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ASSESSING OPTIMAL RELATIONSHIPS AMONG MULTI-TOUCH GESTURES AND FUNCTIONS IN COMPUTER APPLICATIONS

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With touchscreen-enabled devices becoming more prevalent throughout military applications, it is important to create a standardized set of touchscreen gestures for military purposes. This standardized set must easily transfer among devices military personnel use for operations. The authors describe the identification of common gestures using mockups of large-screen and small-screen devices. Results show the majority of gestures were similar among participants, concluding that establishing military gesture standardization is very possible and could be put into practice throughout the military population, with training for less common gestures, and buttons or menu items used for very uncommon gestures. Through this research, the authors provide a beneficial first step in evaluating the set of gestures currently under development, and suggest further research with military personnel as a necessary next step for the development of a standardized gesture set for use in military purposes.

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FOREWORD

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1.0 INTRODUCTION

Touchscreen technology has been around since 1965; however, it is just beginning to come out of its infancy [1]. Widespread use of smart phones, tablets, and personal computers (PCs) has enabled system designers to create a variety of touch-based schemas that allow for control of these devices. Gestures, or recognizable patterns of touch movements [2], are the primary mode of control for touchscreen devices. Very little published research has been conducted to assess the optimal relationship among specific gestures and the functions they control [3]. Further complicating the matter, proprietary gesture libraries usually do not agree as to the most advantageous gesture-function relationships, giving rise to different expectations and preferred control schemas among user groups and competing products [4].

Surface gestures, or points-of-contact moving on a surface, are complex haptic events that dictate how humans interact with touchscreen computing devices. Current technological advancements have enabled versatile, reliable, and affordable touchscreen-enabled devices that support fluid gesture interaction. The two types of gestures are “free-form” and “restrictive.” Free-form gestures usually originate from memory, and are generally created from previous experience with other touchscreen devices or other similar actions. This type of gesture is used to manipulate applications on touchscreen devices. For example, the swipe gesture for turning a page on the Kindle Touch[1] e-reader is a free-form gesture. Restrictive gestures are used to control tools, such as a form slider, on the screen. That form of interaction in an application would be object manipulation, but the slider acts as a guide that essentially tells the user what to do and restricts user interaction to the proper directions.

While researching free-form gestures, human-computer interaction researcher Meredith Ringel Morris and colleagues demonstrated that user-defined gesture sets were more intuitive to the general population than expert-defined gesture sets [5]. The popularity of the gesture (i.e., the number of people who authored the gesture) also correlated to a greater perception of “goodness,” or a quality match of gesture to function. The finding of an inverse significant relationship of goodness to complexity indicated that the more complex referents (the actions taken to perform the gesture) resulted in lower ratings of goodness. Research findings indicated some functions did not have a natural fit to a gesture. Many users cemented these findings by acting on imaginary widgets, such as clicking the “X” in the top right corner of a website or document, rather than creating their own gesture. Previous research has demonstrated protocols that can be used to generate gestures for a function set [6] [7] [8], but little has been done to understand why people find some gestures more intuitive than others—an important factor to consider prior to standardization.

The widespread use of gestures in the public sector has caused the Navy to take interest in the feasibility of implementing touchscreen computing devices aboard surface-ship platforms. To accomplish this task, an appropriate gesture set must be defined and standardized. Research funding has been allocated to develop a touchscreen gesture code library written in Java for use by the entire Navy with an open-source license [9]. The purpose of the following research is to document optimal relationships among gestures, using multi-touchscreen technology to control functions in computer operating systems. The end objective of this project is proper system design and the development of military standards for gesture-to-function mapping. These

[1] registered trademark of Amazon.com, Inc., or its affiliates

standards will be provided to software developers to promote a Navy standard, increasing efficiency and commonality among Navy computing systems.

2.0 RESEARCH PURPOSE AND OBJECTIVES

Individual gestures are commonly and repeatedly used for various functions in a single device or application, depending on current factors such as the application in use, modal instances in each application, and a point on the screen where the gesture is initiated. Beyond the assignment of multiple functions to each gesture, assigning permanent relationships among gestures and functions in certain applications would serve to inhibit the development of unintended gesture-elicited interactions. Because of the reliability and affordability of touchscreen-enabled devices, their use in military applications has become more prevalent and is likely to increase in the future. In military applications, the single-tap movement is most commonly used on touchscreen devices. Since the release of the iPhone[2] in 2007, many devices have been marketed that employ a variety of touchscreen gestures as the principle means of user interaction. New products and novel interaction styles continue to be invented, using gestures in ways not considered just a few years ago, that are incompatible with existing devices or potentially confusing to users of touchscreen systems.

While it is important to be consistent with the appropriate use and development of gesture technology, it is also important to facilitate the ability of users to effectively operate this technology, easily transitioning among different devices and rapidly adopting new implementations. Proprietary gesture libraries do not tend to agree in pairing specific gestures to particular functions, no doubt due in part to the use of intellectual property claims to limit competition and discourage user defection to competing systems [10]. The goal of this research is to develop standards for touchscreen gestures in military applications, with current-effort objectives to:

a. Determine the preferred gesture-function mappings for common computing functions
b. Determine the agreement between the participant gesture and function mapping
c. Identify the gesture-to-function mapping that best reflects participant mappings for a potential standard mapping of military touchscreen devices

3.0 METHODOLOGY

3.1 Participants

Participants were civilian Department of Defense (DoD) personnel chosen based on availability and willingness to participate. Recruitment was conducted through e-mail to inform potential participants of the research intent and paradigm, and time requirements. Age, gender, and experience with touchscreen devices were not used as qualifying or disqualifying factors, but were captured during the experiment.

3.2 Test Materials

Mockups of both larger stationary (e.g., surface or desktop computer) and smaller mobile (e.g., cell phone) devices were used. The mockups represented a 25" x 20" surface device and a 4.5" x 2.5" mobile device, as shown in Figure 1.

[2] registered trademark of Apple Inc.

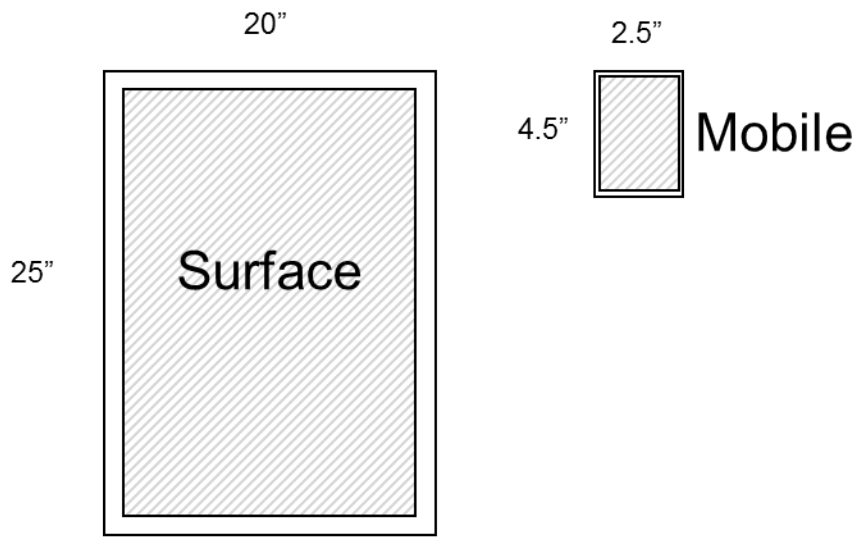

Figure 1. Diagram of Touchscreen Devices

3.3 Procedure

Each participant attended a single one-on-one session lasting approximately two hours. Initially, the researcher gave the participant a consent form, and explained the purpose and expectations of the participant in regards to the experiment. If the participant chose to continue and signed the form, the researcher administered a survey requesting participant demographic information and prior experience with touchscreens, other computing devices, operating systems, applications, and gestures. Next, each participant was asked to demonstrate the gesture he or she considered most natural for 42 common computing functions (e.g., Go to Desktop, Minimize Application, Move Object, Save, Zoom In) on both the surface and mobile device mockups.

Participants were instructed to perform all gestures with one hand; a standardized Navy gesture set must apply to dismounted scenarios where a warfighter might carry a tablet in one hand. Participants performed gestures on a solid white background with a black border indicating screen edges. They were provided appropriately-sized screenshots and were asked to envision those scenarios on the screen; however, the gesture area was blank to prevent users from touching specific parts of the screen. Participants were instructed to verbally indicate if they touched a specific item or any specific location on the screen. They were also told to treat each function independently since it is possible for an individual to give different functions the same gesture. In an effort to control hand availability, device usage was restricted to a stationary, face-up position, with the device resting flat on a table in a vertical orientation (as seen in Figure 1). The participants were then asked to perform their gesture elicitation for each of the 42 gestures on the mobile-device mockup, followed by the larger surface-device mockup. This approach may be unrealistic in respect to mobile devices, which are often held in one hand, but it allowed the isolation of screen size as an independent variable. Freeing both hands also allowed more freedom in elicitation, yielding the participants’ preferences.

3.4 Gesture Agreement Function Analysis

The agreement function is calculated to determine how similarly participants’ responses are to one another when asked to perform a gesture for each function. Agreement is a formula that groups similar proposed gestures, and weights them according to the number of participants proposing each gesture. The formula is presented below, where r is a referent in the set of all referents R, P_r is the set of proposed gestures for referent r, and P_i is a subset of identical gestures from P_r. [8]:

$$A = \frac{\sum_{r \in R} \sum_{Pi \in Pr} \left(\left| \frac{Pi}{Pr} \right| \right)}{|R|}$$

Agreement is scaled from zero to one; one equaling the highest level of agreement. Therefore, the level of agreement will equal 100 percent if all participants' gestures are identical, and equal 0 percent if all participants' gestures are different. A high agreement or a strong gesture-to-function mapping means the proposed gestures should be assigned to those functions on computing systems. Since no accepted threshold currently exists of what the appropriate agreement value should be, thresholds have been established as:

a. High: an agreement value above 0.70
b. Medium: an agreement value from 0.40 through 0.70; represents moderate agreement in gesture-to-function mapping (not immediately natural to all users)
c. Low: an agreement value below 0.40; represents a gesture-to-function mapping not expressed by many participants

Section 4.2 details the result findings.

4.0 RESULTS

4.1 Demographic Results

Twenty subjects participated in the experiment. All participants were DoD civilian employees. Table 1 shows participants' age and gender demographic data.

Table 1. Participant Information

Participants	**Mean (S.D.)**
Age (Years)	35 (12)
Gender	10 M|10 F

Table 2 details the range and average years of experience participants had with both touchscreen (TS) and non-touchscreen (non-TS) devices. An additional component, how many of the participants had experience with each type of device, provided interesting results.

Table 2. Participants' Device Experience

	Personal Computer		**Tablet**		**Mobile Device**		**Navy Console**	
	Non TS	TS	Non TS	TS	Non TS	TS	Non TS	TS
Average	**18.9**	**0.6**	**1.6**	**1.2**	**11.2**	**3.6**	**1.5**	**0.7**
Min	3	0	0	0	5	0	0	0
Max	34	4	25	4	22	7	8	8

Experience with a non-touchscreen PC ranged from 3 to 34 years, with an average of 18.9 years. Experience with the touchscreen PC ranged from 0 to 4 years, with an average of 0.6 years. Overall, 100 percent of the participants had experience with a non-touchscreen PC, and 20 percent had experience with a touchscreen PC.

Experience with a non-touchscreen tablet ranged from 0 to 25 years, with an average of 1.6 years. The touchscreen tablet experience ranged from 0 to 4 years, with an average of 1.2 years. Overall, 20 percent of the participants had experience with a non-touchscreen tablet, and 60 percent had experience with a touchscreen tablet.

Experience with a non-touchscreen mobile device ranged from 5 to 22 years, with an average of 11.2 years. The touchscreen mobile device experience ranged from 0 to 7 years, with an average of 3.6 years. Overall, 100 percent of the participants had experience with a non-touchscreen mobile device, and 90 percent of the participants had experience with a touchscreen mobile device.

Experience with a non-touchscreen Navy console ranged from 0 to 8 years, with an average of 1.5 years of experience. The touchscreen Navy console experience also ranged from 0 to 8 years, with an average of 0.7 years. Overall, 20 percent of the participants had experience with a non-touchscreen Navy console, and 15 percent had experience with a touchscreen Navy console.

4.2 Gestural Agreement Results

The agreement function was calculated for each of the 42 gestures using the agreement formula described in Section 3.4. Figure 2 and Table 3 are color coded according to low-, medium-, and high-agreement thresholds. Figure 2 details the functions with scores in descending order of agreement from left to right. Table 3 provides the agreement score for each function. The gesture functions with a high or medium agreement are listed on the left; the gestures with a low agreement are listed on the right.

As seen in Figure 2 and Table 3, approximately half the gestures had either a medium (40 percent) or high (10 percent) agreement, and the other half had a low-user agreement (55 percent).

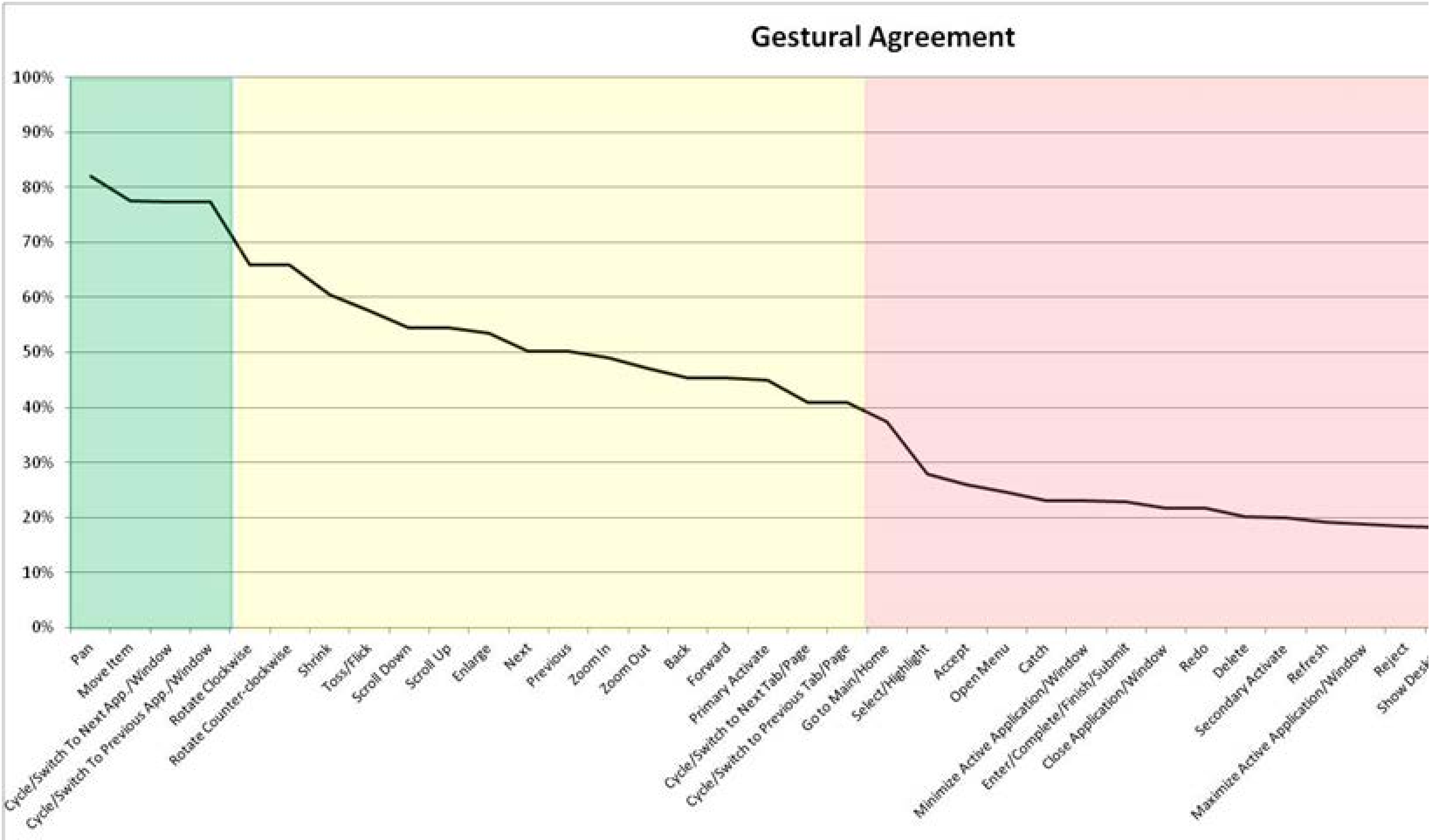

Figure 2. Gestural Agreement Findings

Table 3. Function to Gestural Agreement Value Grouping

Medium and High Agreement		**Low Agreement**	
Gesture Function	Agreement	Gesture Function	Agreement
Pan	82%	Go to Main/Home	37%
Move Item	78%	Select/Highlight	28%
Cycle/Switch to Next App./ Window	77%	Accept	26%
Cycle/Switch to Previous App./ Window	77%	Open Menu	25%
Rotate Clockwise	66%	Catch	23%
Rotate Counterclockwise	66%	Minimize Active Application/ Window	23%
Shrink	61%	Enter/Complete/Finish/Submit	23%
Toss/Flick	58%	Close Application/Window	22%
Scroll Down	55%	Redo	22%
Scroll Up	55%	Delete	20%
Enlarge	54%	Secondary Activate	20%
Next	50%	Refresh	19%
Previous	50%	Maximize Active Application/ Window	19%
Zoom In	49%	Reject	19%
Zoom Out	47%	Show Desktop	18%
Back	45%	Save	18%
Forward	45%	Undo	18%
Primary Activate	45%	Paste	15%
Cycle/Switch to Next Tab/Page	41%	Open Help	14%
Cycle/Switch to Previous Tab/Page	41%	Open Search	14%
		Copy	12%
		Cut	10%

4.3 Function-to-Gesture Mapping Results

The function-to-gesture mapping analysis details both the gesture motion and the draw pattern the participant used. The gesture motion describes the action the participant took to accomplish the gesture (e.g., single tap, double tap, swipe, press and hold). Table 4 is a summary of the most frequently used gesture motions and draw patterns. Appendix A gives more in-depth results: pairs of pie charts detail the gesture motions and draw patterns used for each of the 42 gestures.

Table 4. Summary of Gesture Motion and Draw Pattern

Gesture Function	Top Gesture Motion	Top Draw Pattern
Accept	Single Tap	Point
Back	Swipe	Line
Catch	Press and Hold	Point
Close App./Window	Single Tap	Point
Copy	Press and Drag	Point
Cut	Press and Drag	Point
Delete	Press and Drag	Line
Enlarge	Spread	Line
Enter/Complete/Finish	Press and Drag	Point
Forward	Swipe	Line
Go to Main/Home	Single Tap	Point
Maximize App./Window	Single Tap	Line
Move Item	Press and Drag	Line
Maximize App./Window	Press and Drag/Swipe	Line
Next	Swipe	Line
Open Help	Press and Drag	Point
Open Menu	Single Tap	Point
Open Search	Press and Drag	Point
Pan	Press and Drag	Pan
Paste	Press and Drag	Point
Previous	Swipe	Line
Primary Activate	Single Tap	Point
Redo	Press and Drag	Arc Open Down
Refresh	Press and Drag	Point
Reject	Press and Drag	Point
Rotate Clockwise	Press and Drag	Circle
Rotate Counterclockwise	Press and Drag	Circle
Save	Press and Drag	Point/Line
Scroll Down	Press and Drag	Line
Scroll Up	Press and Drag	Line
Secondary Active	Double Tap	Point
Select/Highlight	Press and Drag	Line
Show Desktop	Swipe	Line
Shrink	Pinch	Line
Switch to Next App./Window	Swipe	Line
Switch to Next Tab/Page	Swipe	Line
Switch to Prev. App./Window	Swipe	Line
Switch to Prev. Table/Page	Swipe	Line
Toss/Throw	Flick	Line
Undo	Press and Drag	Arc Open Down
Zoom In	Spread	Line
Zoom Out	Pinch	Line

Gesture Motions

A maximum of 840 gesture motions were possible. For the mobile and surface devices, 20 individuals performed each of the 42 gestures, creating 840 participant actions. For example, the press and drag gesture motion was performed 256 times out of a possible 840 times, resulting in its use for 30 percent of the trials for the mobile device. Appendix B defines all motion and gesture functions.

The most commonly used gesture motion was press and drag; 32 percent of both mobile and surface devices. The swipe motion was the second most popular motion; 23 percent of both devices. Single tap and double tap were the next most frequently used gesture motions; 14 percent and 10 percent, respectively, for both devices. The other movements were used in 5 percent or less of the trials, including spread, pinch, press and hold, and flick. Detailed results are in Table 5.

Table 5. Most Commonly Used Gesture Motions

Gesture Motion	Mobile Device	Surface Device
Press and Drag	30% (256)	32% (268)
Swipe	23% (194)	23% (194)
Single Tap	14% (118)	14% (114)
Double Tap	10% (84)	10% (82)
Spread	5% (42)	5% (42)
Pinch	5% (41)	5% (44)
Press and Hold	4% (33)	4% (36)
Flick	4% (30)	3% (26)

Draw Patterns

Results show that patterns drawn by participants were simple shapes and lines that were very similar to one another. Table 6 details the draw patterns used for mobile and surface devices. Line draw patterns were used 53 percent of the time, regardless of what device type was used. The point pattern was the second most used; 32 percent for both the surface and mobile devices. All other draw patterns were used 6 percent or less for the 840 total possible actions, including circle, “X,” arc open down, checkmark, and “S.”

Table 6. Most Commonly Used Draw Patterns

Draw Pattern	Mobile Device	Surface Device
Line	53% (415)	53% (417)
Point	32% (255)	32% (254)
Circle	6% (49)	6% (50)
"X"	3% (20)	3% (20)
Arc Open Down	2% (18)	2% (18)
Checkmark	2% (14)	2% (14)
"S"	1% (9)	1% (9)
"?"	1% (9)	1% (9)

4.4 Screen Size Results

This study sought to determine if the size of the touchscreen had an effect on gesture selection. The mobile and surface simulated touchscreen devices represented two ends of the current spectrum: a large-screen computer versus a handheld small-screen mobile device. Results show that, as a rule, participants interacted similarly with the two devices. These results extended to both the gesture motion and draw pattern.

Figure 3 details gesture motions that were used on mobile or surface devices a minimum of five times, showing top gesture-motion differences by device. Figure 4 details the top draw patterns for the two devices. As with the gesture motion, differences between the two devices are nearly nonexistent for draw patterns that have been used a minimum of five times.

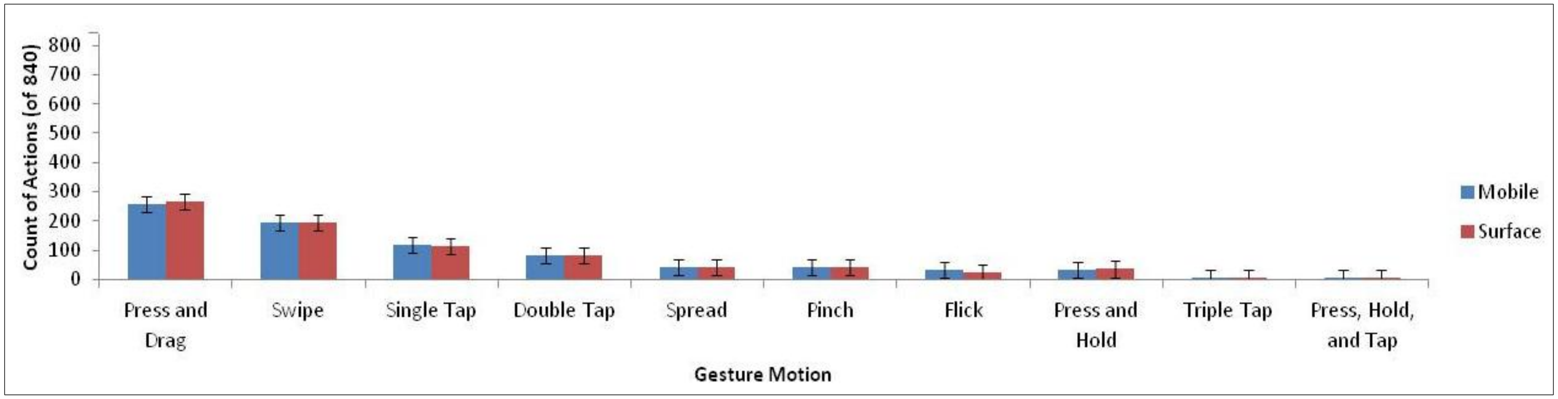

Figure 3. Gesture Motion Based on Screen Size

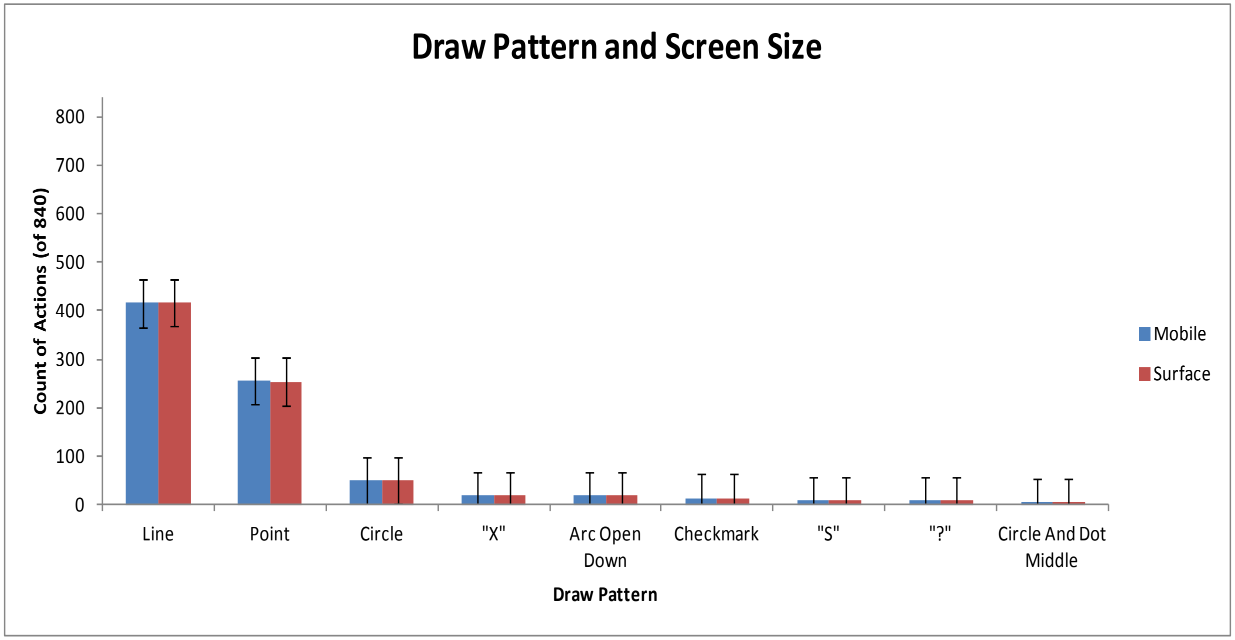

Figure 4. Draw Pattern and Screen Size

A third metric, the number of contact points, was also collected for comparison of the two devices. The larger screen of the surface device provided surface area for additional contact points, but participants rarely used the additional surface area. Figure 5 shows details of those results.

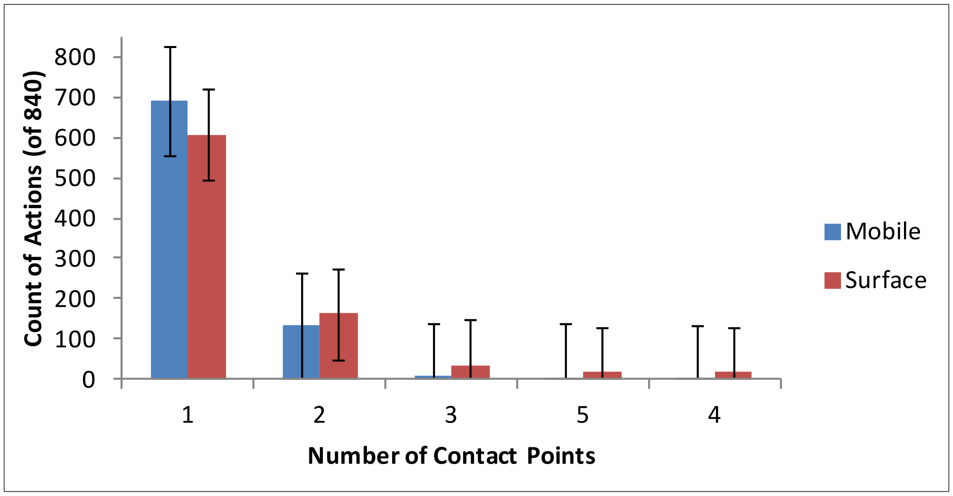

Figure 5. Contact Points and Screen Size

4.5 Button/Menu Expectation Results

The expectation for a permanent, nongestural-based button is most prominent for functions that do not have industry gesture support. Figure 6 details the number of participants expecting a soft-button menu item for each gesture.Support for nongestural-based buttons can be found for a single-tap draw pattern that may indicate a participant click on an "X" to close an application or enable a function. All button requests were followed by reference of a mouse or keyboard system with which the participant had experience. This demonstrates that people previously trained in graphical user interfaces have expectations that transfer to new systems, including those with different modes of interaction, such as with the use of gestures, mice, or video game controllers. Assuming a similar expectation existed for all functions before participants used a touchscreen, the drastic drop on the right may indicate a lack of training or usage in commonly used touchscreen devices. Participants often noted they were using gestures supported by their personal devices for those functions.

As a rule, gestures with a medium- or high-agreement function had a low number of participants indicating the gesture should be a button or soft menu. Conversely, gestures with a low-agreement function had a high number of participants indicating the gesture should be represented by buttons or soft menus. Only one gesture function, secondary activate, was found to violate this trend, as it was a low-agreement gesture that was generally not expected by participants to be a soft menu or button.

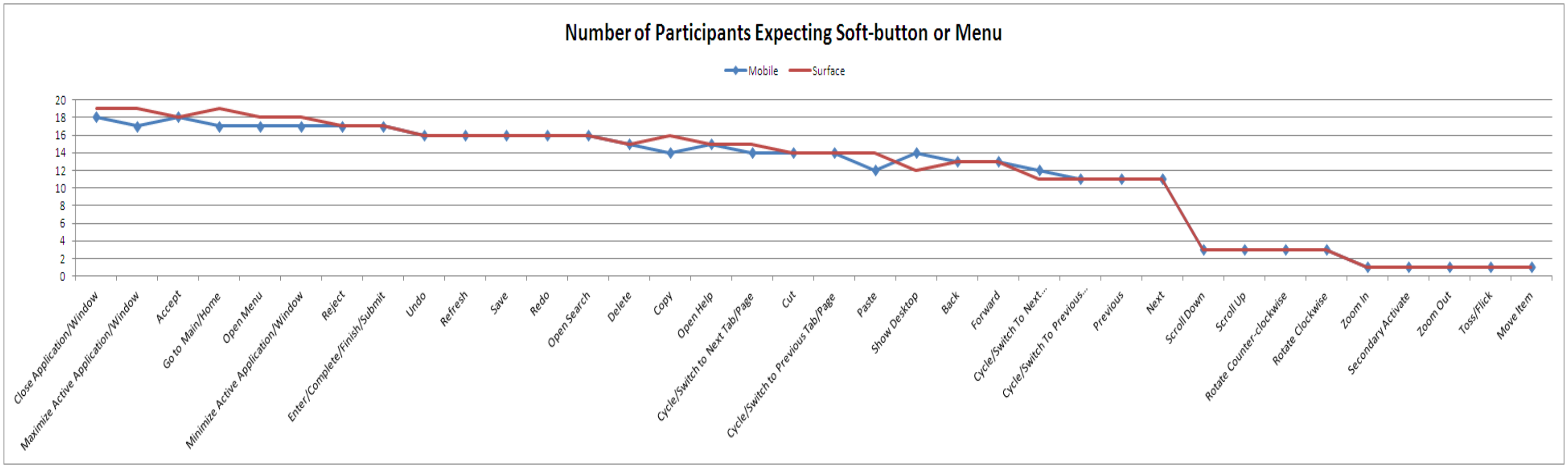

Figure 6. Participant Expectations for On-Screen Buttons or Menus

4.6 Fit and Difficulty

Participants were asked to rate each gesture on a scale from 1 through 7 regarding:

a. How well the gesture matched its intended purpose (with the best fit or strongest association equaling 7)
b. How difficult the gesture was to perform (with the most difficult equaling 7)

As shown in Figure 7, the first question addressed the fit of the gesture to its intended purpose (top dashed blue line), and the second addressed the difficulty of the gesture (bottom solid red line). The average rating of gesture match to intended purpose varied between 4.5 and 6.5 on the 7-point scale, indicating that even the worst fits were reported as being relatively good. As depicted in the graph, little difference was noted in difficulty among gestures, indicating that participants found all gestures relatively easy to perform.

These ratings were determined by participants who created and then rated their own gestures, potentially leading to some high ratings. Although future research may pose this information differently (e.g., rate the following gestures based on these criteria), the information in the current context may still prove useful. If participants are asked to create an action for the copy gesture, but do not think the gesture they created is a particularly good one, they may rate their gesture lower. This effect is illustrated in Figure 8. Many participants rated their gesture relatively low, particularly for the first question that addressed the intended purpose or fit. This same trend was not seen in the gesture difficulty ratings (see Figure 9), possibly due to the opinion by many participants that the gestures, in general, were not very difficult to perform.

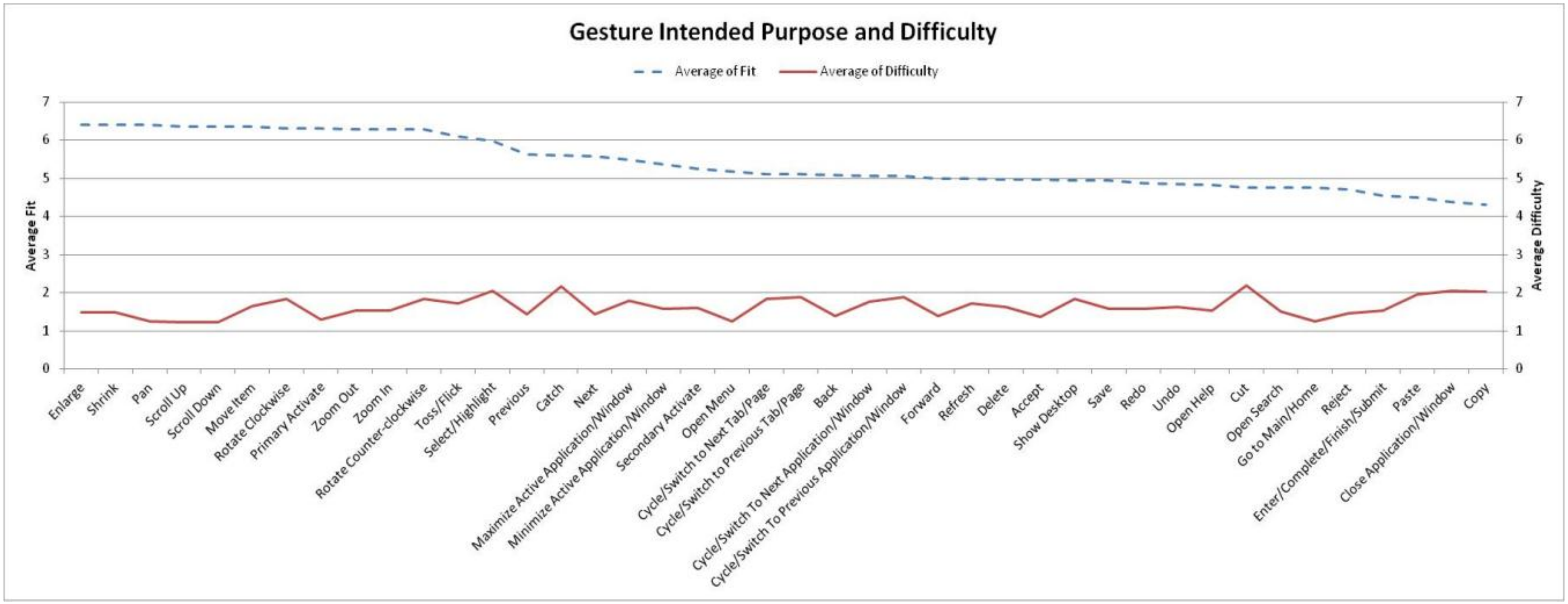

Figure 7. Gesture-Intended Purpose and Difficulty

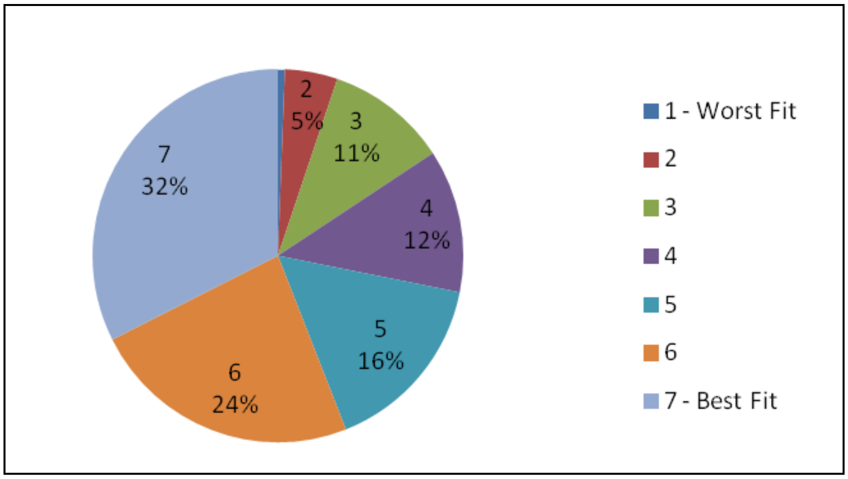

Figure 8. Participants' Rating of Their Gesture: Match to Intended Purpose

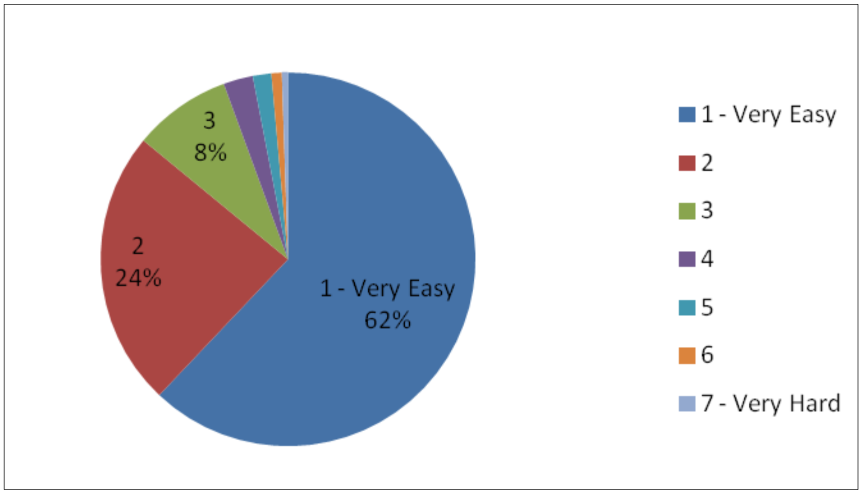

Figure 9. Participants' Rating of Their Gesture: Difficulty to Perform

5.0 CONCLUSIONS

Research results indicate that creating a standardized set of gestures is possible, and may readily transfer among devices. Nearly half of the 42 gestures examined in this study had a medium to high agreement by users. As previous results have revealed, the gestures created by a large number of participants resulted in each participant's determination of a better gesture-to-function match [5]. Therefore, those gestures with a high-agreement rating (calculated by the number of participants who authored the gesture) should be further tested to ensure the trends found in this preliminary study extend to all potential users. The agreement function may reflect a strong consensus among participants with similar experience, signifying the greatest determining factor is experience. However, this strong consensus could be due to prior experience with gestures commonly found on specific widespread touchscreen devices or operating systems, or the similarity to real-world actions (e.g., the swipe gesture that is similar to turning a traditional book's page). These factors should be further explored with the intended user group; in this case, a military population.

Gestures such as copy that are not naturally intuitive to users can be targeted for training.

Decisions will have to be made to identify what non-natural gestures will be used with which draw points, and how gesture training and implementation will occur. Further research will have to be conducted to determine the effects of gesture quantity, complexity, and interference on trainability and memory associations. Ultimately, specific gesture pattern (i.e., the touch combination and movement sequence) must be trained. The ease of training and memory strength will be determined by the intensity of association with real-world actions or prior touchscreen usage. For Navy-focused standards, identifying which types of association (e.g., symbolic, metaphorical, physical) are the strongest should be considered, rather than solely focusing on gestures with wide agreement.

The use of simulated mockup devices in the current study provided a beneficial first step in evaluating the set of gestures currently in development. However, future studies should confirm the results from this experiment with the use of actual touchscreen devices and scenario-based examples where the user can interact with realistic stimuli on touchscreen devices. This additional data, along with the assistance of representative users (i.e., military personnel), is a necessary next step for the development of a standardized gesture set for military purposes.

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[5] Meredith R. Morris, Jacob O. Wobbrock, and Andrew D. Wilson, "Understanding Users' Preferences for Surface Gestures," in *GI '10 Proceedings of Graphics Interface 2010*, Ottawa, ON, 2010, pp. 261-268.

[6] Dan Mauney, Jonathan Howarth, Andrew Wirtanen, and Miranda Capra, "Cultural Similarities and Differences in User-Defined Gestures for Touchscreen User Interfaces," in *CHI '10 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Atlanta, GA, 2010, pp. 4015-4020.

[7] Jacob O. Wobbrock, Htet Htet Aung, Brandon Rothrock, and Brad A. Myers, "Maximizing the Guessability of Symbolic Input," in *CHI '05 Proceedings of SIGCHI Conference Extended Abstracts on Human Factors in Computing Systems*, Portland, OR, 2005, pp. 1869-1872.

[8] Jacob O. Wobbrock, Meredith R. Morris, and Andrew D. Wilson, "User-Defined Gestures for Surface Computing," in *CHI '09 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Boston, MA, 2009, pp. 1083-1092.

[9] In-House Laboratory Independent Research Program Review Poster, 2012, unpublished.

[10] Kevin Xiaoguo Zhu and Zach Zhizhong Zhou, "Research Note---Lock-In Strategy in Software Competition; Open-Source Software vs. Proprietary Software," *Information Systems Research*, vol. 23, no. 2, pp. 536-545, 2012.

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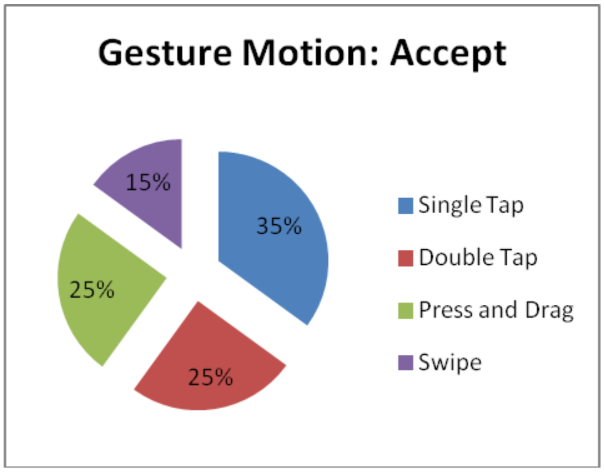
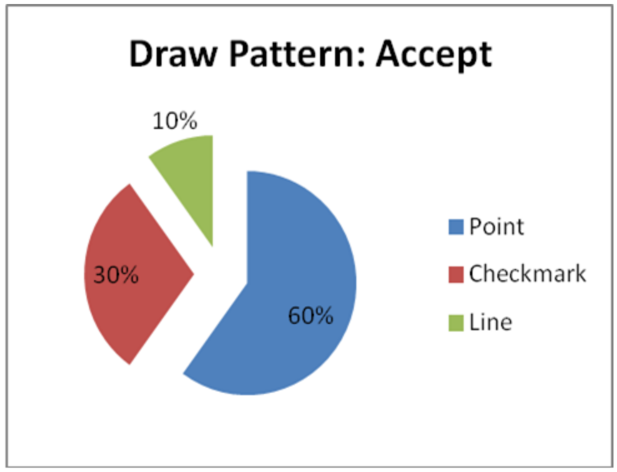
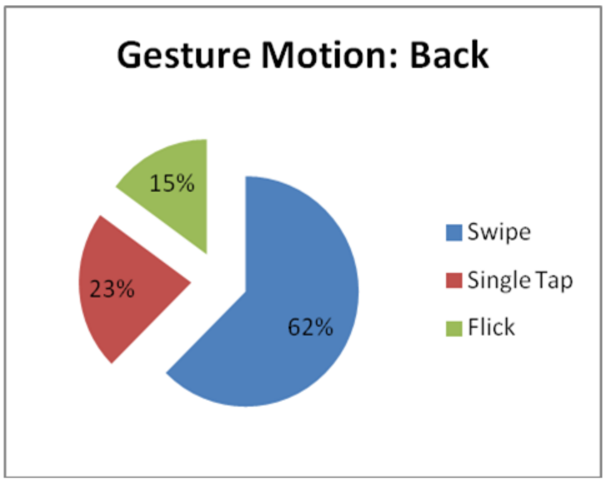
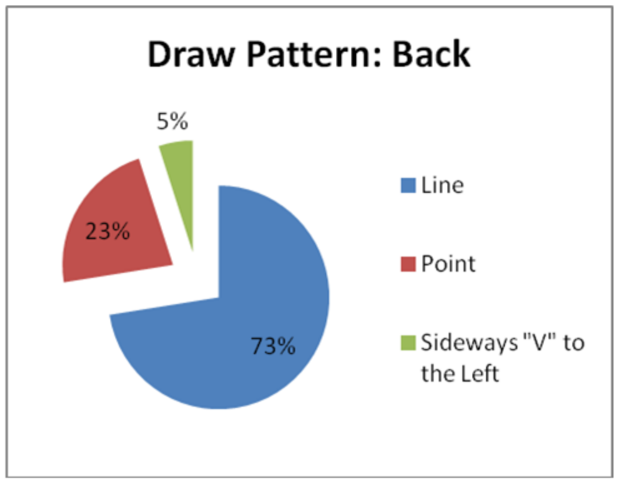
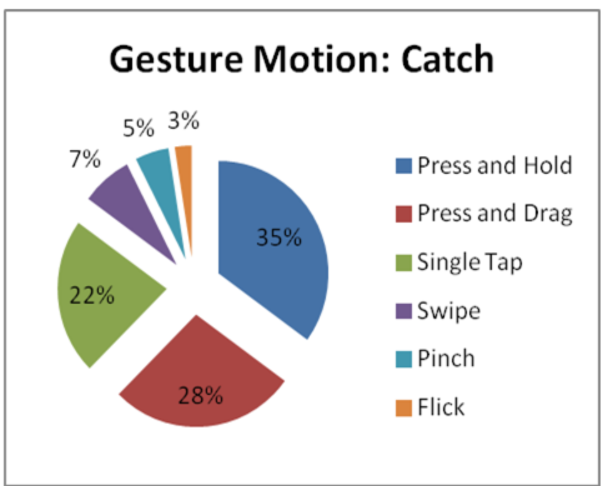
APPENDIX A: FUNCTION-TO-GESTURE MAPPING RESULTS

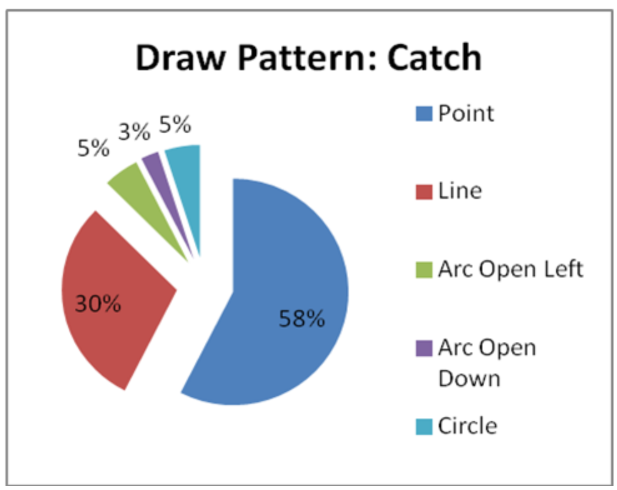

Gesture Motion: Accept
15%
35%
25%
25%
Single Tap
Double Tap
Press and Drag
Swipe

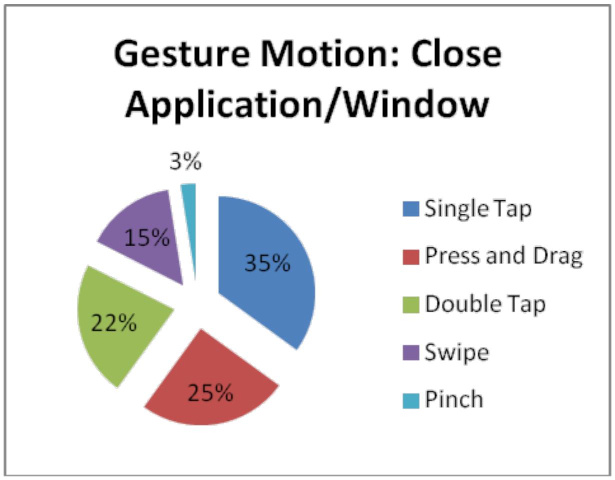

Draw Pattern: Accept
10%
30%
60%
Point
Checkmark
Line

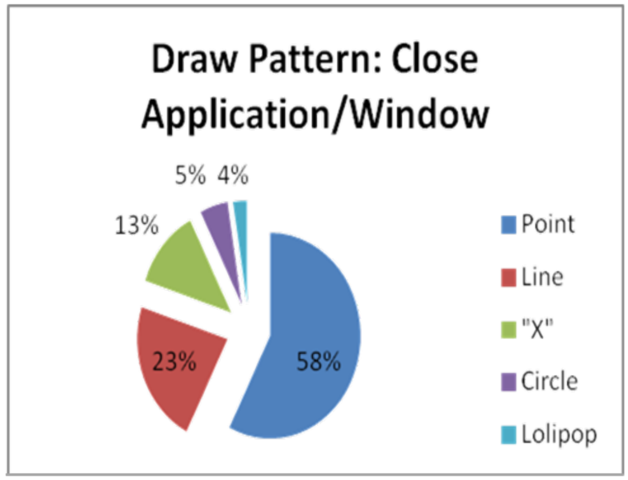

Gesture Motion: Back
15%
23%
62%
Swipe
Single Tap
Flick

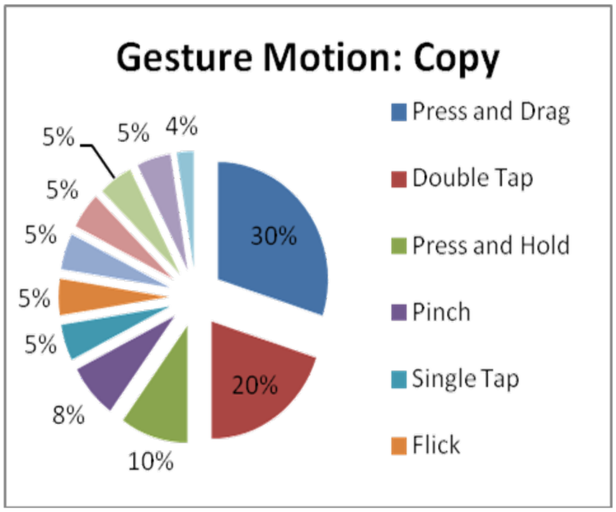

Draw Pattern: Back
5%
23%
73%
Line
Point
Sideways "V" to the Left

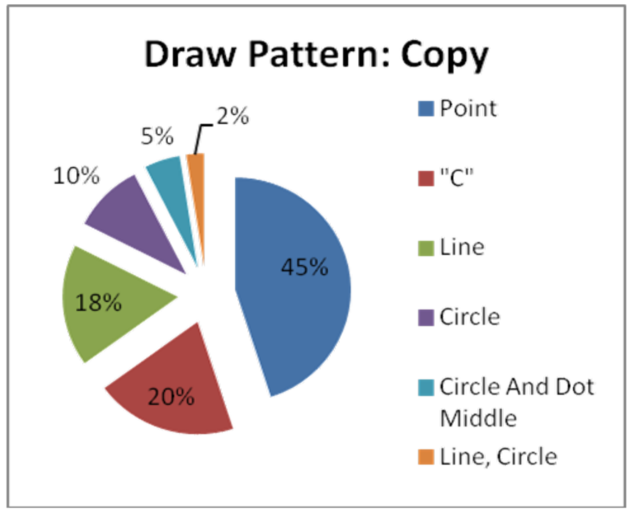

Gesture Motion: Catch
7%
5%
3%
35%
22%
28%
Press and Hold
Press and Drag
Single Tap
Swipe
Pinch
Flick

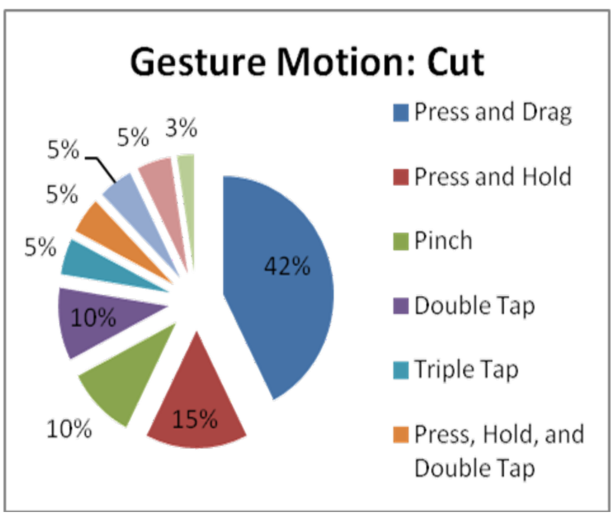

Draw Pattern: Catch
5%
3%
5%
30%
58%
Point
Line
Arc Open Left
Arc Open Down
Circle

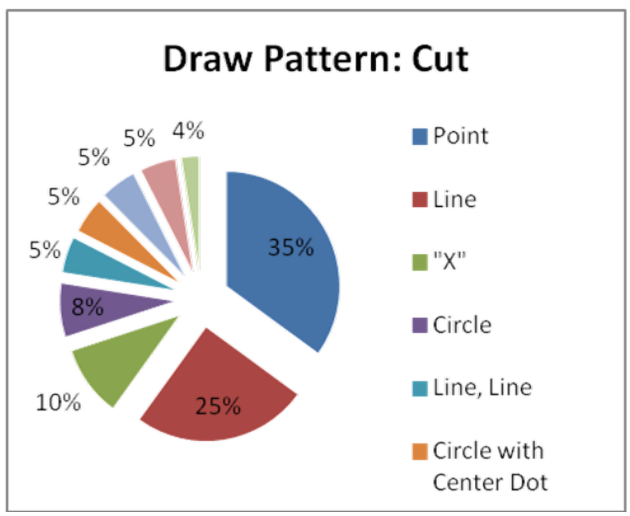

Gesture Motion: Close Application/Window
3%
15%
35%
22%
25%
Single Tap
Press and Drag
Double Tap
Swipe
Pinch

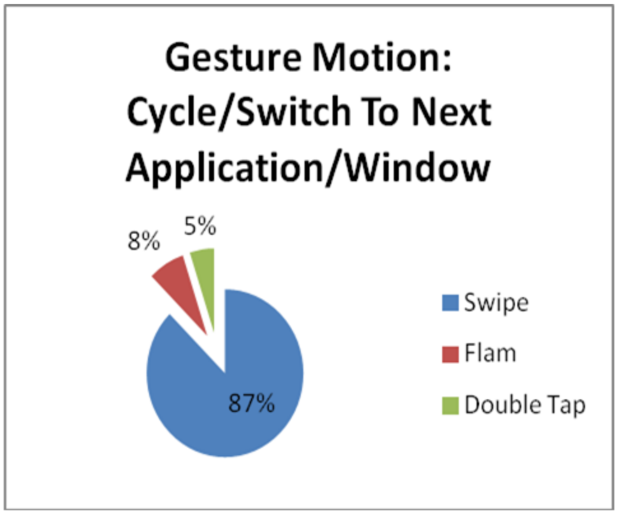

Draw Pattern: Close Application/Window
5% 4%
13%
23%
58%
Point
Line
"X"
Circle
Lolipop

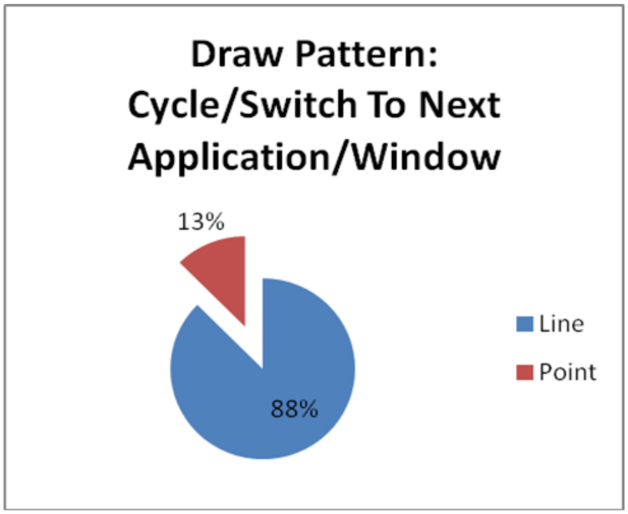

Gesture Motion: Copy
5% 5% 4%
5%
5%
5%
5%
8%
10%
30%
20%
Press and Drag
Double Tap
Press and Hold
Pinch
Single Tap
Flick

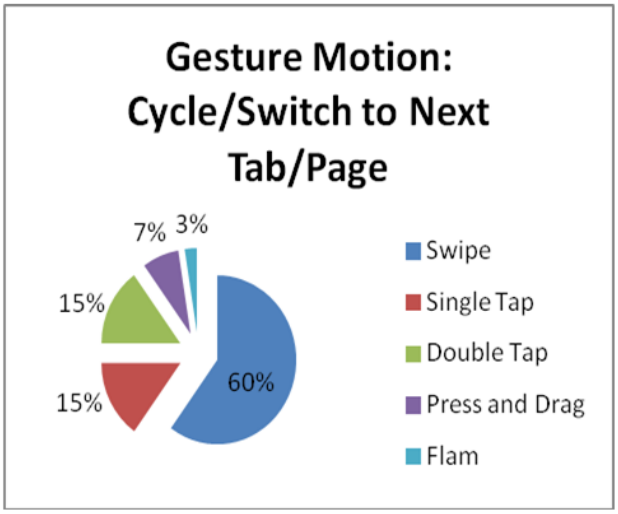

Draw Pattern: Copy
5% 2%
10%
18%
20%
45%
Point
"C"
Line
Circle
Circle And Dot Middle
Line, Circle

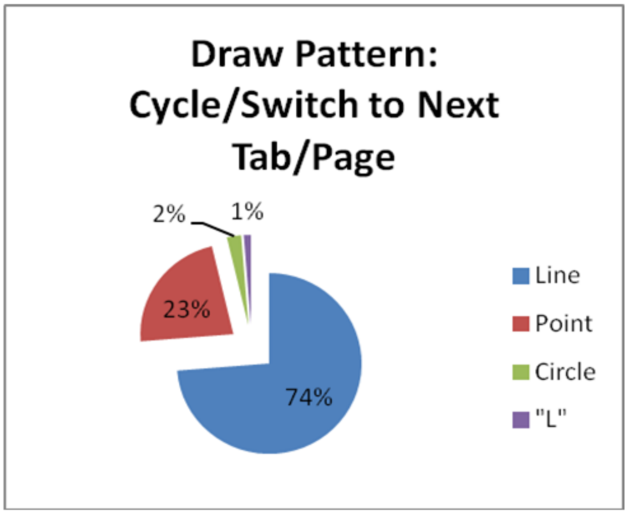

Gesture Motion: Cut
5% 5% 3%
5%
5%
10%
10%
15%
42%
Press and Drag
Press and Hold
Pinch
Double Tap
Triple Tap
Press, Hold, and Double Tap

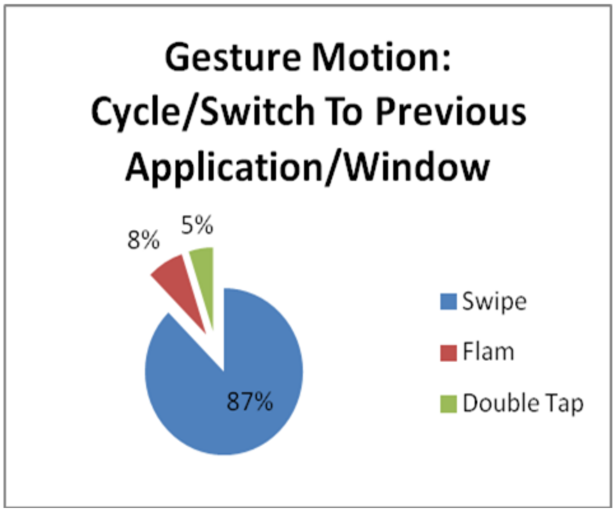

Draw Pattern: Cut
5% 5% 4%
5%
5%
8%
10%
25%
35%
Point
Line
"X"
Circle
Line, Line
Circle with Center Dot

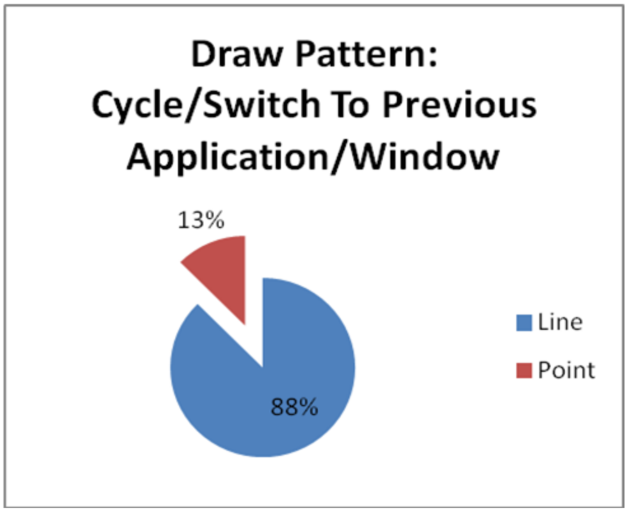

Gesture Motion: Cycle/Switch To Next Application/Window
8%
5%
87%
Swipe
Flam
Double Tap

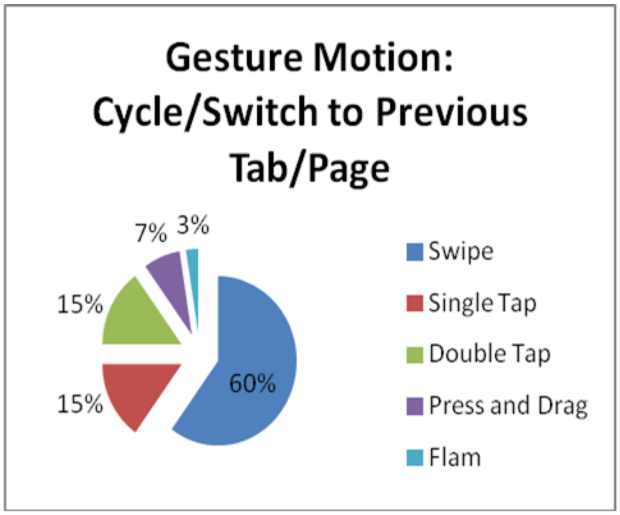

Draw Pattern: Cycle/Switch To Next Application/Window
13%
88%
Line
Point

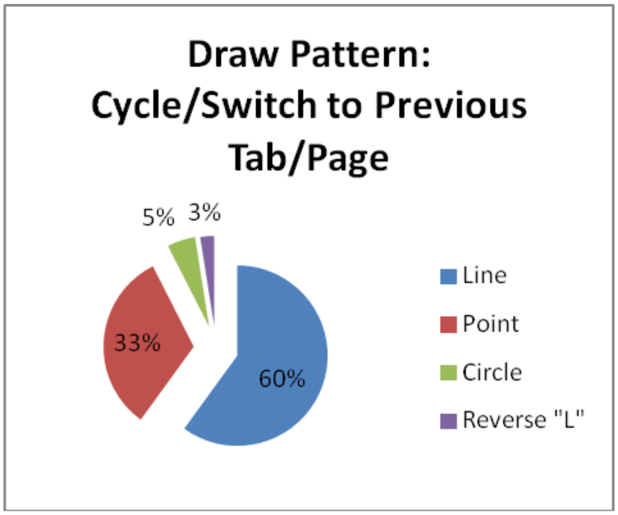

Gesture Motion: Cycle/Switch to Next Tab/Page
7%
3%
15%
15%
60%
Swipe
Single Tap
Double Tap
Press and Drag
Flam

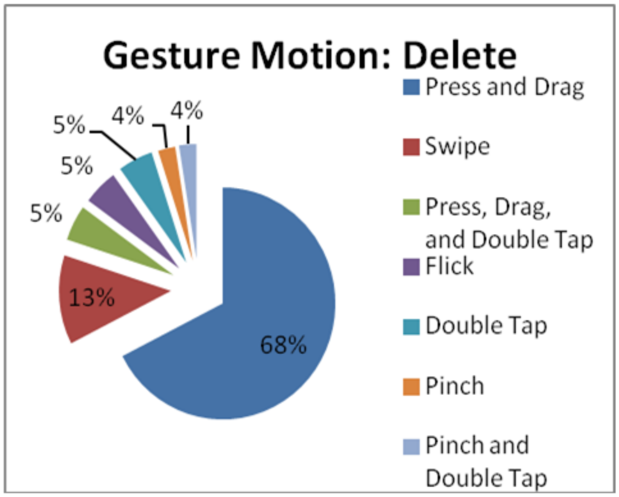

Draw Pattern: Cycle/Switch to Next Tab/Page
2%
1%
23%
74%
Line
Point
Circle
"L"

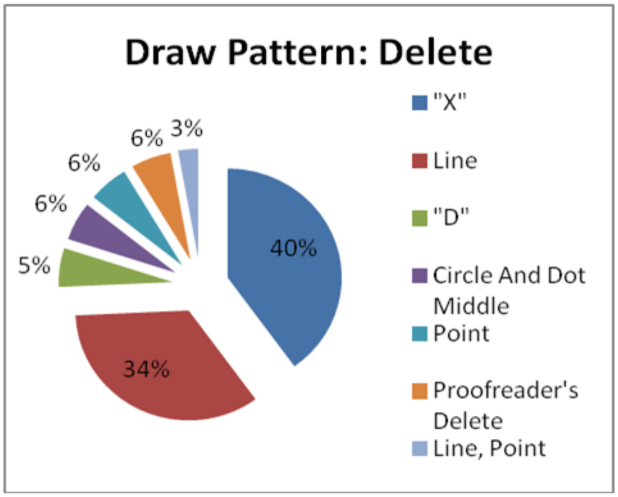

Gesture Motion: Cycle/Switch To Previous Application/Window
8%
5%
87%
Swipe
Flam
Double Tap

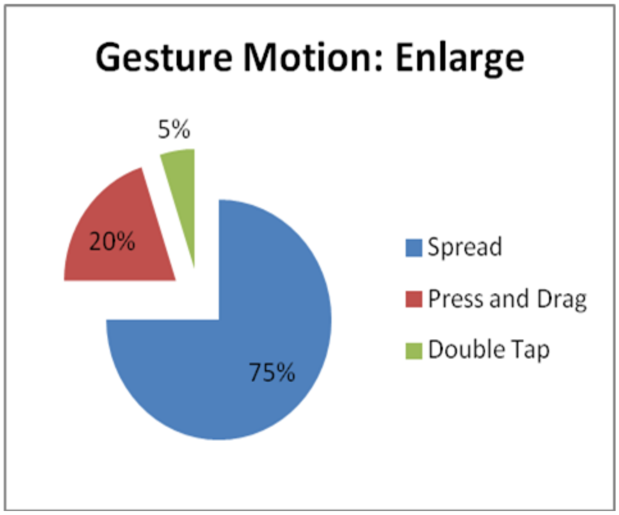

Draw Pattern: Cycle/Switch To Previous Application/Window
13%
88%
Line
Point

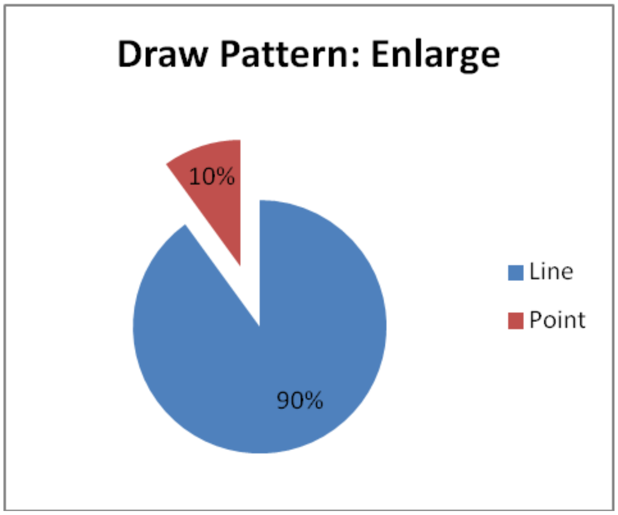

Gesture Motion: Cycle/Switch to Previous Tab/Page
7%
3%
15%
15%
60%
Swipe
Single Tap
Double Tap
Press and Drag
Flam

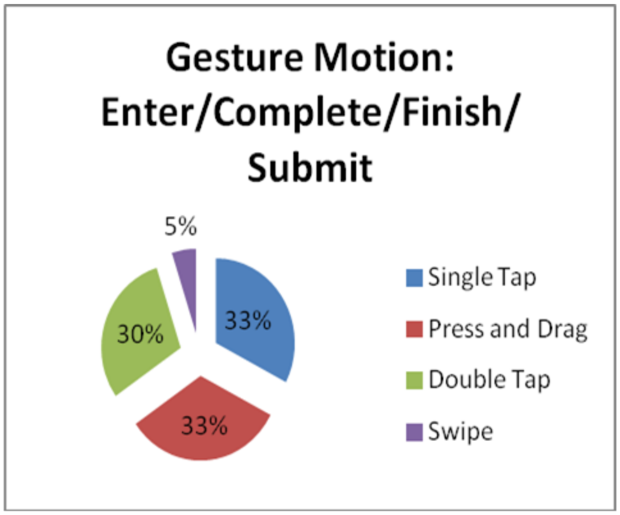

Draw Pattern: Cycle/Switch to Previous Tab/Page
5%
3%
33%
60%
Line
Point
Circle
Reverse "L"

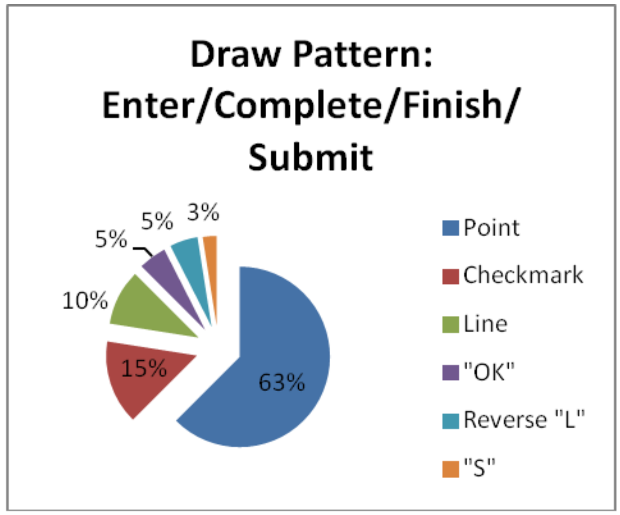

Gesture Motion: Delete
5%
4%
4%
5%
5%
13%
68%
Press and Drag
Swipe
Press, Drag, and Double Tap
Flick
Double Tap
Pinch
Pinch and Double Tap

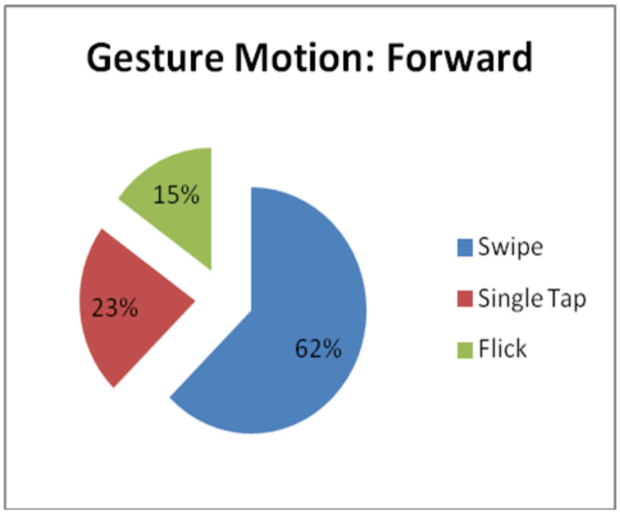

Draw Pattern: Delete
6%
3%
6%
6%
5%
40%
34%
"X"
Line
"D"
Circle And Dot Middle
Point
Proofreader's Delete
Line, Point

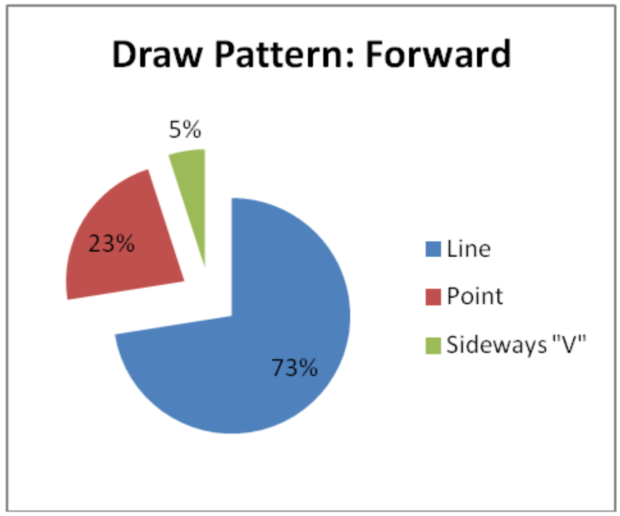

Gesture Motion: Enlarge
5%
20%
75%
Spread
Press and Drag
Double Tap

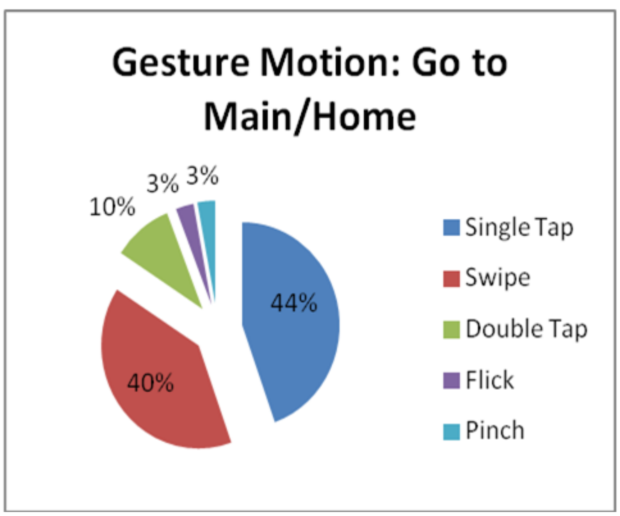

Draw Pattern: Enlarge
10%
90%
Line
Point

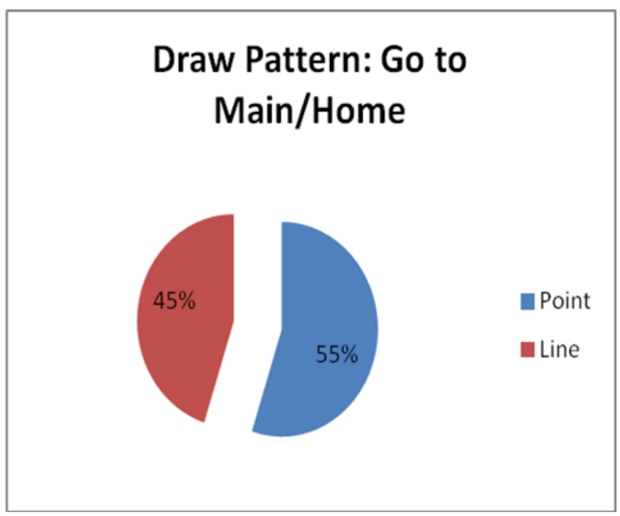

Gesture Motion: Enter/Complete/Finish/ Submit
5%
30%
33%
33%
Single Tap
Press and Drag
Double Tap
Swipe

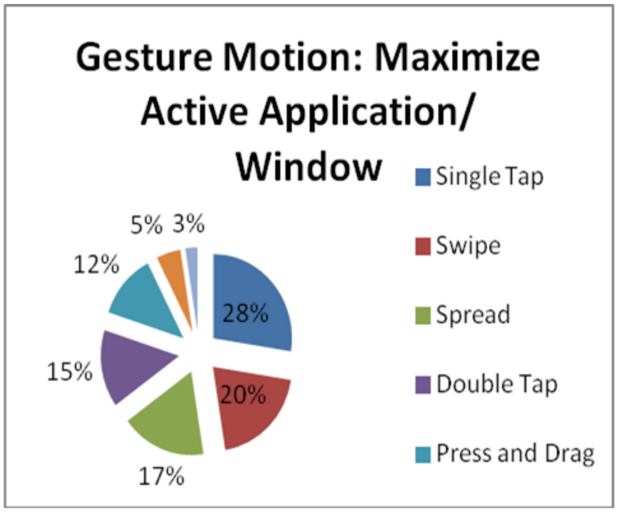

Draw Pattern: Enter/Complete/Finish/ Submit
5%
5%
3%
10%
15%
63%
Point
Checkmark
Line
"OK"
Reverse "L"
"S"

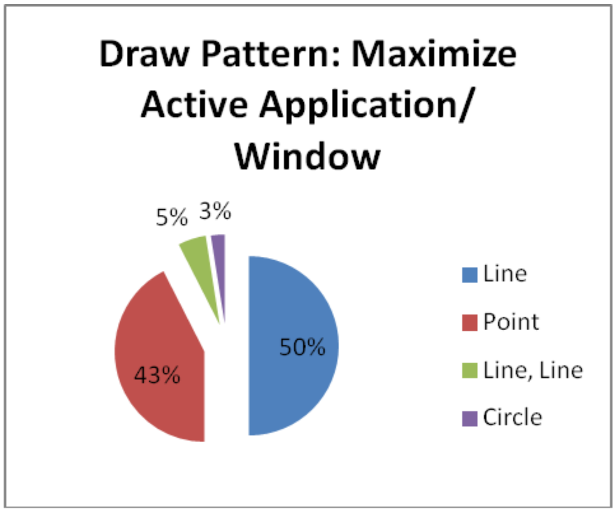

Gesture Motion: Forward
15%
23%
62%
Swipe
Single Tap
Flick

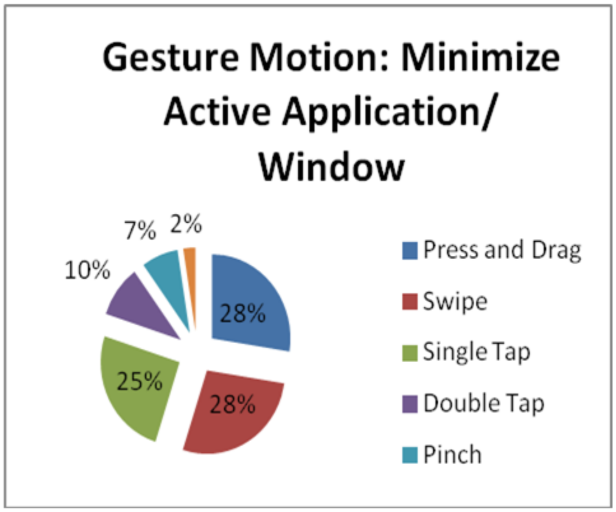

Draw Pattern: Forward
5%
23%
73%
Line
Point
Sideways "V"

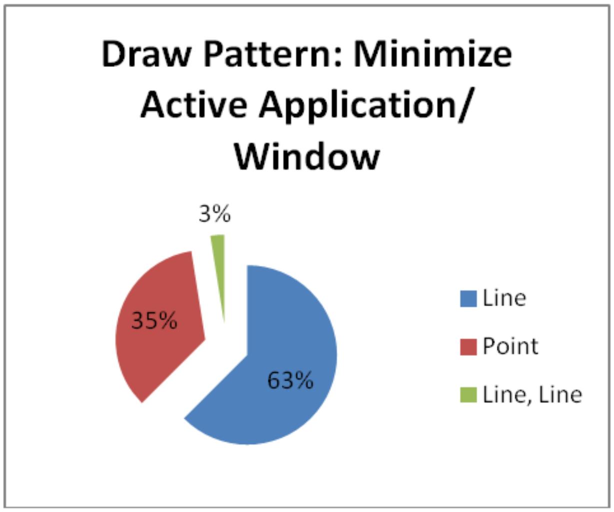

Gesture Motion: Go to Main/Home
3%
3%
10%
44%
40%
Single Tap
Swipe
Double Tap
Flick
Pinch

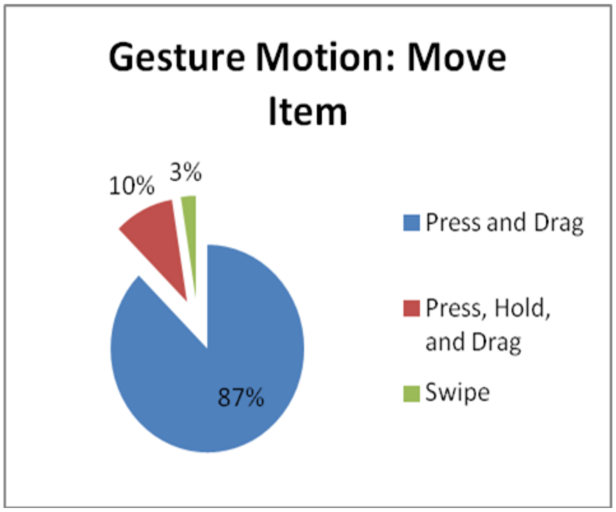

Draw Pattern: Go to Main/Home
45%
55%
Point
Line

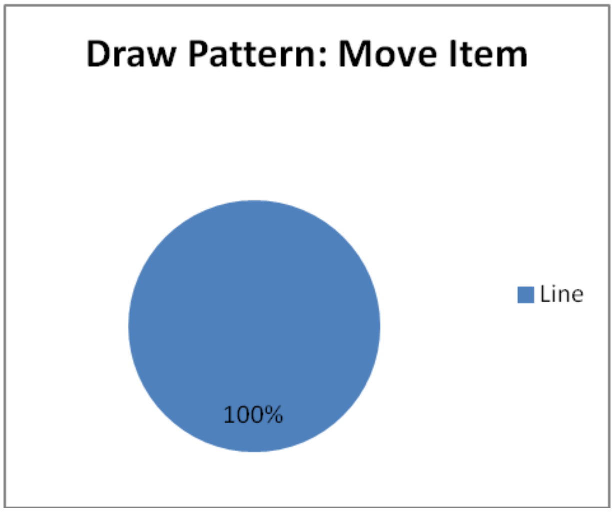

Gesture Motion: Maximize Active Application/ Window
Single Tap
Swipe
Spread
Double Tap
Press and Drag
28%
20%
17%
15%
12%
5%
3%

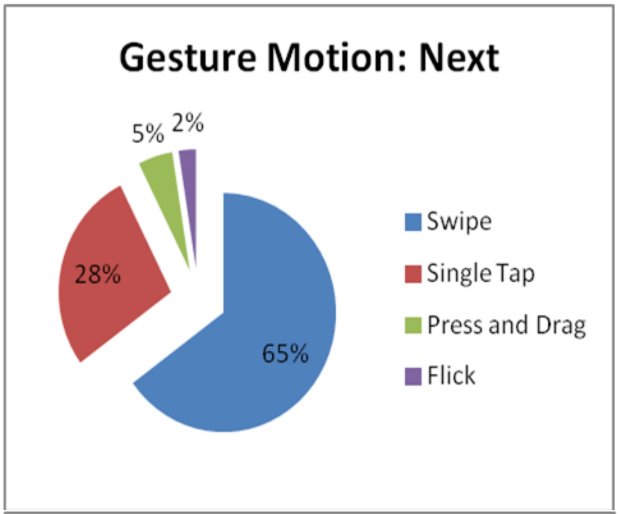

Draw Pattern: Maximize Active Application/ Window
Line
Point
Line, Line
Circle
50%
43%
5%
3%

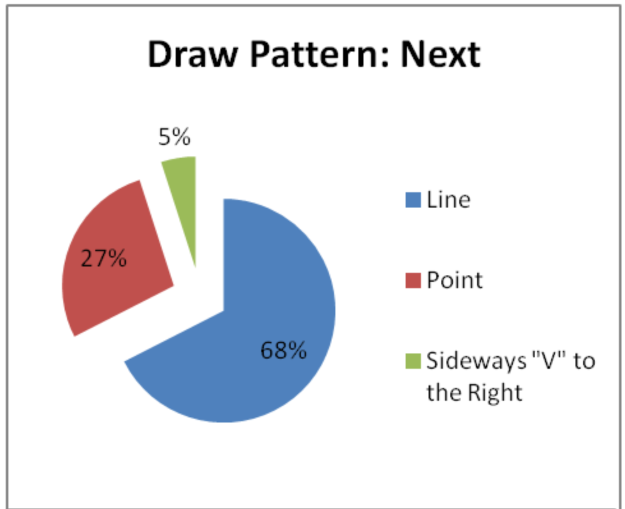

Gesture Motion: Minimize Active Application/ Window
Press and Drag
Swipe
Single Tap
Double Tap
Pinch
28%
28%
25%
10%
7%
2%

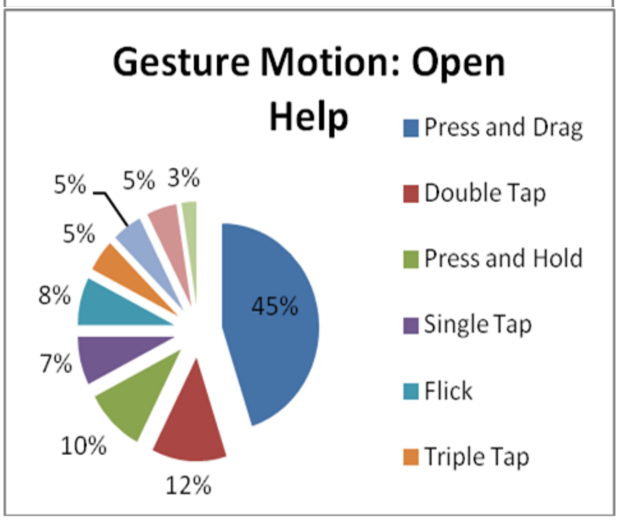

Draw Pattern: Minimize Active Application/ Window
Line
Point
Line, Line
63%
35%
3%

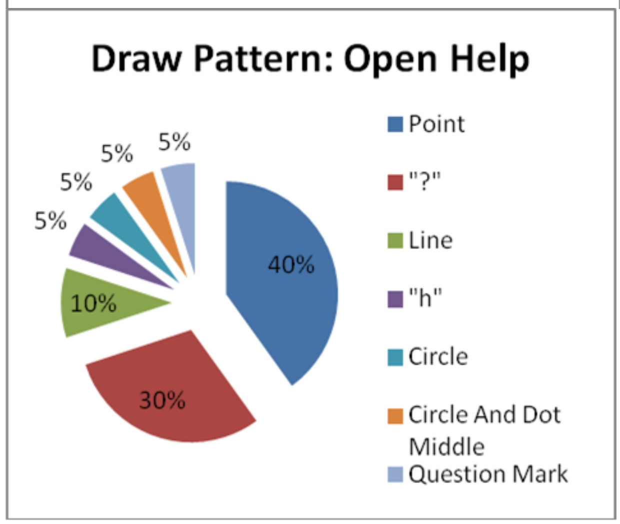

Gesture Motion: Move Item
Press and Drag
Press, Hold, and Drag
Swipe
87%
10%
3%

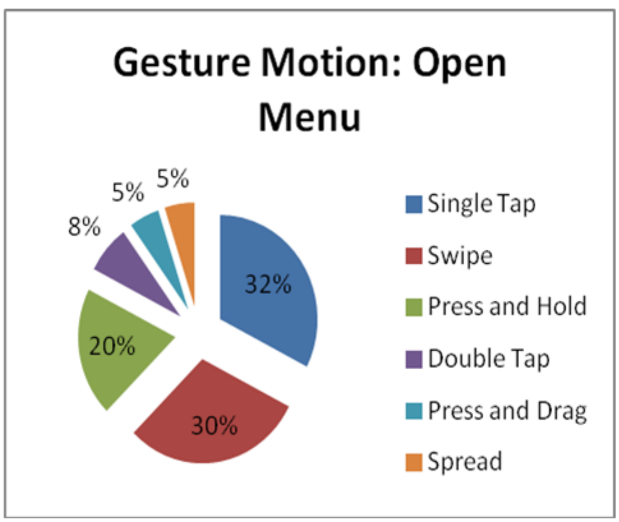

Draw Pattern: Move Item
Line
100%

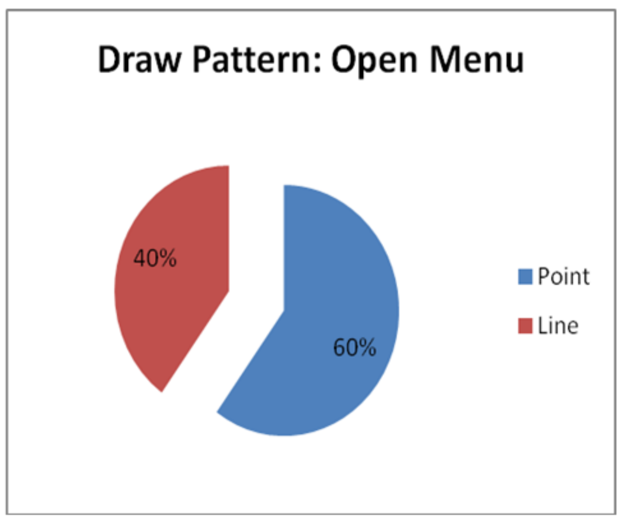

Gesture Motion: Next
5%
2%
28%
65%
Swipe
Single Tap
Press and Drag
Flick

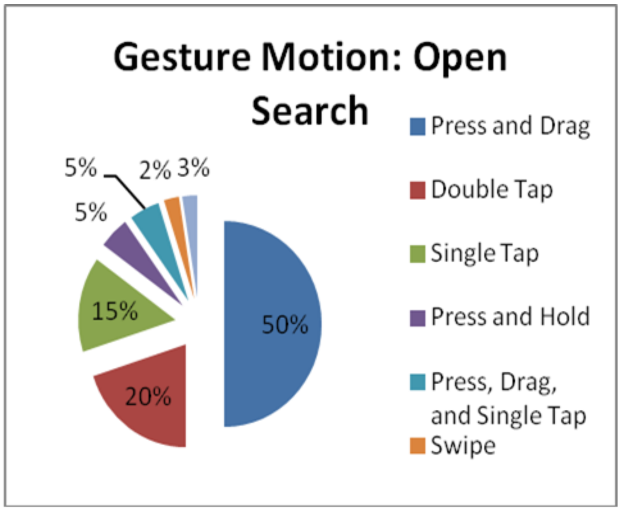

Draw Pattern: Next
5%
27%
68%
Line
Point
Sideways "V" to the Right

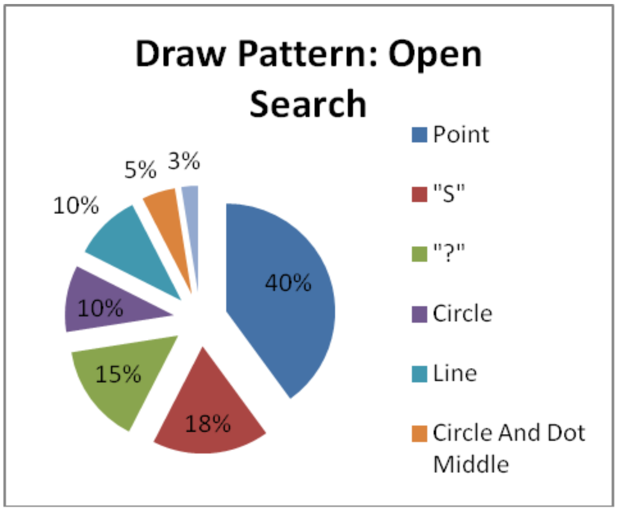

Gesture Motion: Open Help
5%
5%
3%
5%
8%
7%
10%
12%
45%
Press and Drag
Double Tap
Press and Hold
Single Tap
Flick
Triple Tap

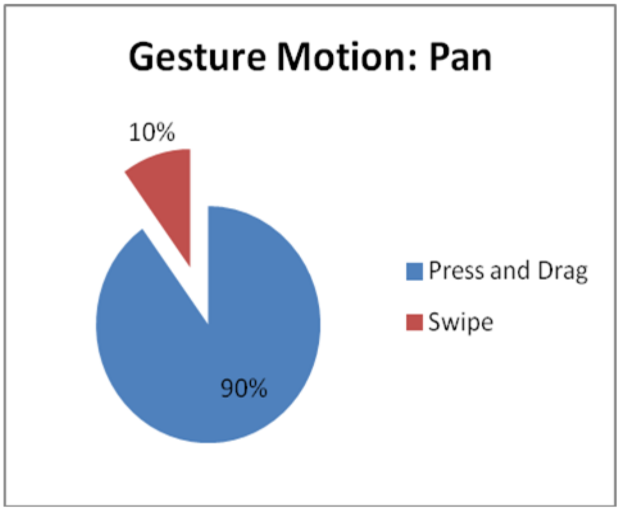

Draw Pattern: Open Help
5%
5%
5%
5%
10%
30%
40%
Point
"?"
Line
"h"
Circle
Circle And Dot Middle
Question Mark

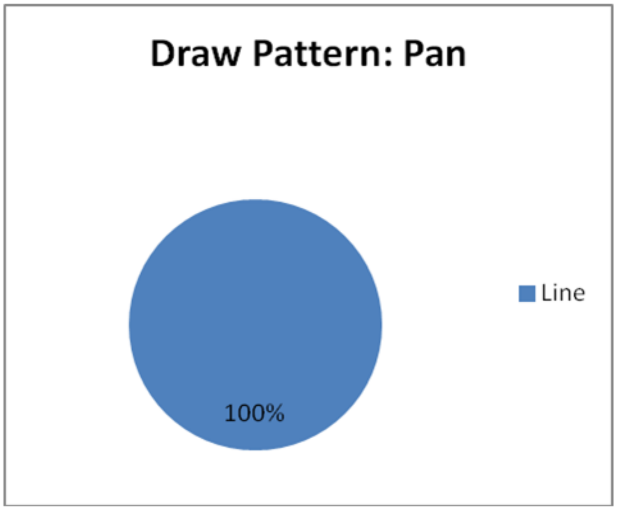

Gesture Motion: Open Menu
5%
5%
8%
20%
30%
32%
Single Tap
Swipe
Press and Hold
Double Tap
Press and Drag
Spread

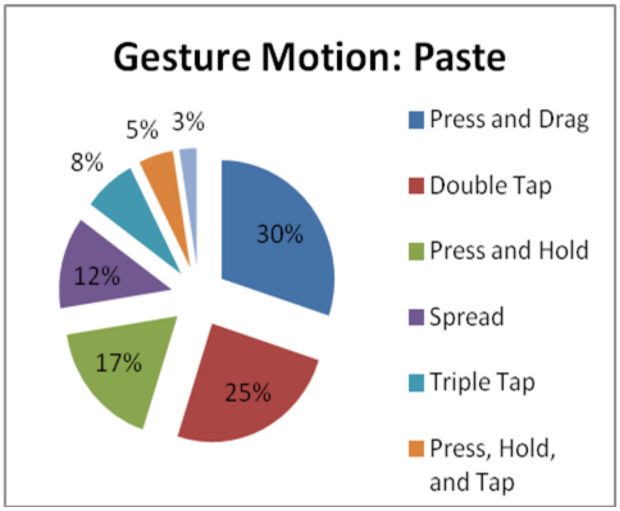

Draw Pattern: Open Menu
40%
60%
Point
Line

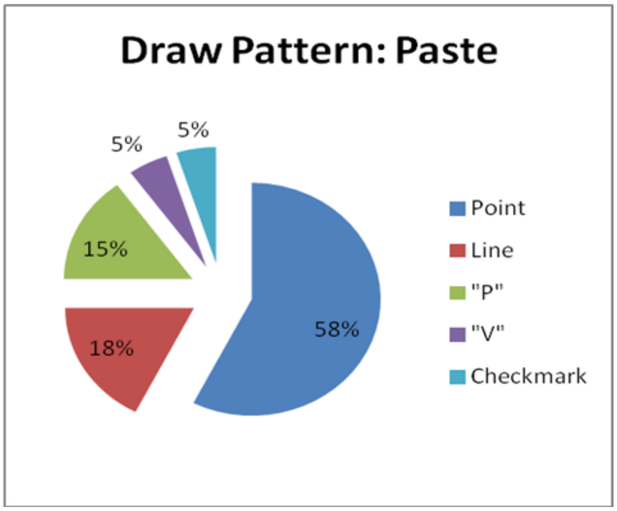

Gesture Motion: Open Search
Press and Drag
Double Tap
Single Tap
Press and Hold
Press, Drag, and Single Tap
Swipe
50%
20%
15%
5%
5%
2%
3%

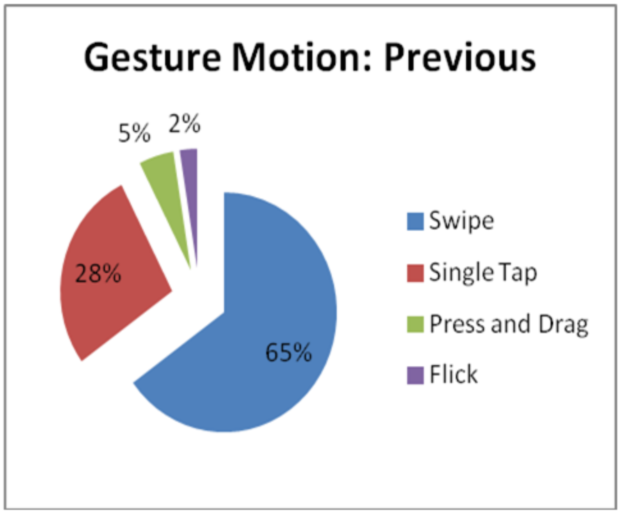

Draw Pattern: Open Search
Point
"S"
"?"
Circle
Line
Circle And Dot Middle
40%
18%
15%
10%
10%
5%
3%

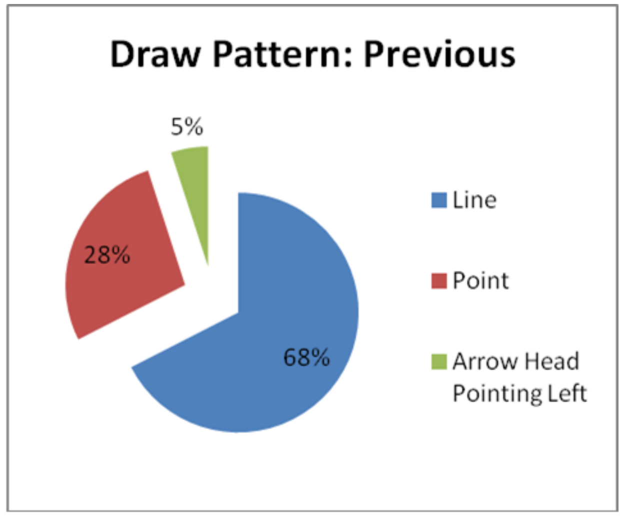

Gesture Motion: Pan
Press and Drag
Swipe
90%
10%

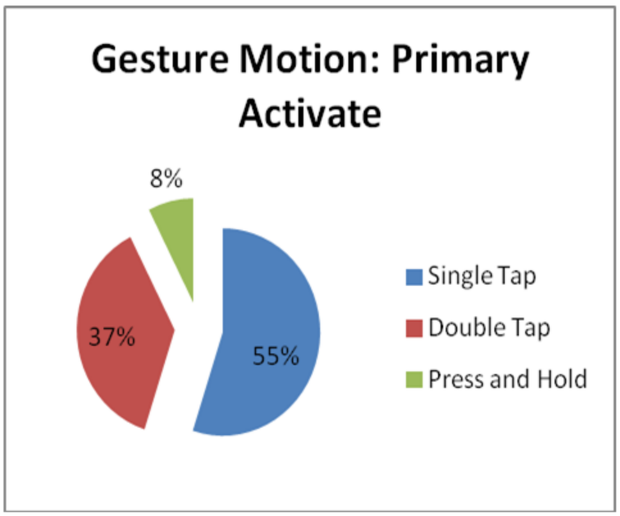

Draw Pattern: Pan
Line
100%

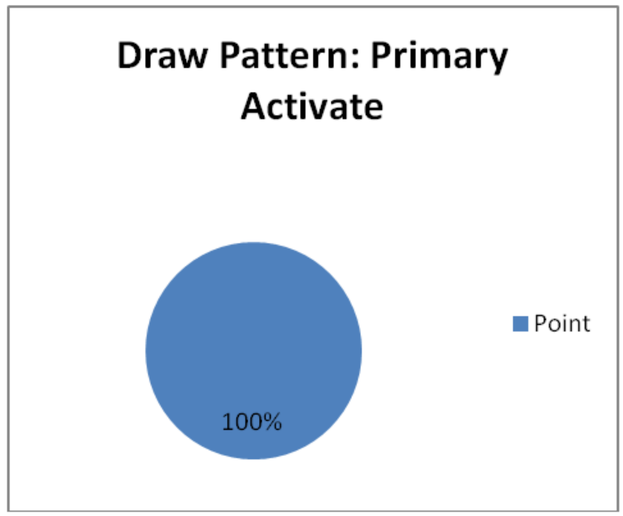

Gesture Motion: Paste
Press and Drag
Double Tap
Press and Hold
Spread
Triple Tap
Press, Hold, and Tap
30%
25%
17%
12%
8%
5%
3%

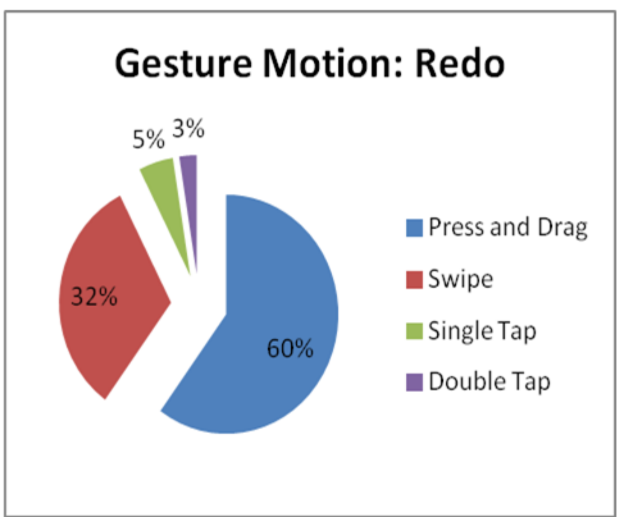

Draw Pattern: Paste
Point
Line
"P"
"V"
Checkmark
58%
18%
15%
5%
5%

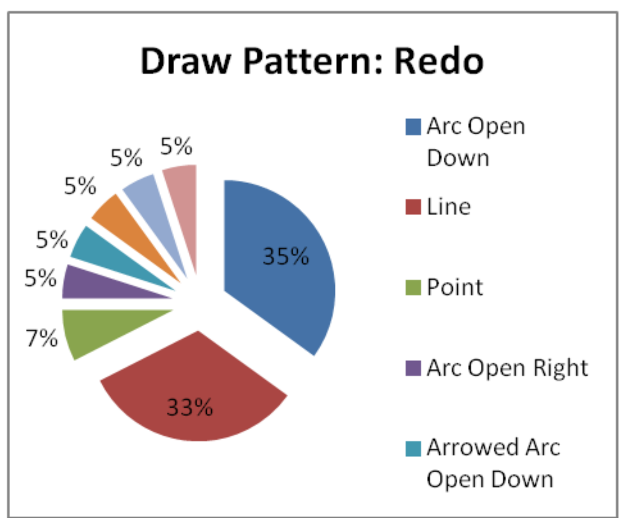

Gesture Motion: Previous
5%
2%
28%
65%
Swipe
Single Tap
Press and Drag
Flick

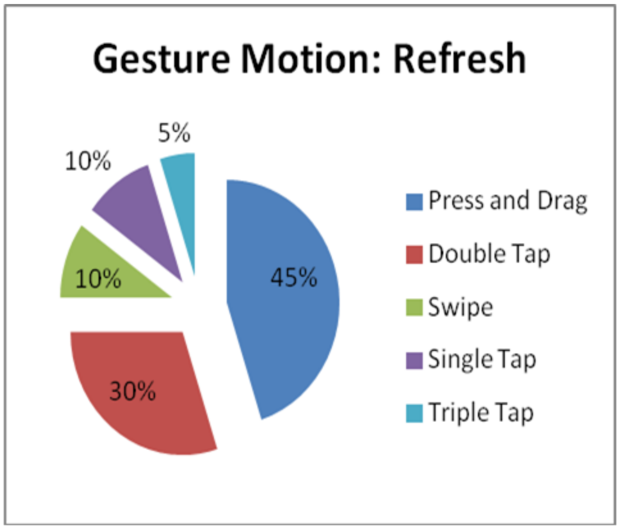

Draw Pattern: Previous
5%
28%
68%
Line
Point
Arrow Head Pointing Left

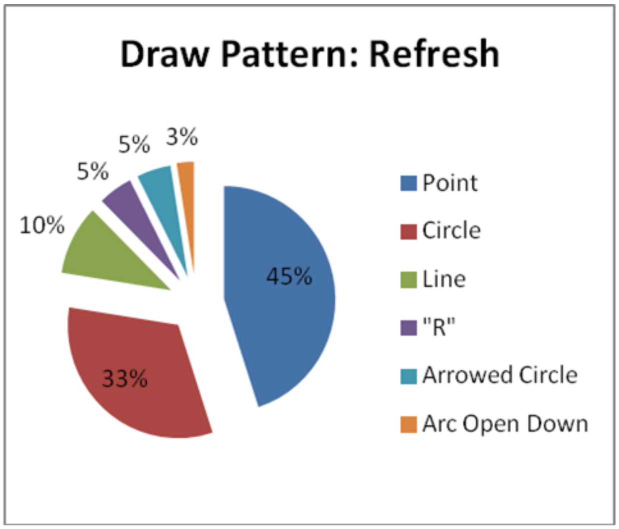

Gesture Motion: Primary Activate
8%
37%
55%
Single Tap
Double Tap
Press and Hold

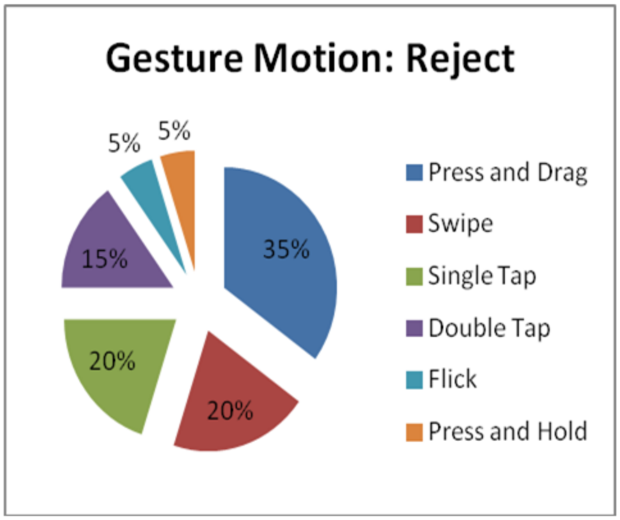

Draw Pattern: Primary Activate
100%
Point

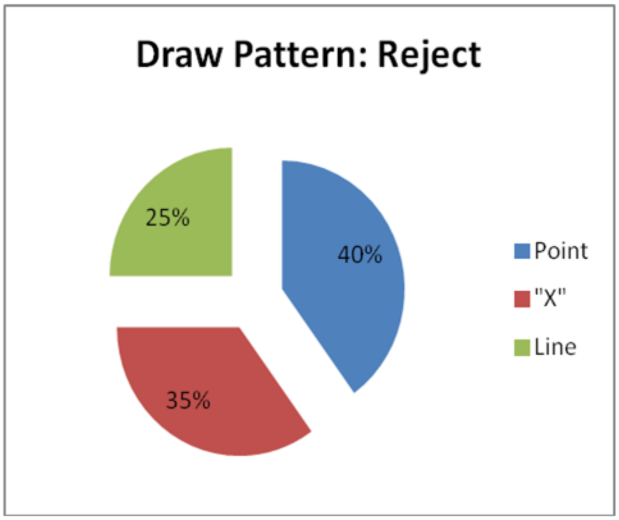

Gesture Motion: Redo
5%
3%
32%
60%
Press and Drag
Swipe
Single Tap
Double Tap

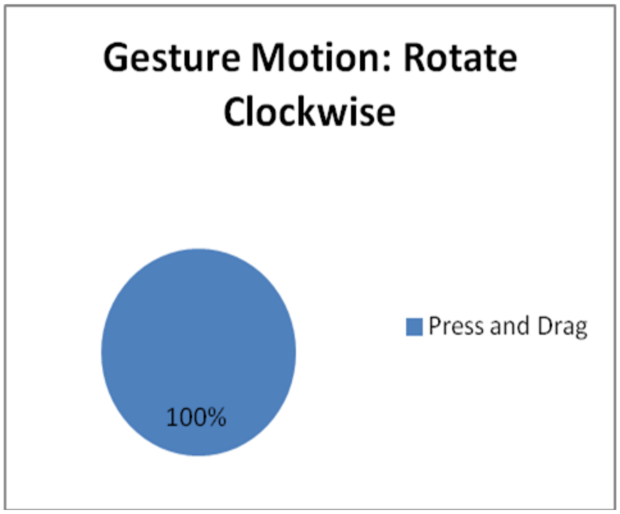

Draw Pattern: Redo
5%
5%
5%
5%
5%
7%
35%
33%
Arc Open Down
Line
Point
Arc Open Right
Arrowed Arc Open Down

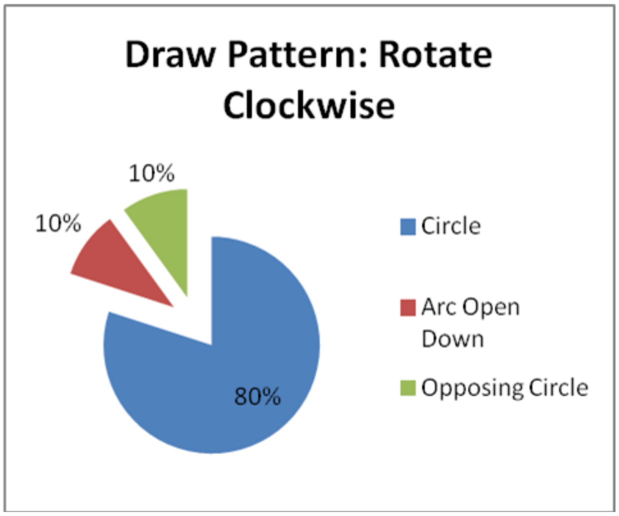

Gesture Motion: Refresh
5%
10%
10%
45%
30%
Press and Drag
Double Tap
Swipe
Single Tap
Triple Tap

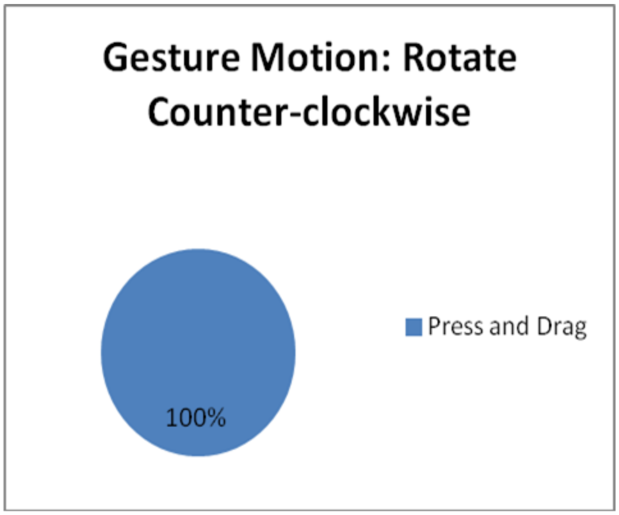

Draw Pattern: Refresh
5%
3%
5%
10%
45%
33%
Point
Circle
Line
"R"
Arrowed Circle
Arc Open Down

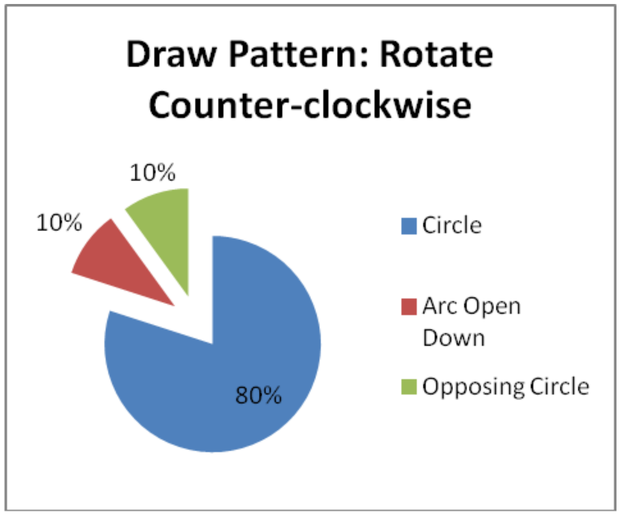

Gesture Motion: Reject
5%
5%
15%
35%
20%
20%
Press and Drag
Swipe
Single Tap
Double Tap
Flick
Press and Hold

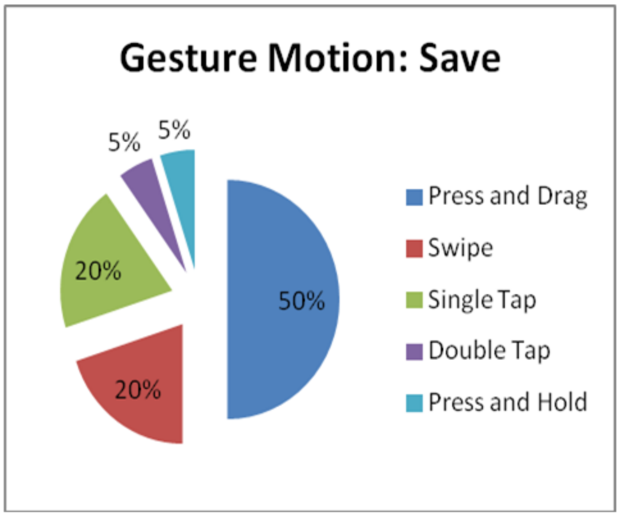

Draw Pattern: Reject
25%
40%
35%
Point
"X"
Line

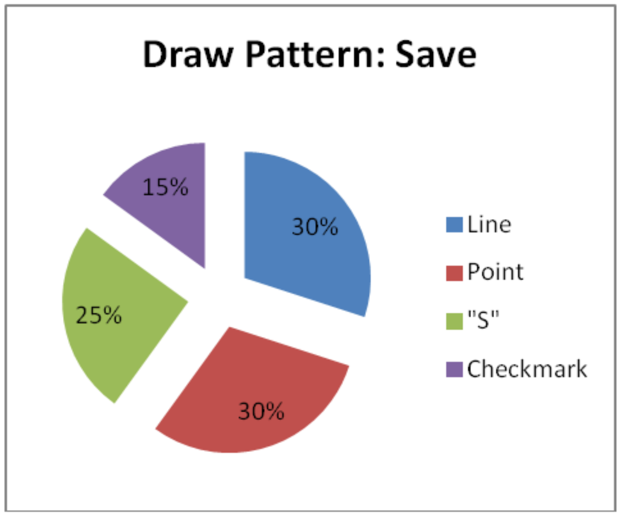

Gesture Motion: Rotate Clockwise
100%
Press and Drag

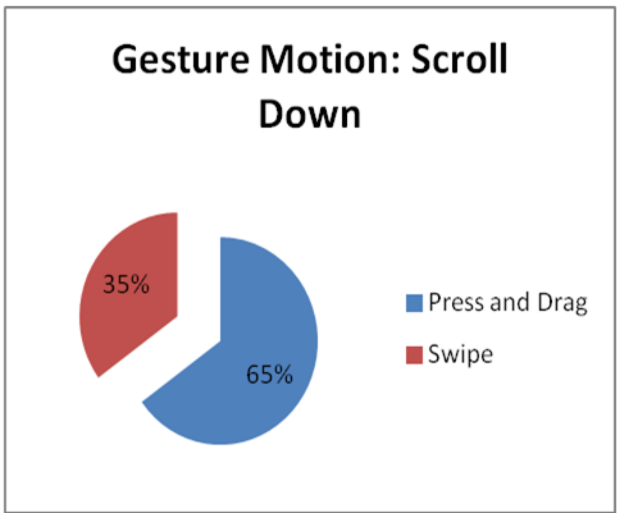

Draw Pattern: Rotate Clockwise
10%
10%
80%
Circle
Arc Open Down
Opposing Circle

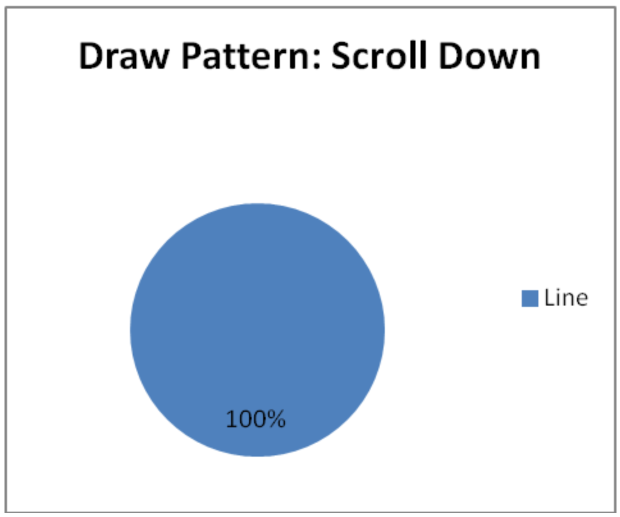

Gesture Motion: Rotate Counter-clockwise
100%
Press and Drag

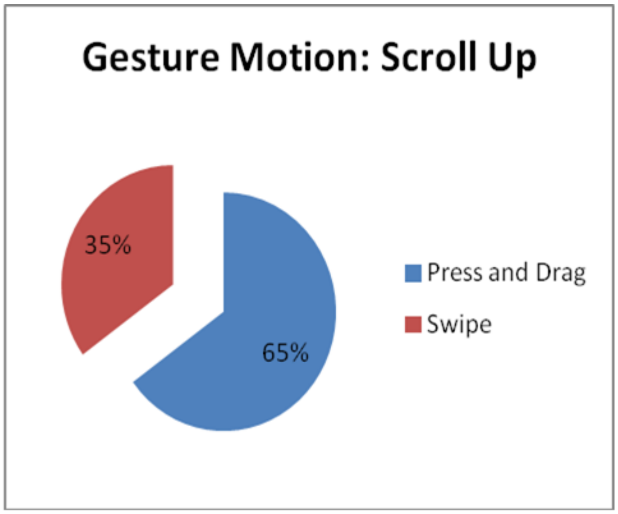

Draw Pattern: Rotate Counter-clockwise
10%
10%
80%
Circle
Arc Open Down
Opposing Circle

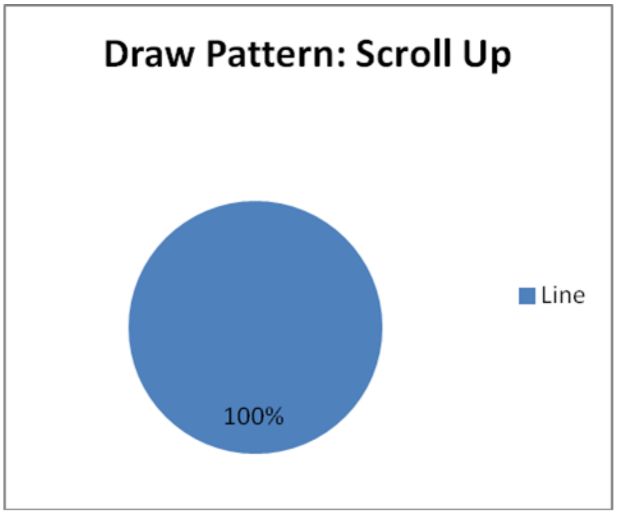

Gesture Motion: Save
5%
5%
20%
50%
20%
Press and Drag
Swipe
Single Tap
Double Tap
Press and Hold

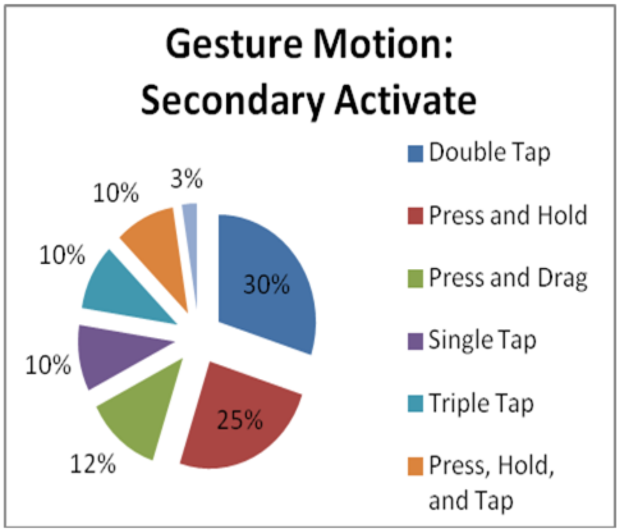

Draw Pattern: Save
15%
30%
25%
30%
Line
Point
"S"
Checkmark

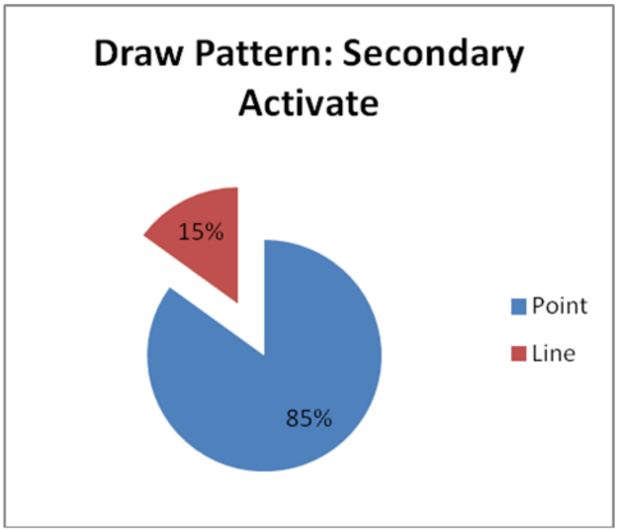

Gesture Motion: Scroll Down
35%
65%
Press and Drag
Swipe

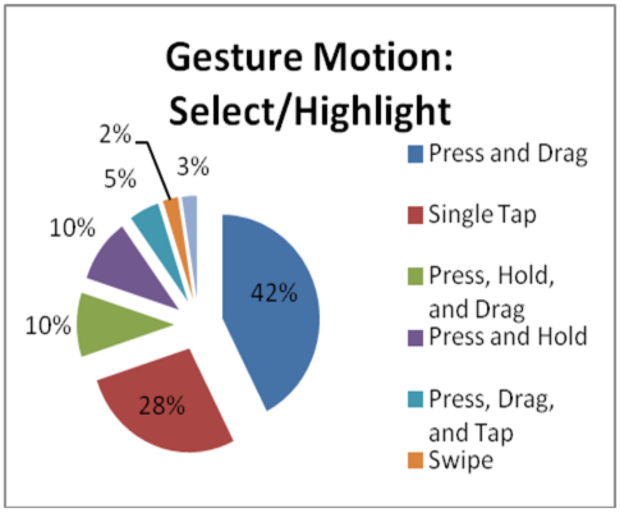

Draw Pattern: Scroll Down
100%
Line

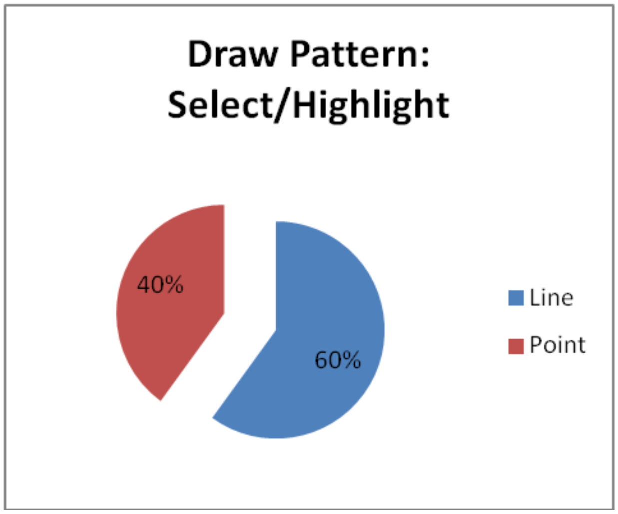

Gesture Motion: Scroll Up
35%
65%
Press and Drag
Swipe

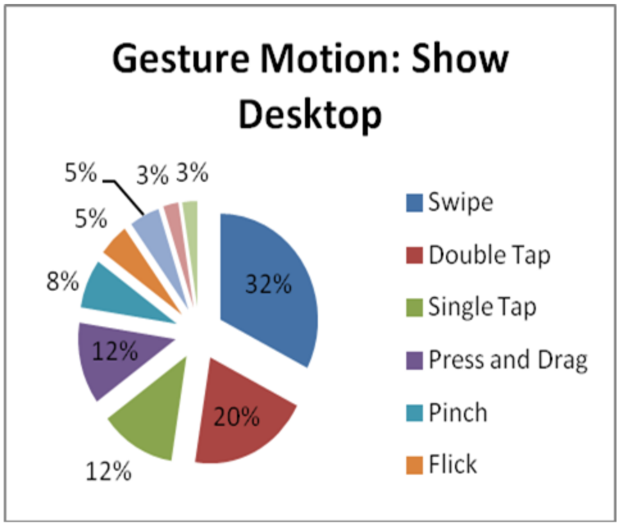

Draw Pattern: Scroll Up
100%
Line

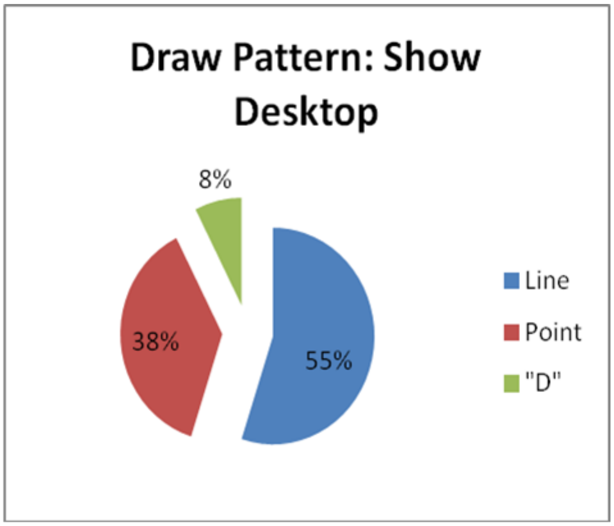

Gesture Motion: Secondary Activate
3%
10%
10%
10%
12%
25%
30%
Double Tap
Press and Hold
Press and Drag
Single Tap
Triple Tap
Press, Hold, and Tap

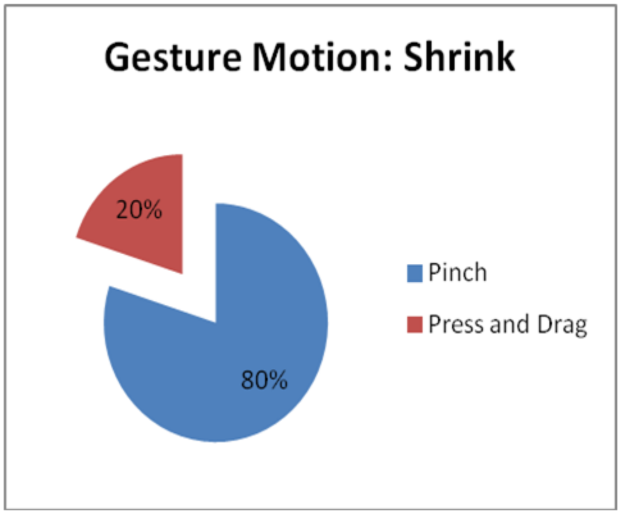

Draw Pattern: Secondary Activate
15%
85%
Point
Line

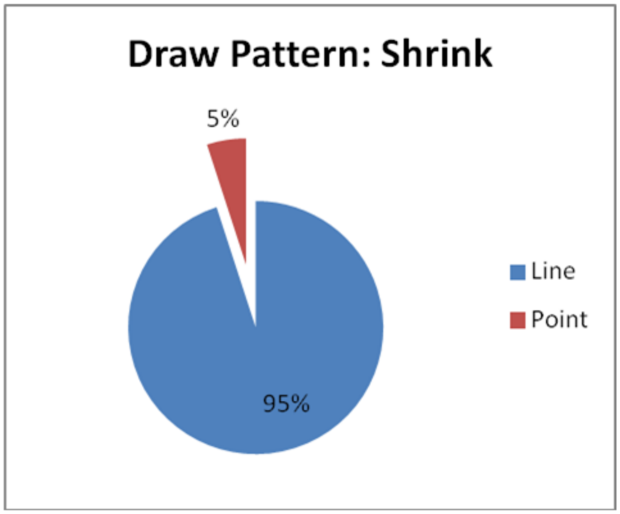

Gesture Motion: Select/Highlight
2%
5%
3%
10%
10%
28%
42%
Press and Drag
Single Tap
Press, Hold, and Drag
Press and Hold
Press, Drag, and Tap
Swipe

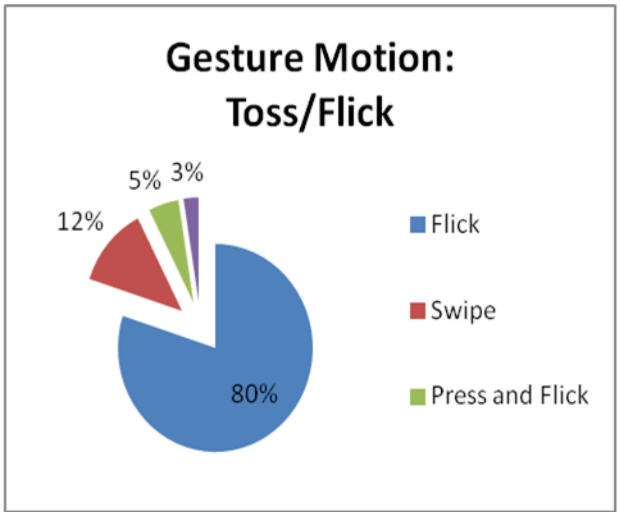

Draw Pattern: Select/Highlight
40%
60%
Line
Point

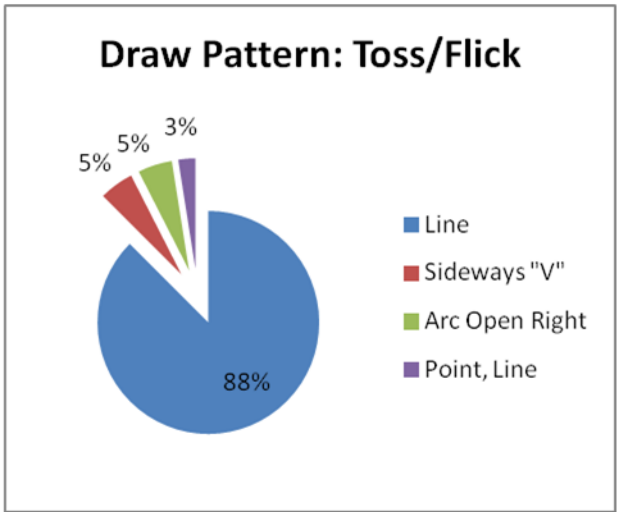

Gesture Motion: Show Desktop
5%
3%
3%
5%
8%
32%
12%
20%
12%
Swipe
Double Tap
Single Tap
Press and Drag
Pinch
Flick

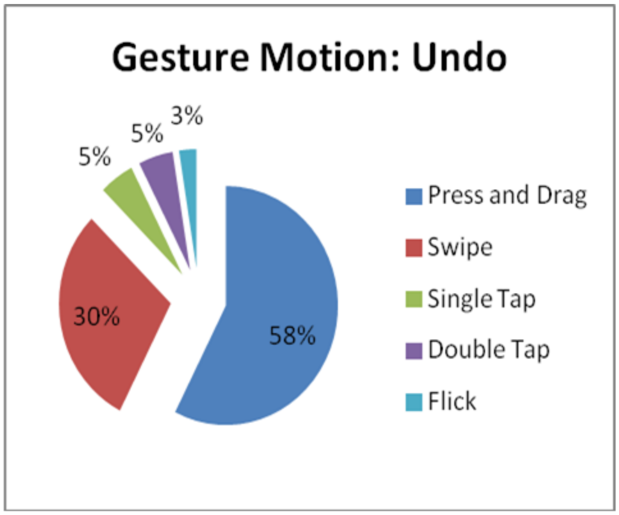

Draw Pattern: Show Desktop
8%
38%
55%
Line
Point
"D"

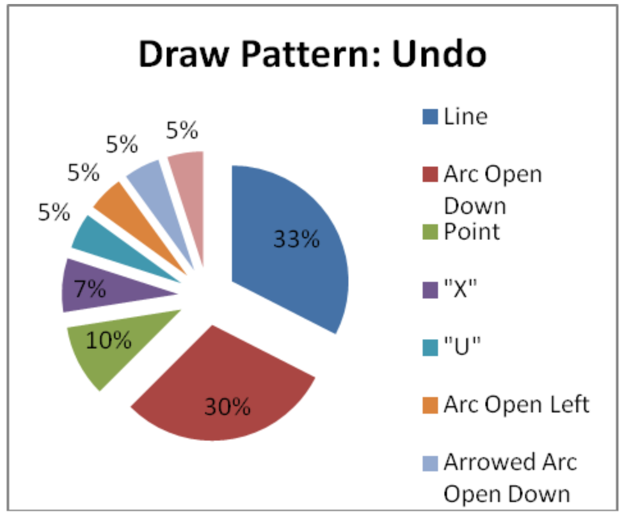

Gesture Motion: Shrink
20%
80%
Pinch
Press and Drag

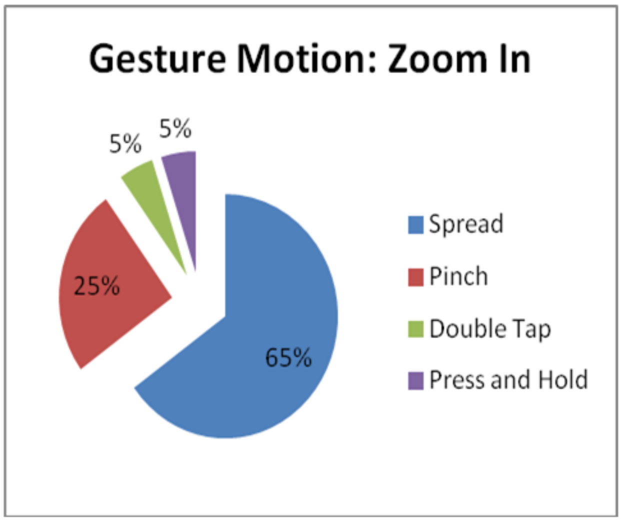

Draw Pattern: Shrink
5%
95%
Line
Point

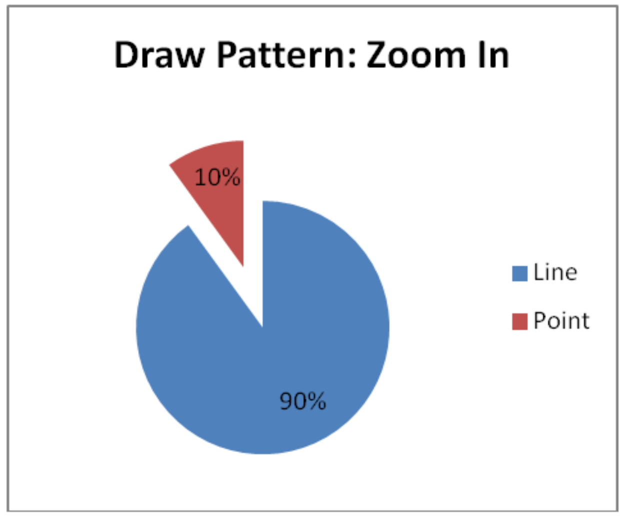

Gesture Motion: Toss/Flick
5%
3%
12%
80%
Flick
Swipe
Press and Flick

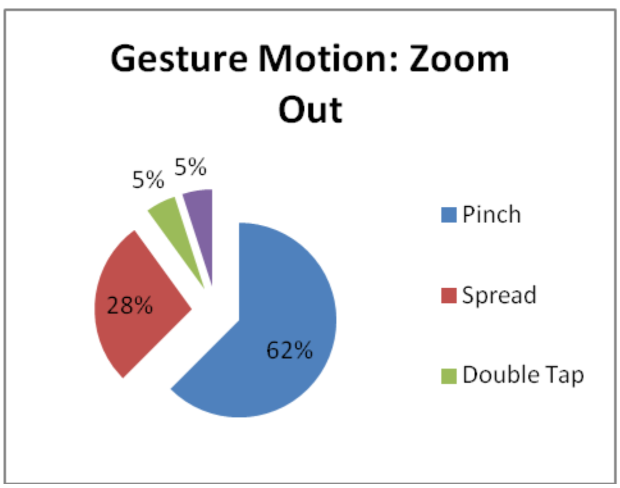

Draw Pattern: Toss/Flick
5%
5%
3%
88%
Line
Sideways "V"
Arc Open Right
Point, Line

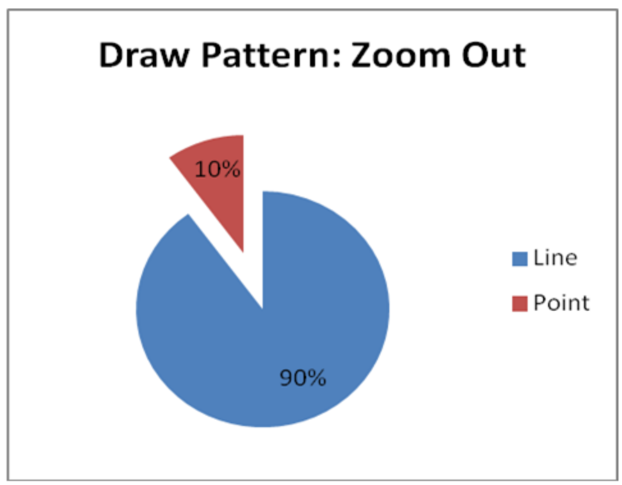

Gesture Motion: Undo
58%
30%
5%
5%
3%
Press and Drag
Swipe
Single Tap
Double Tap
Flick


Draw Pattern: Undo
33%
30%
10%
7%
5%
5%
5%
5%
Line
Arc Open Down
Point
"X"
"U"
Arc Open Left
Arrowed Arc Open Down


Gesture Motion: Zoom In
65%
25%
5%
5%
Spread
Pinch
Double Tap
Press and Hold


Draw Pattern: Zoom In
90%
10%
Line
Point


Gesture Motion: Zoom Out
62%
28%
5%
5%
Pinch
Spread
Double Tap


Draw Pattern: Zoom Out
90%
10%
Line
Point

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APPENDIX B: DEFINITIONS OF GESTURES AND MOVEMENTS

Gesture functions are indicated by plain text, **gesture movements*** are bolded and starred, and *general definitions* are italicized.

Title	Definition
Accept	Agree or consent to an action
Arrowed Circle*	Sideways "V" with encapsulating circle
Back	Move to a former screen or position
Catch	Allow user to take hold and drop item into a specified location (e.g., If a document is dragged into the recycle bin, the document will be caught by the recycle bin.)
Close	Stop or end a program; remove content from view
Copy	Reproduce all or a portion of the content
Cut	Separate content from main body; detach
Cycle/Switch to Next Application/Window	Shift or move to a new page; open an application
Cycle/Switch to Next Tab/Page	Shift or move to a new tab or page; open a tab
Cycle/Switch to Previous Application/Window	Shift or move from one application to another
Cycle/Switch to Previous Tab/Page	Shift or move to the previous tab or window
Delete	Eliminate or completely remove content
Double Tap*	Tapping an item twice with one finger in a rapid succession; acts as a secondary selection used to open files and folders; zoom in or out
Drag*	Move item from one location to another (e.g., used to adjust view on screen [scroll/pan]; move through a list, lasso [group select])
Draw Pattern	*Shape of the gesture (e.g., Line, Point, Arc)*
Enlarge	Increase the size of an area; make larger
Enter/Complete/Finish/Submit	End function or application; fully carry out series of steps
Flam*	Perform two-finger tapping motion in quick succession
Forward	Advance or move forward; progress to the next screen
Gesture	Recognizable pattern of touch movements
Gesture Function	*Title of the gesture (e.g., Accept, Zoom In)*
Gesture Motion	*Movement used to make the gesture (e.g., Swipe, Single Tap)*
Go to Main/Home	Return to home page

Lollipop*	Circle followed by a line that represent the shape of a lollipop(e.g., used to close an application)
Maximize Active Application/Window	Open to full screen; enlarge to fill screen
Minimize Active Application/Window	Reduce the size of content; make smaller on screen
Move Item	Relocate content to another location, screen, or page
Next	Move to content on sequential page or screen
Open Help	Open menu that provides assistance or support for using applications and/or programs
Open Menu	Open drop-down method for allowing user to find and launch programs
Open Search	Allow user to search for information on the World Wide Web
Opposing Circle	Move in a counterclockwise circular motion
Pan	Move between screens in a fluid, continuous-type motion; move content via direct manipulation
Paste	Copy contents of the clipboard into the workspace
Pinch*	Move the thumb and forefinger inward in a pinching motion; used to shrink the specified content of the screen
Press and Hold*	Select content and continue to act as secondary selection; functions can vary with amount of time finger is held down
Previous	Return current item to the previous item accessed
Primary Activate	Activate the system focus of a specified window
Redo	Repeat the most recent action
Refresh	Restore, update, maintain page to provide the most recent content; most likely used on a website
Reject	Refuse action
Rotate Clockwise	Rotate content of screen in a circular motion to the right direction
Rotate Counterclockwise	Rotate content of screen in a circular motion to the left direction
Save	Save item/image/document to be viewed at a later time
Scroll Down	Enable user to scroll content further down screen/window
Scroll Up	Enable user to scroll content further up screen/window
Secondary Activate	Window that is not primary system focus

Select/Highlight	Select content (e.g., word, sentence) to highlight
Show Desktop	The primary display screen of a graphical user interface, on which various icons represent files, groups of files, programs, etc.
Shrink	Decrease size of image or content on screen
Spread*	Enlarge image on screen
Swipe*	Linear motion in some direction
Toss/Flick*	Quick, linear movement associated with scrolling actions and commands
Undo	Reverse the most recent action
Zoom In	Increase size of display; decrease the amount of content on the screen
Zoom Out	Decrease size of display; increase the amount of content on the screen

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