A STUDY OF MUSCULOSKELETAL LOADING IN USING A TOUCHSCREEN SMARTPHONE AMONG YOUNG PEOPLE WITH AND WITHOUT CHRONIC NECK-SHOULDER PAIN

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A Study of Musculoskeletal Loading in Using a Touchscreen Smartphone among Young People with and without Chronic Neck-shoulder Pain

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CERTIFICATION OF ORIGINALITY

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ABSTRACT

An upward increase in the use of touchscreen smartphones in recent years has given rise to a growing concern about its impact on the musculoskeletal health. This study was to investigate the patterns of muscle recruitment and spinal kinematics between young people with and without chronic neck-shoulder pain when they performed smartphone texting and computer typing.

Twenty healthy young adults (mean age=24.6±3.1) and 20 with chronic neck-shoulder pain (mean age=23.2±3.1) were recruited and allocated to Case Group and Control Group, respectively. All subjects were required to perform three tasks, namely: 1) texting on a touchscreen smartphone with both hands ("bilateral texting"), 2) texting with one hand ("unilateral texting"); 3) typing on a desktop computer ("computer typing"). Each task was performed for 10 minutes and the order of tasks was randomized and balanced. During these tasks, surface electromyography was recorded bilaterally from three proximal postural muscles (cervical erector spinae "CES", upper trapezius "UT" and lower trapezius "LT") as well as bilaterally from four distal hand/thumb muscles (extensor carpi radialis "ECR", extensor digitorum "ED", flexor digitorum superficialis "FDS" and abductor pollicis brevis "APB"). The static (10th %ile), median (50th %ile) and peak (90th %ile) activity were computed for each muscle and compared among the three tasks. Meanwhile, median angular displacements and ranges of joint angles were examined in the cervical, thoracic and lumbar regions from three anatomical planes, namely sagittal (flexion/extension), frontal (left/right side flexion) and transverse (left/right rotation) planes. Subjects were also asked to rate their discomfort intensities using numeric rating scale (0-10) and overall fatigue using rate of perceived exertion (RPE) (6-20) after each task. In addition, correlations among muscle activity, kinematics and discomfort scores were examined.

Compared with Control Group, Case Group showed consistently higher activity in bilateral CES and UT while performing the three tasks and this pattern was most prominent for right-sided UT. Case Group also spent more time with a slightly higher angle in thoracic flexion than Control Group during bilateral texting and computer typing. Furthermore, Case Group displayed increased cervical side flexion to the right during smartphone texting and significantly greater ranges in the cervical rotation during performing the three tasks compared with Control Group. Regarding the subjective discomfort, the change of summed discomfort scores and RPE scores were significantly higher in Case Group compared with Control Group after the all tasks. There were no clear patterns of association among muscle activity, kinematics and subjective discomfort.

Generally, unilateral texting was associated with higher activity in right-sided distal muscles, a greater right side rotation angle, a smaller neck flexion angle and greater ranges in cervical rotation and side flexion compared with bilateral texting. Compared with computer typing, smartphone texting was associated with higher activity in CES and APB, lower activity in UT, LT, ECR and ED, greater joint angles in the cervical and thoracic flexion and smaller ranges of movements in cervical flexion/extension and rotation.

In conclusion, this study demonstrated that young adults with chronic neck-shoulder pain consistently displayed altered motor control patterns while performing smartphone texting and computer typing. Smartphone texting was associated with increased cervical and thoracic flexion angles and a relatively static cervical posture.

Compared with texting on a smartphone with one hand, texting with both hands seemed more preferable if users could maintain an upright and neutral spine.

PUBLICATIONS ARISING FROM THE THESIS

Journal article:

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LIST OF ABBREVIATIONS

A/D	Analogue to digital
APB	Abductor pollicis brevis
APDF	Amplitude probability distribution function
B-TEXT	Bilateral texting
CES	Cervical erector spinae
Cx	Cervical spine
3-D	Three-dimensional
DASH	Disability of Arm Shoulder and Hand
ECR	Extensor carpi radialis
ECG	Electrocardiography
ED	Extensor digitorum
EMG	Electromyography
FDS	Flexor digitorum superficialis
IMU	Inertial Measurement Unit
L	Left
LT	Lower trapezius
Lx	Lumbar spine
RPE	Rate of perceived exertion
T	Independent t-test
NDI	Neck Disability Index
NRS	Numerical rating scale
MA	Median angle
MVC	Maximum voluntary contraction
MVE	Maximum voluntary electrical activity

p	*p*-value
RMAVOVA	Repeated measures analysis of variance
R	Right
RVC	Reference voluntary contraction
RVE	Reference voluntary electrical activity
SENIAM	Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles
Tx	Thoracic spine
TYPE	Computer typing
U-TEXT	Unilateral texting
UT	Upper trapezius
VAS	Visual analogue pain scale
VDS	Verbal descriptor scales
wpm	Words per minute
χ^2	Chi-square
Z	Mann–Whitney U test
%ile	Percentile
%EMG_max	Percentage of maximum electromyography activity

CHAPTER 1
INTRODUCTION

This chapter presents briefly the need for conducting this study by considering intensive use of touchscreen smartphones and concerns on the effect of touchscreen smartphone use on musculoskeletal health. Organizations of this thesis are also outlined.

From the advent of personal computers in 1960 to touchscreen smartphones nowadays, electronic devices have undergone rapid evolution. There have been increasing access and exposure to different types of electronic devices such as computers, tablets and touchscreen smartphones in recent years (Kobus, Rietveld, & van Ommeren, 2013; Mezei, Benyi, & Muller, 2007; Wesolowski, Eagle, Noor, Snow, & Buckee, 2012). Among different kinds of electronic devices, touchscreen smartphones have been dominating the market in the recent five to seven years. The sales of smartphones worldwide reached around 1.3 billion in 2014 and are predicted to grow twofold by 2021 (Ericsson mobility report, 2015). The advent of touchscreen technology, the popularity of "app" and excellent internet access make the use of touchscreen smartphones an integral part of modern lifestyle. It seems that young people are the dominant users of touchscreen smartphones. A survey on smartphone adoption among university students in Hong Kong showed that 90% of students were using smartphones (Hong Kong Computer Society, 2013). Among these students, nearly half reported spending over three hours on smartphones per day and they frequently use them for tasks such as texting messages, web browsing and social networking, which involve repeatedly tapping the screen.

The use of electronic devices especially touchscreen smartphones are making a tremendous impact on young people's lifestyle as well as their health (Carson, Pickett, & Janssen, 2011). An accumulative usage of electronic devices at work, at school, at home, on the train and in leisure time has led to a growing trend towards a sedentary lifestyle which is a known risk factor for chronic diseases such as hypertension and diabetes (Carson et al., 2011; Rhodes, Mark, & Temmel, 2012). Musculoskeletal complaints are some of the most common adverse health effects of a sedentary lifestyle (Brandt et al., 2004). A long duration of computer use has been well known to be associated with musculoskeletal disorders in the neck and upper limbs (Korpinen & Pääkkönen, 2011; Waersted, Hanvold, & Veiersted, 2010). Similar to computer use, frequent and prolonged use of touchscreen smartphones may also result in high risks of musculoskeletal complaints (Hakala, Rimpela, Saarni, & Salminen, 2006; G. Y. Kim, Ahn, Jeon, & Lee, 2012). Pain in the neck and shoulder regions among smartphone users have received public attention since many people maintain the neck flexed and the arm flexed in midair while using smartphones (Gold et al., 2012). The common phenomenon of pain in the neck among people that resulted from an intensive use of smartphones or excessive texting has been dubbed "text neck" by chiropractors and some popular press. There have also been a growth of case reports on disorders in the forearm regions such as de Quervain's syndrome (Ming, Pietikainen, & Hänninen, 2006), osteoarthritis of the thumb (Storr, de Vere Beavis, & Stringer, 2007) and nintendinitis (Fernandez-Guerrero, 2014) associated with excessive message texting on mobile phones. However, evidence directly linking overuse of smartphones or excessive texting to neck-shoulder pain is still lacking, partly due to limited biomechanical data on musculoskeletal loading when using smartphones. Given a significant growth of intensive use of electronic devices in modern society, there is a great need to understand the biomechanical effect of smartphone use and computer use on the musculoskeletal system of young people.

The goal of this thesis is to examine the musculoskeletal loading when performing texting on a smartphone and typing on a computer with surface electromyography (EMG) and an inertial measurement unit (IMU) system. Its aims are to explore whether the muscle activity and kinematics varied between young people with and without chronic neck-shoulder pain, when they performed texting/typing tasks on electronic devices. This study contributes to better understanding of the motor control patterns in using touchscreen smartphones. Such information paves the way for developing ergonomic guidelines for the use of touchscreen smartphones.

The chapters of this thesis are organized as follows:

Chapter 1 is the current chapter, which is an introduction to the research topic.

Chapter 2 provides a critical review of earlier research. Research questions based on the knowledge gap and hypotheses established are also presented.

Chapter 3 discusses the methodology employed for data collections. Issues concerning biomechanical measurements, sampling methods and rationales for the choices of statistical methods are covered.

Chapter 4 presents results focused on the surface EMG activity of muscles on the right side and summed subjective discomfort scores.

Chapter 5 delineates the results attained from surface EMG recording for muscles on the left side, discomfort scores in specific body regions, kinematics and correlations between these variables.

Chapter 6 is an overall discussion, including possible mechanisms of chronic neck-shoulder pain and ergonomic implications for the healthy use of touchscreen smartphones. Limitations of the present study and future research directions are also discussed in this chapter.

Chapter 7 concludes the study by considering the potential contributions of the present study to the management of chronic neck-shoulder pain associated with the use of electronic devices.

CHAPTER 2
LITERATURE REVIEW

This chapter reviews studies investigating chronic neck-shoulder pain associated with the use of electronic devices. There are four major sections. Firstly, the terminology of "neck-shoulder pain" is explained. This is followed by a discussion on the impact of chronic neck-shoulder pain. Then the past research work on the risk factors of chronic neck-shoulder pain associated with computer use and conceptual models about the pathomechanisms of this order such as the altered motor control model is reviewed. Recent research studies on handheld devices are also included. These works laid the basis for the present thesis which would examine the patterns of muscle recruitment and kinematics in people with chronic neck-shoulder pain when using electronic devices. Finally, the objectives of this project and the research questions formulated are presented.

2.1. Definitions of "neck-shoulder pain"

Definitions of neck pain in the literature are varied, in particular, in terms of the specific painful anatomical region (Guzman et al., 2009; Hoy, Protani, De, & Buchbinder, 2010). For instance, some studies specified neck pain as pain in the neck region that abounds below the superior nuchal line, above the shoulder blades and laterally by the lateral margins of the neck (Guzman et al., 2009; Hill, Lewis, Papageorgiou, Dziedzic, & Croft, 2004; Paksaichol, Janwantanakul, Purepong, Pensri, & van der Beek, 2012). Others incorporated pain in regions of the shoulder blades and/or the upper back in addition to the neck region when describing neck pain cases (Ghaffari, Alipour, Farshad, Yensen, & Vingard, 2006; Holtermann, Hansen, Burr, & Søgaard, 2010; Smedley et al., 2003; Wahlström, Hagberg, Toomingas, & Wigaeus Tornqvist, 2004). As a result, different terminologies such as “neck pain”, “neck/shoulder pain” and “neck-shoulder pain” have been used.

Subjects with chronic neck-shoulder pain in this study refer to those who had nonspecific or mechanical pain in an absence of histories of traumatic injuries and have a gradual insidious onset. The term of “neck-shoulder pain” is used since it has been widely used to describe pain involves the neck and/or shoulder region which is the focus of the current research work. Anatomical areas of the neck and shoulder in the present study were defined according to the demarcation of body regions in the Standardized Nordic Questionnaire (Kuorinka et al., 1987). Other terms including “neck pain”, “neck/shoulder pain” and “neck or shoulder pain” are also used when referring to those research studies that adopted these terms.

2.2. Chronic neck-shoulder pain and its impact

Musculoskeletal disorders are common public health problems in general populations, especially among the working class. Among many types of musculoskeletal disorders, chronic neck-shoulder pain is one of the most prevalent complaints reported by people throughout the lifespan (Hoftun, Romundstad, Zwart, & Rygg, 2011; Korpinen, Pääkkönen, & Gobba, 2013). The prevalence of chronic neck-shoulder pain is increasing with age (Klussmann, Gebhardt, Liebers, & Rieger, 2008), but it is also commonly encountered in young adulthood. The weekly prevalence of neck-shoulder pain is reported to range from 15% to 30% (Siivola et al., 2004; Vikat et al., 2000) while the one-year prevalence varies from 48% to 78% among young populations (Hayes, Smith, & Cockrell, 2009; Obembe, Johnson, Tanimowo, Onigbinde, & Emechete, 2013). A prospective study among 684 undergraduate students demonstrated that 64% of students developed neck pain one year later, of whom 33% showed persistent neck pain (Kanchanomai, Janwantanakul, Pensri, & Jiamjarasrangsi, 2011). People who use electronic devices such as computers frequently are identified to have the highest incidence of neck/shoulder disorders, with an annual incidence ranged from 34% to 57% in different countries (Hogg-Johnson et al., 2008; Hoy et al., 2010). Additionally, the prevalence of chronic neck-shoulder pain rises over time. The prevalence of chronic neck pain which was 23.6% in Norway during the period from 1995 to 1997 was found to have increased significantly to 25.1% after a decade (Hagen, Linde, Heuch, Stovner, & Zwart, 2011). The most prominent growth in the prevalence of chronic musculoskeletal complaints was demonstrated in the 20- to 34-year-old population (Hagen et al., 2011). The growing use of computers and handheld devices such as mobile phones in the population aged from 20 to 34 years old has been proposed to be "the most probable explanation" for the rise in the prevalence of musculoskeletal complaints during the past decade (Hagen et al., 2011).

Chronic neck-shoulder pain is associated with activity limitation, functional disability and poor future physical quality of life (P. Côté et al., 2009; Nolet et al., 2015; Vos et al., 2013). Neck-shoulder pain has ranked the fourth greatest conditions resulting in worldwide years lived with disability among 291 diseases (Hoy et al., 2014). Furthermore, it is one of the most common disorders contributing to short-term or long-term sick leave, early retirement and high financial cost (Kuijpers, van Tulder, van der Heijden, Bouter, & van der Windt, 2006; Nyman, Grooten, Wiktorin, Liwing, & Norrman, 2007; van den Heuvel, Swenne G, IJmker, Blatter, & de Korte, 2007). Forty-one percentages of sickness absence were noted resulted from neck-shoulder pain among 2329 subjects in a five-year prospective study in Sweden (Nyman et al., 2007). The total cost of neck pain was around 0.1% of the Gross Domestic Product in 1996 in Netherlands (Borghouts, Koes, Vondeling,

& Bouter, 1999). In recent years, the mean annual cost of shoulder pain including costs for healthcare and sick leave have reached up to €4139 per patient in Sweden (Virta, Joranger, Brox, & Eriksson, 2012). Considering the substantial burden of chronic neck-shoulder pain on society and the speculation that the increased prevalence of neck-shoulder pain in the past decade is related to the escalated exposure to electronic devices, it is essential to investigate the biomechanical demands associated with the use of touchscreen smartphones among young people. This investigation provides a better understanding of the association between smartphone use and chronic neck-shoulder pain and implications for the prevention and management strategies of this disorder.

2.3. Chronic neck-shoulder pain related to computer use

With the upsurge of computer use in the workplace since the 1980s, there has been a corresponding growth in incidence rates of chronic musculoskeletal complaints such as neck-shoulder pain. A vast majority of studies have suggested that continuous computer use is closely related to neck-shoulder symptoms such as tension neck syndrome, shoulder tendonitis and trapezius myalgia (Gerr, Marcus, & Monteilh, 2004; B. Larsson, Søgaard, & Rosendal, 2007; Ming, Närhi, & Siivola, 2004; Wahlström, 2005). The association between chronic neck-shoulder complaints and computer use in workplaces has been extensively investigated. Overall, previous research on the association between chronic neck-shoulder complaints and computer work could be grouped into two categories: (i) epidemiological and intervention studies that focus on the association between risk factors and neck-shoulder disorders; (ii) experimental studies that try to understand possible mechanisms or the pathophysiology of computer-related neck-shoulder disorders (J. H. Andersen, Fallentin, Thomsen, & Mikkelsen, 2011).

2.3.1. Common risk factors for chronic neck-shoulder pain

The etiology of chronic neck-shoulder pain is multi-factorial. Generally, long durations of computer use, static postures, high mental demands and poor workstation configurations are believed to be common exposures for developing chronic neck-shoulder pain in computer users (Ariëns, van Mechelen, Bongers, Bouter, & Van Der Wal, 2000; Klussmann et al., 2008; B. Larsson et al., 2007; Silva, Punt, Sharples, Vilas-Boas, & Johnson, 2009).

Daily use of computers for more than two or three hours is reported to be thresholds for neck-shoulder pain and the risk was becoming higher when there was an increasing duration of computer use according to some cross-sectional studies (Blatter & Bongers, 2002; Hakala et al., 2006; Hayes et al., 2009; Klussmann et al., 2008). The association is also supported by some randomized controlled trials suggesting that a regular rest break such as 20 minutes intervals during computer work is beneficial to the recovery of musculoskeletal complaints (Galinsky et al., 2007; McLean, Tingley, Scott, & Rickards, 2001; van den Heuvel, Swenne G, de Looze, Hildebrandt, & Thé, 2003). However, a systematic review for longitudinal studies noted that the causal relationship between long durations of computer use and chronic neck-shoulder pain seemed not supported by strong evidence (IJmker et al., 2007), and same conclusions were also documented by some recent prospective epidemiological studies (IJmker et al., 2011; Richter et al., 2012). More research is needed to determine the association between computer use and chronic neck-shoulder pain.

Static and awkward postures during computer work have often been cited as important biomechanical factors leading to a high risk of developing musculoskeletal disorders. Awkward postures mean the position of the body such as limbs, joints and the spine veering significantly off the neutral position while performing job tasks or activities (Zabel & McGrew, 1997). Some laboratory studies showed that patients with chronic neck or shoulder pain adopted a more flexed neck or upper thorax posture when compared with pain-free individuals in sitting (K. T. Lau, Cheung, Chan, Lo, & Chiu, 2010), standing (Silva et al., 2009) and performing typing tasks (Szeto, Straker, & O'Sullivan, 2005b). Similar postural behaviour was also observed among people in a workplace (Szeto, Straker, & Raine, 2002). Prolonged non-neutral spinal postures very likely prompt an unfavorable length-tension relationship of related muscles. Consequently, this could make the muscles more vulnerable to fatigue and finally may lead to musculoskeletal disorders including chronic neck-shoulder pain. However, only low to moderate but not strong correlations were found between increased cervical/thoracic flexion angles and neck-shoulder discomfort/disability (K. T. Lau et al., 2010; Szeto et al., 2005b; Yip, Chiu, & Poon, 2008). Evidence on the association of static and awkward postures while using computers with musculoskeletal disorders is also mixed. Some studies showed that non-neutral postures such as a flexed neck and a twisted trunk in using computers were predictors for neck and shoulder pain (Brink, Louw, Grimmer, & Jordaan, 2015; Eltayeb, Staal, Hassan, & De Bie, 2009), but others did not establish such correlations (Paksaichol et al., 2012; Straker, O'Sullivan, Smith, & Perry, 2009). Additionally, interventions that aimed at correcting the posture during computer work neither achieve statistically significant reduction of neck and shoulder muscle activation (McLean, 2005) nor showed any effect on reducing the incidence of neck-shoulder pain (Gerr et al., 2005). These results suggest that the association between spinal postures and neck-shoulder pain seems not so straightforward, as there can be other confounding variables that could influence these musculoskeletal disorders.

Although the physical action of typing on a computer keyboard may be a light task, high workloads can still be found among office workers due to the fast typing speed and long hours of computer work. Mental demands of computer work and meeting deadlines have been reported as occupational risk factors for office workers (Cagnie, Danneels, Van Tiggelen, De Loose, & Cambier, 2007; Eltayeb et al., 2009; Tornqvist, Hagberg, Hagman, Risberg, & Toomingas, 2009). A cohort study reported a significant correlation between neck-shoulder symptoms and time pressure among office workers, with odds ratios ranging from 1.31 to 1.53 (Eltayeb, Staal, Khamis, & de Bie, 2011). Some studies identified higher amplitudes of muscle activity and fewer EMG gaps in upper trapezius during stressful computer-based tasks compared with tasks of low mental demands or during a rest period (Mclean & Urquhart, 2002; Schleifer et al., 2008; Wang, Szeto, & Chan, 2011). Therefore, the psychosocial stress during computer work is another important factor that contributes to the musculoskeletal health of workers.

In addition to high mental demands, the poor workstation configuration is also closely related to the development of musculoskeletal disorders (Jacobs et al., 2011; Kanchanomai et al., 2011; Rempel et al., 2006). Examples are studies measuring the effect of forearm/wrist support on muscle activities and postures using surface EMG and motion analysis systems (Cook, Burgess-Limerick, & Papalia, 2004; Delisle, Larivière, Plamondon, & Imbeau, 2006; Nag, Pal, Nag, & Vyas, 2009). These studies illustrated that, compared with performing computer tasks with forearm or wrist support, typing without support is associated with significantly higher activity in the neck and shoulder muscles as well as with non-neutral shoulder postures. This indicates that a lack of arm support while performing a texting task on smartphones would also likely increase the risk of neck-shoulder pain.

2.3.2. Conceptual models of chronic neck-shoulder pain and computer work

In the past decade, some conceptual models were proposed in an attempt to understand the association between musculoskeletal disorders including chronic neck-shoulder pain and computer work. For instance, a model put forward by Wahlström (2005) suggested that there are direct paths from computer work to physical demands and to work organization, which in turn affect musculoskeletal outcomes (Figure 2.1). Physical demands during computer work such as the force of keystrokes on a keyboard could induce increasing physical loads which can be manifested as increased perceived muscular tension. This is conceptualized as one mechanism contributing to musculoskeletal outcomes. Individual factors such as gender and work techniques were proposed to modify the relationship between physical demands and physical loads. There is also a pathway from work organization to metal stress, which could be modified by individual factors as well, and this may finally lead to musculoskeletal symptoms. Both work organization and mental stress could modify the pathway from the physical demands imposed by computer work to musculoskeletal outcomes.

The model proposed by Wahlström (2005), however, is not complete. It is not clear whether computer work is truly associated with increased muscular tension since only subjective perception of muscular tension is shown in that model. This issue was addressed by another proposed model – the altered motor control model, which is based on the objective measurements of musculoskeletal efforts during computer work (Szeto et al., 2005b). According to the model, different subgroups of people with neck pain may present different responses to physical and non-physical risk factors related to computer work in terms of motor control strategies (Figure 2.2). Compared with healthy office workers, those with more severe neck symptoms showed heightened muscle activity of superficial postural muscles such as upper trapezius and cervical extensors (Johnston, Jull, Souvlis, & Jimmieson, 2008; Szeto et al., 2005a). In addition, computer workers with neck pain have also displayed altered kinematics, which includes increased forward head and neck flexion postures (Szeto et al., 2005b; Yip et al., 2008) and reduced cervical rotation ranges (Johnston, Jull, Souvlis & Jimmieson, 2008) while performing computer tasks. This model suggests that altered patterns of motor control in computer workers may be one of the potential mechanisms for the occurrence of chronic neck-shoulder pain. However, the causal relationship between computer work and chronic neck-shoulder pain is still under debate and the possible mechanisms for chronic neck-shoulder pain related to computer use are still not completely understood. This puzzling issue is further complicated with the introduction of new electronic devices, including notebook, cell phones, e-reader, tablets and touchscreen smartphones in particular as they have introduced different factors such as usage environment as well as various screen sizes, weight and inputting methods. This issue has formed the basis for developing the current research project.

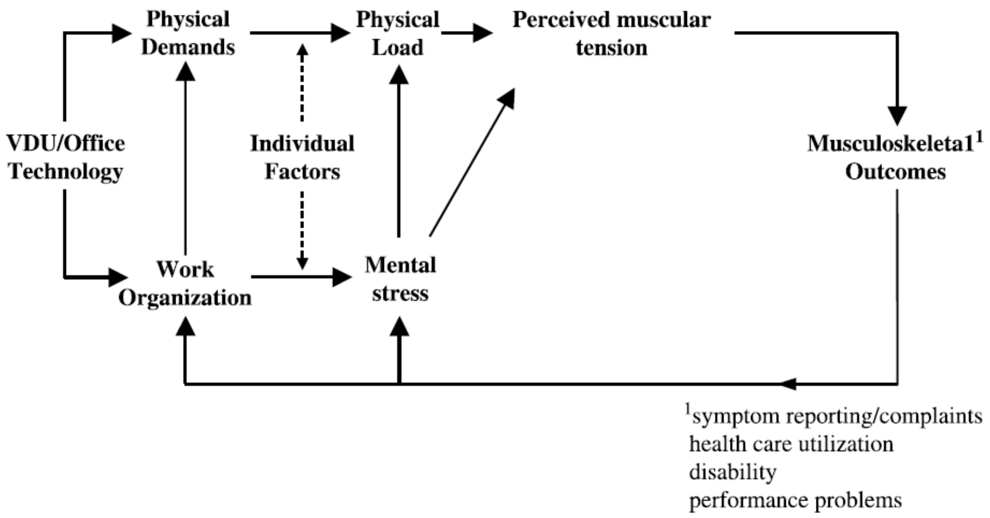

Figure 2.1.A conceptual model of computer work and musculoskeletal disorders (adapted from Figure 1, Wahlström (2005)).

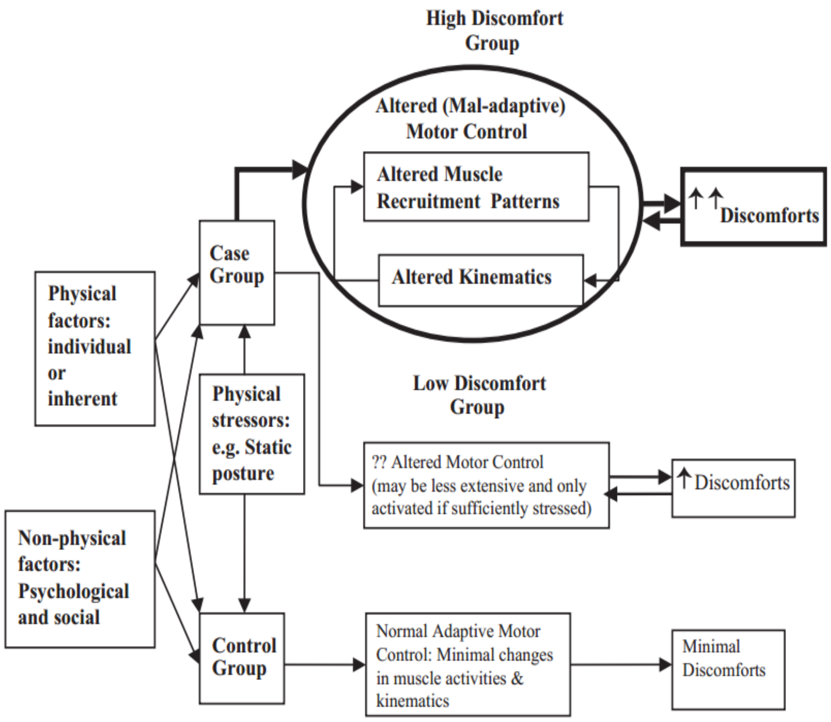

Figure 2.2. The altered motor control model for chronic neck pain (adapted from Figure 3, Szeto et al. 2005b).

2.4. Research on neck-shoulder pain related to handheld devices

Similar to interacting with desktop or laptop computers, the use of electronic handheld devices such as tablet computers and touchscreen smartphones also involves the problems of static awkward postures and poor workstation configurations. Holding these devices in midair against gravity may increase the risk of developing chronic neck-shoulder pain. While there have been extensive amounts of research investigating the relationship of chronic neck-shoulder pain with computer use, investigations on the use of handheld devices, especially touchscreen smartphones, has just emerged in recent years. Some epidemiological studies have reported a high prevalence of neck and shoulder pain among worldwide users of handheld devices. For example, a survey among 140 handheld device users in a Canadian university showed that 68% of users had neck pain, 46% and 52% had pain in left and right shoulders (Berolo, Wells, & Amick, 2011). Another survey among high school students from China found that 40.9% out of 2575 smartphone users and 44.1% out of 1067 tablet computer users reported neck-shoulder pain (Shan et al., 2013). Similarly, 44.4% out of 300 Korean university students who were also smartphone users experienced neck pain and 45.2% suffered from shoulder pain (H .J. D. Kim & J. S. Kim, 2015). Much higher prevalence rates of musculoskeletal pain were presented in users of touchscreen tablets in the United States than in other countries, which were 84.6% in the neck and 65.4% in the upper back/shoulder (Blair, Gama, & Toberman, 2015). The evidence on connections between the use of handheld devices and neck-shoulder pain, however, is mainly based on cross-sectional questionnaire surveys which neither involved assessments of muscular effort nor any other biomechanical factors to confirm the musculoskeletal loading in using handheld devices.

2.4.1. Biomechanical research on the use of handheld devices

There has been only limited research published investigating the biomechanical effect of the handheld device use on the musculoskeletal system. Examples are studies conducted by Gold et al. (2012) and Park et al. (2015) in which subjects' postures when using handheld devices were examined by observation. Gold et al. (2012) reported over 90% out of 879 university students were found to adopt a flexed neck posture with protracted shoulders, and a non-neutral wrist posture on the texting side when they texted on their handheld devices. Park et al. (2015) observed that those addicted to smartphones showed significantly larger head flexion angles compared with individuals who used smartphones regularly or infrequently. However, no quantitative data on the specific angular displacements of the head or neck flexion posture was provided in Gold et al. (2010) and Park et al. (2015). Quantitative evaluations of head and neck flexion are important since they help us to understand the severity of neck flexion among handheld device users and the critical degree of head and neck flexion for increasing the compressive loading on the cervical spine.

A few recent studies published in 2015 assessed cervical postures using advanced equipment such as the 3-D motion capture system, video recording or motion sensors (Kietrys, Gerg, Dropkin, & Gold, 2015; S. Lee, Kang, & Shin, 2015; Ning, Huang, Hu, & Nimbarte, 2015). In these studies, people exhibited head or neck flexion with the angle ranging from 21.5° to 44.7° while performing tasks on smartphones or tablets. There are many factors contributing to the variations in the angle of the head or neck flexion, such as whether the person is standing or sitting, presence or absence of arm support, the location that the devices were used and tasks performed. The neck flexion angle was noted to be largest while texting compared with other tasks such as web browsing, reading, gaming and video watching (S. Lee et al., 2015; Ning et al., 2015), indicating that texting on handheld devices might be a main risk factor contributing to the occurrence of neck pain among intensive smartphone users.

In addition to quantifying head and neck postures, the level of muscle effort when interacting with handheld devices were examined in some studies using surface EMG. Ning et al. (2015) found that the level of activity in the cervical extensor was slightly higher in a 90-second texting task compared with reading on smartphones. Some studies (Kietrys et al., 2015; M. Lee et al., 2015; Ko, Hwang & Liang, 2015) compared the activity of muscles in the shoulder and upper limb regions between two-handed texting and one-handed texting, which are the most frequent techniques for texting on mobile phones (Gold et al., 2012). M. Lee et al. (2015) and Ko et al. (2015) discovered significantly greater activity levels in upper trapezius, forearm extensor and flexor muscles as well as thumb muscles during two- to three-minutes of one-handed texting compared with two-handed texting. However, Kietrys et al. (2015) did not find any differences in the activity levels of upper trapezius and flexor digitorum superficialis between 10-seconds of one-handed texting and two-handed texting. The disparity in the results is probably due to the short duration of texting in Kietrys et al (2015), which may not be sufficient to differentiate the muscle activity levels between two texting techniques.

Some limitations are identified in previous studies on kinematics and muscle activity in using handheld devices. Durations of task performed were not long enough to reflect the reality that people spent an average time of 4.65 hours daily on handheld devices (Berolo et al., 2011). Furthermore, past biomechanical studies were mainly conducted among healthy asymptomatic persons. Studies involving biomechanical loading of the use of handheld devices among symptomatic subjects are very limited. There is a need of a more comprehensive investigation, for instance, studying the effort of neck, shoulder and upper limb muscles as well as the spinal kinematics among people with chronic neck-shoulder pain when using handheld devices. This can help us to understand how the use of handheld devices would affect the musculoskeletal control mechanisms that contribute to chronic neck-shoulder pain.

2.4.2. Issues in the use of handheld devices

The current market of handheld devices is dominated by touchscreen smartphones such as Android smartphones and iPhones. In using touchscreen smartphones, even though the touch action may be light, the speed and high repetition rate of the finger actions may still lead to high muscle loads. Diverse designs in touchscreen smartphones with different weights, screen sizes and key layouts may affect the musculoskeletal system differently. Kietrys et al. (2015) reported that EMG amplitudes of upper limb muscles and the cervical flexion angle increased as the screen size of the phone used became bigger. Therefore, a standardized touchscreen smartphone was used in the present study in order to eliminate confounding factors such as screen sizes and hand actions involved resulting in variations in muscle activity between different people. Text entry tasks were examined because messaging is one of the most frequent forms of smartphone activity (Berolo, Steenstra, Amick, & Wells, 2015). Both two-handed texting and one-handed texting are commonly used methods for text entry. Gold et al. (2012) observed that 46.1% out of 859 university students texted on a mobile phone using both thumbs while 36.2% texted with one thumb. By studying these two methods of texting, evidence based ergonomic recommendations could be made for text entry on electronic devices, particularly on touchscreen smartphones.

2.5. Summary

Many people including young adults suffer from chronic neck-shoulder pain and this disorder is associated with activity limitation, functional disability, work absenteeism, poor future physical quality of life and substantial financial cost. The prevalence of neck-shoulder pain among young people is rising over time and this may be due to the rapidly growing popularity of electronic devices such as computers, tablets and smartphones. There have been numerous studies investigating the association between computer work and chronic neck-shoulder pain. But the pathways from performing computer work to chronic neck-shoulder pain are still not completely understood. This is even more elusive with an intensive use of handheld devices and increasing prevalence rates of neck-shoulder pain among young people. Based on the above literature review, a few previous studies offered some preliminary results indicating a linkage between chronic neck-shoulder pain and the use of handheld devices. There is, however, a lack of biomechanical data reported on muscle effort and spinal kinematics in using touchscreen smartphones. In addition, it remains unclear whether the level of muscle loading in young people with neck-shoulder pain varies from asymptomatic individuals when using touchscreen smartphones.

2.6. Research questions and hypotheses

The purpose of this study is to investigate the muscle activity of proximal postural and distal forearm muscles as well as spinal kinematics when symptomatic and asymptomatic young people performing smartphone texting and computer typing. Acute experimental pain in the region of upper trapezius muscles was found to influence the activation patterns of forearm muscles during computer work (Samani, Fernández-Carnero, Arendt-Nielsen, & Madeleine, 2011). Distal forearm muscles were measured in the present study to examine whether the activity of these muscles would be affected in the presence of chronic neck-shoulder pain during performing texting on a smartphone.

The research questions of this thesis are as follows:

(1) How young people with chronic neck-shoulder pain vary from those without in patterns of muscle activation and spinal kinematics when performing texting and typing tasks?

(2) Whether there are any differences regarding the muscle activity and spinal kinematics comparing texting on a touchscreen smartphone with two hands (bilateral texting), and with one hand (unilateral texting), compared with typing on a desktop computer (computer typing)?

(3) What is the correlation between biomechanical variables (muscle activity and kinematics) and subjective discomfort?

The hypotheses are presented as follows:

(1) Compared with those were healthy, subjects with chronic neck-shoulder pain would have higher levels of activity in muscles including proximal postural and distal forearm muscles, and increased postural angles in the cervical, thoracic and lumbar spines in performing the three tasks as mentioned above.

(2) The muscle activity, particularly in subjects with chronic neck-shoulder pain, would be higher during computer typing compared with smartphone texting in general, and unilateral texting was expected to involve higher muscle activity when

compared with bilateral texting. Furthermore, the spinal flexion angle would be increased in bilateral texting or unilateral texting compared with computer typing.

(3) Increased muscle activity would be correlated with changes in kinematic patterns and with increased subjective discomfort.

CHAPTER 3
METHODOLOGY

The present study employed surface EMG to examine muscle activity and an IMU system to study the kinematics while subjects performed three 10-minute sessions of text entry tasks. There were some basic principles and issues about the use of these biomechanical measurement methods that need to be addressed before the study was conducted. This chapter elaborates on the fundamental principles and rationales for the selection and the design of experimental procedures and statistical analysis for this study.

3.1. Study design

A cross-sectional quasi-experimental design was adopted. Young adults with and without chronic neck-shoulder pain were recruited and allocated into Case Group and Control Group. Details of inclusion and exclusion criteria for subjects are described in the next chapter. The Case-Control study design has been commonly adopted in past research studies that compared the effects of performing different computer tasks or manual tasks between those who are healthy and symptomatic. It is difficult to conduct a longitudinal study since it requires much time to identify smartphone users who develop the chronic neck-shoulder pain, whereas a cross-sectional Case-Control study is less time-consuming. In addition, the Case-Control study design is useful for investigating the association between exposures and diseases that have long latency periods (D'Agata, 2005). Hence, Case-Control study design is adopted for the present study. Such study design helps to find out whether there are differences in biomechanical indicators between painful and healthy groups. This in turn could shed some light on mechanisms of chronic neck-shoulder pain. However, the causal relationship cannot be established with such a study design.

Considering the advantages of a laboratory study that the environmental factors can be controlled and the task performed can also be standardized, quasi-experimental study was employed. The postures, the workstation as well as the touchscreen smartphone and the computer used were standardized in the present study. This would minimize the influence of confounding factors that cause variations in muscle activities and spinal kinematics in different individuals, including random movements, effects of back and/or arm support and the effect of smartphone sizes. However, the downside of such a study design is that it would limit the natural tendency of the individuals to move as when they are using smartphones in their daily lives. The standardized experimental procedures are delineated in the next chapter.

3.2. The measurement of surface EMG

Electromyography has been widely used as a method to record muscle activity in the field of biomechanical and ergonomics research. There are two kinds of EMG techniques including surface EMG and needle (or fine-wire) EMG. Surface EMG is often used in clinical and kinesiological studies because it is non-invasive, simple and painless (Chowdhury et al., 2013). Therefore, surface EMG was employed in the present study to measure muscle activity. Commonly bipolar surface electrodes are used and only the signals of superficial muscles can be accurately measured using this method.

3.2.1. Surface EMG recording in the present study

The Noraxon Telemyo Wireless EMG System (Noraxon USA Inc., USA) was used for surface EMG signal recordings during experimental tasks in this study. Signals of fourteen muscles in total were recorded, which were bilateral proximal postural muscles including cervical erector spinae (CES), upper trapezius (UT) and lower trapezius (LT), and bilateral distal muscles consisting of extensor carpi radialis (ECR), extensor digitorum (ED), flexor digitorum superficialis (FDS) and abductor pollicis brevis (APB). These muscles were selected because they are the active muscles in performing manual tasks such as typing on a computer or texting on a smartphone. As a pair of muscles working in synergy, the actions of UT and LT together control the position of the cervical spine and the scapula. Furthermore, the trapezius muscles are the major postural stabilizers of the upper limb during functional activities such as using mobile devices. Similar to the trapezius muscles, CES plays an essential role in controlling positions of the head and the cervical spine against gravity. In the wrist/hand region, the ECR muscle is an important stabilizer of the wrist posture while the ED, FDS and APB muscles are active in performing the finger actions to interact with the touchscreen on smartphones and also for typing on computers.

3.2.2. Skin preparation and electrode placements

Surface EMG signals can be affected by many factors, for instance, electrode spacing, tissue characteristics, physiological cross talk, movement artifacts, and external noise (Chowdhury et al., 2013). Hence, it is crucial to follow standard procedures in order to acquire surface EMG signals of good quality. Prior to conducting the study, pilot tests were conducted to ensure that the most standardized procedures were adopted and the interference from non-biological sources were minimized. The procedures recommended by the project of Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) were carefully observed and the documentation of electrode positions and procedures has also been based on guidelines from SENIAM (Freriks, Hermens, Disselhorst-Klug,

& Rau, 1999; Hermens & Freriks, 1997). Careful and proper skin preparation were done before attaching electrodes, including cleansing with water and alcohol pads, gentle abrasion with sandpaper, and shaving if necessary (Freriks et al., 1999). Then the skin impedance was checked using an impedance meter (Noraxon USA Inc., Imp. Checker, USA). Bipolar Ag-AgCl surface electrodes (WhiteSensor WS, Ambu A/S, Denmark) of 15 mm diameter were used for all muscles except for APB. Center-to-center inter-electrode distance was set at 2 cm (Freriks et al., 1999). The precise locations of the electrodes were adopted from past studies (Gustafsson, Johnson, & Hagberg, 2010; M. Lin, Liang, Lin, & Hwang, 2004; Madeleine, Lundager, Voigt, & Arendt-Nielsen, 1999; Szeto et al., 2005a; Szeto & Lin, 2011) (Figure 3.1).

Regarding the APB muscle, the electrode placement was more difficult as the skin overlying this muscle is more prone to wrinkle. After many trial attempts, the Blue Sensor electrode (BlueSensor N, Ambu A/S, Denmark) of 10 mm diameter was used instead for this muscle. Although proper skin preparation was done, it was very difficult to achieve skin impedance below 40 kΩ in the thenar area. The high skin impedance for the thenar area is plausibly due to the skin fold characteristic of the area. Hence, skin impedance less than 50 kΩ was considered acceptable for APB muscle while less than 10 kΩ was recorded for the other muscles. Electrodes were fixed with double-sided tapes. Surface EMG connection was checked for each muscle using clinical tests recommended prior to the experiment (Freriks et al., 1999).

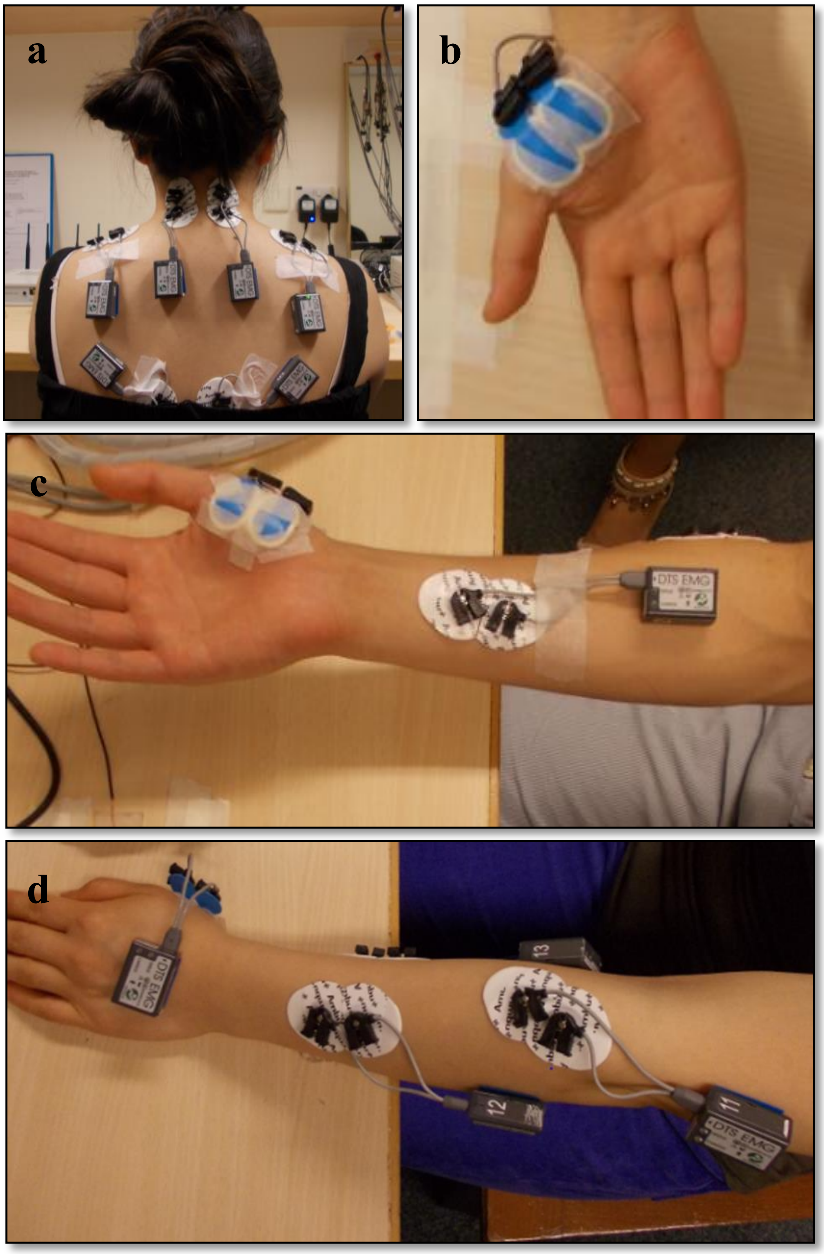

Figure 3.3.1. Placements of surface EMG electrodes in (a) proximal postural muscles, (b) the thumb muscle, (c)-(d) forearm muscles.

3.2.3. Surface EMG normalization

As stated in the last session, surface EMG signals could be influenced by various factors. In order to facilitate comparisons of surface EMG activity among different individuals and between muscles, normalization of surface EMG data is usually recommended to deal with the issue of large variations in the surface EMG data (Sommerich, Joines, Hermans, & Moon, 2000). Surface EMG normalization is a process to divide the derived EMG data by a reference value obtained from the same muscles. Normalization to the isometric maximum voluntary contraction (MVC) is typically used and the muscle activation during a functional task is expressed as a percentage of the maximum voluntary electrical activity (MVE) when MVC normalization is employed (Lehman and McGill, 1999). One of the important advantages of MVC normalization is the estimation of muscle load induced by a given task (Allison, Godfrey, & Robinson, 1998; Yang & Winter, 1984). The intensity of load needed from the same muscle for a given task could also be compared with that for another task (Halaki & Ginn, 2012). It is recommended that the highest value from at least 3 repetitions of MVC tests should be adopted as the normalization value in order to make sure that the recorded MVC value reflects the true maximum voluntary electrical activity (Halaki & Ginn, 2012).

Regarding the MVC method for surface EMG normalization, there is a concern that the subjects, especially those with pain, may not be able to exercise their maximum muscle contractions (Bolgla & Uhl, 2007), which in turn would artificially inflate the percentage values of muscle activity during experimental tasks. Alternatively, normalization to a reference voluntary contraction (RVC) has been proposed and the muscle activity is expressed in terms of a percentage of the reference voluntary electrical activity (RVE). The reference contraction task can be performed using fixed weights. For example, subjects in a number of studies were asked to performed a static arm-abduction (at 90^{o}) task with holding an absolute load for the normalization of UT activity (Gustafsson et al., 2010; Lehman, 2002; Mathiassen & Winkel, 1990). Compared with the MVC method for normalization, a greater variance in the denominator was found in the RVC method (Norcross, Troy Blackburn, & Goerger, 2010). Other studies also reported that MVC method is more reliable than the RVC method (Burnett, Green, Netto, & Rodrigues, 2007; Dankaerts, O'Sullivan, Burnett, Straker, & Danneels, 2004; Lehman, 2002). Furthermore, the RVC method does not allow accurate comparisons of EMG activity between individuals and muscles. This is partly due to the varied lengths of individuals' muscle moment arms and different motor strategies employed by individuals while performing RVC (Halaki & Ginn, 2012). In the pilot study, both MVC and RVC normalization methods were used. For instance, RVE for upper trapezius was determined as the peak of one-second mean activity while subjects' arms were abducted in the frontal plane at 90° and forearms extended at 0° with holding a 1 kg dumbbell in each hand for about 20 seconds. Large variances in RVE were found among different subjects. The RVE values for subjects who had a thin body build such as females were much higher than those who were strong and stout. Also, it is impossible to estimate the muscle effort needed for a given task if the RVC method was used for surface EMG normalization. Due to the disadvantages of RVC method, the isometric MVC method was finally adopted for surface EMG normalization.

In order to ensure that MVE was achieved in all muscles, subjects were instructed to perform three trials of isometric MVC against the resistance of a transducer while sitting in a stable chair. Each trial of MVC was performed for 5 seconds and there was a 30-second to one-minute rest between trials. Consistent verbal instructions were used for each subject to encourage his/her maximum efforts during each trial of MVC. The starting positions and movements for muscle contractions were referenced to past research studies (Gustafsson et al., 2010; M. Lin et al., 2004; Szeto et al., 2005a) (Appendix I). The MVE used to be normalization was determined as the peak of one-second average activity of three trials. These values were also examined for any statistically significant differences between the two subject groups using independent t-tests. Results showed no significant differences in the MVE of all muscles between Case Group and Control Group (Appendix II).

3.2.4. Surface EMG signal processing

Surface EMG signals were sampled at 1500Hz and digitized with 16-bit analogue to digital (A/D) converter. Electrocardiography reduction was performed for all surface EMG channels since ECG waves were visible in the raw signals, especially in the surface EMG channels of proximal postural muscles. Then all EMG signals were processed with a [20-250Hz] band-pass filter. A superimposed peak at the power line frequency which is 50 Hz was also seen contaminating the power spectrum of surface EMG signals. Hence, a notch filter at 50 Hz was also employed to minimize power line interference. Finally, full-wave rectification was applied and the mean absolute value was transformed within windows of 50 milliseconds. These signal processing procedures were similar to those conducted in previous published research (Schleifer et al., 2008; Wang et al., 2011) and also according to international guidelines (Merletti, Farina, Hermens, Freriks, & Harlaar, 1999).

3.2.5. Surface EMG parameters

Different surface EMG parameters were used in different studies depending on specific research questions. Generally, EMG parameters could be grouped into three domains involving amplitude, frequency and time related. In the current study, surface EMG signals are mainly analysed in terms of amplitude parameters using the cumulative amplitude probability distribution function (APDF).

Amplitude related variables are mainly associated with force and muscle activation. The APDF is one common method to quantify the muscle load during a specific task of long durations (B. Jonsson, 1982). It is particularly suitable for studying tasks that involve a static posture without large amplitudes of movements. In the literature on ergonomics and occupational biomechanics, this function is commonly used to examine the muscular efforts required to perform tasks on the computer (Blangsted, Hansen, & Jensen, 2003; Goostrey, Treleaven, & Johnston, 2014; Nordander et al., 2008; Szeto et al., 2005a). The calculation of APDF enables us to obtain information about the probability of surface EMG amplitude that is equal to or less than a certain level of muscle contraction (B. Jonsson, 1982). The values of 10th, 50th and 90th percentile (%ile) APDF represent static, median and peak muscle loads, respectively, according to B. Jonsson (1982). In research concerning muscle activity involved in computer use, three levels of the APDF, especially the 50th %ile APDF which is an indicator of the “average” muscle activity amplitude, have been commonly used (Dumas et al., 2008; Mathiassen, Burdorf, & van der Beek, 2002; Szeto et al., 2005a). These measures are also adopted in the present study to quantify the muscle load so that the results can be compared with other studies.

Frequency related parameters such as the median and mean frequency are mainly applied to estimate localized muscular fatigue (Hansson et al., 1992; Mannion & Dolan, 1994; Masuda, Masuda, Sadoyama, Inaki, & Katsuta, 1999). Time related parameters such as onset and offset calculations are essential parameters to analyze time characteristics of the surface EMG signal in dynamic movements, for instance, gait analysis (Roetenberg, Buurke, Veltink, Cordero, & Hermens, 2003). The text entry tasks involved only light hand actions and only performed in 10-minute sessions, which was not likely to induce muscle fatigue. Therefore, both frequency and time related parameters are not suitable to be analyzed.

3.3. Kinematics

3.3.1. Instrumentation

In addition to surface EMG, kinematics is another important aspect in the research on musculoskeletal loading during functional and occupational activities in past studies (Madeleine et al., 1999; Saito, Miyao, Kondo, Sakakibara, & Toyoshima, 1997; Szeto et al., 2005b). Different instruments have been used to evaluate the spinal posture in studies identifying the risk factors for neck-shoulder pain. For example, many studies employed an optic-based motion tracking system such as the Vicon system to evaluate the static postures or movements of major spinal segments including cervical, thoracic and lumbar spines (K. T. Lau et al., 2010; Silva et al., 2009; Straker, Coleman et al., 2008; Szeto et al., 2002). Although it provides excellent accuracies for estimates of positions, the optic-based motion tracking system has some disadvantages that make it inappropriate for this study, for instance, high cost, occlusions of markers, and time-consuming setup (Li & Buckle, 1999; Perry, Smith, Straker, Coleman, & O'Sullivan, 2008).

Alternatively, an IMU system has been widely used to measure the joint kinematics of the cervical spine (Duc, Salvia, Lubansu, Feipel, & Aminian, 2014; Jasiewicz, Treleaven, Condie, & Jull, 2007), the trunk (Giansanti, Maccioni, Benvenuti, & Macellari, 2007; Goodvin, Park, Huang, & Sakaki, 2006; S. Kim & Nussbaum, 2013) and the upper limb (Cutti, Giovanardi, Rocchi, Davalli, & Sacchetti, 2008; de Vries, Veeger, Cutti, Baten, & Van der Helm, 2010) in both static and dynamic motions due to its relatively low cost, portability and real-time capture. IMU systems incorporate three-axial gyroscopes, accelerometers and magnetometers which could measure angular displacements, velocities and accelerations of movements in three dimensions. Furthermore, IMU systems have demonstrated excellent reliability, validity and repeatability for being used over a long duration compared with the gold standard (Jasiewicz et al., 2007; S. Kim & Nussbaum, 2013; Plamondon et al., 2007; Schall, Fethke, Chen, Oyama, & Douphrate, 2015). The IMU system could also be synchronized with the EMG capture. The aforementioned advantages of the IMU system indicate that it is a reliable choice to evaluate the spinal kinematics.

3.3.2. Placements of sensors

Four IMU sensors (MyoMotion Clinical, Noraxon U.S.A. Inc.) were employed to measure the 3-D spinal kinematics (Figure 3.2a). The IMU used has the accuracy of ±1° of joint angles for static trials and ±2° for dynamic trials (MyoMotion Clinical, Noraxon U.S.A. Inc.). The first sensor was positioned at the external occipital protuberance, the second sensor at the spinous process of C7, the third at the spinous process of T12 and the fourth at the bony area of the sacrum (Figure 3.2b). Sensors were fixed with straps or double-sided tapes. The kinematics of three spinal regions including cervical, thoracic and lumbar segments were measured. The kinematics of the cervical spine was obtained from the relative position and orientation between two receivers located at the external occipital protuberance and the spinous process of C7. The relative position and orientation between receivers at C7 and T12 provided kinematic data of the thoracic spine while sensors between T12 and the bony area of sacrum offered data of the lumbar spine. The six directions of spinal movements in three anatomical planes in terms of positive and negative values in the IMU system are shown in Figure 3.3.

A calibration procedure for IMU sensors was performed before the experiment. The subject’s posture for the calibration was to sit upright in a chair, with the head looking straight ahead, the hips and knees at 90° flexion. Therefore, the angular displacement was referenced to the sitting and resting posture for calibration instead of the absolute vertical position. This could be a downfall of the IMU system, since it is not possible to detect whether the person’s resting posture is within normal range or not. The kinematic data can only reveal the change from data of the resting (reference) angle.

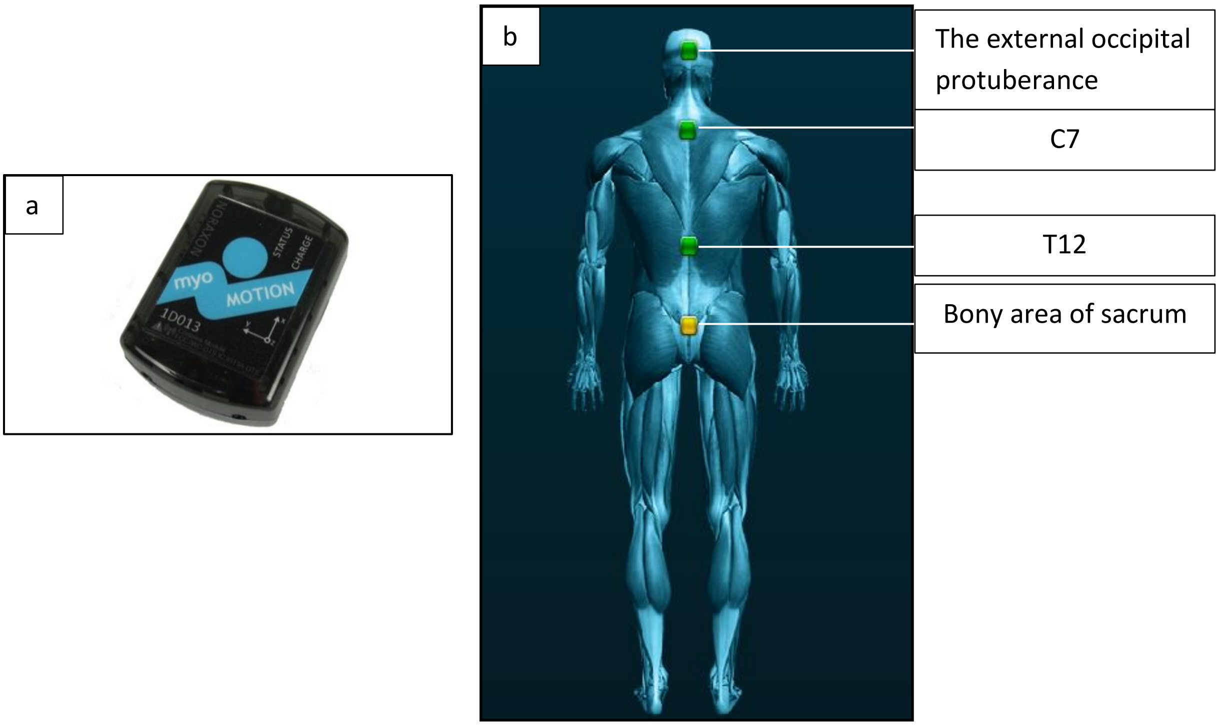

Figure 3.3.2. (a) The inertial measurement sensor used for kinematic measurements; (b) placements of sensors.

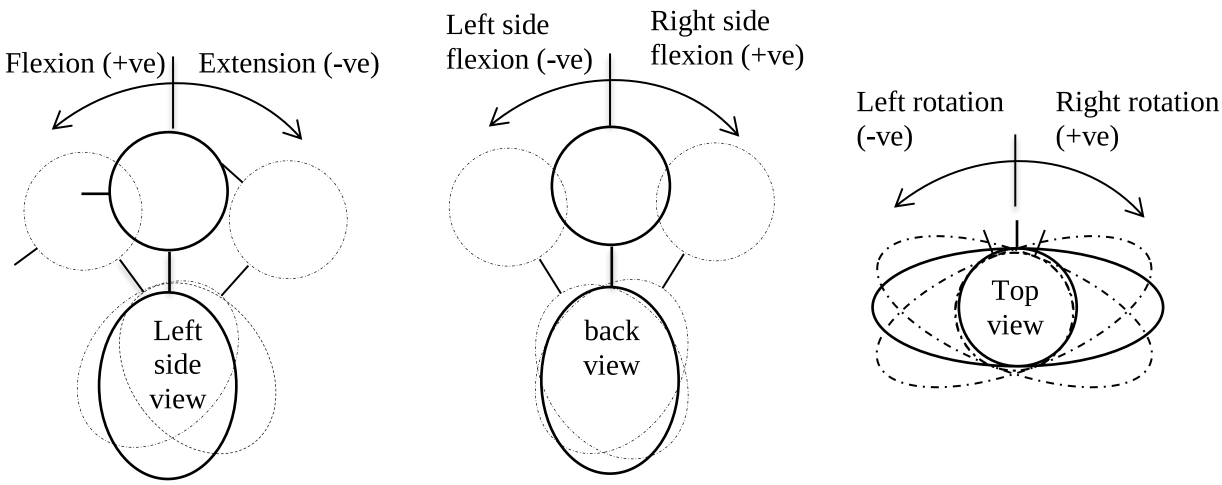

Figure 3.3.3. The directions of movements for the three spine segments including cervical, thoracic and lumbar segments. +ve=positive, -ve=negative.

3.3.2. Kinematic variables

Angular displacements have been widely reported in biomechanical research studying the kinematic pattern of people during different kinds of functional activities. In the research literature concerning the kinematics of the upper limb, cumulative APDF was also commonly used to analyse the kinematic pattern and 50th %ile APDF representing the median angular displacement has been reported in some studies (M. Lin, Hong, Chang, & Ke, 2015; Pereira, Miller, Huang, Odell, & Rempel, 2013; Szeto et al., 2005b). In addition, the difference between the 10th %ile and 90th %ile APDF has been named as the "APDF range" which has been employed to be a measure of the amplitude variability of angular displacements in performing certain functional tasks (Ciccarelli, Straker, Mathiassen, & Pollock, 2014; Straker, Coleman, et al., 2008; Szeto et al., 2005b).

Some researchers proposed that other kinematic variables such as movement velocity and acceleration should also be examined, as these parameters can reveal more useful information about "how" the joint moved. This information can be more meaningful in trying to understand the underlying dysfunction of musculoskeletal disorders (Gregori et al., 2008; Sjölander, Michaelson, Jaric, & Djupsjöbacka, 2008; Tsang, Szeto, & Lee, 2014). Movement velocity and acceleration might provide valuable information regarding the kinematic pattern while performing dynamic tasks that involve a large extent of movements, but they do not provide meaningful information if the tasks performed were static. In the present study, the subject was instructed to keep his/her back against the chair, and therefore the extent of free active movements is very limited. Hence, the movement velocity and acceleration were not examined. Median angular displacements and APDF range of joint angles for cervical, thoracic and lumbar regions in three anatomical movement planes, namely sagittal plane (flexion/extension), frontal plane (left/right side flexion) and transverse plane (left/right rotation) were computed in the present study. Additionally, percentages of time in terms of the whole duration of a task were calculated separately for different directions of movements -- positive values (for flexion, right side flexion and right rotation) and negative values (for extension, left side flexion and left rotation) (Figure 3.3). This information enabled us to understand how long and what kinds of postures subjects adopted and maintained while performing tasks on electronic devices.

3.4. Subjective measurements: discomfort and rate of perceived exertion

Subjective discomfort has been widely reported in the research of work-related musculoskeletal disorders. The most frequently used subjective discomfort rating scales are verbal descriptor scales (VDS), visual analogue pain scale (VAS), and numerical rating scale (NRS) (Salaffi et al., 2004). Evidence for the validity of VDS measuring discomfort intensity is mixed while NRS is demonstrated to be more reliable than VAS (Ferraz et al., 1990). NRS measures the discomfort intensity by asking respondents to choose a whole number (0-10) to best represent their discomfort intensity. The NRS has been adopted to measure the effect of keyboarding on the change of musculoskeletal discomfort in the past studies (Cagnie et al., 2012; Szeto et al., 2005a). It is a proper indicator for the present study to detect the effect of tasks on musculoskeletal discomfort.

The term “discomfort” was used in many previous studies to evaluate pain-free or painful subjects’ subjective symptoms after performing functional tasks (Feuerstein, Armstrong, Hickey, & Lincoln, 1997; Straker & Mekhora, 2000; Szeto et al., 2005a; Voerman, Vollenbroek-Hutten, & Hermens, 2007). There are two main kinds of definition for the term “discomfort”. In some studies, discomfort is interpreted as a subjective unpleasant symptom like tension, strain and soreness; but it does not include pain (Hamberg-van Reenen et al., 2008; Talley et al., 1999; van der Grinten, Maarten P & Smitt, 1992). On the other hand, some studies defined discomfort as mild pain or symptoms including pain (Cameron, 1996; Fjellman-Wiklund & Sundelin, 1998; Holtmann, Stanghellini, & Talley, 1998). In line with previous research on similar topics, the term "discomfort" was adopted to assess subjective symptoms after performing the three experimental tasks. The definition of discomfort in this study was an absence of comfort or ease; the state of being tense and feeling pain (Cameron, 1996).

Rate of perceived exertion (RPE) is also a common subjective instrument to measure physical strain. It is a psycho-physical tool with scores that range from 6 (no exertion at all) to 20 (maximum exertion) for assessing the subjective perception of exertion, effort and fatigue during physical work or exercise. Subjective perceived exertion in the neck is found to be closely correlated with objectively measured muscle fatigue in upper trapezius (Hummel et al., 2005). Asfour, Ayoub, Mital, & Bethea (1983) reported a high correlation between RPE and physiological variables such as heart rate and oxygen consumption, suggesting that RPE is a quick and reliable method to evaluate the severity of manual handling tasks. Hence, RPE was adopted to examine the degree of self-perceived physical exertion induced by the experimental tasks.

3.5. Sample size calculation

The sample size was determined based on the preliminary analysis of a pilot study where there were 5 subjects in Case Group and 6 in Control Group. The effect size "Patial Eta Squared (η^2)" was calculated with these preliminary data using repeated measured analysis of variance (RMANOVA) for the primary outcome which is the median muscle activity. The median activity of the RUT was used for the calculation since this muscle has been found to be most sensitive to changes in symptomatic behavior in past research with similar case-control study design (Szeto et al., 2005a, 2009a). The effect size obtained from the between-subject effect for median muscle activity of RUT was 0.324. Assuming α=0.05, power=0.8 and effect size=0.324, about 20 subjects per group would be required to detect group differences in the median muscle activity of RUT, according to the calculation of G*Power 3.1.9.2. Effect sizes attained from between-subject effects or within-subject effects for other muscles ranged from 0.041 to 0.193. If these effect sizes were used for sample size calculation, then hundreds of subjects in total would be needed. Considering that muscle activity of UT would be an essential primary outcome since it is commonly reported to be dysfunctional in people with chronic neck pain (Falla & Farina, 2005; S. Larsson, Bodegård, Henriksson, & Öberg, 1990; Mork & Westgaard, 2006; Zakharova-Luneva, Jull, Johnston, & O'Leary, 2012), the effect size obtained from the analysis of RUT was finally used for this study to calculate sample size. Therefore, 40 subjects in total were the adopted sample size in this study.

3.6. Statistical analysis

First of all, normality test was performed to check whether the data obtained was normally distributed. If most of the data were normally distributed, then a mixed model repeated measures analysis of variance (RMANOVA) would be adopted to analyze the group, task and group x task interaction effects on dependent variables including muscle activity, spinal kinematics, discomfort scores and RPE, and the Pearson’s correlation analysis would be used to test the correlations among those dependent variables. However, if most of the data were not normally distributed, then nonparametric tests such as the Mann-Whitney U test would be employed to analyze group differences, Friedman two-way analysis of variance by ranks would be adopted to test the task differences and Spearmen's rho correlation analysis would be used to examine the correlations among the dependent variables. According to the normality test, half of the data in this study were normally distributed while half were not. As a result, both parametric and nonparametric tests were tried to examine the group and task effects as well as the correlations among dependent variables and they showed similar results. Furthermore, considering that repeated measures analysis of variance is robust to moderate violations of normality (Portney and Watkins, 2014) and provides the examination of interaction effects, it was finally adopted as the statistical analysis method to examine the group, task and group x task interaction effects on the dependent variables. Spearmen's rho was finally employed to examine the correlations among muscle activity, spinal kinematics and subjective discomfort (see Chapter 5) since it is reported that the Spearmen's rho correlation analysis has shown the better type I error control and more powerful in the context of non-normality compared with Pearson's correlation analysis (Bishara and Hittner, 2012).

CHAPTER 4

COMPARISON OF MUSCLE ACTIVITY IN USING TOUCHSCREEN SMARTPHONE AMONG YOUNG PEOPLE WITH AND WITHOUT CHORNIC NECK-SHOULDER PAIN

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4.1. Introduction

Touchscreen smartphone has become the most popular electronic handheld device in recent years. It has been predicted that there will be more than two billion touchscreen smartphone users worldwide by 2015, which is over one-quarter of the entire world population (Parks Associates, 2012). In the past 2-3 years, touchscreen smartphones have largely replaced most of the keypad phone products, due to their versatility and abundance of applications. However, as many people maintain their neck flexed when using portable devices, there is a growing concern about the impact of touchscreen smartphones on the musculoskeletal system among those who are prolonged users. Similar to desktop and laptop computers, prolonged use of touchscreen smartphones may also contribute to increased risk for the development of musculoskeletal symptoms such as chronic neck–shoulder pain (Berolo et al., 2011; G. Y. Kim et al., 2012).

The possible association between musculoskeletal disorders and use of electronic devices has mainly been investigated for desktop computers in the past two decades. Sustained awkward posture, long duration, repetitive movement and workplace stress have been identified as important risk factors for the development of neck-shoulder pain among computer users (Blatter & Bongers, 2002; B. Larsson et al., 2007; Szeto et al., 2002; Wahlström, 2005). It has been reported in several studies that office workers with neck-shoulder pain have maladaptive muscle recruitment patterns when performing functional tasks such as computer typing (Johnston, Jull, Souvlis & Jimmieson, 2008; O'Leary, Falla, Jull, & Vicenzino, 2007; Szeto et al., 2005a, 2009a). Compared with typing on a computer keyboard which requires 0.5–0.8N force during vertical keystroke (Blackstone, Karr, Camp, & Johnson, 2008), touchscreen keyboard is activated by a very light touch involving significantly lower fingertip forces (J. H. Kim, Aulck, Bartha, Harper, & Johnson, 2012). Although the use of touchscreen smartphone involves low forces from fingers or thumbs, there may still be substantial loading among the postural muscles holding the handheld electronic device, especially when the touch action is performed with high speed and high repetition rates.

Recently, a few epidemiological studies have reported high prevalence rates of neck-shoulder symptoms among mobile device users. A study in Canada has reported prevalence rates of 46-52% in shoulder symptoms among 140 subjects and 68% in neck symptoms (Berolo et al., 2011). Another study in China has reported over 40% of neck-shoulder pain among 2575 young mobile phone users (Shan et al., 2013). To the best of our knowledge, only a handful of studies have investigated biomechanical factors related to the use of handheld devices such as mobile phones or touchscreen tablets. Gold et al. (2012) reported that over 90% of the university students adopted a flexed neck posture, with protracted shoulders and non-neutral wrist postures on the typing side when they used their mobile devices. Lin and Peper (2009) showed increased amplitude of the shoulder and thumb surface electromyography (EMG) in healthy subjects after 1-minute message texting using mobile devices as well as increased neck-shoulder discomfort after the task. Only one laboratory study has examined the shoulder and hand muscle activity while using conventional keypad phones for texting among symptomatic individuals

(Gustafsson et al., 2010). However, the current mobile device market is dominated by touchscreen phones and it is not known whether the use of such devices would also involve similar patterns of musculoskeletal loading. This is substantiated by the fact that touchscreen smartphones have different interfaces, different key layouts, different activation forces as well as different weights from keypad phones.

There is a lack of knowledge regarding the activation level of muscles from the neck and upper limb among touchscreen smartphones users. Furthermore, it is unknown whether the level of muscle activation in young people with and without neck-shoulder pain differs when using touchscreen smartphones. Given the increasing trend of intensive use of both touchscreen smartphones and computers by young people, it is important to investigate the muscle activity pattern when using these devices. Texting on mobile phones with either one hand or both hands has become one new activity of daily living among young people. Therefore, the purpose of this study was to evaluate the distribution of muscle activity in the neck and upper limb when performing texting on a touchscreen smartphone using (i) both hands (bilateral texting), (ii) only one hand (unilateral texting) and (iii) a computer keyboard for text entry (computer typing). We hypothesised that young people with neck–shoulder pain would exhibit higher muscle activity during performing the three mentioned tasks compared with controls.

4.2. Methods

4.2.1. Subjects

Forty young adults (24 females and 16 males) aged 23.9 ± 3.2 from local universities in the Hong Kong vicinity were recruited by convenience sampling. To be recruited, subjects had to have at least 6 months' experience in using smartphones and spend at least 2 hours daily on smartphones. Subjects had to be right hand dominant and prefer to use the right hand in one-handed text entry. Other essential requirements were texting and typing speeds which were to make sure that all subjects had similar skills in texting on a smartphone and typing on a desktop computer. Subjects were asked to perform a texting speed test on iPhone 4s (Apple Inc., USA) using both hands as well as perform a typing speed test on a desktop computer before entering the study. Only subjects who achieved a minimum texting speed of 15 words per minute (wpm) on the smartphone and typing speed of 30 wpm on the computer keyboard were recruited. The exclusion criteria were: (1) history of traumatic injuries or surgical interventions of relevant regions; (2) other medical conditions which may have a negative effect on the spine and upper limb regions; (3) chronic diseases affecting the musculoskeletal system such as rheumatoid arthritis, osteoarthritis and other connective tissue disorders; (4) neurological and orthopeadic disorders as well as sensory deficits. The exclusion criteria were screened mainly from the medical history and clinical examination prior to the start of the study.

Subjects who met the criteria listed above were then asked to complete three questionnaires which were: (1) a modified version of Standardised Nordic Questionnaire (Kuorinka et al., 1987); (2) Neck Disability Index (NDI); (3) Disability of Arm, Shoulder and Hand (DASH). Subjects were allocated into Case Group and Control Group based on their response to these three questionnaires. Subjects who had neck-shoulder pain associated with usage of smartphones or computers for more than 3 months in the past year were allocated into Case Group. In addition, subjects in the Case Group had to report that they still suffered from the pain a week before and at the current time of the study. Furthermore, subjects in the Case Group had to have a NDI score of 8/100 or higher (Johnston, Jimmieson, Jull,

& Souvlis, 2008) and a score of 10.1/100 or higher in the functional part of DASH (Hunsaker, Cioffi, Amadio, Wright, & Caughlin, 2002). All other subjects were allocated into Control Group.

Personal characteristics such as body weight and height, and information about the daily use of electronic devices were also obtained (see Tables 4.1 and 4.2). These included details such as models of smartphones used and daily use patterns of various electronic devices including duration, frequency, smartphone texting time and text entry methods. It is pointed out that hand sizes significantly affects the usability of mobile phones for texting messages (Balakrishnan & Yeow, 2008) as well as the usability and biomechanics in gripping a handheld device (Pereira et al., 2013). Hence the measurements of hand anthropometry such as hand breadth and length as well as thumb length and circumference were also included in this study (see Table 4.1). Prior to launching the study, human ethics approval was sought from the Hong Kong Polytechnic University. Informed consent was obtained from the subjects prior to the recordings. The study was conducted in accordance with the Declaration of Helsinki.

Table 4.1. Subjects' demographic characteristics for Case and Control Groups.

	Case (n=20) Mean (SD)	Control (n=20) Mean (SD)	*p*-value
Age (years)	24.6 (3.1)	23.2 (3.1)	0.181
Height (cm)	168.2 (7.6)	166.7 (11.8)	0.641
Weight (kg)	62.3 (12.9)	60.7 (10.1)	0.658
Right hand breadth (cm)	7.7 (0.8)	7.6 (0.6)	0.654
Left hand breadth (cm)	7.5 (0.7)	7.5 (0.6)	0.940
Right hand length (cm)	17.6 (1.0)	17.8 (1.4)	0.620
Left hand length (cm)	17.7 (1.1)	17.8 (1.4)	0.783
Right thumb length (cm)	5.7 (0.5)	5.9 (0.6)	0.264
Left thumb length (cm)	5.7 (0.5)	5.9 (0.6)	0.344
Right thumb circumference (cm)	5.5 (0.8)	5.4 (0.5)	0.778
Left thumb circumference (cm)	5.5 (0.8)	5.4 (0.6)	0.643
Occupation [proportion]	Student=75% Assistant=25%	Student=75% Assistant=25%	1.000

Table 4.2. Subjects' patterns of using different electronic devices.

	Case (n=20)	Control (n=20)	Group difference
Phone operation system [proportion]	IOS=50% Android=50%	IOS=30% Android=70%	χ^2=1.67, *p*=0.197
Phone screen size (inch) [mean (SD)]	4.3 (0.7)	4.6 (0.6)	*t*=−1.36, *p*=0.181
Smartphone usage (years) [mode (range)]	Mode=>3 (0-6 Month->3 years)	Mode=>3 (0-6 Month->3 years)	z=1.05, *p*=0.306
Total time on smartphones (hrs/day) [mean (SD)]	4.6 (1.6)	3.8 (1.6)	*t*=1.68, *p*=0.099
Total time on tablet use (hrs/day) [mean (SD)]	1.1 (1.3)	0.6 (0.8)	t=1.42, *p*=0.165
Total time on computers use (hrs/day)[mean (SD)]	5.1 (2.1)	4.3 (2.1)	*t*=1.15, *p*=0.259
Total time on texting (hrs/day)[mean (SD)]	1.7 (1.0)	1.2 (0.7)	*t*=1.72, *p*=0.094
Phone input methods [proportion]	Right thumb=65% Both thumbs=35%	Right thumb=50% Both thumbs=50%	χ^2=0.92, *p*=0.337

Note: hrs=hours.

4.2.2. Experimental protocol

Subjects were instructed to text on a smartphone and type on a desktop computer keyboard in 10 min sessions with 5 min rest in between tasks. An iPhone 4s was used as the standard touchscreen smartphone in this study. A standardised typing app, named ‘tap typing’ (Flairify LLC, version 3.4.5, USA) was adopted to display the English story ‘Alice in Wonderland’ on the smartphone screen for the subject to perform copy-texting. The same story was also displayed on screen for subjects to perform copy-typing on the desktop computer. Subjects were instructed to text or type with their customary speed and as accurately as possible, without having to amend any errors while texting or typing. Prior to the actual data collection, subjects were given 3 min to familiarise with the texting/typing tasks. In order to minimise bias of a carry-over effect, the task order was randomised and balanced. The three experimental tasks were as follows:

(i) Texting with both thumbs (Bilateral texting) (Figure 4.1(A)).

(ii) Texting with right thumb only (Unilateral texting) (Figure 4.1(B)).

(iii) Typing on the desktop computer keyboard with both hands (Computer typing) (Figure 4.1(C)).

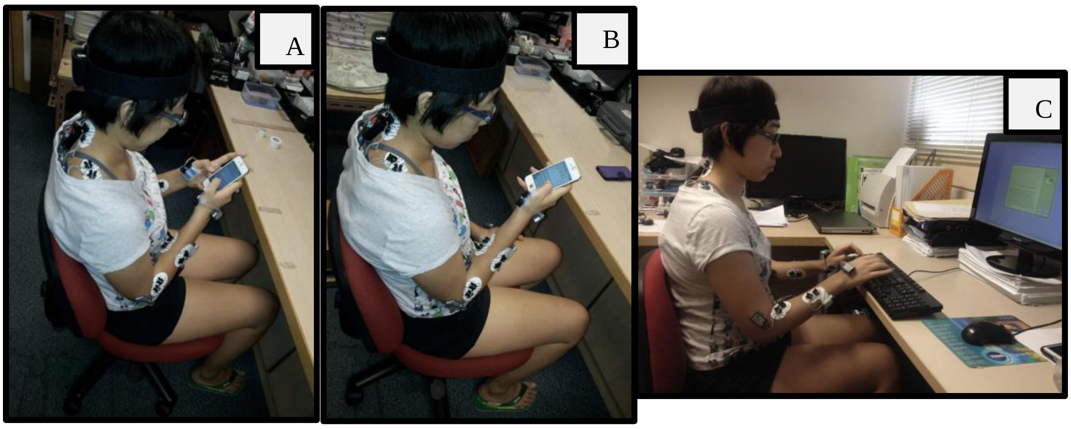


Figure 4.1. The three experimental tasks: (A) bilateral texting; (B) unilateral texting; (C) computer typing.

Subjects were required to grip the smartphone with both hands in bilateral texting, while only the right hand was used during unilateral texting. Subjects were instructed to place their left hands on the thigh in the unilateral texting task. Subjects were asked to type out each word in full on the touchscreen QWERTY keyboard, and were instructed not to use the automatic 'word complete' function during both bilateral and unilateral texting tasks. In addition, subjects were asked to hold the smartphone at about the chest height. The distance from the phone to the body was adjusted by subjects, but subjects had to keep their arms close to the trunk and their elbows bent (Figure 4.1(A),(B)). Subjects were also instructed to sit in a height-adjustable swivel chair with back support but without forearm and wrist support. The chair height was adjusted to a position that was comfortable to the subject, with the knees approximately 90° flexed and the feet resting on the ground. They were required to maintain a stable posture but still allowed to have slight movements spontaneously.

During the typing task, subjects were requested to type the same story on the desktop computer keyboard. Consistent with the workstation of texting tasks, subjects were instructed to perform copy-typing on the computer keyboard with back support but without forearm or wrist support and without using the computer mouse. All subjects used a standardised computer workstation equipped with adjustable screen height, as well as adjustable chair height. The keyboard was put on the edge of the computer desk and the height of the keyboard was fixed at 70 cm from the floor. The subject was instructed to adjust the chair to a level that they assumed to be comfortable with subjects' knees approximately 90° flexed and the feet resting on foot rest. The screen height was adjusted to a level that the top of screen height was at around the horizontal eye level of the subject. Speed (wpm) and accuracy of the texting/typing tasks were recorded during the experimental conditions.

4.2.3. Dependent variables

4.2.3.1. Surface electromyography

The Noraxon Telemyo wireless EMG System (Noraxon USA Inc., USA) was used. Three bilateral proximal postural muscles, namely cervical erector spinae (CES), upper trapezius (UT) and lower trapezius (LT), as well as four bilateral distal muscles, i.e. extensor carpi radialis (ECR), extensor digitorum (ED), flexor digitorum superficialis (FDS) and abductor pollicis brevis (APB) were assessed. As the left-sided proximal postural and distal muscles were not involved in the unilateral texting task, only the EMG data from right-sided postural proximal muscles and distal forearm/hand muscles are reported here. Bipolar Ag–AgCl surface electrodes of 15 mm diameter were used. The specific locations of EMG electrodes were referenced to past research studies (Gustafsson et al., 2010; Madeleine et al., 1999; Szeto et al., 2005a). Subjects' skin was cleaned by water, gently abraded with sandpaper and cleaned again with alcohol (as well as shaved if necessary) before attaching electrodes. An impedance meter was employed to check the skin impedance. Skin impedance below 10 kΩ for the neck, shoulder, forearm regions and 50 kΩ for the thenar area was considered acceptable. The same person placed the electrodes on all subjects. The inter-electrode distance was fixed at 2cm.

The EMG signals were sampled at a frequency of 1500Hz and digitised using a 16-bit analogue to digital (A/D) converter. ECG signals were removed from all EMG channels. Then all EMG signals were processed with a band-pass filter of 20–250Hz. A notch filter centred at 50Hz was also used to reduce power-line interference. Full-wave rectification and signal smoothing with a window of 50 ms were also applied. All the EMG signals recorded were expressed as percentages of the maximum EMG activity (%EMG_max). The muscle activity levels during texting and typing tasks were analysed as the 10th, 50th and 90th percentile (%ile) of the Amplitude Probability Distribution Function (APDF) representing the static, median and peak EMG levels (B. Jonsson, 1982).

EMG normalisation procedures were performed after each subject finished all experimental tasks. To obtain the maximal voluntary electrical activity of each muscle, subjects performed three trials of isometric maximum voluntary contraction (MVC). Each MVC was performed for 5s, with 30-60s rest in between. Subjects performed these contractions while sitting in a stable chair, with forearms supported. The starting positions and movements of muscle contractions were referenced to past studies (Gustafsson et al., 2010; Szeto et al., 2005a).

4.2.3.2. Subjective discomfort and perceived exertion

Subjects were asked to rate their musculoskeletal discomfort in six body areas including the neck, shoulder, upper back, elbow, wrist/hand and thumb/fingers on the dominant side using a 0–10 numeric rating scale anchored with 0: no discomfort at all and 10: extreme or intolerable discomfort before and after each task. Discomfort was defined as an absence of comfort or ease; the state of being tense and feeling pain (Cameron, 1996). Summed discomfort score from six body areas (0–60) was calculated and the changes in the summed discomfort score after each task was compared between groups as well as among the three tasks. Subjects were also asked to mark their rates of perceived exertion (RPE) after each task using a Borg scale where 6 represents ‘very, very light’ and 20 ‘very, very strenuous’ (Borg, 1982).

4.2.4. Data analysis

Most of the data regarding demographic characteristics and the pattern of electronic devices use were compared between groups using independent t-test (t) except data concerning occupations, phone operating systems, smartphone usages and phone input methods. Chi-square (χ^2) was employed to determine whether the proportions of occupations, phone operating systems and phone input methods differed in each category between two groups. Mode was used to present central tendency of smartphone usages, and Mann-Whitney U test (z) was used to determine group differences in smartphone usages. The dependent variables were the three levels of APDF as well as the changes in discomfort scores and RPE. The independent variables were group and task. A mixed-model repeated measures analysis of variance (RMANOVA) was used to evaluate the effect of group as between-subject factor, and task as within-subject factor. The task factor involved three levels – bilateral texting, unilateral texting and typing. For comparing the specific task conditions, post hoc simple contrasts were performed. SPSS version 20.0 (IBM, USA) was adopted for all statistical analysis and significance was assumed at $p < 0.05$.

4.3. Results

4.3.1 Subject characteristics

Tables 4.1 and 4.2 show the demographic characteristics and the pattern of electronic devices use between two groups respectively. There was no significant difference between groups with respect to general characteristics and subjects' patterns of the smartphone as well as general electronic devices use. Subjects in Case and Control Group were also comparable in terms of their frequencies in doing physical activity (Appendix III). The pain profiles during the past 12 months in the

Case Group revealed that 16 subjects had bilateral neck pain (mean pain scores were 4.9±1.8 and 4.8±1.9 for the right and left sides, respectively), and four subjects had unilateral neck pain (mean pain score was 4.5±1.7 on the right side). Most subjects in the Case Group had pain in their shoulders (n=18), with 10 subjects reporting bilateral pain (mean pain scores were 4.7±1.8 and 4.9±1.5 on the right and left sides, respectively), and 8 subjects reporting unilateral pain (mean pain score was 5.3±1.7 on the right side). The pain score ranged from 0 (no pain at all) to 10 (extreme pain). Furthermore, some subjects from the Case Group had additional bilateral or unilateral pain in the upper back (n=9), wrist (n=8) and thumb (n=10). The mean NDI and score in the functional part of DASH in Case Group were 15.2±7.8 and 10.5±8.4, respectively.

4.3.2. Muscle activity in Case and Control groups

The multivariate RMANOVA did not reveal significant group differences in the 50th %ile APDF of CES; however, Case Group showed a trend of consistently higher muscle activity than Control Group in all tasks (Table 4.3). There were also no group differences in 50th %ile APDF of LT. However, a significant between-group effect was found for 50th %ile APDF of UT (Table 4.3), with Case Group showing higher EMG amplitude compared with Control Group for all three tasks (Table 4.3). No task x group interaction was found, but the group difference in UT muscle activity displayed a trend more apparent in computer typing than in smartphone texting. Table 4.3 summarises the muscle activity in 10th, 50th and 90th %ile APDF for all proximal muscles. Group differences in 10th and 90th %ile APDF displayed a very similar pattern as in 50th %ile APDF in all proximal muscles (Table 4.3). Regarding distal muscles, no group effect and group x task interaction effect were found in 10th, 50th and 90th %ile APDF (Table 4.4).

Table 4.3. Group, task and group x task interaction effects on 10th, 50th and 90th percentile (%ile) Amplitude Probability Distribution Function of proximal postural muscles, i.e., right cervical erector spinae (CES), upper trapezius (UT) and lower trapezius (LT). Means (standard deviations) are reported.

Muscle			B-TEXT	U-TEXT	TYPE	Group *p*-value	Task *p*-value	Group x task *p*-value
RCES	10th %ile	Case	8.88 (4.81)	9.20 (4.46)	7.98 (3.73)	0.193	0.004**	0.726
		Control	7.54 (3.01)	7.94 (3.90)	6.10 (3.29)			
	50th %ile	Case	13.32 (6.39)	13.72 (6.13)	12.81 (5.46)	0.160	0.081	0.606
		Control	11.31 (4.18)	11.84 (5.32)	9.86 (5.33)			
	90th %ile	Case	19.11 (8.70)	19.53 (8.41)	19.11 (7.92)	0.153	0.435	0.685
		Control	16.01 (6.16)	16.84 (7.14)	15.08 (8.18)			
RUT	10th %ile	Case	2.52 (1.88)	3.08 (3.19)	4.95 (4.33)	0.006**	0.004**	0.070
		Control	1.12 (1.04)	1.81 (1.85)	1.79 (1.13)			
	50th %ile	Case	5.35 (4.24)	5.98 (5.54)	9.42 (7.00)	0.005**	0.002**	0.131
		Control	2.33 (1.99)	3.25 (2.83)	3.73 (1.83)			
	90th %ile	Case	8.93 (6.92)	10.13 (7.95)	14.72 (11.77)	0.001**	0.003**	0.282
		Control	3.77 (3.09)	5.14 (4.06)	6.56 (2.93)			
RLT	10th %ile	Case	1.90 (1.27)	2.61 (1.65)	3.52 (2.51)	0.682	<0.001***	0.304
		Control	2.21 (1.68)	2.20 (1.59)	3.05 (1.69)			
	50th %ile	Case	3.52 (2.01)	4.89 (2.69)	6.66 (3.73)	0.836	<0.001***	0.474
		Control	3.96 (3.11)	4.37 (2.70)	6.26 (2.92)			
	90th %ile	Case	6.07 (2.92)	8.40 (4.36)	11.18 (5.46)	0.842	<0.001***	0.731
		Control	6.38 (4.97)	7.90 (5.08)	10.61 (4.83)			

Note: B-TEXT=bilateral texting, U-TEXT=unilateral texting and TYPE=computer typing. ***p* significant at <0.01, ****p* significant at <0.001.

Table 4.4. Group, task and group x task interaction effects on 10th, 50th and 90th percentile (%ile) Amplitude Probability Distribution Function of distal muscles, i.e., extensor carpi radialis (ECR), extensor digitorum (ED), flexor digitorum superficialis (FDS) and abductor pollicis brevis (APB). Means (standard deviations) are reported.

Muscle			B-TEXT	U-TEXT	TYPE	Group *p*-value	Task *p*-value	Group x task *p*-value
RECR	10th %ile	Case	1.25 (0.77)	2.09 (1.11)	2.02 (1.09)	0.057	<0.001***	0.579
		Control	1.52 (0.86)	2.26 (1.04)	2.10 (1.05)			
	50th %ile	Case	2.02 (1.16)	3.37 (1.65)	3.92 (2.28)	0.990	<0.001***	0.668
		Control	2.44 (1.25)	3.66 (1.66)	4.00 (2.02)			
	90th %ile	Case	3.13 (1.76)	5.18 (2.43)	7.87 (4.52)	0.587	<0.001***	0.768
		Control	3.66 (1.77)	5.96 (3.35)	8.04 (4.32)			
RED	10th %ile	Case	3.09 (1.32)	4.45 (1.35)	4.80 (2.09)	0.471	<0.001***	0.799
		Control	2.89 (1.77)	4.07 (2.15)	4.25 (2.38)			
	50th %ile	Case	5.90 (2.21)	8.98 (2.54)	10.09 (3.96)	0.379	<0.001***	0.860
		Control	5.42 (2.95)	7.98 (3.64)	9.20 (4.27)			
	90th %ile	Case	11.40 (4.37)	16.93 (5.45)	19.86 (6.84)	0.290	<0.001***	0.880
		Control	9.69 (4.83)	14.83 (6.44)	18.71 (7.25)			
RFDS	10th %ile	Case	0.93 (1.06)	1.35 (1.37)	0.61 (0.68)	0.717	<0.001***	0.986
		Control	0.86 (0.79)	1.24 (0.95)	0.52 (0.45)			
	50th %ile	Case	2.11 (2.17)	3.07 (2.82)	1.79 (1.84)	0.490	<0.001***	0.674
		Control	1.89 (1.62)	2.53 (1.79)	1.35 (0.96)			
	90th %ile	Case	4.03 (3.87)	5.72 (5.15)	8.21 (6.30)	0.213	<0.001***	0.052
		Control	3.26 (2.64)	4.44 (2.76)	5.46 (3.20)			
RAPB	10th %ile	Case	0.30 (0.34)	0.70 (0.42)	0.13 (0.19)	0.831	<0.001***	0.616
		Control	0.33 (0.32)	0.77 (0.63)	0.94 (0.13)			
	50th %ile	Case	1.93 (1.76)	4.79 (2.89)	0.85 (0.81)	0.641	<0.001***	0.444
		Control	2.03 (1.57)	4.80 (2.78)	0.76 (0.81)			
	90th %ile	Case	17.65 (10.76)	32.24 (13.50)	7.87 (6.89)	0.342	<0.001***	0.933
		Control	14.57 (9.33)	29.83 (11.14)	5.95 (5.92)			

Note: B-TEXT=bilateral texting, U-TEXT=unilateral texting and TYPE=computer typing. ***p* significant at <0.01, ****p* significant at <0.001.

4.3.3. Comparing muscle activity in computer typing and bilateral texting

As shown in Figure 4.2, there was an apparent pattern of higher level of median EMG activity in the CES for all tasks, with a marginally higher median activity level of CES in bilateral texting compared with computer typing, though not statistically significant. In contrast, the median EMG amplitude of UT and LT displayed significantly higher activity in computer typing than in bilateral texting for both groups (Figure 4.2).

In terms of task effect on distal muscles, there were also significant differences in the median activity levels of ECR, ED and APB between computer typing and bilateral texting. The median activity levels of ECR and ED were significantly higher in computer typing than in bilateral texting, while APB activity was significantly higher in bilateral texting compared with computer typing (Figure 4.3). No difference in FDS activity was found between bilateral texting and computer typing. The task effect on 10th and 90th %ile APDF of all proximal and distal muscles showed a similar pattern as in 50th %ile APDF of all muscles (Tables 4.3 and 4.4).

4.3.4. Comparing muscle activity in bilateral and unilateral texting

With respect to texting effects on proximal postural muscles, the right side of UT and LT showed a trend of higher muscle activity in unilateral texting compared with bilateral texting for both groups although no significant differences were found (Figure 4.2). There was no difference in the activity of CES between bilateral texting and unilateral texting for both groups. All distal muscles, namely ECR, ED, FDS and APB were significantly higher in median activity in unilateral texting compared with bilateral texting for both groups (Figure 4.3).

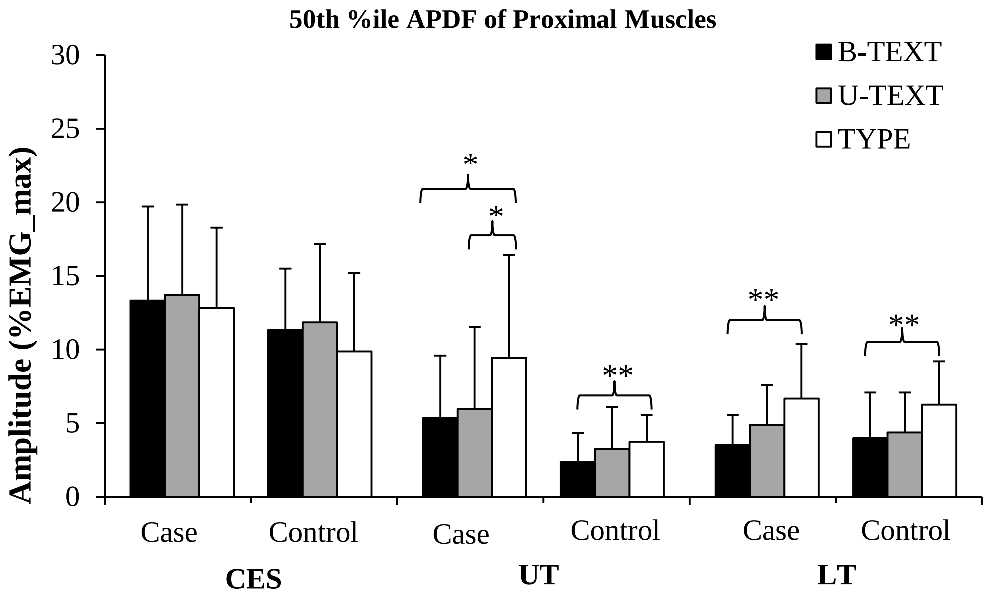


Figure 4.2. Comparison of median muscle activity from the right cervical erector spinae (CES), upper trapezius (UT) and lower trapezius (LT) among Case Group and Control Group during bilateral texting (B-TEXT), unilateral texting (U-TEXT) and computer typing (TYPE). 50th %ile APDF=50 percentile Amplitude Probability Distribution Function. *p<0.05, **p<0.01.

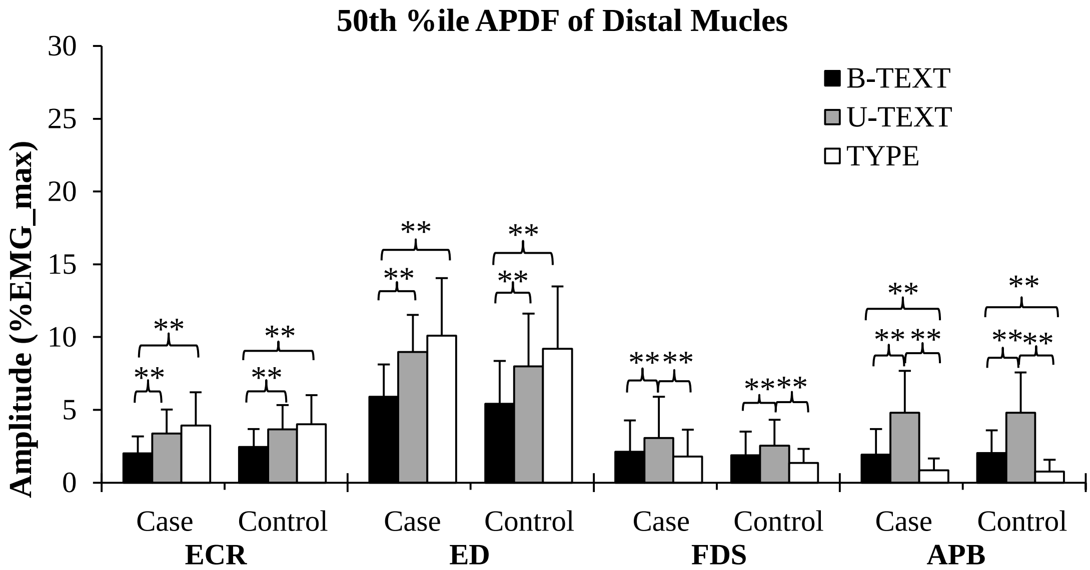


Figure 4.3. Comparison of median muscle activity from the right extensor carpi radialis (ECR), extensor digitorum (ED), flexor digitorum superficialis (FDS) and, abductor pollicis brevis (APB) among Case Group and Control Group during bilateral texting (B-TEXT), unilateral texting(U-TEXT) and computer typing (TYPE). 50th %ile APDF=50 percentile Amplitude Probability Distribution Function. *p<0.05, **p<0.01.

4.3.5. Subjective discomfort, perceived exertion and task performance

The changes in discomfort scores after each task were significantly higher in Case Group compared with Control Group. Similarly, the Case Group reported significantly higher RPE than in Control Group after each task (Table 4.5). However, there were no significant differences in the changes of discomfort scores and RPE among the three tasks within each group. With respect to the task performance, there were no significant differences in texting/typing speed (p=0.210) and accuracy (p=0.402) between groups. The computer typing speed was significantly faster than texting speed on the touchscreen smartphone for both groups (p<0.001).

Table 4.5. Changes in the summed discomfort score from six body areas including neck, shoulder, upper back, elbow, wrist/hand and thumb/fingers on the dominant side (0-60) and rates of perceived exertion (RPE) (6-20) between Case and Control Groups after bilateral texting (B-TEXT), unilateral texting (U-TEXT) and computer typing (TYPE).

		Case Group Mean (SD)	Control Group Mean (SD)	Group *p*-value	Task *p*-value	Group x task *p*-value
Discomfort scores	B-TEXT	7.25 (5.59)	3.40 (4.08)			
	U-TEXT	8.15 (8.62)	3.40 (3.28)	p=0.008**	p=0.494	p=0.731
	TYPE	8.05 (5.95)	4.60 (3.33)			
RPE	B-TEXT	13.85 (2.18)	10.85 (2.13)			
	U-TEXT	13.90 (2.75)	11.35 (1.90)	p<0.001***	p=0.767	p=0.645
	TYPE	13.65 (2.36)	11.35 (2.60)			

Note: ***p* significant at <0.01, ****p* significant at <0.001.

4.4. Discussion

The present study was designed to compare the muscle activity between young people with and without a history of neck-shoulder symptoms when texting on a smartphone with a single hand and with both hands, as both methods are commonly used among smartphone users. Further, the muscle activity results during texting on a smartphone were also compared with a standard typing task on a desktop computer keyboard.

4.4.1. Comparison of muscle activity between Case and Control groups

The present study demonstrated a higher level of muscle activation in CES and UT among young people with neck-shoulder pain compared with asymptomatic subjects in texting and typing tasks. The group differences in muscle activation of the CES and UT are consistent with previous findings reporting 'altered motor control' among office workers with work related musculoskeletal pain (Johnston, Jull, Souvlis & Jimmieson, 2008; Kallenberg & Hermens, 2006; Szeto et al., 2005a). In the present study, higher upper trapezius muscle activity was revealed for the first time among symptomatic subjects compared with asymptomatic subjects during touchscreen smartphone texting. This finding is in agreement with the results found when entering messages on a keypad phone (Gustafsson et al., 2010). A prospective study has reported higher levels of mean EMG activity in upper trapezius prior to and after the occurrence of initial complaints among fish/poultry workers who later developed neck-shoulder complaints compared with those without complaints (Madeleine, Lundager, Voigt, & Arendt-Nielsen, 2003). Similar findings were also reported in different studies showing high amplitude of upper trapezius among individuals who suffered chronic neck and shoulder pain (Falla & Farina, 2005;

Madeleine et al., 1999; Madeleine, Søgaard, Holtermann, & Samani, 2012; Szeto et al., 2005a).

In addition, the present study showed that the difference between the case and control groups seemed to be more apparent during computer typing than texting tasks on a smartphone although no significant interaction between group and task was found. Compared with texting on a touchscreen smartphone, computer typing is considered to impose a higher physical workload with a higher key activation force and more dynamic finger actions. The higher level of activity in the UT muscle among the Case Group during computer typing is consistent with the previous studies supporting an altered motor control associated with musculoskeletal disorders (Madeleine et al., 1999; Szeto et al., 2005a). This is further substantiated by the higher level of activity in the CES muscle among the Case Group although both groups adopted a flexed neck posture when using the smartphone for texting. The altered motor control of the CES and UT in subjects with neck-shoulder pain also provided evidence to support the 'muscle imbalance' concept (Nederhand, IJzerman, Hermens, Baten, & Zilvold, 2000; Novak & Mackinnon, 2002) and the 'Cinderella hypothesis' (Hägg, 1991). The present results showed that despite the fact that using touchscreen smartphones involves very light finger actions, patterns of increased muscle activation in neck-shoulder postural muscles were still present in symptomatic individuals. It has been proposed that 'altered pattern of neuromuscular activation' in neck pain people will result in a loss of synergistic function of deep local muscles, and potentially contribute to the development of musculoskeletal pain (Sterling, Jull, & Wright, 2001).

Furthermore, in this study, the Case Group showed higher levels of 10th and 90th %ile APDF of CES and UT compared with Control Group. This consistent pattern across three levels of APDF confirmed a higher level of muscle activation in young people with neck-shoulder pain compared with asymptomatic subjects. The high muscular activation during the whole period of the texting and typing tasks in the Case Group indicated that the superficial muscles of CES and UT may be 'overloaded' all the time. This pattern may be associated with the presence of neck-shoulder pain. However, as the study design is cross-sectional, it is not possible to determine the cause-effect relationship of neck-shoulder pain and the high levels of muscle activation.

The speculation that altered muscle recruitment pattern is probably associated with the presence of neck-shoulder pain is also supported by the discomfort and RPE findings. The changes in discomfort levels as well as RPE scores were higher in the Case Group compared with Control Group. Interestingly, workers reporting neck pain compared with healthy workers were characterised by increased activity in bilateral cervical extensor muscles when performing functional tasks and by an inability to relax the UT even after task completion (Elert, Kendall, Larsson, Mansson, & Gerdle, 2001; Johnston, Jull, Darnell, Jimmieson, & Souvlis, 2008). Together with previous studies, the present results of 10th, 50th and 90th %ile APDF indicated that a higher muscle activation pattern is somehow persistent in subjects with neck-shoulder pain. These results may suggest that physical therapy and ergonomic intervention such as biofeedback (Madeleine, Vedsted, Blangsted, Sjøgaard, & Søgaard, 2006) facilitating muscle relaxation and correcting such altered motor control are needed in the management of work-related musculoskeletal disorders related to electronic device use.

However, the muscle activity in the forearm region showed a different picture. The lack of group difference in distal muscles in the present study suggests that the muscle recruitment pattern of forearm/hand muscle was not affected by the presence of chronic neck-shoulder pain. This result differs from that reported in a previous study delineating acute experimental muscle pain in trapezius resulting in decreased muscle activity of the wrist extensor during computer mouse work (Samani et al., 2011). The discrepancy was most likely due to the different effects of acute and chronic pain on motor control (Madeleine, Mathiassen, & Arendt-Nielsen, 2008).

4.4.2. Task effect on muscle activity

4.4.2.1 Comparison between computer typing and bilateral texting

Generally, the CES muscle activity was higher during texting on the smartphone compared with typing on the computer, as the subject had to focus on a lower visual target. Previous research that studied the relationship between different computer monitor heights and spinal muscle activity has confirmed that viewing a lower visual target is associated with higher levels of CES activity (Straker, Burgess-Limerick, et al., 2008). Although the smartphone allows people to hold it at the eye level, it is more common for people to hold their phones lower than their eye levels, adopting a flexed neck when using phones (Gold et al., 2012). The different levels of activity in CES between computer typing and bilateral texting in the present study were probably a consequence of the neck postures adopted by subjects during these two tasks. To resist the greater flexor moment related to the flexed neck posture in using the touchscreen smartphone, higher extensor moment is needed most likely accounting for the increased CES activity during bilateral texting.

While the CES mainly stabilises the head posture, the actions of UT and LT are more related to the stabilisation of the neck-shoulder complex. These two muscles displayed higher levels of activity in computer typing compared with bilateral texting. A likely explanation may be that higher key activation force, higher speed and greater involvement of hand activity are required when typing on a computer keyboard. Therefore, greater static activity is needed for UT and LT to control the shoulder girdles and to stabilise the upper limb segment during typing. It has been noted that faster typing speed and higher force are associated with higher activity in UT (Gerard, Armstrong, Martin, & Rampel, 2002; Laursen, Jensen, & Sjøgaard, 1998; Szeto et al., 2005c). To our knowledge, only one study had compared the muscle activity while using a conventional desktop keyboard and a touchscreen keyboard (Shin & Zhu, 2011). However, the touchscreen keyboard in that study was set in a desktop PC setting, so the findings may not be directly comparable with this study.

Concerning the effect of computer typing and bilateral texting on distal muscles, it was found that higher activity in wrist-finger extensors was associated with computer typing whereas thumb muscle showed higher activity during texting. This result was expected considering the difference in the nature between computer typing and texting on a smartphone. During a computer typing task, there is sustained lifting of the wrists and fingers against gravity, leading to higher muscle activity in ECR and ED compared with in bilateral texting where the wrist-finger extensors only contract to support finger flexors. Previous studies have demonstrated that the EMG activity of wrist-finger extensors is high and static during continuous computer typing, which may contribute to lateral epicondylitis (M. Lin et al., 2004). Compared with computer typing where APB is only needed to press the space bar on the keyboard from time to time, APB is responsible for repetitive tapping on the touchscreen smartphone during bilateral texting. As a consequence of this repetitive thumb action, the activity level of APB was higher. These findings showed that different hand actions in computer typing and bilateral texting resulted in different level of muscle activity. Specific ergonomic guidelines regarding the use of different electronic devices especially touchscreen mobile devices are needed for the prevention of neck-shoulder musculoskeletal disorders.

4.4.2.2 Comparison between bilateral texting and unilateral texting

Generally, an increased level of activity was found in the forearm and thumb muscles during unilateral texting compared with bilateral texting. This result was anticipated considering that holding a phone and texting with the same hand lead to increased activity levels of shoulder and forearm muscles. In addition, compared with bilateral texting, larger amplitude and more repetitive thumb movements are involved in unilateral texting, resulting in higher muscle activity in the thumb.

The higher level of muscle activation associated with unilateral texting is in agreement with previous research. In Gustafsson, Johnson, Lindegard & Hagberg (2011), higher muscle activity in extensor digitorum was found among subjects entering text on a keypad phone with one thumb and using one-handed grip compared with using two-handed grip. Young, Trudeau, Odell, Marinelli, & Dennerlein (2013) reported that the angle of wrist radial deviation and EMG amplitude of forearm extensor/flexor muscles increased when supporting a tablet computer with a single hand, which may result in fatigue in wrist muscles and even in upper trapezius. Consequently, texting with two thumbs on touchscreen smartphone should be recommended to lessen the load on proximal and distal muscles and thereby reduce the risk for the development of musculoskeletal disorders.

4.4.3. Limitations of the study

There are limitations to the current study design. The sample size was small and may not furnish sufficient statistical power to detect group differences in some muscles such as the CES. The study is conducted with the individuals' postures standardised in performing texting and typing tasks. This may pose restrictions in their 'natural' postures while using these electronic devices. In addition, each task was performed for a limited time duration. Future studies should examine more different postures and positions during the use of mobile devices. In this study, we compared standardised texting and typing conditions. However, other common functions such as internet browsing, reading and playing electronic games should be investigated in future studies. Only one model of touchscreen smartphone was examined in the present study. Apple and Android products existing with different screen sizes would require different finger actions when operating these devices. Hence there is still a need to carry out larger scale research on the biomechanical loading (EMG, kinetic and kinematics recordings) involved in using such mobile devices.

4.5. Conclusion

The present study demonstrated that young people with neck-shoulder pain had a consistently higher level of muscle activity in CES and UT when performing bilateral texting, unilateral texting and computer typing tasks compared with healthy subjects. This result is consistent with the findings from previous research on altered motor control associated with work-related musculoskeletal disorders.

The use of different electronic devices imposed different physical demands on muscles. While greater muscle loading was recorded on neck extensor and thumb muscles during texting on a touchscreen smartphone, a higher demand was placed on upper and lower trapezius muscles and wrist-finger extensors when typing on the computer compared with texting on a smartphone. Moreover, texting on the touchscreen of a smartphone with only one hand was associated with higher muscle loading in the shoulder and forearm as well as thumb compared with texting using two hands. Specific ergonomic guidelines concerning the use of modern electronic devices should be developed to reduce the risk of developing musculoskeletal disorders.

CHAPTER 5
ASSOCIATION OF MUSCLE ACTIVITY AND SPINAL KINEMATICS DURING SMARTPHONE TEXTING AND COMPUTER TYPING

In the current study, we have examined the surface EMG as well as the spinal kinematics in subjects when they performed texting and typing tasks. In Chapter 4, main results on the surface EMG activity of the right-sided muscles were reported, as the right upper limb was actively involved in all the three experimental tasks. In this chapter, EMG results on the left side are included, as it is relevant to examine these data especially in comparing the bilateral texting and computer typing. These results are examined together with the kinematics data as well as the discomfort scores. The association among bilateral muscle activity, kinematics and perceived discomfort scores after experimental tasks was also examined and presented in this chapter. The aim is to explore how these variables may differ between those with chronic neck-shoulder pain and those without. This provides useful information on the motor control associated with the underlying pathomechanisms. This chapter starts with an overview of past research that examined kinematics and postures in using mobile devices, as this was not introduced in the last chapter.

5.1. Introduction – research on spinal kinematics associated with handheld device use

Since smartphones became popular, there has been increasing interest in the research community about the ergonomic issues in using these touchscreen devices. There have been a few studies examining effects of handheld devices on users' postures in order to understand the health implication of these devices. Users were found to usually display neck flexion angles of 20° or higher while interacting with handheld devices (Kietrys, Gerg, Dropkin, & Gold, 2015; S. Lee, Kang, & Shin, 2015; Ning, Huang, Hu, & Nimbarte, 2015). A study examined gravitational demands for the head-neck musculature via biomechanical modelling, illustrating that gravitational demands produced by flexed head and neck postures while holding a tablet computer is around 3-5 times higher than that posed by a seated neutral posture (Vasavada, Nevins, Monda, Hughes, & Lin, 2015). The aforementioned research studies in this session indicated that the use of handheld devices is very likely to be associated with an increased flexed neck posture and increased demands on the postural muscles to counteract gravity. Furthermore, these research studies are in line with past research on neck pain in computer users which suggested that increased neck flexion or a static neck posture is a potential risk factor for developing neck discomfort or pain (Ariëns et al., 2001; Cagnie et al., 2007).

Various factors have been found to affect the postures during the use of handheld devices, for example, whether using handheld devices in a sitting or standing posture. By comparing the head flexion angle between using smartphones in sitting and standing postures, S. Lee et al. (2015) found that subjects showed a greater head flexion angle in sitting than in standing. Another factor that influences the posture of handheld device users is device features including screen sizes and device configurations. Ning et al. (2015) measured the effects of handheld devices of different screen sizes (iPhone vs iPad) on the neck posture, revealing that subjects maintained their neck more flexed when using iPhone which has a smaller screen size compared with using iPad. Several studies investigated how device configurations, e.g. on the lap, on a flat table, supported by cases of various tilt angles and in a handheld position, influence head and neck postures (Albin & McLoone, 2014; Ko et al., 2015; Ning et al., 2015; Young et al., 2012, 2013). These studies demonstrated that subjects' head and neck flexion angles were around 15°

greater when using touchscreen handheld devices on the lap compared with that in neutral postures. Additionally, the head or neck flexion posture in using mobile phones may also be affected by individual factors such as gender. Female healthy individuals were reported to show significantly smaller head flexion angle and larger neck flexion angle compared with male individuals (Guan et al., 2015). It should be considered that whether these various factors such as the subject's position, features of devices and gender play an important role in the difference of the postures of the spine between symptomatic and asymptomatic individuals

There have been, to the best of my knowledge, only two studies on the cervical posture in symptomatic individuals while using smartphones (Gustafsson et al., 2011; M. S. Kim, 2015). But both studies have some limitations, for example, there was a lack of quantitative measurements for the cervical posture in the study from Gustafsson and her colleagues (2011). Tasks were performed for a short time (5 minutes) and only the sagittal plane of cervical movements was examined in the study from M. S. Kim (2015). Furthermore, these two studies only examined kinematics of the cervical spine instead of the whole spine. Previous research reported that the head/neck posture and cervico-thoracic muscle activity were affected by thoraco-lumbar postures during sitting (Caneiro et al., 2010; Falla, Jull, Russell, Vicenzino, & Hodges, 2007; O'Sullivan et al., 2006). The thoracic flexion angle was suggested to be a better predictor for neck pain than that of the craniovertebral angle (K. T. Lau et al., 2010). Tsang et al. (2013a, 2013b) found high movement coordination between the cervical and thoracic spines, and individuals with chronic neck pain presented with lower degrees of inter-spinal movement coordination compared with healthy individuals. Therefore, in the present study, the measurement of thoracic and lumbar kinematics in addition to cervical kinematics have been included, in order to provide better understanding of how these adjacent spinal regions move during smartphone texting tasks. This aspect of biomechanical study is important and novel since the study involved both symptomatic and asymptomatic subjects.

The spinal kinematics were measured in the cervical, thoracic and lumbar spines. These are compared between symptomatic and asymptomatic individuals and also compared between tasks, namely bilateral texting, unilateral texting and computer typing. The spinal kinematics data are examined in terms of their association with the muscle activity data. In addition, how these biomechanical data are related to the individuals' experience of discomfort after performing the experimental tasks and any possible effect in relation to personal characteristics such as gender are presented.

5.2. Methods

5.2.1. Subjects

The subject population is the same as described in Chapter 4. While all 40 subjects were measured for muscle activity by surface EMG, only 38 subjects in total (20 in Case Group and 18 in Control Group) were recorded for kinematics during the experiment. The data from one subject in the Case Group was discarded due to errors in securing the motion sensor which affected the accuracy of the data. Therefore, in the end, only data from 19 subjects (Male=8, Female=11) in Case Group and 18 (Male=7, Female=11) in Control Group were used for statistical analysis in terms of spinal kinematics. The association between kinematics, the muscle activity in the neck and shoulder regions, and discomfort scores was also examined among these 37 subjects. These 37 subjects have similar demographic characteristics and pain profiles as the full groups delineated in Chapter 4.

5.2.2. Experimental protocols

The experimental protocol was the same as described in Chapter 4.

5.2.3. Kinematic measurements

Synchronized EMG signals and kinematics were captured during each task. An inertial measurement unit system (MyoMotion Clinical, Noraxon U.S.A. Inc.) was employed to track angular displacements of cervical, thoracic and lumbar spines in three cardinal planes (sagittal, frontal and horizontal) during texting and typing tasks. The data of kinematics were captured with a sampling frequency of 1500 Hz. Four sensors were attached to the bony landmarks of the external occipital protuberance, C7, T12 and the bony area of the sacrum (Figure 5.1). The relative position and orientation of receivers secured at C7 referenced to the external occipital protuberance, at T12 referenced to C7, and at the bony area of the scrum referenced to T12 represented the posture of cervical spine, thoracic spine and lumbar spine, respectively, (Figure 5.1). Angular displacements measured were (1) cervical spine (Cx) X (flexion/extension), Cx Y (right/left side flexion) and Cx Z (right/left rotation); (2) thoracic spine (Tx) X, Tx Y and Tx Z; (3) lumbar spine (Lx) X, Lx Y and Lx Z. Movement directions of flexion, right side flexion and right rotation were identified as positive values while extension, left side flexion and left rotation were negative values in the inertial measurement unit system.

Prior to the start of the experiment, a resting trial with the subject sitting upright, the hips and knees 90° flexed and looking straight ahead was recorded to capture reference (zero) positions of the sensors. The angular displacement during each task was processed using amplitude probability distribution function (APDF). 50th percentile (%ile) which is the median displacement as well as the difference between 90th %ile and 10th %ile of APDF (APDF range) representing the joint range of movements were computed (P. Jonsson, Johnson, & Hagberg, 2007; Straker, Burgess-Limerick, Pollock, & Maslen, 2009; Szeto et al., 2005b). An increased APDF range means a greater change in postural angles and therefore reflects the increased variability of movements (Arvidsson, Hansson, Mathiassen, & Skerfving, 2006; Mathiassen, 2006; Straker, Burgess-Limerick, Pollock, & Maslen, 2009; Wahlström et al., 2010). In addition, the percentage of time in each direction of movement, e.g. flexion/extension, was computed with reference to the whole task duration as 100%.

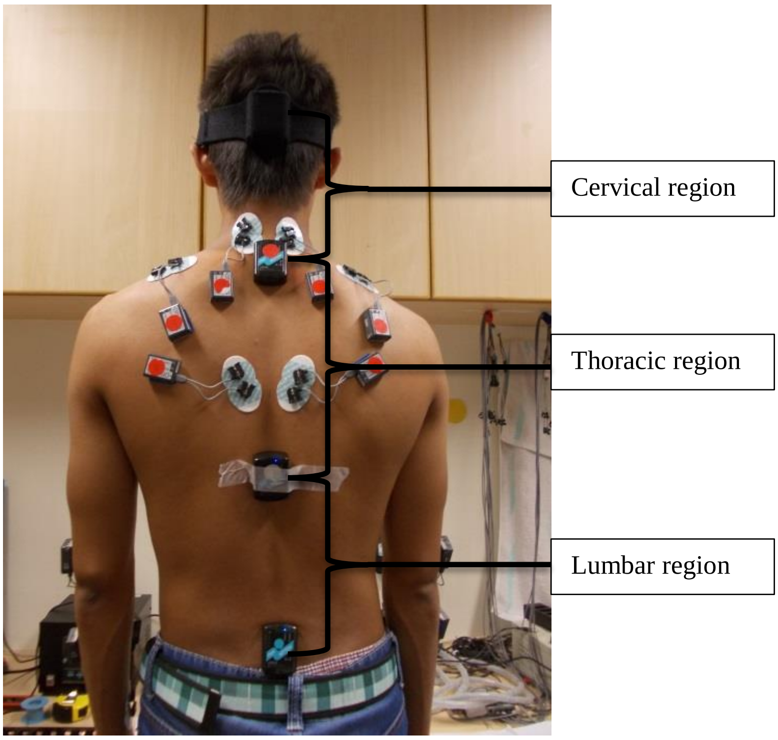


Figure 5.1. Locations of sensors in a subject. The first kinematic sensor was placed at posterior surface of the external occipital protuberance. The second sensor was placed at C7 while the third at T12 and the fourth at bony area of sacrum.

5.2.4. EMG measurements and discomfort scores

Muscle activity of proximal and distal muscles on the left side was measured and processed in the same way as that on the right side which was presented in Chapter 4. In Chapter 4, only the summed discomfort scores were included. In this chapter, bilateral discomfort scores in the neck and upper limb body regions (12 regions in total) before and after each task are presented.

5.2.5. Statistical analysis

Dependent variables of the kinematics were: (i) percentages of time in six movement directions, (ii) median (50th %ile APDF) angular displacements of cervical, thoracic and lumbar spines in three planes (sagittal, frontal and transverse planes), (iii) ranges of movements (APDF range) in three planes.

The independent variables consisted of group (x2 levels) and task (x3 levels) which involved bilateral texting, unilateral texting and computer typing. A mixed model repeated measure analysis of variance (RMANOVA) was performed to examine the effect of group as the between-subject factor and task as the within-subject factor on dependent variables. Post-hoc analysis with Bonferroni correction was conducted where a significant effect for task or group x task interactions was found. Spearmen's rho correlation analyses were performed to examine the association between kinematics, muscle activity, and discomfort scores.

Data of 10th, 50th and 90th %ile APDF of left-sided muscles and discomfort scores of specific body regions before and after tasks were analyzed with the same statistical methods delineated in Chapter 4.

To examine whether the demographics of female/male symptomatic subjects and female/male asymptomatic subjects were matched, Case and Control Group were sub-divided into female and male groups, respectively. Independent t-test was performed to investigate whether demographic characteristics, patterns of using electronic devices and pain profiles were comparable between female/male Case Group and female/male Control Group. If significant differences were found between female/male Case Group and female/male Control Group in the independent t-test, a further statistical analysis would conduct to examine the effect of gender on the results of EMG activity of bilateral muscles and kinematics. In this further analysis, RMANOVA would be adopted where group and gender would be examined as the between-subject factor and task as the within-subject factor to examine whether there were group x gender interactions. SPSS V23.0 (IBM, USA) was adopted for all the statistical analyses and statistical significance was assumed when *p*-value lowered than 0.05.

5.3. Results

In the current section, patterns of kinematics are first presented, followed by the remaining results of surface EMG activity in the left-sided muscles and discomfort scores in specific body regions. Thereafter, the correlation among kinematics, muscle activity and discomfort scores are shown. Finally, further analysis is considered concerning that how gender may modify the difference between groups in dependent variables.

5.3.1. Kinematics

The time spent in two opposite directions of movements in one plane such as flexion and extension in the sagittal plane of cervical, thoracic and lumbar spines is presented as the percentage of the whole 10 minutes, which is the duration of each task. The results of median angles and ranges of movements from three defined segments were analyzed in the texting and typing tasks, and compared between groups. Similar with muscle activity, comparisons of kinematics among three conditions would focus mainly on the contrast between bilateral texting and computer typing as well as between bilateral texting and unilateral texting.

5.3.1.1. Percentages of time in each movement direction

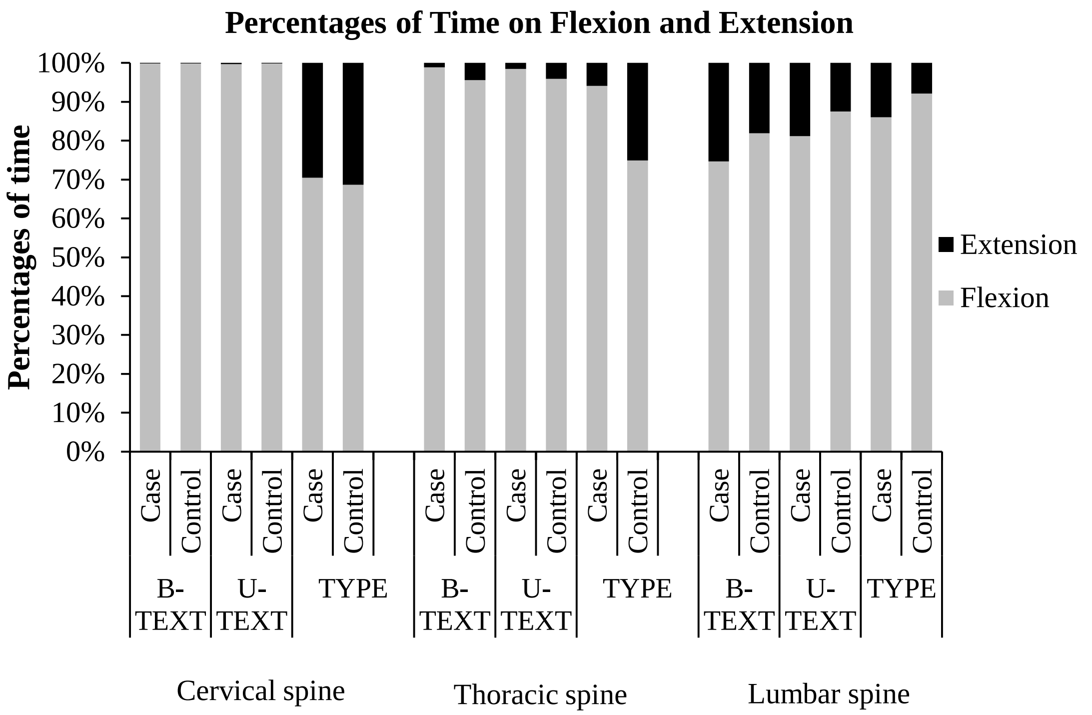
Group mean values of the percentage of time in each movement direction are presented in Figures 5.2 a-c. It is apparent that subjects adopted a flexed spine for most of the time when texting on a smartphone, and this pattern was similar between Case Group and Control Group. The time on the neck and thoracic flexion was 95% or higher in the 10-minute period of smartphone texting while 68% or higher in computer typing for both groups.

In the RMANOVA analysis, no significant differences were found between groups in terms of the percentage of time in each movement direction of cervical, thoracic and lumbar spines, namely flexion, extension, right and left side rotation, as well as right and left rotation. However, Case Group marginally spent more time on thoracic flexion compared with Control Group while texting on the smartphone and typing on the computer ($F_{1,35}$=2.95, p=0.095; Figure 5.2 a).

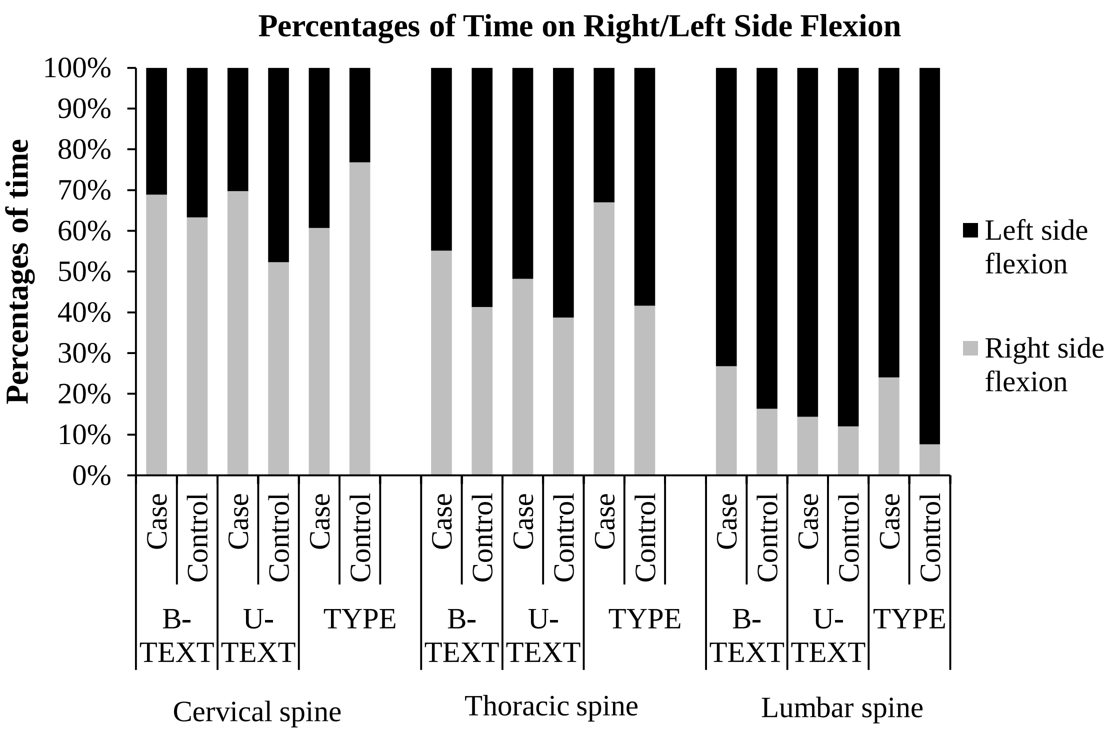
The RMANOVA analysis revealed a significant effect for tasks in percentages of time in cervical flexion ($F_{2,70}$=26.61, p<0.001) and thoracic flexion ($F_{2,70}$=6.71, p=0.002). It can be seen from Figure 5.2a that the duration of time spent in cervical and thoracic flexion during bilateral texting is significantly longer than that during computer typing for both groups. There were no differences between the smartphone texting tasks and the computer typing task with respect to percentages of time spent in right and left side flexion, as well as right and left rotation of cervical, thoracic and lumbar spines in both groups (Figure 5.2 b and Figure 5.2 c).

Regarding the comparison between bilateral texting and unilateral texting, significant difference was only found in the percentage of time in cervical rotation, according to the post-hoc pairwise comparison (t=-0.189, p=0.037). Subjects in both groups spent more time on cervical right rotation while performing unilateral texting compared with bilateral texting (Figure 5.2 c).

(a)


Percentages of Time on Flexion and Extension
Percentages of time
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Extension
Flexion
Case
Control
B-TEXT
U-TEXT
TYPE
Cervical spine
Thoracic spine
Lumbar spine

(b)


Percentages of Time on Right/Left Side Flexion
Percentages of time
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Left side flexion
Right side flexion
Case
Control
B-TEXT
U-TEXT
TYPE
Cervical spine
Thoracic spine
Lumbar spine

(c)

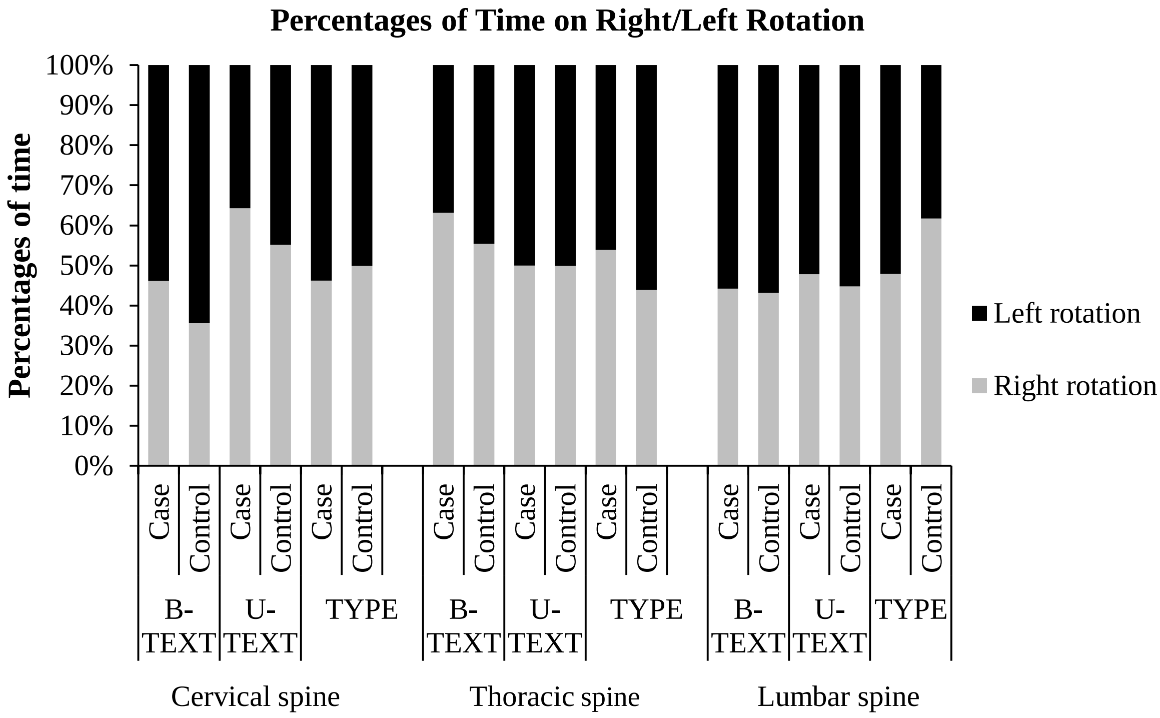


Figure 5.2. Percentages of time in six movement directions of cervical, thoracic and lumbar spines, (a) flexion and extension, (b) left and right side flexion, (c) left and right rotation. B-TEXT=bilateral texting, U-TEXT=unilateral texting and TYPE=computer typing.

5.3.3.2. Median angles and ranges of angular displacements

Generally, all subjects adopted a flexed spine in performing tasks, particularly in smartphone texting tasks. The grand mean values (combined data from two groups) of median cervical flexion angles were 28.4°±1.0° during bilateral texting, 24.8°±1.2° during unilateral texting and 3.6°±1.5° during computer typing. Subjects also displayed a flexed thoracic posture, with 9.4°±0.9° thoracic flexion during bilateral texting, 8.5°±0.9° during unilateral texting and 6.1°±1.1° during computer typing. In addition, grand means of median lumbar flexion angles were 6.6°±1.3°, 8.5°±1.3° and 10.5°±1.4° during bilateral texting, unilateral texting and computer typing, respectively. Mean values of median angles in right/left side flexion and rotation were small, with a variation of 0.1° to 3.1° in the three tasks for both groups. The ranges of angular displacements in frontal and transverse planes in three defined spinal segments were also small and the mean ranges in the sagittal plane varied from 2.8° to 11.4° during the three tasks.

The RMANOVA analysis showed that there was a significant group x task interaction for the angular displacement of cervical side flexion (Table 5.1). As the post-hoc analysis revealed, the joint angle of cervical right side flexion was greater in Case Group than in Control Group during bilateral texting and unilateral texting while the angle was similar between groups during computer typing (Table 5.2). In addition, Case Group had significantly greater ranges in the cervical rotation compared with Control Group while performing the three tasks (Table 5.1 and Table 5.2). With regard to kinematics in the thoracic spine, generally, Case Group displayed a slightly higher median thoracic flexion angle than Control Group, but no significant differences were found (Table 5.1 and Table 5.2). There were no group differences in any kinematic variables in the lumbar spine.

Subjects in both groups presented significantly larger median flexion angles in the cervical and thoracic spines while performing bilateral texting compared with computer typing (Figure 5.3). In contrast, the median angle of lumbar flexion was significantly greater in computer typing than in bilateral texting for both groups (Figure 5.3). There were no differences in median joint angles of other movement planes such as side flexion and rotation of the cervical, thoracic and lumbar spines between bilateral texting and computer typing. In terms of the range of joint angles, compared with bilateral texting, subjects from both groups had around 4.7 ° and 2.2° greater ranges in cervical flexion/extension and rotation respectively while performing computer typing (Figure 5.4).

Generally, subjects from both groups had significantly greater cervical flexion and less right rotation angles in bilateral texting compared with unilateral texting (Figure 5.3 and Figure 5.5). Subjects also presented significantly greater ranges in cervical rotation and side flexion while performing unilateral texting compared with bilateral texting (Figure 5.4). No differences were shown in the kinematics of the thoracic and lumbar spines between bilateral texting and unilateral texting for both groups.

Table 5.1. Summary of multivariate and univariate analyses for the median angles and ranges of joint angles in three spinal segments.

Movements	Effects	Multivariate (Median angles and ranges)	Univariate (Median angles)	Univariate (Ranges)
Cx X	Group	$F_{2,34}$=0.01, *p*=0.993	$F_{1,35}$<0.01, *p*=0.998	$F_{1,35}$=0.02, *p*=0.905
	Task	**$F_{4,32}$=68.36, *p*<0.001**	**$F_{1.4,70}$=207.13, *p*<0.001**	**$F_{1.5,70}$=13.53, *p*<0.001**
	Group x task	$F_{4,32}$=0.30, *p*=0.878	$F_{1.4,70}$=0.41, *p*=0.593	$F_{1.5,70}$=0.22, *p*=0.735
Cx Y	Group	$F_{2,34}$=1.07, *p*=0.354	$F_{1,35}$=1.87, *p*=0.180	$F_{1,35}$=0.44, *p*=0.510
	Task	**$F_{4,32}$=5.83, *p*=0.001**	$F_{1.7,70}$=1.16, *p*=0.314	**$F_{2,70}$=6.01, *p*=0.004**
	Group x task	$F_{4,32}$=1.94, *p*=0.129	**$F_{1.7,70}$=5.62, *p*=0.009**	$F_{2,70}$=0.44, *p*=0.645
Cx Z	Group	**$F_{2,34}$=3.55, *p*=0.040**	$F_{1,35}$=1.62, *p*=0.211	**$F_{1,35}$=6.68, *p*=0.014**
	Task	**$F_{4,32}$=12.25, *p*<0.001**	**$F_{2,70}$=4.80, *p*=0.011**	**$F_{1.6,70}$=9.43, *p*=0.001**
	Group x task	$F_{4,32}$=1.28, *p*=0.300	$F_{2,70}$=1.90, *p*=0.157	$F_{1.6,70}$=0.83, *p*=0.418
Tx X	Group	$F_{2,34}$=2.03, *p*=0.147	$F_{1,35}$=1.40, *p*=0.244	$F_{1,35}$=3.09, *p*=0.087
	Task	**$F_{4,32}$=6.96, *p*<0.001**	**$F_{1.7,70}$=7.49, *p*=0.002**	**$F_{1.7,70}$=3.72, *p*=0.038**
	Group x task	$F_{4,32}$=2.12, *p*=0.101	$F_{1.7,70}$=1.86, *p*=0.171	$F_{1.7,70}$=2.73, *p*=0.083
Tx Y	Group	$F_{2,34}$=2.00, *p*=0.150	$F_{1,35}$=0.84, *p*=0.365	$F_{1,35}$=3.28, *p*=0.079
	Task	**$F_{4,32}$=3.39, *p*=0.020**	$F_{2,70}$=1.50, *p*=0.230	$F_{1.2,70}$=2.96, *p*=0.087
	Group x task	$F_{4,32}$=0.62, *p*=0.649	$F_{2,70}$=0.56, *p*=0.573	$F_{1.2,70}$=0.49, *p*=0.519
Tx Z	Group	$F_{2,34}$=1.25, *p*=0.300	$F_{1,35}$=1.54, *p*=0.223	$F_{1,35}$=1.18, *p*=0.285
	Task	**$F_{4,32}$=5.54, *p*=0.002**	$F_{1.3,70}$=1.20, *p*=0.291	**$F_{2,70}$=3.42, *p*=0.038**
	Group x task	$F_{4,32}$=1.24, *p*=0.315	$F_{1.3,70}$=1.23, *p*=0.286	$F_{2,70}$=0.13, *p*=0.877
Lx X	Group	$F_{2,34}$=0.73, *p*=0.488	$F_{1,35}$=0.29, *p*=0.592	$F_{1,35}$=1.30, *p*=0.262
	Task	**$F_{4,32}$=4.66, *p*=0.004**	**$F_{2,70}$=7.42, *p*=0.001**	$F_{2,70}$=1.01, *p*=0.371
	Group x task	$F_{4,32}$=0.54, *p*=0.709	$F_{2,70}$=1.59, *p*=0.211	$F_{2,70}$=0.11, *p*=0.893
Lx Y	Group	$F_{2,34}$=0.54, *p*=0.590	$F_{1,35}$=0.17, *p*=0.682	$F_{1,35}$=0.97, *p*=0.332
	Task	**$F_{4,32}$=3.35, *p*=0.021**	$F_{2,70}$=2.33, *p*=0.105	**$F_{2,70}$=3.28, *p*=0.044**
	Group x task	$F_{4,32}$=0.30, *p*=0.876	$F_{2,70}$=0.69, *p*=0.507	$F_{2,70}$=0.14, *p*=0.867
Lx Z	Group	$F_{2,34}$=0.89, *p*=0.420	$F_{1,35}$=0.31, *p*=0.583	$F_{1,35}$=0.54, *p*=0.466
	Task	$F_{4,32}$=0.72, *p*=0.585	$F_{1.6,70}$=0.14, *p*=0.819	$F_{1.7,70}$=1.13, *p*=0.323
	Group x task	$F_{4,32}$=1.89, *p*=0.136	$F_{1.6,70}$=3.07, *p*=0.066	$F_{1.7,70}$=0.72, *p*=0.471

Note: Cx=cervical spine, Tx=thoracic spine, Lx=lumbar spine, R=right, L=left, X=flexion/extension, Y=right/left side flexion, Z=right/left rotation.

Table 5.2. Mean ±SD of median angles and ranges in three spinal segments.

	Spinal movements	B-TEXT [mean(SD)]		U-TEXT [mean (SD)]		TYPE [mean (SD)]	
		Case	Control	Case	Control	Case	Control
Median angles	Cx X	28.2 (5.7)	28.6 (6.5)	24.3 (6.4)	25.2 (8.3)	4.3 (11.4)	2.9 (6.6)
	Cx Y	3.1 (5.3)	0.6 (4.3)	2.7 (5.8)	-0.8 (5.4)	1.2 (4.1)	1.6 (2.3)
	Cx Z	-0.4 (2.3)	-1.6 (3.1)	3.4 (6.3)	0.5 (2.2)	-0.4 (1.4)	0.5 (6.6)
	Tx X	10.8 (4.5)	8.0 (6.0)	8.5 (4.1)	8.5 (6.2)	7.7 (7.2)	4.6 (6.6)
	Tx Y	0.2 (2.8)	-0.5 (2.9)	-0.5 (2.4)	-0.8 (2.7)	0.6 (2.1)	-0.5 (2.8)
	Tx Z	0.9 (4.0)	-0.2 (2.1)	0.5 (4.0)	-0.2 (1.4)	0.7 (3.0)	-1.1 (3.4)
	Lx X	5.9 (9.2)	7.3 (6.9)	8.8 (7.5)	8.2 (8.1)	9.0 (9.6)	12.0 (7.2)
	Lx Y	-3.0 (3.5)	-3.2 (3.0)	-3.5 (3.0)	-3.5 (2.6)	-2.2 (3.1)	-3.1 (2.2)
	Lx Z	0.2 (2.6)	0.9 (3.1)	0.8 (4.1)	0.5 (2.5)	0.1 (2.8)	1.3 (3.3)
Ranges	Cx X	6.1 (3.4)	6.4 (3.8)	7.4 (5.3)	7.5 (3.8)	11.4 (7.3)	10.6 (5.6)
	Cx Y	3.1 (1.1)	2.3 (3.7)	4.2 (2.2)	4.2 (2.3)	3.3 (1.3)	3.0 (1.6)
	Cx Z	2.0 (1.4)	0.5 (3.6)	3.7 (3.0)	2.2 (1.9)	3.6 (1.4)	3.3 (1.4)
	Tx X	5.8 (5.1)	2.4 (5.2)	5.4 (3.9)	4.8 (2.9)	4.1 (2.2)	2.8 (1.6)
	Tx Y	2.1 (1.1)	0.3 (6.6)	3.3 (1.9)	2.3 (1.4)	2.3 (1.0)	1.7 (0.9)
	Tx Z	1.2 (0.8)	0.9 (0.6)	1.6 (1.6)	1.1 (1.4)	1.7 (1.1)	1.5 (1.1)
	Lx X	4.2 (4.7)	3.2 (1.7)	5.1 (5.8)	4.0 (2.4)	5.2 (4.7)	3.6 (2.5)
	Lx Y	1.2 (0.8)	0.7 (1.9)	1.6 (1.6)	1.5 (1.2)	1.9 (1.6)	1.6 (1.6)
	Lx Z	0.8 (0.3)	1.0 (1.4)	1.5 (2.7)	1.2 (1.5)	2.2 (4.4)	1.2 (0.9)

Note: Cx=cervical spine, Tx=thoracic spine, Lx=lumbar spine, R=right, L=left, X=flexion/extension (positive values=flexion, negative values=extension), Y=right/left side flexion (positive values=right side flexion, negative values =left side flexion), Z=right/left rotation (positive values=right rotation, negative values=left rotation), B-TEXT=bilateral texting, U-TEXT=unilateral texting and TYPE=computer typing.

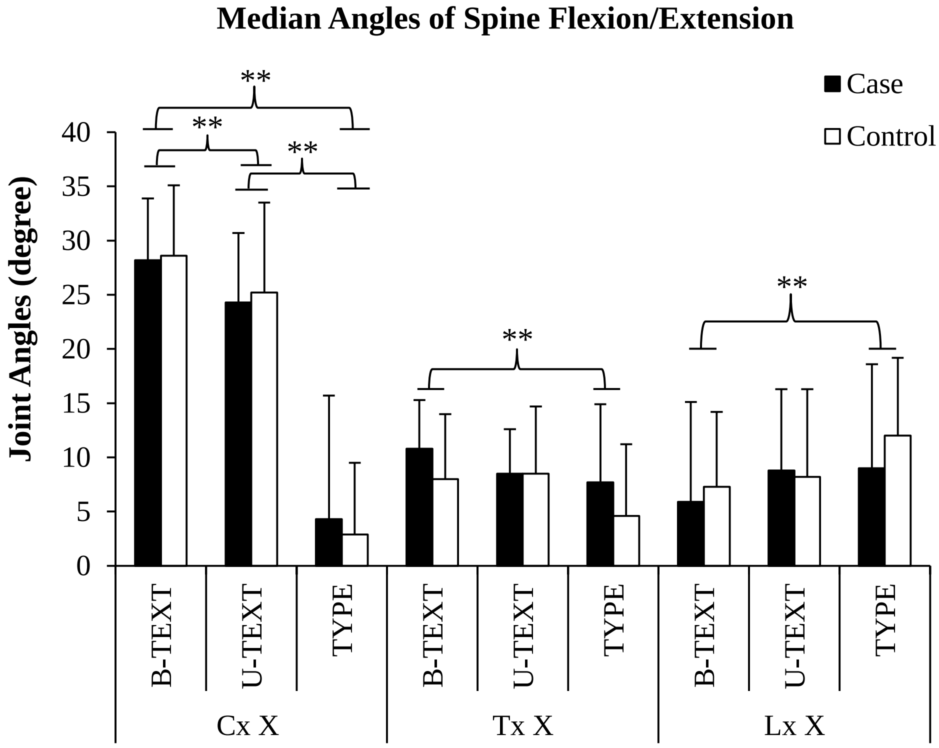


Figure 5.3. Median flexion angles of the three spine segments for Case Group and Control Group during bilateral texting (B-TEXT), unilateral texting (U-TEXT) and computer typing (TYPE). Cx X=cervical flexion/extension, Tx X=thoracic flexion/extension, Lx X=lumbar flexion/extension. Positive values: flexion. **Significant differences between tasks for both groups, p<0.001.

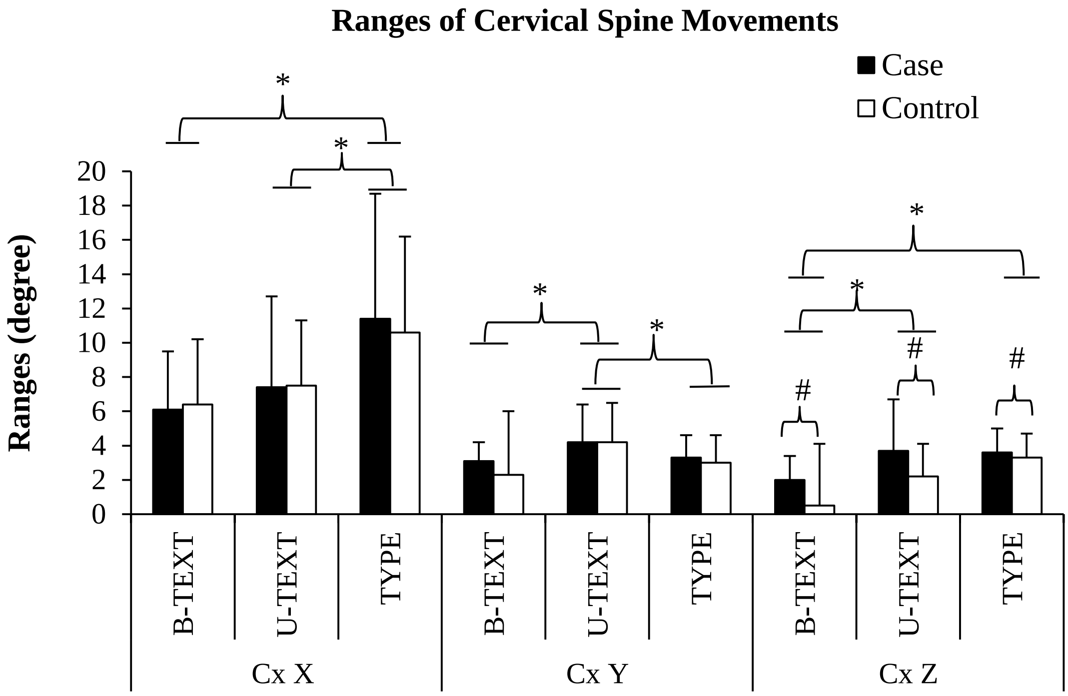


Figure 5.4. Ranges of cervical spine movements in the three anatomical planes for Case Group and Control Group during bilateral texting (B-TEXT), unilateral texting (U-TEXT) and computer typing (TYPE).Cx X=Cervical flexion/extension, Cx Y= Cervical right/left side flexion, Cx Z=Cervical right/left rotation. *Significant differences between tasks for two groups, $p<0.05$. #Significant differences between groups, $p<0.05$.

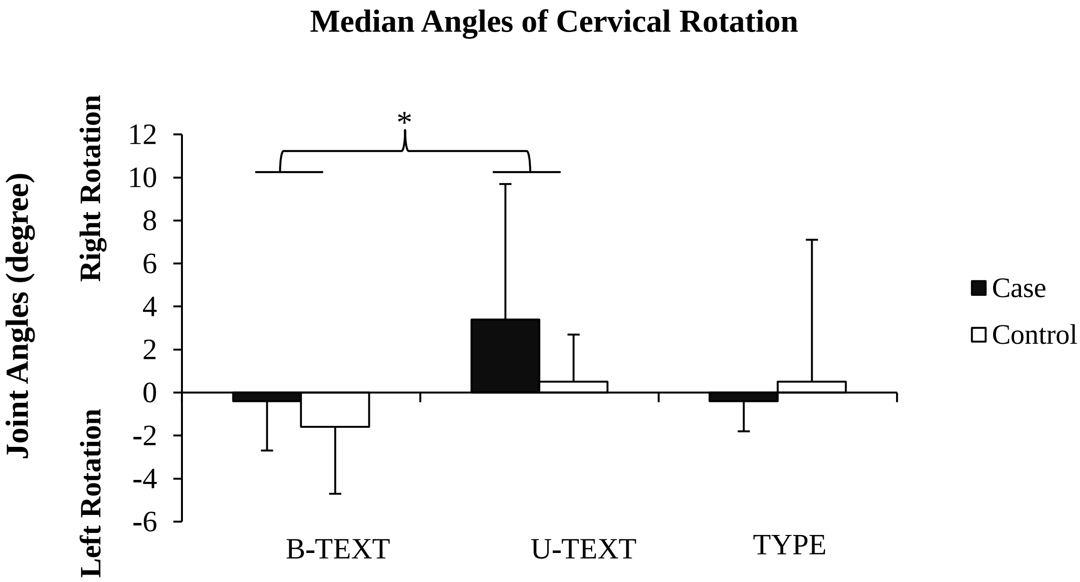


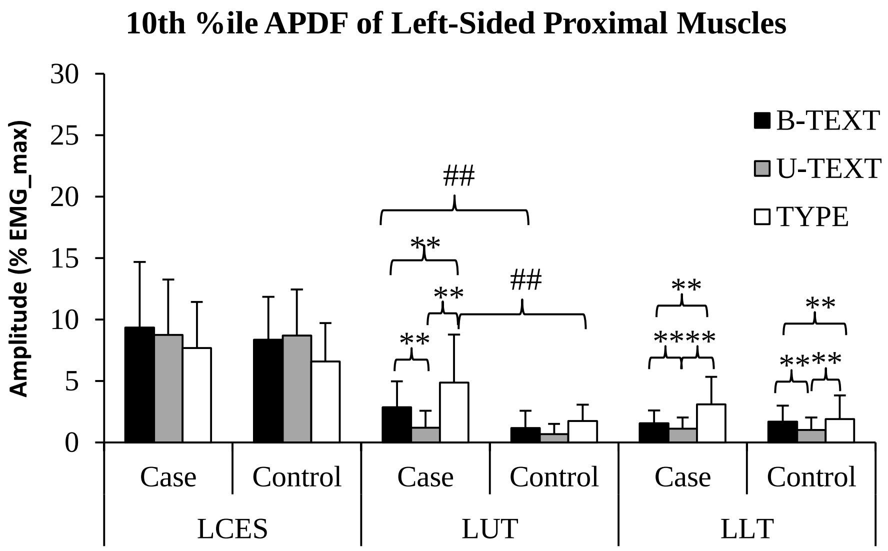
Figure 5.5. Median angles of cervical rotation for Case Group and Control Group during bilateral texting (B-TEXT), unilateral texting (U-TEXT) and computer typing (TYPE). *Significant differences between tasks for two groups, $p<0.05$.

5.3.2. Results of left-sided muscle activity

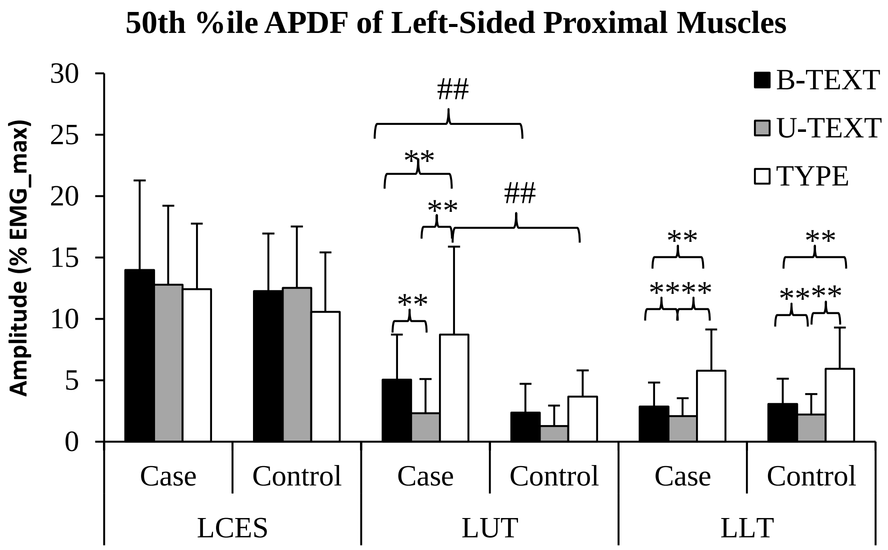
Similar to the results of the EMG activity of muscles on the right hand side, as described in Chapter 4, Case Group showed a trend of higher 10th, 50th and 90th %ile APDF of LCES compared with Control Group although no statistical significance was found (Figure 5.6 a-c). There was a main effect for task in 10th %ile APDF (p=0.001) and 50th %ile APDF (p=0.048) of LCES. Post-hoc analysis revealed that both the 10th and 50th %ile APDF of LCES in both groups were significantly higher in bilateral texting than in computer typing. 50th %ile APDF of LUT showed significant effects for group (p=0.004), task (p<0.001) and group x task interactions (p=0.013). Post-hoc analysis showed significantly higher median muscle activity of LUT for Case Group during bilateral texting (p=0.009) and computer typing (p=0.005) compared with Control Group (Figure 5.6 b). Furthermore, the group difference in computer typing was greater than that in bilateral texting (Figure 5.6 b). The median activity of LUT in Case Group was significantly different among tasks, with highest activity in computer typing, following by bilateral texting and unilateral texting. However, the median activity of LUT in Control Group was similar and maintained at very low levels in all three tasks (Figure 5.6 b). Similar patterns were found in 10th and 90th as in 50th %ile APDF of LUT (Figure 5.6 a, c). There were no significant effects for group and group x task interactions, but there was a significant main effect for task in 10th %ile (p<0.001), 50th %ile (p<0.001) and 90th %ile APDF (p<0.001) of LLT. As depicted in Figure 5.6 a-c, subjects of both groups demonstrated highest activity for LLT during computer typing, less activity during bilateral texting and the least during unilateral texting.

Regarding forearm and thumb muscles, namely LECR, LED, LFDS and LAPB, there was a significant effect for task, but not for group and group x task interactions. By comparing muscle activity between bilateral texting and computer typing in static, median and peak activity for these left-sided forearm and thumb muscles, the results were the same as that in right-sided muscles described in Chapter 4 (Section 4.3.3) (Figure 5.7 a-c). In terms of comparing muscle activity between the two texting tasks, obviously, activity in the left-sided forearm and thumb muscles were significantly higher in bilateral texting than in unilateral texting (Figure 5.7 a-c), the results of which were the opposite as that in right-sided muscle shown in Chapter 4 (Section 4.3.4).

(a)



(b)



(c)

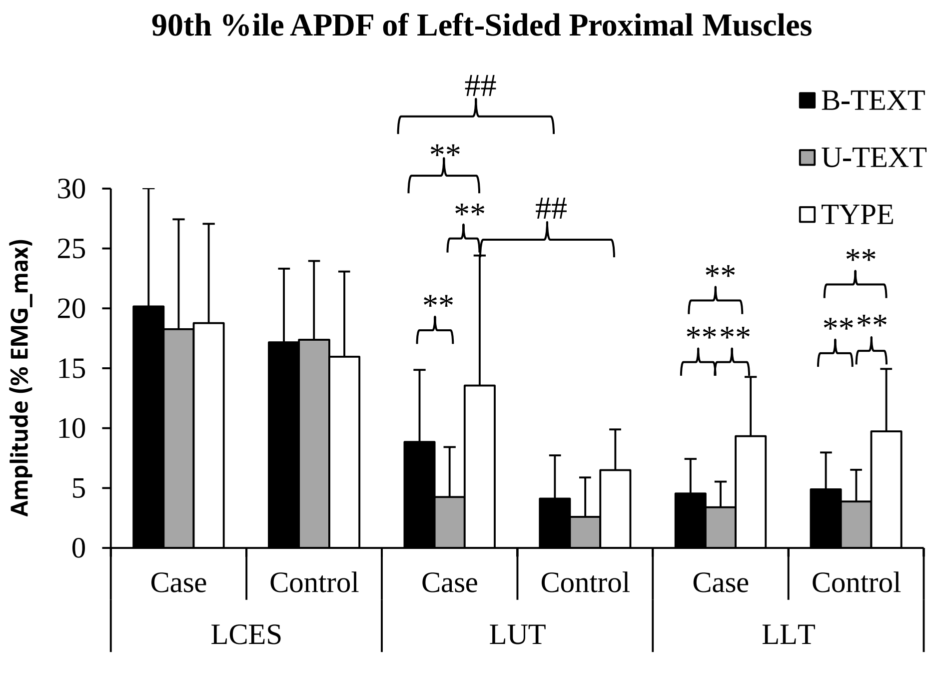
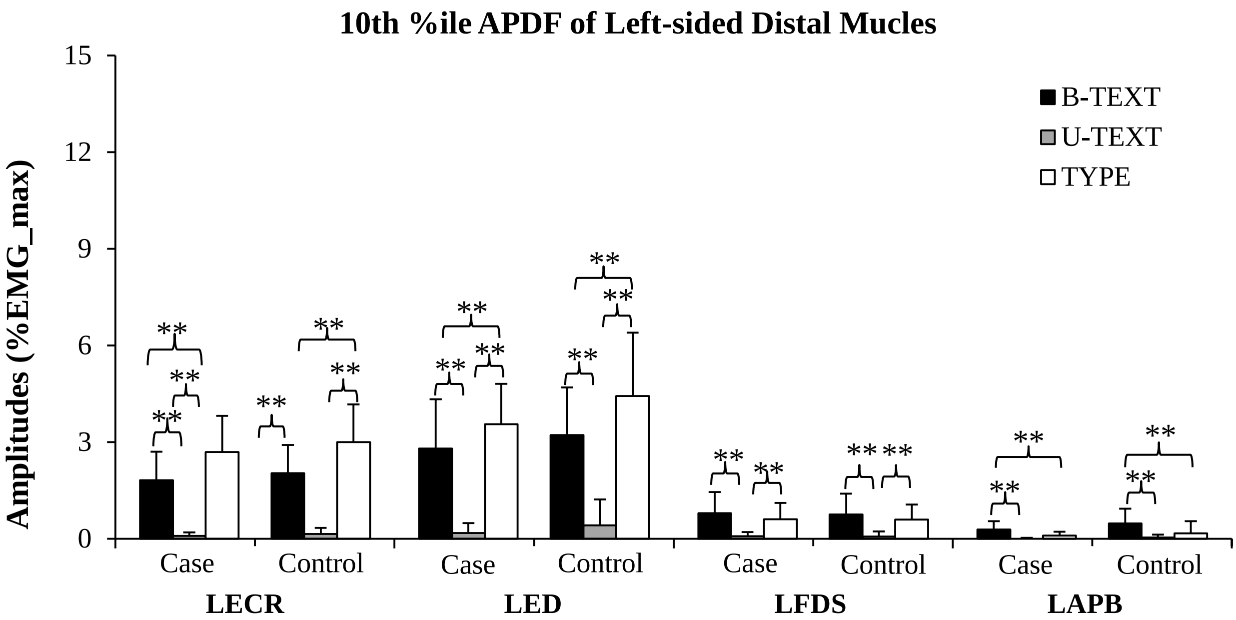


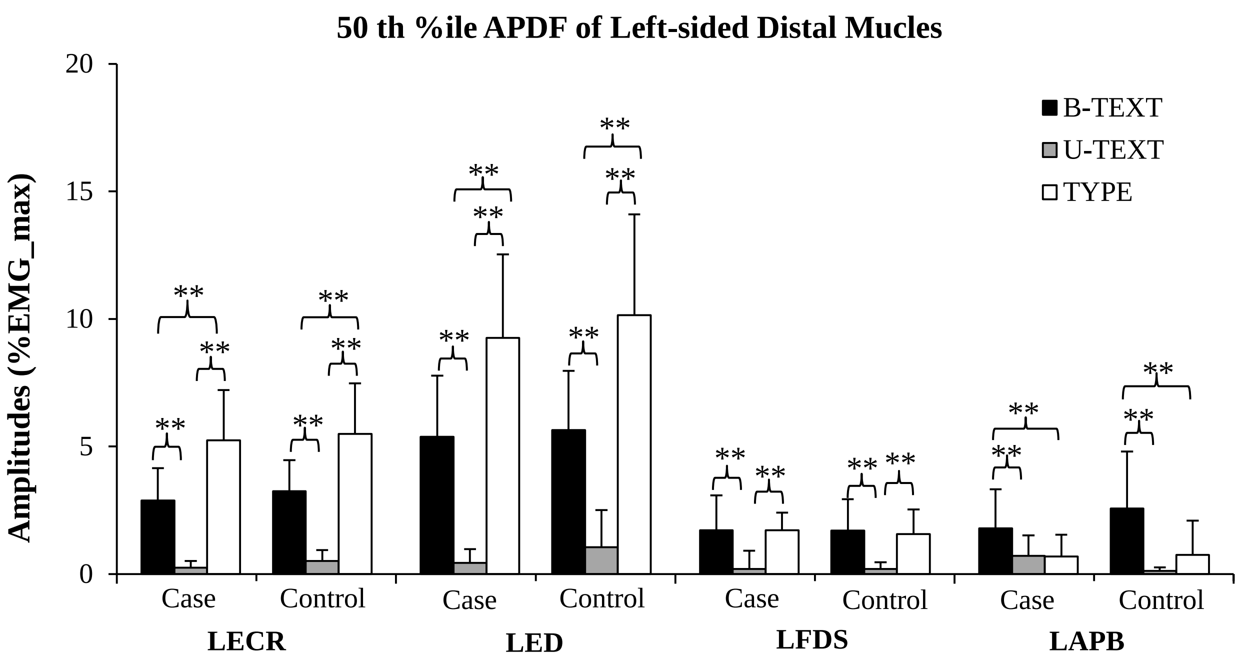
Figure 5.6. Static, median and peak muscle activity of left-sided proximal muscles, (a) static muscle activity, (b) median muscle activity, (c) peak muscle activity. L=left, CES=cervical erector spinae, UT=upper trapezius, LT=lower trapezius, B-TEXT=bilateral texting, U-TEXT=unilateral texting, TYPE=computer typing, 10th/50th/90th %ile APDF=10th/50th/90th percentile amplitude probability distribution function. ##Significant group differences, $p<0.01$; **Significant task differences in Case Group, $p<0.01$.

(a)



10th %ile APDF of Left-sided Distal Mucles
Amplitudes (%EMG_max)
15
12
9
6
3
0
B-TEXT
U-TEXT
TYPE
**
Case
Control
LECR
LED
LFDS
LAPB

(b)



50 th %ile APDF of Left-sided Distal Mucles
Amplitudes (%EMG_max)
20
15
10
5
0
B-TEXT
U-TEXT
TYPE
**
Case
Control
LECR
LED
LFDS
LAPB

(C)

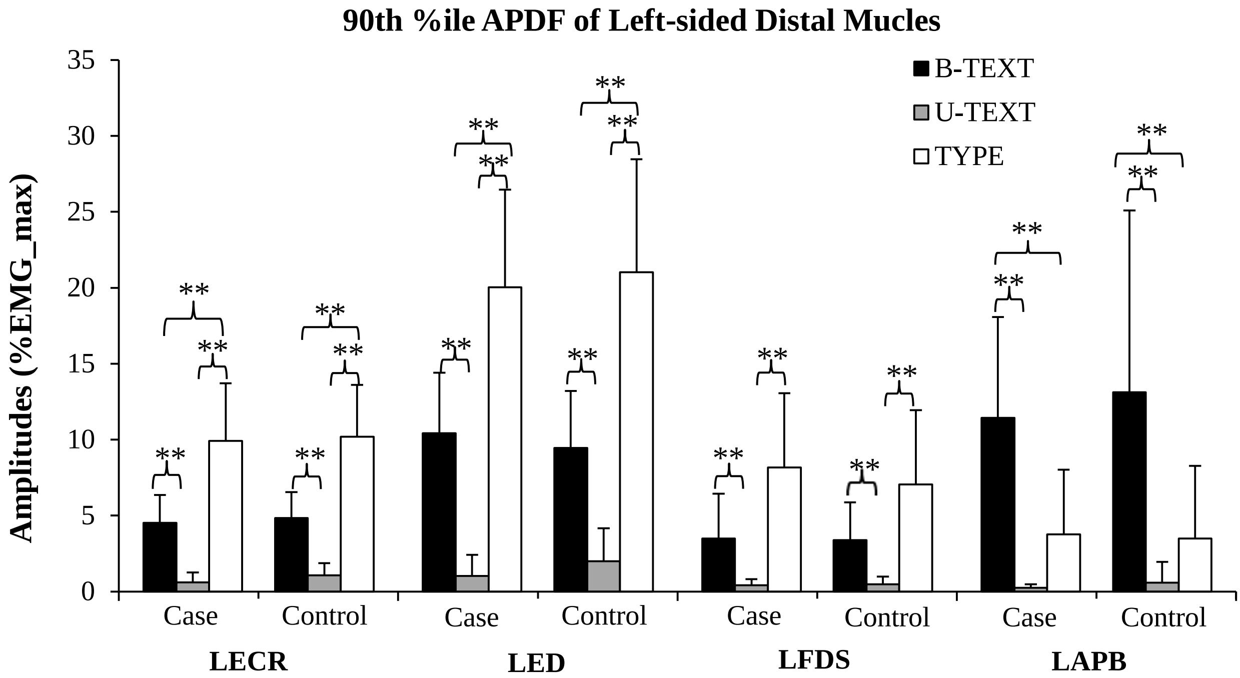


Figure 5.7. Static, median and peak muscle activity of left-sided distal forearm muscles, (a) static muscle activity, (b) median muscle activity, (c) peak muscle activity. L=left, ECR=extensor carpi radialis, ED=extensor digitorum, FDS=flexor digitorum superficialis, APB=abductor pollicis brevis, B-TEXT=bilateral texting, U-TEXT=unilateral texting, TYPE=computer typing, 10th/50th/90th %ile APDF=10th/50th/90th percentile amplitude probability distribution function. *p<0.05, **p<0.01.

5.3.3. Results of discomfort in specific body regions

The changes of the total discomfort scores in all six body regions including the neck, shoulder, upper back, elbow, wrist/hand and thumbs/fingers on the right side after bilateral texting, unilateral texting and computer typing have been reported in Chapter 4. This section provides detailed data of musculoskeletal discomfort in each recorded body region on both sides before and after performing the three tasks. Overall, subjects reported discomfort most frequently at the neck, followed by the shoulder, upper back and thumbs/fingers (Table 5.3). Case Group displayed significantly higher discomfort scores in the neck, shoulder and upper back on both sides as well as in the wrist and thumbs/fingers on the right side at baseline, bilateral texting, unilateral texting and computer typing compared with Control Group ($p<0.01$ in all regions); but no effects for group x task interactions were found in these regions. There was a significant effect for group x task interactions for the elbow on both sides ($p=0.011$, 0.024 for right and left sides respectively), and for the wrist ($p=0.032$) and thumbs/fingers ($p=0.019$) on the left side. Post-hoc analysis revealed that there were no differences in the discomfort scores in the elbow on both sides and in the wrist on the left side between Case and Control Group at baseline (Table 5.3). However, Case Group had significantly higher discomfort scores in the right elbow after the three experimental tasks, in the left elbow after computer typing and in the left wrist after bilateral texting and computer typing (Table 5.3).

In summary, Case Group showed increased discomfort in the right elbow after three experimental tasks, as well as in the left elbow, wrist and thumbs/fingers after bilateral texting and computer typing compared with baseline. In contrast, subjects in Control Group did not report increased discomfort in these body regions after performing the three tasks. There were no differences in discomfort scores of all body regions on the right side as well as neck, shoulder and upper back on the left side among the three tasks for both groups. The discomfort scores in the left forearm regions were significantly lower in unilateral texting than in bilateral texting and computer typing in Case Group (Table 5.3).

Table 5.3. Discomfort scores (0-10) of specific body regions at baseline and after the three tasks.

Regions	Sides	Groups	Baseline	B-TEXT	U-TTEXT	TYPE
Neck	R	Case	**3.3 (2.0)**	**4.2 (2.4)**	**4.2 (2.7)**	**4.1 (2.5)**
		Control	**0.0 (0.0)**	**0.9 (0.9)**	**1.0 (1.0)**	**1.1 (1.2)**
	L	Case	**2.5 (2.4)**	**3.6 (2.8)**	**3.6 (2.8)**	**3.9 (2.9)**
		Control	**0.0 (0.0)**	**0.9 (0.9)**	**0.7 (1.0)**	**0.9 (1.3)**
Shoulder	R	Case	**3.2 (2.5)**	**3.7 (2.5)**	**3.9 (3.1)**	**4.0 (2.0)**
		Control	**0.0 (0.0)**	**0.6 (1.0)**	**0.7 (1.0)**	**1.1 (1.4)**
	L	Case	**2.2 (2.9)**	**2.7 (2.9)**	**1.8 (2.3)**	**3.2 (2.6)**
		Control	**0.0 (0.0)**	**0.7 (1.0)**	**0.2 (0.5)**	**0.8 (1.1)**
Upper back	R	Case	**1.3 (1.9)**	**2.5 (2.6)**	**2.7 (2.5)**	**2.4 (2.4)**
		Control	**0.0 (0.0)**	**0.4 (0.8)**	**0.6 (0.9)**	**0.8 (1.0)**
	L	Case	**1.4 (2.1)**	**2.6 (2.7)**	**2.0 (2.0)**	**2.6 (2.5)**
		Control	**0.0 (0.0)**	**0.5 (0.8)**	**0.3 (0.6)**	**0.6 (0.9)**
Elbow	R	Case	0.0 (0.0)	**2.0 (2.0)**	**2.6 (2.4)**	**2.5 (2.2)**
		Control	0.0 (0.0)	**0.5 (0.9)**	**0.5 (0.8)**	**0.6 (1.0)**
	L	Case	0.0 (0.0)	1.4 (2.1)	0.0 (0.0)	**1.9 (2.3)**
		Control	0.0 (0.0)	0.5 (0.9)	0.0 (0.0)	**0.6 (1.0)**
Wrist	R	Case	**1.6 (2.3)**	**2.8 (2.6)**	**2.9 (3.0)**	**2.8 (2.3)**
		Control	**0.1 (0.2)**	**0.4 (0.7)**	**0.4 (0.8)**	**1.1 (1.2)**
	L	Case	0.4 (1.3)	**2.3 (2.5)**	0.0 (0.0)	**2.6 (2.9)**
		Control	0.0 (0.0)	**0.7 (0.9)**	0.0 (0.0)	**1.1 (1.3)**
Thumbs/fingers	R	Case	**2.0 (2.8)**	**2.9 (3.1)**	**3.3 (3.3)**	**2.7 (2.9)**
		Control	**0.1 (0.3)**	**1.2 (1.4)**	**0.9 (1.2)**	**0.7 (1.2)**
	L	Case	**1.3 (2.4)**	**2.2 (2.9)**	0.0 (0.0)	**2.7 (2.9)**
		Control	**0.0 (0.0)**	**0.9 (1.2)**	0.0 (0.0)	**0.7 (1.2)**

Note: B-TEXT=bilateral texting, U-TEXT=unilateral texting, TYPE=computer typing, R=right, L=left. The bold numbers represented those with statistically significant differences between groups (p<0.05).

5.3.4. Correlations between kinematics, muscle activity and perceived discomfort

Correlations among median joint angles of cervical and thoracic spines, cervical movement ranges in three planes, 50th %ile APDF and the APDF range of proximal muscles and discomfort scores in six body regions of both sides were examined in bilateral texting, unilateral texting and computer typing, respectively.

There were some occasional and isolated correlations of median angles of cervical and thoracic spines and cervical movement ranges with 50th %ile APDF and the APDF range of proximal muscles (Appendix IV A-C). For example, increased thoracic side flexion to the right was significantly associated with the decreased median muscle activity of LUT (r=-0.53, p=0.02) for Case Group during bilateral texting (Appendix IV A). Decreased thoracic flexion was significantly correlated with increased median activity in CES and UT on both sides for Case Group during computer typing (Appendix IV C). However, there were no clear and consistent patterns regarding the correlations of cervical and thoracic kinematics with the activity of proximal muscles during the three tasks. The pattern of correlations of kinematics and muscle activity with perceived discomfort scores did not show a clear picture either (Appendix V A-C). For instance, a significant result was shown in correlations between the increase of thoracic side flexion to the right and increased discomfort scores on both sides of the neck in unilateral texting (r=0.49, p=0.033) (Appendix V B). However, no such correlations were found in bilateral texting and computer typing (Appendix V A, C).

5.3.5. Gender issue

Generally, demographic characteristics, patterns of using electronic devices and pain profiles were comparable between Case and Control Groups in females and males, respectively (Appendix VI, VII and VIII). However, age as well as average daily hours on smartphones, computers and smartphone texting for females were higher in Case Group than in Control Group (Appendix VI, VII). As a result, the further statistical analysis described in session 5.2.5 was conducted to examine how gender modifies the differences in muscle activity and kinematics between Case and Control Group.

Overall, female symptomatic individuals showed consistently higher activity in CES and UT during the three tasks compared with female asymptomatic, male asymptomatic and male symptomatic individuals (Appendix IX). However, significant group x gender interaction effect was only found in 10th %lie (p=0.011), 50th %ile (p=0.021, Appendix IX) and 90th %ile APDF (p=0.046) of RCES. Post-hoc analysis revealed that there were significant differences in the muscle activity of RCES between female symptomatic and female asymptomatic subjects (p=0.008, 0.011, 0.018 for 10th, 50th and 90th %ile APDF, respectively) and these patterns were not found in male groups. There were no significant group x task interactions for static, median and peak activity in UT, LT and distal muscles on both sides as well as kinematic variables.

5.4. Discussion

The following discussion involves interpretations of kinematic patterns, EMG activity of left-sided muscles and discomfort in specific body regions between symptomatic and asymptomatic subjects, as well as among using different electronic devices. Discussions on the activity in left-sided muscles focus on results that were different from right-sided muscles. Discussions on the association of kinematics and muscle activity and subjective measures are also covered here. Finally, gender issue on muscle activity is discussed briefly.

5.4.1. Kinematic patterns in Case and Control Groups

The results of spinal kinematics revealed that young adults adopted a flexed neck posture for at least 95% of the whole 10-minute period while texting on a smartphone. This is in line with other studies observing that handheld device users maintaining a flexed neck and/or a forward head during the operation of handheld devices (Gold et al., 2012; Gustafsson et al., 2011; Kietrys et al., 2015; M. S. Kim, 2015; S. Lee et al., 2015; Ning et al., 2015; Park et al., 2015). The means of 50th %ile APDF of cervical flexion angles for all subjects were 28.4° during bilateral texting and 24.8° during unilateral texting, which are similar to the results noted in Kietrys et al. (2015), but less than the neck flexion angles in healthy subjects reported by Ning et al. (2015) (around 42.4° to 45.6°). The large variations in cervical flexion angles among different studies were probably due to the disparate experimental setups. Subjects in the current study were instructed to sit with the back support in performing texting tasks, while they were required to stand in Ning et al (2015). Furthermore, in Ning et al. (2015), sensors that were positioned at the occipital region referenced to the T10/T11 level represented the neck segment, and the neck flexion angle was identified as the sagittal angular displacement that deviated from an upright neutral trunk posture. The dissimilarity in the definition of the neck flexion angle is also an important factor contributing to differences in neck flexion angles reported by the present study and Ning et al. (2015). Previous studies that investigated head and neck postures in using smartphones have not examined specifically the spinal kinematics in thoracic and lumbar regions. To my knowledge, the current study is the first reported thoracic and lumbar postures in using a smartphone. Subjects were found to display 9.4° thoracic flexion and 6.6° lumbar flexion during bilateral texting. The present findings underlined the complex interplay between cervical, thoracic and lumbar postures during smartphones use. However, angles of thoracic and lumbar flexion are not very big. Further studies are needed to examine whether these slight thoracic and lumbar flexion postures, especially when these postures are maintained for long durations, have a meaningful impact on musculoskeletal disorder risk.

There were no differences in the cervical flexion angle between painful and healthy individuals. This result is inconsistent with a previous study reporting that mild neck pain group displayed significantly higher upper and lower cervical flexion angles during 5-minute smartphone operation (M. S. Kim, 2015). Subjects in M.S. Kim (2015) were asked to adopt their preferred postures while performing the smartphone tasks, whereas the current experimental design has restricted the natural movements of the whole trunk as the subjects were required to lean back against a chair. This may explain the lack of contrast between Case and Control Groups.

Under the circumstance that the external environment was standardized, Case Group showed greater angles of right side flexion in the smartphone texting tasks especially during unilateral texting compared with Control Group. This may suggest an increased neck asymmetry in young adults with neck-shoulder pain when interacting with a smartphone. An asymmetry of spinal posture has been observed in children during using tablet computers (Straker, Coleman, et al., 2008) and this has also been noted as a possible risk factor for musculoskeletal disorders (Faucett & Rempel, 1994; Hunting, Laubli, & Grandjean, 1981; Saarni, Nygård, Kaukiainen, & Rimpelä, 2007; Straker, Coleman, et al., 2008). Prolonged use of smartphones and smartphone addiction were found to be associated with impaired proprioception in the cervical spine (J. Lee & Seo, 2014; Y. Kim, Kang, Kim, Jang & Oh, 2013). The asymmetry of the cervical posture during the use of smartphones is possibly associated with impaired proprioception in people with neck pain. An inability of perceiving and maintaining the neutral position of the cervical spine during smartphone use may be one possible factor in the pathomechanisms of neck-shoulder pain. However, it is impossible to determine cause-effect relationships in the current cross-sectional study. This current study did not found any correlations between increased cervical side flexion angles and perceived discomfort scores either. The association between neck-shoulder pain and asymmetry of cervical postures during texting on a smartphone is yet to be determined.

Case Group presented with significantly greater cervical rotation ranges in performing the three tasks compared with Control Group. The increase in the range of postural angles reflects a greater size of variability of cervical movements in people with neck-shoulder pain. This result, however, is in contrast with previous studies investigating movement variability associated with pain. Chronic pain including neck-shoulder pain and low back pain was reported to be characterised with decreased arm and trunk movement variabilities while performing functional tasks such as repetitive cutting tasks (Madeleine et al., 2008; Madeleine & Madsen, 2009) and walking (Lamoth, Meijer, Daffertshofer, Wuisman, & Beek, 2006; van den Hoorn, Bruijn, Meijer, Hodges, & Van Dieën, 2012). However, tasks performed in previous studies were mainly involved large movements and therefore their results may not be applied directly to the current study where subjects performed relatively static and light hand touch activities. A possible explanation for greater cervical rotation ranges in people with chronic neck-shoulder pain is that their increased discomfort probably made them have difficulty to maintain the required standardized postures while performing smartphone texting and computer typing. This seem also in agreement with the notion that short-term discomfort developed during performing a specific task is associated with greater motor variability, possibly to seek for alternative motor solutions and allegedly in an attempt to relieve pain (Lomond & Côté, 2010, 2011; Srinivasan & Mathiassen, 2012). There were also some previous studies measuring the APDF range to quantify the variability of neck postures and muscle activity during computer typing (Szeto et al., 2005b, 2009a). They found that office workers with neck pain had higher APDF ranges in cervical rotation and muscle activity than healthy workers. It is possible that exposure variations such as the postural variability are motor strategies employed by chronic neck-shoulder pain subjects to relieve increased discomfort during performing sustained static tasks, for example, computer typing and texting on a smartphone. Nevertheless, the APDF range of postural angles is a simple way to quantify postural variation and reflects variability regarding amplitude ranges only (Ciccarelli et al., 2014). Further studies are needed to analyze the size and structure of postural and movement variability by some more advanced measurements during performing light hand touch activities using electronic devices.

This study also identified that Case Group displayed increased percentages of time in thoracic flexion with a slightly higher thoracic flexion angle compared with Control Group. It has been suggested that an increased thoracic kyphosis may provoke dysfunctions of other related joints, for instance, the cervical spine and shoulder girdles, and corresponding muscles as the whole spine is connected in a chain-like manner (Mannion & Dolan, 1994; O'Sullivan, 2005; Page, Frank, & Lardner, 2010). The increased sagittal curvature of the thoracic spine was found to produce increased flexion moments, shear and compression forces on the spine as well as augmented trunk muscle forces, presumably contributing to the development or progression of musculoskeletal disorders such as pain in the cervical spine

(Balzini et al., 2003; Briggs et al., 2007; Pearsaii & Reid, 1992). Recent studies have emphasized the importance of incorporating the thoracic spine into routine clinical assessments and treatments for neck pain (Dunning et al., 2012; K. T. Lau et al., 2010; H. M. C. Lau, Chiu, & Lam, 2011; Tsang et al., 2013a, 2014). However, the difference of thoracic flexion angles was not significant between painful and pain-free groups, which may partially be attributed to the small sample size. It may also be related to the study design of restricting the spinal posture of the subject during texting. Future studies should explore the natural postural habits of the thoracic spine when people use smartphones without any restriction on their postures.

5.4.2. Kinematic patterns during text entry tasks

By comparing the two methods of text entry on the smartphone, bilateral texting was associated with a significantly higher cervical flexion angle. A similar result was also reported in Kietrys et al. (2015), which examined differences of the cervical posture during 10-second two-handed texting and one-handed texting. The difference of cervical flexion angles between bilateral texting and unilateral texting is likely to be attributed to differences in the upper limb postures between the two texting methods. Kietrys et al (2015) observed that subjects held the phone closer to their faces during one-handed texting compared with that during two-handed texting. In the current study, based on the author's observation, subjects tended to keep their upper arms closer to their trunks and subsequently held the smartphone in a higher position after a few minutes during unilateral texting. This may be a natural tendency of the human body to reduce loads on the shoulder by supporting the upper arm with the trunk when holding the phone and texting with one hand only. However, Ko et al. (2015) did not find any differences in the flexion angles of the neck, elbow and wrist, which were measured by electrogoniometers between 2-

minutes of bilateral texting and unilateral texting. The time of texting tasks in Ko et al. (2015) might be too short to detect the change of postures. Although unilateral texting was associated with less neck flexion, it resulted in more cervical asymmetry, characterised by significantly longer time with a larger angle in rotation to the right compared with bilateral texting. It can be envisaged that as the subject held the phone in the right hand, and texted with the right thumb during unilateral texting, some degree of head tilting and cervical asymmetry is inevitable. The cervical asymmetry could also be due to the concurrent higher activation of RCES compared with LCES during unilateral texting.

This study also compared kinematics between texting on a smartphone and typing on a desktop computer. As expected, bilateral texting was associated with longer time and larger flexion angles in the cervical and thoracic spines compared with computer typing in both groups. This is also consistent with the finding of higher activity in CES which is to resist the greater cervical flexion moment in bilateral texting than in computer typing. These results could be explained by the difference in screen heights between the handheld smartphone and the desktop computer. Szeto and Lee (2002) reported an increased upper thoracic flexion angle in using a notebook involving a lower position compared with using a desktop computer. Straker, Burgess-Limerick, et al. (2008) concluded that, by summarizing results from 24 peer-reviewed studies, there is a linear increase in head and neck flexion angles as the visual target becomes lower than the eye level. Alternatively, subjects may increase their neck and thoracic flexion angles in order to facilitate reading the text with a relatively small font size on the smartphone of a small screen compared with that on the desktop computer. In addition to larger cervical and thoracic flexion angles, bilateral texting was also associated with less postural ranges in sagittal and frontal planes of the cervical spine compared with computer typing. This indicates that smartphone texting is associated with more static postures compared with computer typing. A touch keyboard is displayed on the screen of a smartphone, whereas the monitor and the keyboard are separate in a desktop computer. Thus, subjects had to change their viewing targets from the keyboard to the monitor from time to time during computer typing. This would probably explain why subjects showed greater ranges in the cervical sagittal plane in computer typing compared with that in bilateral texting. In addition, subjects had a greater cervical rotation range in computer typing compared with bilateral texting. This is probably because a desktop computer has a larger screen than a smartphone and therefore subjects need to trace the words displayed on a large screen by rotating the neck in order to facilitate typing.

5.4.3. Activity of left-sided muscles

Overall, results of activity in left-sided muscles were similar to that in right-sided muscles described in Chapter 4 except two major aspects. One is that there was a group x task interaction for LUT while no such effect was shown in RUT. The activity level of LUT was significantly higher in Case Group compared with Control Group during bilateral texting and computer typing, whereas no significant group difference was found in the activity of LUT during unilateral texting. This suggests muscle activity of LUT in young adults of chronic neck-shoulder pain may not differ from healthy controls during rest. A similar phenomenon was also found in previous studies. A review reported that 6 out of 7 studies examining EMG amplitude of UT during rest consistently found no differences in activity of UT between subjects with neck pain and healthy controls (Castelein et al., 2015). Falla, Bilenkij, & Jull (2004) showed that compared with healthy individuals, patient with idiopathic neck pain or whiplash-associated disorders was not different regarding the activity level of UT in the left upper limb that rested motionless on the table while the right upper limb performing circles marking activity. Szeto et al. (2009b) also revealed that people with and without neck pain had no difference in activity of UT while resting hands on laps. The present study demonstrated increased activity in LUT during computer typing compared with bilateral texting and unilateral texting in Case Group, whereas the activity in Control Group was similar and maintained low in the all three tasks. Compared with texting on a smartphone, typing on a desktop computer is considered to be of relatively higher physical stress. The muscle tissue such as UT in young adults with chronic neck-shoulder pain appeared to be easily sensitized by even low physical stress such as a light touch on a smartphone. Furthermore, the painful young adults seemed to display more deficit motor response to tasks of relatively high physical stress compared with tasks of low or no physical stress.

Another result differed from activity of right-sided muscles is that activity levels in left-sided distal muscles for both groups were significantly higher in bilateral texting compared with unilateral texting. This is opposite with the comparisons between bilateral texting and unilateral texting in the activity of right-sided distal muscles. The different result is obviously due to the fact that only the right upper limb was involved in the performance of unilateral texting while both upper limbs were engaged in bilateral texting.

5.4.4. Perceived discomfort in body regions

Case Group and Control Group significantly differed in discomfort scores in the neck, shoulder and upper back on both sides, as well as the wrist and thumbs/fingers on the right side both at baseline and after performing tasks. However, no group x task interaction effects were found, suggesting the group differences in discomfort scores in those body regions may not be induced by tasks. O'Leary, Falla, Elliott & Jull (2009) argued that individuals potentially do not report any symptoms even in the presence of motor control dysfunction if the demands of functional tasks performed do not outstrip the physiological capacity of the impaired motor control system. It is possible that the time of tasks in this study was not long enough to elicit marked increased discomfort in the neck, shoulder and some other body regions in Case Group. However, the present study found increased discomfort scores in the right elbow and left forearm regions, including elbow, wrist and thumbs/fingers after performing tasks compared with baseline for Case Group but not for Control Group, indicating a spreading discomfort to forearm regions in subjects with chronic-neck shoulder pain. This possibly also accounts for the significant increase in the change of total discomfort scores after tasks in Case Group compared with Control Group, which was reported in Chapter 4.

5.4.5. Correlations among variables

It was expected that the elevated muscle activity of CES and UT would be associated with altered patterns of kinematics such as heightened thoracic flexion, and these altered patterns of motor control would be correlated with increased subjective discomfort scores after performing tasks. However, these correlations were not clearly established in the present study, as reflected in the inconsistent significant and some non-significant results of correlation analysis. It is likely due to the study design which involved standardizing the body positions of the subjects for the three tasks. Hence this has restricted the normal movement patterns of the individuals if they were to use their phones in their own natural postures.

Another issue may be related to the characteristics of this particular group of subjects. It is relevant to note that the NDI values, DASH scores and the current discomfort scores of the neck and the shoulder were in the low range in the present sample of subjects. These results suggest that the young adults in Case Group had only a mild to moderate degree of pain and disability. It is also important to note that the increase of discomfort scores in the neck, shoulder and forearm regions (the maximal change was 2.6 out of 10) was small after 10-minute smartphone texting and computer typing compared with baseline. It might yield different results if subjects with more severe pain and disability performed longer and more stressful smartphone tasks.

5.4.6. Gender differences

Considering that males and females were reported to have different effects on muscle activity (Ge, Arendt-Nielsen, Farina, & Madeleine, 2005; Johansen, Samani, Antle, Côté, & Madeleine, 2013; Torisu et al., 2006), spinal postures (Straker, O'Sullivan, Smith, & Perry 2009) and prevalence of musculoskeletal disorders (Bot et al., 2005; Siivola et al., 2004), gender may be a confounding factor for the difference in muscle activity and kinematics between Case and Control Group. Healthy women were found to display different muscle activation strategies from men when performing static and dynamic functional tasks (Anders, Bretschneider, Bernsdorf, Erler, & Schneider, 2004; Johansen et al., 2013; Nordander et al., 2008; Meyland et al., 2014). In a study of muscle activity when using mobile phones for texting, a gender difference was also found in the activity of forearm muscles (Gustafsson et al., 2010). The present study found that symptomatic females showed significantly higher activity in RCES compared with asymptomatic females, and this phenomenon was not found among males. However, this gender effect was only shown in one muscle. The results of this study may imply a gender-specific muscular activation pattern in the presence of chronic neck-shoulder pain in response to functional tasks such as smartphone texting and computer typing. If this was true, it would possibly account for the greater risk of musculoskeletal disorders among women than among men. Further studies with a larger sample size are required to confirm this postulation.

Many factors are relevant to the gender effect for the motor control mechanisms that contribute to the development of chronic neck-shoulder pain. Muscle strength, power and endurance were proposed to be related to the gender difference in pain (J. N. Côté, 2012). Men and women differ in muscle morphology, with women characterizing with higher proportions of type I muscle fibers in erector spine muscles (Mannion et al., 1997) and smaller muscle fiber size in trapezius muscles (Lindman, Eriksson, & Thornell, 1991), which potentially influence the muscular activation strategy in the presences of chronic neck-shoulder pain. Other possible mechanisms proposed to be associated with the gender difference in pain include biological, physiological and social factors (J. N. Côté, 2012; Fillingim, King, Ribeiro-Dasilva, Rahim-Williams, & Riley, 2009; Racine et al., 2012; Wijnhoven, de Vet, & Picavet, 2006). However, it is not clear from previous studies whether such gender differences only apply to certain muscles or specifically to some muscles only. Hence, more research is needed to answer these questions.

5.5. Summary

In this study, young adults spent most of the time in the cervical flexion while smartphone texting, but there was no group difference in the angle of cervical flexion. Subjects in Case Group were found to spend more time in thoracic flexion with a slightly increased thoracic flexion angle, as well as significantly larger angles of cervical right side flexion and greater ranges of cervical rotation compared with healthy individuals during smartphone texting.

Compared with computer typing, texting on a smartphone was associated with larger cervical and thoracic flexion angles and relatively more static neck postures. Bilateral texting was associated with a greater neck flexion angle but less cervical asymmetry compared with unilateral texting.

The activity levels of LCES and LUT were higher in Case Group compared with Control Group and this pattern was more noticeable in LUT during bilateral texting and computer typing. Similar to the right distal muscles, no group differences were found in the activity of left distal muscles. The pattern of task differences in left-sided muscle activity is also similar to that of right-sided muscle activity. Regarding the gender effect on EMG activity of bilateral muscles and kinematics, the significant gender x group interaction was only found in the RCES muscle. Female symptomatic subjects had significantly higher activity of RCES compared with asymptomatic subjects, but this pattern was not shown in male subjects.

Case Group reported increased discomfort scores in elbow, wrist and thumbs/fingers after performing text entry tasks and this was not observed in Control Group. However, no clear association was found among increased muscle activity, altered kinematics and increased perceived discomfort scores.

CHAPTER 6
OVERALL DISCUSSION

The aim of this study is to examine the muscle activity of the neck, shoulder and upper limb, and spinal kinematics in young people with and without chronic neck-shoulder pain while they performed bilateral texting and unilateral texting on a smartphone as well as typing on a desktop computer. The main results are:

(1) Generally, compared with Control Group, Case Group consistently displayed increased activity levels in superficial postural muscles including CES and UT on both sides during bilateral texting, unilateral texting and computer typing. Specifically, significant group differences were found in the EMG amplitudes of RUT during three tasks and LUT during bilateral texting and computer typing. The activity levels of CES on both sides during three tasks and LUT during unilateral texting were slightly higher in Case Group than in Control Group; but the differences were not statistically significant. There were no group differences in the activity levels of distal muscles.

(2) Both groups spent 95% or higher of time in cervical and thoracic flexion during texting on a smartphone while around 68% during computer typing. The median cervical flexion angles (grand mean and SD) were in 28.4°±1.0°, 24.8°±1.2° and 3.6±1.5° during bilateral texting, unilateral texting and computer typing, respectively. But there were no group differences in the joint angle of cervical flexion. Case Group spent more time with a slightly higher angle in thoracic flexion compared with Control Group, but the difference was not statistically significant. The joint angle of cervical right side flexion was larger in Case Group compared with Control Group during texting on a smartphone while the angle was similar between groups in computer typing. Case Group also showed significantly greater

ranges in cervical rotation during performing the texting and typing tasks compared with Control Group.

(3) There were no clear patterns in correlations among increased muscle activity in superficial postural muscles, altered kinematics and increased subjective discomfort during the three experimental tasks.

(4) Texting on a smartphone was associated with increased muscle activity in CES and APB while computer typing was associated with higher muscle loading on UT, LT, ECR and ED. In addition, compared with computer typing, subjects in both groups spent significantly more time with greater joint angles in cervical and thoracic flexion and had less movement ranges in cervical flexion/extension and rotation during texting on a smartphone.

(5) Unilateral texting was associated with increased activity in the shoulder, forearm and thumb muscles on the dominant side, a larger right side rotation angle, a less neck flexion angle and greater ranges in cervical rotation and side flexion compared with bilateral texting.

This chapter provides a general discussion on the implications of the main findings. The discussions focus on possible underlying pathomechanisms for the altered patterns of muscle recruitment and kinematics associated with chronic neck-shoulder pain found in the present study. Discussions on ergonomic implications for a healthy use of smartphones are also covered.

6.1. Subjects' characteristics

Subjects in the Case Group were young adults with a mild to moderate degree of pain and slight functional disability at baseline. Therefore, the findings in this study may not be generalizable to other groups of people such as those with severe neck-shoulder pain. Szeto et al. (2005a, 2005b) identified that female office workers with severe neck pain presented greater extents of deficit motor control patterns compared with those had mild pain while performing computer typing. Workers with neck-shoulder pain at different stages, i.e. acute, sub-chronic and chronic pain, may demonstrate a diverse range of motor changes, impaired muscle behaviors and kinematics patterns when performing dynamic functional tasks such as meat cutting (Madeleine, 2010). Neck-shoulder pain is a complex and multi-dimensional problem. The existence of sub-groups of patients with neck-shoulder pain may imply different mechanisms driving the disorder.

This study involved both female and male subjects and a significant group x gender interaction was found with regard to the muscle activity in RCES, suggesting that there may be gender differences in the control mechanisms of the muscle. The present study showed that unlike males, female symptomatic subjects had consistently higher activity in proximal postural muscles such as CES and UT compared with their healthy counterparts in Control Group during the smartphone texting and computer typing tasks. Gender differences in the patterns of muscular behavior in the presence of fatigue or acute experimental neck/shoulder pain were reported in previous studies (Falla, Farina, & Graven-Nielsen, 2007; Fedorowich, Emery, Gervasi, & Côté, 2013; Ge, Madeleine, & Arendt-Nielsen, 2005; Meyland et al., 2014). Fedorowich et al. (2013) found slightly increased co-contraction of neck and shoulder muscles in women, whereas significantly decreased co-contraction in men responding to repetitive motion induced fatigue, suggesting a suboptimal strategy of muscular activation and a greater risk to injury for women. Falla, Farina, & Graven-Nielsen (2007) and Ge, Madeleine, & Arendt-Nielsen (2005) illustrated that women presented continuous activation in the same region of UT and higher activity in UT compared with men when undergoing pain induced by hypertonic saline injection, indicating a less efficient protective adaptation to pain in women. Based on the documented evidence, it seems that there are gender-dependent motor control strategies in the presence of neck/shoulder pain. However, these mechanisms seem to affect some muscles and not others, and there may be individual variations in the male/female responses. Further research is certainly needed to clarify these issues.

6.2. Possible pathomechanisms associated with chronic neck-shoulder pain

A number of pathological mechanisms may be involved in association with chronic musculoskeletal symptoms that are experienced by people who perform light manual tasks such as using computers and mobile phones. The following sections describe the most commonly recognized mechanisms that have been reported and how they match against the results of this study.

6.2.1. Altered motor control

The altered patterns of muscle recruitment and kinematics in the Case Group seem to be in agreement with the theory of the altered motor control model associated with chronic musculoskeletal pain (Johnston, Jull, Souvlis & Jimmieson, 2008; Kallenberg & Hermens, 2008; O'Leary, Falla, & Jull, 2011; Sterling et al., 2001; Szeto et al., 2005a, 2005b). The results of this study showed that young adults with chronic neck-shoulder pain responded to the smartphone texting tasks and computer typing with a consistent increase in the surface EMG activity of superficial postural muscles. This applied especially in the RUT muscle which showed significantly increased activity in computer typing as well as both the texting tasks in painful subjects. On the other hand, LUT was significantly heightened only during bilateral smartphone texting and computer typing in painful subjects, but not in unilateral texting. This is mostly due to the fact that unilateral texting only involved the right hand.

The activity levels of UT on both sides in healthy subjects were low and similar during the three experimental tasks, implying an efficient strategy of muscle recruitment in performing motor tasks. Subjects maintained a flexed neck posture which should involve only low levels of contraction in the postural muscles in the cervical spine. However, these muscles consistently displayed high levels of activation in the Case Group, which may indicate an inefficient strategy of muscle recruitment in subjects with chronic neck-shoulder pain. This notion was also suggested in previous research (Johnston, Jull, Souvlis & Jimmieson, 2008; Madeleine et al., 1999; Szeto et al., 2005a). Additionally, patients with chronic neck pain were reported to show decreased neuromuscular efficiency in other superficial neck muscles such as sternocleidomastoid and anterior scalene while performing the isometric neck flexion movement (Falla, Jull, Edwards, Koh, & Rainoldi, 2004).

Further, the altered motor response of UT for Case Group seemed to be more exaggerated while performing computer typing which is associated with a slightly higher physical stress compared with texting on a smartphone. Previous studies reported that when symptomatic subjects were required to perform physical tasks of different physical stress levels such as increased speeds or increased forces, the phenomenon of altered motor control was accentuated (Szeto et al., 2005c, 2005d; Szeto & Lin, 2011). In this study, the subjects were required to perform smartphone texting or computer typing at their own usual speeds and forces and therefore it is not known whether such phenomena may also present. It would be interesting in future studies to provoke such responses in the symptomatic individuals.

It is noteworthy that painful subjects showed increased movement variability by presenting a greater APDF range in cervical rotation compared with healthy controls during performing the smartphone texting and computer typing tasks. This is consistent with previous studies showing increased APDF ranges in superficial neck muscle activity and in the cervical and shoulder movements among office workers of chronic neck pain while performing computer tasks (Szeto et al., 2005b, 2009a). Increased movement variability was also observed in person with acute experimental pain (Madeleine et al., 2008). However, some studies reported that workers with chronic musculoskeletal pain such as chronic neck-shoulder pain and low back pain were characterised with diminished motor variability while performing functional tasks required large amplitudes of dynamic movements (Lamoth, Meijer, Daffertshofer, Wuisman, & Beek, 2006; Madeleine et al., 2008; Madeleine & Madsen, 2009). The mixed results probably reflected that painful subjects had different adaptive responses to pain while performing different functional tasks. It has been highlighted that the reorganization of motor control strategies associated with pain may be task-specific and each individual with chronic musculoskeletal pain could develop a unique strategy against further pain or injuries based on some factors including but not limiting to pain experience, postures and tasks (Hodges & Tucker, 2011; Hodges, 2011).

In this study, it is not possible to pinpoint whether the deficit motor control causes pain or pain results in the change of motor control patterns. Altered motor control patterns such as the over-activity of superficial postural muscles in Case Group could lead to augmented compressive loading in the cervical spine structures (Szeto et al., 2005b) or impaired properties and physical structures of the muscle fibers (Falla & Farina, 2005), contributing to chronic neck-shoulder pain. The finding of a larger joint angle of cervical right side flexion in Case Group than in Control Group during smartphone texting supports that how the distribution of load may have been altered resulting in uneven stress on pain sensitive structures in the cervical spine (Kumaresan, Yoganandan, & Pintar, 1998). However, it is also plausible that the altered motor control patterns were the resultant responses to pain. Previous studies investigating experimental neck pain discovered some similar maladaptive motor control patterns that were observed in chronic neck pain with the emergence of pain after the injection of hypertonic or isotonic saline to the muscles (Falla, Farina, & Graven-Nielsen, 2007; Madeleine, Leclerc, Arendt-Nielsen, Ravier, & Farina, 2006). The altered motor control pattern is also indicated probably to be an adaptation to pain in order to prevent further pain (Falla, Farina, & Graven-Nielsen, 2007; Lund, Donga, Widmer, & Stohler, 1991). For example, the increased rotation range in Case Group in the present study may reflect a search for pain-relieving postures in performing the static smartphone texting and computer typing. Hodges & Tucker (2011) argued that the heightened superficial postural muscle activity could provide protection to further pain by splinting the painful muscles. Nonetheless, Hodges & Tucker (2011) also suggested that the short-term benefit obtained from motor adaptation to pain could lead to recurrence and persistence of pain in the long run if the altered motor control is not resolved.

6.2.2. Vicious cycle and tissue sensitization models

Other possible pathophysiological mechanisms postulated for chronic neck-shoulder pain include the vicious cycle theory and tissue sensitization models. The "vicious cycle model" is one of theories explaining the changes in motor control associated with chronic musculoskeletal pain (Johansson & Sojka, 1991; Travell, Rinzler, & Herman, 1942). Hägg (1991) proposed that painful muscles were highly activated stereotypically during sustained work even at manual tasks required low levels of physical demands. It was demonstrated in both animal experiments and human research studies on chronic neck pain that long durations of static muscle activation may induce muscle tissue damage resulting in ischemia and aggregation of irritating metabolites (Barbe et al., 2003; Lexell, Jarvis, Downham, & Salmons, 1993; R. Larsson, Öberg, & Larsson, 1999; S. Larsson et al., 1990; Rosendal et al., 2004; Visser & van Dieën, 2006). The ischemia and irritating metabolites in turn plausibly cause muscle spasms and thereby lead to further pain (Travell et al., 1942). An expansion of the theory of pain-spasms-pain was put forward by Johansson and Sojka (1991). It was accepted that the self-perpetuating vicious cycle was an important mechanism contributing to the chronicity and spreading of musculoskeletal pain (Madeleine et al., 1999; Parker, 1990; Roland, 1986).

The present findings seem not exactly to align with the “vicious cycle model”. Despite the activity of postural muscles such as RUT increased regardless of tasks, discomfort levels of neck and shoulder regions in Case Group remained constant and did not show further escalations with subsequent tasks. There was also no corresponding elevation in activity of forearm muscles although the discomfort intensity in forearm regions increased in Case Group compared with Control Group during performing the tasks. Moreover, some previous studies reported no change (Goudy & McLean, 2006; Hallman, Lindberg, Arnetz, & Lyskov, 2011; Nilsen et al., 2006; Voerman et al., 2007; Wegner, Jull, O'Leary, & Johnston, 2010) or decreased in muscle activity among people with chronic neck pain (L. L. Andersen et al., 2008). Therefore, the responses of muscle activation in the various tasks among subjects with chronic neck-shoulder pain could not be fully explained by the “vicious cycle model”.

Tissue sensitization, including peripheral and central sensitizations, is a phenomenon of enhanced responsiveness to various noxious stimuli (Nijs, Van Houdenhove, & Oostendorp, 2010; Raja, Meyer, Ringkamp, & Campbell, 1999). Accumulation of algesic agents resulted from continuously high muscle activations constitute stimuli that excite and sensitize intramuscular nociceptors (Arendt-Nielsen & Graven-Nielsen, 2008; Henriksson, 1999). This is noted to be a peripheral mechanism contributing to subjective symptoms such as tenderness, discomfort or pain during movements as well as highly static contractions of damaged muscles (Graven-Nielsen & Mense, 2001; Henriksson, 1999). The trapezius region is found to be characterised by a low threshold for repetitive stimuli inducing a growing increase in pain sensitivity (Ashina, Jensen, & Bendtsen, 2003). The over-activity of UT in performing such a light hand touch task and slightly increased discomfort scores in the neck-shoulder area after performing tasks possibly suggested a peripheral sensitization in the painful muscle tissue of subjects with neck-shoulder pain. By assessing pressure pain thresholds in different parts of muscles around the neck such as UT and SCM, Park et al. (2015) found heavy smartphone users were characterised with lower pain thresholds in UT and SCM compared with those who use smartphones less frequently. G. Y. Kim et al. (2012) also reported a decreased pain threshold of UT in young adults after 10-minutes of texting on smartphones.

Repetitive peripheral sensitization can initiate a gradual increase of nociceptive input to the spinal cord (Curatolo, Arendt-Nielsen, & Petersen-Felix, 2006), which is thought to elicit the sensitization of the dorsal horn neurons and finally gives rise to central hypersensitivity, consequently contributing to long-lasting pain sensation (Arendt-Nielsen & Graven-Nielsen, 2008; Curatolo et al., 2006; Lidbeck, 2002). A main feature of central sensitization is the amplifying widespread responses to other non-stimulated nociceptors and/or non-nociceptors even when the noxious input only comes from a certain type of nociceptor fibers (Nijs et al., 2010; Thompson, Woolf, & Sivilotti, 1993). As a result, phenomena of sensory amplification occur, including persisting pain after the elimination of stimulations and a spreading of symptom areas (Nijs et al., 2010; Thompson et al., 1993; Woolf, 2011). The central hypersensitivity likely underpins the concurrence of widespread or multiple pain complaints such as pain in bilateral wrists and thumbs in some of the cases in this study and increased discomfort in the upper limb regions in Case Group after the performance of smartphone texting and computer typing. Nevertheless, the pathological changes of muscles could not be confirmed and quantitative sensory tests such as the measurement of pressure pain thresholds during smartphone texting were not performed in this study to provide evidence for central hypersensitivity in painful subjects. Further studies are needed to confirm whether the peripheral and/or central sensitization plays significant roles in the occurrence and persistence of neck-shoulder pain among smartphone users.

6.3. Ergonomic implications for smartphone use

The present study has produced results that are useful for developing ergonomic guidelines on the wise use of smartphones since it offered quantitative information on the muscular effort required and spinal postures during smartphone texting. This study found that in comparison with computer typing, smartphone texting was associated with a relatively more static neck posture as well as larger angles of cervical and thoracic flexion. In addition, subjects with chronic neck-shoulder pain had slightly higher thoracic flexion angles compared with healthy controls. A static neck flexion posture is widely cited as a risk factor for the development of neck-shoulder disorders (Ariëns et al., 2001; Cagnie et al., 2007; da

Costa & Vieira, 2010; Erick & Smith, 2011). The activity of proximal postural muscles for holding the flexed spine when using a smartphone was also high. B. Jonsson (1978) recommended, for performing occupational tasks, that the static load should not exceed 2% of maximum EMG activity; median load should not exceed 10% maximum EMG activity during constrained work with a period of 1 hour or more in order to prevent the development of musculoskeletal disorders. The static load of CES and UT as well as the median load of CES, for subjects with neck-shoulder pain in particular, while 10-minute of smartphone texting found in the present study has already exceeded the “safe” threshold proposed by B. Jonsson (1978). This suggests that smartphone users who adopt a flexed spine posture for long durations are likely to impose even higher demands on the neck and shoulder muscles, which will endanger the musculoskeletal health of users. The flexed cervical and thoracic postures adopted by smartphone users as well as high muscle loads in UT are potentially the most important factors contributing to the high prevalence of neck pain among mobile phone users reported in epidemiological studies (Berolo et al., 2011; H. J. D. Kim & J. S. Kim, 2015; Shan et al., 2013). Based on these results, it is recommended not to use smartphones continuously for long durations in order to reduce the risk of neck-shoulder pain. In addition, users should be trained to be aware of their flexed spine postures and altered patterns of muscle activation while using smartphones, and try to self-correct the maladaptive motor control behavior. Users are also encouraged to take advantage of the portability and mobility of the handheld smartphones, keeping the spine in an erect and upright position by adjusting the height of the phone being held and altering postures periodically while using smartphones. Nevertheless, further studies are still needed to identify the safe or critical threshold regarding the duration, frequency and the degree of spine flexion in using smartphones for not overloading the cervical structures or the whole spine.

This study also compared the muscle activity and spinal kinematics between unilateral texting and bilateral texting. Generally, unilateral texting was associated with higher muscle loads especially in the forearm muscles in the dominate side, as well as with a less symmetrical cervical posture compared with bilateral texting. However, bilateral texting was associated with increased neck flexion compared with unilateral texting. Based on the present results, it seems that firm recommendation regarding using both hands or using one hand while smartphone texting could not be made, since both text entry methods put users at different risks. In addition to the neck posture, other aspects especially ergonomics of the thumbs are needed to consider in terms of the biomechanical effect of the two methods of text entry on the musculoskeletal system. There have been a few studies investigating how texting with one hand and with two hands affect the motor control of thumbs. Gustafsson et al. (2011) documented that mobile phone users who texted with one thumb showed a higher velocity and more repetitiveness of thumb movements compared with those who texted with two thumbs. Trudeau, Udtamadilok, Karlson & Dennerlein (2012) reported that two-handed texting was associated with greater thumb motor performance, a more extended thumb posture and less effort to push distant keys compared with one-handed texting on a smartphone, suggesting two-handed texting method is preferable. In combination with results from previous studies and the present study, with the premise that the spine is in a neutral posture, text with two hands or vary between different texting methods such as entering text with the right thumb, with the left thumb or with other fingers or texting by voice is recommended to lower the risk of musculoskeletal disorders.

The present study, however, only involved one particular model of smartphone and only examined the task of texting. Future studies should evaluate the ergonomic factors when people use different types of phones with different operating models, different screen sizes and different inputting methods. Such research would contribute towards the development of more comprehensive guidelines for the healthy use of touchscreen devices in the future.

6.3. Study limitations and directions for future research

Some limitations of the present study and future research directions regarding touchscreen mobile devices have been discussed in Chapter 4. In addition to what has been discussed in Chapter 4, longitudinal prospective studies are warranted to establish the causal relationship between the use of touchscreen handheld devices and chronic neck-shoulder pain. Other risk exposures such as duration, frequency and the designs of the devices should also be identified in order to develop appropriate methods of prevention and clinical managements for musculoskeletal disorders among touchscreen handheld device users.

This study has some other limitations. As mentioned in session 6.1, results of altered motor control patterns while performing smartphone texting in Case Group may not be directly applied to people of other age groups, with severe pain and disability, and in other stages of pain. Future research should be expanded into different sub-groups of people with neck-shoulder pain and investigate whether these sub-groups will display different patterns of altered motor control. Potential gender differences could also be further explored. In addition, tasks in the present study may not be stressful enough to elicit all motor responses to pain. Future studies should examine the motor control patterns when people of neck-shoulder pain perform some smartphone tasks of high physical stress, for instance, texting with fast speeds and browsing with high frequencies. These studies could help to shed new light on the mechanisms of neck-shoulder pain associated with intensive smartphone use. Further studies may also be needed to investigate whether normal patterns of muscle activation and kinematics could be restored when pain is alleviated or disappears in order to determine the cause-effect relationship between pain and changes of motor control patterns.

Finally, the design of this study in which the subjects' postures were "standardized" in performing smartphone texting may not be able to accurately reflect the motor variability in smartphone users when they perform tasks in their "natural" postures. Motor variability plays an important role in motor learning, motor control and neuromuscular system adaptation to pain (Madeleine & Madsen, 2009; Moseley & Hodges, 2006). It helps to deepen our understanding of the pathways from the use of electronic devices to the development of chronic neck-shoulder pain. Further studies are needed to explore, via advanced measurements, the size and structure of motor variability when subjects performing smartphone tasks in their preferred postures. In addition to the motor variability, the way that muscles work together delineating muscle synergies in stabilizing the motor performance during a given task has also been proposed to be important for understanding the mechanism of fatigue and injury (Fedorowich et al., 2013). Further analysis of the functional connectivity between muscle pairs using the parameter of normalized mutual information is being conducted. Normalized mutual information detects the linear and non-linear statistical dependencies or shared information between time series in surface EMG signals which could reveal the stability among muscles (Madeleine, Samani, Binderup, & Stensdotter, 2011; Svendsen, Samani, Mayntzhusen, & Madeleine, 2011). The data on functional connectivity of muscles is not reported here since it is out of the scope of this thesis. This part of work is in collaboration with Professor Pascal Madeleine from Aalborg University and we aim to publish a paper in an international journal of a high impact factor. The data on muscle functional connectivity will enhance our knowledge on muscle coordination in using touchscreen smartphones. This may also contribute towards understanding the different motor control mechanisms between symptomatic and asymptomatic individuals.

CHAPTER 7
CONCLUSIONS

This study examined muscle activity and spinal kinematics in young adults with and without chronic neck-shoulder pain when they performed texting on a smartphone with one hand, with two hands and typing on a desktop computer. This study has offered some important implications on the association between chronic neck-shoulder pain and the use of smartphones, as well as on the development of ergonomic guidelines on the wise use of smartphones that may help to reduce or prevent chronic neck-shoulder pain among smartphone users.

The present study demonstrated that young adults with chronic neck-shoulder pain displayed altered patterns of motor control when performing text entry tasks. Compared with healthy subjects, subjects with chronic neck-shoulder pain had consistently increased muscle activity levels in CES and UT on both sides in the performance of three text entry tasks and this pattern was most evident for the right UT. In addition, this study found that compared with healthy subjects, painful subjects had greater cervical rotation ranges during performing the three tasks and increased cervical right side flexion angles during the smartphone texting tasks. Subjects with chronic neck-shoulder pain also spent slightly more time in thoracic flexion with increased thoracic flexion angles during bilateral texting and computer typing compared with those without pain. These findings suggest that correcting the altered patterns of motor control during smartphone texting may be an important element of the overall management for smartphone users with chronic neck-shoulder pain.

In the comparison of texting on a smartphone and typing on a desktop computer, the present study showed that smartphone texting was associated with higher activity in the neck and thumb muscles while computer typing was associated with increased activity in the shoulder and forearm muscles. Furthermore, subjects, regardless of pain status, exhibited greater cervical and thoracic flexion angles and relatively more static neck posture in smartphone texting than in computer typing. Compared with two-handed texting, all subjects displayed heightened activity levels in the forearm muscles on the dominant side, more time with a larger angle in the cervical right rotation and less cervical flexion when texting with one hand. On the basis of these findings, it is recommended to maintain an erect spine or to change the posture frequently, and to use both hands or to vary methods for text entry with different fingers while performing smartphone texting in order to lower the risk of developing musculoskeletal disorders. To develop a more comprehensive set of ergonomic guidelines, future research should continue to investigate the use of different models of smartphones, different tasks and different inputting methods.

APPENDICES

Appendix I. Placements of surface electromyography electrodes and maximum voluntary contraction procedures

Muscles	Electrode placements	starting positions of MVC trials	Movements and application loads of MVC trials
Abductor pollicis brevis (APB)	Over the muscle belly between the metacarpophalangeal joint (MCPJ) and the carpometacarpal joint (CMCJ) of the thumb	The forearm, wrist and fingers were stabilized by braces and supported at neutral position. The thumb was positioned in 30° abduction.	Abduction of the thumb—against transducer at MCPJ
Extensor digitorum (ED)	Measured from the lateral epicondyle, on 1/3 of the distance from the lateral epicondyle to the styloid process of radius	The forearm and wrist were stabilized by braces and supported in neutral position, fingers were also in a neutral position	Extension of MCPJ—against a transducer at MCPJ
Flexor digitorum superficialis (FDS)	At around the muscle belly that 5 cm away from the bicep tendon at the elbow	The forearm and wrist were supported in neutral position, The fingers were also in neutral positions	Flexion of MCPJ—against a transducer at MCPJ
Extensor carpi radialis (ECR)	5- 7cm distal to the imaginary line from lateral epicondyle of humerus to the dorsal aspect of base of 2nd metacarpal	The wrist was supported in 0°flexion and 90°pronation	Extension of wrist with radial deviation—against a transducer
Upper trapezius(UT)	2 cm lateral to the mid-point of imaginary line from C7 spinous process to the tip of acromion	The arm was in a neutral position and the scapula in the neutral elevation	Unilateral scapular elevation-against adjustable strap on acromioclavicular joint
Lower Trapezius (LT)	Distal: 2.5-3 cm lateral to T6 Proximal: at 45° parallel to muscle fibres and 20 mm above distal	The arm was in a neutral position and the scapular was in the neutral elevation	Unilateral scapular retraction-against a transducer at the posterior aspect of the scapula at lateral half of the spine
Cervical erector spinae (CES)	Distal:1cm lateral to C5 spinous process Proximal: 20 mm above distal	The head was in a upright position	Neck extension-against a transducer at the posterior occiput

Appendix II. Mean values of maximum voluntary electromyography activity for all muscles examined in Case and Control Group.

Muscles	Case Mean (SD) (μV)	Control Mean (SD) (μV)	Group effect
RCES	49.0 (22.7)	57.7 (34.8)	t (41)=-0.989, *p*=0.328
LCES	47.7 (24.0)	47.2 (21.9)	t (41)=0.072, *p*=0.943
RUT	234.6 (172.5)	341.6 (262.5)	t (27.35)=-1.510, *p*=0.142
LUT	199.7 (143.5)	327.5 (272.0)	t (23.82)=-1.820, *p*=0.081
RLT	210.4 (133.7)	248.1 (147.0)	t (41)=-0.874, *p*=0.387
LLT	195.3 (88.3)	225.9 (157.2)	t (24.69)=-0.746, *p*=0.463
RECR	347.0 (222.0)	344.2 (141.4)	t (41)=0.048, *p*=0.962
LECR	260.1 (112.7)	238.2 (81.8)	t (41)=0.703, *p*=0.486
RED	230.8 (101.3)	239.4 (116.2)	t (41)=-0.261, *p*=0.796
LED	205.5 (77.4)	189.7 (70.1)	t (41)=0.688, *p*=0.495
RFDS	336.1 (155.9)	410.4 (215.9)	t (41)=-1.312, *p*=0.197
LFDS	298.8 (142.9)	313.8 (166.2)	t (41)=-0.317, *p*=0.753
RAPB	508.6 (251.3)	575.8 (322.6)	t (41)=-0.767, *p*=0.447
LAPB	393.2 (120.6)	546.0 (381.0)	t (19.47)=-1.643, *p*=0.117

Note: R=right, L=left, CES=cervical erector spinae, UT=upper trapezius, LT=lower trapezius, ECR=extensor carpal radialis, ED=extensor digitorum, FDS=flexor digitorum superficialis, APB=abductor pollicic brevis.

Appendix III. Information about subjects' physical activity

		Case (Proportions of subjects)	Control (Proportions of subjects)	Group difference
Frequency of doing exercise	Occasionally	50%	45%	χ^2=0.100, *p*=1.000
	Regularly 1-2 sessions/week	50%	55%	
Types of physical activity	Hand-related	20%	70%	χ^2=0.533, *p*=0.716
	Not hand-related	80%	30%	

Appendix IV A-C. Spearmen's rho correlations of median cervical and thoracic joint angles and ranges of cervical movements with 50th %ile amplitude probability distribution function (APDF) and the APDF range of proximal postural muscles.

A. Bilateral texting

		MA_Cx X	MA_Cx Y	MA_Cx Z	MA_Tx X	MA_Tx Y	MA_Tx Z	Range_Cx X	Range_Cx Y	Range_Cx Z
50APDF_RCES	Case	r= -0.16	r= -0.25	r= -0.02	r= 0.05	r= -0.06	r= 0.13	r= -0.25	r= 0.03	r= -0.05
	Control	r= -0.05	r= 0.34	r= -0.24	r= -0.04	r= 0.02	r= -0.10	r= -0.31	**r= -0.53***	r= -0.31
50APDF_LCES	Case	r= -0.29	r= -0.01	r= -0.11	r= -0.14	r= -0.10	r= 0.02	r= 0.01	r= 0.15	r= -0.02
	Control	r= 0.10	r= 0.25	r= 0.18	r= -0.16	r= 0.08	r= 0.23	r= -0.04	**r= -0.47***	r= -0.27
50APDF_RUT	Case	r= -0.02	r= -0.01	r= -0.01	r= 0.26	r= -0.41	r= -0.13	r= -0.09	r= 0.11	r= -0.11
	Control	r= -0.01	r= 0.14	r= 0.30	r= -0.14	r= 0.23	r= 0.07	r= 0.24	**r= 0.48***	r= 0.36
50APDF_LUT	Case	r= -0.38	r= 0.16	r= -0.29	r= -0.09	**r= -0.53***	r= -0.20	r= -0.04	r= 0.04	r= -0.18
	Control	r= 0.19	r= 0.13	r= 0.44	r= -0.17	r= 0.44	r= 0.32	r= 0.23	r= 0.25	r= 0.22
50APDF_RLT	Case	r= -0.33	r= 0.30	**r= -0.54***	r= -0.13	r= -0.19	r= 0.28	r= 0.06	r= -0.06	r= -0.11
	Control	r= -0.05	r= 0.40	r= -0.26	r= -0.29	r= 0.00	r= 0.00	r= -0.11	r= -0.20	r= -0.05
50APDF_LLT	Case	r= -0.06	r= 0.06	r= -0.43	**r= -0.52***	r= -0.35	r= -0.21	r= 0.34	r= -0.19	r= -0.41
	Control	r= -0.26	r= 0.32	r= 0.12	r= -0.03	**r= 0.49***	r= 0.16	r= -0.18	r= -0.45	r= -0.29
APDF	Case	r= -0.12	r= -0.33	r= -0.03	r= -0.11	r= -0.14	r= 0.15	r= 0.00	r= 0.23	r= 0.15
Range_RCES	Control	r= 0.16	r= 0.11	r= -0.20	r= -0.08	r= -0.06	r= -0.04	r= -0.04	r= -0.28	r= -0.36
APDF	Case	r= -0.27	r= -0.04	r= -0.09	r= -0.33	r= -0.26	r= 0.02	r= 0.35	r= 0.38	r= 0.23
Range_LCES	Control	r= 0.10	r= 0.23	r= 0.13	r= -0.39	r= -0.09	r= 0.11	r= 0.06	r= -0.17	r= -0.12
APDF	Case	r= 0.19	r= -0.07	r= -0.10	r= 0.37	r= -0.25	r= 0.04	r= -0.20	r= 0.24	r= -0.04
Range_RUT	Control	r= 0.11	r= 0.00	r= 0.18	r= -0.07	r= 0.15	r= 0.05	r= 0.41	**r= 0.54***	r= 0.22
APDF	Case	r= -0.16	r= -0.08	r= -0.21	r= 0.12	r= -0.38	r= -0.04	r= -0.17	r= 0.15	r= -0.03
Range_LUT	Control	r= 0.20	r= 0.05	r= 0.33	r= -0.14	r= 0.14	r= 0.14	r= 0.45	**r= 0.53***	r= 0.28
APDF	Case	r= -0.36	r= 0.12	r= -0.23	r= -0.12	r= -0.34	r= -0.03	r= 0.28	r= 0.13	r= -0.09
Range_RLT	Control	r= -0.29	r= 0.29	r= -0.31	r= -0.07	r= -0.23	r= -0.14	r= -0.08	r= -0.03	r= 0.10
APDF	Case	r= -0.33	r= 0.04	r= -0.20	r= -0.36	r= -0.34	r= -0.25	r= 0.44	r= 0.06	r= -0.18
Range_LLT	Control	r= -0.38	r= 0.12	r= -0.09	r= 0.16	r= 0.15	r= -0.04	r= -0.08	r= -0.20	r= -0.13

B. Unilateral texting

		MA_Cx X	MA_Cx Y	MA_Cx Z	MA_Tx X	MA_Tx Y	MA_Tx Z	Range_Cx X	Range_Cx Y	Range_Cx Z
50APDF_RCES	Case	r= -0.21	r= -0.34	r= 0.04	r= -0.20	r= -0.01	r= -0.15	r= 0.11	r= -0.16	r= 0.03
	Control	r= -0.15	r= 0.30	r= 0.05	r= -0.11	r= 0.15	r= -0.04	r= 0.01	r= -0.20	r= 0.18
50APDF_LCES	Case	r= -0.22	r= 0.07	r= 0.15	r= -0.41	r= 0.22	r= -0.03	r= 0.00	r= 0.37	r= 0.26
	Control	r= 0.05	r= 0.10	r= 0.03	r= -0.02	r= 0.02	r= 0.14	r= -0.15	r= -0.11	r= 0.23
50APDF_RUT	Case	r= 0.40	r= -0.03	r= -0.09	r= -0.23	r= -0.26	r= 0.44	r= -0.20	r= -0.32	r= -0.05
	Control	r= -0.14	r= 0.06	r= -0.30	r= 0.24	r= 0.14	r= -0.17	r= 0.37	r= 0.30	r= -0.03
50APDF_LUT	Case	r= -0.05	r= -0.05	r= 0.02	r= -0.39	r= 0.04	r= 0.10	r= -0.19	r= 0.11	r= 0.20
	Control	r= 0.01	r= -0.04	r= 0.00	r= -0.03	**r= 0.51***	r= 0.31	r= 0.01	r= 0.11	r= 0.10
50APDF_RLT	Case	r= 0.12	r= 0.12	**r= -0.48***	r= -0.12	r= -0.11	r= -0.09	**r= -0.52***	**r= -0.59****	**r= -0.54***
	Control	r= 0.01	r= -0.02	r= 0.30	r= -0.05	r= 0.03	r= 0.23	r= -0.20	r= 0.08	r= -0.01
50APDF_LLT	Case	r= 0.37	r= -0.04	r= -0.20	r= -0.37	**r= -0.65****	r= 0.08	r= -0.20	r= -0.42	r= -0.21
	Control	r= 0.01	r= -0.22	r= -0.14	r= 0.12	r= -0.03	r= 0.01	r= -0.41	r= -0.41	r= -0.14
APDF Range_RCES	Case	r= -0.20	r= -0.33	r= 0.07	r= -0.13	r= -0.05	r= -0.21	r= 0.19	r= -0.07	r= 0.09
	Control	r= -0.15	r= 0.34	r= -0.11	r= -0.14	r= 0.05	r= -0.16	r= 0.27	r= 0.02	r= 0.21
APDF Range_LCES	Case	r= -0.13	r= -0.01	r= 0.21	r= -0.26	r= 0.24	r= -0.03	r= 0.21	**r= 0.51***	r= 0.34
	Control	r= 0.00	r= 0.17	r= -0.01	r= -0.01	r= -0.04	r= 0.12	r= -0.03	r= 0.05	r= 0.33
APDF Range_RUT	Case	r= 0.37	r= -0.13	r= 0.26	r= -0.06	r= -0.08	r= 0.38	r= 0.14	r= 0.05	r= 0.21
	Control	r= -0.05	r= 0.04	r= -0.35	r= 0.26	r= 0.20	r= -0.10	**r= 0.48***	r= 0.45	r= -0.02
APDF Range_LUT	Case	r= -0.13	r= -0.17	r= 0.12	r= -0.41	r= 0.23	r= 0.10	r= -0.09	r= 0.10	r= 0.19
	Control	r= -0.08	r= -0.01	r= -0.25	r= 0.14	**r= 0.54***	r= 0.09	r= 0.25	r= 0.32	r= 0.12
APDF Range_RLT	Case	r= 0.29	r= -0.02	r= -0.42	r= 0.08	r= 0.08	r= 0.02	r= -0.21	r= -0.41	r= -0.42
	Control	r= -0.08	r= 0.01	r= 0.18	r= 0.10	r= 0.08	r= 0.10	r= 0.10	r= 0.21	r= 0.18
APDF Range_LLT	Case	r= 0.32	r= -0.25	r= -0.05	r= -0.21	**r= -0.46***	r= 0.08	r= 0.11	r= -0.21	r= -0.03
	Control	r= -0.21	r= -0.01	r= -0.32	r= 0.34	r= -0.03	r= -0.07	r= -0.10	r= -0.14	r= 0.17

C. Computer typing

		MA_Cx X	MA_Cx Y	MA_Cx Z	MA_Tx X	MA_Tx Y	MA_Tx Z	Range_Cx X	Range_Cx Y	Range_Cx Z
50APDF_RCES	Case	r= -0.40	**r= -0.49***	r= 0.12	**r= -0.521***	r= -0.05	r= 0.28	r= -0.09	r= 0.01	r=- 0.04
	Control	r= 0.01	r= -0.13	r= 0.07	r= 0.05	r= 0.27	r= -0.22	r= 0.21	r= -0.20	r= 0.11
50APDF_LCES	Case	**r= -0.47***	r= -0.29	r= 0.21	**r= -0.63****	r= 0.05	r= 0.03	r= 0.01	r= 0.14	r= 0.19
	Control	r= 0.15	r= -0.26	r= 0.00	r= -0.11	r= 0.13	r= 0.10	r= 0.05	r= 0.03	r= 0.05
50APDF_RUT	Case	r= -0.26	r= -0.09	r= -0.27	**r= -0.50***	r= -0.25	**r= 0.75****	r= -0.42	r= -0.07	r= -0.04
	Control	r= -0.17	r= 0.05	r= 0.25	r= -0.28	r= 0.27	r= 0.08	r= -0.17	r= 0.02	r= -0.10
50APDF_LUT	Case	r= -0.19	r= -0.06	r= -0.39	**r= -0.70****	r= -0.26	**r= 0.64****	r= -0.32	r= -0.04	r= 0.11
	Control	r= -0.03	r= -0.25	r= 0.29	**r= -0.49***	r= 0.27	**r= 0.59****	**r= -0.56***	r= 0.01	r= -0.39
50APDF_RLT	Case	r= -0.27	r= -0.01	r= -0.04	r= -0.12	r= 0.25	r= 0.07	r= 0.37	r= 0.21	r= 0.45
	Control	**r= -0.65****	r= -0.10	r= -0.15	r= -0.40	r= -0.13	r= 0.17	r= 0.17	r= 0.21	r= 0.06
50APDF_LLT	Case	r= -0.26	r= -0.08	r= 0.10	r= -0.24	r= 0.22	r= 0.15	r= 0.12	r= -0.17	r= 0.11
	Control	**r= -0.54***	r= -0.43	r= 0.11	r= -0.08	r= 0.16	r= -0.23	r= 0.03	r= -0.11	r= 0.06
APDF	Case	r= -0.40	**r= -0.51***	r= 0.16	r= -0.34	r= -0.06	r= 0.23	r= 0.09	r= 0.11	r= 0.08
Range_RCES	Control	r= 0.01	r= -0.10	r= -0.19	r= 0.20	r= 0.05	r= -0.39	r= 0.30	r= -0.01	r= 0.24
APDF	Case	r= -0.45	r= -0.39	r= 0.30	r= -0.42	r= 0.14	r= 0.05	r= 0.15	r= 0.35	r= 0.25
Range_LCES	Control	r= 0.11	r= -0.09	r= -0.16	r= -0.07	r= 0.03	r= -0.07	r= 0.14	r= 0.12	r= 0.18
APDF	Case	r= -0.22	r= -0.09	r= -0.15	r= -0.30	r= -0.29	**r= 0.66****	r= -0.38	r= -0.07	r= -0.07
Range_RUT	Control	r= 0.03	r= 0.22	r= 0.18	r= -0.03	r= 0.22	r= -0.20	r= -0.26	r= -0.04	r= -0.14
APDF	Case	r= -0.23	r= -0.23	r= -0.30	**r= -0.57***	r= -0.26	**r= 0.67****	r= -0.23	r= 0.14	r= 0.14
Range_LUT	Control	r= -0.18	r= -0.30	r= 0.21	r= -0.38	r= 0.15	r= 0.36	**r= -0.54***	r= 0.05	r= -0.29
APDF	Case	r= -0.24	r= 0.01	r= -0.17	r= -0.23	r= -0.06	r= 0.16	r= 0.24	r= 0.25	r= 0.38
Range_RLT	Control	r= -0.44	r= 0.06	r= -0.28	r= -0.17	r= -0.23	r= 0.17	r= 0.27	**r= 0.56***	r= 0.21
APDF	Case	r= -0.19	r= -0.01	r= 0.02	r= -0.32	r= 0.15	r= 0.19	r= -0.01	r= -0.16	r= 0.12
Range_LLT	Control	**r= -0.50***	r= -0.41	r= 0.03	r= 0.29	r= 0.02	r= -0.33	r= 0.13	r= 0.18	r= 0.22

Note: MA=median angle, Range=range of joint angles, Cx=cervical spine, Tx=thoracic spine, X=flexion/extension, Y=right/left side flexion, Y=right/left rotation, R/LCES=right/left-sided cervical erector spinae, R/LUT=right/left upper trapezius, R/LLT=right/left lower trapezius, *p<0.05; **p<0.01.

Appendix V A-C. Spearmen's rho correlations of median cervical and thoracic joint angles, ranges of cervical movements and median activity of proximal postural muscles with discomfort scores in six body regions (summed scores of both sides).

A. Bilateral texting

		Dis_ Neck	Dis_ Shoulder	Dis_ Upper back	Dis_ Elbow	Dis_ Wrist	Dis_ Thumb	Dis_ All
MA_Cx X	Case	r= -0.30	r= -0.22	r= -0.11	r= 0.05	**r= -0.54***	r= -0.26	r= -0.34
	Control	r= -0.16	r= -0.35	r= 0.08	r= -0.28	r= -0.31	r= 0.04	r= -0.11
MA_Cx Y	Case	r= -0.20	r= -0.09	r= 0.00	r= -0.41	r= -0.27	r= -0.05	r= -0.21
	Control	r= 0.09	r= 0.30	r= -0.03	r= 0.05	r= 0.31	r= 0.24	r= 0.24
MA_Cx Z	Case	r= 0.11	r= 0.01	r= 0.07	r= 0.24	r= 0.31	r= 0.22	r= 0.25
	Control	r= -0.09	r= 0.00	r= 0.22	r= -0.07	r= -0.21	r= 0.01	r= -0.11
MA_Tx X	Case	r= -0.29	r= -0.41	r= -0.26	r= 0.30	r= -0.40	r= -0.23	r= -0.27
	Control	r= 0.07	r= -0.22	r= -0.21	r= 0.22	r= -0.18	r= -0.21	r= -0.07
MA_Tx Y	Case	r= 0.15	r= -0.20	r= -0.31	r= 0.33	r= -0.03	r= 0.41	r= 0.11
	Control	r= 0.13	r= 0.15	r= 0.33	r= 0.01	r= -0.10	r= -0.01	r= -0.02
MA_Tx Z	Case	r= 0.41	r= -0.08	r= 0.00	r= 0.44	r= 0.30	r= -0.07	r= 0.23
	Control	r= -0.05	r= -0.16	r= 0.43	r= -0.23	r= -0.24	r= -0.18	r= -0.11
Range_Cx X	Case	r= 0.17	r= 0.24	**r= 0.62****	r= -0.15	r= 0.16	r= -0.04	r= 0.30
	Control	r= 0.10	r= 0.12	r= 0.34	r= 0.23	r= 0.07	r= 0.27	r= 0.42
Range_Cx Y	Case	r= -0.12	r= -0.26	r= 0.11	r= 0.13	r= 0.03	r= 0.27	r= 0.02
	Control	r= -0.05	r= 0.26	r= -0.05	r= 0.34	r= 0.38	r= 0.04	r= 0.08
Range_Cx Z	Case	r= 0.21	r= -0.10	**r= 0.51***	r= 0.24	r= 0.45	r= 0.34	r= 0.43
	Control	r= 0.32	r= 0.45	r= -0.08	r= 0.41	**r= 0.63****	r= -0.10	r= 0.20
50APDF _RCES	Case	r= -0.28	r= -0.07	r= -0.38	r= -0.09	r= 0.21	r= -0.29	r= -0.28
	Control	r= 0.46	r= 0.25	r= 0.04	r= 0.18	r= 0.12	r= 0.32	r= 0.40
50APDF _LCES	Case	r= -0.01	r= 0.08	r= -0.38	r= -0.06	r= 0.25	r= -0.07	r= -0.16
	Control	r= 0.12	r= 0.03	r= 0.02	r= -0.09	r= -0.13	**r= 0.48***	r= 0.31
50APDF _RUT	Case	r= -0.35	r= 0.03	r= 0.01	r= 0.34	r= 0.08	r= -0.20	r= -0.10
	Control	r= -0.10	r= 0.29	r= 0.40	r= 0.04	r= 0.25	r= -0.12	r= 0.10
50APDF _LUT	Case	r= -0.12	r= 0.38	r= 0.03	r= 0.06	r= 0.18	r= -0.20	r= 0.01
	Control	r= -0.12	r= 0.09	r= 0.36	r= -0.08	r= 0.07	r= -0.08	r= 0.02
50APDF _RLT	Case	r= 0.21	r= 0.19	r= -0.01	r= 0.11	r= 0.15	r= -0.09	r= 0.13
	Control	r= 0.13	r= 0.16	r= -0.23	r= 0.12	r= 0.26	r= 0.29	r= 0.25
50APDF _LLT	Case	r= -0.05	r= 0.20	r= -0.02	r= -0.43	r= -0.24	r= -0.28	r= -0.20
	Control	r= 0.08	r= 0.21	r= 0.03	r= 0.07	r= -0.02	r= 0.23	r= 0.28

B. Unilateral texting

		Dis_ Neck	Dis_ Shoulder	Dis_ Upper back	Dis_ Elbow	Dis_ Wrist	Dis_ Thumb	Dis _all
MA_Cx X	Case	r= -0.21	r= 0.28	r= 0.13	r= -0.15	r= -0.25	r= -0.17	r= -0.07
	Control	r= -0.04	r= -0.08	r= 0.05	r= 0.02	r= 0.06	r= 0.20	r= -0.07
MA_Cx Y	Case	r= -0.32	r= -0.36	r= 0.13	r= -0.36	r= -0.25	r= -0.34	r= -0.22
	Control	r= 0.43	r= 0.19	r= 0.19	r= 0.32	r= 0.31	r= -0.11	r= 0.38
MA_Cx Z	Case	r= -0.05	r= -0.34	r= 0.28	**r= 0.61****	r= 0.26	r= 0.45	r= 0.13
	Control	r= 0.26	r= 0.03	r= -0.08	r= 0.04	r= 0.40	r= 0.01	r= 0.23
MA_Tx X	Case	r= -0.02	r= -0.04	r= 0.10	r= 0.20	r= 0.28	r= 0.39	r= 0.12
	Control	r= -0.25	r= -0.42	r= -0.19	r= -0.28	r= -0.05	r= -0.33	r= -0.44
MA_Tx Y	Case	**r= 0.49***	r= 0.22	r= -0.13	r= -0.02	r= 0.15	**r= 0.48***	r= 0.34
	Control	r= -0.19	r= 0.34	r= 0.00	r= -0.09	r= 0.12	r= 0.19	r= -0.03
MA_Tx Z	Case	r= 0.31	r= 0.30	r= 0.13	r= 0.12	r= 0.02	r= 0.29	r= 0.26
	Control	r= -0.08	r= 0.08	r= 0.19	r= 0.13	r= -0.01	r= 0.09	r= 0.01
Range_Cx X	Case	r= 0.18	r= 0.13	r= 0.41	r= 0.26	**r= 0.56***	**r= 0.46***	r= 0.39
	Control	r= -0.24	r= 0.23	r= 0.38	r= 0.40	r= -0.17	r= 0.28	r= 0.13
Range_Cx Y	Case	r= 0.16	r= -0.06	r= 0.32	r= -0.05	r= 0.34	r= 0.28	r= 0.21
	Control	r= 0.07	r= 0.11	r= 0.45	**r= 0.60****	r= -0.16	r= 0.35	r= 0.28
Range_Cx Z	Case	r= -0.02	r= -0.30	r= 0.41	r= 0.38	**r= 0.50***	**r= 0.49***	r= 0.26
	Control	**r= 0.56***	r= 0.15	r= 0.46	r= 0.32	r= 0.23	r= 0.15	**r= 0.65****
50APDF _RCES	Case	r= -0.08	r= -0.28	r= -0.33	r= 0.36	r= 0.03	r= -0.01	r= -0.19
	Control	r= 0.14	r= 0.16	r= -0.22	r= 0.07	r= -0.01	r= 0.18	r= 0.12
50APDF _LCES	Case	r= 0.19	r= -0.15	r= -0.21	r= 0.03	r= -0.01	r= -0.08	r= 0.01
	Control	r= 0.02	r= 0.08	r= -0.09	r= -0.09	r= -0.23	r= 0.20	r= -0.01
50APDF _RUT	Case	r= -0.19	r= 0.07	r= -0.02	r= 0.32	r= 0.14	r= 0.05	r= 0.02
	Control	r= -0.24	r= -0.02	r= 0.08	r= 0.06	**r= -0.51***	r= -0.09	r= -0.31
50APDF _LUT	Case	r= 0.22	r= 0.26	r= -0.08	r= 0.31	r= 0.34	r= 0.27	r= 0.33
	Control	r= -0.11	r= 0.18	r= 0.13	r= -0.09	r= -0.42	r= 0.09	r= -0.17
50APDF _RLT	Case	r= 0.00	r= 0.30	r= -0.03	r= -0.08	r= -0.14	r= -0.18	r= 0.10
	Control	r= -0.09	r= -0.06	r= -0.35	r= 0.21	r= 0.13	r= 0.13	r= 0.01
50APDF _LLT	Case	r= -0.42	r= -0.05	r= -0.02	r= 0.09	r= -0.30	r= -0.42	r= -0.31
	Control	r= -0.21	r= 0.21	r= -0.30	**r= -0.60****	r= -0.09	r= 0.29	r= -0.12

C. Computer typing

		Dis_ Neck	Dis_ Shoulder	Dis_ Upper back	Dis_ Elbow	Dis_ Wrist	Dis_ Thumb	Dis _all
MA_Cx X	Case	r= 0.03	r= 0.30	r= 0.34	r= 0.14	r= 0.16	r= 0.09	r= 0.30
	Control	r= -0.13	r= -0.05	r= 0.11	r= -0.25	r= 0.07	r= -0.37	r= -0.19
MA_Cx Y	Case	r= -0.37	r= -0.13	r= 0.08	r= -0.02	r= 0.06	r= -0.02	r= -0.17
	Control	r= -0.09	r= 0.10	r= 0.07	r= 0.07	r= 0.21	r= 0.06	r= 0.23
MA_Cx Z	Case	r= -0.04	r= 0.02	r= -0.17	r= -0.11	r= -0.14	r= 0.10	r= -0.07
	Control	r= 0.36	r= -0.20	r= 0.11	r= 0.13	r= -0.45	**r= -0.57***	r= -0.27
MA_Tx X	Case	r= -0.23	r= -0.28	r= 0.19	r= 0.26	r= -0.17	r= -0.07	r= 0.03
	Control	**r= 0.50***	r= -0.36	r= 0.17	r= -0.09	r= 0.10	r= -0.05	r= 0.08
MA_Tx Y	Case	r= 0.15	r= -0.04	r= -0.32	r= 0.05	r= -0.29	r= 0.09	r= 0.06
	Control	r= -0.04	r= -0.11	r= 0.20	r= 0.39	r= -0.43	r= -0.39	r= -0.25
MA_Tx Z	Case	r= 0.27	r= 0.15	r= 0.03	r= 0.16	r= 0.24	r= 0.24	r= 0.19
	Control	r= -0.37	r= -0.06	r= -0.14	r= -0.11	r= -0.20	r= -0.38	**r= -0.48***
Range_Cx X	Case	r= 0.22	r= -0.03	r= -0.23	r=- 0.07	**r= -0.47***	r= -0.33	r= -0.16
	Control	r= -0.06	r= -0.09	r= 0.00	r= 0.09	r= 0.08	r= 0.22	r= 0.05
Range_Cx Y	Case	r= 0.30	r= -0.10	r= -0.22	r= 0.26	r= -0.11	r= -0.01	r= 0.02
	Control	r= 0.14	r= 0.22	r= 0.29	r= 0.24	r= 0.32	r= 0.08	r= 0.43
Range_Cx Z	Case	r= 0.25	r= 0.04	r= 0.17	r= -0.02	r= -0.09	r= 0.10	r= 0.07
	Control	r= 0.22	r= 0.04	r= 0.20	r= 0.17	r= 0.27	r= 0.21	r= 0.31
50APDF _RCES	Case	r= 0.11	r= 0.13	r= -0.19	r= -0.39	r= 0.09	r= -0.17	r= -0.09
	Control	r= -0.01	r= -0.11	r= -0.15	r= 0.07	r= -0.17	r= 0.27	r= 0.20
50APDF _LCES	Case	r= 0.09	r= -0.01	r= -0.41	**r= -0.50***	r= 0.10	r= 0.03	-r= 0.21
	Control	r= -0.18	r= 0.09	r= -0.17	r= 0.09	r= -0.05	r= 0.35	r= 0.29
50APDF _RUT	Case	r= -0.03	r= 0.08	r= -0.03	r= 0.05	r= 0.37	r= 0.18	r= -0.03
	Control	r= -0.02	r= 0.20	**r= 0.54***	r= 0.46	r= -0.23	r= 0.04	r= 0.30
50APDF _LUT	Case	r= 0.24	r= 0.21	r= -0.11	r= -0.09	r= 0.26	r= 0.03	r= 0.05
	Control	r= -0.23	r= 0.39	r= 0.32	r= 0.38	r= -0.09	r= -0.16	r= 0.10
50APDF _RLT	Case	r= 0.17	r= 0.12	r= -0.14	r= 0.11	r= -0.31	r= 0.12	r= -0.06
	Control	r= -0.31	r= 0.22	r= -0.38	r= 0.09	r= 0.02	**r= 0.53***	r= 0.05
50APDF _LLT	Case	r= -0.16	r= 0.12	r= -0.12	r= -0.03	r= -0.03	r= -0.03	r= -0.06
	Control	r= -0.07	r= 0.08	r= -0.17	r= 0.01	r= 0.01	**r= 0.49***	r= 0.23

Note: MA=median angle, Range=range of joint angles, Cx=cervical spine, Tx=thoracic spine, X=flexion/extension, Y=right/left side flexion, Y=right/left rotation, 50APDF=50th %ile amplitude probability distribution function, R/LCES=right/left-sided cervical erector spinae, R/LUT=right/left upper trapezius, R/LLT=right/left lower trapezius, Dis=discomfort, Dis_all=total discomfort scores of all recorded body regions, *p<0.05; **p<0.01.

Appendix VI. Subjects' demographic characteristics for Case Group and Control Group which were sub-divided into female and male groups, respectively.

	Case Group (n=20) (Mean±SD)		Control Group (n=20) (Mean±SD)		*p*-value	
	Male (n=8)	Female (n=12)	Male (n=8)	Female (n=12)	p_1	p_2
Age (years)	22.25±2.05	26.08±2.78	22.75±2.12	23.05±3.73	0.639	0.067
Height (cm)	174.75±3.85	163.83±6.08	177.38±3.93	159.63±9.71	0.198	0.216
Weight (kg)	72.95±12.83	56.93±9.11	66.35±9.33	55.25±6.76	0.259	0.614
RHB (cm)	8.29±0.788	7.25±0.45	7.96±0.61	7.30±0.45	0.371	0.787
LHB(cm)	8.15±0.59	7.13±0.33	7.86±0.62	7.29±0.44	0.375	0.303
RHL(cm)	18.40±0.51	17.07±0.96	18.84±1.05	17.10±1.16	0.309	0.940
LHL(cm)	18.48±0.55	17.15±0.99	18.83±1.14	17.10±1.15	0.449	0.911
RTL(cm)	5.98±0.11	5.56±0.57	6.08±0.27	5.65±0.52	0.339	0.714
LTL(cm)	6.00±0.19	5.55±0.55	6.08±0.30	5.60±0.58	0.479	0.831
RTC(cm)	5.66±1.34	5.33±0.35	5.56±0.76	5.30±0.32	**0.033***	0.810
LTC(cm)	5.73±1.16	5.28±0.34	5.56±0.74	5.22±0.34	**0.038***	0.680
Frequency of exercise [mode]	once to twice/week	Occasional	once to twice/week	occasional	0.535	1.000
Occupation[count (expected count)]	student=8 (7.5) assistant=1 (0.5)	student=8 (8.0) assistant=4 (4.0)	student=7 (7.5) assistant=0 (0.5)	student=8 (8.0) assistant=4 (4.0)	1.000	1.000

Note: R/LHB=right/ left hand breadth, R/LHL=right/ left hand length, R/LTL=right/left thumb length, R/LTC=right/left thumb circumference.

p_1: group differences in males; p_2: group differences in females. *$p<0.05$.

Appendix VII. Summary of subjects' patterns of using information technology devices in Case Group and Control Group which were sub-divided into female and male groups, respectively

	Case (n=20)		Control (n=20)		*p*-value	
	Male (n=8)	Female(n=12)	Male (n=8)	Female (n=12)	p_1	p_2
Phone operation system [count(expected count)]	ISO=4(3) Android=4(5)	ISO=6(5) Android=6(7)	ISO=2(3) Android=6(5)	ISO=4(5) Android=8(7)	0.608	0.680
Phone screen size (inch) [mean±SD)]	4.58±0.84	4.12±0.61	4.78±0.69	4.47±0.58	0.589	0.167
Smartphone usage (years)[mode (range)]	Mode=>3 y (0-6 Mo-->3 y)	Mode=>3 y (0-6 Mo-->3 y)	Mode=>3 y (0-6 Mo-->3 y)	Mode=>3 y (0-6 Mo-->3 y)	0.317	0.418
Total time on smartphones (hrs/day)[mean±SD)]	4.25±1.28	4.96±1.81	4.25±1.49	3.54±1.59	1.000	0.054
Total time on tablet use (hrs/day)[mean±SD)]	1.31±1.81	1.00±0.977	0.44±0.68	0.75±0.94	0.222	0.530
Total on computer use (hrs/day)[mean±SD)]	3.63±2.18	5.67±1.78	4.63±2.50	4.13±1.99	0.409	0.058
Total time on texting (hrs/day)[mean±SD)]	1.69±0.98	1.96±0.92	1.23±0.69	1.06±0.65	0.670	**0.012***
Phone input methods [count(expected count)]	Right thumb=5(4.5) Both thumbs=3(3.5)	Right thumb =8(7.0) Both thumbs=6(5.0)	Right thumb=4(4.5) Both thumbs=4(3.5)	Right thumb=4(7.0) Both thumbs=6(5.0)	1.000	0.408
Fastest texting speed (wpm)[mean±SD)]	26.35±4.98	26.58±4.44	23.55±7.04	23.50±6.79	0.508	0.202
Fastest typing speed (wpm) [mean±SD)]	37.25±8.63	39.75±9.13	36.95±7.58	36.50±5.84	0.305	0.204

Note: p_1: group differences in males; p_2: group differences in females. *p<0.05.

Appendix VIII. Body regions with pain and the pain score (0-10) within the past 12 months in Case Group which were sub-divided into female and male groups.

Painful regions	Case (n=20)			
	Bilateral pain		Unilateral pain	
	Male (n=8)	Female (n=12)	Male (n=8)	Female (n=12)
Neck[count] -Pain score [mean±SD]	7 R: 4.6±2.0 L: 4.4 ±1.9	9 R: 5.2±1.6 L: 5.0±1.9	1 R: 2.0±0.0 L: 0.0	3 R: 5.5±0.6 L: 0.0
Shoulder[count] -Pain score [mean±SD]	5 R: 4.4±1.1 L: 4.4±1.1	5 R: 5.0±2.3 L: 5.4±1.8	3 R: 5.3±1.6 L: 0.0	5 R: 5.2±1.9 L: 0.0
Upper back[count] -Pain score [mean±SD]	3 R: 5.0±1.7 L: 2.7±2.3	6 R: 5.2±1.8 L: 4.3±2.9	0	0
Wrist[count] -Pain score [mean±SD]	2 R: 4.0±1.4 L: 2.5±3.5	0	0	6 R: 5.7±2.7 L: 0.0
Thumb[count] -Pain score [mean±SD]	1 R: 5.0±0.0 L: 5.0±0.0	2 R: 6.5±2.1 L: 6.5±2.1	1 R: 3.0±0.0 L: 0	6 R: 6.0±2.7 L:00

Note: R=right, L=left.

Appendix IX. Effects of Group, gender and group x gender interactions for 50th percentile of amplitude probability distribution function of proximal muscles for females and males in Case Group and Control Group.

			B-TEXT	U-TEXT	TYPE	Group *p*-value	Gender *p*-value	Group x Gender *p*-value
RCES	Case	Male	9.94±3.23	11.63±4.74	12.80±4.77	0.326	0.668	**0.021***
		Female	15.57±7.07	15.11±6.73	12.82±6.08			
	Control	Male	13.27±4.43	14.01±6.53	13.63±6.00			
		Female	10.01±3.61	10.39±4.00	7.36±3.00			
LCES	Case	Male	9.96±7.01	9.85±6.83	12.41±5.91	0.617	0.321	0.190
		Female	16.68±6.40	14.74±5.63	12.42±5.22			
	Control	Male	11.81±3.75	11.98±4.58	12.56±4.95			
		Female	12.58±5.35	12.88±5.46	9.25±4.50			
RUT	Case	Male	2.76±2.03	3.02±1.72	8.18±7.62	**0.003***	**0.04***	0.204
		Female	7.07±4.51	7.95±6.36	10.26±8.32			
	Control	Male	1.90±2.09	2.48±2.89	3.28±1.54			
		Female	2.61±1.96	3.77±2.79	4.03±2.01			
LUT	Case	Male	2.94±2.63	0.61±0.73	5.38±3.47	**0.004***	**0.003***	0.171
		Female	6.48±3.64	3.46±3.11	10.95±8.23			
	Control	Male	1.32±1.44	0.57±0.88	2.66±1.96			
		Female	3.07±2.60	1.74±1.95	4.34±2.05			
RLT	Case	Male	3.22±1.68	5.05±2.03	6.12±3.41	0.912	0.971	0.660
		Female	3.73±2.26	4.79±3.15	7.02±4.04			
	Control	Male	4.48±4.07	4.48±3.44	6.22±3.36			
		Female	3.62±2.41	4.30±2.25	6.29±2.76			
LLT	Case	Male	3.53±1.59	2.28±1.44	5.87±2.50	0.790	0.370	0.950
		Female	2.43±2.11	1.95±1.49	5.72±3.94			
	Control	Male	3.36±2.70	1.75±1.28	7.19±3.48			
		Female	2.88±1.59	2.51±1.86	5.10±3.14			

Note: R/LCES=right/left cervical erector spinae, R/LUT=right/left upper trapezius, R/LLT=right/left lower trapezius, B-TEXT=bilateral texting, U-TEXT=unilateral texting, TYPE=computer typing. *$p<0.05$.

Appendix X. Ethical Approval Form

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

To	Szeto Pui Yuk Grace (Department of Rehabilitation Sciences)		
From	TSANG Wing Hong Hector, Chair, Departmental Research Committee		
Email	rshtsang@	Date	26-Sep-2012

Application for Ethical Review for Teaching/Research Involving Human Subjects

I write to inform you that approval has been given to your application for human subjects ethics review of the following project for a period from 02-Sep-2013 to 31-Aug-2015:

Project Title:	A study of musculoskeletal loading in using multitouch technology among young people
Department:	Department of Rehabilitation Sciences
Principal Investigator:	Szeto Pui Yuk Grace

Please note that you will be held responsible for the ethical approval granted for the project and the ethical conduct of the personnel involved in the project. In the case of the Co-PI, if any, has also obtained ethical approval for the project, the Co-PI will also assume the responsibility in respect of the ethical approval (in relation to the areas of expertise of respective Co-PI in accordance with the stipulations given by the approving authority).

You are responsible for informing the Departmental Research Committee in advance of any changes in the proposal or procedures which may affect the validity of this ethical approval.

You will receive separate email notification should you be required to obtain fresh approval.

TSANG Wing Hong Hector

Chair

Departmental Research Committee

Appendix XI. Subject Consent Form

參與研究同意書

研究項目：有頸/肩痛癥和無癥狀的年輕人在使用觸屏手機時的骨骼肌肉負荷情況

研究人员：謝燕菲，香港理工大學康復治療科學系碩士研究生
導師：司徒佩玉博士，香港理工大學康復治療科學系副教授

研究項目簡介

目前不管在哪裏不管什麼時候都能看到人們用觸屏能手機發信息，上網，閱讀，聽音樂，下載軟件等。 觸屏手機大大改變了我們的生活方式。它使我們的生活變得更加方便，讓我們掌握了更多的信息，但同時導致了久坐的生活方式。這種久坐的生活方式以及使用觸屏手機時人們長期處於一個靜態的姿勢，使得頸部或者手部的痛征的發病率也越來越高。

本研究主要觀察年輕人在使用觸屏手機發短信時頸部，上肢和手部的骨骼肌肉負荷情況，探究有頸/肩痛癥的人群和無頸/肩痛癥人群頸部，上肢和手部的肌肉運動模式是否不一樣，從而為臨床幹預措施提供依據。
如果你願意參與這次研究，你需要填寫一份個人信息，關於你使用多點觸控設備的問卷以及一份關於過去十二個月骨骼肌肉癥狀的問卷。在實驗過程中，你也需要參與肌肉活動的測試。測試時需要將電極片貼在你的頸部，背部和手臂的部位，你需要進行一些指定的任務，而這過程將以電圖記錄。你的所有的有關數據僅用於本研究。測試時需要使用的黏貼性電極於頸部，背部，上肢的皮膚，這過程可能會令你的皮膚出現暫時性的發紅。在研究過程中，如果引致不能承受的身體不適，你有權要求退出此研究。

本人______________________________明白這次研究的詳細情況，並願意參與這次研究測試。本人的參與，是屬於自願性質。本人明白在任何時間可以放棄及退出測試，而勿須給予任何理由。本人也不會因為退出測試而受到任何處罰或對本人存在有任何偏見。本人知道並明白參與這次研究所帶來的潛在危險性。除了有關研究人員，本人的個人資料不會展示給予任何人。如未經本人的同意，本人的名字及照片並不會刊登於這次研究的任何發表布告之中。本次研究已通過本研究機構倫理審查委員會審查。

本人如果對這項研究有任何疑問，可以致電 2766　　，與導師司徒佩玉博士聯絡。如果對這次研究或研究員有任何投訴或者建議，可致電 2766　　，與部門研究委員會秘書梁家恩先生聯絡。本人簽署後表明本人已收到此同意書副本乙份。

簽署（參與者）:________________　　名稱（參與者）:________________

簽名（見證者）:________________　　日期:________________

Subject Consent Form

Title of Research Project: A study of musculoskeletal loading in using a touchscreen smartphone among young people with and without chronic neck-shoulder pain.

Investigator: Yanfei Xie, MPhil student, The Hong Kong Polytechnic University
Supervisor: Grace Szeto, Associate Professor, The Hong Kong Polytechnic University

Brief Description of Research Project:

People are using smartphones for texting, browsing internet, reading, listening to music, downloading apps and so on at any time and everywhere. Smartphones make a tremendous impact on our lifestyles. They bring a lot of convenience to our life and make it easier to access information. However, using smartphones also lead to a trend of sedentary lifestyles. The sedentary lifestyle and long duration of static postures while using smartphones may contribute to a high prevalence of chronic neck-shoulder pain or thumb pain.

The aim of this study is to investigate the musculoskeletal loading in neck, shoulder and hand among young adults while texting on a touchscreen smartphone and to examine whether the pattern of muscle activity and kinematics are different between young adults with and without chronic neck-shoulder pain. This study will provide some implications on the prevention and management of chronic neck-shoulder pain among young adults.

If you volunteer to take part in this study, you will be asked to fill in questionnaires regarding the pattern of touchscreen smartphone usage and pain profile during the past 12 months. You will be instructed to do some tasks. The activity of muscles in the neck, shoulder and upper limb will be recorded using surface electromyography while doing experimental tasks. All of your information and data were used only for this study. During the experiment, surface electromyography electrodes will be placed on the muscle belly and skin preparation will be done. Therefore, you might get red skins after the experiment. You have the right to withdraw from this study at any time if you feel unwell during the experiment.

I____________________ have read the details of this study and volunteer to be in this study. My participation in this study is entirely voluntary. I am clear that I can withdraw from this study without giving any reasons. In addition, there is no any penalty and prejudice to you if you withdraw from this study. I have been aware of the potential risk of this study. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. We will neither use your name nor present your pictures in any of the research reports without your permission. The human ethics committee of the Hong Kong Polytechnic University has approved the study.

If you have any questions about this study, please contact my supervisor, Dr. Grace Szeto (Tel: 27666706). If you have any concerns about your rights in this study, please contact the member of Department Research Committee, Mr Ka Yan Leung at 27665398. I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____________________________________ ________________________

Signature of Subject Date

____________________________________ ________________________

Signature of Witness Date

Appendix XII A-C. Samples of questionnaire instruments for screening of subjects at baseline

Appendix XI A. A modified version of Standardised Nordic Questionnaire

Name : _________ Subject code_____ Group_______ Date: __________

第 1 部分：個人資料
The First Part: Personal information

1.姓名 (name): _______________

2.性別 (gender): 1=男 (male)☐ 2=女 (female)☐

3.電話號碼 (Phone No.):_____________________ 0

4.郵箱地址 (e-mail address):__________________

5.年齡 (age):

6.臂长 (arm length):__R:_______L:______cm

7. 手的寬度 (hand breadth): RHB_____ cm LHB______cm

8. 手的長度 (hand length): RHL _______cm LHL ______cm

9. 拇指的寬度 (Thumb length): RTL______cm LTL_____cm

10. 拇指的圍度 (Thumb circumference): RTC______cm LTC______cm

11.身高 (Height): _______ cm 12.重量 (Weight): _______ kg

13. 過去十二個月您的頸部或者肩膊是否疼痛？如有，请回答第三部分问卷。
Do you have pain in neck or shoulder regions in the past 12 months? If yes, please answer questions in the third part
是 Yes ☐ 不是 No ☐

14. 您是否有過脊柱或上肢的外傷史或手術史或其他對脊柱和上肢有不良影響的病史？Do you have history of traumatic injuries or surgical interventions or other medical conditions that have a negative effect on the spine and upper limb regions?
是 Yes ☐ 不是 No ☐

15. 您是否有影響骨骼肌肉系統的疾病史，如類風濕性關節炎，骨關節炎或其他結締組病？Do you have chronic diseases that affecting the musculoskeletal system such as rheumatoid arthritis, osteoarthritis and other connective tissue disorders?

是 Yes ☐　　不是 No ☐

16. 您是否有神經或骨科疾病或感覺障礙? Do you have neurological or orthopedic disorders or sensory deficits?

是 Yes☐　　不是 No ☐

17. 您是全職學生嗎？ Are you full-time students?

是 Yes ☐　　否 No ☐　若否请回答 18 If No, please go to Q18.

18. 您的全职工作是什么？ What is your full-time job?____________________

19. 你慣用左手或右手？ Which one is your dominant hand?

左 Left ☐　　　右 Right ☐

20. 你經常進行運動? Do you exercise?

a. 從未 Never ☐
b. 偶爾 Sometimes ☐
c. 定期每週 1-2 次 Once to twice a week ☐
d. 定期每週 3 節或更多節 Three days or more per week ☐

21. 你有定期使用以下哪種電子儀器 （可選多於 1 答案）? Do you regularly use the following electronic devices (can pick more than one answer)?

a. 桌上型電腦 Desktop computer ☐
b. 筆記本電腦 Notebook ☐
c. 流動電話(帶鍵盤）Keypad phone ☐
d. 流動電話(輕觸屏幕）Touchscreen phone ☐
e. iPad/其他有觸摸式顯示幕的電子儀器 iPad/other touchscreen devices ☐
f. 手提按键遊戲機 Keypad handheld game devices ☐
g. 手提觸屏遊戲機 Touchscreen Handheld game devices ☐

22. 請你估計日常平均花費於各類型電子儀器的時間:（只需回答關於你有定期使用的電子儀器，在相應的方框內打“✓”）. How many hours do you spend on various electronic devices on a typical day :(just pick the time periods for devices that you regularly use)?

	< 1 hour	1-2 hours	2-4 hours	4-6 hours	6-8 hours	>8 hours
桌上型電腦 Desktop computers	☐	☐	☐	☐	☐	☐
筆記本電腦 Notebooks	☐	☐	☐	☐	☐	☐
流動電話(帶鍵盤) Keypad phones	☐	☐	☐	☐	☐	☐
流動電話(輕觸屏幕) Touchscreen phones	☐	☐	☐	☐	☐	☐
其他有輕觸屏幕電子儀器 Other touchscreen devices	☐	☐	☐	☐	☐	☐
手提按键遊戲機 Handheld keypad game devices	☐	☐	☐	☐	☐	☐
手提觸屏遊戲機 Touchscreen handheld game devices	☐	☐	☐	☐	☐	☐

第二部分：以下為有關觸摸式智能手機 的使用習慣
The Second Part: details of the use of touchscreen smartphones

1. 關於你使用的觸摸式智能手機，請說明型號:
   What is the model of your touchscreen smartphones?

1. iPhone ☐
2. Samsung Galaxy ☐
3. HTC ☐
4. Blackberry ☐
5. iPad ☐
6. 其他: ________________________

2. 你一直使用這觸摸式智能手機多久?
   How long have you use this touchscreen smartphone

1. 0-6 months ☐
2. 6-12 months ☐
3. 1-2 years ☐
4. 2-3 years ☐
5. ＞3 years ☐

3. 你平均每天一共花多少小時使用這觸摸式智能手機?
   How many hours did you spend on this touchscreen smartphone in a typical day?

1. 0-1 Hrs ☐
2. 1-2 Hrs ☐
3. 2-3 Hrs ☐
4. 3-4 Hrs ☐
5. over 4 Hrs : _____ Hrs (盡量列舉 write down the hours)

4. 你每天用觸摸式智能手機進行文字輸入/編輯的任務的時間是多少？
   How much time did you use touchscreen smartphone for texting

1. 0-30 mins ☐ 2. 30-1 hour ☐ 3. 1-2 hours□ ☐ 4. 2-3 hours ☐ 5. > 3 hours ☐

5. 你使用觸摸式智能手機時，如何用你的手指輸入資料?
   What is you input method while you perform texting tasks

☐ 主要用右手拇指輸入資料並且只是右手握著電話
Mainly text with right thumb while only right hand holding the phone

☐ 主要用右手拇指輸入資料並且双手握著電話
Mainly text with right thumb while both hands holding the phone

☐ 主要用右手食指輸入資料並且只是左手握著電話
Mainly text with the right index finger while only left hand holding the phone

☐ 主要用左手拇指輸入資料並且只是左手握著電話
Mainly text with left thumb while only left hand holding the phone

☐ 主要用左手拇指輸入資料並且双手握著電話
Mainly text with left thumb while both hands holding the phone

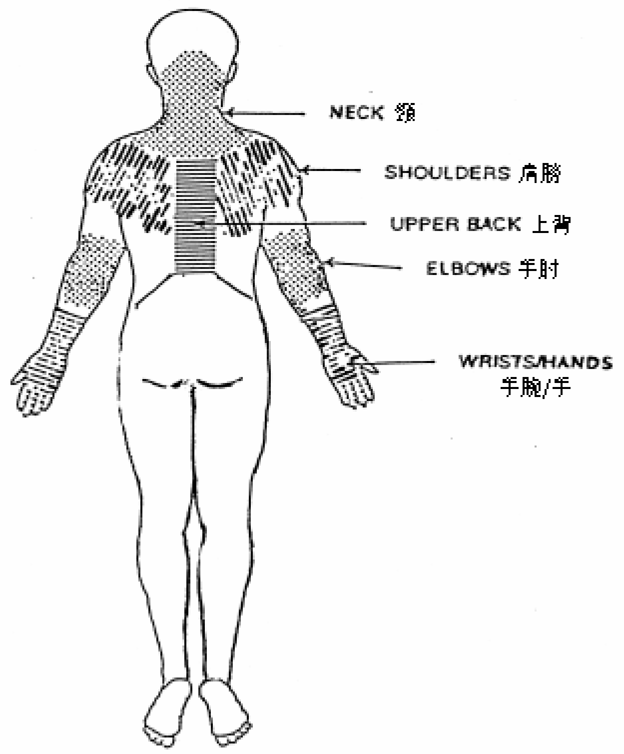
☐ 主要用左手食指輸入資料並且只是右手握著電話
Mainly text with the left index finger while only right hand holding the phone

☐ 主要用雙手拇指並且双手握著電話
Text with both thumbs while both hands holding the phone

☐ 用觸控筆輸入
Text with stylus

第三部分:關於健康問題
The third Part: Questions about musculoskeletal health

請回答以下問題時, 以此圖各部位的位置作參考. Please answer the following questions and refer to the following body chart.



Pain scale 疼痛程度
0 No pain 沒有疼痛
1 Minimal pain 輕微疼痛
2
3
4
5
6
7
8
9
10 Extreme/intolerable pain 極度/不能忍受的疼痛

以上圖像為依據，請列出過去 12 個月期間，**身體有疼痛的部位**(可選多於 1 答案)和**典型的一天里疼痛的水平(0-10)**。Please mark your painful regions (Could tick more than 1 answer) and you pain level in a typical day in the past 12 months:

疼痛部位 Painful regions	1. 左 Left / 疼痛程度 pain level (0-10)	2. 右 Right / 疼痛程度 pain level (0-10)	3. 兩邊 Both / 疼痛程度 pain level (0-10)
a. 頸椎 Neck ☐	☐ / ______0	☐ / ______0	☐ / ______0
b. 肩膊 Shoulder ☐	☐ / ______0	☐ / ______0	☐ / ______0
c. 上背 Upper back ☐	☐ / ______0	☐ / ______0	☐ / ______0
d. 手肘 Elbow ☐	☐ / ______0	☐ / ______0	☐ / ______0
e. 手腕/手部 Wrist/hand ☐	☐ / ______0	☐ / ______0	☐ / ______0
f. 拇指/手指 Thumbs/fingers ☐	☐ / ______0	☐ / ______0	☐ / ______0

以下問題，請根據上題所揀選的身體部位作答
Please answer the following questions according to the painful body region

1.這些身體部位, 曾否因為意外而受傷?
Do you have history of traumatic injuries in the above selected body regions
1=沒有 No ☐ 2= 有 Yes ☐, 請註明 Note:________________________

2.你有沒有因為這些疼痛，而需要轉工或改變工作性質?
Did you change your job or change the contents of your work because of the pain
1=沒有 No ☐ 2=有 Yes ☐, 請註明 Note_______________________________

3.過去 12 個月期間，身體疼痛的時間共多久?
How long did the pain last in the past 12 months?
1= 0 天(0 day) ☐
2= 1-7 天(1-7 days) ☐
3= 8-30 天(8-30 days) ☐
4=多過 30 天，但並不是每天(More than 30 days, but not every day) ☐
5= 1-3 月(1-3 months) ☐
6= 3-6 月(3-6 months) ☐
7=多過 6 個月(More than 6 months) ☐

4. 在過去 12 個月期間，你的工作及閒餘活動曾否因這些身體疼痛而減少？
Did you spend less time for work or leisure activities because of pain in the past 12 months?
a.工作（在家或不在家）Work (at home or outside): 1=沒有 No ☐ 2=有 Yes ☐
b. 閒餘活動 Leisure activities: 1=沒有 No ☐ 2=有 Yes ☐

5.過去 12 個月期間，這些身體疼痛，持續令你不能從事工作（在家或不在家）多久? How long is the work absence because of pain in the past 12 months ?
1= 0 天 (0 day) ☐
2= 1-7 天 (1-7 days) ☐
3= 8-30 天 (8-30 days) ☐
4=多過 30 天，但並不是每天 (More than 30 days, but not every day) ☐
5=1-3 個月 (1-3 months) ☐
6=3-6 個月 (3-6 months) ☐
7=多過 6 個月 (More than 6 months) ☐

6.如你曾被醫生為你診治這些疼痛，請註明診斷結果:____________________
Did you see a doctor because of the pain, what is the diagnosis: ______________

7.你過去有否因為這些疼痛而服用藥物？

Did you take any medicines because of the pain

1=沒有 No ☐ 2=有 Yes ☐ 如有, 請註明 If yes, please note: ____________

8.你現時有否因為這些疼痛而服用藥物？

Did you take any pain-relief medicines now?

1=沒有 No ☐ 2=有 Yes ☐ 如有, 請註明 If yes, please note: ____________

9. 過去有否曾經進行脊骨或上肢部份 X 光檢查?

Did you take x-ray examination for spine or upper limb regions?

1=沒有 No ☐ 2=有 Yes ☐

如有， 請註明檢查日期 If yes, what is the date for examination: ____________

10.你知道 X 光檢查的結果嗎? Do you know the results of x-ray examination?

1=不知道 No ☐ 2= 知道 Yes ☐

如知道, 請註明結果 If yes, what are the results: __________________

11.在過去 7 日，有否感到這些疼痛? Did you feel pain in the last 7 days?

1=沒有 No ☐ 2=有 Yes ☐

12. 你認為這些疼痛，跟使用觸摸式智能手機有關連？

Do you think that the pain is associated with the use of touchscreen smartphones?

1=否 No ☐ 2=是 Yes ☐

13. 這些疼痛，是否通常在使用觸摸式智能手機之後有所增加？

Does your pain level increased after the use of touchscreen smartphone?

1=否 No ☐ 2=是 Yes ☐

14. 你是否認為，這些疼痛是由於長期使用觸摸式智能手機所致？

Do you think that the pain is associated with prolong use of touchscreen smartphones?

1=否 No ☐ 2=是 Yes ☐

15. 你是否認為，這些疼痛是由於長期使用電腦設施所致？

Do you think that the pain is associated with prolong use of computers?

1=否 No ☐ 2=是 Yes ☐

16. 你是否認為，這些疼痛是由於累積地使用各類型電子儀器所致？

Do you think that the pain is associated with accumulative uses of various types of electronic devices

1=否 No ☐ 2=是 Yes ☐

Appendix XII B. Neck Disability Index (NDI)

Name : _________ Subject code_____ Group_______ Date: __________

請仔細閱讀說明。

這項問卷將有助於醫生瞭解頸痛對你日常生活的影響。請閱讀每個部分的專案，然後在最符合你現在情況的專案方框上 “ √ ”。This questionnaire has been designed to give your therapist information as to how your neck pain has affected you in your everyday life activities. Please answer each section; marking only ONE box which best describes your status today.

問題1--疼痛強度 Pain Intensity

□ 我此刻沒有疼痛
I have no pain at the moment.

□ 我此刻疼痛非常輕微
The pain is very mild at the moment.

□ 我此刻有中等程度的疼痛
The pain is moderate at the moment.

□ 我此刻疼痛相當嚴重
The pain is fairly severe at the moment.

□ 我此刻疼痛非常嚴重
The pain is very severe at the moment.

□ 我此刻疼痛難以想像
The pain is the worse imaginable at the moment.

問題 2--個人護理（洗漱，穿衣， 等等）Personal Care (Washing, dressing, etc.)

□ 我可以正常照顧自己，而不會引起額外的疼痛
I can look after myself normally without causing extra pain.

□ 我可以正常照顧自己，但會引起額外的疼痛
I can look after myself normally but it causes me extra pain.

□ 在照顧自己的時候會出現疼痛，我得慢慢的、小心的進行
It is painful to look after myself and I am slow and careful.

□ 我的日常生活需要一些幫助
I need some help but can manage most of my personal care.

□ 我每天的大多數日常生活活動都需要照顧
I need help every day in most aspects of self-care.

□ 我不能穿衣，洗漱也很困難，需要臥床
I do not get dressed, I wash with difficulty and stay in bed.

問題3--提起重物 Lifting

- □ 我可以提起重物，且不引起任何額外的疼痛
  I can lift heavy weights without extra pain.
- □ 我可以提起重物，但會引起額外的疼痛
  I can lift heavy weights but it gives extra pain.
- □ 疼痛會妨礙我從地板上提起重物，但如果重物放在桌子上合適的位置，我可以設法提起它 Pain prevents me lifting heavy weights off the floor, but I can manage if they are conveniently placed, for example on a table.
- □ 疼痛會妨礙我提起重物，但可以提起中等重量的物體
  Pain prevents me from lifting heavy weights but I can manage light to medium weights if they are conveniently positioned.
- □ 我可以提起輕的物體 I can only lift very light weights.
- □ 我不能提起或搬動任何物體 I cannot lift or carry anything.

問題4--閱讀 Reading

- □ 我可以隨意閱讀，而不會引起頸痛
  I can read as much as I want to with no pain in my neck.
- □ 我可以隨意閱讀，但會引起輕度頸痛
  I can read as much as I want to with slight pain in my neck.
- □ 我可以隨意閱讀，但會引起中度頸痛
  I can read as much as I want with moderate pain in my neck.
- □ 因中度的頸痛，使得我不能隨意閱讀
  I can't read as much as I want because of moderate pain in my neck.
- □ 因嚴重的頸痛，使我閱讀困難
  I can hardly read at all because of severe pain in my neck.
- □ 我完全不能閱讀 I cannot read at all.

問題5--頭痛 Headaches

- □ 我完全沒有頭痛 I have no headaches at all.
- □ 我有輕微的頭痛，但不經常發生
  I have slight headaches, which come infrequently.
- □ 我有中度頭痛，但不經常發生
  I have moderate headaches, which come infrequently.
- □ 我有中度頭痛，且經常發生
  I have moderate headaches, which come frequently.
- □ 我有嚴重的頭痛，且經常發生
  I have severe headaches, which come frequently.
- □ 我幾乎一直都有頭痛 I have headaches almost all the time.

問題6--集中注意力 Concentration

- □ 我可以完全集中注意力，並且沒有任何困難
  I can concentrate fully when I want to with no difficulty.
- □ 我可以完全集中注意力，但有輕微的困難
  I can concentrate fully when I want to with slight difficulty.
- □ 當我想完全集中注意力時，有一定程度的困難
  I have a fair degree of difficulty in concentrating when I want to.
- □ 當我想完全集中注意力時，有較多的困難
  I have a lot of difficulty in concentrating when I want to.
- □ 當我想完全集中注意力時，有很大的困難
  I have a great deal of difficulty in concentrating when I want to.
- □ 我完全不能集中注意力 I cannot concentrate at all.

問題7--工作 Work

- □ 我可以做很多我想做的工作
  I can do as much work as I want to.
- □ 我可以做多數日常的工作，但不能太多
  I can only do my usual work, but no more.
- □ 我只能做一部分日常的工作
  I can do most of my usual work, but no more.
- □ 我不能做我的日常工作
  I cannot do my usual work.
- □ 我幾乎不能工作
  I can hardly do any work at all.
- □ 我任何工作都無法做
  I can’t do any work at all.

問題8—駕駛 Driving

- □ 我能駕駛而沒有任何頸痛
  I can drive my car without any neck pain.
- □ 我想駕駛就可以駕駛，僅有輕微頸痛
  I can drive my car as long as I want with slight pain in my neck.
- □ 我想駕駛就可以駕駛，但有中度頸痛
  I can drive my car as long as I want with moderate pain in my neck.
- □ 我想駕駛，但不能駕駛，因有中度頸痛
  I can’t drive my car as long as I want because of moderate pain in my neck.
- □ 由於嚴重的頸痛，我幾乎不能駕駛
  I can hardly drive at all because of severe pain in my neck.
- □ 我一點都不能駕駛
  I can’t drive my car at all.

問題9--睡覺 Sleeping

- ◻ 我睡眠沒有問題
  I have no trouble sleeping.
- ◻ 我的睡眠稍受影響（失眠，少於1小時）
  My sleep is slightly disturbed (less than 1 hr sleepless).
- ◻ 我的睡眠輕度受影響（失眠，1-2個小時）
  My sleep is mildly disturbed (1-2 hrs sleepless).
- ◻ 我的睡眠中度受影響（失眠，2-3個小時）
  My sleep is moderately disturbed (2-3 hrs sleepless).
- ◻ 我的睡眠重度受影響（失眠， 3-5個小時）
  My sleep is greatly disturbed (3-5 hrs sleepless).
- ◻ 我的睡眠完全受影響（失眠，5-7個小時）
  My sleep is completely disturbed (5-7 hrs sleepless).

問題10--娛樂 Recreation

- ◻ 我能參與所有的娛樂活動，沒有頸痛
  I am able to engage in all my recreation activities with no neck pain at all.
- ◻ 我能參與所有的娛樂活動，但有一些頸痛
  I am able to engage in all my recreation activities, with some pain in my neck.
- ◻ 因頸痛，我只能參與大部分的娛樂活動
  I am able to engage in most, but not all of my usual recreation activities because of pain in my neck.
- ◻ 因頸痛，我只能參與少量的娛樂活動
  I am able to engage in a few of my usual recreation activities because of pain in my neck.
- ◻ 因頸痛，我幾乎不能參與任何娛樂活動
  I can hardly do any recreation activities because of pain in my neck.
- ◻ 我不能參與任何娛樂活動
  I can’t do any recreation activities at all.

Appendix XII C. Disability of Arm Shoulder and Hand (DASH)

Name : _________ Subject code_____ Group_______ Date: __________

指示

這份問卷是詢問你在進行某些活動時所產生的病徵及活動的能力。
請根據你上星期的狀況，回答每項問題，並圈出適當的數 字。
如果你在過去的一星期沒有進行該項活動，請你估計該項 活動對你的影響並挑選出一個最準確的選擇。
無論你是使用左手或右手去進行該項活動，請根據你的能 力作出評估，而無需理會所用的方法。

INSTRUCTIONS
This questionnaire asks about your symptoms as well as your ability to perform certain activities.
Please answer every question, based on your condition in the last week, by circling the appropriate number.
If you did not have the opportunity to perform an activity in the past week, please make your best estimate on which response would be the most accurate.
It doesn't matter which hand or arm you use to perform the activity; please answer based on your ability regardless of how you perform the task.

請將你上星期進行以下活動的能力給予評分，根據困難程度圈出適當的選擇。
Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	沒困難 No difficulty	輕微困難 Mild difficulty	中度困難 Moderate difficulty	很大困難 Severe difficulty	做不到 Unable
1. 開啟緊或新樽蓋 Open a tight or new jar	1	2	3	4	5
2. 書寫 Write	1	2	3	4	5
3. 扭鎖匙 Turn a key	1	2	3	4	5
4. 煮飯 Prepare a meal	1	2	3	4	5
5. 推開一扇重門 Push open a heavy door	1	2	3	4	5
6. 將物件放置在高於 頭頂的地方 Place an object on a shelf above your head	1	2	3	4	5
7. 做粗重家務（如：洗地, 抹窗） Do heavy househould chores (e.g., wash floors, wash wall)	1	2	3	4	5
8. 園藝(如：種植、除雜草) Garden or do yard work	1	2	3	4	5
9. 整理床鋪 （如：換床單） Make a bed	1	2	3	4	5
10. 拿購物袋或公事包 Carry a shopping bag or briefcase	1	2	3	4	5
11. 拿重物(超過十磅) Carry a heavy objects (over 10 lbs)	1	2	3	4	5
12. 換天花燈泡 Change a lightbulb overhead	1	2	3	4	5
13. 洗頭或吹頭 Wash or blow dry your hair	1	2	3	4	5
14. 清潔背部 Wash your back	1	2	3	4	5
15. 穿著過頭笠的衣服 Put on a pullover sweater	1	2	3	4	5
16. 用刀切食物 Use a knife or cut food	1	2	3	4	5
17. 不費力的康樂活動（如：玩紙牌、織毛衣、 打麻雀、下棋等） Recreational activities which require little effect (e.g. Cardplaying, knitting ect.)	1	2	3	4	5
18. 手臂、肩膊及手部需要用力的康樂活動(如：打哥爾夫 球、使用鎚子、打網球等) Recreational activities in which you take some force or impact through arm, shoulder and hand (e.g., golf, hammering, tennis ect.)	1	2	3	4	5

19. 手臂需要靈活伸展的康樂 活動(如：打羽毛球等) Recreational activities in which you move your arm freely (e.g. playing frisbee, badminton, ect.)	1	2	3	4	5
20. 乘搭交通工具 Mange transportation needs (from one place to another)	1	2	3	4	5
21. 性生活 Sexual activities	1	2	3	4	5

22. 在過去的一星期，你的手臂、肩膊或手部疾患有否影響你與家人、朋友、鄰居或其 他團體的正常社交活動？（請圈出適當的數字以示影響程度）

During the past week, to what extent has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups? (circle number)

完全沒影響 Not at all	輕微影響 Slightly	中度影響 Moderately	頗有影響 Quite a bit	嚴重影響 Extremely
1	2	3	4	5

23. 在過去的一星期，你的手臂、肩膊或手部疾患有否限制了你的工作或其他日常起居 活動？（請圈出適當的數字以示影響程度）

During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem? (circle number)

完全沒限制 Not limited at all	輕微限制 Slightly limited	中度限制 Moderately limited	頗有限制 Very limited	嚴重限制 Unable
1	2	3	4	5

請在下列 24-28 項圈出適當的數字，以顯示不同病徵在上星期的嚴重程度.

Please rate the severity of the following symptoms in the last week. (circle number)

	無 None	輕微 Slight	中度 Moderate	嚴重 Severe	極為嚴重 Exreme
24. 手臂、肩膊或手部痛楚 Arm, shoulder or hand pain.	1	2	3	4	5
25. 在進行某些特定活動時，手 臂、肩膊或手部感到痛楚 Arm, shoulder or hand pain when you performed any specific activity.	1	2	3	4	5
26. 手臂、肩膊或手部感到針刺 Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5
27. 手臂、肩膊或手部感到乏力 Weakness in your arm, shoulder or hand.	1	2	3	4	5
28. 手臂、肩膊或手部感到僵硬 Stiffness in your arm, shoulder or hand.	1	2	3	4	5

	沒影響 No difficulty	輕微影響 Slight difficulty	中度影響 Mild Difficulty	很大影響 Severe difficulty	極大影響至不能入睡 So much difficulty that can't sleep
29. 在過去的一星期，你有否因為 手臂、肩膊或手部痛楚而影響 睡眠 During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? (circle number)	1	2	3	4	5

	極不同意 Strongly disagree	不同意 Disagree	沒意見 Neither agree nor disagree	同意 Agreee	非常同意 Strongly agree
30. 因為手臂、肩膊或手部疾患而 感到自己不及以前能幹， 自信和有用 I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. (circle number)	1	2	3	4	5

DASH 殘障/症狀數值 =〔〔n 項作答問題分數的總和/n〕−1〕x25, n 是已作答問題的數目. 假如 DASH 有超過 3 項問題未有作答，其數值可能不獲計算. DASH DISABILITY/SYMPTOM SCORE = [(sum of n responses)/n - 1] x 25, where n is equal to the number of completed responses. A DASH score may not be calculated if there are greater than 3 missing items.

工作單元（選擇部份）Work Module (Optional)

以下問題詢問有關你的手臂、肩膊或手部疾患對你工作能力的影響（若家務是你主要的 工作，亦包括在內）. The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

( ) 我的工作/職位是 Your job/work is： ______________________________

( ) 我沒有工作。(可略過此部份）I do not work. (You may skip this section.)

在過去一星期，當你工作時有否感到困難？請根據困難程度圈出適當的數字：
Please circle the number that best describes your physical ability in the past week.
Did you have any difficulty:

	沒困難 No difficulty	輕微困難 Mild difficulty	中度困難 Moderate difficulty	很大困難 Severe difficulty	做不到 Unable
1. 當你運用一貫技巧工作時，是 否感到困難？ Using your usual technique for your work?	1	2	3	4	5
2. 你在執行一貫工作職務時，有 否因手臂、肩膊或手部痛楚而 感困難？ Doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. 在工作時，你能否發揮出你預 期的水準？ Doing your work as well as you would like?	1	2	3	4	5
4. 你能否和以往一樣花相同時間 在工作上？ Spending your usual amount of time doing your work?	1	2	3	4	5

運動 / 表演藝術單元（選擇部份）Sports/ Performance art module (Optional)

以下問題涉及你的手臂、肩膊或手部疾患對你彈奏樂器/ 做運動時的影響。若你所做的 運動或所彈奏的樂器多過一種，請按著你認為最主要做的那一項活動作出回答。The following questions relate to the impact of your arm, shoulder or hand problem on playing your musical instrument or sport or both. If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you

( ) 我有做運動或玩樂器。對我來說，最主要做的運動/玩的樂器是：________
Please indicate the sport or instrument which is most important to you: ________

( ) 我不做運動，也不玩樂器。(可略過此部份)
I do not play a sport or an instrument. (You may skip this section.)

在過去一星期，當你進行該項活動時有否感到困難？請根據困難程度圈出適當的數字 Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	沒困難 No difficulty	輕微困難 Mild difficulty	中度困難 Moderate difficulty	很大困難 Sever difficulty	做不到 Unable
1. 當你運用一貫技巧玩樂器或做 運動時，是否感到困難？ Using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. 你在玩樂器或做運動時，有否因 手臂、肩膊或手部痛楚而感到困 難？Playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. 在玩樂器或做運動時，你能否發 揮出你預期的水準？ Playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. 你能否和以往一樣花相同時間 玩樂器或做運動？ Spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

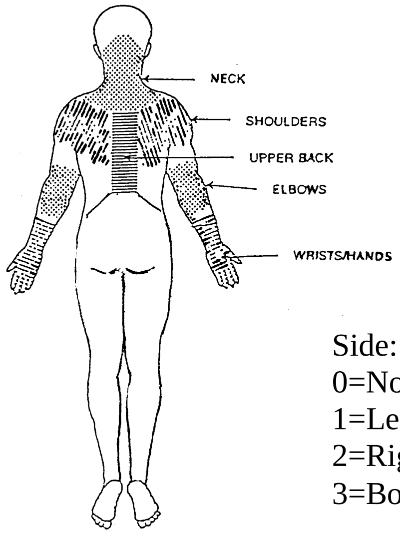
選擇部份單元的評分：將每題作答的指定分數相加後再除 4（即題目的數量）， 然後減 1 再乘以 25。 假如在選擇單元內有任何沒有回答的題目，此單元的數值可能不獲計算. SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25. An optional module score may not be calculated if there are any missing items.

Appendix XIII. Record Form for Discomfort Scores

<u>Discomfort Scale</u>

(Discomfort: an absence of comfort or ease; uneasiness, hardship, or mild pain; the state of being tense and feeling pain)

0	No Discomfort
1	Minimal Discomfort
2	
3	
4	
5	
6	
7	
8	
9	
10	Extreme/Intolerable Discomfort



Side:
0=None
1=Left
2=Right
3=Both

Name : _________ Subject code_____ Group_______ Date: __________

Task	Area	Side	Score
Baseline	Neck		
	Shoulder		
	Upper back		
	Elbow		
	Wrist/hands		
	Thumb/ Fingers		
After Bilateral texting	Neck		
	Shoulder		
	Upper back		
	Elbow		
	Wrist/hands		
	Thumb/ Figure		
After Unilateral texting	Neck		
	Shoulder		
	Upper back		
	Elbow		
	Wrist/hands		
	Thumb/ Fingers		
After computer typing	Neck		
	Shoulder		
	Upper back		
	Elbow		
	Wrist/hands		
	Thumb/ Fingers		

Appendix XIV. Record Form for Task Performances and Rate of Perceived Exertion

Name : _________ Subject code_____ Group_______ Date: __________

Task performances

Orders of tasks	Speed(pwm)	Accuracy(%)	Note
( ) Bilateral texting			
( ) Unilateral texting			
( ) Computer typing			

Rate of Perceived Exertion

6	No exertion at all 完全沒有用力的感覺
7	Extremely light 非常輕松
8	
9	Very light 很輕松
10	
11	Light 較輕松
12	
13	Somewhat hard 有點累
14	
15	Hard (heavy) 累
16	
17	Very hard 很累
18	
19	Extremely hard 非常累
20	Maximal exertion 極度累

Rate of Perceived Exertion

Tasks	Rates
After bilateral texting	
After unilateral texting	
After computer typing	

REFERENCES

Albin, T. J., & McLoone, H. E. (2014). The effect of tablet tilt angle on users' preferences, postures, and performance. *Work: A Journal of Prevention, Assessment and Rehabilitation, 47*(2), 207-211.

Allison, G., Godfrey, P., & Robinson, G. (1998). EMG signal amplitude assessment during abdominal bracing and hollowing. *Journal of Electromyography and Kinesiology, 8*(1), 51-57.

Anders, C., Bretschneider, S., Bernsdorf, A., Erler, K., & Schneider, W. (2004). Activation of shoulder muscles in healthy men and women under isometric conditions. *Journal of Electromyography and Kinesiology, 14*(6), 699-707.

Andersen, J. H., Fallentin, N., Thomsen, J. F., & Mikkelsen, S. (2011). Risk factors for neck and upper extremity disorders among computers users and the effect of interventions: An overview of systematic reviews. *PLoS One, 6*(5), e19691.

Andersen, L. L., Nielsen, P. K., Søgaard, K., Andersen, C. H., Skotte, J., & Sjøgaard, G. (2008). Torque–EMG–velocity relationship in female workers with chronic neck muscle pain. *Journal of Biomechanics, 41*(9), 2029-2035.

Arendt-Nielsen, L., & Graven-Nielsen, T. (2008). Muscle pain: Sensory implications and interaction with motor control. *The Clinical Journal of Pain, 24*(4), 291-298.

Ariëns, G. A., van Mechelen, W., Bongers, P. M., Bouter, L. M., & Van Der Wal, G. (2000). Physical risk factors for neck pain. *Scandinavian Journal of Work, Environment & Health,26*(1), 7-19.

Ariëns, G. A., Bongers, P. M., Douwes, M., Miedema, M. C., Hoogendoorn, W. E., van der Wal, G., . . . van Mechelen, W. (2001). Are neck flexion, neck rotation, and sitting at work risk factors for neck pain? Results of a prospective cohort study. *Occupational and Environmental Medicine, 58*(3), 200-207.

Arvidsson, I., Hansson, G., Mathiassen, S. E., & Skerfving, S. (2006). Changes in physical workload with implementation of mouse-based information technology in air traffic control. *International Journal of Industrial Ergonomics, 36*(7), 613-622.

Asfour, S. S., Ayoub, M., Mital, A., & Bethea, N. (1983). Perceived exertion of physical effort for various manual handling tasks. *The American Industrial Hygiene Association Journal, 44*(3), 223-228.

Ashina, S., Jensen, R., & Bendtsen, L. (2003). Pain sensitivity in pericranial and extracranial regions. *Cephalalgia, 23*(6), 456-462.

Balakrishnan, V., & Yeow, P. H. (2008). Hand anthropometry and SMS satisfaction. *Journal of Applied Sciences, 8*, 816-822.

Balzini, L., Vannucchi, L., Benvenuti, F., Benucci, M., Monni, M., Cappozzo, A., & Stanhope, S. J. (2003). Clinical characteristics of flexed posture in elderly women. *Journal of the American Geriatrics Society, 51*(10), 1419-1426.

Barbe, M. F., Barr, A. E., Gorzelany, I., Amin, M., Gaughan, J. P., & Safadi, F. F. (2003). Chronic repetitive reaching and grasping results in decreased motor performance and widespread tissue responses in a rat model of MSD. *Journal of Orthopaedic Research, 21*(1), 167-176.

Berolo, S., Wells, R. P., & Amick, B. C., 3rd. (2011). Musculoskeletal symptoms among mobile hand-held device users and their relationship to device use: A preliminary study in a Canadian university population. *Applied Ergonomics, 42*(2), 371-378.

Berolo, S., Steenstra, I., Amick, B. C., 3rd & Wells, R. P. (2015). A comparison of two methods to assess the usage of mobile hand-held communication devices. *Journal of Occupational and Environmental Hygiene, 12*(4), 276-285.

Bishara, A. J. & Hittner, J. B. (2012). Testing the significance of a correlation with nonnormal data: Comparison of Pearson, Spearman, transformation, and resampling approaches. *Psychological methods*, 17 (3), 399-417.

Blackstone, J. M., Karr, C., Camp, J., & Johnson, P. W. (2008). Physical exposure differences between children and adults when using standard and small computer input devices. *Ergonomics*, *51*(6), 872-889.

Blair, B., Gama, M., & Toberman, M. (2015). *Prevalence and risk factors for neck and shoulder musculoskeletal symptoms in users of touch-screen tablet computers* (Doctoral thesis). Available from UNLV Theses, Dissertations, Professional Papers, and Capstones. Paper 2320.

Blangsted, A. K., Hansen, K., & Jensen, C. (2003). Muscle activity during computer-based office work in relation to self-reported job demands and gender. *European Journal of Applied Physiology, 89*(3-4), 352-358.

Blatter, B., & Bongers, P. (2002). Duration of computer use and mouse use in relation to musculoskeletal disorders of neck or upper limb. *International Journal of Industrial Ergonomics, 30*(4), 295-306.

Bolgla, L. A., & Uhl, T. L. (2007). Reliability of electromyographic normalization methods for evaluating the hip musculature. *Journal of Electromyography and Kinesiology, 17*(1), 102-111.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine & Science Sports & Exercise, 14*(5), 377-381.

Borghouts, J. A., Koes, B. W., Vondeling, H., & Bouter, L. M. (1999). Cost-of-illness of neck pain in the netherlands in 1996. *Pain, 80*(3), 629-636.

Bot, S. D., van der Waal, J. M., Terwee, C. B., van der Windt, D. A., Schellevis, F. G., Bouter, L. M., & Dekker, J. (2005). Incidence and prevalence of complaints of the neck and upper extremity in general practice. *Annals of the Rheumatic Diseases, 64*(1), 118-123.

Brandt, L. P. A., Andersen, J. H., Lassen, C. F., Kryger, A., Overgaard, E., Vilstrup, I., & Mikkelsen, S. (2004). Neck and shoulder symptoms and disorders among Danish computer workers. *Scandinavian Journal of Work, Environment & Health, 30*(5), 399-409.

Briggs, A. M., van Dieen, J. H., Wrigley, T. V., Greig, A. M., Phillips, B., Lo, S. K., & Bennell, K. L. (2007). Thoracic kyphosis affects spinal loads and trunk muscle force. *Physical Therapy, 87*(5), 595-607.

Brink, Y., Louw, Q., Grimmer, K., & Jordaan, E. (2015). The relationship between sitting posture and seated-related upper quadrant musculoskeletal pain in computing South African adolescents: A prospective study. *Manual Therapy, 20*(6), 820-826.

Burnett, A., Green, J., Netto, K., & Rodrigues, J. (2007). Examination of EMG normalisation methods for the study of the posterior and posterolateral neck muscles in healthy controls. *Journal of Electromyography and Kinesiology, 17*(5), 635-641.

Cagnie, B., Danneels, L., Van Tiggelen, D., De Loose, V., & Cambier, D. (2007). Individual and work related risk factors for neck pain among office workers: A cross sectional study. *European Spine Journal, 16*(5), 679-686.

Cagnie, B., Dhooge, F., Van Akeleyen, J., Cools, A., Cambier, D., & Danneels, L. (2012). Changes in microcirculation of the trapezius muscle during a prolonged computer task. *European Journal of Applied Physiology, 112*(9), 3305-3312.

Cameron, J. A. (1996). Assessing work-related body-part discomfort: Current strategies and a behaviorally oriented assessment tool. *International Journal of Industrial Ergonomics, 18*(5), 389-398.

Caneiro, J. P., O'Sullivan, P., Burnett, A., Barach, A., O'Neil, D., Tveit, O., & Olafsdottir, K. (2010). The influence of different sitting postures on head/neck posture and muscle activity. *Manual Therapy, 15*(1), 54-60.

Carson, V., Pickett, W., & Janssen, I. (2011). Screen time and risk behaviors in 10- to 16-year-old Canadian youth. *Preventive Medicine, 52*(2), 99-103.

Castelein, B., Cools, A., Bostyn, E., Delemarre, J., Lemahieu, T., & Cagnie, B. (2015). Analysis of scapular muscle EMG activity in patients with idiopathic neck pain: A systematic review. *Journal of Electromyography and Kinesiology, 25*(2), 371-386.

Chowdhury, R. H., Reaz, M. B., Ali, Mohd Alauddin Bin Mohd, Bakar, A. A., Chellappan, K., & Chang, T. G. (2013). Surface electromyography signal processing and classification techniques. *Sensors, 13*(9), 12431-12466.

Ciccarelli, M., Straker, L., Mathiassen, S. E., & Pollock, C. (2014). Posture variation among office workers when using different information and communication technologies at work and away from work. *Ergonomics, 57*(11), 1678-1686.

Cook, C., Burgess-Limerick, R., & Papalia, S. (2004). The effect of upper extremity support on upper extremity posture and muscle activity during keyboard use. *Applied Ergonomics, 35*(3), 285-292.

Côté, P., van der Velde, G., Cassidy, J. D., Carroll, L. J., Hogg-Johnson, S., Holm, L. W., . . . Hurwitz, E. L. (2009). The burden and determinants of neck pain in workers: Results of the bone and joint decade 2000–2010 task force on neck pain and its associated disorders. *Journal of Manipulative and Physiological Therapeutics, 32*(2), S70-S86.

Côté, J. N. (2012). A critical review on physical factors and functional characteristics that may explain a sex/gender difference in work-related neck/shoulder disorders. *Ergonomics, 55*(2), 173-182.

Curatolo, M., Arendt-Nielsen, L., & Petersen-Felix, S. (2006). Central hypersensitivity in chronic pain: Mechanisms and clinical implications. *Physical Medicine and Rehabilitation Clinics of North America, 17*(2), 287-302.

Cutti, A. G., Giovanardi, A., Rocchi, L., Davalli, A., & Sacchetti, R. (2008). Ambulatory measurement of shoulder and elbow kinematics through inertial and magnetic sensors. *Medical & Biological Engineering & Computing, 46*(2), 169-178.

da Costa, B. R., & Vieira, E. R. (2010). Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. *American Journal of Industrial Medicine, 53*(3), 285-323.

D'Agata, E. (2005). Methodologic issues of case-control studies: A review of established and newly recognized limitations. *Infection Control, 26*(04), 338-341.

Dankaerts, W., O'Sullivan, P. B., Burnett, A. F., Straker, L. M., & Danneels, L. A. (2004). Reliability of EMG measurements for trunk muscles during maximal and sub-maximal voluntary isometric contractions in healthy controls and CLBP patients. *Journal of Electromyography and Kinesiology, 14*(3), 333-342.

de Vries, W., Veeger, H., Cutti, A., Baten, C., & Van der Helm, F. (2010). Functionally interpretable local coordinate systems for the upper extremity using inertial & magnetic measurement systems. *Journal of Biomechanics, 43*(10), 1983-1988.

Delisle, A., Larivière, C., Plamondon, A., & Imbeau, D. (2006). Comparison of three computer office workstations offering forearm support: Impact on upper limb posture and muscle activation. *Ergonomics, 49*(2), 139-160.

Duc, C., Salvia, P., Lubansu, A., Feipel, V., & Aminian, K. (2014). A wearable inertial system to assess the cervical spine mobility: Comparison with an optoelectronic-based motion capture evaluation. *Medical Engineering & Physics, 36*(1), 49-56.

Dumas, G. A., Upjohn, T. R., Leger, A., Delisle, A., Charpentier, K., Plamondon, A., & Salazar, E. (2008). Effect of a desk attachment board on posture and muscle activity in women during computer work. *Ergonomics, 51*(11), 1735-1756.

Dunning, J. R., Cleland, J. A., Waldrop, M. A., Arnot, C., Young, I., Turner, M., & Sigurdsson, G. (2012). Upper cervical and upper thoracic thrust manipulation versus nonthrust mobilization in patients with mechanical neck pain: A multicenter randomized clinical trial. *Journal of Orthopaedic & Sports Physical Therapy, 42*(1), 5-18.

Elert, J., Kendall, S. A., Larsson, B., Mansson, B., & Gerdle, B. (2001). Chronic pain and difficulty in relaxing postural muscles in patients with fibromyalgia and chronic whiplash associated disorders. *The Journal of Rheumatology*, *28*(6), 1361-1368.

Eltayeb, S., Staal, J. B., Hassan, A., & De Bie, R. A. (2009). Work related risk factors for neck, shoulder and arms complaints: A cohort study among Dutch computer office workers. *Journal of Occupational Rehabilitation, 19*(4), 315-322.

Eltayeb, S. M., Staal, J. B., Khamis, A. H., & de Bie, R. A. (2011). Symptoms of neck, shoulder, forearms, and hands: A cohort study among computer office workers in Sudan. *The Clinical Journal of Pain, 27*(3), 275-281.

Erick, P. N., & Smith, D. R. (2011). A systematic review of musculoskeletal disorders among school teachers. *BMC Musculoskeletal Disorders, 12*, 260-2474-12-260.

Ericsson mobility report (November 2015). Retrieved 12 December, 2015 from http://www.ericsson.com/mobility-report

Falla, D., Jull, G., Edwards, S., Koh, K., & Rainoldi, A. (2004). Neuromuscular efficiency of the sternocleidomastoid and anterior scalene muscles in patients with chronic neck pain. *Disability & Rehabilitation*, *26*(12), 712-717.

Falla, D., Bilenkij, G., & Jull, G. (2004). Patients with chronic neck pain demonstrate altered patterns of muscle activation during performance of a functional upper limb task. *Spine*, *29*(13), 1436-1440.

Falla, D., & Farina, D. (2005). Muscle fiber conduction velocity of the upper trapezius muscle during dynamic contraction of the upper limb in patients with chronic neck pain. *Pain, 116*(1), 138-145.

Falla, D., Jull, G., Russell, T., Vicenzino, B., & Hodges, P. (2007). Effect of neck exercise on sitting posture in patients with chronic neck pain. *Physical Therapy, 87*(4), 408-417.

Falla, D., Farina, D., & Graven-Nielsen, T. (2007). Experimental muscle pain results in reorganization of coordination among trapezius muscle subdivisions during repetitive shoulder flexion. *Experimental Brain Research, 178*(3), 385-393.

Faucett, J., & Rempel, D. (1994). VDT-related musculoskeletal symptoms: Interactions between work posture and psychosocial work factors. *American Journal of Industrial Medicine, 26*(5), 597-612.

Fedorowich, L., Emery, K., Gervasi, B., & Côté, J. N. (2013). Gender differences in neck/shoulder muscular patterns in response to repetitive motion induced fatigue. *Journal of Electromyography and Kinesiology, 23*(5), 1183-1189.

Fernandez-Guerrero, I. M. (2014). "WhatsAppitis". *Lancet, 383*(9922), 1040-6736(14)60519-5.

Ferraz, M. B., Quaresma, M. R., Aquino, L. R., Atra, E., Tugwell, P., & Goldsmith, C. H. (1990). Reliability of pain scales in the assessment of literate and illiterate patients with rheumatoid arthritis. *The Journal of Rheumatology, 17*(8), 1022-1024.

Feuerstein, M., Armstrong, T., Hickey, P., & Lincoln, A. (1997). Computer keyboard force and upper extremity symptoms. *Journal of Occupational and Environmental Medicine, 39*(12), 1144-1153.

Fillingim, R. B., King, C. D., Ribeiro-Dasilva, M. C., Rahim-Williams, B., & Riley, J. L. 3rd. (2009). Sex, gender, and pain: A review of recent clinical and experimental findings. *The Journal of Pain*, *10*(5), 447-485.

Fjellman-Wiklund, A., & Sundelin, G. (1998). Musculoskeletal discomfort of music teachers: An eight-year perspective and psychosocial work factors. *International Journal of Occupational and Environmental Health, 4*(2), 89-98.

Freriks, B., Hermens, H., Disselhorst-Klug, C., & Rau, G. (1999). The recommendations for sensors and sensor placement procedures for surface electromyography. In H. Hermens & B. Freriks (Eds), *SENIAM 8: European recommendations for surface electromyography: Results of the SENIAM project* (pp. 13-54). Enschede, the Netherlands: Roessingh Research and Development BV.

Galinsky, T., Swanson, N., Sauter, S., Dunkin, R., Hurrell, J., & Schleifer, L. (2007). Supplementary breaks and stretching exercises for data entry operators: A follow‐up field study. *American Journal of Industrial Medicine*, 50(7), 519-527.

Ge, H., Arendt-Nielsen, L., Farina, D., & Madeleine, P. (2005). Gender‐specific differences in electromyographic changes and perceived pain induced by experimental muscle pain during sustained contractions of the upper trapezius muscle. *Muscle & Nerve*, 32(6), 726-733.

Ge, H., Madeleine, P., & Arendt-Nielsen, L. (2005). Gender differences in pain modulation evoked by repeated injections of glutamate into the human trapezius muscle. *Pain, 113*(1), 134-140.

Gerard, M. J., Armstrong, T. J., Martin, B. J., & Rampel, D. A. (2002). The effects of work pace on within-participant and between-participant keying force, electromyography, and fatigue. *Human Factors, 44*(1), 51-61.

Gerr, F., Marcus, M., & Monteilh, C. (2004). Epidemiology of musculoskeletal disorders among computer users: Lesson learned from the role of posture and keyboard use. *Journal of Electromyography and Kinesiology, 14*(1), 25-31.

Gerr, F., Marcus, M., Monteilh, C., Hannan, L., Ortiz, D., & Kleinbaum, D. (2005). A randomised controlled trial of postural interventions for prevention of musculoskeletal symptoms among computer users. *Occupational and Environmental Medicine, 62*(7), 478-487.

Ghaffari, M., Alipour, A., Farshad, A. A., Yensen, I., & Vingard, E. (2006). Incidence and recurrence of disabling low back pain and neck-shoulder pain. *Spine, 31*(21), 2500-2506.

Giansanti, D., Maccioni, G., Benvenuti, F., & Macellari, V. (2007). Inertial measurement units furnish accurate trunk trajectory reconstruction of the sit-to-stand manoeuvre in healthy subjects. *Medical & Biological Engineering & Computing, 45*(10), 969-976.

Gold, J. E., Driban, J. B., Thomas, N., Chakravarty, T., Channell, V., & Komaroff, E. (2012). Postures, typing strategies, and gender differences in mobile device usage: An observational study. *Applied Ergonomics, 43*(2), 408-412.

Goodvin, C., Park, E. J., Huang, K., & Sakaki, K. (2006). Development of a real-time three-dimensional spinal motion measurement system for clinical practice. *Medical and Biological Engineering and Computing, 44*(12), 1061-1075.

Goostrey, S., Treleaven, J., & Johnston, V. (2014). Evaluation of document location during computer use in terms of neck muscle activity and neck movement. *Applied Ergonomics, 45*(3), 767-772.

Goudy, N., & McLean, L. (2006). Using myoelectric signal parameters to distinguish between computer workers with and without trapezius myalgia. *European Journal of Applied Physiology, 97*(2), 196-209.

Graven-Nielsen, T., & Mense, S. (2001). The peripheral apparatus of muscle pain: Evidence from animal and human studies. *The Clinical Journal of Pain, 17*(1), 2-10.

Gregori, B., Agostino, R., Bologna, M., Dinapoli, L., Colosimo, C., Accornero, N., & Berardelli, A. (2008). Fast voluntary neck movements in patients with cervical dystonia: A kinematic study before and after therapy with botulinum toxin type A. *Clinical Neurophysiology, 119*(2), 273-280.

Guan, X., Fan, G., Wu, X., Zeng, Y., Su, H., Gu, G., . . . He, S. (2015). Photographic measurement of head and cervical posture when viewing mobile phone: A pilot study. *European Spine Journal, 24*(12), 2892-2898.

Gustafsson, E., Johnson, P. W., & Hagberg, M. (2010). Thumb postures and physical loads during mobile phone use - a comparison of young adults with and without musculoskeletal symptoms. *Journal of Electromyography and Kinesiology, 20*(1), 127-135.

Gustafsson, E., Johnson, P. W., Lindegard, A., & Hagberg, M. (2011). Technique, muscle activity and kinematic differences in young adults texting on mobile phones. *Ergonomics, 54*(5), 477-487.

Guzman, J., Hurwitz, E. L., Carroll, L. J., Haldeman, S., Côté, P., Carragee, E. J., . . . Hogg-Johnson, S. (2009). A new conceptual model of neck pain: Linking onset, course, and care: The bone and joint decade 2000–2010 task force on neck pain and its associated disorders. *Journal of Manipulative and Physiological Therapeutics, 32*(2), S17-S28.

Hagen, K., Linde, M., Heuch, I., Stovner, L. J., & Zwart, J. (2011). Increasing prevalence of chronic musculoskeletal complaints. A large 11-year follow-up in the general population (HUNT 2 and 3). *Pain Medicine, 12*(11), 1657-1666.

Hägg, G. (1991). Static work loads and occupational myalgia-a new explanation model. *Electromyographical Kinesiology, 949*, 141-144.

Hakala, P. T., Rimpelä, A. H., Saarni, L. A., & Salminen, J. J. (2006). Frequent computer-related activities increase the risk of neck-shoulder and low back pain in adolescents. *European Journal of Public Health, 16*(5), 536-541.

Halaki, M., & Ginn, K. (2012). Normalization of EMG signals: To normalize or not to normalize and what to normalize to? In R.N. Ganesh (Ed), *Computational Intelligence in Electromyography Analysis - A Perspective on Current Applications and Future Challenges* (pp. 175-194). Vienna, Austria: InTech.

Hallman, D. M., Lindberg, L., Arnetz, B. B., & Lyskov, E. (2011). Effects of static contraction and cold stimulation on cardiovascular autonomic indices, trapezius blood flow and muscle activity in chronic neck–shoulder pain. *European Journal of Applied Physiology, 111*(8), 1725-1735.

Hamberg-van Reenen, H. H., van der Beek, Allard J, Blatter, B. M., van der Grinten, Maarten P, van Mechelen, W., & Bongers, P. M. (2008). Does musculoskeletal discomfort at work predict future musculoskeletal pain? *Ergonomics, 51*(5), 637-648.

Hansson, G. A., Stromberg, U., Larsson, B., Ohlsson, K., Balogh, I., & Moritz, U. (1992). Electromyographic fatigue in neck/shoulder muscles and endurance in women with repetitive work. *Ergonomics, 35*(11), 1341-1352.

Hayes, M., Smith, D., & Cockrell, D. (2009). Prevalence and correlates of musculoskeletal disorders among Australian dental hygiene students. *International Journal of Dental Hygiene, 7*(3), 176-181.

Henriksson, K. G. (1999). Muscle activity and chronic muscle pain. *Journal of Musculoskelatal Pain, 7*(1-2), 101-109.

Hermens, H., & Freriks, B. (1997).The state of the art on sensors and sensor placement procedures for surface electromyography: A proposal for sensor placement procedures. *SENIAM 5*, Enschede, the Netherlands: Roessingh Research and Developmen BV.

Hill, J., Lewis, M., Papageorgiou, A. C., Dziedzic, K., & Croft, P. (2004). Predicting persistent neck pain: A 1-year follow-up of a population cohort. *Spine, 29*(15), 1648-1654.

Hodges, P. W. (2011). Pain and motor control: From the laboratory to rehabilitation. *Journal of Electromyography and Kinesiology, 21*(2), 220-228.

Hodges, P. W., & Tucker, K. (2011). Moving differently in pain: A new theory to explain the adaptation to pain. *Pain, 152*(3 Suppl), S90-S98.

Hoftun, G. B., Romundstad, P. R., Zwart, J., & Rygg, M. (2011). Chronic idiopathic pain in adolescence–high prevalence and disability: The young HUNT study 2008. *Pain, 152*(10), 2259-2266.

Hogg-Johnson, S., van der Velde, G., Carroll, L. J., Holm, L. W., Cassidy, J. D., Guzman, J., . . . Peloso, P. (2008). The burden and determinants of neck pain in the general population: results of the Bone and Joint Decade 2000–2010 Task Force on Neck Pain and Its Associated Disorders. *Spine, 33*(4 Suppl):S39 –S51.

Hong Kong Computer Society. (2013). *Smartphone Using and Consumption Habit of Hong Kong students. Retrieved from http://www.hkcs.org.hk/en_hk/misc/press/survey.asp*

Holtermann, A., Hansen, J. V., Burr, H., & Søgaard, K. (2010). Prognostic factors for long-term sickness absence among employees with neck-shoulder and low-back pain. *Scandinavian Journal of Work, Environment & Health, 36*(1), 34-41.

Holtmann, G., Stanghellini, V., & Talley, N. J. (1998). 1 nomenclature of dyspepsia, dyspepsia subgroups and functional dyspepsia: Clarifying the concepts. *Baillière's Clinical Gastroenterology, 12*(3), 417-433.

Hoy, D., Protani, M., De, R., & Buchbinder, R. (2010). The epidemiology of neck pain. *Best Practice & Research Clinical Rheumatology, 24*(6), 783-792.

Hoy, D., March, L., Woolf, A., Blyth, F., Brooks, P., Smith, E., . . . Buchbinder, R. (2014). The global burden of neck pain: Estimates from the global burden of disease 2010 study. *Annals of the Rheumatic Diseases, 73*(7), 1309-1315.

Hummel, A., Läubli, T., Pozzo, M., Schenk, P., Spillmann, S., & Klipstein, A. (2005). Relationship between perceived exertion and mean power frequency of the EMG signal from the upper trapezius muscle during isometric shoulder elevation. *European Journal of Applied Physiology, 95*(4), 321-326.

Hunsaker, F. G., Cioffi, D. A., Amadio, P. C., Wright, J. G., & Caughlin, B. (2002). The American academy of orthopaedic surgeons outcomes instruments normative values from the general population. *The Journal of Bone & Joint Surgery, 84*(2), 208-215.

Hunting, W., Laubli, T., & Grandjean, E. (1981). Postural and visual loads at VDT workplaces. pt. I. Constrained postures. *Ergonomics, 24*(12), 917-931.

IJmker, S., Huysmans, M. A., Blatter, B. M., van der Beek, A. J., van Mechelen, W., & Bongers, P. M. (2007). Should office workers spend fewer hours at their computer? A systematic review of the literature. *Occupational and Environmental Medicine, 64*(4), 211-222.

IJmker, S., Huysmans, M. A., van der Beek, A. J., Knol, D. L., van Mechelen, W., Bongers, P. M., & Blatter, B. M. (2011). Software-recorded and self-reported duration of computer use in relation to the onset of severe arm-wrist-hand pain and neck-shoulder pain. *Occupational and Environmental Medicine, 68*(7), 502-509.

Jacobs, K., Foley, G., Punnett, L., Hall, V., Gore, R., Brownson, E., . . . Steinberg, S. (2011). University students' notebook computer use: Lessons learned using e-diaries to report musculoskeletal discomfort. *Ergonomics, 54*(2), 206-219.

Jasiewicz, J. M., Treleaven, J., Condie, P., & Jull, G. (2007). Wireless orientation sensors: Their suitability to measure head movement for neck pain assessment. *Manual Therapy, 12*(4), 380-385.

Johansen, T. I., Samani, A., Antle, D. M., Côté, J. N., & Madeleine, P. (2013). Gender effects on the coordination of subdivisions of the trapezius muscle during a repetitive box-folding task. *European Journal of Applied Physiology, 113*(1), 175-182.

Johansson, H., & Sojka, P. (1991). Pathophysiological mechanisms involved in genesis and spread of muscular tension in occupational muscle pain and in chronic musculoskeletal pain syndromes: A hypothesis. *Medical Hypotheses, 35*(3), 196-203.

Johnston, V., Jull, G., Darnell, R., Jimmieson, N., & Souvlis, T. (2008). Alterations in cervical muscle activity in functional and stressful tasks in female office workers with neck pain. *European Journal of Applied Physiology, 103*(3), 253-264.

Johnston, V., Jimmieson, N. L., Jull, G., & Souvlis, T. (2008). Quantitative sensory measures distinguish office workers with varying levels of neck pain and disability. *Pain*, *137*(2), 257-265.

Johnston, V., Jull, G., Souvlis, T., & Jimmieson, N. L. (2008). Neck movement and muscle activity characteristics in female office workers with neck pain. *Spine, 33*(5), 555-563.

Jonsson, B. (1982). Measurement and evaluation of local muscular strain in the shoulder during constrained work. *Journal of Human Ergology (Tokyo),11*(1), 73-88.

Jonsson, B. (1978). Kinesiology: With special reference to electromyographic kinesiology. *Electroencephalography and Clinical Neurophysiology. Supplement, (34),* 417-428.

Jonsson, P., Johnson, P. W., & Hagberg, M. (2007). Accuracy and feasibility of using an electrogoniometer for measuring simple thumb movements. *Ergonomics, 50*(5), 647-659.

Kallenberg, L. A., & Hermens, H. J. (2006). Motor unit action potential rate and motor unit action potential shape properties in subjects with work-related chronic pain. *European Journal of Applied Physiology, 96*(2), 203-208.

Kallenberg, L. A., & Hermens, H. J. (2008). Behaviour of a surface EMG based measure for motor control: Motor unit action potential rate in relation to force and muscle fatigue. *Journal of Electromyography and Kinesiology, 18*(5), 780-788.

Kanchanomai, S., Janwantanakul, P., Pensri, P., & Jiamjarasrangsi, W. (2011). Risk factors for the onset and persistence of neck pain in undergraduate students: 1-year prospective cohort study. *BMC Public Health, 11*, 566.

Kietrys, D. M., Gerg, M. J., Dropkin, J., & Gold, J. E. (2015). Mobile input device type, texting style and screen size influence upper extremity and trapezius muscle activity, and cervical posture while texting. *Applied Ergonomics, 50,* 98-104.

Kim, G. Y., Ahn, C. S., Jeon, H. W., & Lee, C. R. (2012). Effects of the use of smartphones on pain and muscle fatigue in the upper extremity. *Journal of Physical Therapy Science*, *24*(12), 1255-1258.

Kim, J. H., Aulck, L., Bartha, M. C., Harper, C. A., & Johnson, P. W. (2012). Are there differences in force exposures and typing productivity between touchscreen and conventional keyboard? *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *56*(1) 1104-1108.

Kim, S., & Nussbaum, M. A. (2013). Performance evaluation of a wearable inertial motion capture system for capturing physical exposures during manual material handling tasks. *Ergonomics, 56*(2), 314-326.

Kim, Y., Kang, M., Kim, J., Jang, J., & Oh, J. (2013). Influence of the duration of smartphone usage on flexion angles of the cervical and lumbar spine and on reposition error in the cervical spine. *Physical Therapy Korea, 20*(1), 10-17.

Kim, H. J. D., & Kim, J. S. (2015). The relationship between smartphone use and subjective musculoskeletal symptoms and university students. *Journal of Physical Therapy Science, 27*(3), 575.

Kim, M. S. (2015). Influence of neck pain on cervical movement in the sagittal plane during smartphone use. *Journal of Physical Therapy Science, 27*(1), 15-17.

Klussmann, A., Gebhardt, H., Liebers, F., & Rieger, M. A. (2008). Musculoskeletal symptoms of the upper extremities and the neck: A cross-sectional study on prevalence and symptom-predicting factors at visual display terminal (VDT) workstations. *BMC Musculoskeletal Disorders, 9*, 96.

Ko, P., Hwang, Y., & Liang, H. (2015). Influence of smartphone use styles on typing performance and biomechanical exposure. *Ergonomics,* (Epub ahead of print), 1-8.

Kobus, M. B. W., Rietveld, P., & van Ommeren, J. N. (2013). Ownership versus on-campus use of mobile IT devices by university students. *Computers & Education, 68*, 29-41.

Korpinen, L., & Pääkkönen, R. (2011). Physical symptoms in young adults and their use of different computers and mobile phones. *International Journal of Occupational Safety and Ergonomics, 17*(4), 361-371.

Korpinen, L., Pääkkönen, R., & Gobba, F. (2013). Self-reported neck symptoms and use of personal computers, laptops and cell phones among Finns aged 18–65. *Ergonomics*, *56*(7), 1134-1146.

Kuijpers, T., van Tulder, M. W., van der Heijden, G. J., Bouter, L. M., & van der Windt, D. A. (2006). Costs of shoulder pain in primary care consulters: A prospective cohort study in the netherlands. *BMC Musculoskeletal Disorders, 7*, 83.

Kumaresan, S., Yoganandan, N., & Pintar, F. (1998). Posterior complex contribution to the axial compressive and distractive behaviour of the cervical spine. *Journal of Musculoskeletal Research, 2*, 257-265.

Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G., & Jørgensen, K. (1987). Standardised nordic questionnaires for the analysis of musculoskeletal symptoms. *Applied Ergonomics, 18*(3), 233-237.

Lamoth, C. J., Meijer, O. G., Daffertshofer, A., Wuisman, P. I., & Beek, P. J. (2006). Effects of chronic low back pain on trunk coordination and back muscle activity during walking: Changes in motor control. *European Spine Journal, 15*(1), 23-40.

Larsson, B., Søgaard, K., & Rosendal, L. (2007). Work related neck–shoulder pain: A review on magnitude, risk factors, biochemical characteristics, clinical picture and preventive interventions. *Best Practice & Research Clinical Rheumatology, 21*(3), 447-463.

Larsson, R., Öberg, P. Å, & Larsson, S. (1999). Changes of trapezius muscle blood flow and electromyography in chronic neck pain due to trapezius myalgia. *Pain, 79*(1), 45-50.

Larsson, S., Bodegård, L., Henriksson, K., & Öberg, P. Å. (1990). Chronic trapezius myalgia: Morphology and blood flowlstudied in 17 patients. *Acta Orthopaedica, 61*(5), 394-398.

Lau, K. T., Cheung, K. Y., Chan, M. H., Lo, K. Y., & Chiu, T. T. (2010). Relationships between sagittal postures of thoracic and cervical spine, presence of neck pain, neck pain severity and disability. *Manual Therapy, 15*(5), 457-462.

Lau, H. M. C., Chiu, T. T., & Lam, T. (2011). The effectiveness of thoracic manipulation on patients with chronic mechanical neck pain – A randomized controlled trial. *Manual Therapy, 16*(2), 141-147.

Laursen, B., Jensen, B. R., & Sjøgaard, G. (1998). Effect of speed and precision demands on human shoulder muscle electromyography during a repetitive task. *European Journal of Applied Physiology and Occupational Physiology, 78*(6), 544-548.

Lee, J., & Seo, K. (2014). The comparison of cervical repositioning errors according to smartphone addiction grades. *Journal of Physical Therapy Science, 26*(4), 595.

Lee, M., Hong, Y., Lee, S., Won, J., Yang, J., Park, S., . . . Hong, Y. (2015). The effects of smartphone use on upper extremity muscle activity and pain threshold. *Journal of Physical Therapy Science, 27*(6), 1743.

Lee, S., Kang, H., & Shin, G. (2015). Head flexion angle while using a smartphone. *Ergonomics, 58*(2), 220-226.

Lehman, G. J. & McGill, S. M. (1999). The importance of normalization in the interpretation of surface electromyography: A proof of principle. *Journal of Manipulative and Physiological Therapeutics, 22*(7), 444-446.

Lehman, G. J. (2002). Clinical considerations in the use of surface electromyography: Three experimental studies. *Journal of Manipulative and Physiological Therapeutics, 25*(5), 293-299.

Lexell, J., Jarvis, J., Downham, D., & Salmons, S. (1993). Stimulation-induced damage in rabbit fast-twitch skeletal muscles: A quantitative morphological study of the influence of pattern and frequency. *Cell and Tissue Research, 273*(2), 357-362.

Li, G., & Buckle, P. (1999). Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods. *Ergonomics, 42*(5), 674-695.

Lidbeck, J. (2002). Central hyperexcitability in chronic musculoskeletal pain: A conceptual breakthrough with multiple clinical implications. *Pain Research & Management : The Journal of the Canadian Pain Society, 7*(2), 81-92.

Lin, I., & Peper, E. (2009). Psychophysiological patterns during cell phone text messaging: A preliminary study. *Applied Psychophysiology and Biofeedback, 34*(1), 53-57.

Lin, M., Liang, H., Lin, K., & Hwang, Y. (2004). Electromyographical assessment on muscular fatigue—an elaboration upon repetitive typing activity. *Journal of Electromyography and Kinesiology, 14*(6), 661-669.

Lin, M. B., Hong, R., Chang, J., & Ke, X. (2015). Usage position and virtual keyboard design affect upper-body kinematics, discomfort, and usability during prolonged tablet typing. *PloS One, 10*(12), e0143585.

Lindman, R., Eriksson, A., & Thornell, L. (1991). Fiber type composition of the human female trapezius muscle: Enzyme-histochemical characteristics. *American Journal of Anatomy, 190*(4), 385-392.

Lomond, K. V., & Côté, J. N. (2010). Movement timing and reach to reach variability during a repetitive reaching task in persons with chronic neck/shoulder pain and healthy subjects. *Experimental Brain Research, 206*(3), 271-282.

Lomond, K. V., & Côté, J. N. (2011). Differences in posture–movement changes induced by repetitive arm motion in healthy and shoulder-injured individuals. *Clinical Biomechanics, 26*(2), 123-129.

Lund, J. P., Donga, R., Widmer, C. G., & Stohler, C. S. (1991). The pain-adaptation model: A discussion of the relationship between chronic musculoskeletal pain and motor activity. *Canadian Journal of Physiology and Pharmacology, 69*(5), 683-694.

Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L. (1999). Shoulder muscle co-ordination during chronic and acute experimental neck-shoulder pain. An occupational pain study. *European Journal of Applied Physiology and Occupational Physiology, 79*(2), 127-140.

Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L. (2003). The effects of neck–shoulder pain development on sensory–motor interactions among female workers in the poultry and fish industries. A prospective study. *International Archives of Occupational and Environmental Health, 76*(1), 39-49.

Madeleine, P., Leclerc, F., Arendt-Nielsen, L., Ravier, P., & Farina, D. (2006). Experimental muscle pain changes the spatial distribution of upper trapezius muscle activity during sustained contraction. *Clinical Neurophysiology, 117*(11), 2436-2445.

Madeleine, P., Vedsted, P., Blangsted, A. K., Sjøgaard, G., & Søgaard, K. (2006). Effects of electromyographic and mechanomyographic biofeedback on upper trapezius muscle activity during standardized computer work. *Ergonomics, 49*(10), 921-933.

Madeleine, P., Mathiassen, S. E., & Arendt-Nielsen, L. (2008). Changes in the degree of motor variability associated with experimental and chronic neck–shoulder pain during a standardised repetitive arm movement. *Experimental Brain Research, 185*(4), 689-698.

Madeleine, P., & Madsen, T. (2009). Changes in the amount and structure of motor variability during a deboning process are associated with work experience and neck–shoulder discomfort. *Applied Ergonomics, 40*(5), 887-894.

Madeleine, P. (2010). On functional motor adaptations: From the quantification of motor strategies to the prevention of musculoskeletal disorders in the neck–shoulder region. *Acta Physiologica, 199*(Suppl 679), 1-46.

Madeleine, P., Samani, A., Binderup, A. T., & Stensdotter, A. (2011). Change in spatio-temporal organization of trapezius muscle activity in response to eccentric contraction. *Scandinavian Journal of Medicine & Science in Sports, 21*(2), 277-286.

Madeleine, P., Søgaard, K., Holtermann, A., & Samani, A. (2012). Level of self-reported neck/shoulder pain and biomechanical workload in cleaners. *Work: A Journal of Prevention, Assessment and Rehabilitation, 41*(Suppl 1), 447-452.

Mannion, A. F., & Dolan, P. (1994). Electromyographic median frequency changes during isometric contraction of the back extensors to fatigue. *Spine, 19*(11), 1223-1229.

Mannion, A. F., Dumas, G. A., Cooper, R. G., Espinosa, F., Faris, M. W., & Stevenson, J. M. (1997). Muscle fibre size and type distribution in thoracic and lumbar regions of erector spinae in healthy subjects without low back pain: Normal values and sex differences. *Journal of Anatomy, 190*(4), 505-513.

Masuda, K., Masuda, T., Sadoyama, T., Inaki, M., & Katsuta, S. (1999). Changes in surface EMG parameters during static and dynamic fatiguing contractions. *Journal of Electromyography and Kinesiology, 9*(1), 39-46.

Mathiassen, S. E., & Winkel, J. (1990). Electromyographic activity in the shoulder-neck region according to arm position and glenohumeral torque. *European Journal of Applied Physiology and Occupational Physiology, 61*(5-6), 370-379.

Mathiassen, S. E., Burdorf, A., & van der Beek, A. J. (2002). Statistical power and measurement allocation in ergonomic intervention studies assessing upper trapezius EMG amplitude: A case study of assembly work. *Journal of Electromyography and Kinesiology, 12*(1), 45-57.

Mathiassen, S. E. (2006). Diversity and variation in biomechanical exposure: What is it, and why would we like to know? *Applied Ergonomics*, *37*(4), 419-427.

Meyland, J., Heilskov-Hansen, T., Alkjær, T., Koblauch, H., Mikkelsen, S., Svendsen, S. W., . . ., Simonsen, E. B. (2014). Sex differences in muscular load among house painters performing identical work tasks. *European Journal of Applied Physiology*, *114*(9), 1901-1911.

McLean, L., Tingley, M., Scott, R., & Rickards, J. (2001). Computer terminal work and the benefit of microbreaks. *Applied Ergonomics, 32*(3), 225-237.

Mclean, L., & Urquhart, N. (2002). The influence of psychological stressors on myoelectrical signal activity in the shoulder region during a data entry task. *Work & Stress, 16*(2), 138-153.

McLean, L. (2005). The effect of postural correction on muscle activation amplitudes recorded from the cervicobrachial region. *Journal of Electromyography and Kinesiology, 15*(6), 527-535.

Merletti, R., Farina, D., Hermens, H., Freriks, B., & Harlaar, J. (1999). European recommendations for signal processing methods for surface electromyography. In H. Hermens & B. Freriks (Eds), *SENIAM 8: European recommendations for surface electromyography: Results of the SENIAM project* (pp. 57-70). Enschede, the Netherlands: Roessingh Research and Development BV.

Mezei, G., Benyi, M., & Muller, A. (2007). Mobile phone ownership and use among school children in three hungarian cities. *Bioelectromagnetics, 28*(4), 309-315.

Ming, Z., Pietikainen, S., & Hänninen, O. (2006). Excessive texting in pathophysiology of first carpometacarpal joint arthritis. *Pathophysiology, 13*(4), 269-270.

Ming, Z., Närhi, M., & Siivola, J. (2004). Neck and shoulder pain related to computer use. *Pathophysiology, 11*(1), 51-56.

Mork, P. J., & Westgaard, R. H. (2006). Low-amplitude trapezius activity in work and leisure and the relation to shoulder and neck pain. *Journal of Applied Physiology (Bethesda, Md.: 1985), 100*(4), 1142-1149.

Moseley, G. L., & Hodges, P. W. (2006). Reduced variability of postural strategy prevents normalization of motor changes induced by back pain: A risk factor for chronic trouble? *Behavioral Neuroscience, 120*(2), 474.

Nag, P., Pal, S., Nag, A., & Vyas, H. (2009). Influence of arm and wrist support on forearm and back muscle activity in computer keyboard operation. *Applied Ergonomics, 40*(2), 286-291.

Nederhand, M. J., IJzerman, M. J., Hermens, H. J., Baten, C. T., & Zilvold, G. (2000). Cervical muscle dysfunction in the chronic whiplash associated disorder grade II (WAD-II). *Spine, 25*(15), 1938-1943.

Nijs, J., Van Houdenhove, B., & Oostendorp, R. A. (2010). Recognition of central sensitization in patients with musculoskeletal pain: Application of pain neurophysiology in manual therapy practice. *Manual Therapy, 15*(2), 135-141.

Nilsen, K. B., Westgaard, R. H., Stovner, L. J., Helde, G., Rø, M., & Sand, T. (2006). Pain induced by low-grade stress in patients with fibromyalgia and chronic shoulder/neck pain, relation to surface electromyography. *European Journal of Pain, 10*(7), 615-615.

Ning, X., Huang, Y., Hu, B., & Nimbarte, A. D. (2015). Neck kinematics and muscle activity during mobile device operations. *International Journal of Industrial Ergonomics, 48*, 10-15.

Nolet, P. S., Côté, P., Kristman, V. L., Rezai, M., Carroll, L. J., & Cassidy, J. D. (2015). Is neck pain associated with worse health-related quality of life 6 months later? A population-based cohort study. *The Spine Journal, 15*(4), 675-684.

Norcross, M. F., Troy Blackburn, J., & Goerger, B. M. (2010). Reliability and interpretation of single leg stance and maximum voluntary isometric contraction methods of electromyography normalization. *Journal of Electromyography and Kinesiology, 20*(3), 420-425.

Nordander, C., Ohlsson, K., Balogh, I., Hansson, G., Axmon, A., Persson, R., & Skerfving, S. (2008). Gender differences in workers with identical repetitive industrial tasks: Exposure and musculoskeletal disorders. *International Archives of Occupational and Environmental Health, 81*(8), 939-947.

Novak, C. B., & Mackinnon, S. E. (2002). Multilevel nerve compression and muscle imbalance in work-related neuromuscular disorders. *American Journal of Industrial Medicine, 41*(5), 343-352.

Nyman, T., Grooten, W. J. A., Wiktorin, C., Liwing, J., & Norrman, L. (2007). Sickness absence and concurrent low back and neck–shoulder pain: Results from the MUSIC-Norrtälje study. *European Spine Journal, 16*(5), 631-638.

Obembe, A. O., Johnson, O. E., Tanimowo, T. O., Onigbinde, A. T., & Emechete, A. A. (2013). Musculoskeletal pain among undergraduate laptop users in a nigerian university. *Journal of Back and Musculoskeletal Rehabilitation, 26*(4), 389-395.

O'Leary, S., Falla, D., Jull, G., & Vicenzino, B. (2007). Muscle specificity in tests of cervical flexor muscle performance. *Journal of Electromyography and Kinesiology, 17*(1), 35-40.

O'Leary, S., Falla, D., Elliott, J. M., & Jull, G. (2009). Muscle dysfunction in cervical spine pain: Implications for assessment and management. *Journal of Orthopaedic & Sports Physical Therapy, 39*(5), 324-333.

O'Leary, S., Falla, D., & Jull, G. (2011). The relationship between superficial muscle activity during the cranio-cervical flexion test and clinical features in patients with chronic neck pain. *Manual Therapy, 16*(5), 452-455.

O'Sullivan, P. (2005). Diagnosis and classification of chronic low back pain disorders: Maladaptive movement and motor control impairments as underlying mechanism. *Manual Therapy, 10*(4), 242-255.

O'Sullivan, P. B., Dankaerts, W., Burnett, A. F., Farrell, G. T., Jefford, E., Naylor, C. S., & O'Sullivan, K. J. (2006). Effect of different upright sitting postures on spinal-pelvic curvature and trunk muscle activation in a pain-free population. *Spine, 31*(19), E707-12.

Page, P., Frank, C., & Lardner, R. (2010). *Assessment and treatment of muscle imbalance: The janda approach* (pp27-42). Human Kinetics.

Paksaichol, A., Janwantanakul, P., Purepong, N., Pensri, P., & van der Beek, A. J. (2012). Office workers' risk factors for the development of non-specific neck pain: A systematic review of prospective cohort studies. *Occupational and Environmental Medicine, 69*(9), 610-618.

Park, J., Kim, K., Kim, N., Choi, I., Lee, S., Tak, S., & Yim, J. (2015). A comparison of cervical flexion, pain, and clinical depression in frequency of smartphone use. *International Journal of Bio-Science and Bio-Technology, 7*(3), 183-190.

Parks Associates (2012). *Smartphone Users to quadruple over Next Five Years.* Retrieved November 16, 2012 from http://www.parksassociates.com/blog/article/parks-pr2011-smartphones

Parker, M. W. (1990). A dynamic model of etiology in temporomandibular disorders. *The Journal of the American Dental Association, 120*(3), 283-290.

Pearsaii, D. J., & Reid, J. (1992). Line of gravity relative to upright vertebral posture. *Clinical Biomechanics, 7*(2), 80-86.

Pereira, A., Miller, T., Huang, Y., Odell, D., & Rempel, D. (2013). Holding a tablet computer with one hand: Effect of tablet design features on biomechanics and subjective usability among users with small hands. *Ergonomics, 56*(9), 1363-1375.

Perry, M., Smith, A., Straker, L., Coleman, J., & O'Sullivan, P. (2008). Reliability of sagittal photographic spinal posture assessment in adolescents. *Advances in Physiotherapy, 10*(2), 66-75.

Plamondon, A., Delisle, A., Larue, C., Brouillette, D., McFadden, D., Desjardins, P., & Larivière, C. (2007). Evaluation of a hybrid system for three-dimensional measurement of trunk posture in motion. *Applied Ergonomics, 38*(6), 697-712.

Racine, M., Tousignant-Laflamme, Y., Kloda, L. A., Dion, D., Dupuis, G., & Choinière, M. (2012). A systematic literature review of 10years of research on sex/gender and pain perception–Part 2: Do biopsychosocial factors alter pain sensitivity differently in women and men? *Pain, 153*(3), 619-635.

Raja, S. N., Meyer, R., Ringkamp, M., & Campbell, J. (1999). Peripheral neural mechanisms of nociception. *Textbook of Pain, 4*, 11-57.

Rempel, D. M., Krause, N., Goldberg, R., Benner, D., Hudes, M., & Goldner, G. U. (2006). A randomised controlled trial evaluating the effects of two workstation interventions on upper body pain and incident musculoskeletal disorders among computer operators. *Occupational and Environmental Medicine, 63*(5), 300-306.

Rhodes, R. E., Mark, R. S., & Temmel, C. P. (2012). Adult sedentary behavior: A systematic review. *American Journal of Preventive Medicine, 42*(3), e3-e28.

Richter, J. M., van den Heuvel, Swenne G, Huysmans, M. A., van der Beek, Allard J, & Blatter, B. M. (2012). Is peak exposure to computer use a risk factor for neck and upper-extremity symptoms? *Scandinavian Journal of Work, Environment & Health, 38*(2), 155-162.

Roetenberg, D., Buurke, J., Veltink, P., Cordero, A. F., & Hermens, H. (2003). Surface electromyography analysis for variable gait. *Gait & Posture, 18*(2), 109-117.

Roland, M. (1986). A critical review of the evidence for a pain-spasm-pain cycle in spinal disorders. *Clinical Biomechanics, 1*(2), 102-109.

Portney, L.G. and Watkins, M.P. (2014). *Foundations of clinical research applications to practice*. 3rd Edition. Edinburgh Pearson Education Limited. P822.

Rosendal, L., Larsson, B., Kristiansen, J., Peolsson, M., Søgaard, K., Kjær, M., . . . Gerdle, B. (2004). Increase in muscle nociceptive substances and anaerobic metabolism in patients with trapezius myalgia: Microdialysis in rest and during exercise. *Pain, 112*(3), 324-334.

Saarni, L., Nygård, C., Kaukiainen, A., & Rimpelä, A. (2007). Are the desks and chairs at school appropriate? *Ergonomics, 50*(10), 1561-1570.

Saito, S., Miyao, M., Kondo, T., Sakakibara, H., & Toyoshima, H. (1997). Ergonomic evaluation VDT operation using flat panel display. *Industrial Health, 35*(2), 264-270.

Salaffi, F., Stancati, A., Alberto Silvestri, C., Ciapetti, A., & Grassi, W. (2004). Minimal clinically important changes in chronic musculoskeletal pain intensity measured on a numerical rating scale. *European Journal of Pain, 8*(4), 283-291.

Samani, A., Fernández-Carnero, J., Arendt-Nielsen, L., & Madeleine, P. (2011). Interactive effects of acute experimental pain in trapezius and sored wrist extensor on the electromyography of the forearm muscles during computer work. *Applied Ergonomics, 42*(5), 735-740.

Schall, M. C. Jr, Fethke, N. B., Chen, H., Oyama, S., & Douphrate, D. I. (2015). Accuracy and repeatability of an inertial measurement unit system for field-based occupational studies. *Ergonomics,* (Epub ahead of print), 1-23.

Schleifer, L. M., Spalding, T. W., Kerick, S. E., Cram, J. R., Ley, R., & Hatfield, B. D. (2008). Mental stress and trapezius muscle activation under psychomotor challenge: A focus on EMG gaps during computer work. *Psychophysiology, 45*(3), 356-365.

Shan, Z., Deng, G., Li, J., Li, Y., Zhang, Y., & Zhao, Q. (2013). Correlational analysis of neck/shoulder pain and low back pain with the use of digital products, physical activity and psychological status among adolescents in shanghai. *PloS One, 8*(10), e78109.

Shin, G., & Zhu, X. (2011). User discomfort, work posture and muscle activity while using a touchscreen in a desktop PC setting. *Ergonomics, 54*(8), 733-744.

Siivola, S. M., Levoska, S., Latvala, K., Hoskio, E., Vanharanta, H., & Keinänen-Kiukaanniemi, S. (2004). Predictive factors for neck and shoulder pain: A longitudinal study in young adults. *Spine*, *29*(15), 1662-1669.

Silva, A. G., Punt, T. D., Sharples, P., Vilas-Boas, J. P., & Johnson, M. I. (2009). Head posture and neck pain of chronic nontraumatic origin: A comparison between patients and pain-free persons. *Archives of Physical Medicine and Rehabilitation, 90*(4), 669-674.

Sjölander, P., Michaelson, P., Jaric, S., & Djupsjöbacka, M. (2008). Sensorimotor disturbances in chronic neck pain—range of motion, peak velocity, smoothness of movement, and repositioning acuity. *Manual Therapy, 13*(2), 122-131.

Smedley, J., Inskip, H., Trevelyan, F., Buckle, P., Cooper, C., & Coggon, D. (2003). Risk factors for incident neck and shoulder pain in hospital nurses. *Occupational and Environmental Medicine, 60*(11), 864-869.

Sommerich, C. M., Joines, S. M., Hermans, V., & Moon, S. D. (2000). Use of surface electromyography to estimate neck muscle activity. *Journal of Electromyography and Kinesiology, 10*(6), 377-398.

Srinivasan, D., & Mathiassen, S. E. (2012). Motor variability in occupational health and performance. *Clinical Biomechanics, 27*(10), 979-993.

Sterling, M., Jull, G., & Wright, A. (2001). The effect of musculoskeletal pain on motor activity and control. *The Journal of Pain, 2*(3), 135-145.

Storr, E. F., de Vere Beavis, F. O., & Stringer, M. D. (2007). Texting tenosynovitis. *The New Zealand Medical Journal, 120*(1267), U2868.

Straker, L. M., & Mekhora, K. (2000). An evaluation of visual display unit placement by electromyography, posture, discomfort and preference. *International Journal of Industrial Ergonomics, 26*(3), 389-398.

Straker, L. M., Coleman, J., Skoss, R., Maslen, B., Burgess-Limerick, R., & Pollock, C. (2008). A comparison of posture and muscle activity during tablet computer, desktop computer and paper use by young children. *Ergonomics, 51*(4), 540-555.

Straker, L. M., Burgess-Limerick, R., Pollock, C., Murray, K., Netto, K., Coleman, J., & Skoss, R. (2008). The impact of computer display height and desk design on 3D posture during information technology work by young adults. *Journal of Electromyography and Kinesiology, 18*(2), 336-349.

Straker, L. M., Burgess-Limerick, R., Pollock, C., & Maslen, B. (2009). The influence of desk and display design on posture and muscle activity variability whilst performing information technology tasks. *Applied Ergonomics, 40*(5), 852-859.

Straker, L. M., O'Sullivan, P. B., Smith, A. J., & Perry, M. C. (2009). Relationships between prolonged neck/shoulder pain and sitting spinal posture in male and female adolescents. *Manual Therapy, 14*(3), 321-329.

Svendsen, J. H., Samani, A., Mayntzhusen, K., & Madeleine, P. (2011). Muscle coordination and force variability during static and dynamic tracking tasks. *Human Movement Science, 30*(6), 1039-1051.

Szeto, G. P., Straker, L., & Raine, S. (2002). A field comparison of neck and shoulder postures in symptomatic and asymptomatic office workers. *Applied Ergonomics, 33*(1), 75-84.

Szeto, G. P., & Lee, R. (2002). An ergonomic evaluation comparing desktop, notebook, and subnotebook computers. *Archives of Physical Medicine and Rehabilitation, 83*(4), 527-532.

Szeto, G. P., Straker, L. M., & O'Sullivan, P. B. (2005a). A comparison of symptomatic and asymptomatic office workers performing monotonous keyboard work—1: Neck and shoulder muscle recruitment patterns. *Manual Therapy, 10*(4), 270-280.

Szeto, G. P., Straker, L. M., & O'Sullivan, P. B. (2005b). A comparison of symptomatic and asymptomatic office workers performing monotonous keyboard work—2: Neck and shoulder kinematics. *Manual Therapy, 10*(4), 281-291.

Szeto, G. P., Straker, L. M., & O'Sullivan, P. B. (2005c). The effects of speed and force of keyboard operation on neck–shoulder muscle activities in symptomatic and asymptomatic office workers. *International Journal of Industrial Ergonomics, 35*(5), 429-444.

Szeto, G. P., Straker, L. M., & O'Sullivan, P. B. (2005d). EMG median frequency changes in the neck–shoulder stabilizers of symptomatic office workers when challenged by different physical stressors. *Journal of Electromyography and Kinesiology, 15*(6), 544-555.

Szeto, G. P., Straker, L. M., & O'Sullivan, P. B. (2009a). Examining the low, high and range measures of muscle activity amplitudes in symptomatic and asymptomatic computer users performing typing and mousing tasks. *European Journal of Applied Physiology, 106*(2), 243-251.

Szeto, G. P., Straker, L. M., & O'Sullivan, P. B. (2009b). Neck–shoulder muscle activity in general and task-specific resting postures of symptomatic computer users with chronic neck pain. *Manual Therapy, 14*(3), 338-345.

Szeto, G. P., & Lin, J. K. (2011). A study of forearm muscle activity and wrist kinematics in symptomatic office workers performing mouse-clicking tasks with different precision and speed demands. *Journal of Electromyography and Kinesiology, 21*(1), 59-66.

Talley, N. J., Stanghellini, V., Heading, R. C., Koch, K. L., Malagelada, J. R., & Tytgat, G. N. (1999). Functional gastroduodenal disorders. *Gut, 45*(Suppl 2), II37- II42.

Thompson, S. W., Woolf, C. J., & Sivilotti, L. G. (1993). Small-caliber afferent inputs produce a heterosynaptic facilitation of the synaptic responses evoked by primary afferent A-fibers in the neonatal rat spinal cord in vitro. *Journal of Neurophysiology, 69*(6), 2116-2128.

Torisu, T., Wang, K., Svensson, P., De Laat, A., Fujii, H., & Arendt-Nielsen, L. (2006). Effects of muscle fatigue induced by low-level clenching on experimental muscle pain and resting jaw muscle activity: Gender differences. *Experimental Brain Research, 174*(3), 566-574.

Tornqvist, E. W., Hagberg, M., Hagman, M., Risberg, E. H., & Toomingas, A. (2009). The influence of working conditions and individual factors on the incidence of neck and upper limb symptoms among professional computer users. *International Archives of Occupational and Environmental Health, 82*(6), 689-702.

Travell, J., Rinzler, S., & Herman, M. (1942). Pain and disability of the shoulder and arm: Treatment by intramuscular infiltration with procaine hydrochloride. *Journal of the American Medical Association, 120*(6), 417-422.

Trudeau, M. B., Udtamadilok, T., Karlson, A. K., & Dennerlein, J. T. (2012). Thumb motor performance varies by movement orientation, direction, and device size during single-handed mobile phone use. *Human Factors, 54*(1), 52-59.

Tsang, S. M., Szeto, G. P., & Lee, R. Y. (2013a). Normal kinematics of the neck: The interplay between the cervical and thoracic spines. *Manual Therapy*, *18*(5), 431-437.

Tsang, S. M., Szeto, G. P., & Lee, R. Y. (2013b). Movement coordination and differential kinematics of the cervical and thoracic spines in people with chronic neck pain. *Clinical Biomechanics, 28*(6), 610-617.

Tsang, S. M., Szeto, G. P., & Lee, R. Y. (2014). Altered spinal kinematics and muscle recruitment pattern of the cervical and thoracic spine in people with chronic neck pain during functional task. *Journal of Electromyography and Kinesiology*, *24*(1), 104-113.

van den Heuvel, Swenne G, de Looze, M. P., Hildebrandt, V. H., & Thé, K. H. (2003). Effects of software programs stimulating regular breaks and exercises on work-related neck and upper-limb disorders. *Scandinavian Journal of Work, Environment & Health, 29*(2), 106-116.

van den Heuvel, Swenne G, IJmker, S., Blatter, B. M., & de Korte, E. M. (2007). Loss of productivity due to neck/shoulder symptoms and hand/arm symptoms: Results from the PROMO-study. *Journal of Occupational Rehabilitation, 17*(3), 370-382.

van den Hoorn, W., Bruijn, S., Meijer, O., Hodges, P., & van Dieën, J. (2012). Mechanical coupling between transverse plane pelvis and thorax rotations during gait is higher in people with low back pain. *Journal of Biomechanics, 45*(2), 342-347.

van der Grinten, Maarten P, & Smitt, P. (1992). Development of a practical method for measuring body part discomfort. *Advances in Industrial Ergonomics and Safety, 4*, 311-318.

Vasavada, A. N., Nevins, D. D., Monda, S. M., Hughes, E., & Lin, D. C. (2015). Gravitational demand on the neck musculature during tablet computer use. *Ergonomics, 58*(6), 990-1004.

Vikat, A., Rimpela, M., Salminen, J. J., Rimpela, A., Savolainen, A., & Virtanen, S. M. (2000). Neck or shoulder pain and low back pain in Finnish adolescents. *Scandinavian Journal of Public Health, 28*(3), 164-173.

Virta, L., Joranger, P., Brox, J. I., & Eriksson, R. (2012). Costs of shoulder pain and resource use in primary health care: A cost-of-illness study in Sweden. *BMC Musculoskeletal Disorders, 13*, 17.

Visser, B., & van Dieën, J. H. (2006). Pathophysiology of upper extremity muscle disorders. *Journal of Electromyography and Kinesiology*, *16*(1), 1-16.

Voerman, G., Vollenbroek-Hutten, M., & Hermens, H. (2007). Upper trapezius muscle activation patterns in neck–shoulder pain patients and healthy controls. *European Journal of Applied Physiology, 102*(1), 1-9.

Vos, T., Flaxman, A. D., Naghavi, M., Lozano, R., Michaud, C., Ezzati, M., . . . Aboyans, V. (2013). Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: A systematic analysis for the global burden of disease study 2010. *The Lancet, 380*(9859), 2163-2196.

Waersted, M., Hanvold, T. N., & Veiersted, K. B. (2010). Computer work and musculoskeletal disorders of the neck and upper extremity: A systematic review. *BMC Musculoskeletal Disorders, 11*, 79.

Wahlström, J., Hagberg, M., Toomingas, A., & Wigaeus Tornqvist, E. (2004). Perceived muscular tension, job strain, physical exposure, and associations with neck pain among VDU users; a prospective cohort study. *Occupational and Environmental Medicine, 61*(6), 523-528.

Wahlström, J. (2005). Ergonomics, musculoskeletal disorders and computer work. *Occupational Medicine (Oxford, England), 55*(3), 168-176.

Wahlström, J., Mathiassen, S. E., Liv, P., Hedlund, P., Ahlgren, C., & Forsman, M. (2010). Upper arm postures and movements in female hairdressers across four full working days. *The Annals of Occupational Hygiene, 54*(5), 584-594.

Wang, Y., Szeto, G. P., & Chan, C. C. (2011). Effects of physical and mental task demands on cervical and upper limb muscle activity and physiological responses during computer tasks and recovery periods. *European Journal of Applied Physiology, 111*(11), 2791-2803.

Wegner, S., Jull, G., O'Leary, S., & Johnston, V. (2010). The effect of a scapular postural correction strategy on trapezius activity in patients with neck pain. *Manual Therapy, 15*(6), 562-566.

Wesolowski, A., Eagle, N., Noor, A. M., Snow, R. W., & Buckee, C. O. (2012). Heterogeneous mobile phone ownership and usage patterns in Kenya. *PloS One, 7*(4), e35319.

Wijnhoven, H. A., de Vet, H. C., & Picavet, H. S. J. (2006). Explaining sex differences in chronic musculoskeletal pain in a general population. *Pain, 124*(1), 158-166.

Woolf, C. J. (2011). Central sensitization: Implications for the diagnosis and treatment of pain. *Pain, 152*(3), S2-S15.

Yang, J. F., & Winter, D. (1984). Electromyographic amplitude normalization methods: Improving their sensitivity as diagnostic tools in gait analysis. *Archive of Physical Medicine and Rehabilitation, 65*(9), 517-521.

Yip, C. H. T., Chiu, T. T. W., & Poon, A. T. K. (2008). The relationship between head posture and severity and disability of patients with neck pain. *Manual Therapy, 13*(2), 148-154.

Young, J. G., Trudeau, M., Odell, D., Marinelli, K., & Dennerlein, J. T. (2012). Touch-screen tablet user configurations and case-supported tilt affect head and neck flexion angles. *Work: A Journal of Prevention, Assessment and Rehabilitation, 41*(1), 81-91.

Young, J. G., Trudeau, M. B., Odell, D., Marinelli, K., & Dennerlein, J. T. (2013). Wrist and shoulder posture and muscle activity during touch-screen tablet use: Effects of usage configuration, tablet type, and interacting hand. *Work: A Journal of Prevention, Assessment and Rehabilitation, 45*(1), 59-71.

Zabel, A. M., & McGrew, A. B. (1997). Ergonomics. A key component in a CTD control program. *AAOHN Journal : Official Journal of the American Association of Occupational Health Nurses, 45*(7), 350-8; quiz 359-60.

Zakharova-Luneva, E., Jull, G., Johnston, V., & O'Leary, S. (2012). Altered trapezius muscle behavior in individuals with neck pain and clinical signs of scapular dysfunction. *Journal of Manipulative and Physiological Therapeutics, 35*(5), 346-353.