Not Just Intuitive: Examining the Basic Manipulation of Tangible User Interfaces

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ABSTRACT

Tangible user interfaces have received increasing attention in recent years. People often describe tangible user interfaces as "more intuitive" interfaces because we have learned how to manipulate physical objects throughout our lifetime. However, after almost 10 years of prototype development and numerous conference papers, tangible user interfaces have had minimal impact on everyday use of computers. Is there anything that prevents tangible user interfaces from becoming more widely used? In order to investigate the effect of tangible user interfaces, we designed a spatial task to compare a paper tangible user interface with a mouse-controlled graphical user interface. Using a within-subjects design, data were collected from 12 subjects who used both interfaces. Results indicated that subjects exhibited better performance (center displacement error and reproduction time) with the paper tangible user interface.

Categories and Subject Descriptions: H.5.2 [Information Interfaces and Presentation]: User Interfaces.

General Terms: Experimentation, Human Factors, Measurement, Performance.

Keywords

Tangible user interface, graphical user interface, tangible usability, interface design.

INTRODUCTION

Tangible user interfaces (TUIs) have received increasing attention in recent years. For example, when searching CHI proceedings in the ACM Digital library, we found 81 results (including papers, short talks, demos, etc.) containing the keyword "tangible" from 1998 to 2003. Some projects have started to evaluate the usability of TUIs [2, 3, 4]; however, there still remains a need for a more complete understanding of TUIs.

QUESTION AND HYPOTHESIS

In both Ullmer & Ishii's and Klemmer & Landay's taxonomies [5, 6], TUIs that involve spatial interaction occupied the largest category of TUI systems. Therefore, we decided to focus on "spatial" manipulations using TUIs. We designed the required manipulations to be as simple as possible so that they involved only a few select operations. We used a 2D-only spatial layout task instead of a complex 3D task, as a starting point, to compare a paper TUI with a mouse-controlled graphical user interface (GUI).

The 2D spatial layout task required reproduction of a pattern. The pattern was displayed to the subjects. The subjects were then asked to take as much time as they needed to remember the pattern. Subsequently we asked them to correctly reproduce the pattern using different interfaces.

In order to test the effect of the interfaces, we used the reproduction time and the center displacement error as performance measures. Figure 1 shows a sample layout. Three vectors illustrate the displacement between the initial pattern and subjects' responses. We instructed subjects that accuracy was more important than time.

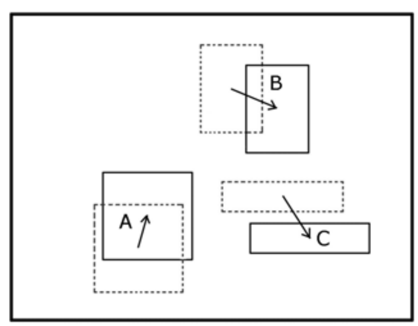

Figure 1. The dashed-line rectangles represent the initial pattern. Rectangles in solid-line represent the subject's responses. A, B, and C indicate three center of displacement vectors.

We displayed the pattern with paper in the paper TUI session and with on-screen rectangles in the mouse-controlled GUI session. Although three objects are much fewer than Miller's magic number of 7±2, we were concerned that subjects' ability to memorize the pattern would be different. To assess effects of different interfaces effects, we recorded the time that subjects needed to memorize the patterns. We asked subjects to take plenty of time to remember the spatial patterns in an effort to insure that they did indeed memorize them.

We tested the manipulation for two interfaces in the same experimental environment. For the mouse-controlled GUI, we used a horizontal screen. The subjects used a wireless optical mouse on the tabletop display.

We used a within-subject design and counter-balanced the order in which the interfaces (TUI vs. GUI) were presented. To avoid the learning effect, we used an initial pattern layout and its mirror-reversed pattern. The order of the task (regular vs. mirrored) was counter-balanced. We checked the reproduction time as an indicator of learning effect.

We hypothesized that subjects' layout reproduction would be better when using the paper TUI than a mouse controlled GUI.

METHOD

Subjects

12 subjects, 6 women and 6 men, ages 25 to 35, were recruited from the Human Interface Technology Laboratory subject pool. All subjects were volunteers. The protocol was approved by the University of Washington Human Subjects Review Committee.

Apparatus

We used the MouseHaus Table system [1] that includes a custom-made table with a rear projection screen, a video camera, and a 800 x 600 pixel projector, as the test environment. Figure 2 shows the physical setup for MouseHaus Table. The dimensions of the table were 105 x 125cm and a 82 x 62 cm window was generated by the MouseHaus Table application on the screen as the manipulation space for both interfaces. The dimensions for the three objects were 6 x 24cm, 12 x 18cm, and 18 x 18cm. Subjects stood on one side of the table, facing the window. The paper TUI consisted of three yellow colored rectangles. A wireless optical mouse controlled the GUI. We also setup a digital camera to record the resulting layout. We manually computed the center displacement error in pixels using Photoshop. Figure 3 shows the experimental environment.

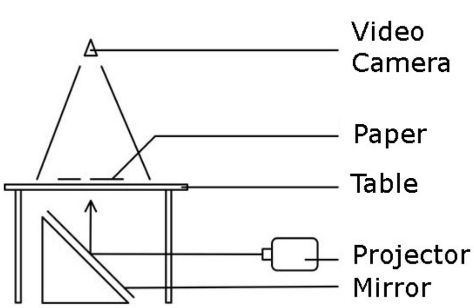

Figure 2. Physical setup of the test system.

Procedure

A practice test using two rectangles for both interfaces was completed before the experimental task. The experimenter reminded subjects that the reproduction required both relative and absolute position correctness before each session. The experiment sequence was as follows:

1. The experimenter asked subjects come to the table with their eyes closed in order to control their memorization time.
2. The experimenter gave the instruction "When I say eyes open, you will start to remember the pattern. You will reproduce the same pattern. Take your time to remember it. When you finish, say stop and close your eyes".
3. The experimenter asked subjects to reproduce the pattern using either the paper interface or the mouse interface.
4. The procedure was repeated using the other interface and the mirror-reversed pattern.

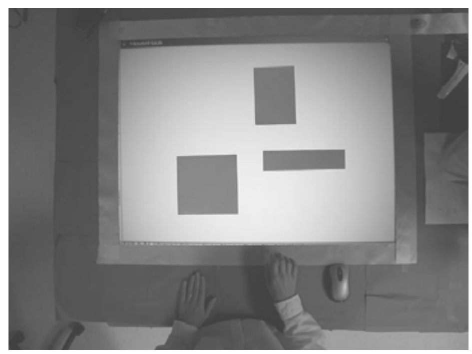

Figure 3. Experimental environment. The paper rectangles are the interface for the paper tangible session.

The experimenter started the timer when giving the instructions "eyes open," and then stopped the timer when subjects said "stop." Subjects also completed a questionnaire regarding their subjective evaluation of the two interfaces. Subjects were randomly assigned the order of the tasks and the initial layout patterns.

For the subjective reports, subjects were asked to rate their preferences for the two interfaces. We first asked subjects to give independent ratings of their preferences based on a Likert scale (1 to 9, 1: most preferred, 9: least preferred). For the second part of the questionnaire, we asked similar questions but regarding relative preferences. We asked subjects which interface they preferred based on a 1 to 5 scale (1: slightly preferred, 5: strongly preferred). These questions addressed: general preferences, ease of use, and manipulation speed.

Results

Memorization time did not differ across the paper and mouse interfaces. A paired sample t-test was performed to identify the effects of the paper pattern versus on-screen pattern on spatial knowledge acquisition. The result of the t-

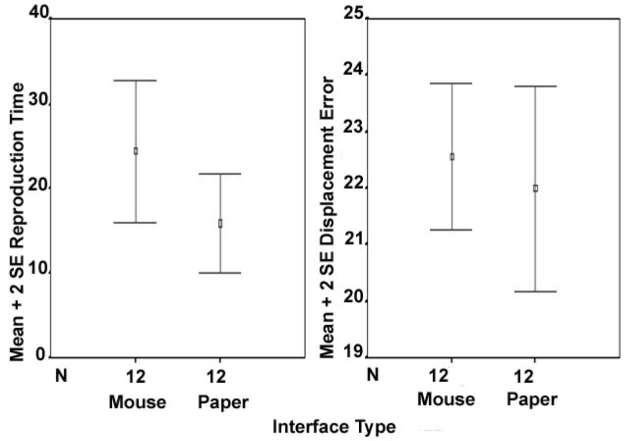

Figure 4. (Left) Means and standard errors of reproduction times. (Right) Means and standard errors of center displacement errors.

test showed no significant difference between the tangible and graphical representations [t (11) = 076, p = 0.94].

A repeated measures multivariate analysis of variance (MANOVA) was calculated to determine the effect of the interfaces. Diagnostic tests for the MANOVA assumption of normality and homogeneity were performed on the center location error and reproduction time data. Based on the quantile-quantile plots and Levene's test of equality of error variances, a log transformation of the center displacement error was performed to satisfy the assumptions of the analysis. The resulting MANOVA showed that, a significant main effect of interface on a linear combination of the two dependent variables, center location error and reproduction time [F (10, 2) = 4.985, p = .031]. Subjects' performance differed significantly across the two interfaces.

We further analyzed the effect of the interfaces on each of the dependent variables with repeated measures univariate analysis of variance (ANOVA). The results indicated that reproduction time contributed most of the MANOVA main effect difference [F (11, 1) = 9.716 p = .010]. The means and standard errors for reproduction times and center displacement errors are summarized in Figure 4.

Interface Type	Mouse	Paper
General Preference	3.50	2.92
Ease of Use	3.67	2.75
Manipulation Speed	4.00	2.41

Table 1. Means of subjects' independent ratings for the two interfaces.

Subjective Reports

Means for subjects' independent interface ratings are summarized in Table 1. Three paired sample t-tests were performed and the results didn't show statistically significant differences (general preference: [t (11) = 0.573, p = .578], ease of use: [t (11) = 0.974, p = 0.351], manipulation speed: [t (11) = 1.55, p = 0.148].

The relative ratings are summarized in Figure 5. Regarding subjects' general preference, 2 subjects preferred the mouse and 10 subjects preferred the paper. The average preferences for the two groups were 1.5 and 3.625. In terms of ease of use, three subjects preferred the mouse, 8 subjects preferred the paper, and 1 had no preference. The average preferences for the two groups were 2.67 and 3.5. Regarding subjects' perception of manipulation speed, 4 subjects felt the mouse was faster, 7 subjects preferred the paper, and 1 had no preference. The average preferences for the two groups were 3.25 and 3.29.

	Mouse	Paper
General Preference	2 1	1 2 2 2 3 3 3 4 4 5
Ease of Use*	3 3 2	1 3 3 3 4 4 5 5
Manipulation Speed	4 4 3 2	2 2 3 3 3 5 5 5

Figure 5. Relative preference of interfaces. Subjects first picked their preferred interface and answered how much they prefer it (1: slight preference, 5: strongly preferred). *For the ease of use category, one subject answered "neither".

DISCUSSION

Our hypothesis that subjects' layout reproduction would be better when using the paper TUI than a mouse controlled GUI was confirmed. Our analysis of the interface effect indicated that reproduction time accounted for most of the difference. An explanation of this finding may be related to our experimental design. We tried to test the effect of interfaces under the assumption that subjects were satisfied with their performance. The subjects were allowed to adjust the paper position freely without a time limit. Center displacement errors therefore did not contribute very much to the performance index. On the other hand, the average manipulation time for the paper TUI was shorter than for the mouse-controlled GUI, as noted previously.

Regarding the subjective preferences for the two interfaces, the independent ratings (Table 1) didn't show a significant difference. However, if we drop a subject who gave extreme responses (a 1 vs. 9 rating) for each question, the paired sample t-test for the general preference showed a trend suggesting that subjects preferred the paper interface [t (10) = 1.902, p = 0.086]. The paired sample t-test for the relative ease-of-use preference indicated a statistically significant difference [t (10) = 3.297, p = 0.008]. Although subjects preferred the paper, their responses about the manipulation speed still did not differ significantly across the two interfaces [t (10) = 1.093, p = 0.30]. The non-significant difference in subjective report differs from previous research, for example, both Fitzmaurice (physical comfort, p < .0008 & p < .0016; ease of use, p < .0001 & p < .0001) and Jacob et al. (preference, p = 0.03) reported subjects significantly preferred TUI over other interfaces.

Fitzmaurice proposed the space-multiplex as a distinct quality for specialized graspable user interfaces (TUIs). He demonstrated that space-multiplex devices outperformed time-multiplex generic input devices in a three set-up experiment: 1) 4 specialized devices on 4 tablets, 2) 4 puck and brick pairs of generic devices on 4 tablets, 3) one puck and brick pair of generic device on a larger tablet. Jacob et al. compared four interfaces (Paper, Reduced-Senseboard, Pen-GUI, and Senseboard) and tried to distinguish the improvement for TUI over merely paper. Jacob et al. reported a non-significant trend (p=0.11) and concluded the difference was due to the imperfect way that TUI simulated paper.

The main difference between our experiment and Fitzmaurice's is that we used everyday objects (papers) instead of very specific devices such as the stretchable square. We focused on testing a very basic manipulation of TUIs and its spatial quality is common in many TUI systems. This difference also applies to Fitzmaurice's study of manipulating physical/logical devices [2]. Regarding Fitzmaurice's findings, he mentioned that subjects used a larger tablet and had longer device-idle times. However, he did not discuss how the size difference (12 " x 12" vs. 18" x 25") contributed to the performance scores (translation, rotation, and scale). For example, on a larger tablet, at least, the physical distance that subjects have to move is inevitably larger. This may contribute to the improved performance of space-multiplex devices.

Jacob et al. attempt to test a simplified TUI manipulation is also closely related to our motivations. However, the experiment by Jacob et al. involved complicated reasoning processes (selecting 3 workers from 6 workers for a 5 day schedule with a set of constraints such as mixed skills.) Jacob et al. didn't report how much time subjects were manipulating the tangible media. There is a chance that subjects' reasoning time (device idle) occupied most of the completion time and washed out the effect of manipulation among different interfaces.

Additional Factors

Using both hands

Using both hands is normally considered advantageous for TUIs. However it became a "noise factor" in this experiment since we were interested in the effect of the most simple TUI manipulation. If we use very basic manipulation without two hands, we would have the ability to say if the basic manipulation contributes to the advantage of using TUIs. Although we seldom saw subjects use both hands at the same time, some switched hands very quickly. It is a possible flaw in our experimental design that we did not ask subjects to use only one hand.

Mirror-reversed pattern

We were concerned that the mirror-reversed pattern would affect the results. Therefore, we used subjects' memorization time to test the difficulty level. We asked subjects to evaluate their difficulty level to remember both patterns. Although four of twelve subjects noticed that the second pattern mirrored the first one, the paired sample t-test of their memorization time did not differ significantly [$t(11) = 0.975$, $p = 0.351$]. The average memorization time for the mirrored pattern [$M_M = 24.58$] was even higher than the original one [$M_O = 22.00$]. Further, the paired sample t-test for their subjective ratings did not show significant differences [$t(11) = 0.821$, $p = 0.429$].

CONCLUSION

This study identified a statistically significant difference between a paper TUI and a mouse-controlled GUI for a spatial layout task.

The contradiction between the significant difference in the spatial layout task and the non-significant result of the subjective reports opens questions about which qualities users really liked about the TUIs. In other words, when designing TUIs, how do we augment computer power by providing interfaces that make more sense to users. We anticipate that additional research about TUIs and the quality of TUI interaction will be completed in the near future. We hope to discover reasons that prevent TUIs from becoming widely adopted for everyday use and suggest changes to make them more acceptable.

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