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What is This?
SUPERIORITY OF FREEHAND POINTING
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There is a possibility that computer mice may be replaced with eye-gaze or touchscreen technologies. Hence, it is imperative that we investigate the effect of the type of input device in conditions having lateral constraints. A set of tracks with different levels of difficulty were tested. The type of device had little influence on movement time for ballistic steering tasks, while movement time was affected by the type of device used in visually controlled steering tasks. It was also found that resting the forearm increased movement time. Subjective evaluations indicated that control is easier with freehand pointing. Considering both comfort and performance it appears that freehand pointing, when resting the forearm, is optimal for a touchscreen.

INTRODUCTION

Trend of Touch Control

Use of a touchscreen on various devices is ubiquitous. For example, Microsoft released Windows 8 (2012) in October 2012 with a new touch-friendly interface. Market analysis has shown a rapid growth in touch technology (Hsieh, 2011), primarily due to improvements in sensitivity and response latency. Hence, it is worthwhile to investigate human performance when using mice and touchscreens.

Many researchers have compared the characteristics of various pointing devices (Card, English, & Burr, 1978; MacKenzie, Sellen, & Buxton, 1991). However, those studies were focused merely on pointing tasks and not steering tasks. Although, Accot and Zhai (1999) have compared steering performance with mouse, trackball, trackpoint, touch-pad and tablet, a touchscreen was not used. It may be said that the research related to user performance and experience when performing steering tasks with touch technology is very sketchy. In this research, we investigated the effect of four input devices with steering movements.

Drury's Steering Law

A majority of tasks on a Graphical User Interface are point, click and drag. These motions can be easily modeled using Fitts’ Law (Fitts, 1954) and Drury’s Law (i.e. steering through a drop down menu) (Drury, 1971). The basic form of Drury’s Steering Law can be expressed as in equation 1 where D (mm) is the length of a constrained path, MT is the movement time and P (mm) is the width of the constrained path.

\[ MT = a \left( \frac{D}{P} \right) + b \]  

(1)

The difficulty of the task (ID) depends on D and P (equation 2).

\[ \text{Index of Difficulty (ID)} = \frac{D}{P} \]  

(2)

The above model has been useful in designing and evaluating 3D human-machine interfaces (Accot & Zhai, 1997) and virtual environments (Zhai, Accot, & Woltjer, 2004). The model has been further verified by Goonetilleke and Hoffmann (2008) in other situations as well.

Ballistic vs. Visual Control Tasks

Drury’s model is only valid for paths with relatively high ID (Drury & Daniels, 1975; Drury, Barnes, & Daniels, 1975). At low difficulty levels, equation 1 changes to a different form (Hoffmann, 2009) and the range of applicability (equation 3) has been reported in Thibbotuwawa, Goonetilleke, and Hoffmann (2012) and Thibbotuwawa, Hoffmann, and Goonetilleke (2012).

\[ MT = \begin{cases} a_1 \times (\sqrt{D}) + b_1, & \left( \frac{D}{P} \right) \leq 8 \text{ to } 10 \\ a_2 \times \left( \frac{D}{P} \right) + b_2, & \text{Otherwise} \end{cases} \]  

(3)

where \( a_i \) and \( b_i \) are constants.

Visual feedback is important to precisely control one’s limb, especially when moving within a constrained path. It is, most often, a “plan” developed after each sub-movement (Ketcham, Dounskaia, & Stelmach, 2006; Thibbotuwawa, Hoffmann, & Goonetilleke, 2012). When \( (D/P) \) is large, continuous limb corrections are necessary to stay within the path. This is known as visual control. However, the correcting actions are non-existent when \( (D/P) \) is small. With a large path width, the path constraint is negligible and visual feedback is not required to get to the destination throughout the complete task. This is known as a ballistic movement.
METHOD

Participants

A total of 10 (5 males and 5 females) right-handed students of the Hong Kong University of Science and Technology participated in the experiment. They were computer and smartphone users with an average computer usage time of 4.05 hours per day. Participants did not have any injuries or surgery performed on their wrists, fingers and elbows. Furthermore, all participants were verbally required to guarantee that they had 20/20 vision. Each participant was paid HK$ 50 for their time.

Equipment

Participants had to complete a computer based steering task programmed using C++ and running on Windows 8. The task was to steer through a set of horizontal tracks, one at a time, where the starting position was marked with a circle and the ending position was marked with a vertical line. Three types of input devices were tested:
1) Logitech G9X optical mouse
2) Genius wireless Pen Mouse
3) Acer T232HL touchscreen monitor with a screen resolution of 1920×1080 pixels. It had a display width of 580 mm diagonally. The monitor was concomitantly used as the output display device throughout the experiment.

A gaming mouse pad was used as the movement surface for the Logitech mouse and the Genius pen mouse. Cursor displacement to mouse or pen-mouse displacement gain was set to be approximately 10 throughout the experiment.

Experimental Design

A set of 22 experimental conditions with 11 different levels of Index of Difficulty (=Path Length D/Path Width P) were chosen. The conditions with an Index of difficulty of 8 or lower were expected to be performed ballistically while the others were supposed to be visually-controlled (Thibbotuwawa, Hoffmann, & Goonetilleke, 2012).

There were 4 device settings. The way in which subjects controlled each of the input devices is shown in Figure 1. For the settings 1, 2 and 3, the monitor was positioned at a 60° angle from horizontal, while it was 20° for setting 4 (required resting the forearm on the table). A practice trial with 48 conditions whose index of difficulties ranged from 0.25 to 45 were given for each setting to eliminate any potential learning effects. Each participant had to run all 22 conditions, three times repetitively for each of the four settings. The conditions in each trial of each subject were presented in a random sequence. The four settings were also randomly assigned to each subject.

RESULTS AND ANALYSIS

Effect of Device Type on Movement Time

Movement time (MT) analysis was performed separately for ballistic tasks (D/P < 10) tasks and visually controlled tasks (D/P > 10). Repeated measures ANOVA for ballistic tasks indicated that $\sqrt{D}$ and device type were significant ($F_{1,4,1}=38.900$, $p<0.001$; $F_{1,4,12}=34.100$, $p<0.001$ with Greenhouse-Geisser corrections), while (D/P) and device type showed significant main effects for visual control tasks ($F_{1,3,11}=68.211$, $p<0.001$; $F_{1,8,10}=21.982$, $p<0.001$ with Greenhouse-Geisser corrections). Tukey's post-hoc tests are given in Table 1.
Table 1: Grouping information of Tukey’s Test. The same letter indicates that there is no significant difference among the conditions.

<table>
<thead>
<tr>
<th></th>
<th>Ballistic</th>
<th>Visual Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouse</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>Pen Mouse</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Touchscreen (freehand)</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>Touchscreen (armrest)</td>
<td>B</td>
<td>B</td>
</tr>
</tbody>
</table>

For ballistic tasks, there was no difference among Mouse, Touchscreen (freehand) and Touchscreen (armrest). The Pen Mouse was different from the other three. However, in visually controlled tasks, the differences were more prominent (Table 1). This indicates that device type, except the Pen Mouse has no performance effect on ballistic tasks while device type has a significant effect on movement time for visually controlled tasks.

The data for ballistic and visual control conditions were fitted separately as shown in Figures 2 and 3 respectively. For visually controlled tasks, touchscreen (freehand) had the lowest movement time at all IDs even though it was not significantly different with that when using the mouse.

**Effect of Resting the Hand**

The movement time relationship between the Touchscreen (armrest) and Touchscreen (freehand) was analyzed separately for ballistic and visual control tasks as shown in Figure 4. The gradient in both cases is greater than 1 indicating that one can perform the task of tracking much faster when using freehand pointing.

**User Preference**

The mean data of the user ratings was also analyzed. As illustrated in Figure 5, touchscreen (freehand) is the easiest to control while the Pen Mouse is the most comfortable. The touchscreen (armrest) is a good trade-off between comfort and controllability.

**DISCUSSION AND CONCLUSIONS**

The movement time effects of input device type on dragging tasks were analyzed. It was found that device type has little effect on ballistic tasks and, there is a significant effect of
device type for visually controlled tasks. Movement time is least when using the hand to point without resting the arm even though it was not significantly different from the mouse. The important aspect here is that the mouse gain was around 10 whereas that when using the touchscreen was 1, indicating that freehand control is superior and easier. Subjects expressed that control easier in the freehand condition relative to when using the mouse or Pen Mouse. However, this type of control may not be biomechanically efficient and hence resting the arm may be better from a musculoskeletal standpoint.

The results can be used in designing and evaluating graphical user interfaces. Since users may have differing devices, steering tasks should be designed so that they can be performed ballistically. For example, the nested drop-down menu shown in Figure 6 has a ID value of 15. Therefore, visual control is needed to steer through “Other Windows” and would take more time to “steer”. A higher depth can create a ballistic event instead, and minimizing any possibility of errors.

References


