# Quickly touched - Shape replication with use of mouse, pen- and touch-input

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## Abstract
This paper presents results of an experimental study of unconstrained line-tracing task with use of mouse, pen- and touch-input. Our results show that participants using touch-input performed as good as with use of mouse in terms of similarity of reproduced shape with pen-input as the best tool for drawing. Touch-input users were also the fastest in comparison to the remaining input methods. Additionally, we have observed subjective operational biases that together with shape-related issues might have an influence on the final scores.

## Keywords
Shape, freehand, tracing, drawing, mouse, stylus, touch, evaluation, comparison, method.

## ACM Classification Keywords
H.5.2 [User Interfaces: Evaluation/methodology].

## Introduction
The way people interact with computers especially, during artistic endeavors is being currently reshaped by the widespread popularity of touch- and pen-sensitive displays. In these particular situations we can observe an increasing number of interaction tasks that are far more complex than typical navigational pointing and selecting. However,

research on input methods and their influence on human input focused mainly on the performance aspects in navigation tasks. These standard navigational tasks eventually became the subjects of mathematical modeling. For example Fitts' Law is a proven method that models linear pointing and clicking tasks. However, Hourcade et al [Hourcade et al. 2004] observed interesting age-dependent properties of the paths taken by participants using a mouse to perform linear pointing task and noted that Fitts' Law doesn't always model children well. Additionally, it also appeared to be not as well suited for modeling two dimensional tasks [MacKenzie and Buxton 1992]. That has been supplemented by the Steering Law, which is a more suitable predictive model for investigating two dimensional navigation tasks by considering them as a constrained motion within predefined tunnels of error [Accot and Zhai 1997]. Additionally, the issue of spatial constraint addressed by the Steering Law has been supplemented by the research on the influence of temporal constraint [Zhou et al. 2009].

Since any surface-based human input can be broken down to a time-series of 2D coordinates - we can use the analogy of line tracing to describe the output of the continuous user's action that takes place e.g. on a touch-sensitive surface. However, while the navigation tasks may be represented as line-tracing tasks - line-tracing tasks cannot be considered as navigation tasks. The main reason is that the line-tracing task represents different user's goal than getting from point X to point Y within a given time-frame as it is in case of navigational task.

Many input devices have been tested on their effectiveness in pointing, dragging, goal crossing and path steering navigational tasks and this knowledge has been used for multitude of analyses and comparisons [Forlines et al. 2007; MacKenzie et al. 1991; Sasangohar et al. 2009]. However, artistic line tracing can be an example of a task which might be negatively influenced by the low accuracy of the input method used for drawing but also by any kind of spatio-temporal constraints imposed on the user. However, we have been unable to find a model describing spatially and temporally unconstrained freehand drawing with initially unpredictable user error and unknown mathematical formula describing the original path or shape. Therefore, we decided to experimentally investigate the user's performance in the unconstrained free-hand shape replication task using mouse, touch- and pen-input. Additionally, we checked if the results are affected by the presence of visual feedback of drawn lines.

## Experiment Design

In order to compare the mouse, stylus- and touch-input in a shape replication task, we performed an experiment to measure the user's error and time in shape tracing with or without visual feedback.

The experiment had a mixed design. 16 participants that have been selected through convenience sampling were all students at Uppsala University and voluntarily participated in the study. 8 of them were randomly assigned to each visual feedback condition. Visual feedback of drawing (visible or invisible) had between subjects design, and had a form of a solid black line of the same thickness as the shape pattern or without any visual feedback of drawing that imitated drawing with an invisible ink. Input methods (mouse, stylus, touch) were tested within subject and randomly assigned for counterbalancing potential order effects.

Participants had to sign consent forms, fill in pre-test questionnaires and take part in a short introductory session for the stylus and touch input in MS Paint. Then, they were presented with a greyed-out shape (70% opacity) and instructed to: "trace over the shape in one stroke, starting from the top right corner". Participants traced over that shape using every input method with or without visual feedback of drawing. After that participants were asked to fill in a post-test questionnaire regarding their preferences and opinions about the input devices they were using.

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 input, 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 inputs had their standard Windows 7 system cursors visible while interacting with mouse cursor visible always.

Timing information about every task was collected and after each task a 1-bit monochrome black and white screenshot of participant's tracing was created and stored as bitmap file.

## Shape

Multiple geometrical properties of shapes have been identified by considering the curvature of a given shape [Costa and Cesar-Jr 2001]. Multiple general characteristics of shapes like transient events or asymmetries have been found having extensive impact on human visual perception; therefore we decided to generate asymmetrical, semi-random, non-sense, contour shapes that did not resemble alphabet characters, well-known shapes or popular objects. We used a modified version of Method 4 described by Attneave [Attneave and Arnoult 1956]. The modification of Attneave's method was limited to making the shapes consisting of at least two instances of each property: convex corner, concave corner, straight line segment, and curve line segment. The linear segments of the shape did not cross at any point. Their parameters like length or corners' angle were randomized. Out of many random shapes that were generated one of them has been selected for the study.

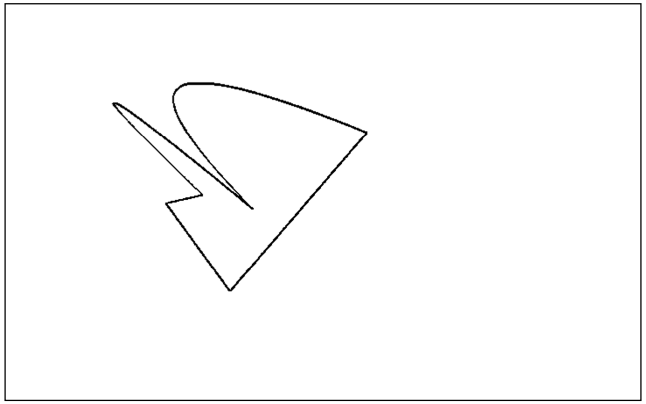

**Figure 1.** The contour shape generated *(referred later to as original shape)* with its placement and proportional size to the test PC's panoramic screen

## User Error

There are many factors that can describe a given shape e.g.: general shape, translation, rotation, and scale. In case of this experiment only general shape was expected to change with remaining factors left unchanged. To estimate that change as a measure of input device induced user error we used a well-established method of measuring similarity between shapes based on shape contexts [Belongie et al. 2002]. In that method the measurement of similarity is preceded by solving for correspondences between points on the drawn and original shapes. The original and drawn shapes are represented by two sets of 104 points sampled from their external contours. They correspond to key-points such as maxima of curvature or inflection points or corners and a number of points in constant quantities roughly uniformly spaced between the shape's key-points.

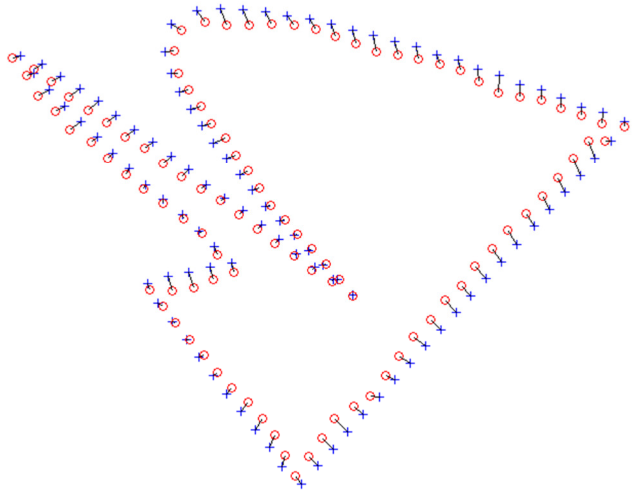

**Figure 2.** Correspondences found (*black lines)* using bipartite matching between points on original shape *(centers of blue crosses)* and user generated shape *(centers of red circles)*.

The correspondence problem is solved by attaching a descriptor to each point (a set of vectors originating from a given point to all other sampled points) - the shape context - that captures the distribution of the remaining points relatively to it and offers a unique characterization of the shape.

As a numeric measure of the difference between both shapes We used the value of "shape context cost" of matching the drawn and original shapes calculated based on $\chi^2$ test statistics of shape contexts that are distributions represented as normalized K-bin histograms. This measure reflects all local differences in general shape and responds even to small deformations of shape features that are the result of user error.

While performing such a tracing task it is theoretically possible to achieve maximum accuracy (error of zero value) meaning that a user has traced over a shape perfectly and created the shape in the exact same position and shape as the original pattern that was presented. Unfortunately, "shape context cost" method does not provide that possibility because it's based on the statistical inference methods and makes the comparison of identical shapes being saddled with a marginal error value.

## Results

Reaction time data are typically non-normally distributed and positively skewed [Heathcote et al. 1991; Hockley 1984; McCormack and Wright 1964] therefore a logarithmic transformation of these data was used before statistical testing.

An ANOVA was performed and the results showed that there was no main effect of visibility of visual feedback of drawing ($F_{1,14}$=2.4035; p=0.1434) on task time, nor any interaction between visibility of visual feedback of drawing and input device used ($F_{2,28}$=0.0051; p=0.995). However, there was a main effect of input device ($F_{2,28}$=24.8818; p<0.0001). A post hoc analysis by the Bonferroni test showed significant difference between touch-input and mouse with resulting p-value being lower than 0.001.

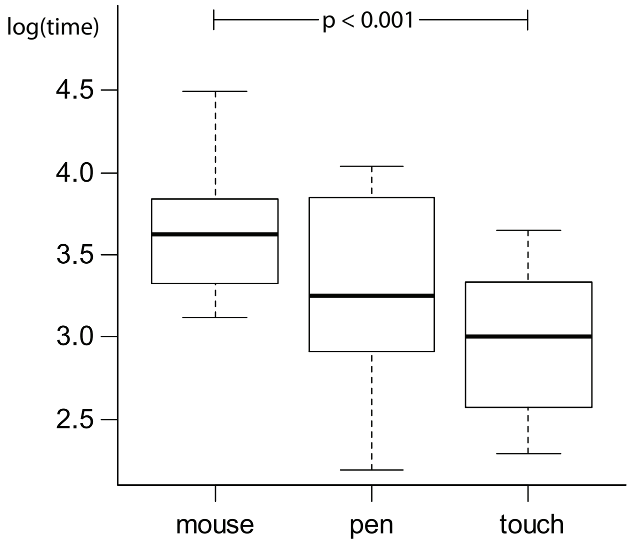


**Figure 3.** Box plot showing comparison of logarithmic values of time measured. Horizontal line with number denotes statistical significance after Bonferroni test.

The mean time values for each input device were: mouse = 39.99 sec., pen-input = 30.11 sec. and touch-input = 21.46 sec.

An ANOVA of the error data showed no significant differences in: visibility of visual feedback of drawing ($F_{1,14}$=0.0461; p=0.833) or the interaction between visibility of visual feedback and input device (F2,28=0.8483; p=0.4388). However, there was a main effect of input device (F2,28=7.3463; p=0.0027).
A post hoc analysis by the Bonferroni test showed significant differences between pen and mouse (p=0.0229) and also pen and touch-input (p=0.0048).

The mean error values for each input device were: mouse = 0.0164, pen-input = 0.0116, touch-input = 0.0174 with the grand mean error value = 0.0151.

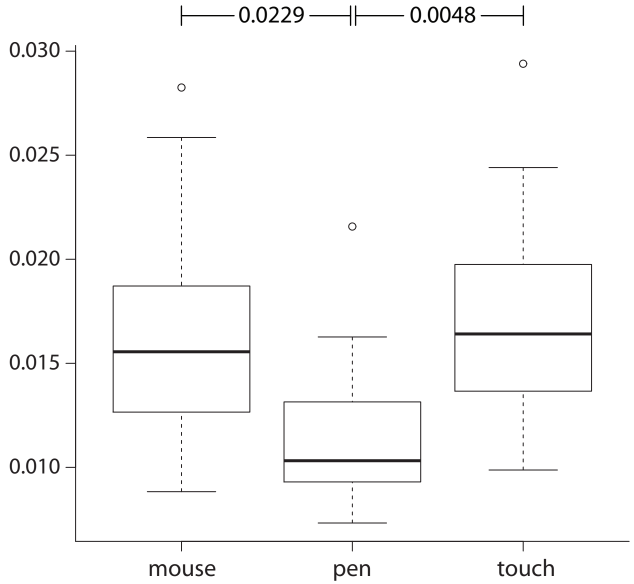


**Figure 4.** Box plot of errors measured. Horizontal lines with numbers denote statistical significance after Bonferroni test.

## Discussion

Our finding that visual feedback of drawing has no influence on user's error or task time is potentially surprising in light of previous research on pointing tasks. We expected it to have an assistive function helping the users to notice their errors while drawing. However, apparently that was not enough to cause frequent correction attempts that would eventually improve the similarity of drawn shape to the original one - what would be reflected by the overall error score. This might suggest that human perception system mostly uses feedforward mechanisms to deal with the drawing process with feed-back considered as secondary ones. That makes this case of drawing task more similar to steering tasks – especially if we take into consideration the visibility of the system cursors as important elements of interaction.

The finding that touch input outperforms pen or mouse in case of task time is potentially surprising in light of previous works on human motor behavior [Balakrishnan and MacKenzie]. But a reason for that might be the bias of navigational tasks used in these studies since tracing movements are rarely simple enough to be sufficiently predicted by Fitts' model.

The finding that touch-input performs with comparative error as mouse in shape replication task can be explained by a few of phenomena that take place during this kind of interaction. For example users' hands caused a big occlusion of the drawing area with drawing fingers occluding the most crucial area where the shape creation took place. Mouse on the other hand is an indirect input method that needs more cognitive effort to be operated. These might be the reasons why pen-input performed best here being a direct input method and minimally occluding the screen in the drawing area.

We have also observed typical speed-accuracy trade-offs which means that the more accurate the tracing was the longer it took and vice versa. However, we have to highlight the fact that our deliberate decision of not imposing any spatio-temporal constraints on participants created a space for subjective operational biases towards speed and/or accuracy. That resulted in setting an unique initial ratio of speed to accuracy what can be seen in huge spread of time measurements between input methods and definitely had its influence on participants' performance but was also noticed previously in target acquisition or trajectory-based tasks [Zhou and Ren 2010].

The important factor additionally influencing the results is the effect of original shape's semi-random properties. We have observed reduced accuracy in replicating the long straight lines.

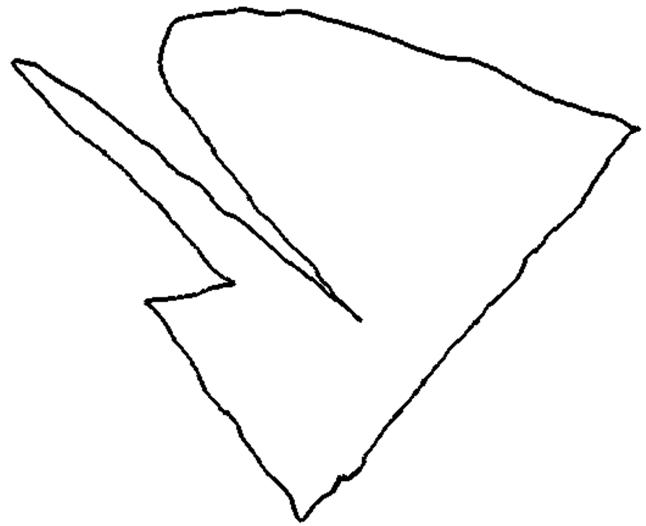

**Figure 5.** Example of low error (0.0073) user generated shape

Additionally, previous research shows that the time taken to complete a trajectory-based task is increased by mere presence of a corner on the trajectory [Pastel 2006]. Interesting user strategies were observed while they were passing a corner and involve "cutting off the corner" – that produced the user's path with rounded corner without slowing the pace of movement or "stop and go" – that produced sharp corners and resulted in temporary deceleration od movement. Moreover, it has been shown that because of biomechanical reasons 45° corners are easier to negotiate than 90° corners or even 135° corners.

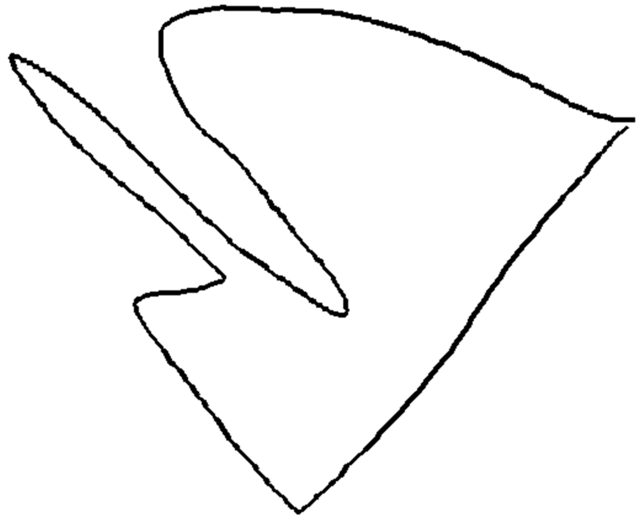

**Figure 6.** Example of high error (0.0294) user generated shape

Another factor is the presence, position and orientation of big concave and convex elements. These features under certain circumstances can be considered as corners what might have an influence on the perception of the shape as a whole and in certain positions or angles can be problematic or time consuming to replicate esp. with mouse.

There was no observable system latency but any potential effect of hardware/software's latency was balanced by the fact that we used the same PC setup for all input methods so we may say all results are affected equally.  Nonetheless, we can assume that mouse needed less processing power than more sophisticated and complex touch- and pen-sensing surfaces.

## Conclusion

The precise line-tracing task might be representative of multiple tasks ranging from creative graphics design and free-hand drawing to complex linear selections of multiple graphical elements. We checked that the presence of visual feedback does not influence the accuracy of drawing what together with the shape-related issues expected or subjective operational bias observed - might also have an influence on gestural interaction. However, further research must be done to determine which features of shapes and in what way do affect user performance in sketching tasks.

Our results show that for the shape that was used participants using touch input performed fastest and as accurate as using mouse. Pen-input seems to be best performing device but the qualitative post-test data collected indicates that touch-input is the preferred input method for drawing, followed by pen-input and mouse as last choice.

## Acknowledgements

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