Relationship Between Operability in Touch Actions and Smartphone Size Based on Muscular Load

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Abstract. The objective of this study was to examine the changes in muscular loads of the forearm/hand areas and in the subjective responses associated with operability and discomfort levels when participants performed touch action on different sizes of smartphones. In the experiment, finger motions and electromyograms (EMGs) of three muscles were recorded during reciprocal tapping tasks with the smartphones while participants were in the seated position. Three sizes of smartphones as well as one with a small soft keyboard for minimizing dynamic thumb motions as an intervention were provided. The data showed that muscular loads on the thumb abduction and flexion of the proximal interphalangeal joints of the finger were affected by the size of the smartphone used. A large smartphone with the keyboard intervention successfully reduced the muscular load for abduction of the thumb and, as a second-order effect, the force for holding the smartphone by using finger flexors. The subjective ratings of difficulty in touch action were significantly affected by the size of smartphone, and the subjective ratings of difficulty in gripping the smartphone were also affected by the size of smartphone. The results implied that both input method for reducing the amount of thumb abduction and key layout for reducing reach by the thumb are recommended to reduce the muscular loads for operating large smartphones.

Keywords: Touch action · Smartphone · Operability · Musculoskeletal disorders

1 Introduction

The recent development of mobile phones with touch displays, including smartphones, has led to an increase in incident cases of musculoskeletal disorders (MSDs). Many studies have focused on the relationship between the use of mobile phones and the factors associated with MSDs. Gustafsson, et al. [1] used electromyography to compare thumb postures and physical loads in relation to mobile phone tasks (such as texting messages), gender, and history of musculoskeletal symptoms. They found that participants with musculoskeletal symptoms had different behavior patterns which

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emphasize lower muscle activity levels for thumb abduction and for fast thumb motions with fewer pauses. Berolo, et al. [2] evaluated the use of mobile phones and its association with the subjective pains of the upper extremity, upper back, and neck. They concluded that the association between the use of hand-held devices and musculoskeletal symptoms raised concern over the intensive use of such devices. These results suggested that the use of mobile phones was related to the potential risk of MSDs.

Under the current development of smartphones, the design of smartphones has become diversified, including the popularity of large-size displays. When the size of the display becomes large, the display area being operated by the thumb needs to be increased. This use of the thumb results in unstable grasping of the device. The emergence of these adverse effects may prompt an increase in the risk of MSDs. Kietrys et al. [3] reported the risk of MSDs accompanied by the growing size of touch-screen devices by monitoring muscular activities by using electromyography for thumb motions and static loads for gripping. They compared a variety of devices, including physical keypad devices and touch screen devices with sizes ranging from 3.5 to 9.5 inches, and found a trend toward high finger flexor, wrist extensor, and trapezius muscle activities when participants used both hands on a device with a large display area. Their results are convincing that it would be important to investigate the effect of smartphone size on operability based on the muscular load when participants use only one hand, which is now the typical operation by smartphone users.

Therefore, the objective of this study was to empirically investigate the changes in muscular loads and in subjective responses associated with operability and discomfort levels of participants when they used different sizes of smartphones.

2 Methods

2.1 Participants

We conducted a laboratory study in which five right handed male subjects, whose ages ranged from 20 to 22 years, participated in the study. Based on the interview, all of the participants regularly used smartphones to send/check SMS messages or to play social games. Their corrected visions were better than 20/30. Each participant gave a written informed consent prior to beginning the study. No history of or symptoms associated with musculoskeletal pains in the upper extremity or the neck were reported at the time of the interview.

2.2 Experimental Apparatus

Figure 1 shows the setup for the experiment. Finger motions were recorded by high speed video camera (HAS-L1, DITECT) with a microzoom unit (JF17095 M, SPACECOM). Muscle activity was measured with a bioamplifier (BA1104 m EMG, Nihon Santeku, low-pass frequency of 1000 Hz, TC: 0.03 s). These signals were synchronized with a sampling rate of 100 Hz at the data logger (GL900, GRAPHTEC). Three types of smartphones were used. Table 1 summarizes the properties of the smartphones and includes their dimensions and weights. In addition to the three smartphones, a large smartphone with a modified soft keyboard (Type Large2) was also tested. The dimensions of the Large2 as compared to the Large are shown in Fig. 2. The size of the soft keyboard in Large2 was as the same as that in the Small condition. The new size of the keyboard was designed to see the effect of redesigning the size of the keyboard.

Table 1. Dimension of the smartphones used in the experiment

Condition	Dimension	Weight
Small (iPhone5S, Apple)	H 123.8 mm W 58.6 mm T 7.6 mm	112 g
Medium (iPhone6, Apple)	H 138.1 mm W 67.0 mm T 6.9 mm	129 g
Large (iPhone6plus, Apple)	H 158.1 mm W 77.8 mm T 7.1 mm	179 g
Large2 (iPhone6plus, Apple) with modification of soft keyboard size 74 %)	H 158.1 mm W 77.8 mm T 7.1 mm	179 g

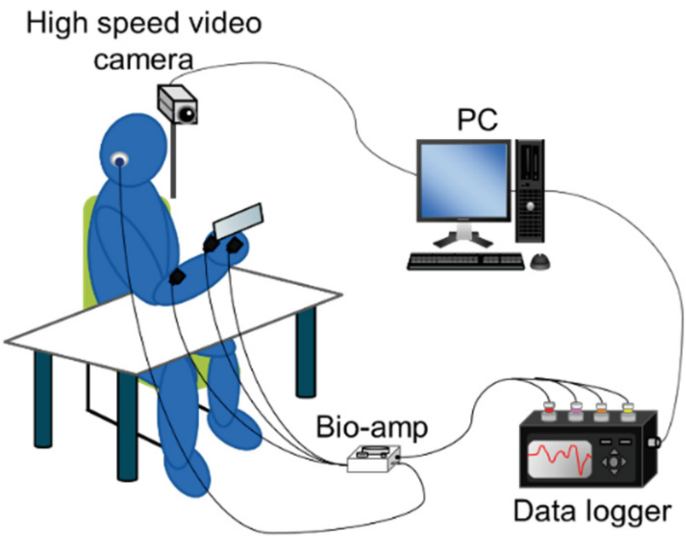

Fig. 1. Experimental setup

2.3 Experimental Protocol

Participants performed reciprocal tapping tasks with smartphones while participants were in the seated position. They used their right hand to hold the smartphone and used their right thumb for the task. They rested their right elbows on a table during the task.

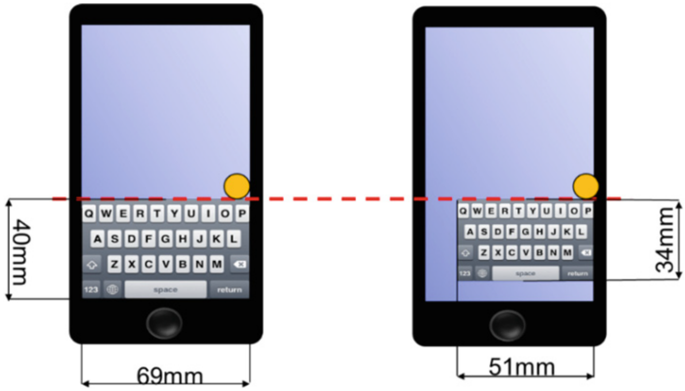

Fig. 2. Smartphones with modification of soft keyboard size. Left: Large condition and Right: large 2 condition, in which the size of large condition was used with modification where the soft keyboard was set to confine the area for the thumb motion.

A total of nine characters (‘q’, ‘t’, ‘p’, ‘a’, ‘g’, ‘l’, shift key, ‘v’, and backspace keys) were selected for the task and were entered with a QWERTY soft keyboard with tap-based touch action. A yellow marker was attached to the surface of the smartphone (see Fig. 3) to define the default position, and participants were asked to enter the characters three times, in reciprocating motions, by starting from the default position each time.

The muscular loads in three muscles in the right forearm/hand areas were registered by electromyography. Table 2 summarizes the muscles and their roles associated with the musculoskeletal motions used in this study. After the task was completed, participants

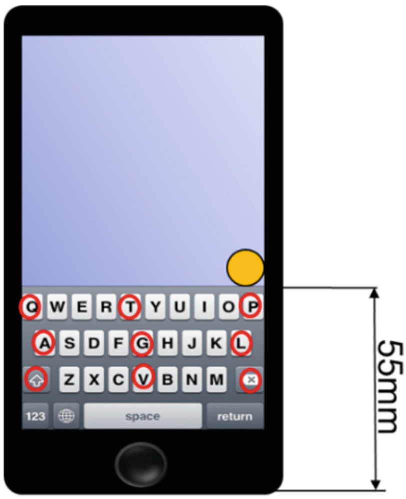

Fig. 3. Smartphone showing the default position (yellow marker) and the keys used for the task (marked in red circles) (Color figure online)

Table 2. Muscles and their functions used in the study

Muscle	Motion
Abductor pollicis brevis (APB)	Abduction of the thumb
Flexor digitorum superficialis (FDS)	Flexion of the PIP joints of fingers
First dorsal interosseous (FDIM)	Abduction/flexion of MP joint of the index finger

were asked to fill out the subjective evaluation form, where they reported the operability, the ease of holding the smartphone, and the level of fatigue suffered from the task on the Likert scale of one to five.

2.4 Data Analysis

For the analysis of electromyogram (EMG)data, band-pass filtering between 5 Hz and 300 Hz was used, followed by root mean square processing, as described by Gustafsson, et al. [1]. The EMG signals during the task were then normalized by the EMG data for standardized contraction protocol, where participants were asked to perform a 5-s maximum contraction. The normalized EMG signal (%maximum voluntary contraction (%MVC)) was assigned to represent the muscular load for each touch action on the display. The onset of touch action was set to the time the thumb started motion from the yellow marker, and the offset of touch action was set to the time the thumb landed on the designated character. Segmentations of videotaped motions were completed manually. A repeated measures analysis of variance was performed on the %MVC and on the subjective ratings for the size of smartphone. P-values less than 0.05 were considered statistically significant, and a post hoc Tukey's significant difference test was applied to determine if differences existed between the measures collected for each size of smartphone.

3 Results and Discussion

3.1 Relationship Between Size of Smartphone and the Muscular Load

Figure 4 shows changes in the muscular load by the size of the smartphone. The muscular loads on two measured muscles were affected by the size of the smartphone ($F (3, 176) = 7.44$, $p < .01$ for FDS, $F (3, 176) = 3.82$, $p < .05$ for APB). However, the muscular loads on the FDIM were not affected by the size of the smartphone ($F (3, 176) = 1.72$, NS). For FDS, the muscular load during the task using the Large smartphone was higher than when using the other smartphones, including the Large2 smartphone. For APB, the result was slightly different: The muscular load during the task using the Large smartphone was marginally significantly higher than when using the Small smartphone, and it was significantly higher than when using the Large2 smartphone. The result apparently indicated that a large smartphone with an intervention to confine the area to be operated by the thumb motions indeed successfully reduced the muscular load for abduction of the thumb and, as a second order effect, reduced the force for holding the smartphone using finger flexors.

Among the three muscles, the muscular load for APB was high, ranging from 20 to 45 % MVC and also showed large differences in the muscular load between the Large and the Large2 smartphone conditions. On the other hand, the muscular load for FDIM was relatively low, and the differences between conditions were small, from 5 % to 10 % MVC. The muscular loads obtained in this study were relatively higher than in the previous study [3] using touch devices with 3.5 to 9.5 inch displays with both hands, with that study showing 8.9 to 26.2 % MVC for APB and 5.9 to 19.4 % MVC for FDS. The relatively high muscular load in this study may come from the task of performing two functions with one hand, i.e., participants had to move the thumb while securely grasping the smartphone at the same time. Especially high muscular load for APB during touch operation was also observed by Xiong and Muraki [4], who compared two sizes of buttons on a smartphone touch screen and concluded that the muscular load for touching the keys by the thumb was due to the increase of the thenar eminence grip. Their results showed that a significant decrease of APB during touching of small keys required less thenar eminent grip. This is consistent with our study, in which participants performed tasks with the Large2 condition which required touch action with a relatively upright thumb posture.

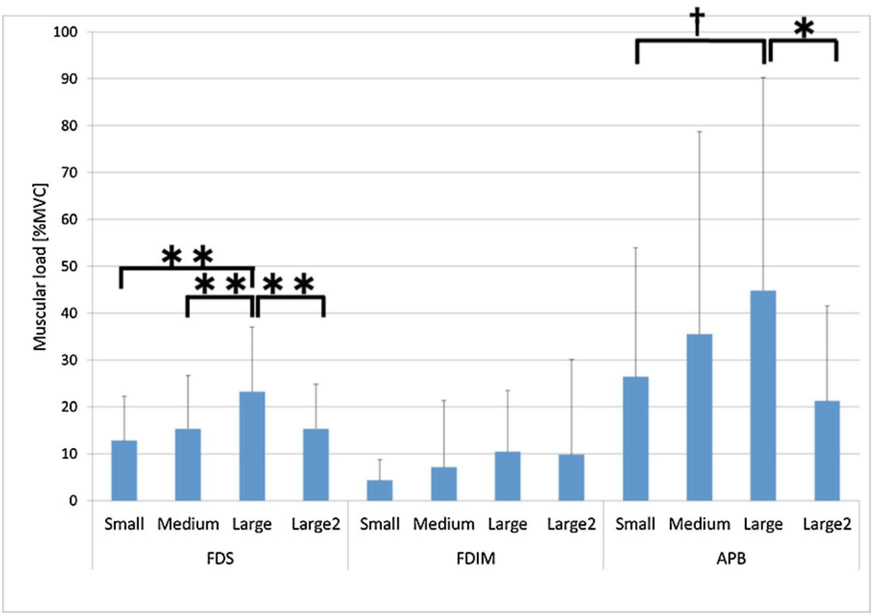

Fig. 4. Changes in muscular load by the size of smartphone. FDS: flexor digitorum superficialis, FDIM: first dorsal interosseous, APB: Abductor pollicis brevis. **: $p < .01$, *: $p < .05$, †: $p < .1$.

3.2 Relationship Between Size of Smartphone and the Subjective Ratings

Figure 5 shows changes in subjective ratings by the size of the smartphone. Subjective ratings of difficulty in touch action were significantly affected by the size of the smartphone ($F(3, 16) = 5.68$, $p < .01$), and subjective ratings of difficulty in gripping the smartphone were also affected by the size of the smartphone ($F(3, 16) = 10.08$, $p < .01$). For both ratings, touch action with a large smartphone showed the highest difficulty ratings. There were no significant differences between the ratings obtained for small and medium smartphones. Although the EMG difference was apparent between the Large and the Large2 conditions, differences in subjective ratings were not present.

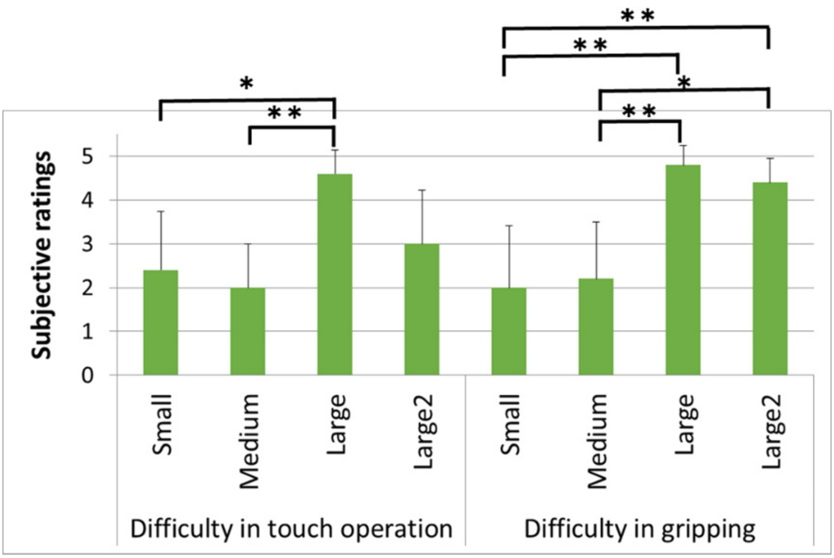

Fig. 5. Changes in subjective ratings by the size of smartphone. **: $p < .01$, *: $p < .05$,

4 Conclusion

In this study, both the muscles associated with gripping the smartphones and the muscles for thumb abduction were affected by the size of the smartphones. High muscular loads measured in participants using a large smartphone were reduced by modifying the size of the soft keyboard on the display to confine the area for thumb motion. Overall, the results implied that input methods to reduce the amount of thumb abduction and key layouts to reduce thumb reach are recommended to reduce the muscular loads for operating large smartphones.

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