Journal of Electromyography and Kinesiology 34 (2017) 6–13

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

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

Fingertip forces and completion time for index finger and thumb touchscreen gestures

Deanna S. Asakawa, George H. Crocker, Adam Schmaltz, Devin L. Jindrich *

Department of Kinesiology, California State University San Marcos, 333. S. Twin Oaks Valley Rd., San Marcos, CA, USA

ARTICLE INFO

Article history:
Received 3 August 2016
Received in revised form 17 January 2017
Accepted 22 February 2017

Keywords:
Hand
Tapping
Mobile computing
Prehension
Haptics

ABSTRACT

Users actuate touchscreen computers by applying forces with their fingers to the touchscreen, although the amount and direction of the force is unknown. Our aim was to characterize the magnitude, direction and impulse of the force applied during single finger (tapping and sliding in four directions) and two finger gestures (stretch and pinch). Thirteen subjects performed repeated trials of each gesture. Mean(±SD) resultant force was 0.50(0.09) N for tap, 0.79(0.32) N to 1.18(0.47) N for sliding gestures, 1.47(0.63) N for pinch and 2.05(1.13) N for stretch. Mean resultant force was significantly less ($p < 0.04$) for tap than for all gestures except slide right. The direction of force application was more vertical for the two-finger gestures as compared to the single- finger gestures. Tap was the fastest gesture to complete at 133(83) ms, followed by slide right at 421(181) ms. On average, participants took the longest to complete the stretch gesture at 920(398) ms. Overall, there are differences in forces, force direction, and completion times among touchscreen gestures that could be used to estimate musculoskeletal exposure and help forge guidelines to reduce risk of musculoskeletal injury.

1. Introduction

Human-computer interactions (HCI) such as keyboarding or mousing use repetitive motions and forces that increase risk for upper-extremity musculoskeletal disorders (Gerr et al., 2014, 2006; Harris-Adamson et al., 2015). However, changes in both workplace and mobile computing technology are increasing the use of touchscreens in HCI (Nacher et al., 2015; Smith, 2015). Touchscreens are becoming increasingly common in both personal and workplace environments (Berolo et al., 2011; Duggan and Rainie, 2012; Smith, 2015). Therefore, determining whether touchscreens also involve exposure to motions and forces that may contribute to injury is important for evaluating the impacts of increased usage.

Several aspects of repetitive motion affect injury risk, including posture, movement extent, frequency, and force (Dennerlein, 2015; Kietrys et al., 2015). Touchscreen device design can change finger posture, affecting performance and potentially also injury risk for tapping tasks (Trudeau et al., 2016, 2013, 2012). Although tapping on a screen requires lower forces than on a keyboard, tapping on virtual keyboards also involves decreased performance and increased discomfort, suggesting that touchscreens may also present risks of musculoskeletal disorders (Kim et al., 2014).

Touchscreen interaction often involves more than tapping, and can include gestures such as swiping and pinching that result in large excursions of proximal finger joints (MCP; Asakawa et al., 2017). Moreover, the forces associated with non-tapping gestures are unknown. Because non-tapping gestures are less constrained than tapping, parameters such as gesture duration and force direction are also important. Therefore, determining force magnitude and direction, force impulse, and task completion time associated with non-tapping touchscreen gestures will be important for understanding the kinetics and potential injury risks of touchscreen use.

Our goal was to determine the parameters associated with force generation for seven common gestures on a touchscreen tablet computer. Based on preliminary work (Asakawa et al., 2014), published performance measures for touchscreen tapping (Kim and Song, 2014), as well as the kinematics and kinetics of the fingers and upper limb during tapping tasks (Asakawa et al., 2017; Dennerlein et al., 2007; Jindrich et al., 2004; Keenan and Massey, 2012), we developed hypotheses regarding the quantitative comparison of touchscreen tapping to other gestures. Specifically, we hypothesize that non-tapping gestures will involve substantially smaller resultant forces, larger force impulses, and longer completion times than tapping on touchscreens. In total, we hypothesized

* Corresponding author at: Dept. of Kinesiology, California State University San Marcos, 333 S. Twin Oaks Valley Rd., San Marcos, CA 92096, USA.

E-mail address: djindrich@csusm.edu (D.L. Jindrich).

http://dx.doi.org/10.1016/j.jelekin.2017.02.007
1050-6411/

that tapping involves the highest mean resultant force but the shortest completion time. We further hypothesize that the two-finger gestures will exert larger resultant forces per finger than single-finger sliding gestures. Because the biomechanics of the sliding motion requires a shear force be applied to the touchscreen, we expect shear forces in the plane of the touchscreen to be a greater percent of the resultant force for the sliding gestures as compared to the tap, pinch and stretch gestures. Finally, we predict that the direction of force application for single-finger sliding gestures would be along the slide direction. To test these hypotheses, we measured force and time parameters for tapping, sliding in four directions, pinching (zoom in) and stretching (zoom out) gestures.

2. Methods

2.1. Subjects

Thirteen unimpaired participants (7 female, 6 male; age 21–33 years) completed gestures on a 10.1-in. touchscreen tablet (Galaxy Tab 2, Samsung Group, Seoul, South Korea). All participants provided written informed consent for protocols approved by California State University San Marcos Institutional Review Board. No participant had a current upper limb injury or history of repetitive strain injury of the upper limb. All participants reported they had previous experience using touchscreen computing. Of the 13 participants, 11 were right-handed and 2 were left-handed. All participants completed gestures using their dominant hand. The subjects' average (SD) height was 1.68(0.10) m and mass was 69.5(14.4) kg. For all participants, we measured dominant hand length from the base of the palm to the tip of the third digit. Hand width was the distance from the second metacarpophalangeal joint (radial side) to the fifth metacarpophalangeal joint (ulnar side). Hand length and hand width averaged 17.8(1.0) cm and 7.9(0.5) cm, respectively. Hand length percentiles for the participants ranged from a 3rd percentile female to a 75th percentile male (Gordon et al., 2012).

2.2. Equipment and setup

Participants were seated in a rigid four-legged chair with seat height of 45.7 cm at a table with height 74.6 cm. During data collection, the participants sat with their sternum aligned at the center of the tablet computer and both feet on the floor. All participants were able to complete gesture interactions comfortably without adjusting sitting posture. The tablet was placed 3.8 cm from the edge of the table with its long edge parallel to the subject's coronal plane (*i.e.*, in landscape orientation, Fig. 1). Participants were not allowed to adjust the position of the touchscreen. The tablet had dimensions of 25.7 × 17.5 × 0.97 cm, and weighed 0.58 kg. We instructed subjects not to rest either hand or arm on the tablet or the table surface to prevent forces or moments not associated with gestures. We visually observed all participants during the data collection to ensure they did not touch the tablet computer except with the finger(s) needed for each gesture. The touchscreen was cleaned with a chamois cloth between participants or whenever necessary to keep the surface free of oils and maintain a consistent screen friction throughout data collection. Room temperature was controlled to maintain approximately 22 °C (72 °F) for all data collection.

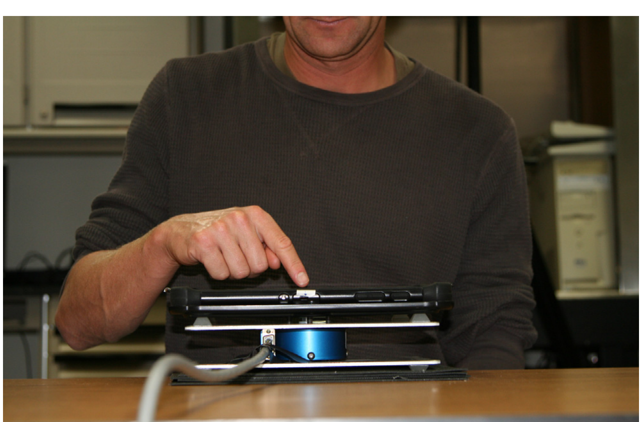

Fig. 1. Experimental set-up. Participants were seated with the touchscreen tablet centered on a table in front of them. The tablet was affixed rigidly to a force transducer that measured the forces applied on the touchscreen.

A custom software application written for the Android operating system (Google, Mountain View, CA) displayed 6 × 6 cm square buttons in the center of the touchscreen for each gesture. The gestures included index finger tap, slide up, slide down, slide left, slide right, and index finger and thumb stretch (zoom an image in) and pinch (zoom an image out). The button size was selected to mimic common size slide or pinch gestures (*e.g.*, for maps or book readers). Participants completed 11 consecutive repetitions of each of the 7 gestures presented in a randomized order. The four sliding gestures involved sliding a 1 × 6 cm bar across the 6 × 6 cm box located in the center of the screen. The tap gesture involved tapping the tablet inside the 6 × 6 cm box. The pinch gesture involved placing the index finger and thumb at the upper right and lower left corner of the 6 × 6 cm box and resizing the box by bringing the finger and thumb together. The stretch gesture required an opposite movement: starting with the finger and thumb together inside a smaller 1.5 × 1.5 cm box and resizing to a 6 × 6 cm box. Before each experiment, we provided a verbal description of the movements required for each gesture, and requested that participants complete gestures at a moderate, self-selected pace. Participants did not practice prior to data collection. No subject reported fatigue during the experiment.

2.3. Data collection

The touchscreen tablet computer was mounted in a fitted rigid plastic case (Ballistic Case Co., Sunrise, FL) affixed to an aluminum plate (24 × 19 × 0.4 cm) bolted to a six degree-of-freedom load cell (JR3 Inc., Woodland, CA; Fig. 1). The load cell measured three-dimensional forces and torques applied to the tablet. When mounted on the load cell, the tablet touchscreen surface was 8.5 cm above the table top.

Calibration and validation indicated that measured forces were accurate to within 4% in the range associated with gestures. We calibrated the touchscreen force measurements by placing known vertical and horizontal weights at nine positions spanning the surface of the touchscreen. The force response of the transducer was linear for both force and moment. We computed a linear calibration matrix, and validated the matrix by placing known weights at positions on the screen not used for calibration. Force transducer data were recorded at 1000 Hz using Labview software (National Instruments Corporation, Austin, TX). During data collection, we used a manual trigger to identify the beginning and end of the gesture in the force recordings. We calculated forces from the transducer output using the calibration matrix, for each time sample between the beginning and end of each gesture using MATLAB (MathWorks, Natick, MA).

2.4. Data analysis

We analyzed data using Microsoft Excel (Microsoft Corporation, Redmond, WA). Only gestures completed in one movement were