Applied Ergonomics 69 (2018) 40–46

Contents lists available at ScienceDirect

Applied Ergonomics

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

Tablet form factors and swipe gesture designs affect thumb biomechanics and performance during two-handed use

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ARTICLE INFO

Keywords:
User interface design
Electromyography
Motion capture
Mobile computing

ABSTRACT

Tablet computers' hardware and software designs may affect upper extremity muscle activity and postures. This study investigated the hypothesis that forearm muscle activity as well as wrist and thumb postures differ during simple gestures across different tablet form factors and touchscreen locations. Sixteen adult (8 female, 8 male) participants completed 320 tablet gestures across four swipe locations, with various tablet sizes (8″ and 10"), tablet orientations (portrait and landscape), swipe orientations (vertical and horizontal), and swipe directions (medial and radial). Three-dimensional motion analysis and surface electromyography measured wrist and thumb postures and forearm muscle activity, respectively. Postures and muscle activity varied significantly across the four swipe locations ($p < .0001$). Overall, swipe location closest to the palm allowed users to swipe with a more neutral thumb and wrist posture and required less forearm muscle activity. Greater thumb extension and abduction along with greater wrist extension and ulnar deviation was required to reach the target as the target moved farther from the palm. Extensor Carpi Radialis, Extensor Carpi Ulnaris, Flexor Carpi Ulnaris, Extensor Policis Brevis, and Abductor Pollicis Longus muscle activity also increased significantly with greater thumb reach ($p < 001$). Larger tablet size induced greater Extensor Carpi Radialis, Extensor Carpi Ulnaris, Flexor Carpi Ulnaris, Flexor Carpi Radialis, and Abductor Pollicis Longus muscle activity ($p < .0001$). The study results demonstrate the importance of swipe locations and suggest that the tablet interface design can be improved to induce more neutral thumb and wrist posture along with lower forearm muscle load.

1. Introduction

Technology users are moving away from stationary computer workstations and migrating to portable units such as the tablet computer because of their mobility and functional versatility. In fact, the term "phablet" has emerged for the class of mobile devices designed to combine or bridge the form of a smartphone and a tablet (Hill, 2013). While these mobile devices are designed to be multi-functional with an often intuitive software interface, their designs may challenge users' biomechanical capabilities and may be associated with musculoskeletal disorders (MSD) caused by overuse. Several studies have explored how tablet design and configuration affect biomechanical factors as well as user experience and performance related issues with these devices.

There is evidence that certain display and hand holding configurations of tablet use is associated with neck and head flexion, as well as wrist extension (Trudeau et al., 2012a,b; Young et al., 2012; Young et al., 2013). Grip and input technique have been shown to affect forearm muscle loading and performance (Gustafsson et al., 2011). Pereira et al. found that during one-handed smaller to medium-size tablet use, using a ledge or handle on the back was associated with greater overall usability compared to the no-handle condition (2013).

Both tablet orientation (portrait/landscape) and its touch keyboard layout can significantly affect users' thumb posture, perceived-comfort, and motor performance while performing a tapping task during two-handed use of tablet computers (Trudeau et al., 2013). Trudeau et al. (2016) found that two-handed grips afforded better performance and

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https://doi.org/10.1016/j.apergo.2017.12.015
Received 19 July 2017; Received in revised form 20 December 2017; Accepted 28 December 2017

greater wrist and proximal thumb joint extension when compared to one-handed grips.

Swiping and tapping are similar gestures that both require the user to identify and reach for a target, but swiping requires prolonged contact with the touchscreen surface to reach a secondary target (Villamor et al., 2010). The user interface (UI) affects biomechanics and motor performance for both gestures. Studies have explored how upper extremity biomechanics and performance are affected by factors such as touch target size and location during tapping tasks (Park and Han, 2010; Ko et al., 2016; Jeong and Liu, 2017). In addition, Jeong and Liu (2017) found horizontal swipes using the index finger had better self-reported performance and lower physical demands than vertical swipes.

Users also use their thumbs to complete swipe gestures (Billinghurst and Vu, 2015). While a few studies have explored thumb functional reach on touch screen devices (Bergstrom-Lehtovirta and Oulasvirta, 2014; Odell and Chandrasekaran, 2012), to our knowledge, there has been no investigation of how different tablet form factors, UI designs, and tasks affect thumb biomechanics and motor performance for swipe gestures.

In the current study, we sought to determine the effect of tablet form factor (size, orientation) and swiping gesture design (location, orientation, direction) on thumb swiping motor performance, thumb posture, forearm muscle activity, and user perception across configurations for a two-handed grip on a tablet device. Similar to typing performance, we expect that swiping performance, self-reported discomfort, and forearm muscle activity would differ across the gesture designs and form factors due to different thumb and wrist postures required to perform swiping tasks. Specifically, we hypothesize that right thumb swiping close to the palm in the bottom right location of the tablet's screen would require less reach than further from the palm in the middle of the screen and that we can measure this as 1) lower forearm muscle activity; 2) lower self-reported discomfort; 3) better performance compared to the top left location.

2. Methods

2.1. Study population

Sixteen healthy right-handed participants (8 males and 8 females, aged from 21 to 40 years old) with no history of upper-extremity MSDs were recruited for the study (Table 1). The Harvard T.H. Chan School of Public Health and Northeastern University institutional review boards approved all protocols and informed written consent forms. For the testing protocols, participants sat on a height adjustable task chair without arm supports. The height of the chair was adjusted while their feet were flat on the floor and their thighs were horizontal with their knees at a ninety-degree angle. All nearby light sources were indirect, and there was no glare on the tablet's screen. Participants were instructed to hold the tablet with two hands and interact with the tablet using only their right thumbs without dropping the tablet. Participants sat upright and were allowed to use their laps (thighs) to help support their hands/wrists/distal forearms while using the device. The entire experiment including set-up took approximately two hours.

Table 1
Anthropometric measures of means (standard deviations) across all participants.

	Males (N = 8)	Females (N = 8)	All
Age (yrs)	25 (4)	24 (3)	24.5 (3)
Height (cm)	180 (8)	167 (7)	173.4 (10)
Weight (kg)	74 (20)	61 (6)	68 (14)
Hand Length (cm)	20 (0.8)	18 (1)	19 (1)
Hand breadth (cm)	8.8 (0.6)	7.4 (0.4)	8.1 (1)
Thumb length (cm)	10 (1)	9.7 (1)	10 (1)

Table 2
Different swipe design characteristics considered in the tablet study. The study protocol consisted of four sets of the presented swiping actions randomized across two different tablet sizes (8″ and 10”) and orientations (portrait and landscape).

#	Orientation	Length	Direction	Starting location
1	Horizontal	Long	Inward	1
2	Horizontal	Long	Outward	2
3	Horizontal	Long	Inward	3
4	Horizontal	Long	Outward	4
5	Vertical	Long	Inward	1
6	Vertical	Long	Outward	3
7	Vertical	Long	Inward	2
8	Vertical	Long	Outward	4
9	Horizontal	Short	Inward	1
10	Horizontal	Short	Outward	1
11	Horizontal	Short	Inward	2
12	Horizontal	Short	Outward	2
13	Horizontal	Short	Inward	3
14	Horizontal	Short	Outward	3
15	Horizontal	Short	Inward	4
16	Horizontal	Short	Outward	4

2.2. Tablet instrumentation and experimental tasks

Participants performed 16 thumb swiping gestures with the thumb of their right hand, repeating each gesture 5 times in four different tablet configurations for a total of 320 swipes. The swipe gestures differed in swipe direction (outward vs. inward), swipe orientation (horizontal vs. vertical), swipe location (4 swipe zones), and swipe length (short vs. long). Tablet configurations differed in tablet size (small vs. large) and tablet orientation (portrait vs. landscape) (Table 2). As defined in Trudeau et al. (2012a,b),“outward” movements of the thumb were defined as consisting primarily in carpometacarpal (CMC) joint flexion or abduction movements with extension of the interphalangeal (IP) and metacarpal (MCP) joints and include the following directions: South(S) → North (N) & East(E) → West(W). “Inward” movements of the thumb were defined as consisting primarily in CMC extension or adduction movements with flexion of the IP and MCP joints and include the following directions: N → S, NW → SE, W → E, and SW → NE.

The swipe gesture required the user to move a cursor along and within a lane created by two lines a specified distance apart (10 mm) for a specified distance (short 20 mm or long 60 mm). To complete the swipe gesture, participants had to touch the screen activating a target bar (10 mm × 2 mm) in the center edge of one of the four zones (Fig. 1) and then steer the bar between two lines while keeping the thumb between the two lines (Accot and Zhai, 1997; Dennerlein et al., 2000). The gesture was completed when the thumb reached and passed the end of these lines without movement going outside the lane formed by these two lines. Each gesture was performed 5 times in the same direction as shown on the screen. The subjects were instructed to swipe in the direction each time and to naturally bring their thumb back to their starting position without swiping backwards on the screen. No time limit was set for each participant as they were only instructed to complete each trial as quickly and accurately as possible. Each 5 trial task typically took around 1 min. A custom native application was created for an Android program to collect completion time data and provide visual guidance for users.

The two tablet computers selected in the study were a Samsung Galaxy III with a 10″ display (Samsung Electronics Co., Ltd., South Korea) and a Samsung Galaxy Note III with an 8” display (Samsung Electronics Co., Ltd., South Korea). Device, device orientation, and each thumb swipe task were presented to the participant in a balanced randomized fashion (Fig. 1).