.67 (2.23)	2.71	.081	-2.17, .037*	-1.54, .132	.078, .939
Rotation (HdZ) mean angle	1.39 (2.26)	2.74 (2.71)	4.23 (2.48)	5.44	.009*	3.29, .002 *	1.29, .206	-1.15, .257
Flexion (HdX) range	6.71 (4.18)	6.92 (3.04)	4.53 (2.05)	2.31	.114	-1.93, .062	-1.57, .125	-.13, .895
Side Flexion (HdY) range	3.89 (2.35)	2.74 (0.61)	2.99 (1.49)	1.32	.279	-1.39, .172	.298, .767	1.32, .197
Rotation (HdZ) range	4.66 (1.62)	3.69 (1.65)	3.40 (1.29)	2.95	.066	-2.39, .023*	-.41, .682	1.34, .188

6.3.2: Thorax postures and movements (p. 210)

Descriptive statistics: mean joint angles and ranges of Thx X (flexion) and Thx Y (abduction) over 5 trials

	Case Group			Control Group		
	10th% APDF	**50th% APDF**	**90th% APDF**	**10th% APDF**	**50th% APDF**	**90th% APDF**
ThxX (Flexion)	13.8 (7.0)	15.1 (6.8)	16.2 (6.7)	13.4 (6.1)	14.4 (6.2)	15.4 (6.3)
ThxY (Side flexion)	-1.6 (3.1)	-1.4 (3.1)	0.1 (3.2)	-1.2 (2.9)	-0.2 (2.9)	-2.0 (2.9)
ThxX range	2.4 (0.3)			2.0 (0.2)		
ThxY range	1.7 (0.1)			0.8 (0.1)		

6.3.3: Bilateral shoulder postures and movements (p. 211)

(Shoulder X=flex/ext, Y=abd/add)

Multivariate

Factor	**F**	**df**	**p**
Group	2.58	6,31	.038*
Time	1.23	24,13	.356
Side	5.35	6,31	.001*
Time x group	1.01	24,13	.508
Side x group	.58	6,31	.745
Time x side	1.52	24,13	.217
Time x side x group	1.74	24,13	.149

Univariate

APDF	**ShX (50th%)**			**ShY (50th%)**			**ShX_range**			**ShY_range**		
	F	**Df**	***p***	**F**	**df**	***p***	**F**	**df**	***p***	**F**	**df**	***p***
Group	.048	1,36	.828	1.36	1,36	.251	.11	1,36	.739	.02	1,36	.893
Time	1.37	4,144	.246	1.78	4,144	.136	1.87	2.3, 82.3	.155	2.35	4, 144	.057
Side	4.30	1,36	.045*	1.31	1,36	.259	25.99	1,36	.000*	7.55	1,36	.009*
Time x group	.97	4,144	.426	.78	4,144	.543	.39	4,144	.703	.10	4, 144	.982
Side x group	1.12	1,36	.298	.74	1,36	.395	.15	1,36	.702	.07	1,36	.792
Time x side	.73	4,144	.571	.18	4,144	.946	.39	2.5, 90.2	.721	4.18	4, 144	.003*
Time x side x group	1.64	4,144	.169	.83	4,144	.509	.28	2.5, 90.2	.800	1.92	4, 144	.110

Chapter 7 (Study 3): Summary of statistical results on EMG data

7.3.1: EMG amplitude analysis (p. 256)

Multivariate: 50th% APDF of 4 muscles

	F	df	*p*
Group	0.20	4,36	.937
Condition	5.60	8,32	**.000***
Time	1.43	16,24	.209
Side	8.81	4,36	**.000***
Condition x group	0.66	8,32	.721
Time x group	0.69	16,24	.772
Side x group	0.84	4,36	.509
Condition x time	0.94	32,8	.587
Condition x side	1.40	8,32	.233
Time x side	1.15	16,24	.370
Condition x time x group	0.98	32,8	.556
Condition x side x group	1.16	8,32	.356
Condition x time x side	2.19	32,8	.123
Time x side x group	2.92	16,24	**.009***
Condition x time x side x group	0.89	32,8	.623

Univariate

APDF	CES_50th%			UT_50th%			LT_50th%			AD_50th%		
	F	df	*p*	F	df	*p*	F	df	*p*	F	df	*p*
Group	0.43	1,39	.516	0.00	1,39	.950	0.21	1,39	.649	0.02	1,39	.888
Cond	17.05	2,78	**.000***	20.35	2,74	**.000***	10.27	2,74	**.000***	6.82	2,74	**.002***
Time	2.84	2.2, 86.1	*.059*	0.77	3.0, 117.9	.513	2.61	2.7, 106.0	*.060*	1.91	2.4, 92.4	.146
Side	0.12	1,39	.728	0.58	1,39	.452	7.42	1,39	**.010***	25.15	1,39	**.000***
Cond x group	0.60	2,78	.550	0.15	2,78	.857	0.01	2,78	.997	1.40	2,78	.254
Time x group	1.01	2.2, 86.1	.375	0.89	3.0, 117.9	.448	0.13	2.7, 106.0	.929	2.07	2.4, 92.4	.123
Side x group	2.55	1,39	.118	1.12	1,39	.297	0.01	1,39	.910	0.06	1,39	.805
Cond x time	1.35	5.2, 204.1	.243	2.23	4.9, 189.7	*.055**	1.15	4.9, 192.1	.335	1.62	4.8, 187.7	.159
Cond x side	0.14	2,78	.866	1.35	1.3, 53.9	.261	3.77	2,78	**.027***	1.04	2,78	.357
Time x side	0.03	1.9, 76.8	.970	1.05	2.8, 111.5	.372	1.49	2.9, 112.3	.223	1.16	3.3, 128.6	.329
Condx time x group	0.33	5.2, 204.1	.903	1.34	4.9, 189.7	.252	0.63	4.9, 192.1	.674	0.76	4.8, 187.7	.575
Condx side x group	4.12	2,78	**.020***	0.03	2,78	.929	0.77	2,78	.467	0.71	2,78	.494
Cond x time x side	0.47	2.6, 104.3	.681	0.98	5.1, 198.	.431	1.24	4.2, 164.4	.296	1.55	5.3, 207.8	.172
Time x side x group	2.16	1.9, 76.8	.123	1.31	2.8, 111.5	.277	0.81	2.9, 112.2	.489	1.81	3.3, 128.6	.143
Condx time x sidexgp	0.84	2.6, 104.3	0.462	0.81	5.1, 198.6	.545	0.50	4.2, 164.4	.745	0.82	5.3, 207.8	.546

7.3.2: EMG Median Frequency (MF) analysis (p. 262)

***Multivariate* : MF of 4 muscles comparing 3 conditions**

Factor	**F**	**Df**	***p***
Group	0.64	4,36	0.634
Condition	4.39	8,32	**0.001***
Time	2.28	16,24	**0.032***
Side	0.03	4,36	0.999
Condition x group	0.60	8,32	0.768
Time x group	0.73	16,24	0.741
Side x group	0.45	4,36	0.775
Condition x time	0.44	32,8	0.952
Condition x side	0.53	8,32	0.822
Time x side	0.78	16,24	0.694
Condition x time x group	0.89	32,8	0.952
Condition x side x group	1.79	8,32	0.115
Condition x time x side	0.93	32,8	0.596
Time x side x group	0.70	16,24	0.764
Condition x time x side x group	0.79	32,8	0.702

Univariate

Factor	**CES**			**UT**			**LT**			**AD**		
	F	**df**	***p***	**F**	**df**	***p***	**F**	**df**	***p***	**F**	**df**	***p***
Group	0.15	1,39	.699	1.24	1,39	.273	1.82	1,39	.185	0.49	1,39	.490
Cond	0.23	2,78	.793	3.84	2,78	**.026***	6.15	2,78	**.003***	17.10	2,78	**.000***
Time	0.96	4,156	.434	2.50	4,156	**.044***	0.90	4,156	.466	2.22	4, 156	*.069*
Side	0.00	1,39	.980	0.07	1,39	.796	0.05	1,39	.818	0.00	1,39	.985
Cond x group	0.21	2,78	.811	0.33	2,78	.721	0.57	2,78	.569	0.03	2,78	.969
Time x group	0.52	4,156	.723	0.02	4,156	.999	1.86	4,156	.121	1.28	4, 156	.280
Side x group	0.57	1,39	.456	0.82	1,39	.371	0.38	1,39	.539	0.00	1,39	.993
Cond x time	1.52	8,312	.151	0.55	5.2, 202.7	.744	0.95	5.0, 194.7	.447	0.65	8, 312	.739
Cond x side	0.99	2,78	.375	0.88	2,78	.421	0.33	2,78	.719	0.11	2,78	.895
Time x side	0.06	4,156	.993	1.40	4,156	.237	0.50	2.9, 129.1	.681	1.50	4, 156	.204
Cond x time x group	0.70	8,312	.690	0.63	5.2, 202.7	.681	0.57	5.0, 194.7	.723	0.76	8, 312	.634
Cond x side x group	1.05	2,78	.352	0.71	2,78	.495	0.31	2,78	.736	0.50	2,78	.610
Cond x time x side	0.64	8,312	.742	2.13	5.0, 196.8	*.062*	0.45	5.7, 221.2	.834	2.28	8,312	**.022***
Time x side x group	1.02	4,156	.400	0.81	4,156	.524	1.72	2.9, 129.1	.167	1.07	4,156	.374
Cond x time x side x group	0.95	8,312	.478	2.02	5.0, 196.8	.076	1.02	5.7, 221.2	.412	0.45	8,312	.892

7.3.3.2: statistical analysis on discomfort scores (p. 263-264)

Multivariate

Factor	F(df)	Sig
Group	??	
Time	15.42 (2,38)	.000*
Cond	20.17 (2,38)	.000*
Time x group	8.77 (2,38)	.000*
Cond x time	2.01 (4,36)	.115
Cond x group	16.59 (2,38)	.000*
Cond x time x group	1.65 (4,36)	.184

Univariate

Factor	F(df)	Sig.
Group	62.64(1,39)	.000*
Time	26.93 (1.3,52.1)	.000*
Cond	16.02 (2,78)	.000*
Time x group	14.28 (1.3,52.1)	.000*
Cond x time	1.77 (4,156)	.138
Cond x group	13.15 (2,78)	.000*
Cond x time x group	1.90 (4,156)	.113

Chapter 8: Summary of statistical results on keyboard (KB) data

8.3.1 – 8.3.2: Group differences in keystroke Mean Speed, Speed Variability, Mean Peak Force and Force Variability (p. 308-311)

Multivariate

Factor	F(df)	*p*
Group	1.12 (7,32)	.376
Cond	18.69 (14,25)	.000*
Cond x group	.88 (14,25)	.588

Univariate

	Mean Speed		**Speed Variability**		**Mean Peak Force**		**Force Variability**	
	F(df)	*p*	**F(df)**	*p*	**F(df)**	*p*	**F(df)**	*p*
Group	.23 (1, 38)	.631	.00 (1, 38)	.973	.25 (1, 38)	.623	.33 (1, 38)	.571
Cond	38.76 (2,76)	.000*	2.74 (2,76)	.071	100.15 (2,76)	.000*	.99 (2,76)	.376*
Group x Cond	1.67 (2,76)	.195	.39 (2,76)	.675	1.74 (2,76)	.183	2.61 (2,76)	.080

Appendix VI

Samples of Raw Data Sheets from Studies 1, 2 and 3

Chapter3 (Study 1): Mean Head Tilt and Neck Flexion Angles (p.100)

Head Tilt (HT) Mean Summary (T1-5)

Subj	Group	HT1 mean	HT2 mean	HT3 mean	HT4 mean	HT5 mean	HT_ tr_me	HTsd
1	1	67.01	59.87	63.88	66.11	64.20	64.21	2.76
2	1	58.83	70.22	68.75	68.50	67.53	66.76	4.54
3	1	59.43	57.17	50.08	58.99	63.57	57.34	4.93
4	1	62.16	58.65	53.83	57.35	58.00	58.00	2.98
5	1	65.06	60.69	56.09	54.94	48.10	57.05	6.38
6	1	55.36	59.81	68.19	60.36	65.03	60.23	4.97
7	1	62.63	65.85	67.23	75.62	75.24	67.29	5.83
8	1	45.71	44.26	53.50	56.79	49.90	49.11	5.23
9	2	51.27	60.32	55.01	51.52	45.71	52.76	5.38
10	2	59.91	59.02	61.47	59.71	59.05	59.83	1.00
11	2	58.75	57.04	59.59	59.00	60.68	59.01	1.33
12	2	69.84	70.40	62.04	69.15	64.13	67.11	3.78
13	2	56.34	53.19	54.43	63.26	58.58	57.16	3.97
14	2	49.07	48.16	48.33	42.45	46.65	46.93	2.66
15	2	57.78	61.79	58.80	62.84	71.31	62.50	5.34
16	2	51.17	57.96	47.10	51.92	52.65	52.16	3.89

Neck Flexion (NF) Mean Summary (Trial 1-5)

Subj	Group	NF1 mean	NF2 mean	NF3 mean	NF4 mean	NF5 mean	NF_ Tr_me	NF_sd
1	1	48.40	53.27	56.67	54.15	53.00	53.10	3.00
2	1	45.14	52.83	45.15	43.82	45.39	46.46	3.61
3	1	56.04	57.31	58.15	56.71	58.36	57.31	0.97
4	1	68.89	65.21	63.85	62.52	65.00	65.09	2.38
5	1	64.27	65.17	63.31	61.30	70.21	64.85	3.32
6	1	54.41	47.84	50.72	42.33	54.10	49.88	5.01
7	1	78.25	76.51	75.27	80.74	75.75	77.30	2.23
8	1	56.79	58.60	63.86	62.54	66.37	61.63	3.90
9	2	48.99	46.85	46.25	44.87	46.59	46.71	1.48
10	2	51.34	51.58	43.24	44.59	47.93	47.73	3.80
11	2	54.57	59.52	51.78	56.26	59.19	56.26	3.25
12	2	66.28	61.74	61.90	65.93	65.55	64.28	2.26
13	2	55.44	54.93	57.77	54.34	55.99	55.69	1.31
14	2	54.24	52.91	52.32	48.87	52.18	52.10	1.98
15	2	55.95	58.45	57.70	56.38	54.33	56.56	1.60
16	2	41.38	36.15	43.59	43.57	40.69	41.07	3.04

Group 1=Case, Group 2=Control

Chapter 4 (Study 2): Means of 50th%APDF over 5 trials for Case and Control Groups (p.136)

Group*	RightCES	LeftCES	RightUT	Left UT	Right LT	LeftLT	RightAD	LeftAD
1	18.47	22.08	5.55	4.79	24.19	11.39	2.70	2.93
1	31.92	16.86	3.94	2.20	14.74	3.04	0.77	2.56
1	16.38	21.76	1.78	0.49	3.84	5.64	1.38	0.01
1	11.49	10.48	6.70	6.63	10.09	24.06	5.91	7.32
1	18.07	7.40	0.44	1.63	20.37	30.44	0.66	0.10
1	11.46	9.62	4.53	3.10	10.88	53.78	20.68	3.28
1	35.80	47.66	18.73	13.93	45.62	32.86	6.35	5.33
1	16.12	14.11	7.33	5.08	13.46	23.80	2.24	3.45
1	44.50	34.91	94.93	99.00	99.00	99.00	67.30	12.41
1	26.85	18.30	37.85	30.84	7.00	20.19	5.20	3.16
1	20.87	19.87	17.95	0.89	4.55	3.40	3.36	1.04
1	3.50	8.05	34.56	0.09	29.04	17.45	2.45	0.54
1	11.78	13.53	4.19	2.53	14.83	20.77	3.71	1.72
1	17.93	14.39	7.92	6.88	30.72	9.08	6.84	4.37
1	11.19	10.55	0.09	1.21	32.54	5.69	7.07	0.87
1	24.11	26.94	14.88	9.12	16.27	7.18	1.41	1.51
1	14.29	5.70	99.00	52.62	12.11	4.34	3.10	2.72
1	6.58	4.26	23.69	2.53	3.32	8.64	2.79	13.04
1	4.35	4.98	24.91	2.97	8.78	14.02	0.73	1.94
1	18.47	34.10	16.70	4.61	13.65	3.75	3.49	3.07
1	38.41	28.28	19.36	1.43	74.19	25.23	4.44	4.38
1	18.85	23.76	25.04	18.96	26.72	36.87	7.32	1.78
1	21.84	7.10	7.31	11.24	16.69	34.65	4.42	10.53
2	48.56	11.63	7.14	8.31	16.49	9.23	12.55	7.45
2	62.20	32.23	34.77	5.14	25.20	5.83	7.60	0.79
2	7.78	7.52	2.40	9.18	91.93	41.51	1.75	10.09
2	9.23	13.75	15.99	3.33	17.97	5.77	6.25	7.06
2	34.49	33.28	28.42	16.60	52.19	81.68	4.84	2.09
2	51.11	30.35	20.24	33.78	5.25	7.35	1.31	1.61
2	18.02	13.18	17.15	9.84	16.80	8.20	2.75	2.49
2	25.44	16.88	7.39	21.98	5.85	11.84	4.84	5.12
2	30.44	14.57	27.89	42.81	50.11	61.68	8.23	5.09
2	7.51	8.21	1.02	1.62	29.35	7.00	2.53	2.65
2	6.56	4.84	2.34	10.01	7.12	20.77	3.55	0.96
2	24.43	18.49	0.43	9.42	44.29	25.12	16.91	3.62
2	8.41	9.96	15.26	13.38	19.52	92.67	15.65	1.20
2	24.07	20.77	14.70	18.53	28.34	34.23	5.27	1.64
2	4.64	29.89	6.45	2.62	5.30	11.82	1.44	2.27

2	70.85	15.80	9.46	3.82	39.14	10.60	5.66	0.55
2	32.20	19.22	16.14	9.93	6.96	2.70	0.83	2.38
2	7.92	17.53	4.39	3.21	7.10	0.11	4.36	0.00
2	8.76	21.50	1.80	3.64	8.33	7.66	3.58	1.53
2	10.72	14.63	3.29	1.64	3.30	1.02	2.66	0.58

***Group 1=Case, 2=Control**

Chapter 6 (Study 2): Mean Head Angles and Ranges (p.206)

Group	HeaddFlex	HeadSideFlex	Head Rot	HeadFlex_rg	HeadSideFlex_rg	HeadRot_rg
1	57.91	-1.43	2.22	4.78	11.33	4.83
1	58.26	-4.70	0.79	9.45	4.83	4.31
1	74.00	-1.78	6.03	2.91	3.20	3.50
1	79.78	0.45	2.19	8.18	3.00	5.27
1	55.64	0.49	6.01	10.82	5.67	4.04
1	71.35	1.10	-0.79	4.70	2.66	5.05
1	76.26	-0.44	2.26	5.87	2.26	3.06
1	84.12	-2.33	-1.76	9.53	2.19	4.59
1	64.22	-0.69	6.98	7.47	3.20	4.81
1	83.35	-0.77	0.90	11.77	4.12	3.49
1	79.52	1.09	3.10	3.49	2.08	2.59
1	67.49	-1.11	3.36	5.57	2.83	3.10
1	51.29	-4.60	2.77	19.75	5.11	8.07
1	75.17	-2.04	0.32	10.08	3.80	5.10
1	68.53	-0.86	0.53	3.19	2.09	8.12
1	55.71	-0.58	-2.20	7.38	3.65	6.51
1	70.10	-4.07	1.29	1.49	2.04	1.45
1	66.89	-1.87	1.01	8.95	2.68	3.89
1	78.41	1.82	0.88	4.99	2.46	3.71
1	51.08	-0.50	-0.49	5.46	3.27	3.76
1	51.59	-1.15	1.92	4.68	2.35	2.86
2	59.73	0.79	3.25	4.14	2.45	6.03
2	46.77	-2.84	0.97	4.91	4.29	3.97
2	76.76	-2.08	5.01	3.74	1.96	1.64
2	63.22	-3.16	1.07	4.59	1.92	3.06
2	76.27	-0.54	3.77	6.51	2.44	2.22
2	41.53	0.33	6.59	4.83	3.71	5.43
2	53.89	-2.11	6.65	3.59	2.28	3.63
2	56.30	-0.75	5.53	3.07	3.21	5.25
2	56.83	-2.80	5.26	3.14	3.25	3.70
2	78.56	-2.48	7.53	3.89	2.12	3.67
2	64.78	-4.33	2.26	2.67	2.06	3.06
2	64.16	-2.52	7.81	2.48	2.15	2.00
2	55.77	-2.44	4.48	11.34	3.23	4.25
2	83.25	-2.09	3.59	3.03	1.51	2.07
2	52.86	-8.41	6.94	5.21	2.67	1.92
2	65.43	-3.74	0.40	4.89	3.78	3.27
2	87.76	-6.18	0.78	6.51	7.93	2.71

Chapter 7(Study 3): Means of 50th%APDF of 8 muscles in 3 conditions (p.252)

Group	Normal_RCES	Faster_RCES	Harder_RCES	Normal_:LCES	Faster_LCES	Harder_ LCES
1	24.78	25.57	23.80	10.54	12.29	10.71
1	27.29	34.53	35.05	22.14	23.48	26.21
1	42.28	66.09	45.85	37.00	47.13	37.82
1	10.49	14.18	11.12	8.65	9.59	8.56
1	24.10	28.53	26.03	31.30	41.64	30.91
1	35.93	38.92	36.89	76.57	76.57	60.43
1	72.31	99.00	98.40	52.21	58.79	56.42
1	9.78	9.31	7.92	13.20	14.43	13.50
1	12.02	23.94	16.69	15.04	19.02	18.18
1	51.03	90.55	91.25	50.65	79.08	71.19
1	10.59	13.26	12.78	10.93	13.37	13.33
1	23.38	31.30	25.87	22.02	24.30	19.69
1	8.58	7.61	7.60	4.79	4.61	4.59
1	17.15	15.20	15.56	18.68	16.31	17.02
1	20.81	23.09	21.40	12.85	18.69	16.15
1	12.42	21.28	12.97	9.42	14.86	9.59
1	12.11	15.56	13.72	15.49	19.62	15.98
1	9.20	8.42	9.51	28.77	29.39	28.42
1	20.03	21.79	22.80	14.75	16.35	17.26
1	51.38	58.65	56.36	59.02	59.02	53.66
1	44.64	49.53	40.60	16.37	17.58	16.54
2	11.75	17.35	20.19	14.59	21.73	26.23
2	20.06	21.41	48.13	16.17	27.37	22.67
2	63.98	60.60	62.35	63.74	92.89	99.00
2	55.60	53.93	50.87	42.76	48.12	46.27
2	6.29	10.61	8.14	4.81	8.21	7.26
2	3.97	4.87	6.64	4.68	5.30	6.92
2	12.99	21.50	15.53	13.91	20.86	15.30
2	9.86	19.39	11.78	13.64	23.43	14.10
2	8.07	10.21	9.07	17.76	26.63	24.59
2	17.84	20.28	18.55	66.79	63.84	70.06
2	15.19	22.51	15.27	27.87	41.13	28.76
2	11.66	14.73	14.77	13.47	18.37	18.15
2	23.68	25.56	24.10	19.19	28.56	22.73
2	43.46	52.67	49.06	23.37	33.22	26.29
2	6.59	5.65	12.47	27.53	22.67	38.71
2	24.47	23.03	23.11	24.86	24.52	25.85
2	5.99	6.00	5.74	8.26	8.07	8.02
2	10.86	23.52	10.11	9.34	16.88	13.85
2	19.13	33.03	20.57	16.62	27.99	17.16
2	28.62	33.20	33.19	24.47	27.93	28.01

Group	Normal_RUT	Faster_RUT	Harder_RUT	Normal_LUT	Faster_LUT	Harder_LUT
1	3.85	13.79	4.78	0.67	12.00	4.64
1	20.19	25.78	29.96	10.22	16.22	18.79
1	8.52	15.31	13.15	9.53	32.52	18.15
1	4.33	9.56	5.04	3.09	5.17	3.09
1	7.71	12.11	13.60	4.40	8.93	6.59
1	2.90	7.06	6.79	14.35	23.43	22.17
1	12.38	33.00	27.76	34.43	36.76	40.16
1	22.05	21.65	21.18	26.99	36.69	36.59
1	5.09	17.67	14.03	6.48	11.29	11.79
1	84.54	99.00	87.93	9.02	28.56	16.99
1	2.37	5.23	2.29	4.71	9.77	4.56
1	27.93	40.74	40.49	2.16	6.22	4.94
1	3.56	2.77	3.34	5.20	3.67	4.34
1	3.22	3.88	3.47	0.68	1.03	0.53
1	6.58	10.09	7.83	8.01	15.19	12.67
1	41.84	36.23	32.46	10.34	15.41	8.90
1	4.16	6.96	4.03	12.91	13.12	8.03
1	15.20	11.90	15.39	11.88	12.37	16.61
1	26.97	26.97	25.96	7.55	14.52	10.81
1	25.97	31.55	31.31	33.62	47.75	34.65
1	17.25	22.34	17.54	20.81	24.53	21.04
2	12.87	22.09	27.65	16.40	25.95	32.22
2	11.17	22.32	17.01	5.59	15.50	14.83
2	7.70	20.02	23.67	12.29	29.95	29.56
2	54.54	51.12	48.83	21.77	24.56	21.44
2	4.49	11.22	6.16	2.40	10.24	4.54
2	1.30	3.12	4.52	1.00	1.67	3.05
2	2.37	13.81	6.62	1.54	7.37	2.33
2	13.73	27.70	14.92	12.29	24.60	11.86
2	8.39	18.58	20.13	2.95	13.56	13.63
2	20.47	27.89	14.53	18.93	21.89	16.16
2	13.21	34.01	15.96	32.38	85.05	37.80
2	4.93	7.96	6.33	9.76	16.30	15.12
2	10.29	14.52	11.83	22.29	12.29	21.03
2	18.29	24.77	21.43	40.97	53.44	44.29
2	9.74	6.33	22.94	6.30	1.67	17.98
2	15.80	17.45	18.32	8.88	11.71	11.73
2	0.25	0.59	0.38	0.49	0.64	0.60
2	12.05	14.73	10.94	6.84	13.62	6.62
2	6.53	11.50	7.13	11.09	15.93	10.27
2	34.19	33.86	31.05	26.19	30.51	29.60

Group	Normal_RLT	Faster_RLT	Harder_RLT	Normal_LLT	Faster_LLT	Harder_LLT
1	25.51	54.15	35.77	3.28	4.92	3.79
1	2.72	4.66	5.77	3.27	4.16	7.76
1	14.55	13.56	15.09	19.59	13.89	14.54
1	39.60	65.41	45.02	19.73	23.67	20.03
1	16.89	22.92	16.37	9.80	8.90	11.96
1	9.53	27.74	26.49	4.26	18.60	14.72
1	45.64	88.37	82.69	16.84	34.71	42.47
1	3.96	5.67	2.83	1.77	2.14	1.66
1	14.28	32.07	27.71	22.24	30.79	29.44
1	27.85	26.40	14.79	9.34	9.02	6.59
1	5.54	9.99	4.35	7.19	14.41	6.32
1	4.95	6.78	4.10	1.12	1.34	0.91
1	2.99	3.54	3.00	3.86	4.54	3.94
1	1.97	1.33	0.73	6.42	5.71	4.59
1	11.69	17.95	11.72	1.73	4.94	3.20
1	5.98	17.05	7.42	15.94	17.62	10.44
1	2.96	9.23	12.35	3.29	9.88	6.89
1	11.34	13.92	27.05	21.30	22.51	42.51
1	19.75	19.85	18.92	39.28	36.15	38.53
1	38.23	35.91	32.84	7.99	7.13	5.82
1	7.08	8.92	5.97	8.15	7.89	8.79
2	13.51	17.54	18.49	19.63	33.77	44.48
2	25.77	22.36	19.52	9.37	7.90	10.11
2	22.20	38.90	36.75	7.82	14.32	16.43
2	6.64	5.87	7.15	5.43	4.83	4.80
2	2.58	3.38	1.63	19.33	13.60	9.15
2	9.87	3.58	21.00	0.74	0.56	2.18
2	4.82	21.54	8.61	7.39	18.12	10.28
2	65.11	84.29	83.99	20.80	27.27	27.18
2	16.70	25.29	25.27	3.96	9.26	7.69
2	3.45	6.05	3.67	2.78	3.27	2.79
2	12.04	18.42	7.32	12.38	21.15	7.45
2	19.13	24.50	21.69	13.82	19.30	17.70
2	3.65	3.83	3.77	4.38	4.70	5.09
2	24.41	75.04	21.58	4.91	9.86	4.63
2	14.13	26.06	53.60	4.92	5.50	6.16
2	14.37	9.91	12.87	11.34	10.92	10.94
2	1.98	3.36	2.86	2.47	3.16	3.00
2	2.42	5.77	3.81	5.09	23.12	5.92
2	2.96	5.11	2.66	5.54	9.83	6.53
2	10.04	12.76	11.95	11.47	11.05	10.51

Group	Normal_RAD	Faster_RAD	Harder_RAD	Normal_LAD	Faster_LAD	Harder_LAD
1	1.35	1.43	1.35	1.01	4.15	1.87
1	4.78	9.86	10.72	2.57	3.54	4.21
1	9.34	10.60	12.66	12.03	8.45	11.38
1	0.62	0.80	0.90	1.53	2.07	4.07
1	2.81	2.38	1.59	2.47	1.35	1.29
1	6.30	10.27	10.16	1.81	3.17	3.18
1	3.47	6.57	7.09	2.59	6.28	8.81
1	2.05	5.76	1.80	0.60	0.94	0.18
1	4.35	13.08	8.49	2.59	9.12	6.05
1	10.10	19.19	16.90	5.63	12.67	14.61
1	2.52	4.04	2.51	3.06	5.58	3.30
1	3.23	4.77	3.91	0.98	1.03	0.83
1	8.58	7.61	7.60	3.09	1.79	2.46
1	1.18	2.10	2.02	0.54	0.59	0.55
1	0.61	2.00	0.91	0.24	3.62	1.80
1	2.20	5.19	2.58	0.65	2.14	0.89
1	3.95	2.39	2.33	2.85	2.68	2.59
1	1.75	1.87	3.95	3.42	3.36	8.14
1	27.08	11.55	13.77	17.86	8.26	13.47
1	7.19	7.74	7.52	2.85	2.64	2.28
1	2.00	3.84	3.19	0.54	0.74	1.21
2	5.72	12.14	15.64	1.83	4.10	10.19
2	8.12	8.35	9.11	2.60	2.29	2.02
2	6.49	5.22	5.08	3.96	7.89	6.99
2	5.64	7.79	7.51	2.17	3.12	3.68
2	4.16	7.02	4.00	3.24	4.33	3.04
2	0.63	1.72	2.01	0.00	0.44	0.40
2	1.84	2.62	1.64	3.23	2.91	2.08
2	2.96	4.60	3.05	2.38	3.64	2.54
2	8.98	13.66	13.00	2.38	10.96	10.35
2	5.55	8.68	7.53	4.37	4.58	4.80
2	3.13	18.36	2.59	1.43	14.39	1.59
2	6.42	10.15	8.06	3.41	5.72	6.28
2	1.46	3.55	1.51	2.31	5.00	4.27
2	4.37	6.86	2.82	2.27	3.38	1.74
2	0.55	0.69	6.62	1.02	1.63	1.88
2	9.93	6.46	8.13	6.25	4.63	4.28
2	1.06	1.05	1.23	1.08	2.96	3.09
2	2.97	9.26	5.94	1.50	12.63	2.43
2	1.75	2.62	1.54	1.52	1.15	0.61
2	9.88	14.98	13.56	5.04	8.94	8.99

Chapter 8 (Study 3): Keystroke Speed Data in 3 conditions (N,F,H) (p.307)

Group	N_Speed Variabiltiy	F_Speed Variabiltiy	H_Speed Variabiltiy	N_Mean Speed	F_Mean Speed	H_Mean Speed
1	25.70	21.66	16.83	302.14	266.85	241.68
1	9.55	9.25	21.52	210.79	192.84	190.20
1	12.37	6.18	42.87	210.94	196.77	230.45
1	23.52	10.85	19.33	236.28	215.79	225.79
1	61.50	13.66	17.07	281.29	221.21	213.25
1	31.19	39.06	20.19	300.99	243.64	255.47
1	32.75	26.51	20.91	333.37	270.11	290.76
1	18.82	29.81	9.78	287.16	268.21	251.24
1	15.89	11.45	13.28	239.14	209.39	221.16
1	15.67	13.53	12.69	222.66	215.03	204.68
1	11.35	10.79	19.88	241.76	182.19	232.88
1	31.69	23.30	8.24	295.82	231.50	216.53
1	24.33	25.25	17.93	305.51	278.90	253.05
1	5.04	7.99	16.08	285.79	262.01	274.73
1	14.45	14.28	20.27	210.76	192.23	212.49
1	16.82	6.41	31.69	321.60	293.33	271.74
1	54.29	101.07	41.85	287.02	292.73	322.17
1	42.21	18.52	14.68	305.88	281.32	257.52
1	19.15	10.09	11.18	215.90	195.96	198.64
1	24.38	14.90	13.62	267.46	252.85	227.97
1	13.43	18.79	17.22	272.60	210.93	232.62
2	19.68	23.24	11.08	261.51	242.09	253.30
2	21.77	6.15	16.51	233.49	193.26	201.57
2	66.25	12.02	12.63	260.58	237.93	245.98
2	21.42	22.26	6.37	207.11	200.54	203.02
2	14.87	20.38	13.24	231.00	187.36	198.05
2	10.59	27.54	63.18	277.19	241.18	232.61
2	16.41	24.22	16.17	247.45	217.68	227.13
2	31.97	15.00	14.59	307.90	240.97	268.31
2	28.79	17.14	33.01	369.74	294.42	339.29
2	9.93	11.98	11.42	250.42	229.97	242.07
2	14.14	18.11	8.47	192.51	190.13	183.58
2	76.83	17.01	18.30	268.44	225.72	281.77
2	13.47	9.13	13.60	223.39	201.51	218.09
2	29.84	28.95	28.07	351.67	284.89	338.94
2	25.71	29.48	16.84	291.75	293.76	273.35
2	14.17	12.99	17.12	333.33	284.68	248.19
2	15.21	13.05	19.86	258.90	193.77	253.43
2	9.18	18.54	12.10	273.60	275.77	282.43
2	63.72	13.42	33.20	312.16	277.06	315.72

Study 3: Keyboard Force Data in 3 conditions (p.310)

Group	N_Force Variability	F_Force Variability	H_Force Variability	N_Mean Peak Force	F_Mean Peak Force	H_Mean Peak Force
1	0.44	0.55	1.16	5.01	8.47	10.06
1	0.24	0.27	0.66	6.16	7.21	10.36
1	0.62	1.10	1.10	7.34	9.38	12.46
1	0.35	0.36	0.49	6.00	6.27	7.75
1	0.44	0.61	0.90	7.27	7.85	9.38
1	0.44	0.34	1.03	6.61	6.90	8.94
1	0.38	0.35	0.39	5.20	6.32	7.69
1	0.34	0.30	0.47	6.29	7.49	7.61
1	0.94	0.57	1.65	8.35	10.31	14.41
1	0.37	4.84	0.49	8.45	14.06	13.31
1	0.53	0.56	0.63	7.95	11.17	13.07
1	0.42	0.88	0.98	7.40	9.20	10.21
1	0.26	0.23	0.75	5.87	6.88	8.66
1	0.35	4.59	0.61	6.87	10.00	8.44
1	0.38	0.79	1.52	7.27	8.39	9.38
1	0.46	0.29	0.52	5.81	6.55	9.28
1	0.67	0.78	0.85	6.09	7.20	9.68
1	1.58	1.14	1.40	10.60	10.51	13.23
1	0.61	0.29	0.52	5.97	6.74	7.06
1	0.56	0.43	0.42	5.39	6.45	6.30
1	0.11	0.43	0.65	5.56	6.53	8.63
2	0.13	0.32	0.18	4.16	4.61	7.49
2	1.05	0.33	2.80	3.09	3.46	5.67
2	1.34	0.53	0.75	8.99	11.60	13.35
2	0.55	0.44	0.62	7.83	10.67	12.58
2	0.58	0.63	0.60	7.31	9.08	12.68
2	0.39	0.24	0.60	3.85	4.10	4.60
2	0.47	0.37	0.32	5.49	6.50	6.18
2	0.36	0.53	0.82	6.30	7.08	12.10
2	0.28	0.21	1.11	5.44	6.61	8.71
2	0.53	0.78	0.33	7.68	11.40	11.03
2	0.48	0.50	0.41	8.69	9.59	12.23
2	0.25	0.32	0.23	6.12	7.52	11.01
2	0.27	0.37	0.59	6.88	7.91	9.87
2	0.57	0.41	2.01	7.28	8.30	15.18
2	0.32	0.30	0.58	6.09	6.72	8.35
2	0.41	0.43	1.05	6.83	7.16	11.52
2	0.38	0.35	0.91	6.57	8.14	10.54
2	4.23	0.57	1.04	12.98	12.03	15.13
2	1.09	1.01	1.04	10.33	14.57	14.17

Chapter 8 (Study 3): Segment of a “Datadump” file* for identifying keystroke peaks from which the speed and force data were computed (p. 304-306)

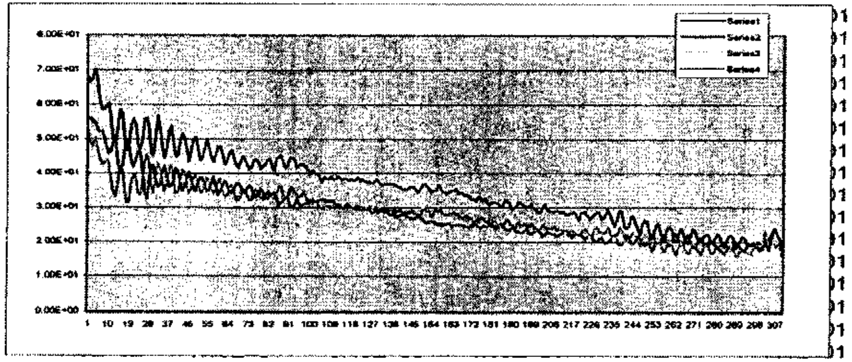
Raw Channel 1	Raw Channel 2	Raw Channel 3	Raw Channel 4	Raw Sum	3pt Moving Average + Scaled Channel 1	3pt Moving Average + Scaled Channel 2	3pt Moving Average + Scaled Channel 3	3pt Moving Average + Scaled Channel 4	3pt Moving Average	Peak Values Channel 1	Peak Values Channel 2	Peak Values Channel 3	Peak Values Channel 4	Peak Values Summed
0	-0.011	0.004	0.026	0.02	0.023	0	0.079	0.426	0.312	0.601	10.171	5.987	0.698	24.456
0.001	-0.008	0.002	0.002	-0.002	0.134	0	0.17	0.164	0.105	4.233	5.103	1.201	6.042	10.647
-0.001	-0.006	0.003	0.01	0.004	0.338	0	0.309	0.373	0.691	3.014	3.316	3.817	1.144	9.778
0.009	-0.019	0.011	0.005	0.006	0.454	0	0.383	0.44	0.921	3.279	1.749	1.161	3.778	11.169
0.021	-0.015	0.017	0.022	0.045	0.585	0	0.471	0.544	1.227	1.348	4.647	3.567	0.995	10.97
0.02	-0.013	0.015	0.018	0.041	0.601	0	0.472	0.523	1.302	2.555	4.001	3.301	3.637	9.274
0.026	-0.015	0.021	0.022	0.054	0.551	0	0.451	0.5	1.229	2.795	3.554	0.949	3.474	4.254
0.023	-0.006	0.017	0.02	0.054	0.474	0	0.383	0.443	1.107	1.308	7.702	1.085	1.059	10.572
0.012	-0.011	0.012	0.015	0.029	0.391	0	0.301	0.358	0.8	0.899	2.767	3.026	1.078	7.568
0.018	-0.006	0.014	0.015	0.041	0.363	0	0.24	0.319	0.685	1.386	0.961	1.422	2.907	19.032
0.014	-0.014	0.007	0.01	0.018	0.26	0	0.114	0.221	0.3	3.048	5.166	5.201	1.57	8.177
0.008	-0.011	0.002	0.011	0.009	0.159	0	0.029	0.165	0.14	1.356	3.678	0.719	5.002	3.201
0.007	-0.009	-0.001	-0.004	-0.008	0.109	0	0	0.04	0	2.49	2.361	1.436	0.713	10.075
0.003	-0.01	-0.004	0.003	-0.009	0.041	0	0	0.04	0	0.551	3.804	3.987	1.579	11.553
0	-0.006	-0.006	-0.009	-0.021	0.042	0	0	0	0	1.871	3.642	0.72	3.982	9.897
-0.002	-0.007	-0.01	-0.001	-0.02	0.042	0	0	0.04	0	3.207	4.527	3.158	0.794	8.55
0.003	-0.01	-0.003	-0.011	-0.02	0.043	0	0	0.04	0	5.547	9.374	0.802	3.097	12.043

Peak Indexes	Peak Indexes	Peak Indexes	Peak Indexes	Peak Indexes		Peak at this index? (Yes/No)	Peak at this index? (Yes/No)	Peak at this index? (Yes/No)	Peak at this index? (Yes/No)	Peak location
Channel 1	Channel 2	Channel 3	Channel 4	Sum	List of all indexes	Ch 1	Ch 2	Ch 3	Ch 4	
5	60	69	40	62	0	0	0	0	0	0
63	112	81	69	95	1	0	0	0	0	0
95	139	95	82	114	2	0	0	0	0	0
114	152	112	95	136	3	0	0	0	0	0
136	170	136	114	152	4	0	0	0	0	0
152	237	152	136	170	5	1	0	0	0	0
170	250	168	152	186	6	0	0	0	0	0
186	260	186	170	237	7	0	0	0	0	0
237	273	237	186	250	8	0	0	0	0	0
250	286	250	237	260	9	0	0	0	0	0
273	309	260	250	273	10	0	0	0	0	0
288	341	287	260	287	11	0	0	0	0	0
309	362	309	288	309	12	0	0	0	0	0
343	386	342	309	342	13	0	0	0	0	0
360	412	355	342	362	14	0	0	0	0	0
387	434	360	355	387	15	0	0	0	0	0
414	457	387	361	413	16	0	0	0	0	0
431	470	414	388	432	17	0	0	0	0	0

***Each file contains 76800 rows of data as the sampling rate was 1920Hz and each data capture =40sec**

Chapter 2 (Method): Calibration trial performed with known weight for constructing the regression model for calculating the Keystroke Peak Force and Speed data (2.5.2: Calibration procedures, p. 77)
(the 4 columns describe the 4 load cells under the keyboard, LR=lower right, LL=lower left, UL=upper left, UR=upper right)

Frames	LR	LL	UL	UR	Sum
1.05E+01	1.27E+01	8.92E+00	1.19E+01	1.25E+01	4.60E+01
3.45E+01	1.15E+01	9.54E+00	1.12E+01	1.25E+01	4.48E+01
5.85E+01	9.83E+00	1.05E+01	1.03E+01	1.05E+01	4.11E+01



4.67E+02	1.01E+01	1.04E+01	1.02E+01	1.04E+01	4.11E+01
4.91E+02	1.12E+01	9.67E+00	1.13E+01	1.17E+01	4.38E+01
5.15E+02	1.34E+01	9.17E+00	1.24E+01	1.23E+01	4.72E+01
5.39E+02	1.31E+01	8.79E+00	1.18E+01	1.18E+01	4.55E+01
5.63E+02	1.09E+01	1.07E+01	1.10E+01	1.16E+01	4.43E+01
5.87E+02	1.10E+01	9.75E+00	1.07E+01	1.08E+01	4.22E+01
6.11E+02	1.18E+01	1.08E+01	1.09E+01	1.13E+01	4.48E+01
6.35E+02	1.23E+01	9.21E+00	1.19E+01	1.22E+01	4.55E+01

	LR	LL	UL	UR	Sum
SLOPE	-4.78	-3.57	-3.25	-3.20	-14.80
INTERCEPT	54.01	42.20	40.76	40.61	177.59

Sample Trial of Placing a known weight on the keys to compute regress