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Thumb postures and physical loads during mobile phone use – A comparison of young adults with and without musculoskeletal symptoms

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ABSTRACT

The aim of this study was to evaluate thumb postures, thumb movements and muscle activity when using mobile phones for SMS messaging and to determine whether there were differences in these exposures (a) across various mobile phone tasks, (b) between gender and (c) between subjects with and without musculoskeletal symptoms in shoulders and upper extremities. Fifty-six young adults (15 healthy and 41 with musculoskeletal symptoms) performed a series of distinct tasks on a mobile phone. Muscular load in four forearm/hand muscles in the right arm and the right and left trapezius muscles were measured using electromyography (EMG). Thumb movements were registered using an electrogoniometer. The results showed that postures (sitting or standing) and the type of mobile phone task (holding the phone versus texting) affected muscle activity and thumb positions. Females compared to males had higher muscle activity in the extensor digitorum and the abductor pollicis longus when entering SMS messages and tended to have greater thumb abduction, higher thumb movement velocities and fewer pauses in the thumb movements. Subjects with symptoms had lower muscle activity levels in the abductor pollicis longus and tended to have higher thumb movement velocities and fewer pauses in the thumb movements compared to those without symptoms.

1. Introduction

Young peoples‘ access and exposure to different kinds of information and communication technologies (ICT) such as computers and mobile phones has dramatically increased during the last decade (Roberts, 2000; Bohler and Schuz, 2004; Schuz, 2005; Dimonte and Ricchiuto, 2006; Nordicom, 2005; Mezei et al., 2007). The use of ICT among young adults in the aspects of experience, attitudes and health beliefs as well as prevalence of perceived stress, symptoms of depression and sleep disturbances has been studied (Gustafsson et al., 2003; Thomée et al., 2007). However, today there is a lack of knowledge on the physical exposures associated with mobile phone use and how to best measure and characterize these exposures.

With each new generation of the mobile phone, there are more built-in functions which lead to increased exposure to and use of the small built-in keypads. In younger persons, these exposures may be of great importance due to their developing musculoskeletal structure, their tendency to use their mobile phone for short message service (SMS) messaging and gaming, and the likelihood of greater exposures as a result of these repetitive SMS and gaming activities.

The physical exposures associated with use of ordinary computer keyboards have been examined in several studies. Prolonged VDU use i.e. use of ordinary keyboards and work in non neutral working postures have been reported to be important risk factors for developing neck, shoulder and upper extremity musculoskeletal disorders (Blatter and Bongers, 2002; Karlqvist et al., 2002; Jensen, 2003; Kryger et al., 2003; Lassen et al., 2004; Gerr et al., 2006).

Several studies have studied finger movements and ordinary keyboard use (Smutz et al., 1995; Keir and Wells, 2002; Jindrich et al., 2004; Kuo et al., 2006) as well as finger movements and computer mouse use (Sjogaard et al., 2001; Sogaard et al., 2001; Thorn et al., 2005). Sustained and prolonged gripping (e.g. during computer mouse or hand tool use), repetitive pushing (e.g. during pipetting), and repetitive movements with the thumb (e.g. during piano-playing or typing) have all been identified as risk factors which may lead to disorders of the thumb and extrinsic thumb musculature in the forearm (Fredriksson, 1995; Moore, 1997; Barr et al., 2004; Gupta and Mahalanabis, 2006). A case report (Ming et al., 2006) describes a 48-years-old man with a diagnosis of the first CMCJ arthritis and with a history of excessive mobile phone use and active texting with mobile phone more than 3 years.

Upper extremity musculoskeletal symptoms have been shown to be common in the working population and among computer users (Marcus et al., 2002; Brandt et al., 2004; Schlossberg et al., 2004; Strazdins and Bammer, 2004; Roquelaure et al., 2006;

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Eltayeb et al., 2007). There are reported a difference between gender with women having higher prevalence of musculoskeletal symptoms/disorders than men (de Zwart et al., 2001; Strazdins and Bammer, 2004; Treaster and Burr, 2004; Roquelaure et al., 2006; Nordander et al., 2007). Studies have reported higher risks for female computer users (Jensen et al., 1998; Gerr et al., 2002) and that women apply a greater relative force and work with higher levels of muscle activity than men (Karlqvist et al., 1999; Wahlstrom et al., 2000).

Today there is a lack of knowledge on the physical exposures and how to best assess and characterize exposures associated with mobile phone use. Considering the increased use of mobile phones among young people as well as among adults it is of importance to identify risk factors for musculoskeletal disorders due to mobile phone use that may exist. Therefore it is of importance to evaluate the physical exposures during mobile phone use, particularly the exposures associated with operating the small keypads.

The aim of this study was to evaluate thumb postures, thumb movements and muscle activity in shoulders, forearm and hand when using mobile phones for SMS messaging. In addition, we wanted to determine whether there were differences in these exposures (a) across various mobile phone tasks, (b) between gender and (c) between subjects with and without musculoskeletal symptoms in shoulders and upper extremities.

2. Methods

2.1. Subjects

Sixty young adults between 19–25 years old were recruited from an ongoing Swedish cohort of young adults (Thomée et al., 2007) where they were asked to fill out a web survey on their use of ICT (information and communication technology) and their musculoskeletal health. In this study, potential study subjects were interviewed over the phone. To be included in the study, subjects had to report that they used their mobile phone daily to send SMS messages or play games. Questions were also asked to ascertain whether subjects were with or without musculoskeletal pain. Subjects without symptoms were the subjects who reported to be pain-free at the time of interview and reported no pain in the shoulder girdles/arms/wrists/hands or numbness/tingling in hand/fingers during the last 12 months in the web survey. The subjects with symptoms were the subjects who reported to be in pain at the time of interview and reported ongoing symptoms in the last seven days in the web survey. The subjects with symptoms were all clinical examined according to a protocol (Hagberg and Violante, 2007) by a physician. Three of the subjects were excluded from the study after the clinical examination due to inflammatory disease. The diagnoses of the 41 subjects with symptoms were neck pain (cervicalgia M542 ICD-10, $n = 13$), neck and arm pain (cervicobrachial syndrome M553 ICD-10, $n = 22$) and arm-hand pain (brachialgia M796 ICD-10, $n = 6$). There were 34 subjects with neck symptoms (neck or neck and arm pain). Forearm/hand pain was present in 25 subjects (neck and arm/hand pain or arm/hand pain). Most subjects with neck pain had also tenderness of palpation in the neck and pain with contraction of neck muscles. Two of the subjects with forearm/hand pain met the criteria for De Quervain disease (M654 ICD-10). The others had non-specific pain or tingling in the forearm or/and hand.

One more subject was excluded after the data collection since he used his index finger rather than his thumb to perform the SMS tasks. Fifty-five out of remaining 56 subjects were right handed (98%) however all subjects used the mobile phone in their right hand when entering an SMS, including the left handed subject.

2.2. Experimental protocol

The subjects performed four distinct tasks with the same "standard" mobile phone (Nokia model 3310, Eshoo, Finland, 113 mm × 48 mm × 22 mm) and one task on their own personal mobile phone. At the time of the present study, the Nokia 3310 phone was one of the most common mobile phone models at the time. The design of the phone keypads was similar to most of the other phone models at the time. Almost 50% of the subjects owned or had owned that specific model or a similar, older model made by Nokia. Most of the other subjects had experience with the phone model through friends or siblings.

The first task they performed was making a phone call with the standard mobile phone and then talking on the phone for four minutes (A). This task acted as a reference task since talking required gripping the phone (as during text messaging) but not pressing the keys (the factor we were interested in studying). Then, the subjects performed three different SMS tasks with the standard phone: entering a 300 character standardized SMS message from a piece of paper while sitting (B), composing and entering their "own" 300 character SMS message while sitting (C) and composing and entering their "own" 300 character SMS message while standing (D). The experiment concluded with subjects composing and entering their own 300 character SMS message on their own personal mobile phone while sitting (E). During the standardized SMS task (B) the subjects were instructed to turn off and not use the automatic word completion function, which required that they had to text every character. During their "own" SMS tasks (C–E) they were instructed to write and use the functions they normally did when entering an ordinary SMS message. The order of the four SMS tasks (B–E) was randomised for each subject and the time it took subjects to enter each message was measured.

The standardized SMS message task (B) was performed by all 56 subjects and 24 of the 56 subjects performed all tasks (A–E).

The subjects were instructed to sit and stand using the same positions and working techniques that matched how they used their mobile phones in real life. The chair used in sitting tasks had a backrest, and armrests and no wheels. The subjects' hand size (width and length) was measured according to Pheasant (Pheasant, 1986) and a video documentation was made of the subjects' posture during every task.

The muscular load in six muscles in the right forearm/hand and both shoulders were registered by electromyography (EMG) and thumb position and movements in the right thumb were registered by an electrogoniometer during each task.

2.3. Measurement methods

2.3.1. Registration of muscular load

Muscle activity was measured with an EMG system (Muscle Tester ME 3000P8, Mega Electronics Ltd., Kuopio, Finland) in six muscles using two 10 mm diameter disposable EMG electrodes (N-00-S; Medicotest A/S, Ølstykke, Denmark) with a 20 mm inter-electrode spacing. Prior to electrode attachment, the skins was dry shaved, cleaned with alcohol, abraded with sandpaper and cleaned with a gauze pad saturated with water.

Muscle activity was registered in the right extensor digitorum (ED), the right first dorsal interossei (FDI), the right abductor pollicis longus (APL), the right abductor pollicis brevis (APB) and the pars descendent of the right (RTRAP) and left trapezius (LTRAP) muscle. The elctrodes for the ED were placed, measured from the lateral epicondyle, on 1/3 of the distance between the epicondyle and the styloid process of radius (ED), for the FDI over the muscle belly in the web between the thumb and the index finger, and for the APB over the muscle belly between the MCP and the CMC joints (Perotto, 1994). The APL electrodes were placed on the forearm proximal to the styloid process of radius where the working muscle was palpated. The electrodes for the trapezius muscles were placed 20 mm lateral to the midpoint of the line between the seventh cervical vertebra and acromion (Mathiassen et al., 1995).

The EMG signals were monitored in real-time for quality control and recorded on-line at 1000 Hz to the hard disc of a laptop computer. The EMG signal was bandpassed filtered between 8 and 500 Hz. In the data analysis, the EMG signal was rectified and averaged using a 125 ms moving window.

Standardized contractions were performed by the subjects in order to normalise muscle activity. For the ED, FDI, APL and APB, maximal voluntary electrical activity (MVE) was obtained while the subject was asked to perform a 5 s maximum contraction against manual resistance. The subject performed these contractions while seated, with the forearm supported on a table surface individually adjusted to elbow height. For the trapezius muscles a submaximal reference voluntary electrical activity (RVE) was used for normalisation. The RVE was determined as the mean activity recorded while the subject was seated and abducting both arms to 90° (in the frontal plane) while holding a 1 kg dumbbell fully pronated in each hand for 15 s.

2.3.2. Registration of thumb positions and movements

A biaxial electrogoniometer (Model SG 110, Biometrics; Gwent, UK) was used to measure adduction/abduction i.e. palmarabduction (Greene and Heckman, 1994) and flexion/extension of the thumb. The endblocks of the goniometer were applied on the dorsal side of the proximal phalange on the right thumb and on the medial aspect of the radius just proximal to the wrist joint (Fig. 1). Both goniometer endblocks were rigidly secured to the subject's wrist and thumb using double-sided tape. The thumb's general orientation was considered as the orientation of the proximal phalange.

The goniometer was calibrated with the subject's wrist in a neutral pronation/supination position in a calibration fixture (Fig. 1). The calibration fixture allowed thumb adduction/abduction (Ad/Ab) and flexion/extension (F/E) movements while simultaneously restricting any changes in wrist position. Neutral thumb Ad/Ab (0°) during the calibration procedure was defined as the position where olecranon, the distal part of radius, the CMC-joint, the MCP-joint and the proximal phalange of the thumb were all in line. Neutral thumb F/E (0°) during the calibration procedure was defined as the position where the proximal phalange of the thumb was parallel to and in line with the radius.

Using an acryl plastic manual goniometer, the thumb was put in two calibration positions, 20° of abduction and 40° of extension respectively. These calibration positions were used to set the electrogoniometer gain settings for each movement direction.

The electrogoniometer signals were monitored in real-time and recorded on-line at 1000 Hz at the same time as the EMG signals.

2.4. Data analysis

The electrogoniometer and EMG data were analysed using a program written in Labview (version 6.1; National Instruments; Austin, TX, USA). With the EMG data the program calculated the 10th (static level), 50th (median level) and 90th (peak level) percentile muscle activity. With the electrogoniometry data, by taking every 50th sample, the program down sampled the data to 20 Hz. For each movement axis, the program calculated the 50th percentile thumb postures, the median thumb velocity, the mean power frequency (MPF) of the movements, the pause percentage – defined as the percentage of time thumb velocities were below 5°/s, the mean pause duration and the number of pauses per minute.

2.5. Statistics

The muscle activity and thumb electrogoniometer data across the four tasks (A, C–E) are presented as group means ± one standard error in the text, figures and tables ($n = 24$). As these data was approximately normally distributed, repeated measures analysis of variance methods were used to compare the different tasks (Fig. 2, Table 3), one model for each parameter. Fixed effects included in the model were task, gender, group and all interactions (Random Effects-Mixed Model in statistical program JMP). Where significant differences were found between tasks, a Tukey's HSD post-hoc analysis was used to identify tasks that were different from one another.

Group and gender differences in muscle activity and thumb goniometry measures when performing the standardized SMS task (B) were analysed with linear regression ($n = 56$, Tables 2 and 4). Determinants included in this model were group, gender and the interaction.

A power calculation showed that we had a power of 99% to detect a difference of 5%RVE in median muscle activity and a difference of 5° in the median angle of the thumb movements between the groups.

Significance was accepted when p-values were less than 0.05. The calculations were made in the statistical program JMP (version 5.0.1, SAS Institute Inc., NC, USA).

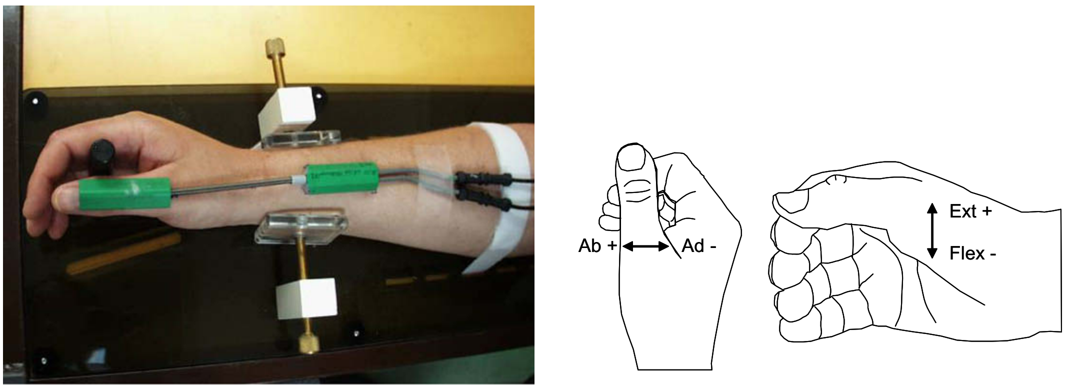

Fig. 1. Hand with electrogoniometer in the goniometer calibration fixture (left), thumb in neutral adduction/abduction and flexion/extension position. Definition of the neutral adduction/abduction (Ad/Ab) and flexion/extension (Flex/Ext) posture and sign conventions used to define thumb positions (right).

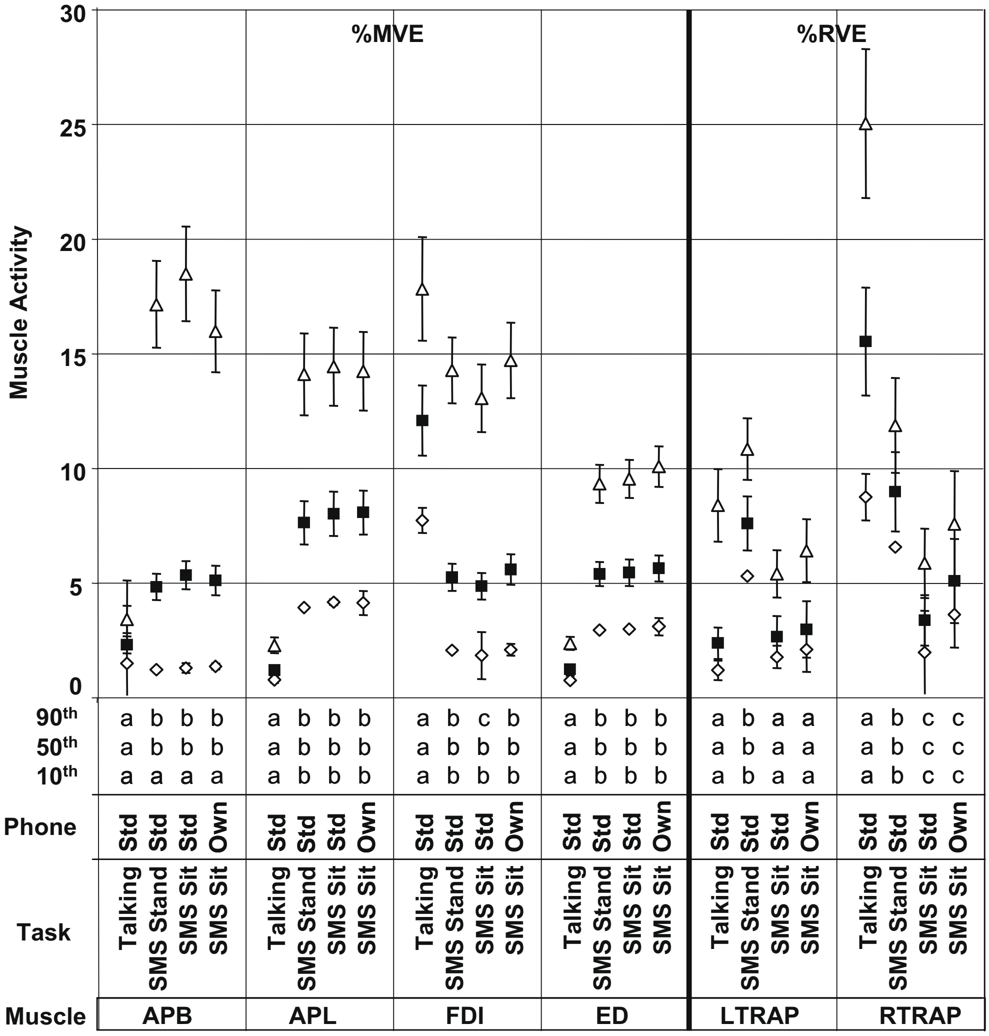

Fig. 2. 10th (◇), 50th (■) and 90th (△) percentile muscle activity levels measured from subjects (n = 24) while talking on the standard phone, entering an SMS message on the standard phone while standing, entering an SMS on the standard phone while sitting and entering an SMS on their own phone while sitting. Group means and one standards error are presented. For the 10th, 50th and 90th muscle activity levels, tasks with different letters are significantly different (adjusted for group and gender). (APB = appollicis brevis; APL = appollicis longus; FDI = first dorsal interossei; ED = extensor digitorum; LTRAP = left trapezius; RTRAP = right trapezius).

3. Results

3.1. Muscular activity during mobile phone use

Compared to talking, muscle activity was higher in four of the six muscles when entering SMS messages into the mobile phone (Fig. 2). The two exceptions were the FDI and RTRAP muscles. While seated the median muscle activity levels in the APB averaged 5.2 ± 0.6%MVE, 8.0 ± 0.9%MVE in the APL, 5.2 ± 0.6%MVE in the FDI, 5.6 ± 0.6%MVE in the ED and 2.8 ± 1.1% and 4.3 ± 1.5%RVE in LTRAP and RTRAP respectively. Sitting and standing influenced trapezius muscle activity. When entering an SMS message while standing, LTRAP and RTRAP 10th, 50th and 90th percentile muscle activity was significantly higher compared to performing the same task sitting. Finally, when comparing muscle activity when subjects entered SMS messages on their own and the

Table 1
Phone size, anthropometry and selected mobile phone usage habits of subjects with and without musculoskeletal symptoms and of females and males. Group means are given. L = length; W = width; T = thickness; AWC = automatic word completion.

	Healthy n = 15	w/symptoms n = 41	Females n = 31	Males n = 25
Female; Male	7;8	24;17	–	–
Phone size, $L \times W \times T$ (mm)	108 × 47 × 21	107 × 47 × 20	105 × 46 × 21	111 × 48 × 20
Hand size, $L \times W$ (cm)	18.5 × 9	18 × 8.5	17.5 × 8	19.5 × 9.5
Maximal thumb abduction (°)	29	31	30	31
Maximal thumb flexion (°)	47	45	46	44
Number of SMS per day	5	4	5	3
Number of letters per SMS	122	115	119	115
Sitting/standing during SMS (%)	54/46	53/47	55/45	51/49
Use of AWC function (n)	13	31	24	20

Table 2
Gender and group differences in 10th, 50th and 90th percentile muscle activity levels while performing the standardized task. Group means and standards error are given. Asterisks indicate significant differences between groups (adjusted for gender). (APB = appollicis brevis; APL = appollicis longus; FDI = first dorsal interossei; ED = extensor digitorum; LTRAP = left trapezius; RTRAP = right trapezius; %MVE = % maximal voluntary electrical activity; %RVE = % reference voluntary electrical activity).

Muscle		Female $n = 30$	Male $n = 25$	Diff	Healthy $n = 15$	w/Symptoms $n = 40$	Diff	Gender p-value	Group p-value	Interaction p-value
APB (%MVE)	p0.10	1.4 ± 0.2	1.3 ± 0.2	0.1	1.0 ± 0.2	1.5 ± 0.2	−0.5	0.70	0.17	0.94
	p0.50	5.3 ± 0.6	3.8 ± 0.6	1.5	4.2 ± 0.8	4.8 ± 0.5	−0.6	0.12	0.60	0.81
	p0.90	16.2 ± 1.5	12.7 ± 1.6	3.5	15.9 ± 2.2	14.2 ± 1.3	1.7	0.21	0.41	0.68
APL (%MVE)	p0.10	3.8 ± 0.3	2.8 ± 0.4	1.0	4.2 ± 0.7	3.1 ± 0.2	1.1	0.10	0.04*	0.75
	p0.50	7.3 ± 0.6	5.2 ± 0.7	2.1	7.7 ± 1.3	5.8 ± 0.7	1.9	0.04*	0.04*	0.93
	p0.90	12.9 ± 1.1	8.9 ± 1.2	4.0	13.3 ± 2.2	10.3 ± 0.8	3.0	0.02*	0.06	0.98
ED (%MVE)	p0.10	3.2 ± 0.3	2.0 ± 0.2	1.2	2.9 ± 0.5	2.5 ± 0.2	0.4	<0.01*	0.23	0.99
	p0.50	5.5 ± 0.4	3.5 ± 0.4	2.0	5.0 ± 0.7	4.5 ± 0.4	0.5	<0.01*	0.23	0.58
	p0.90	9.2 ± 0.6	6.0 ± 0.5	3.2	8.0 ± 1.0	7.6 ± 0.5	0.4	<0.01*	0.44	0.33
FDI (%MVE)	p0.10	2.1 ± 0.3	1.5 ± 0.2	0.6	1.7 ± 0.2	1.8 ± 0.3	−0.3	0.39	0.80	0.37
	p0.50	4.9 ± 0.6	3.4 ± 0.5	1.5	3.8 ± 0.5	4.4 ± 0.6	−0.6	0.26	0.66	0.37
	p0.90	12.3 ± 1.3	9.2 ± 1.3	3.1	10.3 ± 1.3	11.2 ± 1.2	−0.9	0.25	0.78	0.54
LTRAP (%RVE)	p0.10	2.0 ± 0.5	1.5 ± 0.6	0.5	0.8 ± 0.3	2.1 ± 0.5	−1.3	0.61	0.17	0.83
	p0.50	3.5 ± 0.8	2.8 ± 0.8	0.7	1.7 ± 0.6	3.7 ± 0.7	−2.0	0.52	0.13	0.9
	p0.90	7.9 ± 1.1	6.1 ± 1.1	1.8	5.0 ± 1.0	7.9 ± 1.0	−2.9	0.29	0.11	0.72
RTRAP (%RVE)	p0.10	2.2 ± 0.8	2.7 ± 1.1	−0.5	2.0 ± 0.8	2.6 ± 0.9	−0.6	0.76	0.66	1.00
	p0.50	3.8 ± 1.1	4.0 ± 1.4	−0.2	3.1 ± 1.2	4.2 ± 1.1	−1.1	0.95	0.60	0.90
	p0.90	6.7 ± 1.4	6.7 ± 1.8	0.0	4.7 ± 1.6	7.4 ± 1.4	−3.0	0.98	0.29	0.79

Table 3
Comparison of thumb positions and movements during four different tasks. Group means and standards error are given. Different letter superscripts indicate significant differences between tasks (adjusted for group and gender). A positive value in median angle stands for abduction and extension while a negative value stands for adduction and flexion. (Ad/Ab = adduction/abduction; Flex/Ext = flexion/extension; STD phone = Standard phone).

Parameter	Position	Task			
		Talking STD phone sitting $n = 24$	Own SMS STD phone standing $n = 23$	Own SMS STD phone sitting $n = 24$	Own SMS own phone sitting $n = 24$
Median angle (°)	Ad/Ab	−8.0 ± 3.4^{a}	9.4 ± 2.4^{b}	20.1 ± 2.6^{c}	14.8 ± 3.4^{b}
	Flex/Ext	16.9 ± 2.7^{a}	−16.7 ± 2.8^{b}	−12.6 ± 2.5^{b}	−12.8 ± 2.4^{b}
Median velocity (°/s)	Ad/Ab	1.4 ± 0.2^{a}	11.1 ± 1.4^{b}	12.0 ± 1.0^{b}	9.8 ± 1.2^{b}
	Flex/Ext	1.5 ± 0.2^{a}	7.7 ± 0.5^{b}	8.6 ± 0.5^{b}	9.0 ± 0.7^{b}
MPF (Hz)	Ad/Ab	0.14 ± 0.01^{a}	0.48 ± 0.02^{b}	0.45 ± 0.02^{b}	0.42 ± 0.02^{b}
	Flex/Ext	0.13 ± 0.01^{a}	0.51 ± 0.02^{b}	0.48 ± 0.02^{b}	0.47 ± 0.03^{b}
Pause %	Ad/Ab	0.77 ± 0.03^{a}	0.06 ± 0.01^{b}	0.08 ± 0.01^{b}	0.09 ± 0.02^{b}
	Flex/Ext	0.82 ± 0.03^{a}	0.08 ± 0.02^{b}	0.10 ± 0.01^{b}	0.10 ± 0.02^{b}
Pause duration (s)	Ad/Ab	3.68 ± 1.2^{a}	0.86 ± 0.05^{b}	0.86 ± 0.04^{b}	0.87 ± 0.04^{b}
	Flex/Ext	4.05 ± 0.7^{a}	0.83 ± 0.04^{b}	0.89 ± 0.04^{b}	0.88 ± 0.04^{b}
Pauses/Minute (n)	Ad/Ab	10.9 ± 1.1^{a}	3.2 ± 0.7^{b}	5.3 ± 0.5^{b}	5.3 ± 0.8^{b}
	Flex/Ext	11.1 ± 1.0^{a}	4.8 ± 0.8^{b}	6.2 ± 0.6^{b}	5.5 ± 0.9^{b}

Table 4
Gender and group differences in thumb postures and movements while performing the standardized task. Group means and standards error are given. Asterisks indicate significant differences between groups (adjusted for gender). A positive value in median angle stands for abduction and extension while a negative value stands for adduction and flexion (Ad/Ab = adduction/abduction; Flex/Ext = flexion/extension).

Parameter	Position	Female $n = 31$	Male $n = 25$	Diff	Healthy $n = 15$	w/Symptoms $n = 41$	Diff	Gender p-value	Group p-value	Interaction p-value
Median angle (°)	Ad/Ab	18.2 ± 1.9	12.1 ± 2.8	6.1	13.0 ± 2.1	14.9 ± 2.2	−1.9	0.24	0.52	0.20
	Flex/Ext	−9.5 ± 2.4	−11.5 ±1.8	−2.0	−13.2 ± 3.2	−9.4 ± 1.8	3.8	0.89	0.34	0.86
Median velocity (°/s)	Ad/Ab	6.6 ± 0.5	6.2 ± 0.5	0.4	6.2 ± 0.7	6.6 ± 0.4	−0.4	0.64	0.72	0.94
	Flex/Ext	6.3 ± 0.3	5.7 ± 0.3	0.6	5.2 ± 0.4	6.5 ± 0.3	−1.3	0.20	0.20	0.67
MPF (Hz)	Ad/Ab	0.35 ± 0.01	0.31 ± 0.01	0.04	0.32 ± 0.01	0.34 ± 0.01	−0.02	0.58	0.63	0.11
	Flex/Ext	0.40 ± 0.01	0.37 ± 0.02	0.03	0.38 ± 0.02	0.39 ± 0.01	−0.01	0.71	0.67	0.09
Pause%	Ad/Ab	0.19 ± 0.02	0.18 ± 0.02	0.01	0.22 ± 0.03	0.19 ± 0.02	0.03	0.93	0.43	0.19
	Flex/Ext	0.17 ± 0.01	0.20 ± 0.02	−0.03	0.21 ± 0.02	0.17 ± 0.01	0.04	0.20	0.60	0.78
Pause duration (s)	Ad/Ab	1.05 ± 0.03	1.06 ± 0.03	−0.01	1.06 ± 0.04	1.05 ± 0.03	0.01	1.00	0.80	0.21
	Flex/Ext	1.04 ± 0.03	1.04 ± 0.04	0.00	1.07 ± 0.03	1.03 ± 0.03	0.04	0.88	0.63	0.27
Pauses/Minute (n)	Ad/Ab	10.0 ± 0.8	10.0 ± 0.8	0.0	10.9 ± 1.2	10.0 ± 0.6	0.9	0.91	0.17	0.40
	Flex/Ext	9.4 ± 0.6	11.0 ± 0.8	−1.6	11.3 ± 0.8	8.8 ± 0.6	1.5	0.13	0.35	0.84

standard phone while sitting, only small differences were observed in FDI muscle activity. When subjects used their own phone, both median ($p = 0.052$) and peak 90th percentile muscle activity was higher.

3.2. Comparison of muscle activity between gender and between subjects with and without musculoskeletal symptoms

There were significant differences in muscle activity between gender in the extensor muscle and the abductor pollicis longus with females having higher muscle activity than men when entering the standardized 300 character SMS message, while seated, using the standard phone.

There were significant differences in muscle activity in the abductor pollicis longus between the subjects with and without musculoskeletal symptoms with higher muscle activity in the group without symptoms. The trapezius muscle activity was consistently higher in the group with symptoms, though not statistically significant.

There were no differences between the different groups of diagnosis (neck/arm pain, forearm/hand pain or both locations of pain) compared to the healthy group. All three groups showed the same pattern as the whole group of subjects with symptoms compared to the healthy group.

3.3. Thumb postures and movements during mobile phone use

With respect to thumb position, entering an SMS message placed the thumb in abduction and flexion relative to adducted and extended thumb posture assumed when talking. In comparison with talking on the phone which was used as a reference task entering SMS messages increased the physical load of the thumb (Table 3). During SMS messaging, the MPF and thumb movement velocities were significantly higher compare to talking, with higher velocities in Ad/Ab compared to F/E. Finally, when looking at pauses, during SMS messaging there was significantly less pause time, significantly fewer pauses and shorter mean pause durations relative to talking on the phone.

There were also some differences across the SMS tasks themselves. When comparing the results when subjects entered SMS messages with their own versus the standard phone, subjects were less abducted ($p = 0.02$) when using their own phone, all other differences were not statistically significant. Whether the subject was sitting or standing also affected thumb position, subjects worked with less thumb abduction ($p = 0.04$) when entering an SMS message while standing.

3.4. Comparison of thumb postures and movements between gender and between subjects with and without musculoskeletal symptoms

Thumb movement differences were seen between subjects with symptoms compared to subjects without symptoms, though none of these differences were statistically significant (Table 4). The subjects with symptoms moved the thumb faster, took fewer and shorter pauses than the subjects without symptoms. Similar to the muscular activity results there were no differences in thumb movements between the different groups of diagnosis compared to the healthy group.

There were also some gender differences with females working in larger abduction, moving the thumb with higher velocity and taking fewer pauses than males; however none of these differences were statistically significant.

4. Discussion

4.1. The muscular activity

Median muscle activity when entering an SMS message on mobile phone while seated was ranged between 5–8%MVE in the forearm and below 5%RVE (i.e. approximately 1%MVE) in the trapezius muscles. Compared with previous reported median muscle activity levels during common computer activities, including gripping, mouse clicking and/or key pressing, exposures associated with musculoskeletal symptoms (Aaras and Ro, 1997; Jensen et al., 1998; Laursen et al., 2001; Thorn et al., 2005; Thorn et al., 2007), the trapezius and forearm muscle activity levels associated with mobile phone use were relatively low.

Compared to talking, muscle activity was higher in four of the six muscles when entering SMS messages into the mobile phone. The two exceptions were the FDI muscle, which contributes to holding the phone in the hand in opposition with the thumb and the right trapezius muscle. The higher muscle activity in the FDI muscle during talking compared to entering an SMS message is likely due to the fact that subjects had to grip the phone with more force when holding it up against the ear. When an SMS message is being entered, the phone can rest in the palm of the hand, and as a result, unlike when held against the ear, less grip force is needed to hold the phone since users do not have to counteract gravity in order to prevent the phone from slipping out of the hand. The higher muscle activity in the RTRAP while talking is likely due to this muscle's role elevating the arm and stabilizing the shoulder girdle when holding the phone up against the ear.

Sitting or standing while performing an SMS message influenced the muscle activity in the trapezius muscles. When entering an SMS message while standing, the muscle activity in the trapezius was significantly higher compared to performing the same task sitting. Mork and Westgaard (2007) have found that muscle activity in the trapezius was elevated in standing compared to sitting during computer work. However, while standing the subjects in their study were not doing the same task as in sitting position using the computer but talking to colleagues, handling print-outs etc. In the present study while sitting, subjects were able to rest their arms on their thighs, the armrests or on the table in front of them, the higher trapezius muscle activity while standing was probably due to subjects not being able to support their arms. Forearm support during keyboard and mouse use has been reported to decrease neck and shoulder muscle activity (Aaras et al., 1998; Aaras et al., 2001; Woods et al., 2002; Cook et al., 2004) and the results in this study indicate that having arm support, while entering an SMS message, may reduce trapezius muscle load.

When comparing muscle activity when subjects entered SMS messages on their own and the standard phone while sitting, differences were only found in FDI muscle activity. When subjects used their own phone, both median ($p = 0.052$) and peak muscle activity was higher. This difference in FDI muscle activity could partially be due to the subjects' own phones being smaller in size relative to the standard phone (Table 1).

4.2. Thumb postures and thumb movements

Entering an SMS message placed the thumb in an abducted and flexed posture. When subjects entered SMS messages with their own versus the standard phone, subjects were less abducted ($p = 0.02$) when using their own phone, all other differences were not statistically significant. These differences in thumb posture may be partially due to phone size since the subjects' own phones were on average shorter, narrower and thinner than the standard phone.

Whether the subjects were sitting or standing also affected the thumb position. Subjects worked with less thumb abduction but larger flexion while standing. These postural differences are likely the result of the arms being unsupported allowing a greater flexibility in the wrist and hand when entering an SMS message while standing.

4.3. Differences between gender and between subjects with and without symptoms

There were significant gender differences in muscular activity in the extensor digitorum and the abductor pollicis longus with females having higher muscle activity levels. Other studies have demonstrated that, during computer mouse use, females tend to have higher muscular activity levels than males (Karlqvist et al., 1999; Wahlstrom et al., 2000). These muscle activity differences were assumed to be related to differences in anthropometry and muscular strength. The larger thumb abduction for the females in the present study is probably due to smaller hand size resulting in larger thumb movements in order to reach the keys. This, perhaps together with the females having higher median velocity, less pause percentage and fewer pauses than males, could explain the higher muscle activity in the ED and the APL.

There were significant differences in muscle activity in the abductor pollicis longus between subjects with and without symptoms; however subjects without symptoms tended to have higher levels of muscle activity. The trapezius muscle activity was consistently higher in subjects with symptoms, though not statistically significant. Johansson and Sojka (1991) suggested when they presented "the vicious circle model" that muscle pain probably lead to increased muscle activity during muscle work. In accordance with this, one study has found higher electromyographic activity in the neck and shoulder muscles in subjects with neck and shoulder complaints (Madeleine et al., 2003). The lower muscle activity in the APL in the group with symptoms is a contradictory result but might be explained by the findings in a study where they found lower electromyographic activity in the extensor carpi ulnaris in high activity phases in low precision computer mouse work during experimental muscle pain (Birch et al., 2000).

In a study with female industrial workers with highly repetitive work tasks it was found that subjects with hand/wrist pain moved their wrists with lower velocity compared with subjects without pain (Balogh et al., 1999). It would be reasonable to expect that due to pain subjects with symptoms in the present study should move the thumb slower. On the contrary, the subjects with symptoms tended to move their thumbs with higher speed compared to those without symptoms. The higher velocity may partially explain why they have developed symptoms/disorders. High movement velocity has been shown to be a risk factor for musculoskeletal disorders (Marras and Schoenmarklin, 1993) and fast thumb movements are considered to be a risk factor for developing De Quervain's disease (Moore, 1997). One study have shown that occupations involving repetitive thumb movements and perceived as not having enough rest breaks were risk factors for osteoarthritis of the thumb (Fontana et al., 2007) which also is in accordance with the earlier described case report of excessive texting on the mobile phone in pathophysiology of the first CMCJ arthritis (Ming et al., 2006).

The subjects with symptoms also tended to have fewer and shorter pauses compared with those without symptoms. Several studies have found that subjects with neck/shoulder complaints show less trapezius muscle rest than those without complaints (Veiersted et al., 1993; Hagg and Astrom, 1997; Sandsjo et al., 2000; Thorn et al., 2007). If one presumes that the pause pattern of the thumb movements are linked to the pauses of muscle activity in the thumb muscles, perhaps one can consider the pause pattern as a probable risk factor for musculoskeletal disorders in the hand and forearm.

4.4. Limitations of the study

We are fully aware of the difficulty in measuring thumb movements due to the complexity of its function with the principal motions flexion/extension, adduction/abduction and opposition. The proximal phalange of the thumb was used to measure thumb position/orientation relative to the forearm. However, the thumb is composed of more than just the proximal phalange and articulates about multiple joints and bones. As a result, the electrogoniometer in this study was measuring over three joints (the MCP-joint, the CMC-joint and the radiocarpeal joint), so it was possible that the measured position/orientation at the proximal phalange could have contributions from more than one joint.

However, it has been shown (Jonsson et al., 2007) that an electrogoniometer has validity for measuring simple thumb movements and that electrogoniometers can provide quantitative information on thumb movements during thumb intensive activities such as writing an SMS message on a mobile phone.

5. Conclusions

In summary, we found that the thumb, forearm and trapezius muscle activity during SMS messaging was relatively low. Relative to sitting, entering an SMS while standing increased trapezius muscle activity. Females, compared to males, typically had higher muscle activity levels and they tended to work in greater thumb abduction, to move their thumbs with higher velocities and to have fewer pauses in the thumb movements. Subjects with musculoskeletal symptoms had lower muscle activity levels in the abductor pollicis longus and tended to move their thumbs with higher velocities and to have fewer pauses in the thumb movements compared to those without symptoms.

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