

HOLDING A TABLET COMPUTER WITH ONE HAND

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Tablets computers are being rapidly adopted in commercial and home settings. However, there are no guidelines on design features of tablets to optimize usability. The purpose of this study was to evaluate tablet size, weight, orientation, grip shape, texture, and stylus shape on productivity, usability, and biomechanics when the tablet is held with just the left hand. Thirty subjects tested eight tablets and three styluses. Overall, the usability, fatigue and biomechanical evaluation of tablet design features supported the use of smaller to medium sized tablets, with a ledge or handle shape on the back and surfaced with a rubberized texture. Larger tablets had significantly worse usability and biomechanics. The stylus with a tapered grip (7.5-9.5 mm) or larger grip (7.6 mm) had better usability and biomechanics than one with a smaller grip (5 mm). These design parameters may be important when designing tablets that will be held with one hand.

1. INTRODUCTION

Tablet computer use has increased in applications such as retail, books, retail, auto navigation, home controls and home health care (Jana, 2011). As computer technology moves towards higher mobility through the use of handheld tablets and smart phones, there is a need for empirical evidence of tablet and smart phones design features that increase usability and improve biomechanics.

Concern that early desktop computer designs were associated with discomfort and musculoskeletal problems was one of the factors that prompted the creation of design guidelines for computer workstations such as the ISO-9241 and ANSI/HFES 100. No such national or international guidelines exist for mobile devices. In 1995, the United States Department of Defense released guidelines for PDAs and tablets (Department of Defense, 1995). They recommended that hand-held equipment should not weigh more than 2.3 kg; should be capable of being held and operated with a single hand; and be smaller than 100 mm high, x 255 mm long, by 125 mm wide.

Few studies have evaluated the effects of tablet size, orientation, grip shape, and texture on biomechanics, usability, or health. Case studies have noted potential musculoskeletal risks (Storr, 2007 and Ming, 2006) of increased cellphone use and texting. A study of mobile hand-held devices among university students and faculty found that neck, shoulder and thumb pain increased with hours of use (Berolo, 2011). Holding a tablet requires non-dominant shoulder flexion, increased shoulder load, neck flexion and a sustained pinch grip (Young 2012). Mobile device use is associated with greater head and neck flexion and shorter viewing distances than desktop computers (Heasman, 2000). Laboratory studies of tablet use have demonstrated increased left arm muscle activity (Lozano, 2011) which may increase left arm fatigue and risk for musculoskeletal disorders (Werner, 2005 and Fischer, 2009).

One of the few studies of tablet use evaluated seated young children using tablets placed on a table compared to use of desktop computer (Straker 2008). Tablet use was associated with more neck and trunk flexion, more flexed and elevated shoulders, and greater muscle activity around the neck. However, there was a greater variation of both posture and muscle

activity with tablet use which, the authors noted, may offset the non-neutral postures and higher muscle activity.

On the other hand, a pilot study of five adults compared use of a tablet and stylus to use of a desktop computer with a mouse and found decreased muscle activity of the shoulder and forearm muscles with the tablet and stylus (Kotani, 2003). The study also reported better performance with the tablet and stylus (10 mm diameter, 15 grams). However, the tablet was not hand-held, it was supported on a table.

Use of a stylus with a tablet can provide greater accuracy and precision than input with the finger. The additional precision may be beneficial to those with limited mobility, especially for older users (Greenstein 1997). Few studies have evaluated the effect of stylus diameter on performance. A study four different diameter styluses (5.5, 8, 11, and 15mm) and three lengths (80, 110, and 140 mm) found a productivity and preference advantage for the 8 mm diameter stylus (Wu, F. & Liu S., 2005). At least a 100 mm length was preferred so that the stylus extended beyond the side of the hand. However, the study did not evaluate hand muscle activity. A study of ball point pens with a diameter of 8 mm compared to a concave grip diameter of 12 mm found a significant reduction of user pain and right thumb muscle activity with the 12 mm diameter pen (Udo, 1999).

It is desirable to be able to hold mobile devices in a single hand. This is necessary to enable stylus input and pointing over the full screen of the device. Additionally, allowing the tablet to be held in a single hand allows the other hand to be used for non-tablet tasks common to mobile activities. Finally, people simply prefer to hold mobile devices with a single hand. One set of studies on one-handed cell phone usage found that people overwhelmingly preferred to use one hand instead of two across 18 different tasks (Karlson, 2007). The same paper reported observing higher frequencies of one-handed cell phone use versus two-handed use in an airport field study. To enable this type of usage, mobile devices must be designed so that they can be held securely and comfortably with a single hand.

The purpose of the present study was to determine how tablet size, orientation, grip shape, and texture effects usability, muscle activity, posture, productivity, and shoulder moments when gripped with the left hand by users with small hands. Because styluses are frequently used in conjunction

with tablets, stylus design was also examined. The null hypotheses are that these factors do not cause (1) a decrease in usability or comfort or (2) an increase in left arm muscle activity, awkward wrist postures, or shoulder moments. The answers to these questions will provide tablet designers with empirical evidence for tablet design features which may decrease the risk of dropping the tablet, decrease musculoskeletal disorder risk and improve comfort, usability, and productivity.

2. METHODS

In this laboratory study, 30 subjects with small hands held a tablet with the left hand and performed data entry tasks with the right hand using eight different tablet and three different stylus test conditions. The independent variables were tablet size, orientation, grip shape, tablet texture and the shape of styluses. Dependent variables were typing speed; subjective ratings of usability and fatigue; upper extremity and neck posture, forearm muscle activity; and preference. The study was approved by the University Institutional Review Board and subjects signed a consent form.

2.1 Subjects

Eligibility criteria were: 1) age between 18 to 65 years, 2) own or regularly use a touch screen tablet or smart phone, and 3) a middle finger length (from palmer proximal metacarpophalangeal crease to tip of finger) of less than 1.93 cm or proximal interphalangeal joint breadth (at proximal interphalangeal joint) of less than 7.71 cm for females or 2.24 cm and 8.37 cm respectively for males. The finger length and breadth thresholds were the 50th percentile based on hand anthropometry from the US military (Greiner, 1991). Subjects were excluded if they reported current upper extremity musculoskeletal disorders. Fifteen females completed the study. Average middle finger length and joint breadth were 7.58 cm and 1.84 cm, respectively.

2.2 Tablet Test Conditions

Non-functional tablet models were created in three different sizes approximating the iPad 2 (241x186 x 9 mm; 613 g), Kindle Fire (189 x 120 x 11 mm; 400 g) and Samsung Galaxy Note (147 x 83 x 10 mm; 178 g). The aspect ratio, 1.6:1, was the same for all devices, which somewhat changed the model size from the original device (Tablet 2). The tablet test conditions were: tablet size (3 levels with flat grip (Large, Medium, Small) and 2 levels with ledge grip (Large Ledge, Small Ledge)); orientation (2 levels: Large Portrait Ledge and landscape Large Ledge); grip shape (3 levels: flat Large, Large Ledge and Large Handle and 2 levels for small tablet: flat Small and Small Ledge); and texture (2 levels: smooth (Large) and rough (Large Rubberized)). All tablets were 10 mm thick with 4.75 mm radius back edges and 0.32 mm radius front edges. The ledge grip (Large Ledge, Large Portrait Ledge, and Small Ledge) was cut into the back of the tablet, reducing the thickness at the grip location and the Large Handle tablet grip protruded from the back left edge of the tablet. The ledge

grip was a 3 mm step on the back of the tablet that was 40 mm and parallel to the entire left side. The ledge corner had a radius of 0.32 mm. The 8.5 mm thick handle grip protruded from the back left edge of the tablet at a 27 degree angle for 40 mm and had corner radius of 4.25 mm. The smooth surface texture was flexible urethane paint (Color Coat, Satin Black, SEM Products INC, Rock Hill, SC) and the Large Rubberized tablet rough surface texture was a rubber coating (Plasti-Dip, Black, Rubber Coating, Blaine, MN).

The prototype screens were not functional. Therefore, a scaled paper screen shot of an empty email form from an iPad was inserted beneath a clear plastic sheet on the front of each of tablet (Figure 1). The email form included a QWERTY keyboard which was approximately half the size of the screen.

Tablet	Size mm	Weight g	Orientation	Grip Shape	Texture
Large	233x147	694	Landscape	Flat	Smooth
Large Rubberized	233x147	694	Landscape	Flat	Rough
Large Ledge	233x147	601	Landscape	Ledge	Smooth
Large Portrait Ledge	147x233	599	Portrait	Ledge	Smooth
Large Handle	233x147	620	Landscape	Handle	Smooth
Medium	190x120	446	Landscape	Flat	Smooth
Small	147x93	241	Landscape	Flat	Smooth
Small Ledge	147x93	218	Landscape	Ledge	Smooth

Table 1: Descriptive parameters of eight tablet configurations.

2.3 Stylus Test Conditions

Three different stylus designs were evaluated: a small diameter (5.0 mm; 6.62 g), large diameter (7.6 mm; 6.78 g), and a tapered diameter (7.5-9.5 mm; 6.90 g). The tip of the stylus was a felt marker.

2.4 Tablet Task

For each tablet, subjects performed a simulated typing task using their right hand while holding the tablet with their left hand. Subjects were required to hold the tablet with their thumb along the front left edge of the tablet. The other fingers of the left hand could be placed against the back of the tablet as they chose. Subjects stood upright for each task and sat during the three minute breaks between tasks. A computer based random number generator was used to assign the test order of tablet.

For four minutes, pangrams were read to each subject while they typed the pangrams with their right hand. Dictation speed was matched to the subject's typing speed. The number of words completed in four minutes was recorded and reported as words per minute (WPM). WPM was calculated from gross typing speed of total letters divided by typing duration (e.g., keystrokes per minute (KPM)). KPM was divided by the standard word length of 5-letters to calculate typing speed in word per minute.

2.5 Stylus Task

For four minutes, subjects wrote numbers and then spelled the numbers starting from the number 1 and increasing

by one digit. Spelling was written longhand. Subjects were instructed to use a majority of the screen area for writing. The middle sized tablet (190x120 mm) was used for the task. Productivity was estimated using the number that the subject reached at the end of each four-minute session. The task was repeated for each stylus and the order was randomized.

2.6 Usability and Fatigue Ratings

After each tablet or stylus was used, usability and fatigue were assessed with a modified ISO questionnaire (ISO9241-410; 2008). The tablet survey questions were: posture required for tablet use, overall usability, overall productivity, overall security (from dropping the tablet), fatigue in left hand or wrist, fatigue in left forearm, fatigue in left shoulder, fatigue in neck, and how many additional minutes could you hold the tablet in this posture. The stylus survey questions were: posture required for stylus use, overall usability, overall productivity, overall security (from dropping the stylus) fatigue in right hand or wrist, fatigue in right forearm, and fatigue in right shoulder? Fatigue was rated on a scale from 1 = high, least comfortable to 7 = low, most comfortable and the remaining questions used a scale with 1 = worst to 7 = best. At the end of testing all tablets, the tablets were rank ordered from least to most preferred. The same was done at the end of the stylus testing.

2.7 Forearm Electromyography

Muscle activity was recorded from five left forearm muscles during the tablet tasks: extensor digitorum communis (EDC), flexor carpi radialis (FCR), flexor digitorum superficialis (FDS), upper trapezius (UT), extensor carpi radialis (ECR). These were the muscles used for gripping and stabilizing the tablet. During the stylus task, muscle activity was recorded from the right ECR and flexor pollicis brevis (FPB); the stylus was always gripped with the right hand. Additional methods on forearm electromyography are presented in Pereira et al. (2012).

2.8 Posture Measurement

Posture measurements and statistical analysis are described in Rempel et al. previous publication (2007).

RESULTS

3.1 Productivity

There were no significant differences in measured typing speed across any of the tablet or stylus design features. Results for other outcome measures are presented by feature group, e.g., tablet size, orientation, grip shape, surface texture and stylus design.

3.2 Tablet Size

Differences in usability ratings and biomechanical measures are discussed by tablet size (Large, Medium, Small).

Higher usability numbers represent better ratings. For *overall usability* and *overall productivity*, the Medium tablet was rated significantly better than the Large tablet ($p < .01$). *Overall security* was rated better for the Medium and Small tablets compared to the Large tablet ($p < .01$). *Posture required for tablet use* was rated better for the Small tablet than the Large tablet ($p < .01$). *Fatigue in the left hand or wrist* was better for the Medium and Small tablet compared to the Large tablet ($p < .01$). *Fatigue in the left forearm* was better for the Small tablet compared to Medium and Large tablets, and the Medium tablet was better than the Large Tablet ($p < .01$). *Fatigue in left shoulder* and *fatigue in neck* were better for the Medium and Small tablets compared to the Large tablet ($p < .01$). The smaller tablets could be held comfortably for more time than the Large tablet ($p < .01$). Significant differences in biomechanical factors also favored the smaller tablets. Left FDS muscle activity was less for the Medium and Small tablets compared to the Large tablet ($p < .01$). Left FCR activity was less for the Small tablet compared to the Medium and Large tablets, and the Medium tablet was less than the Large tablet ($p < .01$). For UT, the Small tablet was less than the Large tablet ($p < .01$). The FDS muscle is used for gripping, the FCR is for stabilizing the wrist and the UT is involved in supporting the head and elevating the shoulder. Left wrist extension was less for the Small tablet compared to the Medium and Large tablets ($p < .01$). Left shoulder moment was less for the Small tablet compared to the Medium and Large tablets, and the Medium tablet was less compared to the Large tablet ($p < .01$).

Generally the findings for the two tablets of different size with a ledge grip were similar. All usability ratings were significantly better for the lighter, Small Ledge tablet than the Large Ledge tablet ($p < .01$), except for the ratings for *overall usability* and *overall productivity*. Left FDS and FCR muscle activity were less for the Small Ledge tablet compared to the Large Ledge tablet ($p < .01$). Left wrist extension was less for the Small Ledge tablet compared to the Large Ledge tablet ($p < .01$).

3.3 Tablet Orientation

There were no significant differences in writing speed or muscle activity for tablet orientation. Wrist extension was significantly less in the portrait orientation compared to landscape ($p < .01$). Subjects reported less *fatigue in the left forearm* and *left shoulder* when using the tablet in the portrait orientation ($p = .05$). The portrait orientation could be held comfortably for more time than landscape ($p = .04$).

3.4 Tablet Grip Shape

The effects of different grip shapes when using the large tablets (233 x 147 mm). All usability and fatigue ratings were significantly better for the Large Ledge or Large Handle tablets compared to the conventional, flat Large tablet ($p < .01$). Shoulder moment was less for the Large Ledge and Large Handle tablets compared to the Large tablet ($p < .01$). There were no significant differences in muscle activity between grip shapes.

The effects of grip shape (ledge and flat) for the smallest tablet (147x 93 mm) were much less than the effects on the large tablet. The only usability rating difference was an increased *overall security* rating with the ledge shape grip ($p = .01$). There were no biomechanical differences between grip shapes for the small tablet.

3.5 Tablet Surface Texture

The only significant difference in usability ratings between conventional smooth tablet surface versus a rubberized rough tablet surface was that subjects rated the rough surface significantly better for *overall security* ($p = .03$). There were no significant differences in biomechanical measures.

3.6 Comparison Across Tablets Design Features

After using all the tablets, subjects ranked all in order from their *least favorite* to *most favorite*. The only significant difference within a design feature (e.g., within grip type or within orientation) was on size; subjects again preferred the smallest tablets more than the Large tablet, with or without a ledge ($p = .02$).

3.7 Stylus Design

Overall security was better for the large diameter stylus than the small diameter one ($p = .03$). Fatigue in the right hand or wrist was less for tapered stylus compared to small stylus ($p = .05$). The order of preference was tapered, large, then small.

4. DISCUSSION

Tablet size (and weight) had a strong effect on usability, fatigue, and biomechanics. Overall, subjects preferred the small and mid-size tablets to the large tablets. They reported improved usability and security and less fatigue with the small and mid-size tablets. They estimated that they could continuously hold the small and mid-size tablets for more than twice as long as the large tablet. Shoulder moments increased as tablet size and weight increased which may explain the higher shoulder and neck fatigue, higher neck muscle activity (UT) and shorter holding time with the large tablet. There were few differences in usability, fatigue and holding time between the small and mid-small sized tablets, indicating a possible threshold effect on size. That is, reducing tablet size and weight below the mid-size tablet provides no additional advantages on usability, fatigue and holding time. While subjects reported better productivity with the mid-size tablet compared to the large tablet, there were no differences in measured productivity between any of the tablets.

Tablet size also had an important effect on hand and wrist biomechanics. As tablet size, increased there was an increase in wrist extension and finger grip (FDS) and wrist (ECR) muscle activity. For all tablets, the right side of the tablet was approximately 10° below the left side. Knowledge of tablet angles may be useful for design of tablet grips and for hardware (e.g., accelerometers). The viewing distance to the tablets was approximately 33 cm and the distance did not change

significantly with tablet size. There was a weak correlation ($r = 0.31$) of eyesight to viewing distance; subjects with lower vision tended to hold the tablet closer.

Tablet orientation, portrait vs. landscape, influenced hold time and wrist posture. Subject estimated hold time increased and there was less wrist extension in the portrait compared to landscape mode. There was a non-significant trend for more forearm and shoulder fatigue in the landscape mode. All other things being equal, these findings provide some support for the use of tablets in the portrait orientation over landscape for one-handed use. More comfort would be expected for the portrait mode due to the lower moment arm at the wrist due to the tablet mass in this orientation.

Grip shape had an effect on usability and fatigue. For the large tablets, all usability and fatigue ratings, including security from dropping, were better for the Large Ledge and Large Handle tablet grips compared to the conventional flat Large tablet grip. Usability ratings and preferences were slightly better for the ledge grip compared to the handle grip but the differences were not significant. Shoulder moment was less with the ledge and handle tablets, but this was likely due to differences in weight between the tablets. The ledge and handle tablets weighed 10-15% less than the conventional flat tablet, however, it is unlikely that this small weight difference influenced usability and fatigue ratings. For the small tablet, the ledge grip improved security from dropping but had no other effects on usability or fatigue ratings. There was a slight but non-significant preference for the ledge grip over the flat grip for the small tablet.

Overall, subjects most preferred the Tapered stylus, followed by the Large stylus. The Small stylus was least preferred. Fatigue ratings of the right hand and wrist followed a similar trend. Security from dropping was also rated better for the Large stylus than the small one. The findings match other studies of styluses (Kotani, 2003), pens (Wu, 2005) and dental tools (Dong, 2006). Larger diameter (up to 11mm) and lighter tools are preferred over smaller diameter precision tools.

A post-hoc analysis of correlations of outcome measures revealed some interesting findings. There was a correlation between left hand/wrist, forearm, shoulder and neck fatigue to security from dropping ($r = 0.66, 0.61, 0.57,$ and 0.45 respectively). As fatigue increased, users felt less secure from dropping the tablet. The highest correlation was between fatigue of the hand/wrist and security, which highlights the interrelationship between hand fatigue and a sensation of a secure grip. The second interesting correlation was that downward gaze angle increased as subjects leaned their torso forward ($r = 0.74$) or decreased their elbow height ($r = 0.67$). It is likely that as subjects brought the tablet in towards their body to reduce shoulder moment (shoulder moment and gaze angle $r = 0.54$) they compensated by leaning their torso forward and increasing head flexion and downward gaze angle.

A limitation of the study was the use of tablets with non-functional screens. Productivity measures and usability ratings may be different if productivity and error were measured while subjects used functional screens. The study examined the effects of tablet design features among users with small hands. It is possible that findings from users with large hands, who are likely to be stronger, would be different. However,

users with small hands are at a higher risk of fatigue and usability problems due to the size of the tablet relative to their reduced grip span and strength.

Future studies should examine the effects of tablet size with functional tablets to more realistically assess productivity and error. A wider range of ledges and handles dimensions could be explored to identify designs that improve security with minimal increase in weight. Additionally, studies with longer duration tasks would be better able to discriminate difference in fatigue between devices.

5. CONCLUSION

Overall, this study of usability, fatigue and biomechanics of tablet design features supports the use of the smaller to medium sized tablets over large tablets when tablets are held with one hand. Larger tablets had significantly higher forearm muscle activity, shoulder moments and wrist extension and lower preference ratings and holding time. Security, usability and fatigue were better with the ledge or handle grip compared to the conventional flat grip, especially for the large tablet. There was a non-significant trend for better usability and fatigue when the tablet was coated with a rough rubberized texture or when the tablet was used in portrait orientation compared to landscape orientation. The tapered and large diameter (8 mm) styluses were preferred over the small diameter (5 mm) stylus.

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