Determining the Benefits of Direct-Touch, Bimanual, and Multifinger Input on a Multitouch Workstation

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ABSTRACT

Multitouch workstations support *direct-touch*, *bimanual*, and *multifinger* interaction. Previous studies have separately examined the benefits of these three interaction attributes over mouse-based interactions. In contrast, we present an empirical user study that considers these three interaction attributes together for a single task, such that we can quantify and compare the performances of each attribute. In our experiment users select multiple targets using either a mouse-based workstation equipped with one mouse, or a multitouch workstation using either one finger, two fingers (one from each hand), or multiple fingers. We find that the fastest multitouch condition is about twice as fast as the mouse-based workstation, independent of the number of targets. Direct-touch with one finger accounts for an average of 83% of the reduction in selection time. Bimanual interaction, using at least two fingers, one on each hand, accounts for the remaining reduction in selection time. Further, we find that for novice multitouch users there is no significant difference in selection time between using one finger on each hand and using any number of fingers for this task. Based on these observations we conclude with several design guidelines for developing multitouch user interfaces.

Keywords: multitouch, mouse, direct-touch input, bimanual input, multifinger input, multitarget selection

Index Terms: H.5.2 [Information Interfaces and Presentation (e.g., HCI)]: User Interfaces—Input Devices and Strategies (e.g., mouse, touchscreen)

1 INTRODUCTION

Traditional desktop workstations consisting of a monitor, keyboard, and mouse, and the graphical user interfaces that rely on them, have changed little in the past decade. Recently however, a new workstation design based on a multitouch display has become commercially available, as exemplified by the Mitsubishi Diamond-Touch [24], the Microsoft Surface [25], and the Perceptive Pixel Media Wall [13, 30]. Large format multitouch displays are especially useful for co-located collaborative work in which two or more people interact simultaneously with a shared display [26, 32]. However, the desirability of multitouch workstations for single user applications is less clear.

In the single user setting, multitouch workstations offer several potential benefits over mouse-based workstations. Unlike *indirect* mouse-based interfaces that require users to visually track an on-screen cursor away from the hand, multitouch workstations offer *direct-touch* input in which input and display are co-located such that users can touch the graphical elements they are interacting with. Multitouch workstations can also detect and track many simultaneous touches, thereby supporting *bimanual* as well as same-hand *multifinger* interaction.

Previous work has studied the factors of direct-touch, bimanual and multifinger interaction independently. For instance, Sears and Shneiderman [33] have shown that for a single target selection task direct-touch input can outperform indirect mouse input. Bimanual interaction offers several advantages over unimanual interaction. The actions of two hands often overlap in time, and the resulting parallelism can increase task performance [2, 6, 7]. Moreover, each hand can remain in the proximity of the area of work it is responsible for, thereby reducing large-scale movements that may be required in unimanual interactions [9]. Finally, there is the potential for users to further increase the amount of parallelism and input bandwidth through the use of multifinger interaction on a workstation that supports full multitouch.

Yet, because prior work has examined direct-touch, bimanual and multifinger interactions separately, they have not been able to quantify and compare the benefits of direct-touch and potential increases in parallelism from multitouch. As a result many issues remain unclear. For instance, is a multitouch workstation that detects a single touch significantly less effective than one that detects two simultaneous touches? Is it essential for a multitouch workstation to detect all ten fingers simultaneously?

In this paper we take an initial step towards answering these questions by examining direct-touch, bimanual and multifinger interactions all together in the context of a multitarget selection task using the traditional mouse-based workstation as a performance baseline. More specifically we measure and compare performance of four input methods; 1) one mouse (indirect, unimanual), 2) one finger (direct-touch, unimanual), 3) two fingers, one on each hand (direct-touch, bimanual), and 4) any number of fingers (direct-touch, bimanual, multifinger). From this empirical data we determine the speedup due to direct-touch input over indirect mouse input as well as the additional speedup due to using two fingers and the contribution of unrestricted use of all fingers.

We focus our study on target selection because it is one of the most common tasks in current graphical user-interfaces and applications. Thus, any gains in selection performance are likely to improve task completion time in a variety of real-world applications. Although less common than single selection, multitarget selection is a frequent task in every day computer usage. For example, users often select multiple files or photos for reorganization or multiple objects in a graphical drawing program for grouping.

In the context of multitarget selection with randomized target locations we find that for novice multitouch users:

- The fastest multitouch interaction is about twice as fast as mouse-based selection, independent of the number of targets.

- The majority of the reduction in selection time is due to the direct-touch nature of multitouch (about 83% of the reduction). Bimanual interaction, using at least one finger on each hand, accounts for the remaining reduction in selection time.

- There is no significant difference in multitarget selection time and error rate between using two fingers, one on each hand, and using any number of fingers.

Based on these results, we believe that multitouch workstations are a better alternative than traditional mouse-based workstations for applications (i.e. photo sorting, graphical drawing, etc.) that often involve multitarget selection. Moreover, if multitarget selection is the primary task, the multitouch workstation need only support simultaneous detection of two contact points. While support for detecting more than two contact points may be useful for increasing gestural bandwidth, such support does not provide much benefit in the context of multitarget selection.

2 RELATED WORK

Although table-sized multitouch workstations have only become commercially available in the last few years, studies of touch-based interaction techniques have a long history in human-computer interaction and psychology. The prior research falls into three main categories; studies of 1) *indirect* versus *direct* touch 2) *unimanual* versus *bimanual* interactions, and 3) same-hand *multifinger* techniques. We consider the related work in each of these categories.

2.1 Indirect versus Direct-Touch Techniques

Early touchscreens were designed to detect a single point of contact and studies comparing these devices to mouse-based interactions in a selection task found speed advantages for the touchscreen [19, 28]. However, occlusion due to the fingers and imprecision in locating touchpoints also reduced accuracy of the direct-touch input. Sears and Schneiderman [33] investigated the effect of target size on speed and accuracy. They found that targets of size 0.64 cm in width or larger were faster to select with a touchscreen than a mouse, while error rates were roughly equal in both conditions. At a target size of 1.28 cm users made 66% fewer errors with the touchscreen than with the mouse. These studies focused on direct versus indirect interaction and did not consider the effects of unimanual versus bimanual interaction.

2.2 Unimanual versus Bimanual Techniques

There is a vast body of prior work on bimanual interaction. Beginning with Guiard's seminal work on the Kinematic Chain theory [11, 12], prior empirical studies have examined how the hands work together when they are assigned either *asymmetric* roles [1, 6, 17, 18] or similar, *symmetric* roles [2, 7, 22, 23]. Researchers have also shown that for target selection tasks there is significant overlap, or *parallelism* in movement between the hands [8, 20, 21]. These studies have informed the design of a large variety of bimanual interaction techniques [4, 5, 15, 16, 29, 34]. However, these studies focus primarily on the advantages of bimanual over unimanual techniques and do not examine the effects of direct versus indirect interaction.

With the advent of multitouch workstations [13, 24, 25, 31] that offer both direct-touch and bimanual interaction, a few groups have begun studying these two factors in combination. Barnert [3] designed an asymmetric task and found that users are better at target selection and dragging using either one or two mice than using one or two hands on a multitouch table. However, Barnert's task required single pixel-accuracy which Sears and Schneiderman [33] showed to be very difficult for direct-touch devices. It is unlikely that these results would apply to selection tasks with larger targets.

Forlines et al. [10] conducted a pair of experiments that compared target selection on a mouse workstation and a multitouch workstation. In the first study they focused on unimanual interaction and showed that in a single-target selection task with targets of size 1.92 cm and larger, direct-touch offers modest speed advantages over the mouse. However, the direct-touch device also produced twice the error rate of the mouse and therefore Forlines et al. recommend using a mouse for single-target selection. In the second experiment they studied a symmetric bimanual selection and docking rectangle resizing task. Users first selected target handles at diagonally opposite corners of a rectangle using both hands and then dragged those handles onto the corners of a differently sized target rectangle. In this case they found large speed advantages for direct bimanual multitouch over a pair of mice. However error rates for the target selection part of the task were twice as large in the multitouch condition. Nevertheless Forlines et al. recommend using direct multitouch interaction for such symmetric bimanual tasks because of the speed advantages.

Because Forlines et al. do not consider unimanual and bimanual conditions together in the same task, their studies cannot directly compare the performance advantages due to the multiple input capabilities of a multitouch display versus those only due to direct-touch. Our work fills this gap by considering both interaction dimensions indirect/direct and unimanual/bimanual together. We also consider the performance of multifinger input.

2.3 Multifinger Techniques

There has been some work investigating the performance of same hand multifinger dragging techniques. Moscovich and Hughes [27] compared the performance of using two fingers on the same hand against two fingers on separate hands to perform an object alignment task using an indirect multitouch pad. They found that two handed manipulation is better for performing separable tasks, such as manipulating separate control points of a graphical object, but that two finger unimanual manipulation is better for integral tasks such as simultaneous translation and rotation of a 2D object. For a docking task in which users controlled 5 or 6 translation and rotation degrees of freedom simultaneously, Hancock et al. [14] found that performance was best using a three finger technique - two fingers on the dominant hand and one finger on the non dominant hand. These multifinger techniques focus on using the increased input bandwidth to more easily control additional degrees of freedom in interactive tasks. In contrast, we consider the potential for using multiple fingers to perform many independent (i.e. symmetric) selection tasks. Multiple fingers do not increase the degrees of freedom our users control, but rather increase the potential for overlapping, or simultaneous selection of targets.

3 MULTITARGET SELECTION EXPERIMENT

Our experiment focuses on studying multitarget selection because it is a common task in many real-world applications, from file and photo sorting to manipulation of graphical objects. With a mouse-based workstation and a single input touchscreen, users are forced to serially select multiple targets. In contrast, a multitouch workstation that detects multiple contact points permit the possibility of selecting the targets in parallel. In theory users could simultaneously select targets with all ten fingers on both hands and thereby increase performance.

We expect one finger direct-touch to perform better than the mouse for multitarget selection. For single target selection Sears and Shneiderman [33] have shown that direct-touch outperforms the mouse. Since multitarget selection in the unimanual case requires a series of single selections, we expect direct-touch to provide better performance than the mouse. We further expect that two-finger bimanual multitarget selection will be faster than one-finger unimanual selection. Researchers have previously shown that for many tasks bimanual techniques perform better than unimanual techniques due to the parallelism achieved from two hands [2, 8, 17, 20, 21]. These studies show that there can be significant overlap in the movement of two hands for selection tasks, and we therefore expect bimanual selection of multiple targets to be faster than unimanual selection of targets. Two hands also provide a division of labor for multitarget selection. Each hand can work in its respective area of the screen and thus does not need to travel long distances [9]. Finally, bimanual, multifinger selection has the potential to exhibit
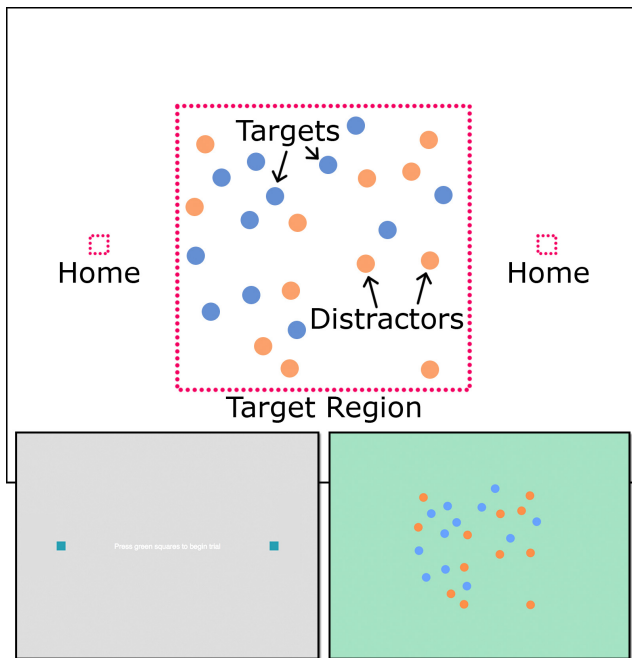
Figure 1: Top: Conceptual layout of the multitarget selection task. Bottom: Screenshot of home positions and screenshot of task. Text in left screenshot reads: "Press green squares to begin trial."

even more overlapping action as each finger on each hand can simultaneously move towards a different, nearby target.

Note however, that even though both the two finger and multifinger conditions permit parallelism, the one finger condition has some advantages that can make up for its serial nature. Using a single hand rather than two hands can decrease occlusion due to the hands and thereby make it easier to see the targets on the display surface. In addition, since the one finger condition forces serializing the task, users may realize it more quickly when they miss a target and which target they missed. They may be able to correct this mistake before moving too far away.

3.1 Task and Experiment Design

To separate the effects of direct-touch, bimanual and multifinger interaction, we compare the performance on a multitarget selection task across four input conditions: 1) one *mouse* (indirect, unimanual), 2) *one finger* (direct-touch, unimanual), 3) *two fingers*, one on each hand (direct-touch, bimanual), and 4) unconstrained *multifinger* input (direct-touch, bimanual, multifinger). For the one finger condition, subjects were required to use the same finger during the duration of a trial but were permitted to change the finger between trials. For the two finger condition, subjects were instructed to use one finger on each hand and to use those same two fingers during the duration of a trial. Subjects were allowed to change fingers between trials. For the multifinger condition, subjects could use all ten fingers. Subjects could choose to select targets serially or in parallel in the two finger and multifinger conditions.

Our experiment did not include a two-mouse condition because we did not expect it to perform well based on the results of prior work. Forlines et al. [10] found the time to select two corners of a rectangle to be much longer for two mice than for two fingers on a multitouch display. Balakrishnan and Hinckley [2] suggested that visually tracking two mice is difficult for users especially when no line or other visual mark connects the two. In our own experience operating two mice, we found that selecting targets, especially with the non-dominant hand, was imprecise and indeed difficult.

To begin a trial, subjects first selected home positions. For the one mouse and one finger conditions, there was a single home position located on the right side of the screen. For the two finger and multifinger conditions, there were two home positions, one located on each side of the screen (see Figure 1). After selecting the home position(s), the subject was immediately presented with blue target discs and orange, non-selectable distractor discs that were randomly placed between the two home positions. All discs were presented simultaneously. We instructed subjects to select all the blue targets as quickly and as accurately as possible for each trial. We included the orange distractors to mimic cases in which a user could not simply lasso select all the targets and had to select each one individually. We counted a target as hit when the mouse cursor fell within the target on a mouse click or when the center of a finger's contact area fell within the target. On successful hits, the system played a *ding!* sound. A trial ended after all blue targets were selected. Our multitouch workstation is incapable of identifying which finger or which hand corresponds to each touch. We identified the finger and hand after the experiment, by manually reviewing a video recording of the multitouch trials.

Because multitouch workstations are relatively new we believe that there is no clear consensus on best practice methods for adapting single user applications, originally designed to work with a mouse and a desktop display, to the larger tabletop display format of a multitouch workstation. Therefore, we designed our experiments to work comfortably for desktop display sizes and then uniformly scaled them up for use on our multitouch display.

We varied the number of blue targets across five levels: 3, 6, 9, 12, and 15, with an equal number of orange distractors. The diameter of both the targets and distractors were 1.5 cm and 2.1 cm for the mouse-based and multitouch workstations respectively. We chose these diameters based on the recommendations of Sears and Shneiderman [33], and we believe they are large enough for us to expect that direct-touch selection would be faster than mouse-based selection. We used a Poisson disk distribution to randomly place targets and distractors and to prevent them from overlapping one another. Thus all of the targets and distractors were separated by at least the width of a target. The centers of all targets and distractors were situated in the 22.6 cm x 24.0 cm and 32.3 cm x 34.3 cm region of the center of the screen for the mouse and multitouch workstations respectively. The home positions were placed on the horizontal midline of the screen, 7.5 cm and 10.7 cm away from the target region for the mouse and multitouch workstations respectively.

We used a within subject design so that each subject used each of the 4 input methods in 4 blocks of trials, with 5 levels for number of targets and 2 trials per level. To account for ordering effects we used a Latin square to set the order of the input methods across subjects. Thus, for each subject there were 4 input methods x 4 blocks x 5 levels x 2 trials = 160 total trials. Subjects had the option to rest between trials. To mitigate learning effects we required subjects to execute one block of 10 practice trials when initially starting with a new input method. After completing the practice block, subjects could perform as many additional practice trials as they wanted until they felt comfortable enough to begin the experiment.

3.2 Subjects and Apparatus

We recruited eight subjects (7 male, 1 female) who were all experienced desktop workstation users, but had no significant experience with a multitouch workstation. Seven subjects were right-handed, and one subject claimed to be ambidextrous but used the right hand to control the mouse.

For the one and two finger conditions, one subject exclusively used middle fingers and five subjects exclusively used index fingers. The other two subjects used index fingers for the two finger case, but for the one finger case, one subject used the middle finger, while the other subject used the index finger but switched to the middle
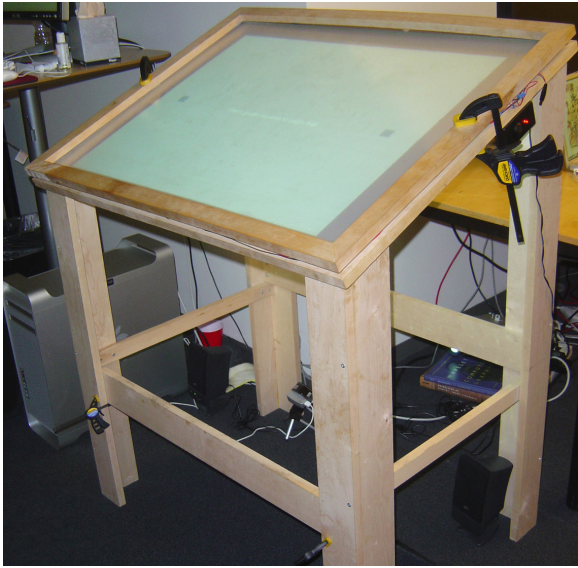
Figure 2: Our multitouch workstation.

Figure 3: Average total selection times of the four input methods as a function of number of targets. The standard error bars are shown.

	mouse	one finger	two fingers	multifinger
3	2.69 (.053)	1.62 (.035)	1.44 (.031)	**1.37** (.021)
6	4.90 (.102)	2.75 (.057)	**2.26** (.060)	2.32 (.049)
9	6.93 (.111)	3.72 (.077)	3.14 (.090)	**3.10** (.072)
12	8.91 (.135)	4.79 (.108)	**4.00** (.099)	4.15 (.105)
15	10.68 (.160)	5.68 (.113)	**4.79** (.123)	5.14 (.133)
avg	6.82	3.71	3.12	3.22

Table 1: The rows correspond to number of targets and the columns correspond to input method. Each table contains the average time to select the corresponding number of targets using the corresponding input method. Standard errors are noted in parentheses. The fastest selection time per number of targets is given in bold. The last row contains the average completion time for each input condition.

finger between trials.

To increase the ecological validity of our study, we chose our workstation configurations for the task to reflect current best practices for professional single user applications. We used a Dell optical wheel mouse for the indirect input with mouse acceleration enabled and a 30" HP LP3065 monitor at its native resolution of 2560 x 1600 pixels. Using the Mac OS X system preferences keyboard and mouse controls we set the mouse tracking speed to a comfortable level so that a user could traverse the entire screen without the need for reclutching the mouse. We used the built-in Mac OS X mouse acceleration profile.

We built the multitouch workstation used in this experiment (see Figure 2) - it is patterned after a drafting table and uses the frustrated total internal reflection technique described by Han [13]. The table is capable of detecting an arbitrary number simultaneous of touches. The size of the screen is 76.2 cm x 57.2 cm with a resolution of 1024 x 768 pixels. Subjects stood in front of the screen, which was mounted at a 23 degree incline off horizontal.

As explained in the previous section, we chose to uniformly scale our experiment from the desktop display to our larger tabletop multitouch display. To guarantee uniform scaling it is important that the desktop and multitouch displays use the same aspect ratio. Since the native aspect ratios differ (4:3 for multitouch, 8:5 for the desktop), we chose to use only a 4:3 portion (53.3 cm x 40.0 cm, 2133 x 1600 pixels) of the HP monitor for the mouse condition.

3.3 Results

For each trial of the experiment we recorded the total selection time. We started the timer immediately after the subject touched the home position(s) to begin a trial and stopped the timer as soon as the subject successfully finished selecting all presented targets. Because misses occur naturally in real-world target selection tasks, we included the time to correct misses in the total selection time. The average selection times are shown in Table 1 with a corresponding graph of the data in Figure 3. An RM-ANOVA on the selection times finds significant main effects for input method ($F_{3,21}$=418.02, p<0.001) and number of targets ($F_{4,28}$=509.77, p<0.001), as well as a significant interaction between these two independent variables ($F_{12,84}$=99.18, p<0.001). The effect size of the interaction (η^2=.071) is small relative to the effect sizes of the input method (η^2=.372) and the number of targets (η^2=.464). We attribute the
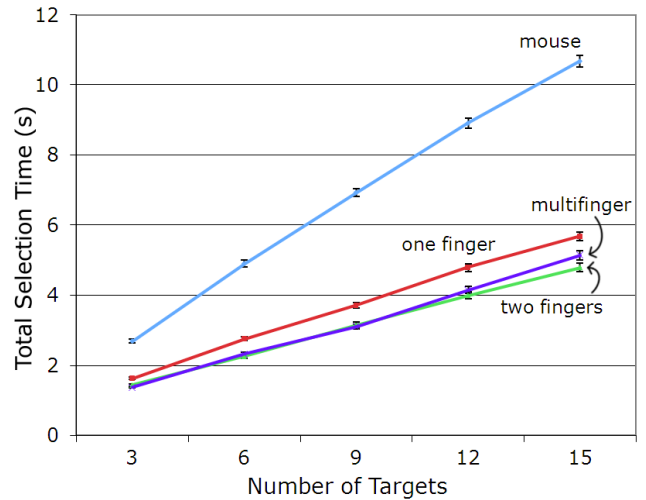
interaction to the observation that the selection time for the mouse increases at a much faster than rate than for the other input conditions as the number of targets increases (Figure 3).

Pairwise comparisons of selection times for each pair of input methods reveals significant differences between all pairs (p<0.012 between one finger and multifinger and p<0.001 for the rest), with the exception of the difference between the two finger and multifinger conditions (p=0.426). The fastest multitouch condition (either two finger or multifinger) is always between 1.96 and 2.33 times faster than the mouse. The two finger and multifinger conditions are consistently faster than one finger which is consistently faster than the mouse condition. The direct-touch, one finger condition accounts for about 83% of the reduction in selection time, while bimanual interaction, either two finger or multifinger, accounts for the remaining reduction. There is little difference in average selection times between the two finger and multifinger conditions even in the densest condition of 15 targets.

We counted a miss each time a mouse click or a touch event did not successfully hit a target. Hitting a target that was already selected was also counted as a miss. Each subject had to select a total of 360 targets for each input method. As shown in Figure 4 subjects had an average miss rate of 8.51% for the mouse, 7.29% for one finger, 10.45% for two fingers, and 13.75% for multifinger. An RM-ANOVA finds a significant effect due to input method ($F_{3,21}$=3.72 p=0.027) and number of targets ($F_{4,28}$=46.11 p<0.001) as well as a significant interaction between these two factors ($F_{12,84}$=3.74 p<0.001). However, pairwise comparisons across pairs of input methods reveals that the only significant difference
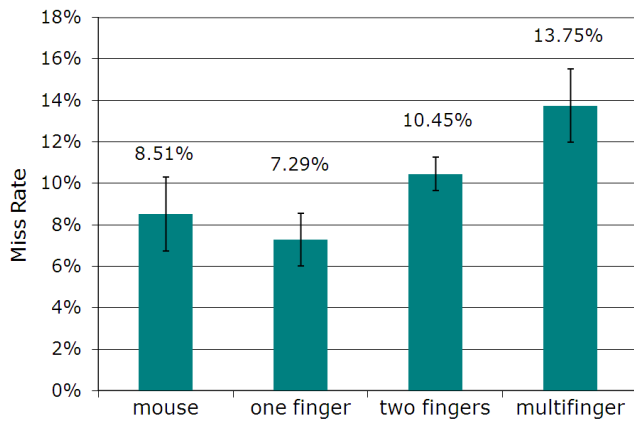
Figure 4: Average miss rate per input method, with standard error bars.
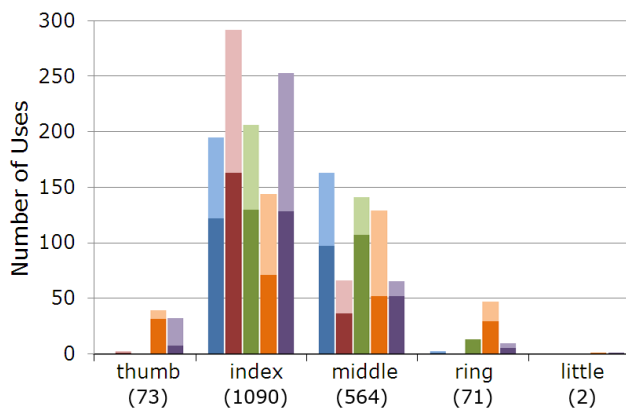

Figure 5: Number of uses per finger type across subjects in parentheses. Distinct colors denote distinct subjects. The dark and light hues correspond to the right and left hand contributions respectively.

in miss rate is between the one finger and multifinger conditions (p<0.001). The effect size of the number of targets (η^2=0.144) is much larger than the effects of the input device (η^2=0.030) and the interaction (η^2=0.030).

For the multifinger condition, five subjects opted to use more than two fingers, while the remaining three subjects preferred to just use two fingers, one on each hand. Figure 5 shows the number of times each finger was used to select a target aggregated across the five subjects that used more than one finger on each hand. Out of 1800 total uses of the different fingers these five subjects used the index fingers most frequently with 1090 uses and they used the little fingers least frequently with 2 uses. The data also show that for all subjects in the multifinger condition, one finger was in contact with the multitouch surface 68.5% of the time, two fingers were simultaneously in contact 30.0% of the time, and three and four fingers were simultaneously in contact 1.2% and 0.3% of the time respectively. We never observed more than four fingers in contact with the surface simultaneously.

In addition to measuring selection time and miss rates we also collected subjective preference data from the subjects in an exit survey. We asked the subjects to rate the mouse-based workstation versus the multitouch workstation on a scale 1-9, with 1 indicating preference for the mouse mouse and 9 indicating preference for multitouch.

The average rating was 8.4. We also asked the subjects which of the four input conditions they thought was fastest for selection.

Four subjects rated themselves as fastest using two fingers, while three thought they were fastest in the multifinger condition. One subject thought he was fastest with just one finger. The proponents for two fingers thought that using multifinger caused more screen occlusion from fanning their fingers, and found it difficult to orient multiple fingers on a single hand and target multiple targets at the same time. Those who thought multifinger was the fastest condition liked the option of being able to reach for a target with a different finger on the same hand.

3.4 Discussion

The goal of our experiment was to compare the performance of one mouse, one finger, two finger and multifinger techniques for multitarget selection. Consistent with previous work, we find that using one finger direct-touch is faster than using a mouse and, as expected, bimanual interactions are faster than using one finger. About 83% of the decrease in selection time is due to moving from the indirect mouse to the one finger direct touch with remaining benefit of about 27% due to moving from unimanual multitouch to bimanual multitouch.

Miss rates are similar across the four input methods. However, the bimanual conditions tend to have higher miss rates than the uni-manual conditions and the difference of about 6.5% between one finger and multifinger is significant. Even though misses occur more frequently in the bimanual conditions and we include the time to correct these misses in the total selection times, we find that users are still able to successfully complete the multitarget selection task faster using two hands.

Although the multifinger condition provides more opportunity for simultaneously selecting multiple targets, it does not perform better than the two finger condition, at least for novice multitouch users. The data reveals a strong preference for using one or two index fingers, even when given the opportunity to use more. We find that in the multifinger condition users rarely put more than two fingers in contact with the table simultaneously (just 1.5% of the cases) and never placed more than four fingers in contact simultaneously. This suggests that the tracking of two simultaneous contacts may be enough to support even multifinger multitarget selection. The relatively high miss rate for multifinger may be due to increased cognitive load required to plan movements for multiple fingers independently. In addition, fingers on the same hand are physically constrained to the palm, which limits the set of targets these fingers can touch simultaneously.

Design Guidelines: Based on our experiment we recommend the following set of design guidelines for developing applications for multitouch workstations. Since our studies focus on multitarget selection, all of these guidelines are aimed at applications where target selection is the primary task.

- A one finger direct-touch device delivers a large performance gain over a mouse-based device. For multitarget selection tasks even devices that detect only one point of touch contact can be effective.

- Support for detecting two fingers will further improve performance, but support for detecting more than two fingers is unnecessary to improve multitarget selection performance.

- Reserve same-hand multifinger usage for controlling multiple degrees of freedom or disambiguating gestures rather than for independent target selections.

- Uniformly scaling up interfaces originally designed for desktop workstations for use with large display direct-touch devices is a viable strategy as long as targets are at least the size of a fingertip.

Limitations: It is worth noting that several aspects of our experimental design limit generalizability of our results. For example, we do not vary the size or shape of our targets. As a result targets of differing sizes and shapes may affect performance. Prior work has shown that targets must be larger than the size of a fingertip to obtain good performance with multitouch devices [33].

While our experiment does not explicitly control density of targets at a fine-grained level, we do test different numbers of targets. Since we place targets randomly based on a Poisson disk distribution it is unclear how well our results would generalize to the case when targets are placed extremely close (within a target diameter) to one another. Moreover real-world applications rarely layout targets randomly and therefore our results may not generalize cleanly to more realistic applications. The performance impact of bimanual and multifinger interactions may increase or decrease depending on the layout and clustering of targets. Nevertheless, because our experiments are based on randomized layouts they may serve as baseline data for the more structured target layouts.

Learning, practice effects and muscle-memory may also play important roles in target selection. A practiced pianist or touch-typist can simultaneously target keys in fixed locations with many fingers. Such learning effects and chording for multitarget selection on a multitouch workstation require further study.

4 CONCLUSIONS AND FUTURE WORK

We have presented an experiment that compares the performances of direct-touch, bimanual, and multifinger interactions for a multitouch workstation for the single task of multitarget selection. We show that direct touch with a single finger provides a large performance benefit over using a mouse and that bimanual interaction provides a smaller additional benefit. Allowing the use of more than two fingers provides no additional benefit for multitarget selection and may in fact reduce targeting accuracy.

Many possible directions for future work exist. Our work focuses on target selection. It is important to consider other common interactions such as dragging and text entry in multitouch settings. More, multitouch allows for multifinger gestures and future work should investigate the benefits of the increased input bandwidth due to detection of multiple contact points. We believe that further studies may be needed to establish guidelines for such interactions.

5 ACKNOWLEDGMENTS

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