Applied Ergonomics 70 (2018) 232–239

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Texting with touchscreen and keypad phones - A comparison of thumb kinematics, upper limb muscle activity, exertion, discomfort, and performance

Ewa Gustafsson[a,*], Pieter Coenen[b,c], Amity Campbell[c], Leon Straker[c]

[a] Occupational and Environmental Medicine, University of Gothenburg, Box 414, SE-405 30, Göteborg, Sweden
[b] Department of Public and Occupational Health, Amsterdam Public Health Research Institute, VU University Medical Center, Amsterdam, The Netherlands
[c] School of Physiotherapy and Exercise Sciences, Curtin University, Perth, Australia

ARTICLE INFO

Keywords:
Smartphones
Hand size
EMG

ABSTRACT

This study aimed to compare thumb kinematics and upper limb muscle activity, and the influence of hand size, when texting on a keypad smartphone and a touchscreen smartphone. Furthermore, the study compared exertion, discomfort, and performance when texting on the two phones. The thumb kinematics were tracked using a 3D motion analysis system and muscle activity was registered in six upper limb muscles using surface electromyography in 19 participants. When texting on the touchscreen phone compared to the keypad phone thumb flexion ($p = 0.008$) and flexion/extension range of motion were smaller ($p = 0.02$), the thumb was on average less internally rotated ($p = 0.02$), and activity (50th and 90th percentile) of the thumb and forearm muscles was lower ($p \le 0.05$). The differences in thumb flexion were found only in the group with shorter hands and the differences in muscle activity was found only in the group with longer hands. These findings suggest there are differences in risks for developing musculoskeletal disorders during smartphone use with different key activation mechanisms and different hand sizes.

1. Introduction

Over the last 20 years, mobile phone use has become ingrained in daily life for many people all over the world, in particular since the introduction of the smartphone about ten years ago. The smartphone, with its multi-functionality, has quickly become the most common type of mobile phone. For example, in Sweden 97% of the population (aged 9–79 years) had a mobile phone and 80% had a smartphone in 2016 (Nordicom). In Australia, as many as 89% of the population (aged 18–75 years) had a smartphone in 2014 (Mackay, 2014).

Accompanying the considerable use of mobile phones there have been concerns raised about possible musculoskeletal problems. Indeed, excessive texting with mobile phones has been associated with musculoskeletal disorders in the thumb and upper limb in case reports, and in experimental and epidemiological studies (Eapen et al., 2014; Gustafsson et al., 2017; Johnson et al., 2016; Ming et al., 2006; Storr EF and Stringer, 2007; Williams and Kennedy, 2011) suggesting that these concerns may be justified.

Highly repetitive thumb movements have been identified as a potential musculoskeletal disorder risk factor related to mobile phone use (Gold et al., 2012; Gold et al., 2009; Gustafsson et al., 2010, 2011). Much of the interaction with the smartphone is through tapping with the thumb as the most used digit for the interaction (Gold et al., 2012). The movements of the thumb are complex, and include flexion/extension, adduction/abduction, and opposition (Greene and Heckman, 1994) with involvement of muscles in the hand and forearm. Furthermore, during single-handed mobile phone texting when tapping with the thumb muscles on the dorsal and the palmar side of the forearm are involved in stabilizing the wrist.

Considering the immense and widespread use of smartphones for texting in almost all age groups, understanding the underlying causes of musculoskeletal disorders related to smartphone use is important.

There are two basic designs of smartphones. I. Phones with a physical keypad keyboard in the bottom half and with the screen occupying the top half of the phone (Fig. 1, phone A). II. Phones with a touchscreen occupying most of the phone front, with a virtual touchscreen keyboard available as needed, usually in the bottom half of the screen (Fig. 1, phone B). Today touchscreen phones are by far more popular and there is a trend that smartphones are becoming touchscreen only. But phones with physical keypads are still commercially available, showing there are still populations that use keypad phones. For example, the ability for keypad phones to be operated in a wider variety

* Corresponding author.
E-mail address: ewa.gustafsson@amm.gu.se (E. Gustafsson).

https://doi.org/10.1016/j.apergo.2018.03.003
Received 9 May 2017; Received in revised form 2 March 2018; Accepted 5 March 2018
Available online 20 March 2018
0003-6870/

Fig. 1. Keypad phone, Nokia model E5 to the left (phone A), and touchscreen phone, iPhone model 3 GS to the right (phone B).

of situations (such as rain and with normal gloves) makes these designs attractive for military use (J. Coleman, personal communication, August 2015).

Considering the higher popularity of the touchscreen phone compared with the keypad phone, it is important to investigate if there is a difference in risk for developing musculoskeletal disorders in order to provide the users with appropriate guidance in selection and use of phones.

The two basic designs of smartphones have different key activation mechanisms and tactile feedback. Our hypothesis is that these differences, when using the different phones for texting, may pose different physical stresses on the upper extremities, e.g. differences in thumb postures and muscle activity, and thus influence the usability and musculoskeletal risk of phone use.

Prior studies on the effect of different types of information and communication technology input devices have demonstrated that design differences can have significant impacts on posture, muscle activity and discomfort in neck and upper extremities (Briggs et al., 2004; Chany et al., 2007; Gustafsson and Hagberg, 2003; Oude Hengel et al., 2008; Rempel et al., 2007; Straker et al., 2008b; Xiong and Muraki, 2014). However, there is very limited knowledge about differences in thumb postures, muscle activity, and discomfort during the use of these two basic types of phones. A recently published study reported higher muscle activity in one thumb muscle and two muscles in the forearm when entering text on a keypad phone compared to a touchscreen phone (Kietrys et al., 2015), but no details on kinematics of these activities were provided. Given prior evidence on the importance of a variety of thumb and forearm muscles for thumb movement and wrist stabilization (van Oudenaarde et al., 1997) a better understanding of both kinematics and muscle activity during use of the two types of phones is required. There is also a lack of knowledge about how thumb kinematics and muscle activity are influenced by hand size when entering text on a touchscreen phone and a keypad phone. The perceived exertion and discomfort during phone use may also be important early indicators of musculoskeletal risk and should be further explored. Finally, differences in performance using the different types of phones are likely to be important for guiding appropriate selection and use of phones.

Therefore, the aim of this study was to compare thumb kinematics and upper limb muscle activity, and the influence of hand size when texting on a touchscreen smartphone and a keypad smartphone. Furthermore, the user ratings of perceived exertion and discomfort, and their performance when texting on the two phones were compared.

Table 1
The study population's age, anthropometric data and their current used phone (own phone). For age, hand and thumb size mean and range are given.

	All	Women	Men
	(n = 19)	(n = 12)	(n = 7)
Age (yr)	30.1 (21; 51)	30.9 (21; 51)	28.7 (21; 43)
Hand (cm)			
Length	18.3 (16.5; 20)	17.8 (16.5; 19)	19.1 (18; 20)
Width	8.6 (7.5; 9.5)	8.3 (7.5; 9)	9.2 (8.5; 9.5)
Thumb (cm)			
Length	6.4 (5.5; 8)	6.3 (5.5; 8)	6.6 (6; 7.5)
Width	6.3 (5.5; 7)	6.0 (5.5; 6.5)	6.7 (6; 7)
Hand length (n)			
Short (≥ 18.5 cm)	8	7	1
Long (≤ 18 cm)	11	5	6
Current phone (n)			
Keypad	5	3	2
Touchscreen	14	9	5

n = number; yr = year.

2. Method

2.1. Study participants

Nineteen participants (aged 21–51 years, 7 men, 12 women) without ongoing musculoskeletal symptoms in the thumb and upper extremities were recruited from the local university community (Curtin University, Perth, Australia). All participants had daily use of either a keypad phone in portrait mode for typing or a touchscreen phone with a keyboard in portrait mode (Table 1). Fourteen participants were currently using a touchscreen phone, and had owned and used a keypad phone within the last 12 months. Five participants were currently using a keypad phone and all five had the experience of using a touchpad phone. One woman and one man were left handed, the other seventeen participants were right handed.

2.2. Experimental protocol

The study was a laboratory study with a cross-over design in which all participants performed a texting task for 3 min with a keypad phone and a touchscreen phone. The order of the phones being used (keypad and touchscreen) was randomized. For each phone, a text was randomly assigned from three different paragraphs of texts from an athlete's autobiography. All paragraphs of text had a similar number of words, characters, syllables, and spaces.

The keypad phone used was a Nokia model E5 (Eshoo, Finland, size 115 × 58.9 × 12.8 mm; 126 g; key size 6 × 4 mm; distance from bottom of the phone to lowest key row 15 mm; mechanical key force 1.6 N; key travel 0.7 mm) with full qwerty keyboard and the touchscreen phone used was an iPhone model 3 GS, Apple Inc., (Cupertino, CA, USA,115.5 × 62.1 × 12.3 mm; 135 g; key size 6 × 4 mm; distance from bottom of the phone to lowest key row 22 mm). These phones were chosen to represent the two basic designs of smartphones studied in this study and these particular phones were chosen to be as similar in size, weight, key size, and key position as possible (Fig. 1).

The texting tasks were performed with participants in a sitting position on a chair with backrest and without armrests. The phone was held in one (preferred) hand while the thumb on this hand was used to activate the keys. The participants were instructed to sit upright with their back against the backrest, their elbow against their body, and without any forearm support. The participants read the text from a paper copy on a document holder placed at eye level in front of them. The participants were instructed to copy the text as correctly as possible using their normal typing speed and to type as they normally would do but without punctuations or capital letters. Similar display text sizes were used on both phones.

The participants were not allowed to use the automatic text function or to correct mistakes while texting, since the study aimed to compare number of correct typed characters and the number of typed characters without interference from text corrections. Following the trial, the typed text was emailed by the participant to the researchers, who transferred it into the study database.

Prior to application of the measuring equipment a 5 min training session was offered with the unfamiliar phone (i.e. the keypad phone if their own phone was a touchphone and vice versa) and a short practice session (30 s) was offered prior to each texting task with both phones.

Hand size was measured from the crease of the wrist to the tip of the middle finger with the hand held straight using a measuring tape. Outcomes were dichotomized using a median split into long hands (≥18.5 cm) and short hands (≤18 cm).

2.3. Dependent variables

2.3.1. Kinematics

The movements of the preferred thumb were tracked using an 18 camera 3D motion analysis system (Vicon Oxford Metrics, inc), operated at 250 Hz. For this purpose, retro-reflective markers (9 mm diameter for the hand markers and 5 mm in diameter for the thumb) were fixed to the skin surface above specific anatomical landmarks for the hand and thumb. A cluster of markers was secured to the middle of the proximal phalanx (Fig. 2). Four individual calibration markers were also placed on the medial and lateral aspects of interphalangeal and metacarpal joints. Hand markers were secured to the skin surface above the 3rd metacarpal and a bar of two markers placed mid-segment. Two individual calibration markers were then fixed to the ulnar styloid process and radial styloid process. A static trial was performed after which calibration markers were removed.

2.3.1.1. Kinematics data processing. The Vicon data was checked for occlusions/breaks in trajectories using Vicon Nexus software (Oxford Metrics Inc, Oxford, U.K). Breaks of less than 20 frames were filled using cubic spline interpolation or pattern fill. A residual analysis was performed to determine the optimal filter cut off frequency (3), and trajectories were then filtered using a Woltring filter (Woltering, 1986). A customized model was used to calculate thumb kinematics, written in Body Builder software (Oxford Metrics Inc, Oxford, U.K).

The thumb segment was created using the right hand rule, with the positive z-axis between the medial and lateral markers on the metacarpal joint. The positive y-axis was created between the midpoint of the metacarpal joint markers and the midpoint of the interphalangeal joint markers. The positive x-axis was created as the cross product of z- and y-axes. The hand was modelled according to previously outlined procedures (Gonsalves et al., 2015). The thumb coordinate system was outputted relative to the hand coordinate system using a ZXY Euler angle decomposition. Thumb movements in three dimensions (flexion/extension, adduction/abduction, rotation) relative to the hand are depicted in Fig. 3.

A customized Labview program (version 11.0; National Instruments;

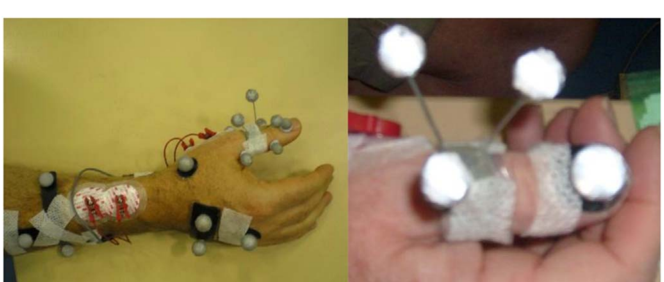

Fig. 2. Hand with retro-reflective markers and electrodes (left). Thumb without calibration markers (right).

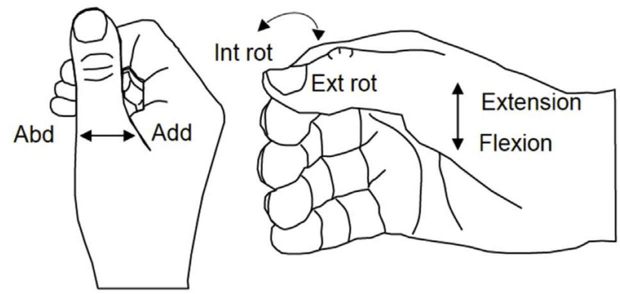

Fig. 3. Definition of the neutral adduction/abduction (Ad/Ab), flexion/extension (Flex/Ext) and internal/external rotation (Int rot/Ext rot) posture used to define thumb positions (right). The position of the thumb shows a 90° angle.

Austin, TX, USA) was used to output time series of kinematic data from the middle minute of each 3 min typing trial. The first and last minute were discarded as users may adjust their behavior when “settling in” to a task and when they start to anticipate an end to the task.

Time series of kinematic data were further analyzed using Matlab (Mathworks Inc, Natick USA), during which the 10th, 50th (median) and 90th percentile of the signals were calculated for each participant. Range of motion (ROM) was expressed as the difference between the 90th and 10th percentile.

2.3.2. Muscle activity

The muscle activity of trapezius (TRAP), extensor digitorum (ED), flexor carpi ulnaris (FCU), abductor pollicis longus (APL) and abductor pollicis brevis (APB) was registered using an 8-channel Octopus Cable Telemetric system (Bortec Electronics Inc., Calgary, Canada). EMG signals were digitally sampled at 1000 Hz and band-pass filtered between 8 and 500 Hz.

Prior to electrode attachment the skin area was dry shaved, abraded with sandpaper and cleaned with alcohol. Two self-adhesive disposal bipolar Ag/AgCl surface electrodes (Red Dot, 3M Health Care Products, London, Ontario, Canada) with an active contact surface of 15 mm^2 and with a 25 mm inter-electrode spacing were fixed to the skin surface above each muscle.

Electrodes were placed 20 mm lateral to the midpoint of the line between the seventh cervical vertebra and the acromion for TRAP (Mathiassen et al., 1995), 1/3 of the distance between the lateral humeral epicondyle and the radial styloid process for ED (Perotto, 1994), two fingerbreadths volar to ulna for FCU, at 1/3 of the distance between the medial humeral epicondyle and the ulna styloid process for FCU (Perotto, 1994), on the radius, one hand breadth proximal to wrist for APL and over the muscle belly between palmer aspect of MCP (metacarpophalangeal) and CMC (carpometacarpal) joints for APB (Perotto, 1994). The ground electrode was placed on mid right clavicle. The skin impedance was checked with an impedance meter and values below 5 kΩ were considered acceptable.

In order to normalize the muscle activity amplitude, three maximal 5-s contractions for each muscle were performed by the participants. Two minutes of rest were provided between each standardized contraction and verbal encouragement was provided by the tester.

For ED, FCU, APL, and APB the maximal contractions were performed against manual resistance with the participant in a seated position with their forearm and hand stabilized against a bench. For TRAP, the participant stood on a wooden platform with a plastic handle in each hand connected by a metal chain to the platform while pulling their shoulders up with straight arms.

2.3.2.1. EMG data processing. The EMG signals were de-averaged (to remove direct current offset) and rectified (to obtain amplitude) using a 125 ms moving window and the signals were low-pass filtered with a 4 Hz cut-off frequency (to remove movement artefacts). EMG signals were expressed in percentages of maximal voluntary electrical activity

(%MVE).

A customized Labview program (version 11.0; National Instruments; Austin, TX, USA) was used to output time series of EMG data from the middle minute of each 3 min typing trial. The first and last minute were discarded as users may adjust their behavior when "settling in" to a task and when they start to anticipate an end to the task.

Time series of EMG data were further analyzed using Matlab (Mathworks Inc, Natick USA), during which the 10th, 50th (median) and 90th percentile of the normalized signal amplitudes were calculated for each participant.

2.3.3. Subjective ratings of exertion and discomfort

Perceived exertion was rated for the neck, shoulder, upper arm, forearm, hand and thumb with Borg's CR 10 scale (Borg, 1990) together with a body map (Gustafsson et al., 2010). The participants were asked if they perceived any exertion and, if they did, they were asked to indicate their perceived exertion on the body map as well as the extent of their exertion (according to the CR 10 scale).

Perceived discomfort was rated for the same body regions with a visual numerical 0–10 scale. The participants were asked if they perceived any discomfort and, if they did, they were asked in which body areas (defined on a body map described above) and how much according to the numerical scale. Exertion and discomfort were rated at the start of the experiment and immediately before and after each texting task. The difference between the rated perceived exertion and discomfort before and after texting with the two different phones was calculated for every rated body area.

2.3.4. Performance

Performance was measured as the total number of characters typed per minute, total number of correct typed characters per minute, and the proportion of correct characters for each texting task.

2.4. Statistics

The outcome variables thumb kinematics and upper limb muscle activity were continuous variables. The relationships between the outcomes and the independent variables were assessed by using linear regression models for repeated data. We used the Proc Mixed (SAS 9.4) to perform regression analysis for repeated data, which accounts for within subject correlations. We assumed phone as a fixed effect, i.e. the model holds true across the sample and with the same slope. We used the unstructured covariance structure in the regression analyses.

Univariate regression analyses for repeated data with type of smartphone (keypad, touchscreen) as an independent variable was used to compare kinematics and upper limb muscle activity between smartphones.

To compare kinematics and upper limb muscle activity between smartphones for small and large hands hand size was added as an independent variable and the interaction terms between type of phone and hand size were included in the regression models.

As the perceived data (exertion and discomfort) and performance data were not normally distributed, Wilcoxon signed rank test was used to compare the differences between keypad and touchscreen phones.

Statistical significance, alpha was set at 0.05. All statistical analyses were performed with SAS 9.4 for windows (SAS Institute Inc., Cary, NC, USA).

3. Results

3.1. Kinematics

Statistically significant differences between the two phones were found in thumb flexion/extension and rotation movements (Table 2). When texting on the touchscreen phone compared with the keypad phone the median flexion was smaller (85.1° and 80.7° respectively, $p = 0.008$) that is, the thumb was on average closer to the neutral position (with the neutral position being 90°, Fig. 3) when texting on the touchscreen phone. The median ROM in flexion/extension movements was also smaller when texting on the touchscreen phone (14.3° and 17.6° respectively, $p = 0.02$). In addition, when texting on the touchscreen phone the median angle in rotation was smaller (28.2° and 33.4° respectively, $p = 0.02$) that is, the thumb was on average less internally rotated and closer to the neutral position (Table 2), but no difference in the median ROM in internal/external rotation was seen ($p = 0.29$). The median ROM in adduction/abduction movements also appeared smaller when using the touchscreen phone compared with the keypad phone but this difference was not statistically significant (23.9° and 27.9°, $p = 0.06$).

Table 2
Differences in thumb kinematics when texting on a keypad phone (key) and a touchscreen phone (touch). Mean and standard error are given. Positive value in median angle stands for flexion, adduction, and internal rotation respectively. Statistically significant results are presented in bold.

Position	Key	Touch	Diff	95% CI
Flex/Ext (°)				
Median	80.7 ± 5.1	85.1 ± 5.0	−4.4	**−7.53;-1.30**
ROM	17.6 ± 2.3	14.3 ± 1.9	3.3	**0.56;6.05**
Ad/Ab (°)				
Median	−91.5 ± 4.0	−90.5 ± 3.9	−1.0	−4.78; 2.87
ROM	27.9 ± 3.3	23.9 ± 2.3	4.0	−0.26; 8.27
Int/Ext Rot (°)				
Median	33.4 ± 3.7	28.2 ± 4.4	5.1	**0.94;9.34**
ROM	21.7 ± 1.9	20.3 ± 1.6	1.4	−1.25; 3.95

Flex/Ext = flexion/extension; Ad/Ab = adduction/abduction;
Int/Ext rot = internal/external rotation; ROM = range of motion;
Diff = difference; 95% CI = 95% confidence interval.

3.1.1. The influence of hand size

When using the touchscreen phone, the median flexion was found to be smaller, that is closer to the neutral position of the thumb (with the neutral position being 90°) in the group with shorter hands (≤18 cm) compared with the keypad phone (84.1° and 78.5° respectively, $p = 0.04$) (Table 3). This difference was not found in the group with longer hands (≥18.5 cm). No influence of hand size was found in adduction/abduction or rotation movements for none of the phones.

3.2. Muscle activity

Statistically significant differences in muscle activity were found in the APB (10th, 50th, 90th percentile, $p \le 0.03$), APL (50th, 90th percentile, $p \le 0.02$), ED (50th, 90th percentile, $p \le 0.05$) and FCU (50th, 90th percentile, $p = 0.04$) muscles with lower muscle activity when using the touchscreen phone compared with the keypad phone (Table 4). Muscle activity in TRAP appeared higher when using the touchscreen phone but this difference was not statistically significant.

3.2.1. The influence of hand size

When using the touchscreen phone, participants with long hands (≥18.5 cm) were found to have lower muscle activity in the APB ($p \le 0.02$), APL ($p = 0.01$), ED ($p \le 0.05$), and FCU ($p \le 0.02$) muscles (Table 5). These differences were not found in the group with short hands (≤18 cm).

3.3. Perceived exertion and discomfort

No statistically significant differences were found in rated perceived exertion and discomfort when texting on the two phones.

A majority of the participants (17–19 participants) rated the exertion as low (0–3 on the 0–10 scale) in all body regions for both phones. The median, 1st quartile (Q1), and 3rd quartile (Q3) of the differences

Table 3
Differences in thumb kinematics between the groups with short hands (≤18 cm) and long hands (≥18.5 cm) when texting with a keypad phone (key) and a touchscreen phone (touch). Mean and standard error are given. Statistically significant results are presented in bold.

Position	Short hands			95% CI	Long hands			95% CI
	Key	Touch	Diff		Key	Touch	Diff	
Flex/Ext (°)								
Median	78.5 ± 8.9	84.1 ± 8.7	−5.6	**−11.00;-0.24**	81.9 ± 6.6	85.6 ± 6.4	−3.8	−7.73; 0.21
ROM	17.7 ± 4.0	13.4 ± 3.3	4.3	−0.42; 9.08	17.5 ± 3.0	14.8 ± 2.5	2.7	−0.76; 6.26
Ad/Ab (°)								
Median	−95.1 ± 6.9	−93.9 ± 6.7	−1.2	−7.90; 5.46	−89.4 ± 5.1	−88.6 ± 5.0	−0.8	−5.74; 4.13
ROM	29.6 ± 5.8	23.9 ± 4.0	5.7	−1.65; 13.06	27.0 ± 4.2	23.9 ± 2.9	3.1	−2.36; 8.51
Int/Ext Rot (°)								
Median	23.7 ± 5.6	17.6 ± 6.8	6.1	−1.23; 13.39	38.7 ± 4.1	34.0 ± 5.0	4.6	−0.77; 10.03
ROM	18.0 ± 3.1	17.8 ± 2.6	0.2	−4.27; 4.68	23.6 ± 2.3	21.7 ± 1.9	1.9	−1.34; 5.28

Flex/Ext = flexion/extension; Ad/Ab = adduction/abduction; Int/Ext rot = internal/external rotation; ROM = range of motion;
Diff = difference; 95% CI = 95% confidence interval.

Table 4
Differences in muscle activity when texting on a keypad phone (key) and a touchscreen phone (touch). Mean in %MVE and standard error are given. Statistically significant results are presented in bold.

Muscle	Key	Touch	Diff	95% CI
APB (%MVE)				
p0.10	3.3 ± 0.9	1.9 ± 0.6	1.4	**0.49;2.37**
p0.50	9.4 ± 1.5	6.4 ± 1.0	3.0	**1.04;4.90**
p0.90	24.1 ± 3.0	20.1 ± 2.8	4.0	**0.36;7.72**
APL (%MVE)				
p0.10	5.0 ± 0.8	4.5 ± 0.7	0.4	−0.26; 1.13
p0.50	9.7 ± 1.2	8.6 ± 1.5	1.0	**0.31;1.73**
p0.90	17.6 ± 1.9	15.6 ± 1.9	2.0	**0.28;3.72**
ED (%MVE)				
p0.10	5.2 ± 1.0	4.8 ± 0.8	0.4	−0.62; 1.48
p0.50	8.7 ± 1.5	7.4 ± 1.3	1.4	**0.00;2.73**
p0.90	14.5 ± 2.4	11.0 ± 1.9	3.5	**0.95;6.08**
FCU (%MVE)				
p0.10	3.4 ± 0.6	3.0 ± 0.4	0.4	−0.05; 0.88
p0.50	6.1 ± 0.9	5.0 ± 0.7	1.0	**0.38;1.73**
p0.90	10.5 ± 1.7	8.2 ± 1.1	2.4	**0.87;3.86**
TRAP (%MVE)				
p0.10	3.9 ± 1.7	5.0 ± 1.9	−1.1	−2.71; 0.54
p0.50	5.7 ± 2.4	6.8 ± 2.5	−1.0	−3.06; 0.98
p0.90	8.1 ± 3.2	9.1 ± 3.3	−1.1	−3.72; 1.59

APB = abductor pollucis brevis; APL = abductor pollicis longus; ED = extensor digitorum;
FCU = flexor carpi ulnaris; TRAP = trapezius; %MVE = maximal voluntary electrical activity;
p0.10, p0.50 and p0.90 = 10th, 50th and 90th percentile; Diff = difference;
95% CI = 95% confidence interval.

in perceived exertion were 0 in all body regions except for Q1 for the shoulder (1 scale step higher for the touchscreen phone) and Q3 for the thumb (1 scale step higher for keypad phone) and the hand (0.5 scale step higher for keypad phone).

A majority of the participants (17–19 participants) rated the discomfort as low (0–3 on the 0–10 scale) in all body regions for both phones. The median, 1st quartile (Q1), and 3rd quartile (Q3) of the differences in perceived discomfort were 0 in all body regions except for Q3 for the forearm (0.5 scale step higher for the touchscreen phone).

3.4. Performance

The total number of produced characters per minute was significantly higher (z-score = −3.1; p = 0.002) and the total number of correct typed characters per minute was higher though not statistically significant (z-score = −1.9; p = 0.054) when texting on the touchscreen phone (group mean 90 characters per minute, range 34; 139) compared to the total number of correct typed characters per minute when texting on the keypad phone (group mean 79 characters per minute, range 47; 128).

The proportion of correct characters was higher (z-score = −3.6; p value < 0.001) when texting on the keypad phone (96.1%, range 91.6; 99.6) compared with the touchscreen phone (89.0%, range 74.5; 96.9). Sixteen out of nineteen participants had higher proportion of correct characters when texting on the keypad phone compared with the touchscreen phone.

4. Discussion

This is the first study that has compared both thumb kinematics and upper limb muscle activity during texting with a touchscreen smartphone and a keypad smartphone. The influence of hand size on the kinematics and the muscle activity was also examined, along with phone differences in perceived exertion and discomfort and performance. Differences were found in both kinematics and muscle activity when texting on a touchscreen phone compared to a keypad phone, and hand size was shown to influence some of these differences. Perceived exertion and discomfort when texting on the two phones did not differ. However, differences in performance were found.

4.1. Thumb kinematics

The touchscreen phone required smaller thumb movements in flexion and in internal rotation compared with the keypad phone. This is likely the result of differences in key activation mechanisms. Pushing the keypad keys might require or at least stimulate a larger force and therefore larger movements may be used to create this force compared with the touchscreen phone where you achieve a keystroke with only a light touch. Furthermore, when texting on a phone the tapping with the thumb can be done with different areas of the fingertip e.g. the upper middle or the upper medial area of the fingertip, the pad of the finger or the nail, which likely influence the thumb position. It is likely that different parts of the fingertip are used when texting on a touchscreen phone compared with a keypad phone due to the different key activation mechanism. Non-neutral positions of the joints have been identified as a risk for developing musculoskeletal disorders (Schoenmarklin et al., 1994).

The differences in median flexion with smaller flexion when texting on the touchscreen phone was found only in the group with short hands and not in the group with long hands. It is possible that different hand lengths influence which area of the fingertip that are used. Further studies examining kinetic measures should accurately assess the influence of used fingertip area and hand length.

4.2. Muscle activity

The muscle activity in the thumb and forearm was consistently

Table 5
Differences in muscle activity between the groups with short hands (≤18 cm) and long hands (≥18.5 cm) when texting with a keypad phone (key) and a touchscreen phone (touch). Mean in %MVE and standard error are given. Statistically significant results are presented in bold.

Muscle		Short hands			95% CI	Long hands			95% CI
		Key	Touch	Diff		Key	Touch	Diff	
APB (%MVE)									
	p0.10	1.6 ± 1.2	1.0 ± 0.8	0.6	−0.70; 1.82	4.9 ± 1.2	2.7 ± 0.7	2.2	**1.02;3.40**
	p0.50	7.2 ± 2.1	5.5 ± 1.5	1.6	−1.10; 4.41	11.4 ± 2.0	7.2 ± 1.4	4.1	**1.54;6.74**
	p0.90	23.3 ± 4.4	21.7 ± 4.0	1.6	−3.46; 6.64	24.9 ± 4.4	18.4 ± 4.0	6.5	**1.44;11.54**
APL (%MVE)									
	p0.10	5.4 ± 1.3	5.1 ± 1.1	0.4	−0.75; 1.46	4.6 ± 1.1	4.1 ± 0.9	0.5	−0.45; 1.43
	p0.50	9.9 ± 2.0	9.1 ± 1.8	0.7	−0.39; 1.84	9.5 ± 1.7	8.3 ± 1.5	1.2	**0.28;2.19**
	p0.90	16.1 ± 2.9	15.4 ± 3.0	0.6	−1.96; 3.19	18.8 ± 2.5	15.8 ± 2.6	3.0	**0.81;5.20**
ED (%MVE)									
	p0.10	5.1 ± 1.7	5.0 ± 1.4	0.1	−1.61; 1.86	5.3 ± 1.4	4.6 ± 1.1	0.6	−0.75; 2.01
	p0.50	8.0 ± 2.5	7.4 ± 2.2	0.7	−1.52; 2.93	9.2 ± 2.0	7.4 ± 1.7	1.8	**0.002;3.56**
	p0.90	12.3 ± 4.0	10.9 ± 3.2	1.4	−2.64; 5.37	15.9 ± 3.2	11.0 ± 2.5	4.9	**1.69;8.07**
FCU (%MVE)									
	p0.10	3.2 ± 0.9	2.9 ± 0.7	0.4	−0.39; 1.10	3.6 ± 0.7	3.2 ± 0.6	0.4	−0.18; 1.09
	p0.50	5.3 ± 1.4	4.4 ± 1.1	0.9	−0.15; 1.98	6.6 ± 1.2	5.5 ± 0.9	1.2	**0.26;2.07**
	p0.90	8.3 ± 2.6	6.6 ± 1.7	1.6	−0.72; 3.94	12.2 ± 2.2	9.2 ± 1.4	2.9	**0.93;4.90**

APB = abductor pollucis brevis; APL = abductor pollicis longus; ED = extensor digitorum; FCU = flexor carpi ulnaris; TRAP = trapezius; p0.10, p0.50 and p0.90 = 10th, 50th and 90th percentile; %MVE = maximal voluntary electrical activity; Diff = difference;
95% CI = 95% confidence interval.

lower when texting on the touchscreen phone compared with the keypad phone. This is in accordance with the previous study by Kietrys et al. (2015), which found lower mean muscle activity in the thumb muscle abductor pollicis brevis, the finger flexor muscle flexor digitorum superficialis, and the wrist extensor muscle extensor carpi radialis when using a touchscreen phone compared with a physical keypad phone. It is likely that the differences in muscle activity in the thumb and forearm when texting on the two phones were mainly due to the different key activation mechanism and key activation force.

Previous studies have shown associations between key activation force and muscle activity in both traditional computer input devices and touchscreen interfaces (Kim et al., 2014; Lee et al., 2009; Radwin and Ruffalo, 1999; Rempel et al., 1999). Although texting on a smartphone requires only low levels of muscle activity, it has been concluded that no safe lower limit of prolonged periods of muscular load exists (Westgaard and Winkel, 1996).

This study found that it was the group with long hands that had lower muscle activity when texting on the touchscreen phone compared with the keypad phone. When texting on a mobile phone using a single-hand grip and activating the keys with the thumb, the phone is usually held with the four ulnar fingers behind the phone and the nearest bottom corner of the phone in the palm. The participants with longer hands may held the phone further from the thumb base and more with the four ulnar fingers compared with the users with shorter hands. This may have resulted in a less steady grip, which may require counterbalancing muscle activity, i.e. an increase in activity of muscles required to grip the phone and oppose the key activation force, especially when using a physical keypad phone with larger key activation force. (Johanson et al., 2001; van Oudenaarde et al., 1997). However, since this study measured only the angles and not the exact position of the thumb base, further studies examining differences in the exact position of the thumb base between users with shorter and longer hands are required to confirm this theory.

Unlike the lower muscle activity in the thumb and forearm, there was a trend of higher muscle activity in the trapezius muscle when texting on the touchscreen phone compared with the keypad phone, though these differences were not statistically significant. This may be related to differences in tactile feedback and visual demands. Since the touchscreen phone do not provide tactile feedback (Hoggen et al., 2008), the users may either lift the phone or bend their head forward in order to get visual feedback which may result in a higher muscle activity in the trapezius muscle (Ko et al., 2016; Lee et al., 2015; Straker et al., 2008a).

4.3. Perceived exertion and discomfort

In the present study, no statistically significant differences were found in rated perceived exertion or discomfort when texting on the two phones.

4.4. Performance

A statistically significant larger amount of typed text was produced when texting on the touchscreen phone compared with the keypad phone. After adjustment for erroneously typed characters, the statistical significance of the difference disappeared, though there was still a larger amount of typed text for the touchscreen phone.

Best performance has previously been found when the thumb was in a more neutral posture (Park and Han, 2010). This could partly explain the higher text production with the touchscreen phone in the current study as the thumb position was closer to neutral during touchscreen use. However, the proportion of correct written characters was higher when texting on the keypad phone. This may be due to the tactile feedback helping to identify the location of the physical keys prior to activation of the keys. This differs from the touchscreen phone interface, which provides no tactile key location feedback and a keystroke can be achieved with only a light touch. A previous study has shown that additional tactile feedback on key activation for mobile touchscreens can improve the text entry (Hoggen et al., 2008), although this does not aid key identification. Thus, keypad phones are likely to have performance advantages in perturbing environments such as in a vehicle travelling over rough roads or in airplanes in turbulence.

4.5. Limitations

The phones were as similar as possible with available common commercial equipment and very comparable in overall size, weight, and key size. However, the key locations on the keypad phone were slightly further down the face of the phone, i.e. closer to the bottom of the phone, which may have affected the findings of our study. However, the differences in key location were quite small which make it easy for users to compensate for this difference with a small change of grip so that the phone sits a little bit higher in the hand in order to have the keys within a comfortable reach for the thumb.

The instruction to the participants was to hold the phone in a one-hand grip and use the tapping technique they usually did. Grip posture or individual tapping technique was not evaluated. These factors likely influence thumb kinematics and muscle activity in the hand and forearm and could provide further valuable information for a better understanding of mechanisms of musculoskeletal symptom development during texting. Thumb movements are complex with the three thumb joints involved in the movements to different extents and we are fully aware of the difficulty in measuring these movements. Surface electrodes were used to register the muscle activity, which mean the study was limited to examining only superficial muscles. Nevertheless, the muscles in this study were chosen because of their involvement in thumb movements and handgrip, and other studies have shown that they provide a good representation of the muscular load when texting on a mobile phone (Gustafsson et al., 2010; Jonsson et al., 2011).

A limitation of this study is that only the angles of the thumb but not the exact position of the thumb base was measured. This could have explained the differences in thumb kinematics and muscle activity between the short and long hand groups.

The markers used in the study (9 mm for the hand and forearm, 5 mm for the thumb) are standard for the Vicon system which is a widely used and well developed motion analysis system. Prior studies have shown that increased marker size generally enhances the accuracy of marker detection (9.5 mm up to 25 mm studied), however the differences within this large size range when using optimal camera setting were less than 1 mm (Windolf et al., 2008). In the current study, smaller markers were used on the smaller segments (thumb) so that they did not interfere with thumb movements or screen vision. Thus, the marker sizes used represent a best compromise for the purposes of this study.

No differences were found in rated perceived exertion or discomfort when texting on the two phones. This may possibly be due to the short texting time and a longer period of texting may have given other results.

Familiarity with one of the two different phone design may have influenced the results. A majority of the participants were currently using a touchscreen phone. However, all of them had owned and used a keypad phone within the last 12 months. Moreover, all participants that currently were using a keypad phone had experience using a touchscreen phone. Furthermore, prior to application of the measuring equipment the participants were offered a 5 min training session with the phone that was not their current phone type and a short practice session prior to each texting task with both phones.

4.6. Implications

Smartphone users who prefer high texting speed should consider choosing a touchscreen phone. However, users who require high accuracy with written text may have more accurate texting if they choose a keypad phone. Further, keypad phones may enable better use in difficult environmental conditions such as rain and rough transport.

Implications for smartphone users include the need to select a phone which fits their hand size, especially if they intend doing intensive text entering. Smartphone users and designers should be aware that hand size influences thumb kinematics and muscle activity and thus manufacturers should consider offering phones in different sizes to suit the range of user hand sizes. Indeed many smartphone manufactures now offer smartphones in different sizes.

Moreover, manufacturers of new smartphones should carefully consider key location, key activation mechanism, and key tactile feedback design as these features probably affect the thumb kinematics and muscle activity when texting. These implications for designers and manufacturers are irrespective of whether the interaction is via keypad or touchscreen.

4.7. Conclusions

Texting on a touchscreen phone compared with a keypad phone resulted in smaller thumb movements and lower muscle activity in the thumb and forearm. For thumb kinematics, the effect of different phones was found in those with short hands while for muscle activity in the thumb and forearm, the effect was found in those with long hands. No effects of different phones on exertion or discomfort were identified during the brief trials. However, texting on the touchscreen phone resulted in a lower proportion of correct typed characters.

The observed differences in kinematics and muscle activity suggest that there are differences in risks for developing musculoskeletal disorders during smartphone use with different key activation mechanisms, and different hand sizes. The principles underlying this potential for increased risk and the performance differences need to be understood to support appropriate design and use of smartphones in the future.

Acknowledgments

The study was financially supported by the Swedish Research Council for Health, Working Life and Welfare. The authors would like to thank the participants in this study, Paul Davey for all valuable help with the data processing program, and Adnan Noor for valuable help with the statistics.

References

Borg, G., 1990. Psychophysical scaling with applications in physical work and the perception of exertion. Scand. J. Work. Environ. Health 16 (Suppl. 1), 55–58.
Briggs, A., Straker, L., Greig, A., 2004. Upper quadrant postural changes of school children in response to interaction with different information technologies. Ergonomics 47 (7), 790–819.
Chany, A.M., Marras, W.S., Burr, D.L., 2007. The effect of phone design on upper extremity discomfort and muscle fatigue. Hum. Factors 49 (4), 602–618.
Coleman J., 2015. Personal communication.
Eapen, C., Kumar, B., Bhat, A.K., Venugopal, A., 2014. Extensor pollicis longus injury in addition to de Quervain's with text messaging on mobile phones. J. Clin. Diagn. Res. 8 (11), LC01–LC04.
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. Appl. Ergon. 43 (2), 408–412.
Gold, J.E., Kandadai, V., Hanlon, A., 2009. Text Messaging and Upper Extremity Symptoms in College Students. American Public Health Association, Philadelphia, PA.
Gonsalves, L., Campbell, A., Jensen, L., Straker, L., 2015. Children with developmental coordination disorder play active virtual reality games differently than children with typical development. Phys. Ther. 95 (3), 360–368.
Greene, W.B., Heckman, J.D., 1994. The Clinical Measurement of Joint Motion. American Academy of Orthopaedic Surgeons, Rosemont, IL.
Gustafsson, E., Hagberg, M., 2003. Computer mouse use in two different hand positions: exposure, comfort, exertion and productivity. Appl. Ergon. 34 (2), 107–113.
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. J. Electromyogr. Kinesiol. 20, 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.
Gustafsson, E., Thomee, S., Grimby-Ekman, A., Hagberg, M., 2017. Texting on mobile phones and musculoskeletal disorders in young adults: a five-year cohort study. Appl. Ergon. 58, 208–214.
Hoggen, E., Brewster, S.A., Johnston, J., 2008. Investigating the Effectiveness of Tactile Feedback for Mobile Touchscreens. CHI 2008-Tactile and Haptic User Interfaces, Florence, Italy.
Johanson, M.E., Valero-Cuevas, F.J., Hentz, V.R., 2001. Activation patterns of the thumb muscles during stable and unstable pinch tasks. J. Hand Surg. Am., Jul. 26 (4), 698–705.
Johnson, J.D., Gaspar, M.P., Shin, E.K., 2016. Stenosing tenosynovitit due to excessive texting in an adolescent girl: a case report. J. Hand Microsurg. 8, 45–48.
Jonsson, P., Johnson, P.W., Hagberg, M., Forsman, M., 2011. Thumb joint movement and muscular activity during mobile phone texting - a methodological study. J. Electromyogr. Kinesiol. 21 (2), 363–370.
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. Appl. Ergon. 50, 98–104.
Kim, J.H., Aulck, L., Bartha, M.C., Harper, C.A., Johnson, P.W., 2014. Differences in typing forces, muscle activity, comfort, and typing performance among virtual,

notebook, and desktop keyboards. Appl. Ergon. 45 (6), 1406–1413.
Ko, P.H., Hwang, Y.H., Liang, H.W., 2016. Influence of smartphone use styles on typing performance and biomechanical exposure. Ergonomics 59 (6), 821–828.
Lee, D.L., Kuo, P.L., Jindrich, D.L., Dennerlein, J.T., 2009. Computer keyswitch force-displacement characteristics affect muscle activity patterns during index finger tapping. J. Electromyogr. Kinesiol. 19 (5), 810–820.
Lee, S., Kang, H., Shin, G., 2015. Head flexion angle while using a smartphone. Ergonomics 58 (2), 220–226.
Mackay, M.M., 2014. Australian Mobile Phone Lifestyle Index, tenth ed. AIMA – The Digital Industry Association of Australia December 2014.
Mathiassen, S., Winkel, J., Hagg, G., 1995. Normalization of surface EMG amplitude from the upper trapezius muscle in ergonomic studies - a review. J. Electromyogr. Kinesiol. 5 (4), 197–226.
Ming, Z., Pietikainen, S., Hanninen, O., 2006. Excessive texting in pathophysiology of first carpometacarpal joint arthritis. Pathophysiology 13 (4), 269–270.
Nordicom, Nordicom, 2017. The Swedish Media Barometer 2016. Nordic Information Centre for Media and Communication Research, University of Gothenburg, Sweden.
Oude Hengel, K.M., Houwink, A., Odell, D., van Dieen, J.H., Dennerlein, J.T., 2008. Smaller external notebook mice have different effects on posture and muscle activity. Clin. Biomech. (Bristol, Avon) 23 (6), 727–734.
Park, S.Y., Han, S.H., 2010. Touch key design for one-handed thumb interaction with a mobile phone: effects of touch key size and touch key location. Int. J. Ind. Ergon. 40, 68–76.
Perotto, A., 1994. Anatomical Guide for the Electromyographer: The Limbs and Trunk. Charles C Thomas, Springfield, IL.
Radwin, R.G., Ruffalo, B.A., 1999. Computer key switch force-displacement characteristics and short-term effects on localized fatigue. Ergonomics 42 (1), 160–170.
Rempel, D., Barr, A., Brafman, D., Young, E., 2007. The effect of six keyboard designs on wrist and forearm postures. Appl. Ergon. 38 (3), 293–298.
Rempel, D., Tittiranonda, P., Burastero, S., Hudes, M., So, Y., 1999. Effect of keyboard keyswitch design on hand pain. J. Occup. Environ. Med. 41 (2), 111–119.
Schoenmarklin, R.W., Marras, W.S., Leurgans, S.E., 1994. Rapid Communication Industrial wrist motions and incidence of hand/wrist cumulative trauma disorders. Ergonomics 37 (9), 1449–1459.
Storr EF, d.V.B.F., Stringer, M.D., 2007. Texting tenosynovitis. N. Z. Med. J. 120 (1267).
Straker, L., Burgess-Limerick, R., Pollock, C., Coleman, J., Skoss, R., Maslen, B., 2008a. Children's posture and muscle activity at different computer display heights and during paper information technology use. Hum. Factors 50 (1), 49–61.
Straker, L., Pollock, C., Burgess-Limerick, R., Skoss, R., Coleman, J., 2008b. The impact of computer display height and desk design on muscle activity during information technology work by young adults. J. Electromyogr. Kinesiol. 18 (4), 606–617.
van Oudenaarde, E., Brandsma, J.W., Oostendorp, R.A., 1997. The influence of forearm, hand and thumb positions on extensor carpi ulnaris and abductor pollicis longus activity. Acta Anat. (Basel) 158 (4), 296–302.
Westgaard, R.H., Winkel, J., 1996. Guidelines for occupational musculoskeletal load as a basis for intervention: a critical review. Appl. Ergon. 27 (2), 79–88.
Williams, I.W., Kennedy, B.S., 2011. Texting tendinitis in a teenager. J. Fam. Pract. 60 (2), 66–68.
Windolf, M., Gotzen, N., Morlock, M., 2008. Systematic accuracy and precision analysis of video motion capturing systems–exemplified on the Vicon-460 system. J. Biomech. 41 (12), 2776–2780.
Woltering, H.J., 1986. A fortran package for generalized, cross-validatory spline smoothing and differentiation. Adv. Eng. Software 8 (2), 104–113.
Xiong, J., Muraki, S., 2014. An ergonomics study of thumb movements on smartphone touch screen. Ergonomics 57 (6), 943–955.