Easy vs. Tricky: The Shape Effect in Tracing, Selecting, and Steering With Mouse, Stylus, and Touch

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ABSTRACT
This short paper is a work-in-progress report on an experimental comparison and evaluation of users' performance in four line-tracing tasks based on two shapes and performed with three input methods (mouse, stylus, and touch-input). The shapes' properties used in the study created the two classes of shapes: easy and hard to replicate. As expected these two classes had different impact on user's performance in each task tested (tracing, lasso selection, steering through narrow and wide tunnel). The results show that participants replicating the shapes using touch-input were the least accurate but were the fastest in comparison to the remaining input methods. The stylus was the least error-prone method and the mouse was the slowest device in drawing tasks (tracing and selection). The differences in error distances between the input methods were less pronounced in steering tasks but timing data showed that mouse was still the slowest one. While the time of replication did not differ between the two shapes tested, the differences between the errors participants made were significant for all tasks and input devices, and patterns of these differences were consistent between the shapes. These results confirm predictions from a previous study and show which shapes' properties can make their replication more difficult. The results can be used to design shapes that are easy to replicate, e.g., in surface-based gestural interaction.

Categories and Subject Descriptors
H.5.2 User Interfaces: Input devices and strategies.

General Terms
Measurement, Performance, Experimentation, Human Factors.

Keywords
Mouse, stylus, pen, touch, shape, tracing, drawing, steering.

1. INTRODUCTION
How accurately humans can interact with a system depends not only on the input device but also on task difficulty. For free-hand line-tracing, as typically used in creative drawing or surface-based gesturing, the outcome depends on the tool used as well as what shape and how accurately it is being drawn. A classic example is the problem of adding a signature to a document with a mouse as input device. Free-hand drawing provides the opportunity to create a shape that can be either easy or difficult to draw, exploit the constraints of task formulation, or be influenced by the properties of the tool used for drawing.

Each popular input device, such as a mouse, stylus, or touch sensitive screen, delivers a different user experience that potentially translates to different outcomes for the same action performed with those tools. In contrast to pure pointing tasks – where the main user's goal is getting from point A to point B as fast as possible – shape drawing demands a different context. To describe such a continuous user action, e.g. performed on a touch-sensitive surface, we can use a time-series of 2D coordinates of the center of the touch area like in the Contact Area Model [1].

Sketching behavior has been already experimentally studied [2] but mainly in collaborative and creative contexts. Also many input devices have been tested on their effectiveness in tracing and path steering navigational tasks and this knowledge has been used for multitude of analyses and comparisons [3–5].

On one hand, tracing over a contour shape is an unconstrained interaction. Theoretically, the user can make infinitely large errors (i.e. deviations from the intended path). In comparison, lasso selection is similar to tracing just outside a polygon shape [6] and has an implied one-sided constraint (polygon's area) – but still with the possibility for infinite error. On the other hand, a tunnel steering task involves a two-sided constraint implied by the tunnel's walls. The task of steering a cursor within tunnels of constant width [7] was the basis for deriving the Steering Law (SL). The SL allows to predict the time needed to move the cursor through a tunnel of known width and length. It demonstrated an effect of shape between linear and circular tunnel paths of the same lengths and widths, and potential problems with user's handedness influencing results [5]. The consequences of spatial constraints originating from the task formulation and their influence on the outcome of the interaction creates an interesting problem. On one hand, complete freedom is related to operational biases [8]. On the other hand, the presence of constraints can help to better model the task in question.

However, independently from the set of constraints of given drawing task formulation - the shape used as a basis for comparisons might also significantly influence the outcome of the interaction. Based on previous studies [9], we expect that the properties of a shape make it either easy or hard to replicate. To expand our knowledge on how the individual's performance in using popular computer input methods is influenced by the differences between easy and complicated shapes in tracing tasks we performed a comparative user study.

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2. METHODS AND PROCEDURES

We performed an empirical study to compare how the shape of an object or path influences its replication with the mouse, stylus, and touch-input. We measured the timing and deviation from the ideal shape that contained features that were expected to be easy or hard to replicate.

2.1 Tasks

Four types of tasks have been created and offered to participants:

a) *tracing* – drawing over the contour shape
b) *selection* – drawing around the polygon shape
c) *steering in a narrow tunnel* - following the 25px wide path without crossing its walls
d) *steering in a thick tunnel* - following the 50px wide path without crossing its walls

Steering outside of tunnel's walls required the task to be repeated. For each task, the participants were asked to start drawing clockwise from the top left corner of the shape presented, and to draw as fast and as accurate as possible with one stroke.

2.2 Shapes

The geometrical properties of shapes have an extensive impact on human visual perception [10, 11]. Corners, i.e. elements where two line elements meet at an angle, have been recognized by previous research as perceptually challenging [12]. Pastel has shown that because of biomechanical reasons, 45° corners are easier to negotiate than 90° or even 135° corners, and even the mere presence of a corner increases the time taken to complete a trajectory-based task [13]. We have classified corners into categories based on their relation to the original shape (concave, convex), and also based on their angle (acute between 0° and 90° and obtuse between 90° and 180°). For this study, two asymmetrical, non-meaningful, contour shapes have been created that consist of mixed number of the following elements: convex corner, concave corner, straight segment, and curved segment. Both shapes were generated under the constraints that the segments do not intersect at any point and they have equal length of 1879 pixels. The particular set of properties of each shape, such as lengths or angles, was selected on the basis of the results of previous studies on shape tracing [9] with an aim of creating one shape that is easy and one that is hard to replicate (in terms of expected user-generated error). These properties were:

- for the easy shape (shape 1): long and short straight lines, strongly concave and convex curved lines, acute concave and convex corners, and a compact form.
- for the hard shape (shape 2): long and short smoothly curved lines, convex and concave obtuse corners, and a dispersed form.

The resulting shapes fulfill these requirements as much as possible (see Fig. 1 and 2). To remove potential bias, shapes were also selected not to resemble letters, well-known shapes, or popular objects. Using each shape as a basis, we created contour line, polygon, narrow tunnel (25 pixel), and wide tunnel (50 pixel) versions of these shapes.

2.3 Experimental Setup

An HP Touchsmart TM2-1090eo Tablet PC with a 12.1 inch diagonal LED display and a resolution of 1280*800 pixels, equipped with stylus and finger sensitive display, as well as a Logitech basic optical mouse were used. The PC was used in "tablet mode" with the stylus and finger input, lying flat on the desk or in "laptop mode" while used with the mouse. All three input methods used their default settings and their standard Windows 7 system cursors visible while interacting.

A Java-based application was used to present the shapes, to show the solid black trace of each user's action, and to collect time referenced coordinates of cursor position during the interaction in every task.

2.4 Participants

Twelve participants (3 females, 9 males, 27 years old on average) were selected through convenience sampling from the local university campus. All were right-handed and had normal or corrected-to-normal vision. They reported their average daily computer use = 7.5h, and average experience with mouse = 3h (10 participants), stylus = 0.2h (2 part.), and touch = 2.1h (7 part.).

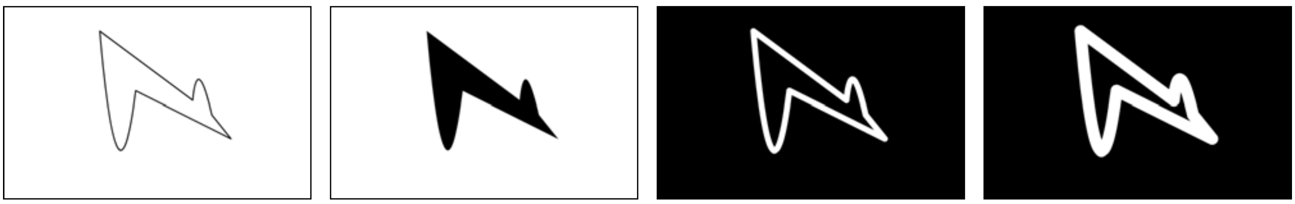

Figure 1. Shape 1 *(easy)* and its contour, polygon, narrow tunnel, and wide tunnel versions *(respectively)* with their placement and size proportional to the whole computer screen.

Figure 2. Shape 2 *(hard)* and its contour, polygon, narrow tunnel, and wide tunnel versions *(respectively)* with their placement and size proportional to the whole computer screen.

3. Experiment Design

The experiment had a within subject design. After a short introductory session for the mouse, stylus, and touch input in MS Paint every participant used all the three input methods to trace or steer over four greyed-out versions (70% opacity) of each of the two shapes (see Fig. 1 and 2). Input methods, shapes and task's versions were administered randomly to counter potential order effects.

3.1 Average Deviation (Error)

Error is defined here as a measure of the deviation between the original shape and the version created by the participant [14]. Error is equal to the average value of pixel-wise distances between 125 sampled points located correspondingly on the original shape and on the user-generated one, as in [4].

4. RESULTS

The performance measurements included tasks' time and error.

4.1 Time

Our reaction time data were non-normally distributed and positively skewed, which is typical [15, 16]. Therefore a logarithmic transformation of these data was used before statistical testing. An ANOVA yielded a significant main effect for the input device ($F_{2,22}=85.9$; $p<0.0001$) such that the average tasks time (for all tasks and shapes) was significantly higher for mouse (M=23.38s, SD=12.23s) than for stylus (M=15.46s, SD=9.4s) and touch (M=14.54s, SD=7.12s). The main effect of task type (for all shapes and input methods) was also significant ($F_{3,33}=33.27$; $p<0.0001$) such that the average tasks time was significantly lower for steering through wide tunnels (M=11.4s, SD=5.46s) than for tracing (M=20.95s, SD=12.06s), selecting (M=21.38s, SD=11.26s), and steering through narrow tunnels (M=17.44s, SD=9.12s). The main effect of shape (for all types of task and all input methods) was non-significant ($F_{1,11}=0.11$; n.s.). However, the interaction of these factors was significant ($F_{14,154}=2.69$; $p=0.002$) but dissordinal. Post-hoc comparisons of means with Tukey HSD tests were performed at the 95% family-wise confidence level. All pairwise significant differences between shapes and tasks are summarized in Fig. 3. Table 1 presents input-wise summary of these results.

Table 1. Significant differences in task time between the input devices for each task type and for each shape.

Shape	Task	Mouse-Stylus	Mouse-Touch	Stylus-Touch
1 (easy)	a	p = 0.039	p < 0.01	n.s.
	b	n.s.	n.s.	n.s.
	c	p = 0.004	n.s.	n.s.
	d	p = 0.002	p = 0.032	n.s.
2 (hard)	a	n.s.	p = 0.035	n.s.
	b	n.s.	p = 0.005	n.s.
	c	p = 0.036	p = 0.014	n.s.
	d	p = 0.017	n.s.	n.s.

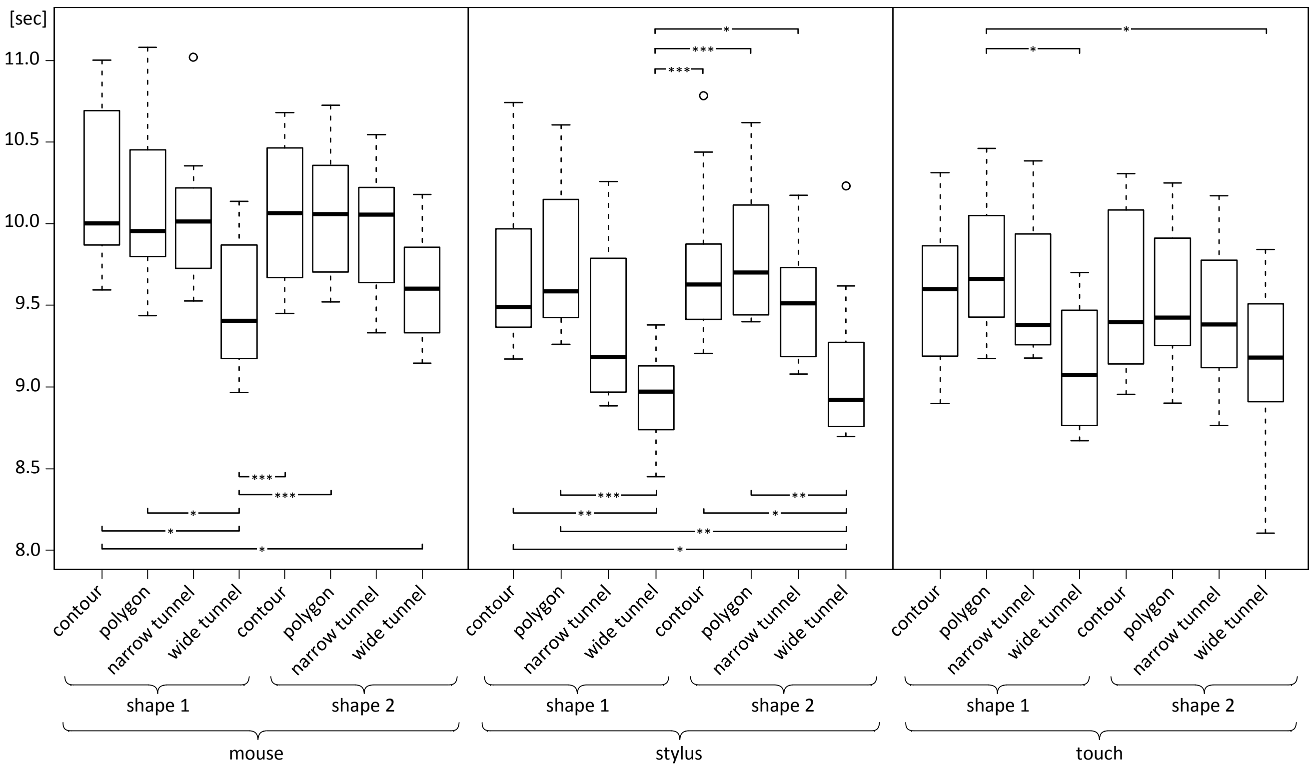

Figure 3. Times measured for each version of each shape for each input method used. The results of multiple ANOVAs are encoded as follows: '*' – denote a p value < 0,001, '**' – denote a p value between 0,001 and 0,01, and '*' – denote a p value between 0,01 and 0,05.**

4.2 Error

An ANOVA yielded a significant main effect for the input device ($F_{2,22}=7.68$; $p<0.003$) such that the average error (for all tasks and shapes) was significantly higher for touch (M=15.26px, SD=5.4px) then for stylus (M=12.89px, SD=5.63px) but insignificantly higher than for mouse (M=14.25px, SD=5.71px). The main effect of task type (for all shapes and input methods) was also significant ($F_{3,33}=49.56$; $p<0.0001$) such that the average error was significantly lower for tracing (M=10.77px, SD=4.48px), than for selecting (M=13.07px, SD=5.64px), steering through narrow tunnels (M=13.7px, SD=4.35px), and steering through wide tunnels (M=18.84px, SD=4.83px). Only, the difference between selecting and steering through narrow tunnels was n.s. The main effect of shape (for all types of task and input methods) was also significant ($F_{1,11}=73.52$; $p<0.0001$) such that the average error was significantly lower for shape 1 (M=11.4px, SD=4.9px) than for shape 2 (M=16.9px, SD=5.01px). The interaction of these factors was also significant ($F_{14,154}=2.71$; $p<0.002$) but dissordinal. A post hoc analysis by the Tukey HSD test showed significant differences between: stylus and mouse (p=0.005) and stylus and touch (p=0.001) for selecting task with shape 2, and stylus and touch (p=0.026) for all tasks with shape 2. All pairwise significant differences between shapes and tasks are summarized in Fig. 4.

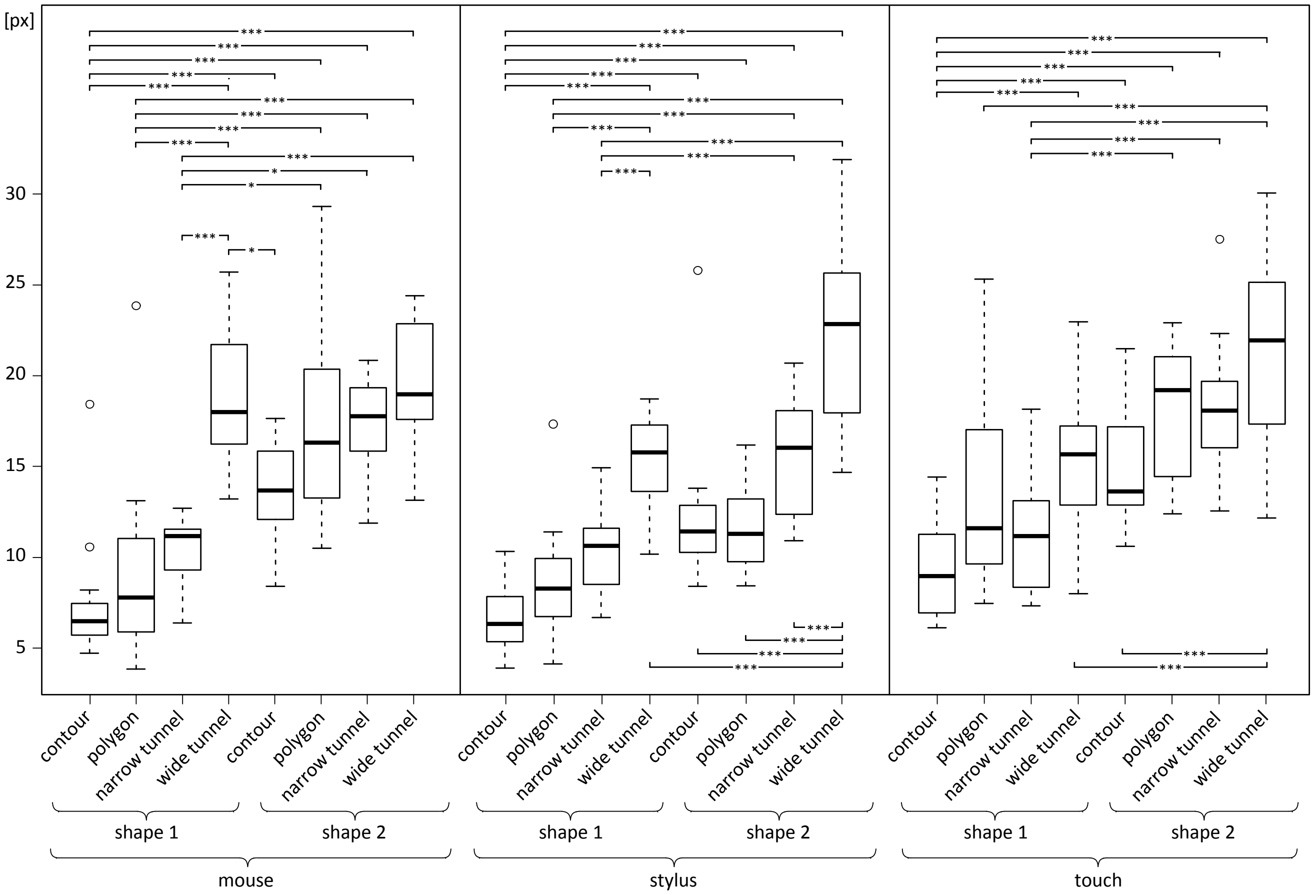

Figure 4. Errors measured for each version of each shape for each input method used. The results of multiple ANOVAs are encoded as follows: '*' – denote a p value < 0,001, and '*' – denote a p value between 0,01 and 0,05.**

5. DISCUSSION AND CONCLUSION

We can distinguish several kinds of effects observed in this study. Shape based differences observed in this study confirmed the expectations from the previous research on shape tracing. The "easy" shape (shape 1) was indeed easier to replicate than the "hard" one (shape 2). It is reflected by the errors measured. However, these differences are not reflected in the time data what might be related to the equal length of both shapes suggesting a time-based response priming effect for the speed-accuracy trade-off in tracing.

Input-related effects observed in other studies on tracing [9] found patterns of differences between input devices similar to the ones observed in this study within each shape. This confirms observations around a speed-accuracy trade-off.

The mouse is overall slowest device and touch is the fastest one but insignificantly. different from stylus. However, the touch is also the least accurate input of all tested in most of the tasks but the differences between these devices are mostly insignificant. We expect that task formulation forcing users to perform "as fast and as accurate as possible" is responsible for creating different operational bias [8] resulting in smaller differences between the input devices in comparison to spatio-temporarily unconstrained tracing where that bias can be more subjective [9]. That could also explain relatively worse performance of mouse that is harder to be operated with fine-tuned finger movements, even though the participants reported their highest daily experience with it.

The precise line-tracing task used here was also compared to lasso selection and tunnel steering, showing significant differences distinguishing these tasks from each other. In general, we find it hard to characterize tracing activities in terms of a tunnel steering task. Especially the width of the "tunnel" for tracing would have to be defined a priori, which is very difficult when we deal with complicated shapes composed of simple ones joined with corners. Previous studies on the SL modeled only very simple shapes – i.e. a straight line and a circle [7]. Our current study is the first attempt to experimentally characterize the SL in more complicated paths. The results show that tracing over a contour shape or around a polygon shape are as time consuming as steering in narrow tunnels but the errors produced are higher in case of tunnel steering. This suggests that the SL may *not* model tracing of paths and steering in narrow tunnels with more complicated shapes. We are planning to address the verification of theoretical predictions of the SL compared to our results in future work.

The results of this study can be also used to design shapes that are easy to replicate, e.g. for surface-based gestural interaction. However, we have to assume that presented results are only true for the family of shapes used here.

6. ACKNOWLEDGMENTS

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