Tapping vs. Circling Selections on Pen-based Devices: Evidence for Different Performance-Shaping Factors

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ABSTRACT

Tapping-based selection methods for handheld devices may need to be supplemented with other approaches as increasingly complex tasks are carried out using those devices. Circling selection methods (such as the Lasso) allow users to select objects on a touch screen by circling with a pen. An experimental comparison of the selection time and accuracy between a circling method and a traditional tapping style of selection was carried out. The experiment used a two dimensional grid (varying in terms of the sizes and the distances of the targets). Analysis of variance showed that tapping selection time differed significantly depending on the size and spacing of the targets. In contrast, circling selection times differed significantly for different levels of target cohesiveness and shape complexity. The results are discussed in terms of implications for design of new pen-based selection methods for handheld devices, and also in terms of evaluation methodology for input selection methods.

Author Keywords

Handheld devices, input and interaction technologies, pen user interface, gesture input, target selection

ACM Classification Keywords

H.5.2 User Interface: Interaction styles, I.3.6 Methodology and Techniques: Interaction techniques

INTRODUCTION

Increasingly, computing tasks are being carried out on small handheld devices. This has created a set of challenges for user interface designers ranging from design of visual feedback on a small screen to difficulties concerning selection and input using pen interactions. In response to these challenges, new selection methods are being developed. In this paper, we describe an implementation of a circling selection method on a handheld device, and we evaluate both its properties and its performance, in comparison with a tapping style of selection.

New selection methods for handheld devices are needed as ever more complex tasks are carried out using those devices. These tasks include traditional PDA functionality (calendar, to-do list, address book, etc.) as well as text messaging, mobile versions of desktop applications (e.g., spreadsheets and word-processing) and mobile access to large databases. In addition, gaming has been identified as an important driver for usage of handheld devices, as the power of such devices (in terms of screen resolution, color depth, CPU speed, storage capacity, etc.) increases.

In this paper we address a particular input problem, namely the selection of items laid out in a two-dimensional grid. This type of selection might be appropriate in choosing small icons from a handheld version of the computer desktop, or in certain types of games. An additional motivation for carrying out research on handheld selection methods using two-dimensional grids is to construct evaluation methodologies in a mathematically tractable context where well-defined predictive models can be developed.

This paper will report on an experimental comparison of circling and tapping styles of selection over two-dimensional grids that varied in terms of the sizes of the regions (squares) to be selected, and in terms of the distances between the selection regions (i.e., the intra-grid boundaries). Figure 1 shows the different combinations of grid layout that were used in the experiment.

In addition to the experimental comparison, we analyzed how well the following target properties predicted circling selection times: 1) Subjective shape complexity, 2) the length of perimeter divided by the number of sides and 3) the minimum distances between targets.

CHI 2004, APRIL 24–29, 2004, Vienna, Austria.

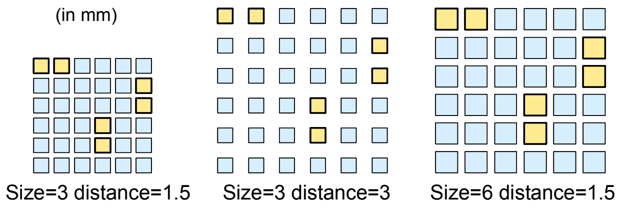

Figure 1. Three Combinations of Target Square Size and Inter-Square Distance in a Two-Dimensional (6x6) Grid.

BACKGROUND

Interaction style with pen

In most current pen user interfaces users are required to interact with items on the screen by tapping them. However, step-by-step interaction limits the amount of bandwidth of the input channel. New styles of interaction such as bi-manual or multi-modal input (e.g., [1]) are potentially much more efficient (i.e., provide a much higher communication bit-rate through the interface. Card et al. [2] and others have shown that there is a potentially large design space for input devices and methods, but this space is mostly unexplored. Empirical research is needed to assess the effectiveness of different devices and approaches for particular types of task. In the remainder of this section we will focus on area selection tasks in particular.

"Rubber-banding" is the standard technique for selecting multiple objects in an area. With this method, the diagonal extent of the drag operation specifies the size (i.e., diagonal) of the (rectangular) selection region. This method is implemented in most current graphical user interfaces. It provides efficient object selection, but has the limitation that users can only select multiple objects when they are arranged within a rectangular region. When users want to select multiple objects in a scattered layout, they are required to press another key (such as Shift key) to select subgroups of objects.

Krishnan and Moriya [3] proposed a rubber-banding selection with a pen in a editor application. The "Lasso" is another approach for area selection that differs from rubber-banding in tracing around a group of objects (rather than tracing out a rectangular shape by specifying the origin and length of its diagonal. It enables users to select a contiguous set of objects that form an arbitrary shape. Wills [4] discussed a taxonomy for selection mechanisms, and contrasted brush and lasso styles of area selection.

Other area selection methods also provide alternatives to step-by-step tapping. Ren and Moriya [5] studied entering and leaving a graphical object as alternatives to pointing selections. Acott and Zhai [6] called this process of moving a cursor across the boundary of a targeted graphical object a goal-crossing task, and compared subjects' selection performance when pointing versus goal-crossing. In other research, they developed a predictive model ("Steering law") for trajectory-based tasks (e.g. hierarchical menu selections) [7].

Models for target selection

Discrete tapping selections have been successfully modeled using Fitt's law [8, 9, 10]. Both Fitt's law and the Hick-Hyman law [11, 12] represent an information-theoretic view of complexity and processing. While Fitts' law is typically used as a model of acquisition and selection, the Hick-Hyman law has often been used to explain perceptual (rather than input) complexity. In the case of circling selection, it seems possible that selection time may be influenced not only by the input complexity (i.e., how far one has to move, and the target size) but also by the visual complexity of the shape around which a circle is to be drawn. There are extensive research literatures on the visual complexity of two-dimensional patterns [13, 14, 15]. Measures that have been found to be related to visual complexity include "jaggedness" (quantified as the ratio between the perimeter of a figure and its area) and the perimeter of a figure divided by its number of sides. The use of handheld devices with pen-based input increases the desirability of marking interfaces as a means of overcoming the limitations of input on a small screen using gestures and conversational (dialogue) styles of interaction [16]. Denoue, Chui and Fuse [17] provide an example of a markup interface explicitly designed for a handheld device. Detailed models of the efficiency of these gestural types of interaction have yet to be developed. However, analysis of particular attributes (e.g., shape complexity) that are implicated in particular gestural tasks (circling selection) may be a useful starting point for development of those models.

CIRCLING SELECTION METHOD

Circling is a natural way to select visual material. For instance, proof-readers and editors frequent circle (i.e. draw an enclosing line around) sections of text in order to indicate the scope of an operation (such as move, delete, or italicize) [18]. In this study, we developed the circling selection method as follows. In the case of squares on a grid different strategies can be used to make selections when groups of adjacent squares are highlighted. Figure 2 illustrates a case where a single outline ("circle") has been drawn around a group ("cluster") of highlighted squares. Multiple discrete circling operations may also be used to select a group of adjacent squares (e.g., an overall circling task may be sub-divided into two nested circling tasks).

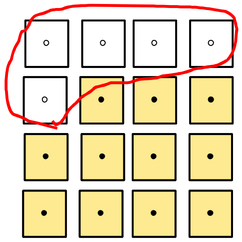

Figure 2 A Circling Selection of a Group of Squares.

The circling selection method used in this study will now be described. Figure 3 shows visually how an enclosing circle is detected. Each of the three circling operations on the left side of Figure 3 selects the target, since the circles all enclose the critical center point of the square. In contrast, the circling operation at the right of Figure 3 does not select the square, because the circle does not enclose the center point of the square.

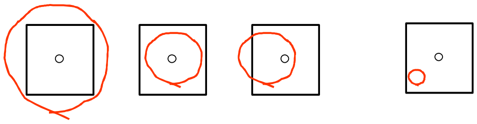

Figure 3. Three Circling Selections (on the left) Contrasted with a Non-Selection (rightmost square)

In cases where the circle is not closed, the software program automatically completes the circle. If the resulting completed circle then encloses the center point (as shown in Figure 4), then the square is selected.

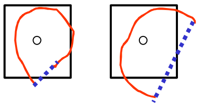

Figure 4. An Illustration of Automated Circle Completion.

It seems likely that the relative difficulty of selection for different patterns will vary between tapping and circling styles of selection. For instance, where there are a number of squares that are adjacent to each other, it may be relatively easier to circle the entire group in either one or two circling motions. In contrast, tapping will require each of the circles in the group to be selected separately. Where none of the highlighted squares are adjacent, there is no benefit to circling, and tapping would likely be a more efficient method of selection. Thus, in comparing circling and tapping for different selection tasks, we would expect an interaction between the type of selection method (circling vs. tapping) and the amount of grouping of the highlighted squares.

If circling can be shown to lead to faster selection time in some contexts, then it may be a useful supplement to tapping styles of selection. Analysis of circling response times may also lead to new models of selection performance which could in turn facilitate the design of new styles of selection for handheld devices.

Hypotheses

The following experimental hypotheses were developed.

1. Circling will be more accurate than tapping overall
2. Circling will be faster than tapping overall
3. Tapping selection times will differ between the experimental conditions, whereas Circling selection times will not differ significantly
4. There will be an interaction between selection method and type of selection task, with circling being faster than tapping when the targets are grouped together, but slower than tapping when the targets are spatially separated
5. For selection tasks where the targets are grouped together, circling selection time will be longer for groups that form a more complex visual pattern, whereas tapping selection time will be unaffected by shape complexity.

The corresponding null hypotheses to be tested were that none of the differences predicted in the experimental hypotheses would in fact exist. The first two hypotheses were based on the expectation that circling is generally more efficient than tapping. The third hypothesis is based on the expectation that circling will be less affected by differences in target size and separation between targets. In the circling algorithm used in this study, target selection is based on circling a critical region within each target, and the size of this region did not change across the experimental conditions. In contrast, the different experimental conditions change the indices of difficulty for the tapping task (which should obey Fitts' law). The fourth hypothesis reflects the expectation that circling should be more advantageous when the targets are grouped together. In the case where targets are selected one at a time, tapping should always be faster, since the movement to the target is the same in both cases, but tapping is a simpler movement than circling, once the target is reached. The fifth hypothesis was generated from the consideration that while grouping confers no benefit for tapping selections, the benefit of grouping for circling will depend on how difficult it is to "draw around" the group (shape). Thus more complex (difficult to draw around) shapes should lead to longer circling selection times (as compared with selection times for simpler shapes).

Experiment Method

Participants

Twelve paid volunteer participants (9 male, 3 female) were recruited from a university campus and from a company office. Participants ranged in age from 21 years to 48 years (*mean* = 28.8, *sd* = 8.0). None of them were daily users of PDAs or any other pen-based devices.

Apparatus

The experiment was conducted in a quiet room using a PDA (iPaq 3630) running under Linux (version 2.4.18). The device had a 240 x 320 TFT LCD touch screen display.

Stimulus Materials and Task

For each trial, thirty-six squares were shown on a 6x6 grid. Target squares were shown in red (255, 0, 0 in RGB), and the other (non-target) squares were colored pale blue (214, 238, 254). (should you mention the RGB colours after selection/highlighted as well?)

Six target squares within the 6x6 grid were shown in each of thirty experimental trials per subject. Targets were shown in three levels of "Cohesiveness" (i.e., amount of group ranging from all targets being separated to all targets being joined in a contiguous group). In the low cohesiveness (C1) condition all six targets were shown separately, in medium cohesiveness (C2) there were three pairs of targets, and in the high cohesiveness (C3) condition all six targets were shown in one cluster. Figure 5 shows examples of stimulus patterns used for each of the three levels of cohesiveness.

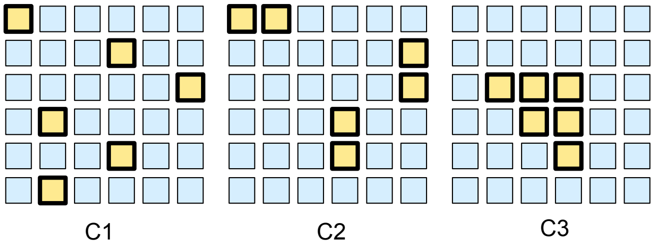

Figure 5. Example Stimulus Patterns in different cohesiveness levels (C1,low; C2,medium; C3,high).

The patterns used were automatically generated by the test program, and shown to the subjects in random order, with the constraint that each of the three cohesiveness levels appeared equally often (ten times per set of thirty trials).

Subjects were instructed to select the 6 targets on each trial as quickly and as accurately as possible. They were instructed to press the "Start" button on the screen to start the selection task, and to press the "Stop" button when they had finished making the selection (Figure 6).

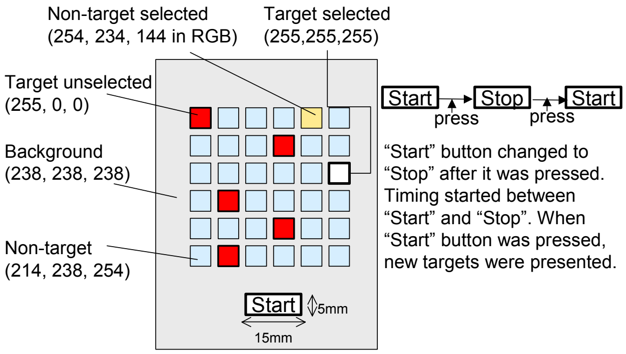

Figure 6. A Sample Stimulus Pattern showing the location of the Start and Stop Buttons.

Experimental software

The experimental software was developed in the C programming language. The program presented the tasks to participants and logged pointing coordinates and movement times in a text file. Each pointing trial began when the participant clicked a "start" button appearing in the bottom of the screen.

Experimental Design

6 conditions (2 selection methods x 3 target size-distance conditions) were presented in different orders for each subject. As shown in Figure 1, there were three target size-distance conditions; small (3mm) target size with narrow (1.5mm) distance (SN), small targets size with wide (3mm) distance (SW), and large (6mm) target size with narrow distance (LN). Each condition consisted of 10 practice trials followed by a block of 30 experimental trials. The three size-distance conditions were nested within selection method so that half the participants used circling for all three experimental conditions, followed by tapping, while the remaining participants did tapping first. The order of the three experimental conditions was also counterbalanced so that each possible order was seen equally often within the experiment. Each participant carried out a total of 60 practice trials and 180 experimental trials (30 trials for each of the six combinations of selection method and experimental condition). Time and accuracy data, plus detailed logs of pen taps and circling motions were captured on the handheld device. Video data was captured using a mini-camera attached to the device.

Results

There was no significant effect involving presentation order of the experimental conditions. Thus presentation order is not considered in the analyses reported below. The results were analyzed with respect to each of the experimental hypotheses. Hypotheses concerning response time were tested using repeated measures analysis of variance (using the Greenhouse-Geisser criterion). For effects illustrated by line charts, the error bars indicate the range of two standard errors of the mean (above and below the mean).

Hypothesis 1: Circling will be more accurate than tapping overall.

A total of 44 errors were made in the experiment, out of 2,154 trials (i.e., an overall error rate of 2.04%). There were no significant differences in the error rates between the experimental conditions. However, there was a significant difference ($p<.05$) between circling and tapping accuracy, as assessed using a binomial test. 30 of the errors occurred using the circling method (an error rate of 2.8%) versus only 14 errors (i.e., a 1.3% error rate) when using the tapping method. Thus circling was less, rather than more accurate than tapping, which contradicted the first experimental hypothesis.

Hypothesis 2: Circling will be faster than tapping overall.

The selection time was calculated as the latency between the first touch after the pen left "Start" button, and the last touch before the pen touched the "Stop" button. The response times thus calculated were subjected to a log transformation prior to carrying out the analyses of variance reported below (in order to remove positive skew in the data and to improve the fit with normality assumptions). Log transformation of the data was also used for the other ANOVA analyses of selection time reported below.

There was a significant main effect of selection method ($F[1,11]=8.75$, $p<.05$), that is, selection times for tapping were generally faster than selection times for circling.

Average selection time for circling was 2.4 seconds, and the average selection time for tapping was 2.0 seconds. Thus Hypothesis Two (circling will be faster than tapping overall) was not confirmed. Instead, tapping selection times were significantly faster overall (with the stimulus materials and tasks used in this study).

Hypothesis 3: Tapping Selection times will differ between the experimental conditions, whereas Circling Selection times will not differ significantly.

Figure 7 shows mean selection times and standard errors by selection method and experimental condition. For the log transformed selection time, there was a significant interaction between selection method and experimental condition (F[2,22] = 82.94, p<.001).

For tapping, selection times differed significantly between the three experimental conditions, whereas selection time for circling did not differ significantly between the experimental conditions (F<1, as assessed using a one way ANOVA for the circling data only). This finding was in agreement with Hypothesis Three.

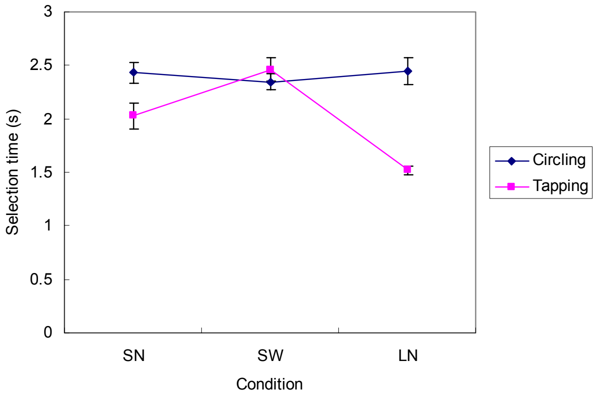

Figure 7. Mean Selection Times by Selection Method and Experimental Condition.

Separate paired samples t-tests (with data averaged within subjects) were then run for each of the three conditions, comparing mean selections times for tapping and circling. For the SN and LN conditions there were significant differences (SN: t[11] = 2.71, p<.05, LN: t[11] = 7.11, p<.001), with selection time being significantly longer for the circling method (SN: 2.43 seconds for circling vs. 2.03 seconds for tapping, LN: 2.44 seconds for circling vs. 1.52 seconds for tapping). However, for the SW condition there was no significant difference between the selection methods (t[11] = -1.89, p>.05, 2.35 seconds for circling vs. 2.46 seconds for tapping) .

Hypothesis 4: There will be an interaction between selection method and target cohesiveness, with circling being faster than tapping when the targets are grouped together, but slower than tapping when the targets are spatially separated.

Figure 8 shows mean selection times and standard errors by selection method and level of cohesiveness.

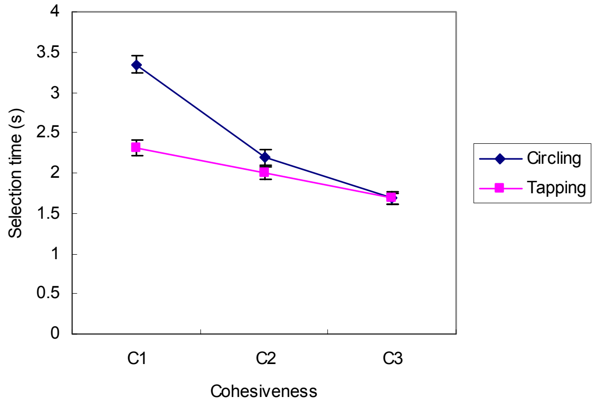

Figure 8. Mean Selection Times by Selection Method and Level of Cohesiveness.

As predicted by this hypothesis, there was a significant interaction (for selection time) between selection method and target cohesiveness (F[2,22]=73.91, p<.001). As can be seen in Figure 8, the benefit of target cohesiveness was greater for the circling method than it was for the tapping method. Separate paired samples t-tests (with data averaged within subjects) were then run for each of the three cohesiveness levels, comparing selections times for tapping and circling. For low cohesiveness there was a significant difference (t[11] = 8.66, p<.001), with selection time being significantly longer for the circling method (3.35 vs. 2.31 seconds on average for the tapping selection times in the low cohesiveness condition). For moderate cohesiveness the size of the difference was reduced, although circling selection time was also significantly longer (t[11] = 2.43, p<.05), (2.19 vs. 2.0 seconds on average for the tapping selection times in the moderate cohesiveness condition) In contrast, circling selection times tended to be slightly (.01 of a second) shorter for the high cohesiveness condition, but this effect was not statistically significant (t[11] = -0.99, NS).

Thus the general intent of Hypothesis 4 (i.e., that circling would benefit more from higher cohesiveness) was supported, but the benefit of higher cohesiveness to circling did not overcome the overall performance advantage of tapping.

Hypothesis 5: For selection tasks where the targets are grouped together, circling selection time will be greater for groups that form a more complex visual pattern, whereas tapping selection time will be unaffected by shape complexity.

Figure 9 shows 35 different visual patterns (all possible shapes made up of 6 adjoined target squares [19]) used in the high cohesiveness condition. In the experiment, these shapes were shown in different position on the grid and with varying rotations.

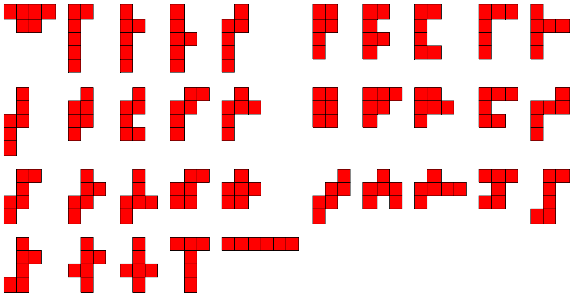

Figure 9. 35 possible shapes using 6 adjoined target squares

The complexity of these patterns was assessed by a separate sample of 12 participants. The participants were asked to rate each shape in terms of how difficult they thought it would be to draw around it, using the following five-point rating scale (1=very easy, 2=easy, 3=neither easy nor difficult, 4=difficult, 5=very difficult) Prior to making the judgments, the participants were shown all 35 patterns, so that they could internally calibrate the scale they were using according to the range of drawing difficulty actually present in the sample of 35 patterns. Participants viewed the patterns one at a time, rating each pattern before the next one was shown. The order of presentation of the patterns was randomized, with each participant being exposed to a unique random order. The ratings across the 12 participants were then averaged to create a scale of drawing complexity on which each pattern was located.

The resulting scale of complexity was then categorized into 3 levels (low: rated complexity score was below 1.25, moderate: rated complexity score was between 1.25 to 2.67, high: rated complexity score was over 2.67) to create a complexity pseudo-factor. A complete factorial ANOVA was then carried out on the high cohesiveness data only (i.e., where all six target squares were adjacent to each other, forming a single shape). Selection method, experimental condition, and complexity were the three factors in this analysis.

The three-way interaction between complexity, experimental condition, and selection method was not significant (F<1). The two-way interaction between complexity and experimental condition was also not significant (F<1). However, there was a significant two-way interaction between complexity and selection method (F[2,22]=34.45, p<.001). As can be seen in Figure 10 (and consistent with Hypothesis 5), tapping selection time was relatively unaffected by shape complexity, whereas circling selection time increased with increasing shape complexity.

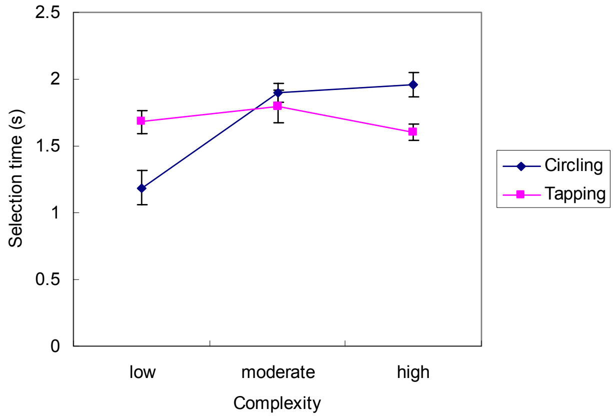

Figure 10. Mean Selection Times by Selection Method and Level of Shape Complexity for High Cohesiveness Patterns (C3) only.

Separate paired samples t-tests (with data averaged within subjects) were then run for each of the three levels of shape complexity, comparing selections times for tapping and circling. For low shape complexity there was a significant difference (t[11] = -3.21, p<.01), with mean selection time being significantly shorter for the circling method (1.18 seconds for circling vs. 1.68 seconds for tapping). In contrast, tapping selection times were significant faster for both moderate complexity (1.90 vs. 1.80 seconds, t[11] = 2.37, p<.05) and high complexity (1.96 seconds vs. 1.60 seconds, t[11] = 4.26, p<.01) shapes.

The next portion of the analysis examined whether objective properties of the patterns could be used to predict shape complexity, for those trials where the targets were grouped into a single pattern (with all squares adjacent to each other). Based on a review of the prior literature (e.g., [14, 15]) a number of measures were examined. A measure based on the number of sides in the pattern divided by the perimeter of the pattern (NS/P, Figure 11) was found to have the strongest relationship with the subjectively rated complexity measure (r = 0.87, explaining 75% of the variance in the complexity ratings).

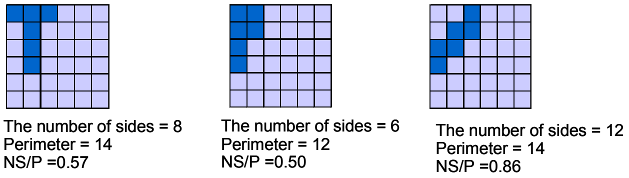

Figure 11. Examples of NS/P

An analysis of variance was carried out on the log selection time, with selection method and 3 levels (low: Under 0.43, medium: 0.43 – 0.67, high: over 0.67) of P/NS as the factors. There was a significant interaction between selection method and NS/P (F[2,22] = 61.37, p<.001), as shown in Figure 12.

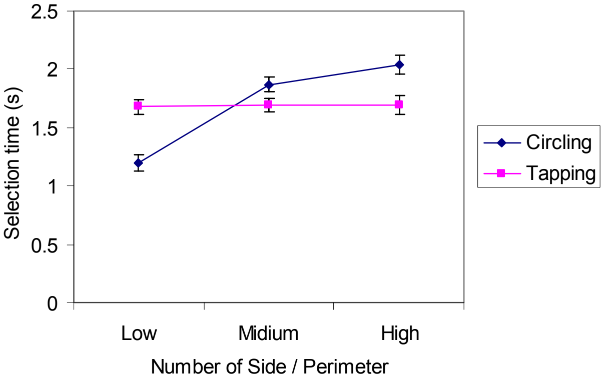

Figure 12. Mean Selection Times by Selection Method and three levels of NS/P (for High Cohesiveness Patterns only).

Separate paired samples t-tests (with data averaged within subjects) were then run for each of the three levels of NS/P, comparing mean selections times for tapping and circling. For the Low condition there was a significant difference (t[11] = -2.92, p<.05), with selection time being significantly shorter for the circling method (1.18 seconds for circling vs. 1.68 seconds for tapping). For the Medium condition there was no significant difference between the two methods (t[11] = 1.63, p>.05). For the High condition selection time was significantly longer (t[11] = 3.67, p<.01) for the circling method (2.08seconds for circling vs. 1.67 seconds for tapping).

Discussion

The hypotheses that circling would be faster and more accurate (overall) than tapping selection was not supported. However, circling selection times did not differ between the experimental conditions (which were designed to vary the index of difficulty from a Fitts' law perspective), whereas tapping selection times did. In contrast, target cohesiveness had little effect on tapping selection time, but a large effect on circling selection time. Circling selection times were particularly long for targets with low cohesiveness (i.e., where none of the six target squares were adjacent to each other). Only for high cohesiveness targets did circling selections tend to be slightly faster, but this difference was not statistically significant.

Shape complexity was shown to have a significant impact on circling (but not tapping) selection time for targets that were highly cohesive. In contrast to the general tendency for tapping selections to be faster, circling selections were found to be significantly faster in the special case of high cohesiveness targets that had low shape complexity.

Shape complexity was found to be related to the perimeter of the shape divided by the number of sides (with the R-squared being .75, i.e., 75% of the variance being shared). However, shape complexity was better at discriminating between the two selection methods (with a large effect size for its interaction with the method factor).

While tapping selection times differed across the three experimental conditions (reflecting the impact of experimental conditions on the index of difficulty for tapping selections), circling selection times differed by level of target cohesiveness, and by shape complexity (for highly cohesive targets).

Conclusions

Circling appears to be a viable alternative to tapping as a pen input selection method only in certain situations. In the present study, circling was faster than tapping only for highly cohesive targets with low shape complexity. In tasks that have this property, or perhaps tasks that require selection followed by movement (e.g., a drag and drop style of interaction), circling may be a useful supplement to tapping (with the possibility of developing mixed mode interactions that utilize both circling and tapping).

One feature of circling selection time in this study was that it was relatively insensitive to changes in the size of the individual target squares and in the distances between the squares (factors which had a major impact on the speed of tapping selections). Instead, circling speed was sensitive to cohesiveness and shape complexity (in contrast to tapping selection time, which was relatively unaffected by these factors).

While more research needs to be done with different types of target and experimental condition, based on the present findings it should be possible to develop predictive models of circling selection time on a two-dimensional grid, using some combination of target cohesiveness, shape complexity, and Fitts' law considerations based on the positions (and spaces between) target patterns. These predictive models might eventually influence the design of new input and interaction methods, for particular types of handheld selection task.

With respect to shape complexity, the results of this study were consistent with earlier research on judged shape complexity, with the perimeter divided by the number of sides being a good predictor. Seventy-five percent of the variance in rated complexity judgments was accounted for by a measure based on the ratio between the perimeter and the number of sides of the figure.

Tapping is a relatively popular method for pen-based selection on a small screen. The present results do not support the replacement of tapping with circling, although they do highlight some interesting differences in the performance-shaping factors that affect selection speed for circling and tapping. In view of these differences it seems likely that gestural interfaces that combine a variety of operations (including circling and tapping) may allow users to carry out selection tasks more efficiently, particularly when they are more complex than the simple selection tasks executed on a two-dimensional grid, as in this study.

This study shows how constructs such as shape complexity and target cohesiveness can be predictive of selection time in a gestural interaction. It represents a starting point for the development of methodologies needed to evaluate gestural interactions on handheld devices. It may not be possible for such methodologies to achieve a level of precision comparable to Fitt's law analysis of tapping selections. However, predictive linear models using quantifiable constructs such as shape complexity and target cohesiveness may nevertheless be sufficient to provide useful guidance to designers of handheld interactions.

ACKNOWLEDGMENTS

The main experiment reported in this paper was carried out at Nokia Research Center and Keio University in Japan. This paper was written while the author was a visiting scientist at the Interactive Media Lab (Department of Mechanical and Industrial Engineering, University of Toronto). The authors would like to thank the members of that lab for their insight and encouragement, and would particularly like to thank Mark Chignell, David Ha, Jacek Gwizdka, and Vyacheslav Morozov for their assistance with the data analyses and with collection of the subjective complexity data. The first author would like to thank Scott MacKenzie and Michael McGuffin for their insightful discussion.

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