Applied Ergonomics 60 (2017) 282–292

Contents lists available at ScienceDirect

Applied Ergonomics

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

Effects of button position on a soft keyboard: Muscle activity, touch time, and discomfort in two-thumb text entry

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A R T I C L E I N F O

Article history:
Received 17 April 2016
Received in revised form
12 December 2016
Accepted 16 December 2016

Keywords:
Soft keyboard
Two-thumb input
Smartphone

A B S T R A C T

Intensive use of the thumbs for text entry on smartphones may contribute to discomfort, pain, or musculoskeletal disorders. This study investigated the effect of twenty-five button positions (5 rows × 5 columns) on a soft keyboard for two-thumb entry. Two experiments measured muscle activity, touch time, and discomfort as a function of the button positions. In Phase I, the muscle activities of two intrinsic (abductor pollicis brevis and first dorsal interossei) and two extrinsic (abductor pollicis longus and extensor digitorum communis) muscles associated with thumb motions were observed for ten college students (age: 24.2). In Phase II, touch time and discomfort were measured for 40 college students (age: 23.6). The results demonstrated that the %MVCs of the intrinsic muscles significantly increased when the thumbs flexed and abducted. Also, the button positions near the rest positions of the thumbs resulted in significantly shorter touch times (0.66 s) and lower discomfort ratings (0.70 pt) than their peripheral buttons (0.76 s; 2.29 pt).

1. Introduction

Frequency of text entry on mobile phones has been increasing with the popularity of mobile networks and messaging services. eMarketer (2015) reported that more than 1.4 billion consumers used mobile phone messaging apps worldwide in 2015, which indicated that 75% of smartphone users used mobile phone messaging apps. Furthermore, it was informed that approximately half of emails were opened on mobile phones (Jordan, 2015) and 52.7% of mobile phone users accessed the internet through their smartphones (Statista, 2016). These statistics imply that text entry on smartphones has become an important communication tool worldwide (Hsiao et al., 2014; Xiong and Muraki, 2014; Park et al., 2015).

A soft keyboard (or on-screen keyboard) is widely adapted for text entry on smartphones. A soft keyboard is a graphical keyboard displayed on a touch-screen instead of a conventional hard keyboard (Kim et al., 2014; Ryu et al., 2013; Yin and Su, 2011). This soft keyboard can be hidden when a user wants to utilize a full screen in mobile apps and appear spontaneously when text entry is needed (Lee and Zhai, 2009). In addition, the layout of a soft keyboard can be modified according to users' preferences, which improves its usability and the user experience. However, intensive and excessive use of the thumbs while texting may induce discomfort, pain, or musculoskeletal disorders on the thumbs and upper extremities (Berolo et al., 2011; Korpinen and Paakkonen, 2010).

Two representative soft keyboards (a telephone keyboard and a QWERTY keyboard) have been popularly used for text entry on smartphones, but they have distinct pros and cons in terms of user experience. A telephone keyboard was inherited from a keypad employed on a traditional wired telephone, and it has been the de facto standard for mobile phones (Silfverberg et al., 2000). Since the telephone keyboard consists of a fewer number of buttons ($n = 12$) than the number of alphabet letters ($n = 26$), two or more letters are assigned to each button; consequently, the telephone keyboard layout allows for relatively large buttons which enable users to find and press them easily. However, using a standard telephone keyboard is often inefficient because the arrangement of the letters is unfamiliar to users as well as multiple tapping is required to toggle between letters (Yin and Su, 2011). On the other hand, a QWERTY keyboard on smartphones employs a very similar layout to traditional QWERTY keyboards used for personal computers. It consists of the same number of buttons as the traditional QWERTY

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http://dx.doi.org/10.1016/j.apergo.2016.12.008
0003-6870/

keyboards, so users could feel more familiar with the keyboard because their prior knowledge can be transferred from personal computers to smartphones. However, the button sizes on the QWERTY keyboard are relatively small since more than 30 buttons are assigned to a small space. Therefore, using a QWERTY keyboard on smartphones is prone to cause unintentional touch errors and may require more precise touch interactions (Jung and Jang, 2015).

Many researchers have examined the effect of button positions on entire touch-screens of smartphones for single-handed mobile phone use; however, the results are limited in their direct application to soft keyboard designs. Park et al. (2008) and Kim et al. (2011) analyzed touch time and discomfort for buttons which were randomly displayed on an entire touch-screen. Park and Han (2010b) observed input accuracy and pressing patterns of the thumb as a function of different button positions. More recently, Trudeau et al. (2012a, 2012b) investigated kinematic thumb motions on different button positions using a 3D motion capture system. However, these studies may have limited impacts on the design of soft keyboards because the hand grip position to hold an entire touch-screen (called the *middle point grip*) is different from the grip position required to use the lower part of a touch-screen where soft keyboards are generally placed; therefore, corresponding thumb motions could have different patterns and performance.

A limited number of studies have investigated the effect of button positions on a soft keyboard (the lower part of touch-screen); however, they failed to examine a comprehensive effect of various button positions, which could be useful for designing soft keyboards. Jonsson et al. (2011) observed thumb movements and muscle activities during two-thumb text entry on a soft keyboard and found that the extensor digitorum communis (ED) and first dorsal interosseous (FDI) were associated with thumb movements. Choi and Jung (2013) investigated touch discomfort and muscle activity for various button positions (5×5) on a soft keyboard and found that buttons that were closer to the initial position of the thumb produced relatively lower discomfort and muscle activities. Xiong and Muraki (2014) also observed thumb motions for different button positions (2×2) on a soft keyboard and reported that the adduction-abduction movements of the thumb showed better motor performance than its flexion-extension movements. Although the aforementioned studies have scientifically investigated the effect of button positions by considering thumb text entry on soft keyboards, a comprehensive map of muscle activity, touch time, and discomfort for various button positions has not yet been provided for two-thumb text entry.

This study analyzed muscle activity, touch time, and discomfort as a function of various button positions on a soft keyboard for two-thumb text entry. Two research questions were tested: (1) buttons positions on a soft keyboard significantly affect muscle activities in two-thumb text entry and (2) buttons positions influence significantly to touch performance and discomfort. To test the two research questions, twenty-five buttons displayed on the lower part of a touch-screen were prepared by separating rows ($n = 5$) and columns ($n = 5$). In Phase I, Electromyography (EMG) was measured for 10 participants to observe the muscle activity of the thumb during a touch motion. In Phase II, touch time and discomfort were measured for 40 participants under the same experimental conditions. Lastly, EMG, touch time, and discomfort were statistically tested by the rows and columns of buttons.

2. Phase I – muscle activity

2.1. Method and materials

2.1.1. Participants

Ten college students who experienced smartphone-use (average 3.9 years) were recruited for this EMG experiment. They were all right-handed males with normal vision and their average age was 24.2 years (SD: 1.4). No participants reported any musculoskeletal pain or discomfort on their thumbs and upper limbs on the experiment day. They agreed with an informed consent form and were given a description of the study procedures.

2.1.2. Touch-screen device

A small touch-screen device (MiMo UM-720S, Mimo monitors, USA) was employed in the experiment. The resolution was 800×480 pixels. Its overall size and touch-screen size were 18 cm (height) $\times$ 12 cm (width) $\times$ 2.2 cm (thickness) and 15.2 cm (height) $\times$ 9.1 cm (width), respectively. The touch-screen device was linked to a desktop computer (OptiPlex 980, Dell, South Korea) in order to display and control an experimental screen on the touch-screen.

This study developed an experimental software (Fig. 1) using Visual Basic 6.0 (Microsoft, USA). An experimental screen was divided into two sections: (1) instruction section (upper) and (2) touch section (lower). The instruction section was designed to provide experimental instructions and help participants proceed the present experiment. The touch section consisted of 25 buttons (5 rows $\times$ 5 columns) and was used for text entry. The touch section was programmed to randomly display one target button among the 25 buttons at a time; then either the letter L (left thumb) or R (right thumb) appeared on the button after counting down numbers from 5 to 0 (pre-signal), which indicated a designated thumb work to use.

2.1.3. EMG measurement

EMG data were measured on the abductor pollicis brevis (APB), abductor pollicis longus (APL), first dorsal interossei (FDI), and extensor digitorum communis (ED) of both the hands and forearms

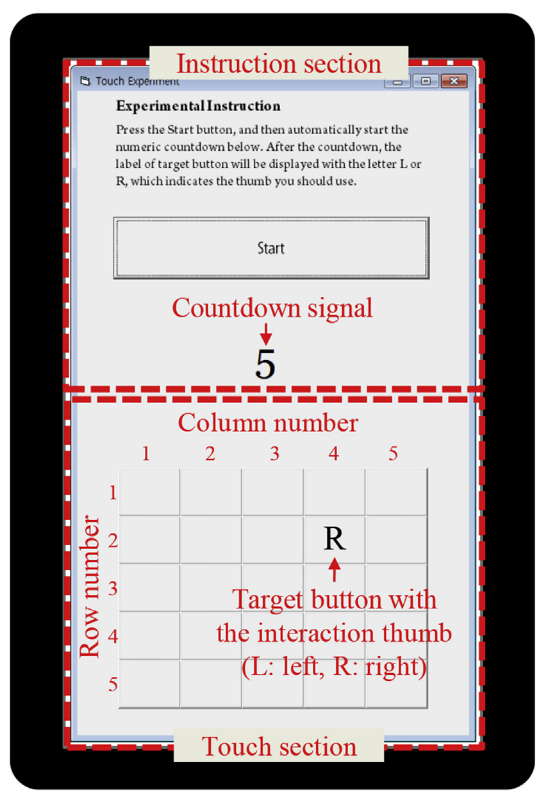

Fig. 1. An experimental screen used in the experiment.