USABILITY TESTING OF SMARTPHONE HOLDER

By
Advisor and Agent – **Dr. Eunsik Kim**, Assistant Professor in Mechanical, Automotive & Materials Engineering, University of Windsor

Student - **Roopak Sri Venkata Sai Madhavarapu**, pursuing a Master of Applied Science in Industrial Engineering at University of Windsor

A **Technical Report**

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Executive Summary

A smartphone is a frequently used device that users hold and operate in a one- or two-handed posture while sitting, standing, or walking. However, prolonged usage of smartphones can lead to musculoskeletal symptoms such as chronic neck and shoulder pain. The purpose of this study is to propose a smartphone holder that will increase the range of thumb motion while decreasing the severity of ergonomic risk postures, particularly in the neck and wrist in one-handed usage of smartphones. Five different parameters were evaluated on 30 participants for the Orthotext in comparison to the Pop Socket and to no holder at all: range of thumb motion and performance (speed and accuracy), muscle activity, subject discomfort, wrist and neck postures, and pitch of the device. These parameters were measured for each user during tasks of gaming, tapping, typing, scrolling, and swiping in sitting and walking postures. User preference data was collected based on a questionnaire (7-point Likert scale). The results showed a statistically significant difference ($p<0.05$) in the range of motion of the thumb, user preference, and in some cases, the pitch of the device and performance. We expect that this study will contribute to increasing the range of motion for the thumb, improve usability, and reduce risk factors of musculoskeletal symptoms in one-handed usage of smartphones.

Keywords: Smartphone, Smartphone holder, text-neck symptoms, Usability testing, walking, EMG, thumb muscles

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1 Introduction

1.1 Background

A smartphone holder is a small object used to prop up a smartphone. It is designed to sit on a hard surface and provide a secure grip while the user is texting, snapping pictures, and scrolling, thereby preventing droppage. There are different types and styles of smartphone holders on the market, including Pop Sockets, Rings, Auto Mounts, Folding Holders, and so on, as shown in Figure 1.

According to a summary of mobile usage statistics, there are almost 6.8 billion smartphone users worldwide, and this number will increase significantly to 7.33 billion by 2023 (M, 2021; Berolo, Wells, & Amick, 2011). Smartphone usage statistics suggest that an average person spends 2 hours and 51 minutes per day on their mobile device (M, 2021). Users engage in several postures to hold and operate the pocket device, including one- and two-handed usage while sitting, standing, or walking, and most users prefer to operate their phone in one-handed mode, even in distraction-free situations (Amy K. Karlson, 2006).

Before 2011, nearly every phone on the market measured between 2.5 and 4 inches (on the diagonal), but now smartphone sizes are increasing due to changes in consumer demands, especially those related to camera quality and wider screens (FindTheBest, 2014). As a result of increasing phone size, one-handed usage is making it more challenging for users to reach the entire area of the smartphone without changing hand posture. Larger phone screens require users to modify their grip to avoid covering an area of the screen with their hand and thumb (Xiong & Muraki, 2016), which would affect perceived usability and experience for smartphone users. As device size increases, the single-handed grip may ultimately constrain thumb movement and require sub-optimal postures to achieve accuracy and performance.

Figure 1: Different types of smartphone holders available in the market (Image source: 6 ways to get a better grip on your phone)

1.2 Problem Statement

The main problems associated and reported with one-handed usage of smartphones

- Many users cannot reach targets in the upper half of the screen due to the limited length of the thumb **(Park & Han, 2010)**, and they may compensate with a change in hand posture and a less stable grip on the phone, which can, in turn, lead to dropping the device or assuming awkward postures in the wrist and thumb.

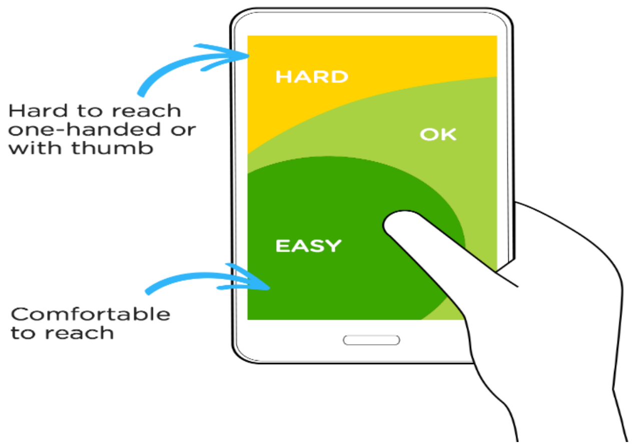

Figure 2: Range of motion for the thumb (Image source: Designing for Thumbs)

- Another problem is the development or occurrence of musculoskeletal problems in the neck, often referred to as text-neck **(Berolo et al., 2011)**

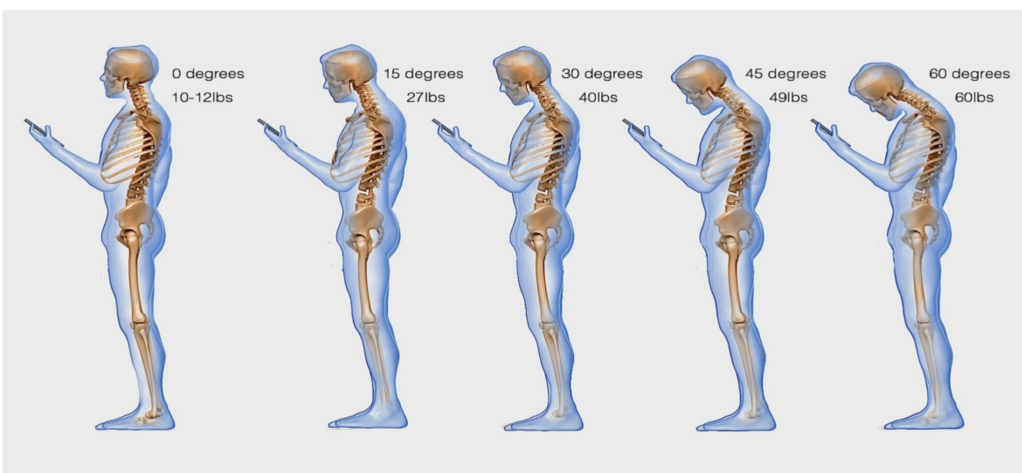

Figure 3: Neck posture using a smartphone (Image source: Texting neck)

1.3 Purpose

The purpose of this study is to evaluate the effect of an Orthotext (which attaches along the long side of the smartphone case) on one-handed usage of smartphones as compared with 1) a similar market available product, i.e., the Pop Socket (which attaches to the back of the smartphone), and 2) a phone with no holder at all (No Holder).

Figure 4: Example of smartphone holders: (L) Traditional holder (Pop Socket), (R) Orthotext

1.4 Research Hypothesis

- The Orthotext will permit a greater range of motion for the thumb than the Pop Socket and the phone with No Holder.
- The Orthotext will lead to lower muscle activities in the thumb and forearm in contrast to the Pop Socket and No Holder.
- The Orthotext will have a low level of ergonomic risk in wrist and neck postures compared to the Pop Socket and No Holder.
- The Orthotext will allow better performance in terms of speed and accuracy than the Pop Socket and No Holder.
- When compared to the Pop Socket and the phone with No Holder, the Orthotext will result in less subject discomfort.
- Users will greatly prefer the Orthotext over the Pop Socket and No Holder.
- The Orthotext will give the smartphone an ergonomic level pitch, especially as compared to the Pop Socket and No Holder.

2 Methodology and Procedures

2.1 Participants

In this study, only female subjects were considered. Thirty healthy female subjects were recruited to participate. All participants were right-handed and collectively had a mean age of 25 (Standard Deviation of 3), a mean height of 159.2 centimeters (SD of 5.9), and a mean weight of 61.7 kilograms (SD of 12.6). The participants were all University of Windsor students, reported no musculoskeletal disorders in the upper limb or neck within the previous 12 months, and had more than one year of daily smartphone usage experience. Demographic data and hand anthropometric data were collected. Prior to the study, participants were informed of the study's process and objective and subsequently filled out a letter of consent. This study was approved by the University of Windsor's research ethics board. Detailed demographic and anthropometric participant data are presented in Table 1.

Table 1: Demographics and personal characteristics of participants (n = 30)

Variables	Mean	Standard Deviation
Age (yrs.)	25	3
Height (cm)	159.2	5.9
Weight (Kg)	61.7	12.6
Smartphone usage (yrs.)	8	2
Time spent using the smartphone (hrs./day)	5.4	1.6
Hand Length from Digitizer (cm)	170.64	29.77

2.2 Design of the experiment

2.2.1 Independent variables

For this study, there are three independent variables, as shown in Figure 5: screen size (large and small), posture (sitting and walking), and type of smartphone holder (Orthotext, Pop Socket, and none). The materials used in this experiment were: a chair for sitting, a treadmill for walking, an iPhone 13 Pro Max, an iPhone 13 mini, an iPad mini 6th generation, a traditional smartphone holder (e.g., a Pop Socket, which is attached at the back of the smartphone case) and the Orthotext, which is attached along the length side of the smartphone case. For the sitting posture, each participant was asked to sit in an adjustable chair with knees flexed at 90° and feet resting on the floor, as shown in Figure 6. For the walking posture, each participant was asked to walk on a treadmill at a speed of 2km/hr., as shown in Figure 6.

Posture: Sitting & Walking

Screen Size: Small & Large

Type of Holder : Othotext, Pop Socket, and No Holder.

Figure 5: Independent variables

Figure 6: Sitting and Walking postures

2.2.2 Dependent Variables

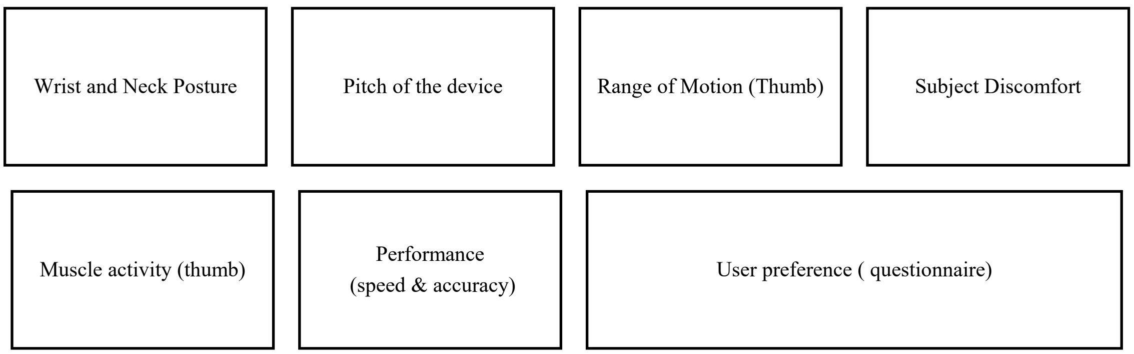

Figure 7: Dependent variables

2.3 Tasks conducted in the research study

In total, five tasks were conducted in this experiment to evaluate the effects of smartphone holders: **Tapping, Typing, Scrolling, Swiping and Gaming**. The tapping task, scrolling task, typing task and gaming task were used to measure speed and accuracy. The swiping task gave the range of motion for the thumb. A **Phone Grip Evaluation App**, written using React Native Framework in JavaScript, was used for all participants. Each participant entered their name, dominant hand and posture they are in while using the smartphone. There are four types of tests in this app: typing, swiping, scrolling, and tapping, as shown in Figure 8. All tasks were performed according to the design of experiment.

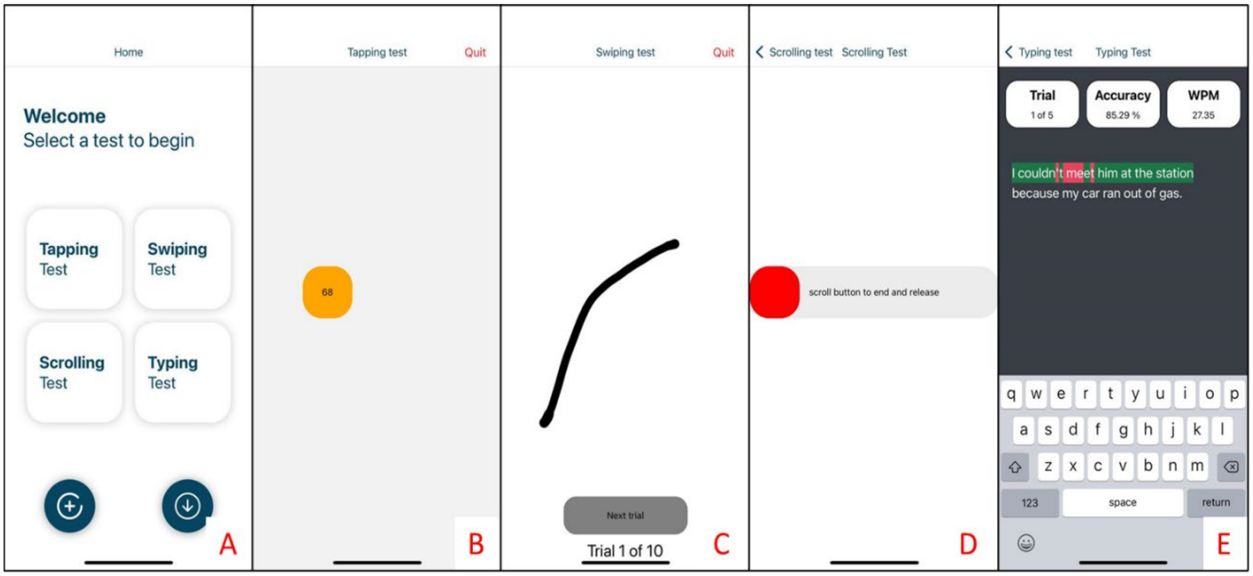

Figure 8: Phone Grip Evaluation App: (A) Home Screen, (B) Tapping Task, (C) Swiping Task, (D) Scrolling Test, and (E) Typing Task

2.3.1 Tapping task

In the tapping test, the test area is divided into two zones, as defined by a previous study (Wroblewski, 2012). Zone-1 refers to the easy access area (i.e., close to the thumb) and zone-2 refers to the difficult access area (i.e., away from the thumb). For the tapping test, each participant was asked to press a small, square button that appears on the screen and to repeat this motion for 40 trials, 20 trials in zone-1 and 20 trials in zone-2. This task measures speed and accuracy and takes approximately 1-2 minutes for each participant to complete. The participant may tap on the white space if he or she is unable to tap on the square shaped button.

2.3.2 Scrolling Task

In the scrolling test, each participant was asked to move the square button on the screen to the goal (i.e., swipe to unlock). This is done in four orientations: left to right scroll, right to left scroll, top to bottom scroll, and bottom to top scroll. Each participant repeated each scrolling task a total of 10 times. The participant could tap on the white space if he or she was unable to swipe on the square button, and each trial had a 5 second time limit once begun. The total task completion time was around 1-2 minutes. Speed and accuracy were measured in this task.

2.3.3 Typing Task

In the typing test, each participant was asked to type a short sentence in every trial, totaling 3 sentences. After the sentence was typed, the correctly entered characters were shown in green and incorrectly entered characters were shown in red. There is no delete option for incorrectly entered characters. The total task completion was around 3-4 minutes. Words per minute (wpm) and accuracy were calculated from this task.

2.3.4 Swiping Task

In the swiping test, each participant was asked to draw the biggest arc they comfortably could using their thumb and the iPad mini 6th generation. This task was repeated for 3 trials. The total time required to complete this task was 1-2 minutes. The range of motion for the thumb (in centimetres) was measured in this task.

2.3.5 Gaming Task

In the gaming task, each participant was asked to play a game called **Temple Run (Version 1.19.1,** developed by Imanji Studios LLC, as shown in Figure 9), and their performance in the game was calculated as a score. The task was conducted for 20 minutes in sitting posture only while using a large-screen device.

Figure 9: Gaming task pictures

2.4 Study design

To evaluate these smartphone holders, respective parameters, described in section 2.2.2, were measured. Equipment used for these measurements are discussed below.

2.4.1 Muscle activity

Muscle activities in the thumb and forearm were measured by the **EMG system (Delsys Trigno Research+)**, shown in Figure 10, in which electrodes are attached to specific points on the participant's hand and forearm. This system collects and records the electrical activity of muscle movement. The muscles that were examined during the experiment were the M. extensor digitorum communis (ED), the M. first dorsal interosseous (FDI), the M. flexor digitorum superficialis (FDS), and the Flexor Digitorum Profundus (FDP), as shown in Figure 11. These are the primary muscles involved in thumb and forearm movement. Muscle activity was only measured in the gaming task with the participant in a sitting posture holding a large device.

Figure 10: EMG system and sensors

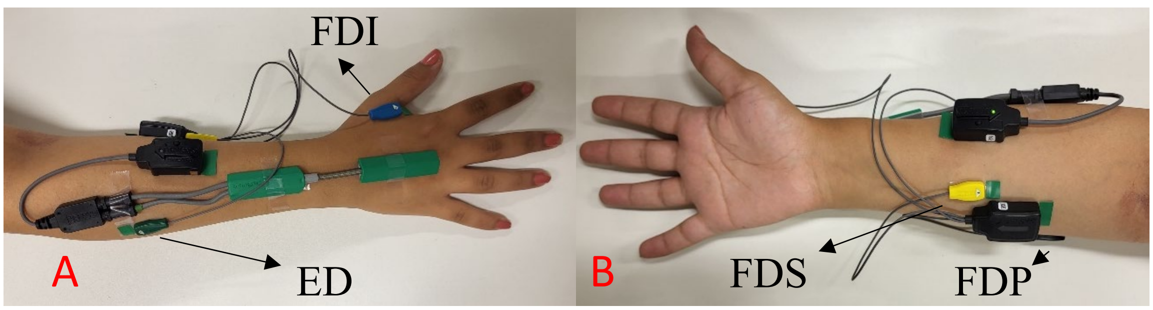

Figure 11: Sensors and Goniometer attached on the hand: A. Top view, B. Underside view

2.4.2 Wrist Posture

Wrist posture was measured using an **electro goniometer**. This measurement was used to help detect whether wrist posture was within the allowable range and was collected in Gaming, Tapping, Typing and Scrolling and under all conditions. Wrist extension/flexion and ulnar/radial were measured while participants performed the established tasks.

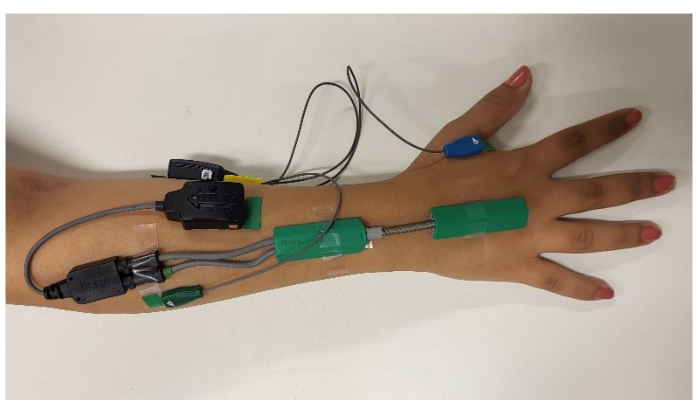

Figure 12: Electro goniometer

2.4.3 Performance (Speed and accuracy)

Task performance data were collected and recorded in the Phone grip Evaluation app for Tapping, Typing and Scrolling. For Gaming, data was recorded in the game, as shown in Figure 9.

2.4.4 Neck Posture

We recorded a side-angle video based on each participant's dominant hand to determine neck angle using a computer vision algorithm. Figure 13 shows the sitting and standing neck posture analysis in the developed computer vison algorithm. Neck posture is measured in all the tasks and recorded in degrees.

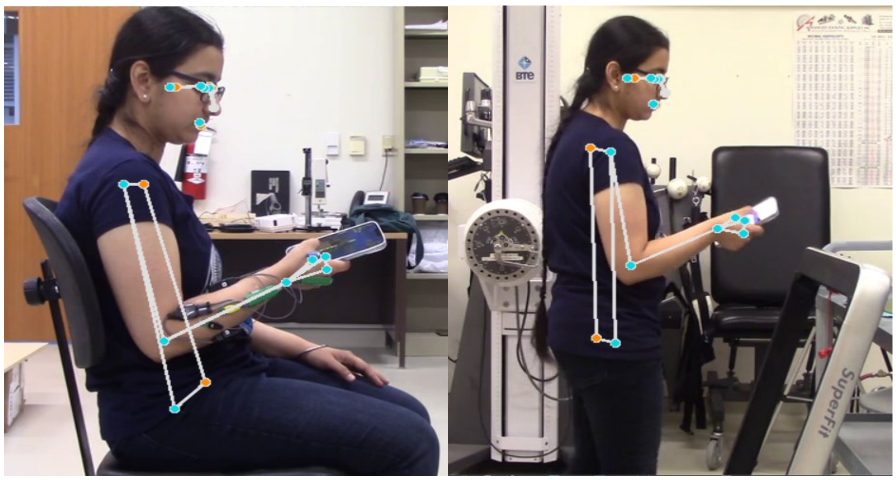

Figure 13: Neck posture Analysis

2.4.5 Subject Discomfort

The Borg CR10 scale method was used to measure subject discomfort in the gaming task, recording each participant's perceived exertion and pain after playing the game for 20 minutes. The body parts selected for evaluation were the hand, thumb, wrist, neck, and shoulder. The participant used the scale laid out in Table 2 to rate their perceived exertion in each body part.

Table 2: Borg CR10 Scale

Rating	Description
0	Nothing at all
0.5	Extremely Weak (Just noticeable)
1	Very Weak
2	Weak (Light)
3	Moderate
4	Somewhat Strong
5	Strong (heavy)
6	
7	Very Strong
8	
9	
10	Extremely Strong

2.4.6 Pitch of the device

The smartphone itself contains an accelerometer which can report X, Y and Z axis orientations, as shown in Figure 14. Accelerometer data from the smartphone was used while tapping, scrolling, and typing to measure the pitch of the device.

Figure 14: Pitch of the device

2.4.7 User Preference

After the experiment, a 7-point Likert Scale questionnaire with 8 questions was used to determine user preference among the three holders.

Table 3: 7-Point Likert Scale questionnaire

1	I found it easy to use this holder
2	I was able to complete all the tapping, typing, scrolling, and gaming tasks accurately using this holder
3	I was able to complete all the tapping, typing, scrolling, and gaming tasks quickly using this holder
4	It was more comfortable to use this holder
5	I was confident that I will not drop the phone when using this holder
6	I prefer to use this holder on my smartphone.
7	I will recommend this holder to my friends and family.
8	I am fully satisfied with this holder

2.5 Selecting the finger for Orthotext usage

After doing a 10-participant pilot study involving the insertion one, two, and four fingers at a time in the Orthotext device, it was determined that inserting one finger, specifically the middle finger, was highly preferred by all participants in the pilot study.

2.6 Experimental Procedures and Protocols

During the experiment, each participant was asked to use each of the three holders (Orthotext, Pop Socket and No Holder) in sitting and walking postures and holding large and small smartphone devices with their dominant hand, as shown in Figure 6. The experiment began with the gaming task, which took approximately 20 minutes, and after each trial with each holder, the participant was given a rest time of 5 min. During the rest time, the participant was asked to rate wrist, hand, thumb, shoulder, and neck discomfort verbally using a Borg CR-10 scale (Borg, 1998). After the Gaming task, the other tasks—Typing, Tapping, Scrolling and Swiping—were performed with a rest time of 2 minutes between each trial of the smartphone holders. Finally, at the end of the experiment, each participant took a standard usability questionnaire with a 7-point Likert scale to assess their preference among the three smartphone holders. The experiment was undergone by 30 participants, and all tasks for each participant were finished within five hours of the respective start time.

Horizontal Multi-level Hierarchy was used to show participant interactions with the smartphones during task performance, as shown in the Figure 15.

The tasks done with the large display (**iPhone 13 Promax**):

- Gaming (only sitting)
- Tapping
- Scrolling
- Typing

The tasks done with the small display (**iPhone 13 mini**):

- Tapping
- Scrolling
- Typing

The tasks done with the **Tablet**:

- Swiping

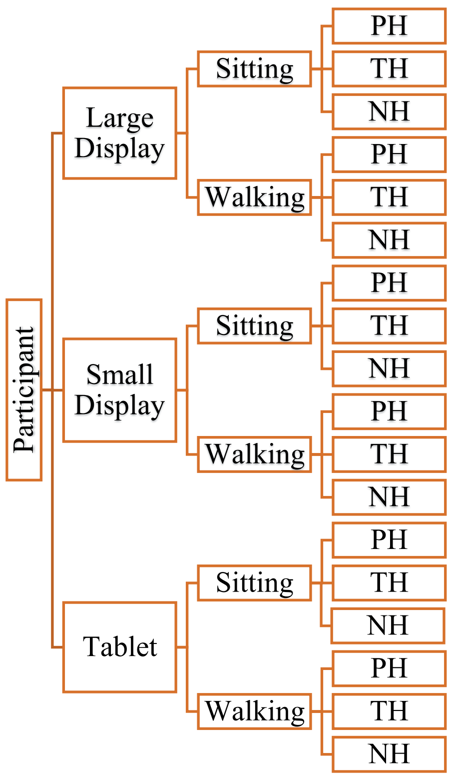

Figure 15: PH = Proposed holder = Orthotext, TH = Traditional Holder = Pop Socket, NH = No Holder

2.7 Statistical analysis

One-, two-, and three-way ANOVA tests were applied to the collected data using IBM SPSS software version 28.0 (IBM Corp., Armonk, NY). The one-way ANOVA was calculated for the variables involved in the Gaming task (muscle activity, subjective discomfort rating, performance in Gaming task, wrist posture and neck posture in Gaming task, and user preference) to determine significant differences among the three holders. This process was followed by a post hoc comparison. A two-way ANOVA was performed on range of motion and followed by post hoc comparison. A three-way ANOVA was performed for the Tapping, Scrolling, and Typing variables. For all tests, $p < 0.05$ was considered statistically significant.

3 Results & Discussion

3.1 User Preference

The questionnaire results at the end of the experiment for all 30 participants showed that, for all questions, the Orthotext was significantly preferred to the Pop Socket and No Holder ($p<0.05$). Indeed, responses to Question 8, which asks participants to rate each holder's ease of use, showed that the Orthotext was rated at 7, the highest available rating. For the two questions regarding recommendation and preference, the Pop Socket received the lowest score of 3 while the Orthotext scored twice as high at 6, as shown in Figure 16. Overall, while the Orthotext was rated higher than 6 points for all questions, there was no single question for which the Pop Socket and No Holder were rated higher than 6 points.

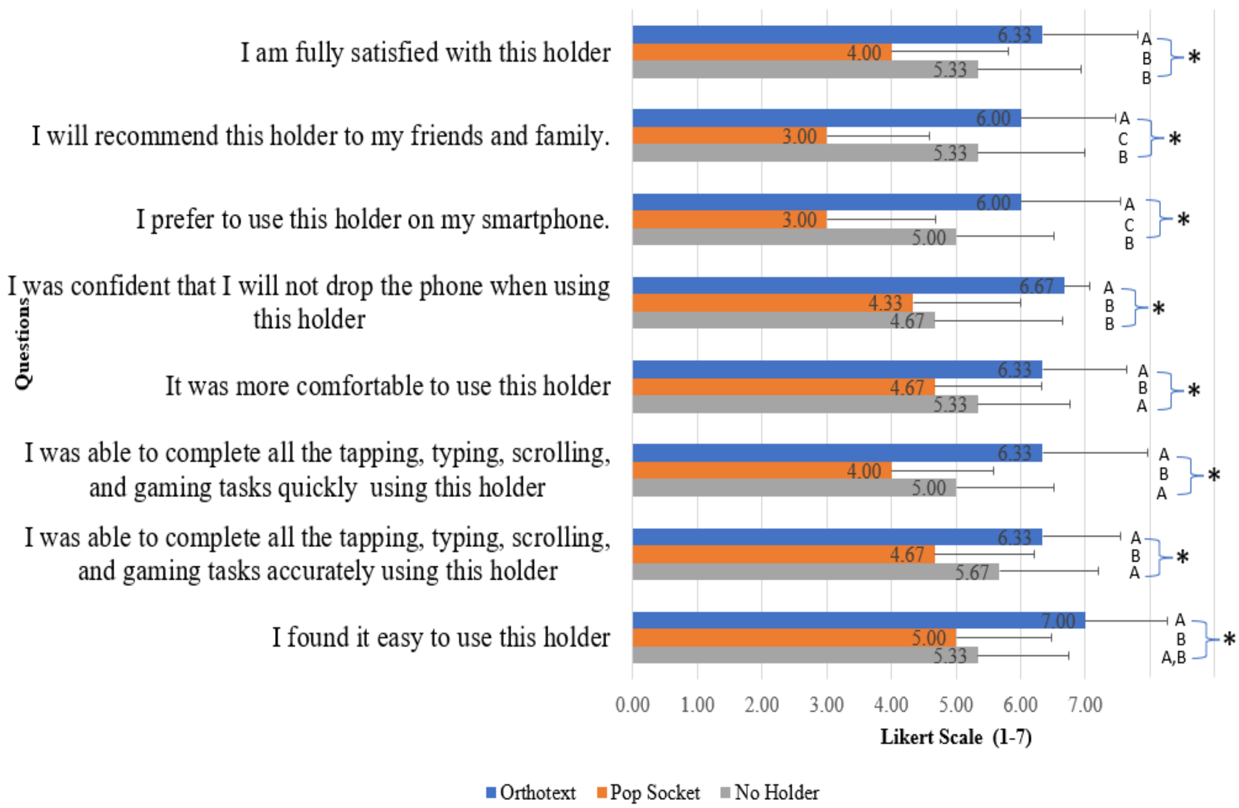

Figure 16: User Preference (asterisk indicates significance at $p < 0.05$) and means that do not share a letter are significantly different.

3.2 Range of motion for thumb

Figure 17 shows the results from the swiping task. There is a significant difference between different smartphone holders in the range of motion for thumb (P<0.05). The greatest vertical distance reached by the thumb is achieved with the Orthotext in the walking posture, and the lowest value is with the Pop Socket in sitting posture. Similarly, the greatest horizontal distance reached by the thumb is achieved with the Orthotext in walking posture, and the lowest value is with the Pop Socket in sitting posture. Overall, the range of motion for the Orthotext improved about 39% vertically and 18% horizontally.

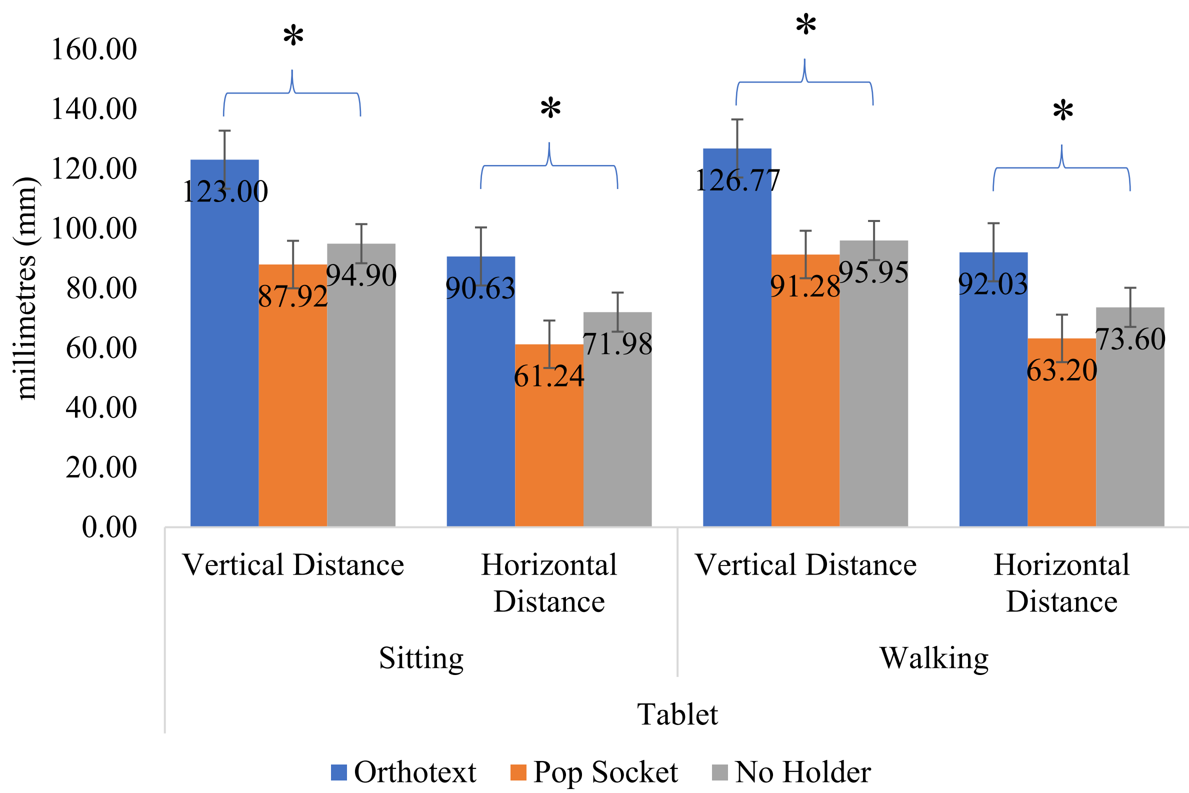

Figure 17: Range of motion for thumb in Swiping task (asterisk indicates significance at $p < 0.05$)

3.3 Subject discomfort

In the Gaming task, the lowest discomfort occurred while using the Orthotext with the large device, yielding a significant difference ($p<0.05$) in the shoulder. The greatest discomfort occurred in the hand while using the Pop Socket holder, and the lowest discomfort occurred in the thumb with the Orthotext holder. Overall, in all body parts measured, the Orthotext smartphone holder showed the lowest discomfort compared to other smartphone holders, as shown in Figure 18.

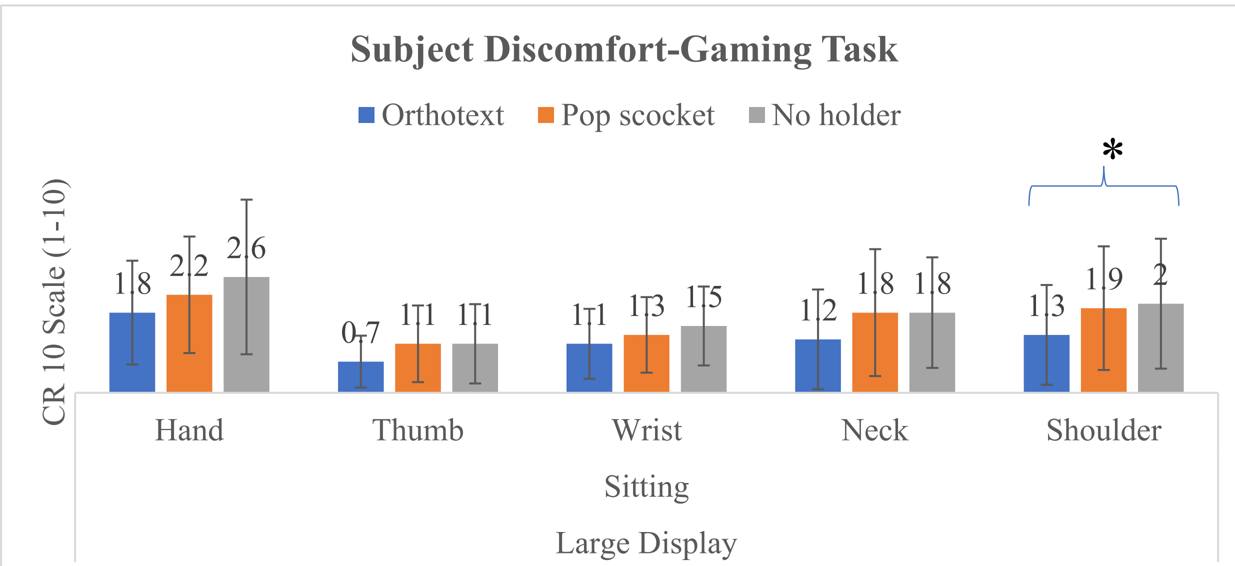

Figure 18: Subject Discomfort in Gaming Task (asterisk indicates significance at $p < 0.05$)

3.4 Muscle activity

As shown in Table 4, there is no significantly different muscle activity between the four muscles and across the three holders. However, considering that the average value of muscle activity is less than 15% of MVC, there are no risk factors of musculoskeletal disorders for smartphone usage.

Table 4: Results from a one-way ANOVA on the effects of different holders based on Muscle Activity

Muscle		Type of Holder						F-value	p-value
		HN		HP		HT			
		Mean	SD	Mean	SD	Mean	SD		
FDI	10th	0.63	0.75	0.51	0.66	0.68	0.81	0.42	0.66
	50th	1.02	0.95	0.82	0.82	1.05	1.12	0.49	0.62
	90th	2.27	2.03	2.21	1.99	2.41	2.61	0.07	0.93
FDS	10th	3.87	2.33	3.45	1.90	3.71	2.34	0.28	0.76
	50th	6.10	3.26	5.64	2.73	5.54	2.98	0.29	0.75
	90th	8.85	4.51	8.65	3.81	8.06	4.01	0.30	0.74
ED	10th	3.09	3.03	4.02	3.04	3.35	4.01	0.59	0.56
	50th	4.91	4.51	7.60	4.91	5.76	5.80	2.19	0.12
	90th	9.39	6.88	13.96	7.82	11.27	8.89	2.54	0.09
FDP	10th	1.04	0.54	1.21	0.77	1.06	0.64	0.61	0.55
	50th	1.60	1.05	1.85	1.19	1.53	1.03	0.70	0.50
	90th	2.98	2.42	3.44	2.03	2.81	2.27	0.63	0.54

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

3.5 Wrist Posture

Overall, as shown in the results of the one-way ANOVA test for the gaming task and the three-way ANOVA for Tapping, Scrolling, and Typing tasks (as seen in Table 5, Table 6, Table 7, and Table 8), there is no statistically significant difference among holders in the wrist posture or among all holders in sitting and walking postures with large and small devices. Overall, comparing the mean value for each type of holder, the Orthotext showed the largest Extension and Ulnar angles compared with the Pop Socket and No Holder.

Table 5: Results from a one-way ANOVA on the effects of different holders in Gaming task

Gaming task - Wrist Posture						
Device	Posture		(-) Flexion / (+) Extension		(-) Radial / (+) Ulnar	
		F	0.47		0.13	
		p	0.63		0.88	
			Mean	SD	Mean	SD
Large Display	Sitting	NH	18.85	16.51	15.43	12.89
		PH	21.09	17.27	17.60	13.20
		TH	16.59	16.07	16.39	13.90

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

Table 6: Results from a three-way ANOVA on the effects of different holders in Scrolling task

Scrolling task - Wrist Posture										
			(-) Flexion / (+) Extension				(-) Radial / (+) Ulnar			
Device	Posture	Holder	Mean	SD	F - value	p value	Mean	SD	F - value	p value
Large Display	Sitting	NH	15.08	17.25	0.00	0.999	16.37	11.00	0.31	0.737
		PH	15.11	18.70			18.97	12.37		
		TH	14.88	17.14			16.99	11.84		
	Walking	NH	16.33	13.99	0.009	0.991	15.06	8.13	0.308	0.735
		PH	16.86	17.29			17.73	9.06		
		TH	15.89	14.71			15.73	9.56		
Small Display	Sitting	NH	15.78	14.07	0.003	0.997	16.91	9.76	0.365	0.694
		PH	15.77	16.31			19.54	10.29		
		TH	15.43	14.03			17.27	10.39		
	Walking	NH	16.31	12.74	0.022	0.978	17.72	9.71	0.142	0.867
		PH	16.93	15.71			18.81	10.61		
		TH	15.89	13.76			16.79	10.60		

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

Table 7: Results from a three-way ANOVA on the effects of different holders in Typing task

Typing task - Wrist Posture										
			(-) Flexion / (+) Extension				(-) Radial / (+) Ulnar			
Device	Posture	Holder	Mean	SD	F - value	p value	Mean	SD	F - value	p value
Large Display	Sitting	NH	16.59	11.03	0.94	0.392	12.64	8.65	2.16	0.118
		PH	13.14	11.38			18.09	9.22		
		TH	15.46	10.66			13.36	11.07		
	Walking	NH	16.98	9.38	0.337	0.714	12.18	7.14	0.801	0.450
		PH	15.03	10.14			15.57	8.99		
		TH	15.25	11.00			12.98	9.19		
Small Display	Sitting	NH	14.97	10.19	0.156	0.855	12.88	8.15	0.920	0.400
		PH	14.17	12.34			16.41	8.51		
		TH	15.53	10.27			14.34	9.07		
	Walking	NH	16.14	8.93	0.004	0.996	14.14	7.67	0.341	0.712
		PH	16.17	10.74			16.18	8.88		
		TH	16.23	9.90			15.07	9.34		

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

Table 8: Results from a three-way ANOVA on the effects of different holders in Tapping task

Tapping task - Wrist Posture										
			(-) Flexion / (+) Extension				(-) Radial / (+) Ulnar			
Device	Posture	Holder	Mean	SD	F - value	p value	Mean	SD	F - value	p value
Large Display	Sitting	NH	15.01	17.43			16.02	11.03		
		PH	17.32	19.16	0.54	0.585	18.44	12.94	0.27	0.765
		TH	12.92	15.61			15.96	11.70		
	Walking	NH	16.28	14.55			15.15	8.86		
		PH	18.12	18.15	0.207	0.813	17.45	8.95	0.237	0.789
		TH	15.39	14.63			16.75	10.93		
Small Display	Sitting	NH	15.40	13.73			17.29	8.62		
		PH	16.57	17.81	0.131	0.877	18.71	9.40	0.404	0.668
		TH	14.40	13.21			15.77	8.92		
	Walking	NH	16.18	11.64			17.20	9.68		
		PH	17.57	16.07	0.176	0.839	18.28	11.06	0.191	0.826
		TH	15.06	13.40			15.92	10.01		

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

3.6 Neck Posture

Overall, as shown in the results of a one-way ANOVA in the gaming task and a three-way ANOVA in tapping, scrolling, and typing tasks (seen in Table 9, Table 10, Table 11, and Table 12), there is no statistically significant difference among any of the holders in the neck posture or in any of the holders in sitting and walking postures with large and small devices. Overall, three type of holder showed very similar neck angle. However, comparing the posture, the user have more bent their neck when they use the smartphone while walking.

Table 9: Results from a one-way ANOVA on the effects of different holders in Gaming task

Gaming task - Neck Posture				
Device	Posture		Neck angle	
		F	0.098	
		p	0.906	
			Mean	SD
Large Display	Sitting	NH	12.47	4.77
		PH	12.92	4.74
		TH	12.42	4.93

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

Table 10: Results from a three-way ANOVA on the effects of different holders in Tapping task

Tapping task – Neck Posture						
			Neck angle			
Device	Posture	Holder	Mean	SD	F - value	p value
Large Display	Sitting	NH	14.21	5.53	0.04	0.96
		PH	13.84	5.02		
		TH	13.54	5.13		
	Walking	NH	19.54	11.95	0.05	0.95
		PH	19.92	13.39		
		TH	19.11	13.42		
Small Display	Sitting	NH	14.45	5.70	0.52	0.60
		PH	13.72	4.48		
		TH	12.00	4.79		
	Walking	NH	19.13	12.04	0.04	0.96
		PH	19.16	12.01		
		TH	19.74	12.09		

Table 11: Results from a three-way ANOVA on the effects of different holders in Scrolling task

Scrolling task – Neck Posture						
			Neck angle			
Device	Posture	Holder	Mean	SD	F - value	p value
Large Display	Sitting	NH	14.47	6.01	0.07	0.93
		PH	14.64	6.14		
		TH	13.75	5.59		
	Walking	NH	19.70	13.16	0.02	0.98
		PH	19.15	13.61		
		TH	19.46	13.37		
Small Display	Sitting	NH	14.32	5.74	0.24	0.79
		PH	13.68	5.36		
		TH	12.57	5.23		
	Walking	NH	19.55	12.40	0.05	0.95
		PH	19.61	12.30		
		TH	18.87	12.15		

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

Table 12: Results from a three-way ANOVA on the effects of different holders in Typing task

Typing task – Neck Posture						
			Neck angle			
Device	Posture	Holder	Mean	SD	F - value	p value
Large Display	Sitting	NH	17.06	7.56	0.09	0.91
		PH	16.65	6.37		
		TH	16.00	6.09		
	Walking	NH	21.27	12.88	0.36	0.70
		PH	23.26	12.55		
		TH	21.53	12.45		
Small Display	Sitting	NH	16.54	7.00	0.24	0.79
		PH	15.50	5.93		
		TH	14.81	5.81		
	Walking	NH	21.07	12.33	0.26	0.77
		PH	22.41	12.00		
		TH	20.66	11.61		

3.7 Pitch of the device

As shown from the results of the Tapping task and Scrolling task, there is a statistically significant difference ($p<0.05$) in all conditions. The mean and standard deviation in each case is listed.

Table 13: Results from a three-way ANOVA on the effects of different holders in Tapping task

Tapping task - Pitch of the device						
Device	Posture	Holder	Mean	SD	F - value	p value
Large Display	Sitting	NH	23.52	8.17	16.19	0.000
		PH	36.26	10.27		
		TH	35.21	11.60		
	Walking	NH	18.22	7.91	5.909	0.003
		PH	26.42	8.39		
		TH	24.40	9.86		
Small Display	Sitting	NH	29.1664	10.5442	14.651	0.000
		PH	40.0318	10.4011		
		TH	41.4605	12.2429		
	Walking	NH	21.7793	7.48193	10.956	0.000
		PH	32.9288	7.85024		
		TH	30.2147	9.32171		

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

Table 14: Results from a three-way ANOVA on the effects of different holders in Scrolling task

Scrolling task - Pitch of the device						
Device	Posture	Holder	Mean	SD	F - value	p value
Large Display	Sitting	NH	21.79	7.10	16.17	0.000
		PH	33.49	10.87		
		TH	33.78	10.60		
	Walking	NH	17.29	7.75	4.197	0.016
		PH	21.97	9.15		
		TH	24.09	9.94		
Small Display	Sitting	NH	26.02	8.18	17.948	0.000
		PH	37.40	8.06		
		TH	39.35	10.86		
	Walking	NH	19.77	7.79	11.145	0.000
		PH	28.21	9.21		
		TH	30.57	11.03		

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

Table 15: Results from a three-way ANOVA on the effects of different holders in Typing task

Typing task - Pitch of the device						
Device	Posture	Holder	Mean	SD	F - value	p value
Large Display	Sitting	NH	29.84	11.91	0.66	0.515
		PH	27.48	10.85		
		TH	30.75	12.18		
	Walking	NH	27.00	13.21	2.641	0.073
		PH	20.29	10.93		
		TH	24.13	12.74		
Small Display	Sitting	NH	37.04	10.94	0.114	0.892
		PH	37.83	9.26		
		TH	38.44	11.03		
	Walking	NH	31.73	10.62	0.648	0.524
		PH	30.12	9.73		
		TH	33.46	12.05		

3.8 Performance

As shown in the one-way results of the gaming task performance, there was no statistical difference between the holders. However, for the three-way ANOVA results from the Tapping task performance in zone-1 in sitting posture with the large device, there was a significant difference between the holders (P<0.05). Similarly, in the Scrolling task there was a statistically significant difference in task completion time and accuracy for participants using the large display in sitting and walking postures (P<0.05), showing that users exhibited better performance in terms of speed and accuracy while using the Orthotext rather than the Pop Socket. In the Typing task, for the small display both in sitting and walking postures and for the large display in sitting posture, there was a significant difference (P<0.05).

Table 16: Results from a one-way ANOVA on the effects of different holders in Gaming task

	Gaming task	
	Performance - Distance covered in KM	
F	1.031	
p	0.361	
	Mean	SD
NH	23.42	3.68
PH	24.24	2.82
TH	22.99	3.71

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

Table 17: Results from a three-way ANOVA on the effects of different holders in Tapping task

Tapping task - Performance														
			Zone 1 Task Completion Time				Zone 2 Task Completion Time				Overall Task Completion Time			
Device	Posture	Holder	Mean	SD	F - value	p value	Mean	SD	F - value	p value	Mean	SD	F - value	p value
Large Display	Sitting	NH	0.68	0.07			0.81	0.15			0.74	0.10		
		PH	0.75	0.16	3.79	0.024	0.78	0.14	0.90	0.407	0.77	0.13	0.39	0.675
		TH	0.69	0.06			0.82	0.14			0.75	0.09		
	Walking	NH	0.64	0.07			0.72	0.13			0.68	0.09		
		PH	0.66	0.08	2.737	0.066	0.70	0.11	0.533	0.587	0.68	0.09	1.153	0.317
		TH	0.70	0.27			0.72	0.10			0.71	0.15		
Small Display	Sitting	NH	0.64	0.06			0.68	0.08			0.66	0.07		
		PH	0.66	0.07	0.481	0.619	0.68	0.09	1.014	0.364	0.67	0.07	0.879	0.416
		TH	0.67	0.08			0.71	0.09			0.69	0.08		
	Walking	NH	0.64	0.08			0.65	0.09			0.65	0.07		
		PH	0.64	0.07	0.062	0.940	0.64	0.08	0.944	0.390	0.64	0.07	0.204	0.815
		TH	0.63	0.05			0.68	0.08			0.65	0.07		

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

Table 18: Results from a three-way ANOVA on the effects of different holders in Tapping task

Tapping task - Performance														
			Zone 1 Accuracy				Zone 2 Accuracy				Overall Accuracy			
Device	Posture	Holder	Mean	SD	F - value	p value	Mean	SD	F - value	p value	Mean	SD	F - value	p value
Large Display	Sitting	NH	96.17	4.68			81.50	15.66			88.83	9.00		
		PH	94.17	4.75	1.03	0.357	80.33	16.97	2.60	0.075	87.25	9.96	2.23	0.109
		TH	92.50	8.48			73.50	18.76			83.00	12.82		
	Walking	NH	92.67	18.18			81.17	14.18			86.92	14.75		
		PH	92.33	15.01	0.054	0.947	82.83	19.51	4.746	0.009	87.58	16.17	2.354	0.097
		TH	91.83	15.89			72.00	21.56			81.92	17.90		
Small Display	Sitting	NH	95.33	6.01			94.5	7.11			94.92	5.78		
		PH	97.17	4.49	0.855	0.426	94.17	8.82	1.245	0.289	95.67	5.68	1.210	0.299
		TH	93.83	7.03			89.17	12.18			91.5	8.77		
	Walking	NH	96.17	5.83			93.17	7.37			94.67	5.20		
		PH	93.67	9.09	0.736	0.480	91	15.05	0.280	0.756	92.33	10.58	0.334	0.716
		TH	96.5	5.11			90.5	9.59			93.5	6.42		

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

Table 19: Results from a three-way ANOVA on the effects of different holders in Scrolling task

Scrolling task - Performance										
			Task Completion Time				Accuracy			
Device	Posture	Holder	Mean	SD	F - value	p value	Mean	SD	F - value	p value
Small Display	Sitting	NH	0.74	0.21			93.33	6.80		
		PH	0.79	0.30	0.12	0.886	93.42	8.50	0.98	0.378
		TH	0.80	0.25			89.00	11.25		
	Walking	NH	0.75	0.25			90.92	9.97		
		PH	0.75	0.28	0.008	0.992	91.08	7.65	0.320	0.726
		TH	0.76	0.37			88.50	9.50		
Large Display	Sitting	NH	1.12	0.47			78.17	15.18		
		PH	1.23	0.61	9.535	0.000	74.75	13.64	6.298	0.002
		TH	1.66	1.03			65.75	21.28		
	Walking	NH	0.96	0.38			80.08	16.31		
		PH	0.93	0.37	5.760	0.003	78.25	16.64	7.074	0.001
		TH	1.33	0.82			67.50	21.13		

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

Table 20: Results from a three-way ANOVA on the effects of different holders in Typing task

Typing task - Performance										
			WPM				Accuracy			
Device	Posture	Holder	Mean	SD	F - value	p value	Mean	SD	F - value	p value
Small Display	Sitting	NH	28.93	4.70			95.28	3.66		
		PH	25.09	4.51	3.64	0.027	93.87	4.60	0.37	0.689
		TH	27.39	3.89			94.74	3.95		
	Walking	NH	31.19	5.97			94.17	3.27		
		PH	27.19	4.69	4.257	0.015	91.70	6.62	1.147	0.319
		TH	30.22	5.58			93.16	5.33		
Large Display	Sitting	NH	24.69	5.92			93.26	7.22		
		PH	21.13	5.79	3.127	0.045	93.06	4.85	3.002	0.051
		TH	22.60	7.18			89.68	9.19		
	Walking	NH	27.13	5.80			92.86	6.54		
		PH	24.98	5.53	1.237	0.292	91.83	7.33	1.833	0.161
		TH	25.50	6.17			89.77	9.77		

PH = Proposed holder = Ortho text, TH = Traditional Holder = Pop Socket, NH = No Holder

4 Conclusions

As shown in Figure 17, the range of motion for the thumb exhibits a significant difference ($p<0.05$) between the smartphone holders with respect to vertical and horizontal distances reached, which supports the hypothesis. Participants in sitting posture showed a 39.89% greater thumb range of motion for the vertical distance and 47.99% greater thumb range of motion for the horizontal distance as compared to the Pop Socket. Similarly, participants in walking posture showed a 38.88% greater range of motion for the vertical distance reached by the thumb and a 45.61% greater range of motion in horizontal distance reached by the thumb as compared to the Pop Socket and No Holder.

We assumed that the Orthotext would yield lower muscle activity in the thumb and forearm in contrast to the Pop Socket and No Holder, but there was no significant difference ($p<0.05$) between the holders; however, as shown Table 4, especially in the FDI and FDS muscles, the muscle activity means values associated with the Orthotext were lower compared to those associated with the Pop Socket. The 10^{th}, 50^{th}, and 90^{th} percentiles of FDI muscle activation with the Orthotext were 33.33%, 28.04% and 9.04% lower in respective contrast to the Pop Socket. In addition, the 10^{th} percentile of the FDS muscle activation was 7.53% lower compared to that of the Pop Socket. The lack of significant difference may be because the amount of effort required to operate the smartphone Gaming task for 20 minutes is the same with all holders.

We assumed that the Orthotext would have a low level of ergonomic risk in wrist and neck postures as compared to the Pop Socket and No Holder, but there was no significant difference between the holders, and no reported values for wrist posture in any conditions exceeded 21.09 degrees for extension and 19.54 for ulnar deviation, which were the highest values recorded in the Gaming task with the small display and in the Scrolling task with the Orthotext sitting posture. In the Typing task, the level of ergonomic risk in wrist extension mean values of the Orthotext was lower compared to that of the Pop Socket in all conditions with both large and small display, and in sitting and walking postures. Similarly, in the neck posture, as shown in Table 10, the level of ergonomic risk was 3.02% lower for the Orthotext, in contrast to Pop Socket, in the tapping task with the small display in walking posture, and, as shown in Table 11, the level of ergonomic risk was 1.61% lower for the Orthotext in the scrolling task with large display in walking posture. Finally, posture analysis of user wrist movement to reach the upper and lower diagonal sections of the smartphone screen were exactly the same for all holders because the user needs to bend the wrist to reach the target. Similarly, the neck posture in which the user operates the Orthotext was the same for the Pop Socket, according to users' natural usage of smartphone. Because there was no significant difference for these aspects, the trend was the same for all holders.

We assumed that the Orthotext would perform better in terms of speed and accuracy than the Pop Socket and No Holder, but there was no significant difference in overall performance between holders. However, when we compare the mean value, for the Orthotext in the scrolling task with large display in sitting posture, as shown in Table 19, task completion time was 0.43 seconds faster and accuracy was 13.68% higher compared to Pop Socket results. In walking posture, the Orthotext task completion time was 0.40 seconds faster and accuracy was 15.92% higher compared to Pop Socket results. Finally, the Orthotext in the Typing task, as shown in Table 20, had 3.76% higher accuracy compared to the Pop Socket. The Orthotext and Pop Socket exhibited a similar trend in the mean values in all conditions.

We assumed that, when compared to the Pop Socket and No Holder, the Orthotext would yield less subject discomfort, and this hypothesis was proved for only one of the five body parts, the shoulder, which showed a significant difference ($p<0.05$), as seen in Figure 18, with 46.15% lower subject discomfort rating. The mean values of other body parts, including the hand, thumb, neck, and wrist, also have lower subject discomfort ratings compared to the Pop Socket.

We assumed the Orthotext would be highly user preferred over the Pop Socket and No Holder, and this hypothesis was proved by the significant difference ($p<0.05$) between the holders for all questions, as shown in Figure 16.

We assumed that the Orthotext would yield an ergonomic, level pitch of the device when compared to the Pop Socket and No Holder, and this hypothesis was partially proved. There was a significant difference between holders in Tapping and Scrolling tasks, where the pitch of the device was higher in Orthotext in tapping task and some conditions of scrolling task.

In summary, in this project, we compared the performance, user preference, muscle activity, subject discomfort, device pitch, wrist posture, neck posture, and range of motion during the use of an Orthotext holder, a Pop socket holder, and a phone with no holder with participans in sitting and walking postures while performing a tapping task, a swiping task, a scrolling task, a gaming task, and a typing task. The results showed that there is a significant difference in the range of motion for the thumb, user preference the subject discomfort of the shoulder between the three holders ($p<0.005$). Thus, based on our results, we recommend the Orthotext holder over the Pop Socket because of the Orthotext's greater range of motion, lower subject discomfort, and increased user preference. The remaining dependent variables exhibited a similar trend but there was no negative effect on Orthotext compared with other holders.

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