The Benefits of Physical Edges in Gesture-Making: Empirical Support for an Edge-Based Unistroke Alphabet

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ABSTRACT
People with motor impairments often cannot use a keyboard or a mouse. Our previous work showed that a handheld device, connected to a PC, could be effective for computer access for some people with motor impairments. But text entry was slow, and the popular unistroke methods like Graffiti proved difficult for some people with motor control problems. We are now investigating how physical edges can provide stability for stylus gestures, and we are designing a unistroke alphabet whose letter-forms are defined along the edges of a small plastic square hole. This paper presents data on the benefits of physical edges in making gestures. It then describes *EdgeWrite*, a new unistroke alphabet designed to leverage physical edges for greater stability in text entry.

Keywords
EdgeWrite, motor impairments, PDA, Pebbles, text entry.

INTRODUCTION
As part of the Pebbles project, we have developed a handheld application called *Remote Commander* that allows full control of a desktop PC via a connected Palm PDA [5]. Our studies show that off-the-shelf handheld devices can be effective for computer access for some people with motor impairments [4]. This is because while they may lose their gross motor control, they often retain some of their fine motor control and can move a stylus across the small expanse of a handheld screen. However, this movement is often slow and unstable, which is consistent with findings about cursor control on the desktop [2]. Similarly, text entry using Graffiti is difficult, slow, and prone to err for some people with motor control problems. Increased stability and the ability to move quickly without sacrificing accuracy are crucial for the success of handheld-based computer access.

To this end, we have conducted a pilot study to discover how physical edges—such as those around the perimeter of a handheld screen—affect stylus gestures by people with Cerebral Palsy (CP) and Muscular Dystrophy (MD). The results of this study confirm that edges are highly beneficial for stability, accuracy, and speed in straight-line gestures. We verify that our subjects could exert enough pressure against an edge to enjoy these benefits. Inspired by these results, we designed an edge-based unistroke alphabet, *EdgeWrite*. This alphabet makes use of a plastic overlay that sits on top of the text entry area of a Palm PDA and creates a square hole within which all EdgeWrite letters are made.

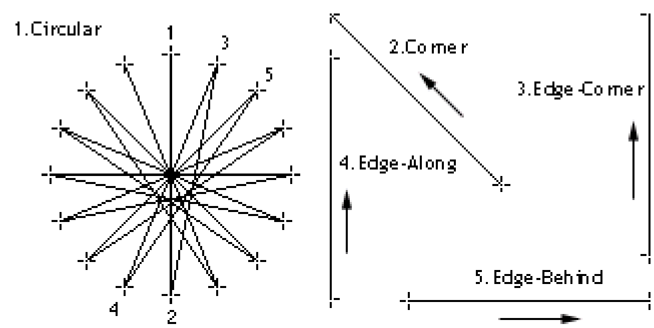

Figure 1. Two Palm PDA screens showing different line placement conditions for our line-tracing tasks. *Left*: An adaptation of the ISO 9241-9 standard [1]. *Right*: An example of each of the other four line types. Labels and arrows are provided for clarity. During the test, only one task line was visible at a time.

THE BENEFITS OF EDGES: PATH ANALYSIS RESULTS
MacKenzie et al. developed path analysis techniques to compare pointing devices on the desktop [3]. These analyses were extended for motor-impaired users on the desktop [2]. However, as far as we know, this paper is the first to use these techniques to analyze stylus movement on handhelds. We compared different line placements (Figure 1)—some in the center of the screen, some along edges and into corners—in order to see exactly how physical edges and corners affect stylus movement by motor-impaired users.

Pilot Study: Line Tracing on a Handheld Screen
Three subjects, two with CP and one with MD, each were presented with a series of line-tracing tasks on a standard Palm V*x* screen (160×160 pixels). Five line-types varied according to placement with respect to edges and corners: (1) circular in the ISO 9241-9 standard pattern [1]; (2) at three different angles into each of the upper corners; (3) along an edge and terminating in a corner; (4) along an edge but terminating *prior* to the corner; (5) not along an edge but orthogonal to and terminating on an edge. These numbers correspond to the five line types in Figure 1 and Table 1.

Analysis of Movement
MacKenzie et al.'s analyses provide a detailed account of what happens *during* a path of movement (see reference [3] for details). We wrote a Java program that performs these analyses on movement data, which are often quite copious.

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We also added two of our own measures to the analysis. These were Start Error (SE) and End Error (EE), which were the pen-down and pen-up distances from the start and end of the line segment, respectively.

As the data show, the line types that run along an edge (3 and 4) are better than those that do not (1, 2, and 5) with respect to speed (MT), directional changes (MDC, ODC), deviation from the task line (TAC, ME, MO, MV), and hitting the target end-point (EE). Edge lines therefore seem faster, more stable, more consistent, and more accurate.

Line Type	MT	TAC	MDC	ODC	ME
1. Circular	2.7 (1.4)	3.1 (4.4)	40.1 (23.0)	5.1 (5.5)	3.9 (2.1)
2. Corner	2.1 (1.0)	3.2 (3.3)	29.6 (17.3)	3.1 (3.4)	4.5 (4.0)
3. Edge-Corner*	1.5 (0.9)	0.0 (0.0)	0.8 (1.7)	1.2 (1.3)	0.4 (0.9)
4. Edge-Along*	2.0 (0.9)	0.0 (0.0)	3.6 (5.5)	2.8 (2.7)	1.6 (5.7)
5. Edge-Behind	2.4 (1.4)	1.3 (1.3)	10.3 (6.6)	1.6 (2.8)	3.3 (3.3)

Line Type	MO	MV	SE	EE
1. Circular	3.1 (2.8)	2.2 (1.5)	6.5 (3.9)	9.0 (14.8)
2. Corner	2.4 (5.4)	3.3 (2.8)	8.3 (7.6)	4.6 (8.5)
3. Edge-Corner*	0.4 (0.9)	0.6 (0.7)	8.9 (6.3)	1.9 (2.9)
4. Edge-Along*	0.4 (5.9)	1.0 (2.3)	9.6 (13.7)	11.0 (19.8)
5. Edge-Behind	2.6 (3.6)	2.4 (2.9)	6.6 (3.8)	5.2 (9.0)

MT = Movement Time, TAC = Task Axis Crossings, MDC = Movement Direction Changes, ODC = Orthogonal Direction Changes, ME = Movement Error, MO = Movement Offset, MV = Movement Variability, SE = Start Error, EE = End Error. ***Units:*** MT (sec); TAC, MDC, ODC (no. per trial); ME, MO, MV, SE, EE (pixels).

Table 1. Means and standard deviations of path analysis measures for three motor-impaired subjects (smaller values are better). The Edge-Corner condition (3) is better ($p < .05$) than all conditions not along an edge (1, 2, and 5) for all measures except Start Error (SE).

EDGEWRITE: AN EDGE-BASED UNISTROKE ALPHABET

The evidence in favor of edge-based gestures begs for designs that leverage them for more stable input. We are developing *EdgeWrite*, a new unistroke alphabet whose strokes are made inside a small plastic square hole 1.3 cm on a side. The square hole can be placed over the Graffiti area on a Palm PDA. Unlike Graffiti, EdgeWrite recognition does not depend on the path of movement, but on the order in which the *corners* of the square are hit. This allows users to depart from edges or slide into corners, and "wiggliness" does not degrade recognition.

Pilot Study: Graffiti and EdgeWrite

Our three subjects, who had no previous experience with handheld text entry, made each of 11 Graffiti letters three times. The letters were K, T, X, U, G, N, V, J, E, D, and Y, chosen for their mixture of straight lines and loops. Subjects also made the same 11 letters using the prototype EdgeWrite letter-forms (Figure 2). We wrote the letter-forms from both alphabets individually on note cards and placed them one at a time in front of the subjects as they made their strokes.[1]

[1] In a few trials there was some confusion about how to make a letter. These trials were thrown out and the letters were repeated.

Graffiti letters took 2.47 seconds on average, EdgeWrite letters 2.82 seconds—statistically a non-significant difference. Graffiti recognition was quite low at 64.6%. Though the EdgeWrite recognition engine is still under development, we graphed the subjects' EdgeWrite and Graffiti strokes. EdgeWrite letters appeared to be much smoother (Figure 3) and we expect high recognition rates. In addition, all 3 subjects said they preferred EdgeWrite to Graffiti because "the strokes were easier to make."

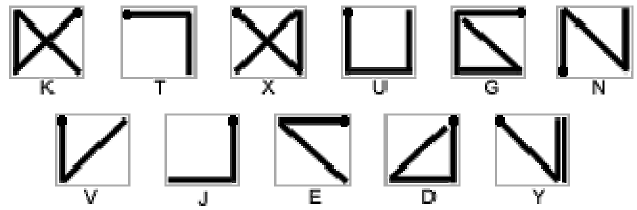

Figure 2. Prototype EdgeWrite letter forms for the 11 letters in the study. All forms are made within a small plastic square hole. The double line on the Y indicates a re-trace over the same edge.

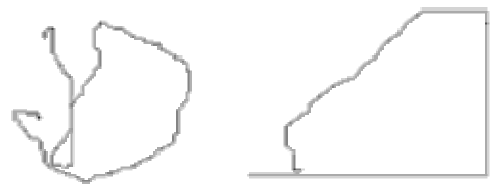

Figure 3. *Left:* A Graffiti D by a subject with Cerebral Palsy that was misrecognized as an H. *Right:* An EdgeWrite D by the same subject, who only needed to hit the corners in the correct order. Thus the wiggly diagonal and the "slide" near the corners were fine.

CONCLUSIONS

Physical edges provide an advantage in making gestures with a stylus on a handheld screen. In our pilot study, motor-impaired users found edge-based strokes to be easier, faster, more stable, and more accurate than strokes "in the open." The EdgeWrite unistroke alphabet we are developing capitalizes on these advantages. We plan to fully develop EdgeWrite and compare it to other means of handheld text entry for both able-bodied and motor-impaired users.

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