

Barrier Pointing: Using Physical Edges to Assist Target Acquisition on Mobile Device Touch Screens

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ABSTRACT

Mobile phones and personal digital assistants (PDAs) are incredibly popular pervasive technologies. Many of these devices contain touch screens, which can present problems for users with motor impairments due to small targets and their reliance on tapping for target acquisition. In order to select a target, users must tap on the screen, an action which requires the precise motion of flying into a target and lifting without slipping. In this paper, we propose a new technique for target acquisition called *barrier pointing*, which leverages the elevated physical edges surrounding the screen to improve pointing accuracy. After designing a series of barrier pointing techniques, we conducted an initial study with 9 able-bodied users and 9 users with motor impairments in order to discover the parameters that make barrier pointing successful. From this data, we offer an in-depth analysis of the performance of two motor-impaired users for whom barrier pointing was especially beneficial. We show the importance of providing physical stability by allowing the stylus to press against the screen and its physical edge. We offer other design insights and lessons learned that can inform future attempts at leveraging the physical properties of mobile devices to improve accessibility.

Categories and Subject Descriptors

H.5.2. [Information interfaces and presentation]: User interfaces – input devices and strategies. K.4.2. [Computers and society]: Social issues – assistive technologies for persons with disabilities.

General Terms: Design, Experimentation, Human Factors.

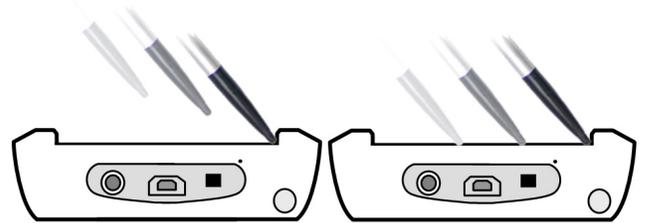
Keywords: Target acquisition, touch screens, edges, corners, accessible interfaces, motor impairments, mobile phones, PDAs.

1. INTRODUCTION

In 2006, the number of mobile phone subscribers in the world surpassed 2.5 billion.¹ This is more than *twice* the number of PC users worldwide. The technology curve shows mobile phones and PDAs getting smaller and more powerful every year, providing features that extend beyond voice calls and text messaging. People with motor impairments, however, often find these devices difficult to use [3][14]. Their reduced size makes input challenging as the buttons are small, condensed and sometimes

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ASSETS'07, October 15–17, 2007, Tempe, Arizona, USA.
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(a) Fly-in directly to barrier target (b) Rest the stylus against the screen and stroke into the target.

Figure 1. Two ways the physical properties of a touch screen device can be leveraged to assist movement: (a) The screen's physical edge catches the stylus as it flies into a target. (b) The screen itself provides an additional flat plane to aid movement.

recessed. Prior work has shown that motor-impaired users may not have the physical strength to press hard physical buttons [14]. And certain device form factors (e.g., clamshell phones) require dexterity and strength just to open.

Many emerging high-end phones such as the Microsoft Windows Mobile Smartphone and the Apple iPhone contain touch screens. The iPhone features only one physical button, relying instead almost exclusively on touch screen interactions.² However, touch screens pose an additional set of challenges for mobile device accessibility: they lack tactile feedback and the physical stability available with hard buttons, and their interfaces often require dexterous motor control.

Still, touch screen devices offer rich potential for motor-impaired users. Myers et al. [14] demonstrated the use of Palm PDAs as viable alternatives to the mouse and keyboard for users with muscular dystrophy. Touch screens have the potential to support more fluid interactions than their button-based counterparts as they are *direct interaction* systems; that is, the point of stylus or finger contact is co-located with the screen's output. Thus, unlike traditional mobile phones, where target selection is accomplished *indirectly* via button presses and/or joystick movements, touch screen-based targets can be selected and manipulated directly.

Wobbrock et al. [24][25] demonstrated how physical edges could be used to assist motor-impaired users with touch screen-based text entry. Walker and Smelcer [21] demonstrated the benefits of impenetrable borders on targets to reduce mouse movement time. Our work expands into the realm of target acquisition on mobile

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device touch screens. In particular, we exploit the fact that most touch screens are inset into the device chassis, thus providing a raised physical edge around the screen’s perimeter (Figure 1). We propose a set of new interaction techniques, collectively referred to as *barrier pointing* techniques, which use the screen edges, corners, and the screen surface to support faster and more accurate touch screen target acquisition.

One key aspect of our approach is that it requires no additional hardware and can work on commercially available touch screens with only a software modification. This is important because it increases the diversity of devices available to motor-impaired users without increasing device cost. Prior research has shown that specialized hardware can have high abandonment and low adoption rates [3][12][15]. Therefore, we feel it is important to improve the effectiveness of *ordinary* mobile device touch screens by fundamentally changing the way the devices can be used.

After developing our barrier pointing techniques, we conducted an initial study aimed at understanding the parameters of people and techniques that make barrier pointing useful. We also sought to refine our techniques in preparation for a full study of human performance in barrier pointing tasks. The contributions of this paper include the barrier pointing designs, the lessons we learned from our initial study, and an in-depth analysis of two motor-impaired users who greatly benefited from barrier pointing. For example, error rates were reduced for these two users from 37.5% to 12.5% and 22.2% to 6.7%, respectively, when using barrier pointing versus the traditional fly-in-and-tap technique. Target acquisition times resulted in a similar benefit: 1.6s to 1.0s and 4.2s to 3.1s, respectively. Thus, it seems that barrier pointing may have potential benefits that warrant further design and investigation.

2. RELATED WORK

Some previous studies have explored how motor impairments affect target acquisition with the mouse [10][19]. Results show that participants have difficulty positioning the cursor over small targets, keeping the cursor over the target while clicking, and clicking the mouse button unintentionally before reaching the target [18]. Prior work has also shown that physical disabilities resulting in tremor, low strength, poor coordination, and rapid fatigue also contribute to touch screen interaction difficulties [24]. For example, in [25], Wobbrock et al. found that tremor and fatigue dramatically reduced a user’s ability to make smooth, accurate, and controlled movements. Specifically, they found that tremor made it difficult or impossible for some motor-impaired users to gesture computer-recognizable characters on Palm PDAs. In addition, many users would “bounce” the stylus on the screen, triggering unwanted modes and selections.

A number of techniques have been proposed to aid target acquisition using a mouse including dynamic target expansion [13], “sticky” targets [26], area targets [8][26], goal crossing [1], and Steady Clicks [18]. However, many of these techniques do not translate to touch screens—for example, “sticky” targets work by dynamically increasing the control-display ratio while the cursor is over a target. This results in a perceptible slowdown, or “stickiness,” of the mouse cursor while over a target. But such a technique is infeasible for touch screens and inert styli or fingertips.

Instead, touch screen interaction designs have tended to focus on features that can be controlled such as target width and movement distance (e.g., by dynamically increasing target sizes [13] or moving targets to reduce movement distance [2]). However, even

then, the interaction technique may not be suited for a motor-impaired user. Dynamic target expansion, for example, works by increasing the target size based on cursor/stylus movement. This technique assumes that the user is always moving accurately towards the target. For motor-impaired users, tremors or spastic movements may invalidate this assumption [18].

Our paper proposes general interaction techniques for touch screens that rely on the screen and screen’s edges to stabilize movement and increase target acquisition performance for motor-impaired users. Our proposed techniques could work in conjunction with many of the techniques listed above.

2.1 Edges in User Interfaces

Fitts’ law predicts that target acquisition time is logarithmically related to both the travel distance and target size [7]. Many of the target acquisition techniques just described work by dynamically manipulating the target size or distance based on the user’s movement, thereby reducing acquisition time. A third approach is the use of *impenetrable boundaries* in the user interface.

The Apple Macintosh menu bar provides a familiar example of how *virtual* edges can be used to facilitate target acquisition (Figure 2). Unlike in Microsoft Windows, the Macintosh menu bar is flush against the top edge of the computer screen, providing an impenetrable border for the mouse cursor. This has been shown to improve target acquisition times [21]. Farris et al. [6] also utilized an impenetrable edge to achieve faster acquisition of the browser’s back button.

Despite the known benefits of virtual edges in aiding interaction, the use of *physical* edges has only recently been investigated. EdgeWrite [25] relied on physical edges to support stylus text entry. EdgeWrite was not the first to realize the benefits of physical edges in writing. More than a century ago, Lewis Carroll, author of *Alice in Wonderland*, developed a similar system called the Nycetograph as a way to write in the dark [4]. Both the Nycetograph and EdgeWrite use a physical template with square holes to give the user stability while writing specialized alphabets.

Wobbrock also experimented with using the physical edges of the screen itself (rather than a template) in a system called Edge Keyboards [22]. The character buttons, which surrounded the screen’s perimeter, could be stroked over or tapped like ordinary soft buttons. Using the stroke technique, users could enter text

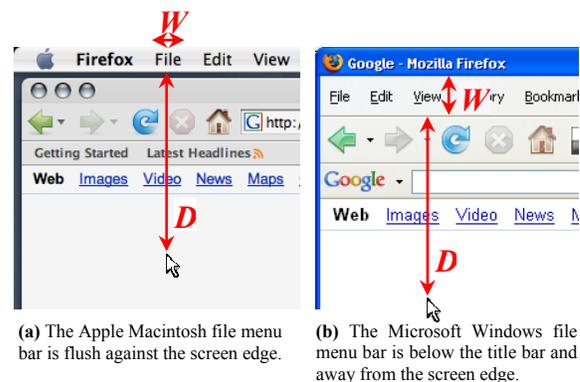


Figure 2. Pointing to an item in the file menu on the Macintosh is faster and more accurate than in Windows [21]. On the Macintosh, the screen edge serves as a trap for mouse movement in the vertical direction. This is not the case in Windows, where the file menu is positioned away from the screen edge making menu access more difficult.

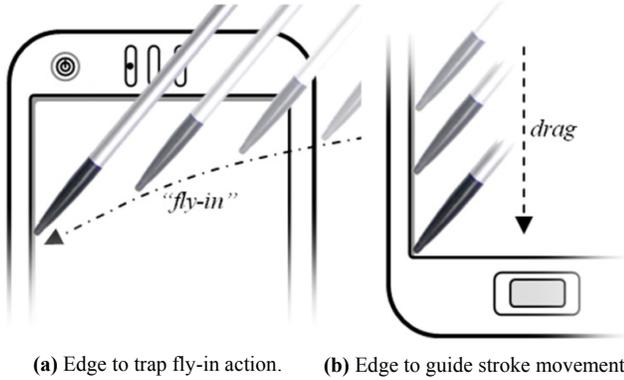


Figure 3. The physical edges of the device screen can be used to support various interactions.

without ever lifting their stylus. We investigate a similar technique but focus on target acquisition rather than text entry.

Finally, laptop touchpads often provide special modes of interaction in their corners and along their edges. For example, a user can assign short-cuts to the four corners of the touchpad, which are accessed by tapping. These interactions work well because the user can feel the edge with his fingertips and access the shortcuts without looking.

3. BARRIER POINTING

The motivating principle behind barrier pointing is to leverage the physical properties of mobile touch screens to provide stability and increased accuracy for target acquisition. We focused on three physical affordances:

Edges: Similar to the impenetrable virtual border on the Macintosh menu bar [21], barrier pointing takes advantage of the screen edge to assist the user in acquiring the target. In our case, the border is not virtual, but *physical* (Figure 1a). In barrier pointing, targets are placed around the screen’s perimeter to exploit the following benefits provided by the edge:

1. The ability to fly-in and catch the edge of the screen, guiding the stylus down to the screen’s surface. Of the devices we explored (primarily Pocket PCs and Smartphones), the screen was sufficiently deep-set into the device for this interaction (Figure 1a and Figure 3a);
2. The ability to guide the stylus along screen edges. A motor-impaired user can push the stylus against the edge and, without much effort, smoothly move in a single cardinal direction [22] (Figure 3b).

Corners: Corner-based interactions can provide even more stability than individual edges. The Microsoft Pocket PC operating system interface already takes advantage of this property by positioning the most frequently used targets in the four corners of the screen. Corners are particularly suited for trapping a fly-in stylus or an edge-based movement (Figure 3b). A user who has jitter or poor coordination may choose to first fly the stylus into a corner and then guide it along the edge to a target.

Screen Surface: If user interfaces are designed accordingly, the screen itself can be a useful resting place to stabilize a tremulous hand [9]. Barrier pointing interfaces allow the user to continuously hold their stylus against the screen (Figure 3b) and stroke, rather than fly into targets. To eliminate errors from stylus “bounce,” brief lifts of less than 100 ms are ignored.

3.1 Barrier Targets

Barrier targets are positioned around the perimeter of the screen. Depending on the application, barrier targets could extend continuously along all four edges of the screen, or simply along one or more edges. The center of the screen could be “inert” space used for output only, not input, allowing the stylus to be placed there for increased stability. All widgets would be placed around the screen perimeter as barrier targets. As in mouse-based interaction, barrier targets have five states: normal, hover, select, confirm, and cancel. The ways in which these states are accessed depend on the interaction technique. Unlike traditional touch screen targets, barrier targets can always be stroked into rather than tapped. Note that to acquire a target, the user must always first *select* and then *confirm*, no matter what the technique.

Some of our barrier targets contain *selection troughs*. These are small *edge-aligned* areas that function as selection boundaries for the target (visible in Figure 4 and Figure 5). The idea behind selection troughs is to reduce the selectable area of a target along the non-edge dimension in order to prevent erroneous selections. A stylus may stroke into a selection trough from any of its three exposed borders or fly-in directly. When the stylus enters the selection trough, the target becomes selected. The non-selection trough area of the target is called the *hover area*. The user may enter the hover area without selecting the target. The semantics of barrier selection troughs depends on the interaction.

3.2 Barrier Interaction Techniques

The following sub-sections introduce the barrier pointing techniques that we investigated during our study.

3.2.1 Edge Stroke with Lift Confirmation

The interaction here is similar to Potter et al.’s [16] *take-off* strategy for touch screens, where the user is able to contact the screen surface at any point and drag his/her stylus (or finger) to a target. In this case, a *selection* is made when the user strokes into the target’s selection trough (Figure 4c). This selection is confirmed by lifting the stylus anywhere within the selected target’s *full* boundary. That is, once a target is selected, the stylus may leave the selection trough and enter the hover area while maintaining the selection. The user cancels the selection by exiting the target area and lifting. As barrier targets are contiguous along an edge, exiting a selected target into a neighbor’s trough selects this neighbor. Thus, the presence of the physical edge can help the stylus slide into the desired target before that target is acquired via lifting.

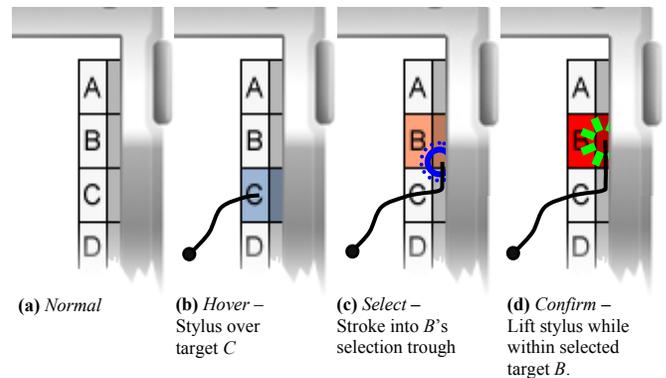


Figure 4. The “edge stroke with lift confirmation” barrier interaction. The selection troughs are the darker shaded areas of the widget that line the edge-side border of each target.

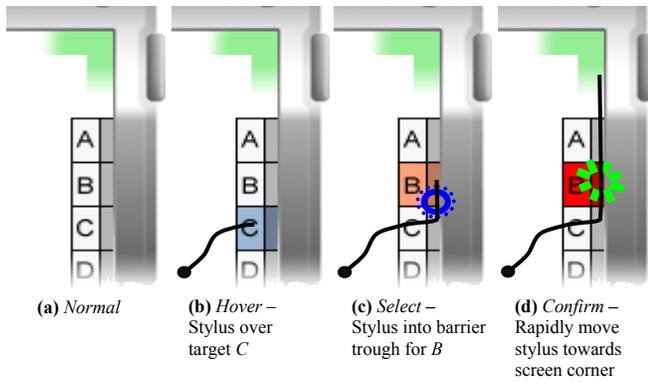


Figure 5. The “velocity stroke with corner confirmation” interaction. By eliminating the need for lift, the stylus is able to rest on the screen throughout a series of interactions; however, the user must reach the escape velocity before exiting the selected target.

3.2.2 Velocity Stroke with Corner Confirmation

This interaction is similar to the previous technique except for the confirmation step. Rather than lift, the user must stroke into a *confirmation corner* to confirm his/her selection (Figure 5). Confirmation corners allow the user to operate the device with the stylus continuously pressed against the screen. Once a target is selected and a confirmation corner is accessed, the user may begin another target acquisition *without lifting* the stylus.

In order to distinguish between a confirmation corner stroke and a target selection stroke, a speed threshold (“escape velocity”) is used as a mode switch. The user must maintain this escape velocity after exiting a selected target until the stylus reaches the confirmation corner. If the velocity is not maintained, the current selection is canceled or if the stylus is over another target’s trough, this new target becomes selected. Currently, this threshold is set to 200 pixels/second, which was derived empirically with able-bodied testers. This value is slightly slower than the threshold used to ignore mouse clicks in *Steady Clicks* [18].

3.2.3 Reverse Stroke with Corner Confirmation

Because moving the stylus at escape speeds may be difficult for motor-impaired users, we developed an alternative method for selection. The “reverse stroke with corner confirmation” technique uses a direction reversal stroke along the target’s edge to indicate a selection. For example, if the user is running south along the right edge of the screen, the user would reverse directions (by stroking north) within a target to select that target (Figure 6). The user must then move the stylus along the edge to a corner to confirm. Note that unlike the previous two barrier techniques, “reverse stroke with corner confirmation” does not use selection troughs—thus, its selectable area is the full size of the widget. We found this made it easier for subjects to reverse directions accurately. Note that the direction change can be made as slowly or quickly as desired; speed is not an issue.

4. INITIAL STUDY

In order to better understand barrier pointing, we conducted an initial study of 18 subjects, 9 of whom had motor impairments and 9 of whom did not. For each subject, we administered the 3 aforementioned barrier techniques in addition to the two baseline fly-in-and-tap conditions. This study was meant to provide both quantitative and qualitative insights into how barrier techniques may be used by motor-impaired and able-bodied users.

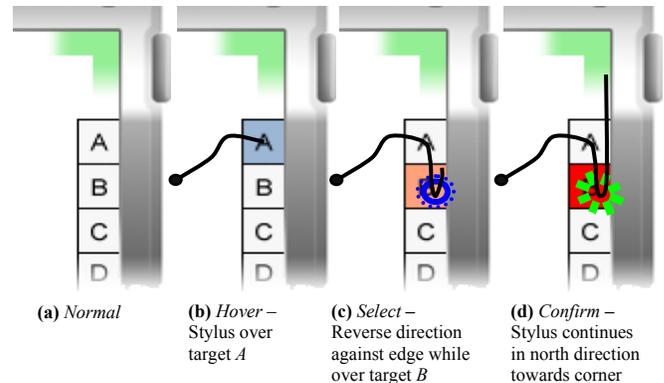


Figure 6. The “reverse stroke with corner confirmation” barrier interaction. For illustrative purposes, these figures demonstrate a reverse stroke slightly away from the edge. The ideal interaction, however, is simply running the stylus along the edge and reversing direction.

4.1 Method

4.1.1 Subjects

Eighteen subjects volunteered for the initial study: 9 able-bodied (AB) and 9 motor-impaired (MI). Two females participated in the AB group and 4 in the MI group. The average age was 23.9 ($SD=2.4$) and 37.7 (12.5) for the AB and MI groups, respectively. All subjects indicated that they used a desktop computer for at least an hour every day. Similarly, all subjects, with the exception of one MI participant, owned and used a mobile phone multiple times a day. Two MI subjects (MI1 and MI6) indicated that they currently own a touch screen mobile device. The MI subjects and their health conditions are listed in Table 1. Note that the motor impairments of our subjects covered a very broad range. This was by design, as we wanted to determine what types of users might benefit most from barrier pointing.

4.1.2 Apparatus

The initial study was conducted on two HTC Wizard Pocket PC Phones running Windows Mobile 5. One of the devices was outfitted with Velcro and attached to a clipboard for stability; the other was held in the hand. Participants were able to choose either device. The HTC Wizard is 5.3 ounces, 2.83”×4.25”×0.93” in size, and contains a 1.75”×2.25” single-touch touch screen with a QVGA resolution of 320×240 pixels. The touch screen sampling rate was measured empirically at ~100 Hz. The screen edge is 1.7 mm high. As the HTC Wizard ships with a small, ponderous stylus, we offered two alternatives: (1) a thick 5.75” stylus with a rubber grip, or (2) a 6.25” stylus, which was much lighter than (1) and about 40% smaller in diameter.

Subj	Sex	Age	Condition
MI1	M	48	Neuromuscular condition, low strength
MI2	F	55	Parkinson’s, slight jitter, good motor control
MI3	M	38	Limited hand function, limited trunk balance
MI4	M	39	Tetraplegia (SCI C5), no use of triceps, pectorals, hands.
MI5	M	50	Limited coordination, episodic peripheral neuropathy
MI6	F	21	Cerebral Palsy (CP)
MI7	F	41	Degeneration of neck and spine
MI8	M	23	Spastic CP, lack of fine motor skills
MI9	F	24	Poor motor control as result of injury

Table 1. MI Study Participants

The experiment software (Figure 7) was developed in C#. The experiment was done in full-screen mode (320×240 pixels). Trial data, including target locations, stylus locations, and stylus movement, were logged to XML files with millisecond timestamps. A high-performance counter was used rather than the default system clock to obtain millisecond resolution. A separate C# application was used to parse, analyze, and translate the XML files into a tab-delimited format for analyses.

4.1.3 Procedure

Our experiment consisted of five separate target acquisition techniques administered in random order. A trial set comprised an equal number of trials per target size and target edge. For both the MI group and the AB group, three target sizes were used (pixels: small 15×16, medium 26×16, and large 59×28). The target sizes were taken directly from real Pocket PC interfaces. We tested three edges (all but the bottom) for the MI group and all 4 edges for the AB group. Thus, the MI group completed 45 trials per technique (3 target sizes × 3 edges × 5 trials/edge) and the AB group completed 72 trials per technique (3 target sizes × 4 edges × 6 trials/edge). Each interaction technique received its own trial set for a total of 225 trials per MI subject and 360 trials per AB subject. The five interaction techniques are listed below.

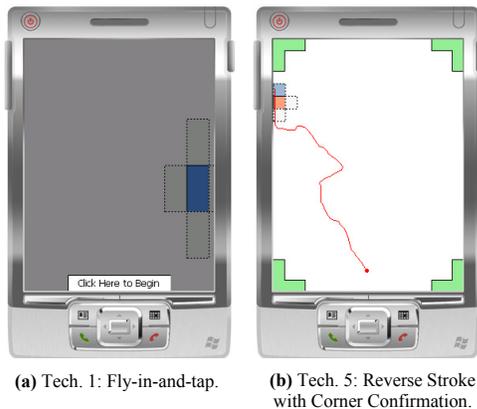


Figure 7. Two screenshots from our experiment software. The primary target is blue and the distractor targets are white with a dashed border. Note that (a) shows the start button that must be tapped before each trial begins. This allowed us to collect accurate timing and distance-to-target data.

Baseline techniques:

1. **Fly-in-and-Tap:** This is the normal mode of interaction on most mobile device touch screens. Targets are *selected* on stylus-down and *confirmed* on stylus-up while within the target. The stylus can not stroke into a target, but instead is required to fly into the target directly. Targets are set 10 pixels from edge; otherwise they have the same positions as the other techniques.
2. **Edge Fly-in-and-Tap:** Same as #1, but targets are positioned flush against the screen edge.

Barrier pointing techniques (from section 3.2):

3. **Edge Stroke with Lift Confirmation:** Targets are *selected* by stroking into their selection troughs (which are against the edge) and are *confirmed* by lifting.
4. **Velocity Stroke with Corner Confirmation:** Same as #3, but selection is confirmed by rapidly stroking into a corner along the same edge.

5. **Reverse Stroke with Corner Confirmation:** Targets are *selected* by reversing directions within the target and are *confirmed* by stroking into a corner along the same edge.

At the beginning of the experiment, our software calculated a random set of target positions around the screen edges for each of the three target sizes. These same positions were used across all five techniques; however, their presentation order was randomized within each trial set. The target was always positioned such that its long side was against the edge. For techniques 2-5, four targets were displayed during each trial: one primary target (in blue) and three distractor targets (in light gray with a dashed border). The distractor targets surrounded the primary target in the three available cardinal directions. For technique 1, the primary target was shifted 10 pixels away from the edge and was thus surrounded by *four* distractor targets.

In order to begin a trial, the subject would tap a “start button,” centered on the bottom edge of the screen (Figure 7) using the traditional fly-in-and-tap technique. Each trial consisted of the acquisition of a single target. Subjects were instructed to move as quickly and accurately as they could to acquire the target. The trial would end if either the primary target or one of the distractor targets was acquired. A “miss” was logged if the subject lifted the stylus without performing an acquisition. Multiple misses could occur during each trial, but only one acquisition could occur. Audio feedback was used to indicate both target state change and task performance. At the end of the five trial sets, a brief paper questionnaire was administered.

4.2 Results

Overall target acquisition times for the various techniques were not statistically significantly different for either the AB or MI group; we therefore examined individual motor-impaired participant performances to gain insight into the effect of different techniques on movement time and errors. Two participants in particular, MI4 and MI8, benefited greatly from barrier pointing. We highlight the specifics of their impairments and their barrier pointing performance in the next section.

4.3 Case Studies: MI4 and MI8

Subject MI4 is a 39 year old male with C5 tetraplegia and no use of his triceps, pectorals, and hands (Figure 8a). Subject MI8 is a 23 year old male with spastic cerebral palsy, which severely affects his motor skills (Figure 8b). Despite their conditions, both subjects indicated that they use a desktop computer for multiple hours a day; however, neither use a traditional mouse. MI4 uses a trackball and MI8 relies primarily on the keyboard. Both subjects also own and use a mobile phone at least once a day. MI4 uses a clamshell model phone, which he cannot open himself—it sits unfolded on his lap throughout the day.

During the study, we observed that both subjects labored with the tapping conditions. Even tapping the start button (see Figure 7a) at the beginning of each trial was arduous and effortful. Often, during downward motions, MI8’s spastic movements would cause him to strike the buttons at the bottom of the device or miss the device entirely. In the baseline fly-in-and-tap condition, both subjects not only had difficulty landing the stylus directly on a target but also lifting while remaining within the target to confirm their selection. However, we observed that when putting downward pressure on the screen edge with the stylus and

stroking, both subjects' movements stabilized considerably, a finding consistent with prior work [22].

Note that MI4 participated in a slightly modified version of the study that did not use selection troughs. Instead, the entire target was active, not just the trough. We made this change to see if it lessened the accuracy demands of the tasks. (This change affected techniques #3 and #4.) As MI4 was easily fatigued, we also lowered the trials per technique count from 45 to 24 in order to complete all conditions. During the experiment, he wore a pen holster so that he could grip the stylus (see Figure 8a).

Table 2 provides a legend to the x-axis numeric labels used in this section's figures. Note: MI4 is always the left figure (in blue) and MI8 is always the right figure (in red).

#	Technique Name
1	Fly-in & Tap
2	Edge Fly-in & Tap
3	Edge Stroke with Lift Confirmation
4	Velocity Stroke with Corner Confirmation
5	Reverse Stroke with Corner Confirmation

Table 2. X-Axis Legend for Figures

4.3.1 Target Acquisition Times

Figure 9 shows the average target acquisition time for each of the five techniques in the experiment. Technique 3, "edge stroke with lift confirmation," resulted in the fastest target acquisition time for MI8 ($avg=2.8s$) and a close second for MI4 (1.2s)—a speed gain over fly-in-and-tap of 48.5% and 40.5% respectively.

Interestingly, unlike for MI4, the average target acquisition time did not change significantly between "fly-in-and-tap" (4.2s) and "edge fly-in-and-tap" (4.3s) for MI8. We expected the edge to provide some measurable speed benefit for both subjects; however, the presence of the edge *did* result in lower miss rates and error rates for MI8 so its existence had some positive effect. Due to his spastic movements, MI8 struggled more than MI4 with the fly-in conditions. This was not an issue for the edge stroke techniques (#3, #4 and #5) because MI8 could land the stylus anywhere on the screen before acquiring his target, which stabilized his movement considerably.



(a) MI4 – C5 Tetraplegic

(b) MI8 – Spastic Cerebral Palsy

Figure 8. Neither MI4 and MI8 have the ability to hold their arms steady and thus relied extensively on the device's screen surface and edges to guide movement.

A second interesting result relates to the poor performance of technique #4, "velocity stroke with corner confirmation" (1.9s for MI4 and 5.2s for MI8). This was because both subjects had difficulty accelerating to the escape velocity speed before exiting their selected target, particularly for small targets. It may not be surprising that speed- or time-dependent designs would be difficult, but we wanted to see if an edge made them feasible.

Finally, notice how MI8 benefited from technique #5, "reverse stroke with corner confirmation," while MI4 did not. MI8 explained that he found this technique difficult because it required

so much movement. He felt most comfortable "pulling towards his body" and this technique forced him to switch directions.

4.3.2 Misses

A "miss" was defined as the stylus lifting from the screen before a target was acquired. Multiple misses could occur per trial; however, the miss rate was the number of trials where at least one miss occurred. The miss rates for both users are presented in Figure 10. As with acquisition time, technique #3, "edge stroke with lift confirmation," performed the best (4.2% for MI4 and 13.3% for MI8). The miss rate decreases from the baseline condition with the introduction of the edge (technique #2) and decreases further with the introduction of stroking and the added stability of holding the stylus against the screen (technique #3).

Average Target Acquisition Time per Technique for Subjects MI4 and MI8

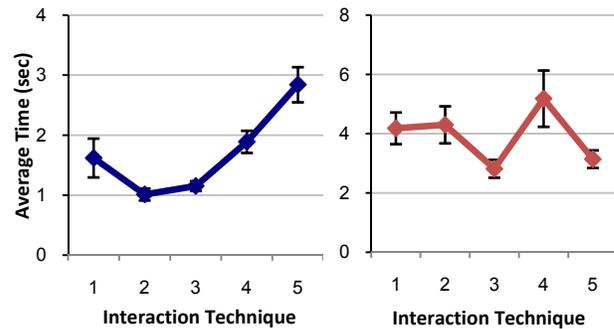


Figure 9. Technique #3, "edge stroke with lift confirmation," performed well for both subjects. It was 40.5% and 48.5% faster for MI4 and MI8 respectively than technique #1, "fly-in-and-tap." Note the different ranges on the y-axes. Error bars represent ± 1 standard error.

Miss Rates per Technique for Subjects MI4 and MI8

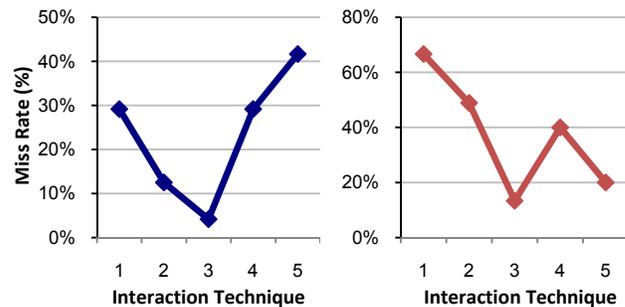


Figure 10. Technique #3, "edge stroke with lift confirmation," had the lowest miss rate for both subjects: 4.2% and 13.3% for MI4 and MI8, respectively. Note that the y-axes have different ranges.

MI8's performance reveals a dramatic difference between the barrier pointing techniques and the traditional "fly-in-and-tap" techniques. The basic "fly-in-and-tap" technique accumulated 92 misses in 45 trials. MI8 incurred at least one miss in 30 of the 45 (66.7%) trials. It appears that the combination of the stylus against the edge and screen generated fewer misses.

4.3.3 Wrong Target Acquisition

A wrong target acquisition occurred when a distractor target was selected and confirmed, thereby ending the trial. This is defined as an "error" in our analysis. The worst performing technique for both subjects was technique #4, "velocity stroke with corner

confirmation,” which resulted in an error rate of 41.7% for MI4 and 42.2% for MI8 (Figure 11). This was because as the subjects stroked along the edge out from the primary target to the corner, their velocities did not reach the escape speed threshold until after they had entered an adjacent distractor target. Thus, their confirmation stroke erroneously selected a distractor target en route to the screen corner.

With the exception of technique #4, all other techniques resulted in better error rates compared to technique #1, “fly-in-and-tap.” The lowest error rate for both subjects came from technique #5, “reverse stroke with corner confirmation” (12.5% for MI4 and 6.7% for MI8). As this condition required more stylus movement than any other, we believe that the subjects had time to verify their selection before stroking into the corner and confirming.

MI4’s moderate error rate for technique #3, “edge stroke with lift confirmation,” can be attributed to the lift operation. Lifting was a challenge for MI4, as the stylus would occasionally slip from the primary target into a distractor target. MI8 also struggled with slippage, although to a lesser degree. Confirmation slippage has also been shown to be difficult for mouse-based interaction [18]. Further design may be able to alleviate this problem, as discussed below.

We can also see why MI4’s target acquisition time was so inflated for technique #5. His miss rate was quite high, but his error rate is low. Thus, he was spending time correcting his misses so that he would acquire the correct target. This creates a classic speed-accuracy tradeoff, which does not exist for technique #3.

Wrong Target Acquisition Rates per Technique for Subjects MI4 and MI8

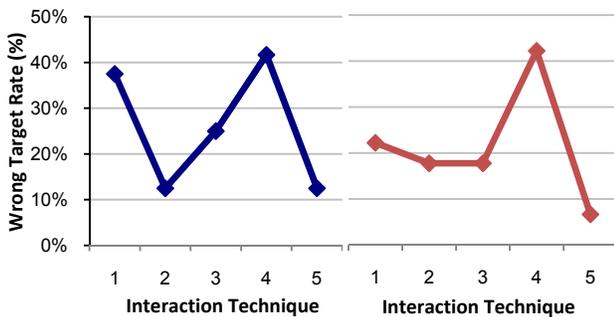


Figure 11. Both subjects had difficulty reaching the escape velocity threshold for technique #4, “velocity stroke with corner confirmation.” The other edge conditions outperformed technique #1.

5. DISCUSSION

Our preliminary investigation suggests that certain motor-impaired users may benefit from barrier pointing, particularly those who have extremely limited fine motor control. In the post-study questionnaire, MI8 indicated that he had trouble flying into targets and preferred barrier pointing to direct tapping. MI4 mentioned that he found it easier to rest the stylus on the screen and move into a target compared with flying-in directly.

From the two case studies, technique #3, “edge stroke with lift confirmation,” appears to be the most promising. The user can place the stylus on the screen, move onto an edge target, and confirm his/her selection by lifting. This technique provides both the screen surface and the edge for stability. If the wrong target is initially slid into, the stylus can be moved easily along the edge into the desired target, allowing for easy mid-course corrections.

By comparison, techniques #1 and #2 lack the stability of the screen, while techniques #4 and #5 require finer speed or direction control.

However, technique #3 suffers from lift-off errors. This should be remediable with better design. One solution may be to dynamically increase the size of the edge target that the stylus is currently in. The expansion may only be a few pixels in each direction, but would bleed over into adjacent targets. Thus, the larger size would mitigate accidental slippage; if slippage did occur, the stylus must travel more pixels to reach a neighboring target. The disadvantage of this design, however, is that purposefully moving from one target to its neighbor requires slightly more effort. However, our data suggests that this is not an error-prone action, as the user’s stylus can follow the edge until his selection is reached.

Without the pen holster, MI4 was unable to generate enough strength to register his stylus press on the touch screen. The holster allowed him to position his arm such that gravity could assist his movement. However, the rigidness of the pen holster combined with his inability to make wrist movements made it difficult to reach certain edges of the device. In addition, he preferred strokes that *pulled* toward his body. Further investigation is needed to understand if, in general, certain edges are superior to others.

A similar problem was posed by the selection troughs. The troughs were meant to encourage edge usage and thus were only seven pixels wide along the screen. However, depending on which hand the subject used and the orientation of their stylus, the troughs were not always reachable. For example, approaching a right-edge aligned trough with the right hand required the subject to increase the stylus angle with respect to the screen; otherwise the edge would prevent the stylus tip from fully reaching the edge. A similar finding was found in prior work [25].

To eliminate the escape velocity problems found in technique #4, “velocity stroke with corner confirmation,” the threshold parameter should be set dynamically based on previous movement profiles or, at the very least, be dependent upon target size and not statically defined. A smaller target should require a lower escape velocity as the user has less time to accelerate. Even then, escape velocities may prove unsuitable for users who have spastic movements, uncontrollable jitter, or an inability to make fast motions, even while moving along edges.

6. FUTURE WORK & CONCLUSION

This initial study provided some promising results and directions for design. Our next step is to recruit subjects who exhibit similar motor impairments as subjects MI4 and MI8 and run a full quantitative analysis of improved barrier pointing techniques. We first plan on refining barrier pointing and the study procedure based on our experience thus far.

In the initial study, subjects performed only one target acquisition per trial. In our follow-up study, we would like to explore multiple target acquisitions per trial to further investigate the benefits of maintaining the stylus pressed against the screen and edges. We also plan on adding another baseline technique where *barrier pointing* strategies are used on targets offset from the edge. This will allow us to better determine the benefits of the screen itself in stabilizing movement. Finally, we plan on

eliminating selection troughs and escape velocities in our techniques.

We will draw on the results of these studies to begin designing barrier pointing widgets and interfaces. For example, we might develop a reverse-cascading menu bar that expands along the edge, keeping the active menu items against the edge while older items cascade into the screen's interior.

In the future, we would like to tailor barrier pointing to finger/thumb-based touch screen interactions [11][20][23]. We suspect that users will benefit from the passive haptic feedback provided by the screen's edge. Additionally, we plan on leveraging the vibro-motor contained in many mobile devices to provide active haptic feedback when the finger is within a barrier target. We hope that this combination of passive/active haptic feedback will have positive ramifications on touch screen-based blind-input.

In conclusion, this paper introduced a series of barrier pointing techniques that utilize the physical affordances of mobile device touch screens to support more accessible target acquisition. In addition, we conducted an initial study of 9 AB subjects and 9 MI subjects, discovering that users with severely impaired motor control (e.g., spastic movements, extremely low strength and coordination) benefited the most from our new techniques. Finally, we presented an in-depth analysis of two users who benefited greatly from barrier pointing. Results from these users showed the benefits provided by stabilizing physical edges and the screen surface compared to unsupported fly-in-and-tap target acquisition. These insights can be used to take the next steps in developing more low-cost, readily-available solutions for improving mobile device accessibility.

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