2007

THE EFFECT OF ORIENTATION-NEUTRAL CURSORS ON MOVEMENT TIME, POSITIONING PERFORMANCE, AND STIMULUS-RESPONSE (S-R) COMPATIBILITY

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B.S., The University of Montana, Montana, 2004

Thesis

presented in partial fulfillment of the requirements
for the degree of

Master of Science
in Computer Science

The University of Montana
Missoula, MT

Spring 2007

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ABSTRACT

Very little research exists on the topic of computer cursor design and utilization. Since this is an important area in successful and efficient user interaction with graphical user interfaces, additional study is necessary. To investigate the impact of cursors with no implicit directional cues *(orientation-neutral cursors)* on movement time, positioning performance, and stimulus-response compatibility, six experiments were designed. In these experiments, six orientation-neutral cursors were compared against each other as well as against four directional cursors. Twelve participants with advanced computer skills between the ages of 18 and 30, right-handed, and normal or corrected-to-normal eyesight participated in the experiments, which were conducted in a tightly controlled environment.

The study contained six different experiments, each designed to evaluate and analyze a set of cursor types. Each experiment consisted of nine targets, eight arranged on an imaginary circle surrounding a central target. Participants were instructed to point-and-click alternating between the center target and highlighted targets on the outer circle with emphasis on speed (movement time) and accuracy (positioning performance).

All experiments measured two dependent variables, movement time and positioning performance. Statistical analysis tests revealed a correlation for some cursor types between the two dependent variables, while changing target shapes indicated no statistical significance on the overall results. Slower movement times resulted in more precise positioning performances (greater degree of accuracy) and vice versa.

This study concludes that there is no one cursor of those tested that performed best for anyone. Moreover, this study did not provide the same results in the replication of the mouse-input-portion of Po et al. (2005). The results of this study provide material upon which further studies could expand.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation and profound thanks to those who helped me with various aspects of conducting the research and the writing of this thesis. I would especially like to extend my thanks and gratitude to Dr. Joel E. Henry for his mentoring and guidance provided during my graduate education. Additionally, I want to extend special thanks to the other committee members, Dr. Yolanda Jacobs Reimer, Chair of the Committee, for her patience and guidance throughout this process, and Dr. Rudy A. Gideon for his support, expertise, and lengthy discussions making me understand the statistical aspects of my research. Last but not least, I thank my family for their ongoing support and love throughout my graduate studies.

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CHAPTER 1 INTRODUCTION

1.1 Statement of the Problem

In today's world, the physical interaction between user and computer through a graphical user interface (GUI), using a mouse as an input device, is mainly based on moving, pointing, and clicking on buttons, links, or various other "targets" on a GUI using an arrow shaped cursor that generally points to the upper left (). Very little research appears to have been done that focuses on cursor design and its utilization despite the fact that this is such an important area in successful and efficient user interaction with the GUI. Thus, it is important that cursor shapes and their affect and motion with respect to a given target be subject to further research. We should seek to understand the relationship between cursor shapes and different target locations because the knowledge gained could be used to design future software applications more efficiently. Appropriate usage of cursor designs for specific programs will lead to more intuitive interactions between the user and the application's Graphical User Interface (GUI). This makes programs easier to use, more user friendly, and overall a more "pleasant" user experience. Hence, both companies selling these programs and consumers using them will benefit from a better understanding of how cursor shapes and target locations affect each other.

In 2005, Po, Fisher, and Booth, notable researchers of this topic, conducted a study research in this area and published a paper titled *"Comparing Cursor Orientations for Mouse, Pointer and Pen Interaction."* The experiments covered in this thesis research replicate some of Po et al's results and extend their experiment to evaluate different orientation-neutral cursors. According to Po et al's study and the community involved in this particular research area, cursor shapes are categorized into two distinctive groups: 1) *directional cursors* (cursor shapes providing implicit directional cues), and 2) *orientation-neutral cursors* (cursors that do not indicate any direction).

The study conducted by Po et al. concentrated on the impact of different cursor types with respect to different directions on movement time, positioning performance, and stimulus-response (S-R) compatibility. The theory of stimulus-response (S-R) compatibility refers to the fact that the displayed visual stimulus (the cursor) should match the actual intended movement direction (response). Their study compared four arrow shaped cursors (*directional cursors)* and one circle shaped cursor (*orientation-neutral)*. The arrows provided directional cues while the circle cursor did not. These results provided a better understanding of how different arrows impact directional cursors but since only one orientation-neutral cursor was included in this study, it did not explain how the plain circular shaped cursor compared to other orientation-neutral cursors. There might be one orientation-neutral cursor design that performs better than others. It was important to replicate the process of the mouse-input portion of Po et al's research as closely as possible in order to provide meaningful results in this research study (see Table 3.1). Extending their study by introducing differently designed orientation-neutral cursors and determining the effect on movement time and positioning performance will provide a better understanding whether there is one particular orientation-neutral cursor that performs better than the others tested.

1.2 Contribution to this Research Area

While Po et al's (2005) results suggested that the circular shaped orientation-neutral cursor (○) showed an overall best performance compared to the four directional arrows (↖ ↗ ↙ ↘) it did not address the question as to whether other orientation-neutral cursors would show different performances. This study expands Po et al's original research to include the same four directional cursors and the one orientation-neutral cursor with an additional five orientation-neutral cursors. Thus, a total of ten cursors (four directional cursors and six orientation-neutral cursors) were studied as to their effect on movement time, positioning performance, and S-R compatibility. To expand on Po et al's original work, six orientation-neutral cursor types (⊙ ○ × ⊗ + ⊕) were carefully selected and compared with each other to determine whether significant performance differences exist. This study will add to the scientific knowledge that others could use for further research analysis. Long-term impacts of this study could result in a completely new, improved, and more efficient choice of cursor use by everyone working with computers. The next generations of applications could benefit from a better understanding of the effectiveness of different orientation-neutral cursors. This knowledge could allow usability analysts to select a specific cursor design for particular GUI improving overall mouse efficiency. For example, using a computer aided design (CAD) program that requires precise mouse movements, a cursor design with best performance results in accuracy would be chosen. On the other hand, for general point and click actions on a web browser, where speed might be more important than accuracy, the cursor design with the best speed performances would be selected.

1.3 Research Questions

In order to analyze the issues addressed in the previous sections, the following questions were used to guide this research:

1) Can the results of the mouse and cursor orientation portion of the experiment conducted by Po et al. (2005) be replicated?

2) Extending this research to compare six orientation-neutral cursor types, is there one cursor design (⊙ ○ × ⊗ + ⊕) that performs better than the others?

3) Will the best performing orientation-neutral cursor yield the best results when compared to directional cursors?

4) Will the same results be obtained using the same experimental setup, and replacing all target menu circles with squares? Does the shape of a target have significant impact on the user's ability completing the same experiments conducted to address the first three questions?

1.4 Methodology

To answer the research questions outlined above, a new experimental design that presents four different experiments to each participant was created. One experiment replicates Po et al's (2005) mouse-input portion of their research study, and the other three focus on extending their experiment by evaluating six orientation-neutral cursors and analyzing a different target shape.

Using three different input devices, pointer, pen, and mouse, Po et al. focused on comparing four directional cursors and one orientation-neutral cursor. These were four different arrows, pointing to the upper left, upper right, lower right, lower left respectively, and one circular cursor. Their results show that depending on how cursor type and movement direction are chosen differences exist. Different combinations affect the participant's performance measured in accuracy and speed. It also shows there is a difference in performance over all three input devices.

Motivated by Po et al's research study, this empirical user study consisted of four different experiments, replicated the mouse-input portion of his research and significantly extended it to evaluate six different orientation-neutral cursors. Comparing cursors without any directional cues will provide valuable information and a better understanding as to how they impact the user's efficiency in movement time, positioning performance, and S-R compatibility.

Movement time, measured in milliseconds (ms), was defined as the time elapsed from first clicking within the center target and then clicking within the highlighted target on the circular menu located around the center target. On the other hand, positioning performance was measured as a rate of accuracy. Highest rate of accuracy was achieved by clicking the highlighted target exactly in its center and recorded as $x = 0$ and $y = 0$ coordinates. In Chapter 3.4 the measurement units for both movement time and positioning performance will be discussed. Additionally, Chapter 4.3 provides a more detailed explanation on these two dependent variables.

1.5 Hypotheses

The experimental design will test the following hypotheses. The general questions are repeated followed by the research hypotheses that address each specific question. The NIST/SEMATECH e-Handbook of Statistical Methods states that "a statistical test requires a pair of hypotheses . . . a null hypothesis… [and] an alternative hypothesis. The null hypothesis is a statement about a belief. We may doubt that the null hypothesis is true, which might be why we are 'testing' it. The alternative hypothesis might, in fact, be what we believe to be true" (Anonymous, n.d.-a). Similar to the study of Po et al. (2005), all null hypotheses were tested at the 0.05 level of significance, also known as "alpha level" ($p \leq 0.05$). This means that any statistical significance (rejecting the null hypothesis at the 5 % level) in each tested hypothesis would be indicated in the ANOVA tests as statistically significant ($p \leq 0.05$) two-way and/or three-way interaction effects between participants, cursor types, and targets.

Research Question (addressed by Hypotheses 1 and 2)

1) Can the results of the mouse and cursor orientation portion of the experiment conducted by Po et al. (2005) be replicated?

   Their results revealed that comparing "performance for trial situations where cursor type and menu position were compatible (i.e. an upper-left cursor was used to point at the menu item in the upper-left direction and so on) against the averaged movement time for that particular menu position, regardless of cursor type . . . yielded consistent average improvements [in movement time]. . . for mouse input" (Po et al., 2005, p. 296). Refer to Chapter 2.2 for a detailed description of their work.

1.5.1 Hypothesis 1

NULL: Pointing movements with directional cursors (↖ ↗ ↙ ↘) aligned with specific axes of movements does not yield improved movement times and positioning performance consistent with those predicted by the theory of S-R compatibility.

ALTERNATIVE: Pointing movements with directional cursors aligned with specific axes of movements yields improved movement times and positioning performance consistent with those predicted by the theory of S-R compatibility.

1.5.2 Hypothesis 2

NULL: The orientation-neutral cursor (○) used in Po et al's experiments will not yield the best performance (movement time and positioning performance) when compared across a variety of movement directions to cursors that cue for movement in one specific direction (↖ ↗ ↙ ↘).

ALTERNATIVE: The orientation-neutral cursor (○) used in Po et al's experiments will yield the best performance (movement time and positioning performance) when compared across a variety of movement directions to cursors that cue for movement in one specific direction.

<u>Research Question (addressed by Hypothesis 3)</u>

2) Extending Po et al's mouse input potion of their research to compare six orientation-neutral cursor types (⊙ ○ × ⊗ + ⊕), is there one cursor design that performs better than the others? In other words, will one of the six selected cursor types show better results in movement time (faster) and/or positioning performance (achieves on average more accurate results clicking the target's center more precisely)?

1.5.3 Hypothesis 3

NULL: The augmented circle cursor (⊙) will not yield the best performance (as defined above) when compared to other orientation-neutral cursors (○ × ⊗ + ⊕).

ALTERNATIVE The augmented circle cursor (⊙) will yield the best performance when compared to other orientation-neutral cursors (○ × ⊗ + ⊕).

<u>Research Question (addressed by Hypothesis 4)</u>

3) Will the best performing orientation-neutral cursor yield the best results when compared to directional cursors? Only if hypothesis NULL 3 from above would be rejected, favoring the alternative hypothesis, the augmented circle cursor would be substituted in Po et al's initial experiment. Repeating the experiment under these conditions, would the augmented circle cursor still produce superior results compared to the four directional cursors?

1.5.4 Hypothesis 4

NULL: The best performing orientation-neutral cursor will not yield better performance when compared to the four directional cursors (↖ ↗ ↙ ↘).

ALTERNATIVE: The best performing orientation-neutral cursor will yield better performance when compared to the four directional cursors.

Research Question (addressed by Hypothesis 5)

4) Will the same results be obtained using the same experimental setup, and replacing all target menu circles with squares? Does the shape of a target have significant impact on the user's ability completing the same experiments conducted to address the first three questions and their stated hypotheses?

1.5.5 Hypothesis 5

NULL: Changing all target shapes from circles to squares will have no significant effect on the results.

ALTERNATIVE: Changing all target shapes from circles to squares will have significant effect on the results.

To test the hypotheses a carefully planned and well thought-out experiment was designed and implemented.

1.6 Thesis Organization

The remaining portion of this thesis is organized into five additional chapters: Chapter 2 provides an overview of related literature pertinent to S-R compatibility and other studies done on cursor design and their impact on movement time and positioning performance. Chapter 3 highlights the decisions made to implement the experimental design and steps taken to prepare for and conduct the experiments in this study including measurement procedures. Chapter 3 also briefly discusses variations of results obtained in this study as compared to the research study done by Po et al. (2005). Chapter 4 describes the procedures used in this research to replicate the mouse-input portion of Po et al's study. Also included in Chapter 4 are details about the six experiments and the methodology applied to them. Chapter 5 contains discussion of the five different hypotheses formalized for this specific study and the detailed results of each experiment and the method of recording and analyzing data gathered during the experiments and the overall results. Finally, Chapter 6 addresses conclusions drawn from this user study, and provides suggestions for future work.

CHAPTER 2 LITERATURE REVIEW

Other studies and relevant research on this topic was necessary. The following pertinent terms and research were reviewed.

2.1 Stimulus-Response Compatibility

In behavioral as well as in cognitive psychology, stimulus-response (S-R) theory is a well known and often used practice in various research areas (Fitts, and Seeger, 1954; Lippa, and Adam, 2001). For example, S-R theory could shed light into the phenomenon why certain commercials on television, in newspapers, magazines, etc. provide a stimulus that causes many consumers to buy the product without really needing it while other advertisements do not produce the same response.

In today's age of technology computers are used for almost everything in one's daily life. With the increased usage of and dependence on Graphical User Interfaces (GUI), the Human Computer Interaction (HCI) community is particularly interested in the compatibility of both stimulus and response, introducing a research area known as S-R compatibility. Understanding the compatibility between movement time and positioning performance will allow the software industry to design and develop more efficient GUIs. "Easy-to-use" software applications will make users more efficient in achieving their goals and reducing the frustration that often result in badly designed and inefficient GUIs.

The theory of S-R compatibility, applied to this research study, refers to the fact that the displayed visual stimulus (the cursor) should match the actual intended movement direction (response), which is illustrated in Figure 2.1. For example, target 2 (T2) is compatible with the arrow pointing in the upper right (UR) corner of the display. Following the same principle, T4 is compatible with the LR arrow, T6 shows compatibility with the LL arrow, and T8 is compatible with the UL arrow. This theory is of great importance due to the increasing number of computer programs that promise to accomplish every-day tasks more efficiently. Instead, "fancy looking" incompatible cursor designs with the presented GUI confuse the user and do not improve his or her productivity by achieving the intended goal of moving the cursor to the target more quickly – the cursor does not support the movement direction. This research study focuses on different cursor designs tested and compared against each other with respect to movement direction. The goal is to provide results that enable application and interaction designers to implement the most efficient cursor design for a given GUI.

2.2 Research conducted by Po, Fisher, and Booth (2005)

The research of Po et al. (2005) focuses on the influence of five different cursor representations (↖ ↗ ↙ ↘ ○) and three different pointing devices on tasks performed with a Graphical User Interface (GUI). They studied how the combination of cursor orientation and pointing device impacted the user's effectiveness as measured in time. This effectiveness, tested in their hypotheses, was influenced by the theory of stimulus-response (S-R) compatibility which refers

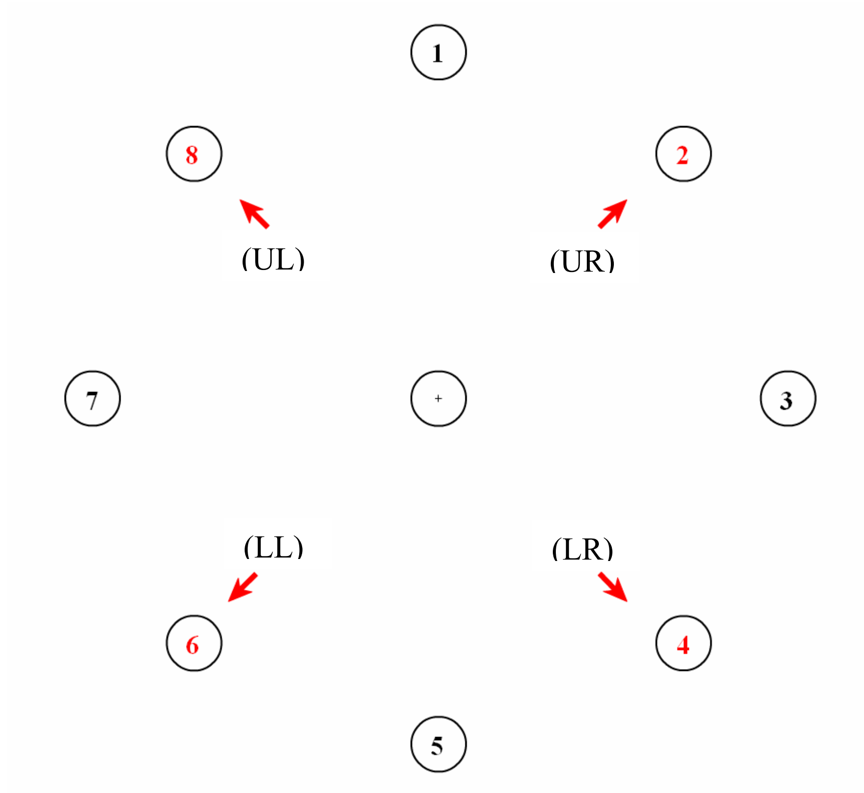


Figure 2.1 Directional cursor types and their compatible targets.

to the fact that the display visual stimulus (the cursor) should match the actual intended movement direction (response) and that there is as well some impact because of the type of input device. The cursor orientations considered were upper-left, upper-right, lower-left, lower-right, and an orientation-neutral circle (↖ ↗ ↙ ↘ ○). The pointing devices selected for their study were a Logitech optical mouse used with a PC, a Compaq Tablet PC with a pen, and a pointer in combination with a SMART Board 3000i (see Figures 2.2, 2.3, and 2.4). Figures 2.2.-2.4 are from "Comparing Cursor Orientations for Mouse, Pointer, and Pen Interaction," by Po, B. A., Fisher, B. D., and Booth, K. S., 2005, *Proceedings CHI 2005, ACM Press*, p. 293. Copyright 2005 by Po et al. Reprinted with permission of the author.

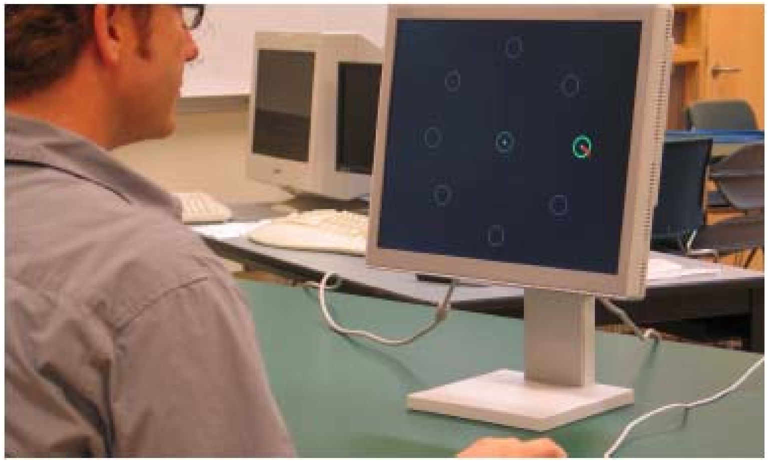


Figure 2.2 Mouse use with a PC.

Figure2.3 Tablet PC with a pen.

Figure 2.4 Pointer on a large screen.

Po et al. (2005) conducted a fully counterbalanced controlled user study with twelve subjects (nine females and three males) ranging in age from 18-34. All were right-handed and had normal or corrected to normal vision. The experimental design consisted of a circular menu selection task in which participants completed three blocks of 120 fully randomized selections (5 cursor orientations x 8 menu positions x 3 repetitions = 120). Each block used a different input device, thus, a total of 360 trials were completed by each participant. Each block consisted of moving a circular cursor to a highlighted centered circle target whereupon the cursor would change to one of five randomly chosen cursor designs and one of the eight circular menu positions would change color to indicate the next target. Participants were asked to complete each trial focusing on speed and accuracy. After completing each block, the cursor was reset to the circular orientation-neutral cursor. The participants took five-minute breaks between blocks resulting in a session that lasted 40 minutes.

Prior to beginning each block participants completed a minimum of 20 practice blocks presented in the same manner as the experimental trials. These practice blocks lasted until the subject completed the task as instructed.

Analyzing the collected data, movement time and positioning performance among the three input devices, Po et al. concluded that the results of their usability testing confirmed all three of their experimental hypotheses. These hypotheses were:

Hypothesis 1 – Considering only the arrowed cursor orientations, the movement times (speed) and positioning performances (accuracy) were affected by the directional cues of the cursor. Alignment with the direction of movement showed better results in both points of consideration, while non-alignment with the direction of movement slowed down the performance of the user. These results match predictions formulated by using the S-R compatibility theory.

Hypothesis 2 – Independent of the pointing device used, the orientation-neutral cursor showed the shortest averaged movement time. Compared to the other four cursor orientations, the largest difference in movement time was observed with the pointer. The mouse and pen input were very close together, but the pen still outperformed the mouse.

Hypothesis 3 – Each of the three input devices will have different affects on the test user's ability to perform the selections from the circular menu. It was predicted correctly that movement and positioning performance between pointer, mouse, and pen improves respectively. The biggest impact on performance decrease was observed with the pointer, the smallest impacts resulted from the pen, and the mouse was between both but much closer to the pen. These results were consistent with S-R compatibility but could also be partially explained by the performance characteristics of each of the devices.

2.3 Research conducted by Phillips, Meehan, and Triggs (2003)

In 2003, a study by Phillips, Meehan, and Triggs, titled "Effects of Cursor Orientation of Positioning Movements on Computer Screens", found that directional cursors used with a Graphical User Interface (GUI) include implicit directional cues that may not be compatible with desired axis of motion and may not afford the best cues for location. They concluded that compatible directional cursors are beneficial when a task requires the target to be hit accurately, but if speed of cursor placement is more important than accurate placement, an orientation-neutral cursor might be preferable.

Phillips et al. conducted a study with 12 participants with a mean age of 21.3 with all participants being right-handed. The task was performed on an Aridyne 486 IBM-compatible desktop computer with a 17-inch VGA monitor and a Microsoft two-button mouse. The directional cursors were arrows pointing to the upper left or upper right of the screen. Participants used the mouse to place a cursor in a starting position on either the left or right side of the screen and were (then) required to move the cursor to the right or left to three different sized circular targets. They were instructed to use the mouse to position the cursor in the starting location, as indicated by the computer. The computer sampled cursor location and prompted the experimenter when the cursor was in the starting location. To start the trial, the subjects clicked the mouse. Targets were then presented on the computer on the opposite side of the screen, to which the test candidate was instructed to move the cursor quickly and accurately. Trials terminated after the cursor entered the target.

Reaction time was defined as the duration of time from target presentation to onset of cursor movement, while *movement time* was defined as the interval of time from the beginning of cursor movement to the point in time when maximum displacement occurred. Cursor orientations (left or right), direction of movement (left or right), and target size (small, medium, large) were varied to produce 12 different conditions. Each subject performed 10 trials in each condition.

According to Phillips et al. (2003) "there were significant effects of experimental manipulations on the extent to which cursors overshot the target, these effects were not as impressive in the context of the long periods of time spent moving" (p. 383). There was a significant tendency for cursors to overshoot the target when moving to the right when compared with movements to the left. Phillips et al's study suggests that directional cursors may assist the initiation of movement when they point in directions compatible with desired direction of motion, but any benefits may not extend to the positioning of the cursor (the greater ease of response initiation actually detracts from cursor placement) and that speed is best achieved by using an orientation-neutral cursor design.

Results of this research study agree with the conclusions of Po et al. (2005), which also suggested that an orientation-neutral cursor provides a performance advantage when speed is of greater importance than positioning performance. Phillips et al. did not investigate additional cursor designs with the same behavior. Hence, this research study will consider six orientation-neutral cursors to find answers as to whether these cursor designs show differences with respect to movement time and/or positioning performance.

2.4 Research conducted by Callahan, Hopkins, Weiser, and Shneiderman (1988)

Callahan, Hopkins, Weiser, and Shneiderman (1988) conducted a menu evaluation study that compared the time efficiency of commonly used drop down menus in software applications versus a specially designed pie menu. Eight menu items, each representing a word, were positioned around a circle, with each menu item having the same distance to the circle's center. During each experiment, participants were asked to click menu items that matched a randomly selected word displayed to the participant on their pie menu as well as from a regular drop down menu. Analyzing and comparing the experimental data, Callahan et al. drew the conclusion that participants were more efficient selecting menu items from a pie menu opposed to a drop down menu used in most programs.

To more closely replicate the mouse-input portion conducted by Po et al. (2005), this experimental design also used a circular menu that is a modified version of Callahan et al's pie menu used in their menu evaluation task. Po et al. state that "the circular menu selection task was chosen both because it permits measurement of pointing performance along bivariate directions of movement and . . . [because it] shares similarities to a menu evaluation task conducted by Callahan, Hopkins, Weiser, and Shneiderman" (p. 293).

The research done by the three groups reviewed in this chapter influenced the implementation and execution of the experiments conducted in this study. However, every aspect of the experiment needed to be addressed first to make sure that best practices were applied to this user study. The design decisions that made the experiments feasible and experimentally rigorous are discussed in Chapter 3.

CHAPTER 3 EXPERIMENTAL DESIGN DECISIONS

Scientific research like this, involving an experimental design conducted on a specific population, requires thorough research and preparation. A number of key design decisions were made to ensure that the experiments in this study were both feasible and experimentally rigorous. These critical decisions are discussed in detail in this chapter.

3.1 Pilot Study

Pilot studies are a common practice in empirical user studies to identify, account for, and remove problems in the experimental design and/or environmental test set up. Four volunteer participants, three female and one male, representing an age range between 19-39 years, were used to conduct the pilot study for this experiment. Three of the four participants were undergraduate and graduate students and one volunteer was a faculty member from The University of Montana. All participants had advanced computer skills (15+ hours per week of general computer work) and normal/corrected-to-normal eyesight. They all were right-handed to avoid fluctuations in the results that might be caused by non-conformity of the subject's handedness. These pilot studies identified a number of problems with the initial experimental design, and resulted in the following modifications:

- The test script was modified to clarify the tasks that the participant was asked to complete.

- The mouse pad was removed during the experiment to avoid time delays when repositioning the mouse.
- A technical problem with mouse cursor movement was discovered and successfully resolved by correcting the ActionScript.
- An initial training session prior to the experiment was included so that participants could better understand and familiarize themselves with the tasks they were required to perform.

3.2 User Study

The formal experiment consisted of 12 participants, 8 males and 4 females, undergraduate and graduate students, from The University of Montana. All users were volunteers representing an age range between 18-30 years with a broad variety of academic majors. The selection criteria required all participants for this study to be the same as those used for Po et al. (2005) so that the results would be comparable (refer to Table 3.1 for a side-by-side comparison of the user population for both studies). The experiments were only conducted when each participant successfully passed the criteria requirements stated above by answering the five questions regarding each individual's age, computer skills, eyesight, condition, and right-handedness. If only one criterion did not match the student was excused from this research study.

Table 3.1 Comparing user population between this study and Po et al's study

	User Population	
	This Study	**Po et al. (2005)**
Female	4	9
Male	8	3
Age Range	18 - 30	18 - 34
Right-handed	yes	yes
normal/corrected-to-normal eyesight	yes	yes
University Students	yes	yes
Computer Skills (hrs/week)	15+	unknown
broad variety of academic majors	yes	yes

3.3 Training

Experimental designs often face the question whether training should be part of the preparation of each participant before performing the actual trials. It could be beneficial when training is provided at the beginning of each user's experiment session so that everyone has the same fundamental skills and understanding of the task/action sequence he or she will be required to perform. On the other hand, initial training may have an impact on the user's behavior at the beginning of the experiment, which might affect the data gathered and its subsequent analysis. Another disadvantage might be that training takes more time that could make the users tire more easily.

For this experimental design minimal training was provided at the beginning of each experimental session so that all participants had the same fundamental understanding of the action sequence he or she would be required to perform. Each participant was given an initial test session of 40 trials. This not only provided a chance for participants to practice, but it also allowed the opportunity to explain to each participant what data was being collected during the experiments while they familiarized themselves with the experiment tasks. The sequence of cursor types and the order in which the targets needed to be selected were identical for all participants.

3.4 Experimental Design

This research study contained six different experiments that were designed to evaluate and analyze 10 different cursor types – four directional and six orientation-neutral cursor designs. Experiment 1 (E1) was the replication of Po et al's (2005) mouse-input portion, while Experiment 2 (E2) through Experiment 6 (E6) were all extensions using a different target shape and evaluating five additional orientation-neutral cursor types. Due to differences in the design of the experiments they were separated into two phases. Phase 1 consisted of experiments E1 – E4 separated into two groups each consisting of two experiments, while Phase 2 included experiments E5 and E6. It is important to note that Phase 2 was dependent on the outcomes from Phase 1.

A key factor for fair comparison of the gathered data was the number of trials completed per experiment. Depending on the cursor types tested in an experiment, the total number of trials was either 120 or 144. Experiment 1 (E1) and Experiment 2 (E2) formed Group 1 (each with 120 trials) and Experiment 3 (E3) and Experiment 4 (E4) created Group 2 (each with 144 trials). As explained in detail in Chapter 5, the analysis of all data from E3 and E4 concluded that Phase 2, including E5 and E6, was not required to be executed. This is depicted in gray in Table 3.2 that shows an overview of all experiments and visually explains the division of the experiments.

Table 3.2 Overview of all experiments (E1-E6). E5 and E6 in Phase 2 were not conducted because the statistical analysis of E3 and E4 did not reveal one true cursor type that clearly outperformed any other, which was a necessary condition for both E5 and E6.

		Experiment Overview			
		Experiment	**Target Shape**	**Cursor Types**	**Number of Trials/Experiment**
Phase 1	Group 1	E1	○	↖ ↗ ↙ ↘ ○	120
Phase 1	Group 1	E2	□	↖ ↗ ↙ ↘ ○	120
Phase 1	Group 2	E3	○	⊙ ○ × ⊗ + ⊕	144
Phase 1	Group 2	E4	□	⊙ ○ × ⊗ + ⊕	144
Phase 2		E5	○	↖ ↗ ↙ ↘ ?[1]	120
Phase 2		E6	□	↖ ↗ ↙ ↘ ?[2]	120

[1]? = best performing cursor type from E3

[2]? = best performing cursor type from E4

3.5 Measurement Units

Two quantitative measures, total movement time and positioning performance (in all experiments defined as the degree of accuracy clicking the mouse cursor in the target's center) were the relevant data to be analyzed in this research study. Data that is presented in an appropriate measurement unit can be more easily analyzed and understood by others (see the following example for more details). Thus, it was crucial to find a measurement unit that would fulfill both requirements. To measure movement time, milliseconds were chosen as the measurement unit; to measure positioning performance, pixels were preferred over inches as the measurement unit to design and record all data. This enabled a high level of accuracy to capture and calculate data for both quantitative measures. To provide a better understanding how one pixel compares to one inch, consider the following example:

1 inch = 96 pixels or 1 pixel = 0.01042 inch (Anonymous, n.d.-b)

The resolution of a computer screen is measured in pixels, where each pixel represents a dot on the screen. For example, the resolution of the Liquid Crystal Display (LCD) screen used for the experiments was set to 1024 x 768 (1024 pixels in every row and 768 pixels in every column). Instead of using inches as measurement units, pixels provided a more accurate mean of positioning targets on the screen. Furthermore, the data recorded in pixels provided a more readable representation. For example, an x-coordinate of 3 pixels was easier to read than 0.03125 inch.

3.6 Random Numbers

In empirical research studies, the order in which the independent variables are presented to the participant is critical. Targets and cursor types that were presented to the participant must be unique to prevent order effects. A *random number generator* was used to create random sequences for all independent variables in the all experiments. To provide a counter-balanced experimental design the software package Mathematica® 5 was used to create unique sequences of experiments in which they were presented to each participant. For example, participant one (P1) started with Experiment 1 (E1), followed by Experiment 4 (E4), Experiment 2 (E2), and Experiment 3 (E3). P2's distinct sequence was: E3, E4, E1, and E2 and so forth until 12 unique sequences were established (see Figure 3.1 to see the distinct experiment sequences for P1-P12 created with Mathematica® 5). Flash® Pro 8 could be used to create such a sequence but unfortunately, it includes a *pseudo-random number generator*, which means that numbers generated are not truly random. Numbers are generated by an algorithm that is often based on one or more mathematical formulae. "Modern algorithms for generating them are so good that the numbers look exactly like they were really random. Pseudo-random numbers have the characteristic that they are *predictable,* meaning they can be predicted if you know where in the sequence the first number is taken" (Haahr, 1999).

Weisstein (n.d.) explains that

> "a random number is a number chosen as if by chance from some specified distribution such that selection of a large set of these numbers reproduces the underlying distribution. . . Computer-generated random numbers are sometimes called pseudorandom numbers, while the term "random" is reserved for the output of unpredictable physical processes. . . Most random number generators require specification of an initial number used as the starting point, which is known as a "seed."

Mathematica® 5 provided the best means for this experiment, thus, it was the best choice for this research study. "Permutations and subsets are the most basic combinatorial objects. `DiscreteMath`Combinatorica`` provides functions for constructing objects both randomly and deterministically. . ." (Mathematica® 5 built-in Help) Distinct sets of *Random Permutations* were created for each participant and each experiment ensuring that none of the 12 participants experienced the exact same sequence of experiments, cursor types, and targets during a user study.

```
<<DiscreteMath`Combinatorica`
 expNum = {E1, E2, E3, E4}
 {E1,E2,E3,E4}
 Table[ RandomPermutation[ expNum ], {12} ]
P1 {{E1,E4,E2,E3},     P7 {E2,E4,E1,E3},
P2 {E3,E4,E1,E2},      P8 {E1,E3,E4,E2},
P3 {E3,E1,E4,E2},      P9 {E3,E2,E1,E4},
P4 {E2,E4,E1,E3},      P10 {E4,E2,E3,E1},
P5 {E4,E3,E2,E1},      P11 {E4,E2,E1,E3},
P6 {E4,E1,E3,E2},      P12 {E2,E1,E3,E4}}
```

Figure 3.1 Distinct set of permutations created with Mathematica® 5 to establish experiment sequences for all 12 participants (P1-P12).

3.7 Significant Differences from Po et al.

Although every attempt was made to replicate the exact conditions of Po et al's experiment in E1, certain constraints necessitated some changes.

1) Po et al. used Java as the programming language of their choice while this experimental design utilized Macromedia's FLASH® Pro 8 and its ActionScript 2.0 language because of its visualization features. This decision had no significant impact on the results of this study.

2) The colors for all targets displayed on the screen were a little different because the application used in Po et al's study was not available to confirm the same colors. The photos in their publication, showing screenshots of the experiments, were the only source to use as a guide during this experimental design. The final design of this research study shows the same overall color scheme. When not highlighted, dark colored targets were displayed on a black background and changed to a brighter green color when highlighted indicating the destination for the participant. This design decision did not seem to have any significant impact on the experiment.

3) Po et al. required a minimum of 20 training trials or more, depending on the volunteer's performance. This replication (E1) and the extension (E2-E6) of their research work strictly forced all subjects to complete 40 trials to give no participant any additional learning advantages.

4) As mentioned in the discussion of Po et al's publication, their experiment exposed all participants more often to the circle shaped cursor because this cursor type was always used between all experimental trials, which might have lead to some unwanted learning affects. To eliminate the potential bias using the orientation-neutral circle cursor more often between trials when returning to the center target to initiate a new trial, experiments three and four (E3 and E4) in this study introduced a square shaped "neutral" cursor that was not used in any of the experiments as one of the tested cursor designs.

After careful consideration of all factors addressed in this chapter, an experiment was designed to compare both orientation-neutral and directional cursors against each other, measuring the differences in movement time and positioning performance. The mouse input portion of the study conducted by Po et al. was closely replicated. Differently designed orientation-neutral cursors were introduced into the study and a process to capture and measure movement time and positioning performance was developed. The methodology to conduct the experiment is explained in Chapter 4.

CHAPTER 4 EXPERIMENTAL METHOD

The methods and procedures used by Po et al (2005) in their research experiments were closely followed in this study.

4.1 Apparatus

The experiments for both the pilot group and user group were performed on a Dell Desktop computer with an Intel® Pentium® D CPU 3.40 GHz with dual core technology running Microsoft Windows XP Professional, using a 19" LCD flat-screen monitor with 1024 x 768 resolution, and an ATI Radeon X600 video card. A standard optical mouse served as user input. Figure 4.1 and Figure 4.2 show two photos displaying the apparatus and an experiment participant.

Figure 4.1 Apparatus used for all experiments.

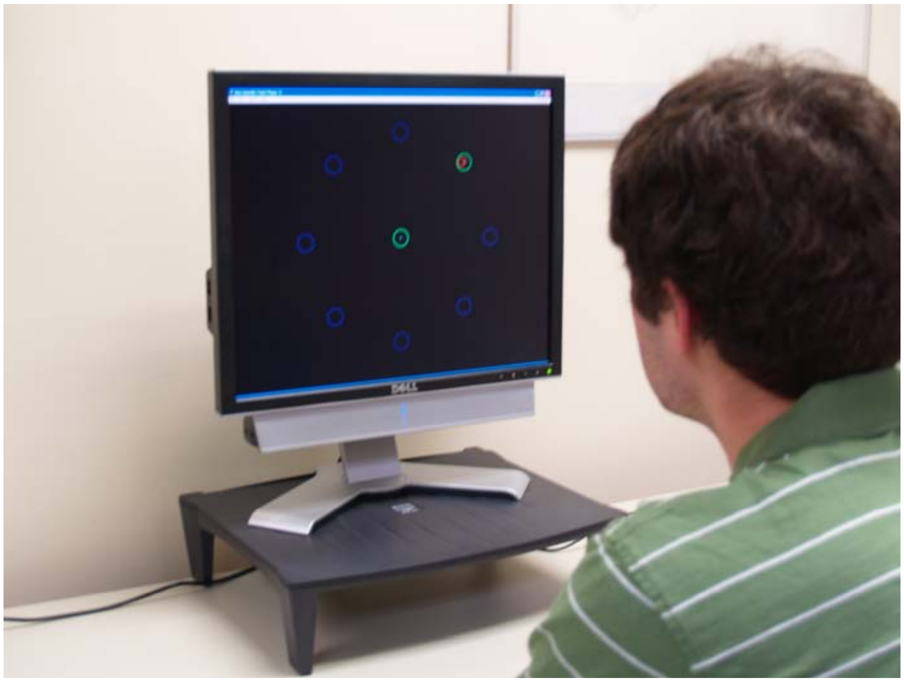


Figure 4.2 Apparatus with experiment participant.

4.2 The Experiment – Implementation Details

This research study utilized Macromedia's FLASH® Pro 8 with its ActionScript 2.0 language as a platform to replicate Po et al's (2005) experiment as closely as possible but using only the mouse input method. The screen presented to each user during each experiment is a modified version of Callahan, Hopkins, Weiser, and Shneiderman (1988) pie menu used in their menu evaluation task. Modifying Callahan et al's (1988) version, each experiment consisted of nine targets (60 x 60 pixels). Eight were arranged around one centered target on an imaginary outer circle. All targets were positioned in equal distances from the center target and the spaces between the targets on the outer circle were equal as well. To determine the exact position of all nine targets, geometric and trigonometric principles were applied. The position coordinates of each target were checked and if necessary adjusted to create symmetry between all targets.

All ten cursor types (32 x 32 pixels) examined in this research study were created in Macromedia's Flash® Pro 8. The four directional cursors and one orientation-neutral cursor (↖ ↗ ↙ ↘ ○) used in the replication of Po et al's experiment followed the same design used in their research study. Each arrow pointed in a 45-degree angle toward the corner of a display; arrows pointed to the upper left, upper right, lower left, and lower right.

4.2.1 Capturing and Recording Data

Two dependent variables were of primary interest for this empirical study and needed to be captured and recorded correctly in real-time. Variable 1 (movement time) was the time from when the user started the trial by clicking the center target until completion of the trial when the cursor was clicked within the boundaries of the highlighted target. A lesser time was considered as time improvement. Variable 2 (positioning performance) was the point within the target boundary where the user clicked indicating the completion of the trial. Positioning was measured as an x and y-coordinate. This was used to determine how close the user clicked to the exact center of the highlighted target. The best positioning performance was achieved when the user clicked exactly in the center of the target, recorded as $x = 0$ and $y = 0$.

In order to calculate the total movement time of each trial during each experiment, time was captured at the beginning and end of each trial. Calling ActionScript's built-in function getTimer( ) the number of milliseconds (ms) elapsed from the moment the flash file is executed is returned. Thus, the elapsed time (from trial start to trial end) was determined performing some simple arithmetic (Elapsed time = end time – start time).

Another useful built-in feature in Flash® Pro 8 is that "all Movieclips automatically receive notification of the *Key, Stage* and *Mouse* events automatically" (Flashguru, 2002). Thus, all targets rendered to the screen were movie clips permitting the capture and recording of the exact mouse coordinates (using the mouse class properties *_xmous* and *_ymous*) within the boundary of a target, where its center is always defined as the origin (x = y = 0). This greatly simplified recording mouse coordinates during the experiment.

The following data, shown in Table 4.1, was captured and written to a comma separated value (csv) file and stored on the local hard drive in real-time for each participant's experiment:

- Column A: "Target" – which of the eight targets was clicked during each trial (clockwise, starting at 12 o'clock, numbered T1-T8, see Figure 4.3)
- Column B: "Target Count" – how often each target was clicked during each experiment. This should total 3 for each target because each target was required to be clicked three times by each cursor type
- Column C: "Rel xPos" – relative x-position to target center (x = 0)
- Column D: "Rel yPos" – relative y-position to target center (y = 0)

- Column E: "Time Elapsed" – time measured in milliseconds from start to finish for each trial
- Column F: "Cursor Type" – which of the ten different cursors used during each trial. Cursor type abbreviation: C = circle shaped, LL = arrow pointing towards the lower left corner, LR = arrow pointing towards the lower right corner, UL = arrow pointing towards the upper left corner, UR = arrow pointing towards the upper right corner.

Table 4.1 Snapshot of data file recorded for Participant 1 labeled "User Study (P1-E1)_ActivityLog.csv"

	A	B	C	D	E	F
1	Collected Data - User Study					
2	Participant 1: Tue Oct 24 12:40:33 GMT-0600 2006					
3						
4	Target	Target Count	Rel xPos	Rel yPos	Time Elapsed	Cursor Type
5	T7	1	-1	0	1408	LL
6	T8	1	0	1	1376	LR
7	T1	1	2	2	1424	LR
8	T3	1	-3	2	1256	UR
9	T4	1	4	-1	1544	LL
10	T2	1	0	0	1120	LL
11	T5	1	1	2	1320	LR
12	T6	1	1	1	1272	UL
13	T2	2	1	3	1536	UR
14	T6	2	0	0	1289	UL
15	T1	2	2	-4	1191	LL
16	T5	2	3	1	1775	UR
17	T4	2	0	0	1207	LR
18	T7	2	1	0	1128	LR

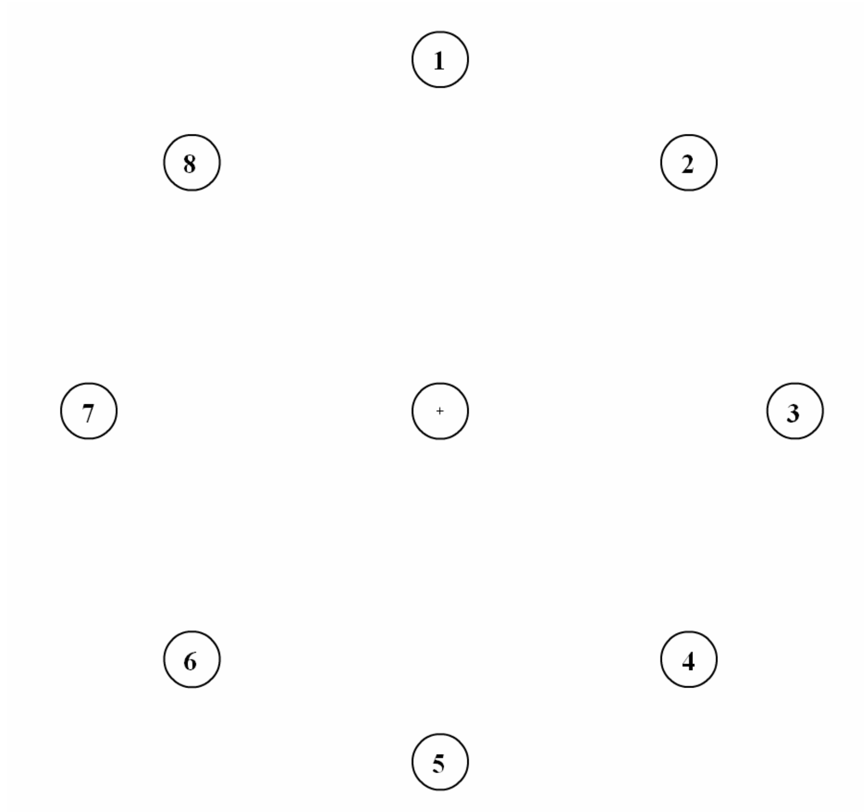


Figure 4.3 Targets and their associated numbers (T1-T8).

4.2.2 Creating the Flow of the Experiments

The distinct permutation sets for all experiments were computed with Mathematica® 5 and the data output formatted to permit Flash® Pro 8 to read it into two arrays, one holding the distinct order of targets and another specifying the sequence of cursor types. Both arrays controlled the order in which targets and cursor shapes were presented to the participant.

According to the sequence computed in Mathematica® 5, which determined the order in which the experiments were presented to the participants, the experiments were manually started during the five-minute break taken by each participant between experiments. For each participant six flash applications, one for each experiment, were implemented. A total of 72 files were created for this user study, each containing a distinct experiment sequence for all targets and cursor types. One universally usable training session application was created, which started each participant's experiment sequence.

For each participant, four separate comma separated value (csv) files were created, each containing the complete data for E1 to E4 respectively, resulting in a total of 6,336 records.

4.3. Procedure/Experiment Method

A tightly controlled test environment was chosen to conduct this empirical user study. The same conditions existed for every participant. All participants performed the experiments in room SS415, the Human-Computer Interaction (HCI) Lab located in the Department of Computer Science at The University of Montana, using the same desktop machine under the same lighting conditions. This minimized the possibility that the data collected during the experiments might have been affected by changing test environments. A controlled user study was designed and applied to the extended research of Po et al's within-subjects experimental design as closely as possible. According to Martin (2004), experimental designs "can expose each individual to only one level of the independent variable [between-subject design] or you can expose each individual to all levels [within-subject design]." In a "within-subject design . . . the independent variable is manipulated within a single subject, or participant." Martin (p. 150) Therefore, within-subject designs allow fewer people to conduct the experiments Martin also states that this design is beneficial when the participant pool meeting the requirements for a study is limited or the number of qualified participants in general is restricted. However, this design also includes the risk of order effect. One form of order effect is known as transferred learning. Martin describes this phenomenon the following way:

> The basic problem is that once participants are exposed to one level of the independent variable, there is no way to change them back into the individuals they were before being exposed. The exposure has done something irreversible, so we can no longer treat them as pure, uncontaminated, and naïve. Because the way participants are changed depends on the order in which they are exposed to the levels of independent variable, these are called order effects. An **order effect** in a within-subject experiment occurs when the behavior resulting from the level of the independent variable depends upon the order in which that level was presented. (p. 157)

According to Martin, counterbalancing minimizes the effect of transferred learning. This means that every user is exposed to the levels of independent variables such as X and Y in alternating order (i.e., participant 1: XY, participant 2: YX, participant 3: XY, and so forth).

All independent variables (cursor orientation/shape and destination target) were controlled by randomizing their order. Moreover, dependent variables are the ones that will be measured and recorded during the experiment (movement time and positioning performance). Additionally, to more closely replicate the experiment performed by Po et al., red cursors on a black background and dark blue targets were used while the target to be highlighted turned to a distinctive (neon green) color. The experimental design also used the circular menu that is a modified version of Callahan, Hopkins, Weiser, and Shneiderman (1988) pie menu used in their menu evaluation task.

During this study, all participants completed four experiments with 120 or 144 trials, depending on the experiment conducted (see Table 3.2). A trial was initiated by moving a "neutral" cursor to the highlighted centered circle target where the cursor would change to a randomly chosen design. Next, one of the eight targets would change color and display a small crosshair in its center to indicate the target to which the cursor was to be moved. Finally, the target returned to its default state after a trial was completed when clicked within its boundary and the cursor was reset to the neutral cursor. Note, that Po et al. defined the circular shaped cursor as "neutral" and was used only in E1 and E2. The extensions to their work, implemented in E3 and E4, introduced a square shaped cursor to reduce the transferred learning affect.

At the beginning of each trial, the subject moved the neutral cursor to the highlighted center circle. Once clicked, the cursor changed randomly to one of the five cursor orientations and one of the eight outer circles was highlighted. The participants were instructed to move the cursor to the highlighted target as quickly and accurately as possible. The trials were repeated randomly until each of the five cursor orientations were used on each of the eight outer circles a total of three times (5 cursor orientations x 8 outer circles x 3 repetitions = 120 trials; using the same formula, experiments that tested the six orientation-neutral cursor types required 140 trials).

Each experiment was manually started after the initial training session and during the five minute breaks between experiments. Experiments 2 to 6 were formatted and carried out in the same manner as Experiment 1 using the experiment specific set of cursor types, neutral cursor, and target shapes. As shown in Table 3.2 in Chapter 3.5, E5 and E6 were never conducted because the statistical analysis of the previous two experiments (E3 and E4) did not reveal one true cursor type that clearly outperformed any other, which was a necessary condition for both E5 and E6. Figure 4.4 shows a typical sequence of events in a single trial from Experiment 1. For display purposes the black color of the background and the colored targets are not shown as used in the actual experiment. For the same purpose arrows have been added to indicate direction of movement of cursor. a) Participant moves a "neutral" cursor to center target; b) Mouse is clicked (trial time starts recording) and one of the randomly selected cursors appeared and simultaneously one of eight outer targets was highlighted; c) User moves selected cursor from center target to the highlighted target and clicks mouse (trial time stops recording), which removes the highlighted color and completes this trial; d) To initiate a new trial, the subject moves the "neutral" cursor back to center target where the mouse is clicked to initiate the next trial, repeating steps b) through d) until the experiment is completed. Identical to Po et al. (2005), all participants are instructed to emphasize speed and accuracy.

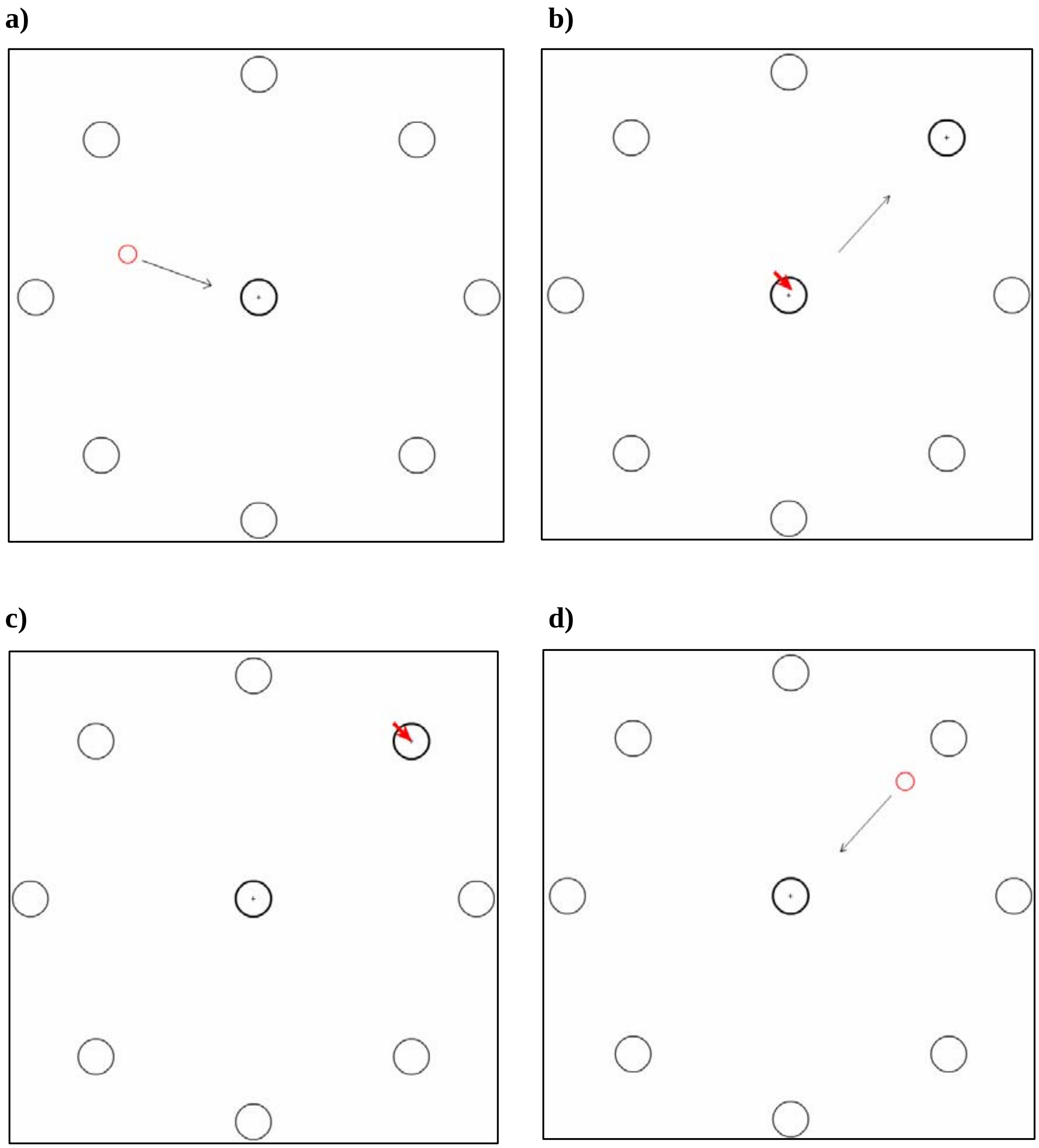


Figure 4.4 Illustration of a typical trial of Experiment 1 (the same format is used in all other experiments but with different cursor orientations and target shapes).

4.4 Experiments

The following experiments were designed to find answers to the research questions posed in Chapter 1.3 and to address whether the hypotheses statements would be retained or rejected.

4.4.1 Experiment 1 (120 trials) – Four directional cursors (↖ ↗ ↙ ↘), one orientation-neutral cursor (○), and <u>circular</u> targets (Hypotheses 1 and 2):

<u>Research Question</u>

Can the results of the mouse and cursor orientation portion of the experiment conducted by Po et al. (2005) be replicated?

This experiment replicated the mouse input portion of Po et al's experiment. This setup tested whether the collected and analyzed data would result in similar conclusions suggested by Po et al. Figure 4.5 shows a typical example of this experiment.

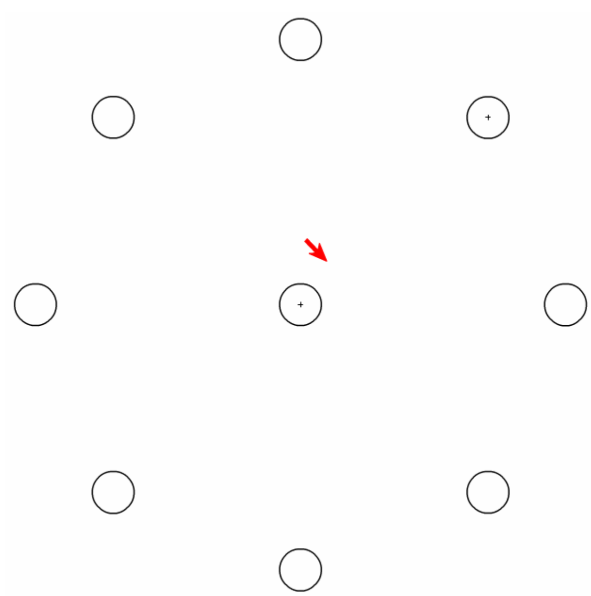


Figure 4.5 Circular targets and a directional cursor tested in Experiment 1.

4.4.2 Experiment 2 (120 trials) – Four directional cursors (↖ ↗ ↙ ↘), one orientation-neutral cursor (○), and <u>square</u> targets (Hypotheses 1, 2, and 5):

<u>Research Question</u>

Using the same experimental setup and extending this research by replacing all target menu circles with squares, will the same results be obtained? In other words, does the shape of a target have significant impact on the user's ability completing this experiment compared to Experiment 1?

This experiment was designed to examine whether movement time, positioning performance, and/or S-R compatibility were significantly impacted by a different shaped target, using four directional and one circle shaped cursor. Figure 4.6 demonstrates a typical example of this experiment.

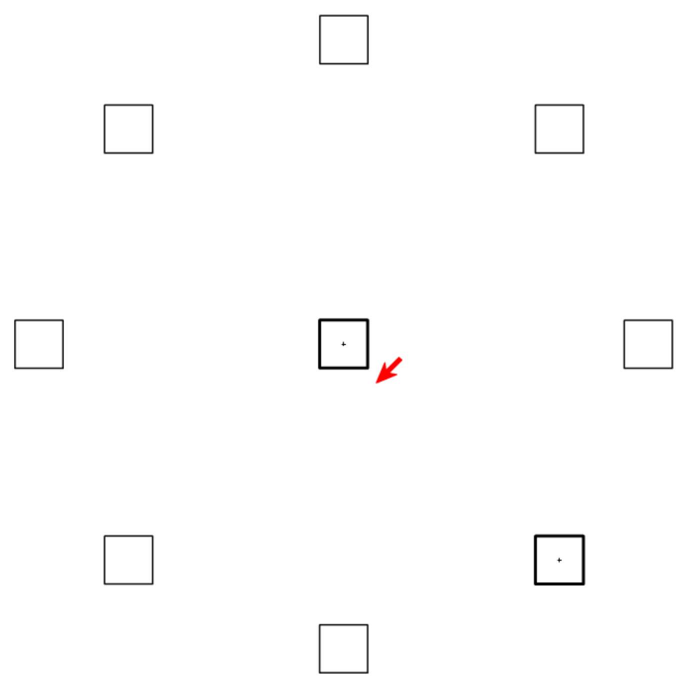


Figure 4.6 Square targets and a directional cursor tested in Experiment 2.

4.4.3 Experiment 3 (144 trials) – Six orientation-neutral cursors (⊙ ◯ × ⊗ + ⊕) and <u>circular</u> targets (Hypothesis 3):

<u>Research Question</u>

Extending this research to compare six orientation-neutral cursor types, is there one cursor design (⊙ ◯ × ⊗ + ⊕) that performs better than the others?

In this experiment a total of six orientation-neutral cursors were evaluated. The goal of this experiment was to determine whether the circular shaped cursor (◯) used in Po et al's study is the most efficient cursor compared to the other five orientation-neutral cursors.

Additionally, the circular shaped neutral cursor displayed after each trial was completed was replaced with a square shaped (☐) neutral cursor to prevent any possible learning effects between trials. Po et al. used a plain circular shaped cursor type that was also used in the measured trials and to some degree caused unwanted learning effect of that particular cursor type. All participants used this neutral cursor to return to the center target initiating the next trial, gaining additional practice. This would likely be reflected in an improved performance of that cursor type when chosen in a measured trial. The square shaped cursor is not one of the six tested orientation-neutral cursor types in this and the following experiment. Consequently, none of tested cursor types received any additional practice time between trials. Figure 4.7 shows a typical example of this experiment.

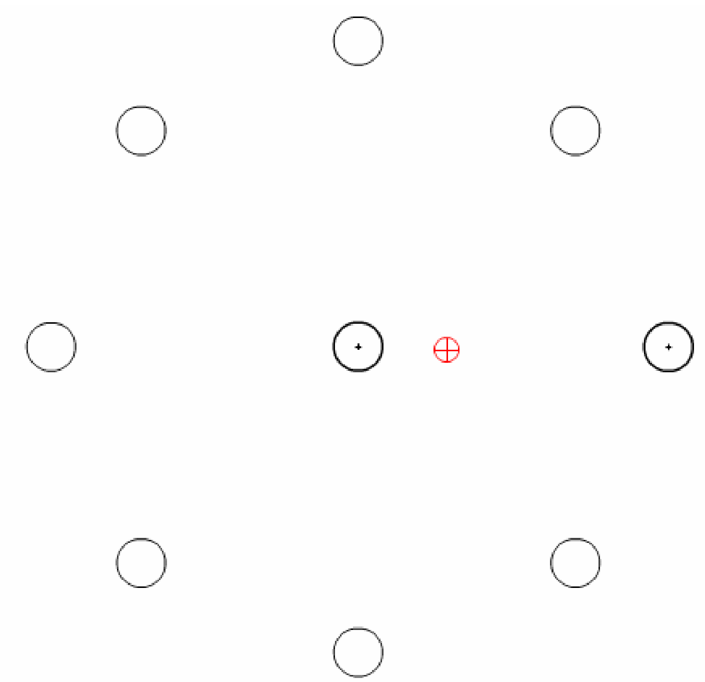


Figure 4.7 Circular targets and an orientation-neutral cursor tested in Experiment 3.

4.4.4 Experiment 4 (144 trials) – Six orientation-neutral cursors (⊙○×⊗+⊕) and <u>square</u> targets (Hypotheses 3 and 5):

<u>Research Question</u>

Using the same experimental setup and extending this research by replacing all target menu circles with squares, will the same results be obtained? In other words, does the shape of a target have significant impact on the user's ability to complete this experiment compared to Experiment 3?

This experiment was designed to examine whether a different shaped target had significant impact on the efficiency of movement time, positioning performance, and S-R compatibility of the selected orientation-neutral cursor types. To prevent any learning effects between trials for the same reasons presented in

Experiment 3 the circle shaped neutral cursor was replaced with a square. For the same reason mentioned in Experiment 3, the circle shaped neutral cursor was replaced by a square shaped cursor. Refer to Figure 4.8 to see a typical example of this experiment.

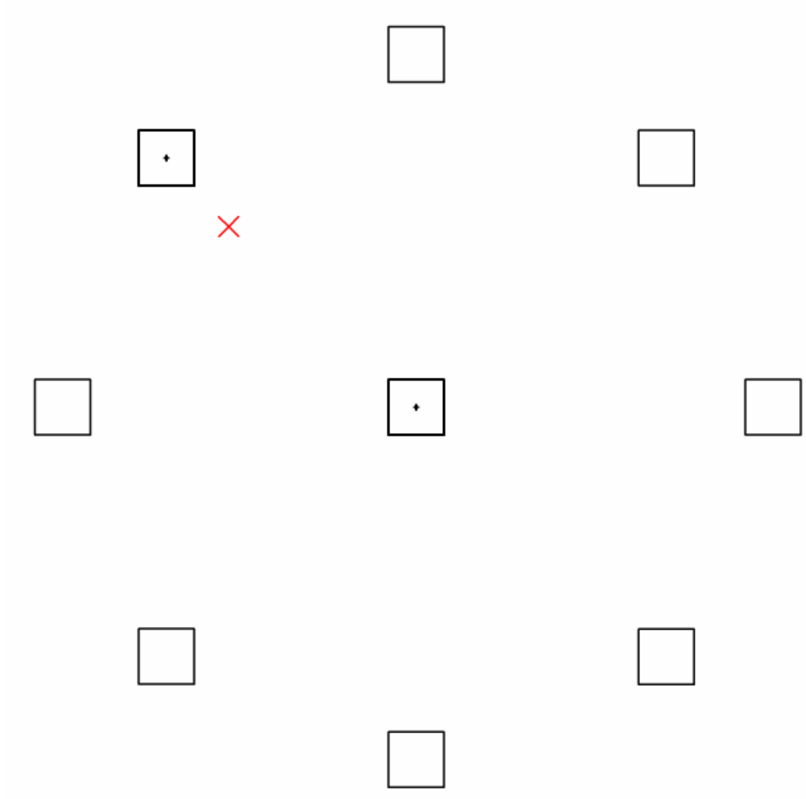


Figure 4.8 Square targets and an orientation-neutral cursor tested in Experiment 4.

4.4.5 Experiment 5 (120 trials) – Four directional cursors (↖ ↗ ↙ ↘), the overall best performing orientation-neutral cursor, and circular targets (Hypothesis 4):

Research Question

Will the best performing orientation-neutral cursor yield the best results when compared to directional cursors?

This experiment was to be conducted only if the results of E4 show that the plain circle cursor is not determined to have the best performance compared to the other five the orientation-neutral cursors. In that case, E1 was to have been repeated using the same four directional cursor orientations plus the best performing orientation-neutral cursor in E3 with circle shaped targets. Since results of E3 did not reveal one true cursor type that clearly outperformed any other, E5 was never conducted.

4.4.6 Experiment 6 (120 trials) – Four directional cursors (↖ ↗ ↙ ↘), the overall best performing orientation-neutral cursor, and square targets (Hypotheses 4 and 5):

Research Question

This experiment was to be conducted only if the results of E4 show that the plain circle cursor was not determined to have the best performance compared to the other five the orientation-neutral cursors. In that case, E2 was to have been repeated using the same four directional cursor orientations plus the best performing orientation-neutral cursor in E4 with square shaped targets. Since results of E4 did not reveal one true cursor type that clearly outperformed any other, E6 was never conducted.

A total of six experiments were designed for implementation of this study. However, only four experiments were actually completed since E5 and E6 were to be conducted dependent of the results of E3 and E4 (none of them revealed one cursor type that clearly outperformed any other). The experiments used the methodology of that used by Po et al (2005) as closely as possible. The results of each experiment were recorded and analyzed as indicated in this chapter. The analysis tests applied and the results of the experiments as well as other findings are included in Chapter 5.

CHAPTER 5 RESULTS

Statistical tests appropriate for this experimental design will present scientifically valid and useful interpretations of the data to the research community. The analysis and findings are described in this chapter.

5.1 Statistical Analysis Tests Applied

The statistical software package SPSS Graduate Pack 14.0 for Windows® was used for this experiment. Two-way and three-way Univariate Analysis of Variance (ANOVA) tests were used to analyze the data. In addition, descriptive statistics provided useful summaries of the data gathered. A Univariate Analysis of Variance (ANOVA) "can perform an analysis of variance for factorial designs. For example, a simple factorial design can be used to test whether a person's household income and job satisfaction affect the number of years with the current employer." SPSS 14.0 Brief Guide (Additional Statistical Procedures, p. 235) Applied to this study an ANOVA test determines whether cursor type, movement direction, and target shape affect movement time, positioning performance, and S-R compatibility. Descriptive statistics can be used to generate summaries of individual variables displayed in frequency tables. For example, frequency distributions of cursor types and selected targets provided an easy way to check whether all data recorded in the experiments was complete. This was particularly important during the pilot study in order to ensure that all data pertinent to the analysis was recorded but also to check for missing or invalid data in the user study.

5.2 Data Collection

As a reminder, this experimental user study focused on measuring two dependent variables for each trial: (1) movement time measured in milliseconds (ms) and (2) positioning performance (accuracy) measured in pixels. Movement time was calculated from the (first) click on the center target to the (second) click within the boundaries on one of one of the eight targets on the circular menu located around the center target. The highest rate of accuracy was achieved when the study participant left-mouse-clicked the current cursor type exactly in the center of the highlighted target. A precise click in the center was recorded as a set of coordinates (x = 0, y = 0). Any mouse click deviating from the target's center was recorded with its positive and negative coordinates. For example, if the participant left-mouse clicked in the upper left quadrant of the target both the x and y coordinates had negative values. Clicking the target in the upper right quadrant resulted in values of a positive x-coordinate and a negative y-coordinate. A click in the target's lower right quadrant results in positive values in both coordinates. Lastly, a click within the target's lower left quadrant lead to positive x-coordinate and negative y-coordinate values. Figure 5.1 shows a graph displaying the range for each coordinate. Each time a participant completed a trial (i.e., a click in center target followed by a click in highlighted target). These two measurements were written dynamically to a comma separated values (csv) file.

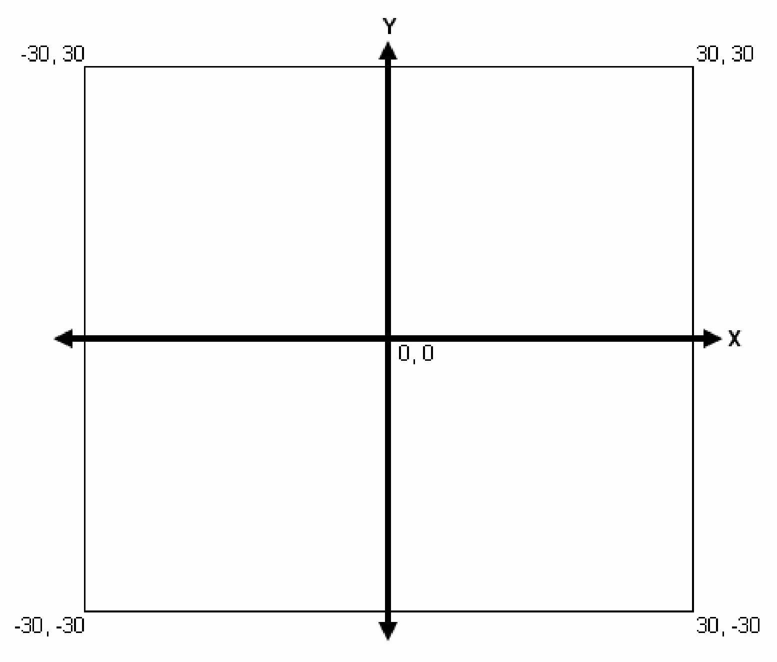


Figure 5.1 Coordinate range used to measure positioning performance. The coordinates (0, 0) indicate the center of the target.

Excel was used to compute the positioning performance (*accuracy*) for all trials. Accuracy was defined as the distance between the center of the target and the point where the cursor type was clicked. This was achieved by applying Pythagorean's Theorem (see Equation 5.1). Given any right triangle with sides *a*, *b*, and *c*, it states

$$c^2 = a^2 + b^2$$
$$c = \sqrt{a^2 + b^2}$$

Equation 5.1 Pythagorean Theorem

Variable *c* represents the distance between the two points with units measured in pixels and serves as a measurement to compare accuracy within this study.

For example, the recorded data for a trial performed by Participant 1 (P1) in Experiment 1 (E1) clicking on target 1 (T1) resulted in an x-position (xPos) of -1 and a y-position (yPos) of 4. Hence, variable a = -1 and variable b = 4. Solving for variable c in Equation 1 calculated c = 4.123. The data for this example can be seen in Row 4 of Table 5.1, which shows an Excel data table recorded during an experiment. A visualization of these coordinates is illustrated in Figure 5.2. P1 indicates the center of the target and P2 represents the point where the participant clicked in the trial. The solid red line, labeled *c,* between the P1 and P2 represents the distance while the dotted black lines, labeled *a* and *c,* correspond to the other two sides of the right triangle. The information recorded and prepared in Excel was imported to and analyzed in SPSS Graduate Pack (Version 14) [Computer Software].

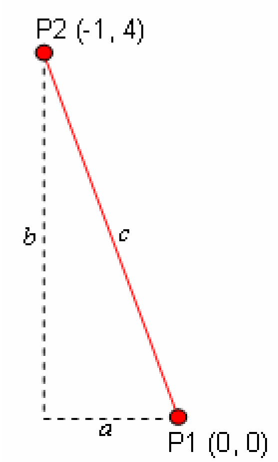


Figure 5.2 Applying the Pythagorean Theorem to calculate the distance between target center and actual mouse click.

5.2.1 Precautions Taken for Accuracy

Fourty-eight comma separated value (csv) files were generated during this entire experiment, one for each of the 12 participant's experiments 1 – 4. Each file was checked for missing or invalid data entries by sorting the data file by fields. For example, the data was sorted first by the field 'Target' and then by 'Cursor Type'. If the collected data was complete, each cursor type was listed exactly three times within the 15 records sorted together for that particular target number. During an experiment, each target was to be clicked exactly three times with each cursor, shown in Rows 17–31 (red circles) of Table 5.1. A check of all files using this method ensured complete data.

The accuracy of the data imported from Excel to SPSS Graduate Pack (Version 14.0) [Computer Software] was independently verified by two people, comparing a printout from Excel and SPSS. Additionally, the summary tables in the descriptive statistics produced with SPSS confirmed completeness of the records. A total of 6,336 trials were conducted and correctly recorded.

5.3 Results

The results of this study contain comparisons of movement time and positioning performance. First, by replicating the mouse-input portion of Po et al's (2005) study and, secondly extending their work with five additional orientation-

Table 5.1 Snapshot of Excel table sorted by Target and Cursor Type

	A	B	C	D	E	F	G	H	I
1	Target	xPos	yPos	Elapsed Time	Cursor Type	Accuracy	Experiment	Target Shape	Participant
2	T1	2	0	776	C	2	E1	Circular	P1
3	T1	4	0	1616	C	4	E1	Circular	P1
4	T1	-1	4	1352	C	4.123	E1	Circular	P1
5	T1	2	-4	1191	LL	4.472	E1	Circular	P1
6	T1	-1	3	1192	LL	3.162	E1	Circular	P1
7	T1	2	-2	1336	LL	2.828	E1	Circular	P1
8	T1	2	2	1424	LR	2.828	E1	Circular	P1
9	T1	-1	1	1160	LR	1.414	E1	Circular	P1
10	T1	-1	-4.05	1432	LR	4.172	E1	Circular	P1
11	T1	-4	2	1447	UL	4.472	E1	Circular	P1
12	T1	0	0	1592	UL	0	E1	Circular	P1
13	T1	-2	5	1159	UL	5.385	E1	Circular	P1
14	T1	-2	-1	1419	UR	2.236	E1	Circular	P1
15	T1	-2	5	1328	UR	5.385	E1	Circular	P1
16	T1	1	-2.05	1465	UR	2.281	E1	Circular	P1
17	T2	-5	0	864	C	5	E1	Circular	P1
18	T2	-3	5.05	1073	C	5.874	E1	Circular	P1
19	T2	2	2	1197	C	2.828	E1	Circular	P1
20	T2	0	0	1120	LL	0	E1	Circular	P1
21	T2	1	2	1231	LL	2.236	E1	Circular	P1
22	T2	-4	1	1151	LL	4.123	E1	Circular	P1
23	T2	1	1	1336	LR	1.414	E1	Circular	P1
24	T2	-2	3	1199	LR	3.606	E1	Circular	P1
25	T2	0	0	1320	LR	0	E1	Circular	P1
26	T2	-7	6.05	1035	UL	9.252	E1	Circular	P1
27	T2	0	3	960	UL	3	E1	Circular	P1
28	T2	-16	5	800	UL	16.763	E1	Circular	P1
29	T2	1	3	1536	UR	3.162	E1	Circular	P1
30	T2	-2	1	1143	UR	2.236	E1	Circular	P1
31	T2	-1	0	1168	UR	1	E1	Circular	P1
32	T3	2	0	1464	C	2	E1	Circular	P1
33	T3	-1	1	976	C	1.414	E1	Circular	P1
34	T3	2	-1	1303	C	2.236	E1	Circular	P1
35	T3	0	3	1278	LL	3	E1	Circular	P1
36	T3	2	1	[illegible]	LL	2.236	E1	Circular	P1

neutral cursors. The details and findings of each experiment, E1-E4, are contained in the following sections.

5.3.1 Hypothesis 1

Hypothesis 1 addressed the research question whether the results of the mouse and cursor orientation portion of the experiment conducted by Po et al. can be replicated. To find an answer, experiment one (E1) was conducted to test the effects of S-R compatibility between a target and cursor that aligned with specific axis of movement. E1 replicated Po et al's mouse-input portion. As stated previously, this hypothesis was formalized to test the following statements:

> NULL: Pointing movements with directional cursors (↖ ↗ ↙ ↘) aligned with specific axes of movements does not yield improved movement times and positioning performance consistent with those predicted by the theory of S-R compatibility.

> ALTERNATIVE: Pointing movements with directional cursors aligned with specific axes of movements yield improved movement times and positioning performance consistent with those predicted by the theory of S-R compatibility.

Using SPSS to aggregate and graph the data collected in this experiment with respect to positioning performance (accuracy) and movement time (speed) provided detailed insight about S-R compatibility between the two factors of interest (targets T2, T4, T6, and T8 and their compatible directional cursor UR, LR, LL, and UL respectively). For experiment one (E1), the ANOVA revealed main effects for target and participant. They suggest that movement time and positioning performance are influenced by the position of target that is highlighted on the circular menu [Movement time: $F(7, 77) = 4.376$, $p < 0.001$; positioning performance: $F(7, 77) = 2.199$, $p = 0.043$] and that some participants show better performances than others [Movement time: $F(11, 41.509) = 73.259$, $p < 0.001$; positioning performance: $F(11, 23.594) = 27.877$, $p < 0.001$]. There was also a main effect for the cursor type's movement time (speed) that suggests that some cursor types are better than others [$F(4, 44) = 5.389$, $p = 0.001$]. On the other hand, the cursor type's positioning performance showed no main effect [$F(4, 44) = 0.981$, $p = 0.428$], suggesting that accuracy is not impacted by the cursor type that is selected. Although there were some main effects, two-way ANOVAs between cursor type and target [Movement time: $F(28, 308) = 0.998$, $p = 0.472$; positioning performance: $F(28, 308) = 0.860$, $p = 0.674$] and between target and participant [Movement time: $F(77, 308) = 1.146$, $p = 0.212$; positioning performance: $F(77, 308) = 0.708$, $p = 0.965$] found no significant interactions. Combined with the results discussed above, Figure 5.3 shows a visual representation of the recorded and analyzed data from E1. All directional cursor types were analyzed for each compatible target with respect to the "Mean Movement Performance". The arrows added to the graph indicate the cursor type that is compatible with that target. Improved positioning performance, measured in pixels, was indicated when the symbol representing the arrow that aligned with the target had lowest positioning performance values, where lower values meant a higher degree of accuracy. In E1 only target two (T2) recorded an improved positioning performance. Similar to Figure 5.3 the data graphed in Figure 5.4 displays all directional cursor types analyzed for each compatible target with respect to the "Mean Movement Time". The arrows also indicate the cursor type that is compatible with that target. Like in Figure 5.3, improved mean movement time, measured in milliseconds, was indicated when the symbol representing the arrow aligning with the target had lowest time movement values, where lower values meant faster execution. In E1 only target eight (T8) recorded a movement time improvement.

These results suggested accepting the null hypothesis. Improved movement times and positioning performance consistent with those predicted by the theory of S-R compatibility could not be established in this experiment. E1, replicating the mouse-input portion, did not agree with the results found by Po et al. (2005).

5.3.2 Hypothesis 2

Hypothesis 2 also addressed the research question finding out whether the results of the mouse and cursor orientation portion of the experiment conducted by Po et al. can be replicated. Experiment one (E1) also focused on the orientation-neutral cursor (○) selected by Po et al. The hypothesis tested whether this non-directional cursor type, compared to the four directional cursors, showed better movement performances, based on time and precision. As stated previously, this hypothesis was formalized to test the following statements:

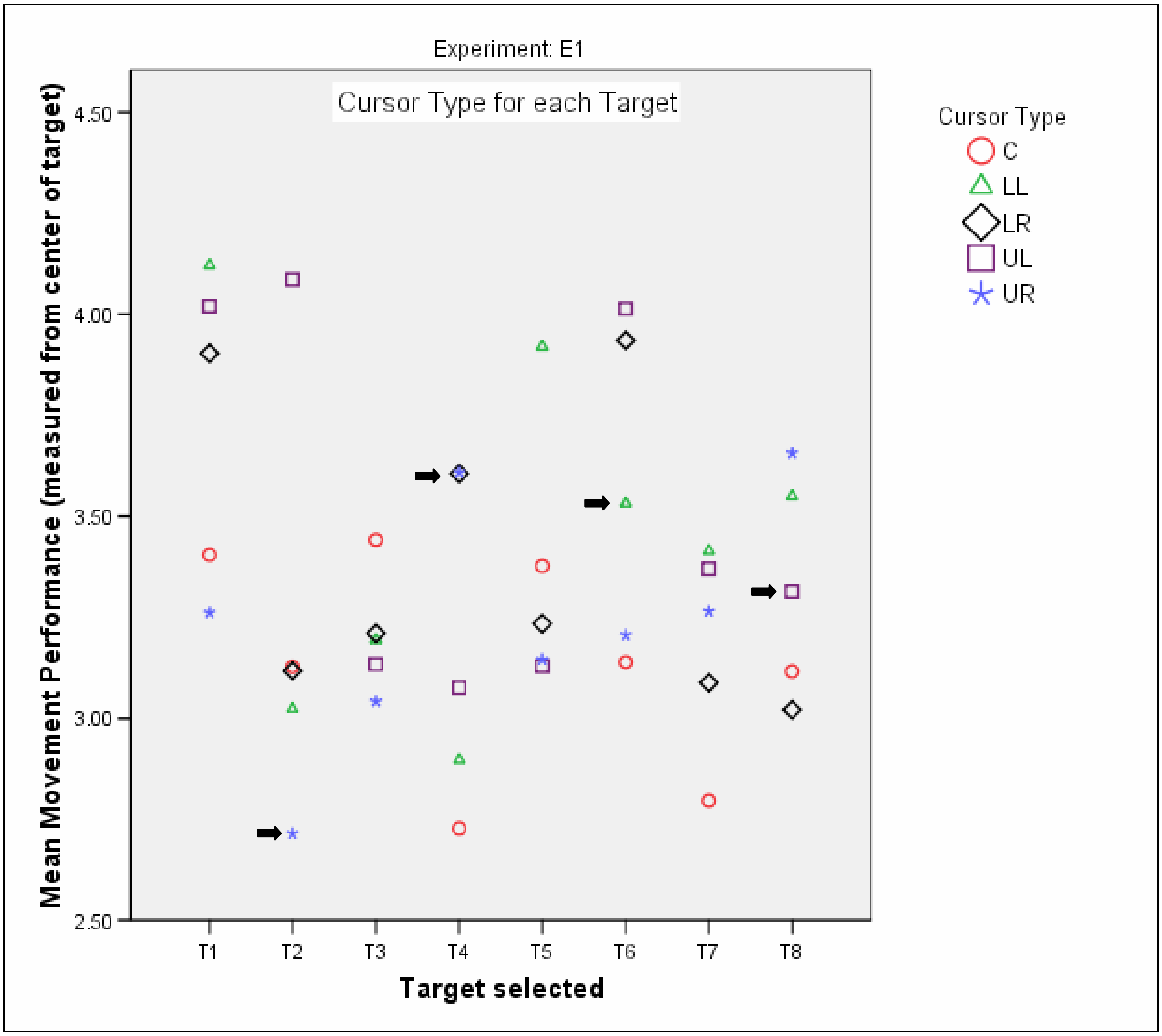


Figure 5.3 Experiment 1: Directional cursors analyzed for each compatible target with respect to the "Mean Movement Performance".

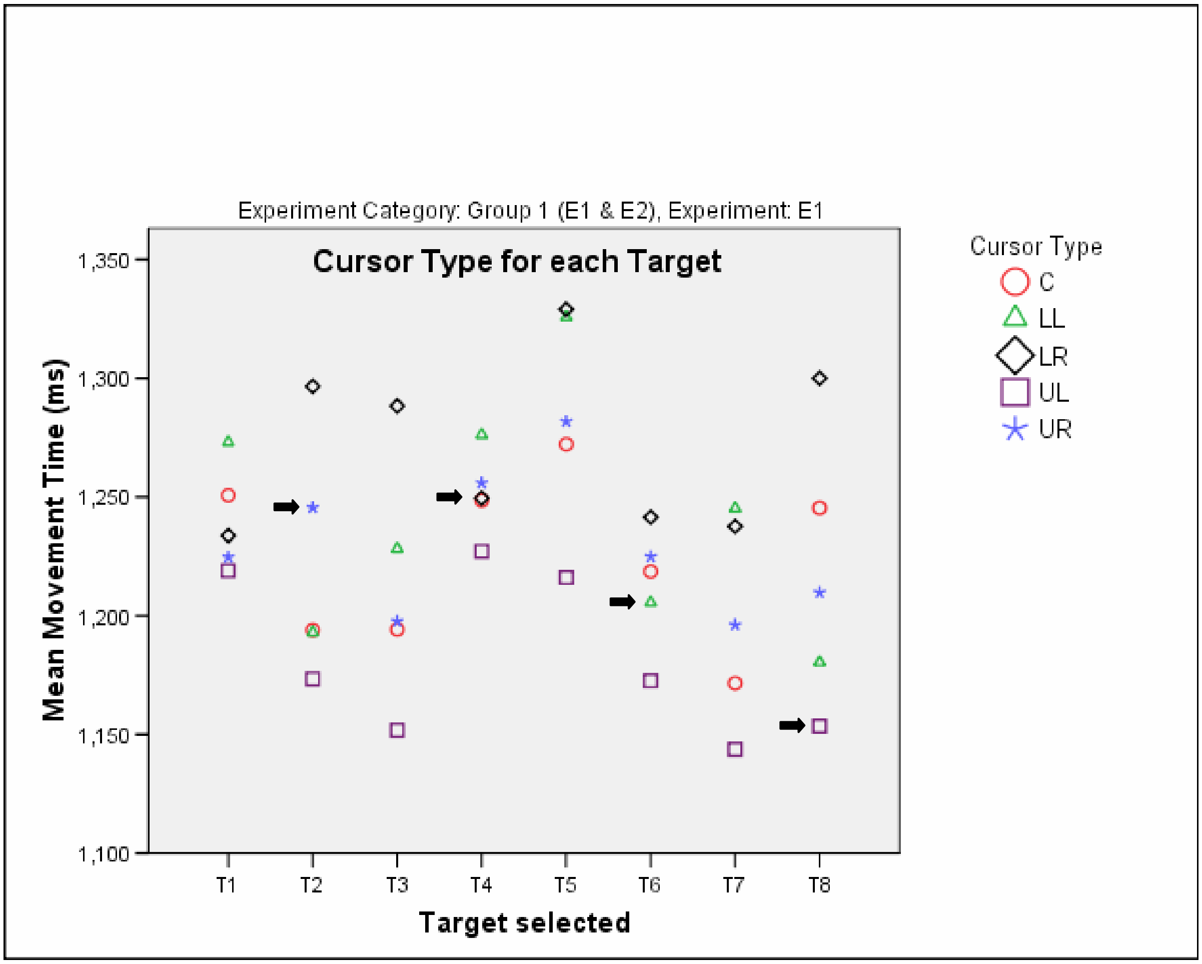


Figure 5.4 Experiment 1: Directional cursors analyzed for each compatible target with respect to the "Mean Movement Time".

NULL: The orientation-neutral cursor (○) used in Po et al's experiments will not yield the best performance (movement time and positioning performance) when compared across a variety of movement directions to cursors that cue for movement in one specific direction (↖ ↗ ↙ ↘).

ALTERNATIVE: The orientation-neutral cursor (○) used in Po et al's experiments will yield the best performance (movement time and positioning performance) when compared across a variety of movement directions to cursors that cue for movement in one specific direction.

Identical with Hypothesis 1, the ANOVA found a main effect for cursor type movement time (speed) that suggests that some cursor types are better than others [$F(4, 44) = 5.389$, $p = 0.001$]. On the other hand, the cursor type positioning performance showed no main effect [$F(4, 44) = 0.981$, $p = 0.428$], suggesting that accuracy is not impacted by the cursor type that is selected. Two two-way ANOVAs analyzing movement time and positioning performance showed a significant interaction between cursor type and participant [Movement time: $F(44, 308) = 2.023$, $p < 0.001$; positioning performance: $F(44, 308) = 1.470$, $p = 0.034$]. This showed that varying the cursor type during E1 resulted in significantly different movement time and positioning performances. Since all five cursor types did not perform in the same way, the null hypothesis was rejected in favor of the alternative hypothesis.

To get a better understanding of whether the circle cursor outperformed the four directional cursors used in experiment one (E1), a "paired contrast" of the orientation-neutral cursor against the directional cursors across the two dependent variables (movement time and positioning performance) was performed using SPSS. Investigating the data with focus on the first dependent variable (movement time) showed three different results. The arrow pointing in the upper left (UL) of the screen was better than the circle cursor (mean difference = 42.267, $p < 0.001$), two showed no statistical difference in performance (LL arrow: $p = 0.156$ and UR arrow: $p = 0.659$), and the arrow pointing in lower right (LR) corner of the display was the worst (mean difference = -47.632, $p < 0.001$). This indicated that the circle shaped cursor did not outperform the arrow shaped cursors. Similar results were achieved contrasting the orientation-neutral cursor against the directional cursors with respect to positioning performance. The circle cursor only outperformed the UL arrow by a small margin (mean difference = -0.377, $p = 0.022$) while the other three directional cursors showed no statistical performance difference.

From these results it seems that the UL arrow showed performance improvements over the one orientation-neutral cursor and the four directional arrows. However, it must be noted that the UL arrow is closest to the cursor used in most general GUIs. This might explain the superior results in its positioning performance. A closer look at the significance levels of the other three directional cursors showed also lower significance values, indicating that a higher level of significance existed between the four arrow-shaped cursors and the orientation-neutral cursor (the lower the value the higher the level of significance). The significance values, comparing the four directional-cursors to the orientation neutral cursor, are displayed in Table 3.1 This observation could be explained by the fact that precise positioning performance greatly depended on the cursor type. Generally, when emphasis was on accuracy rather than speed, any of the four arrow shaped cursors should support this goal in greater magnitude rather than when emphasizing speed during the same task. During the latter, the shape of the cursor does not affect the goal of clicking a target faster since accuracy becomes secondary to achieve the goal.

Table 3.1 Significance levels (positioning performance) of all four directional cursors (LL, LR, UL, and UR) compared to the non-directional cursor (C)

Experiment 1 (E1)		
Cursor Type	**Cursor Type**	**Sig.**
C	LL	0.056
	LR	0.131
	UL	0.022
	UR	0.558

Combined with the results discussed above, the two grouped scatter charts, shown in Figure 5.5, emphasize that the orientation-neutral cursor (C) in E1, analyzed across all twelve participants, did not show performance improvements over the four directional cursors, neither in positioning performance nor movement time. If the circle cursor would have shown overall superior performance, the lowest values would have been indicated by the orientation-neutral cursor for both dependent variables, movement time and positioning performance, for all participants (P1 through P12). For some participants the orientation-neutral cursor recorded lowest values for one of the dependent variables, but not consistently for both at the same time. In other words, the circle cursor did not stand out as the

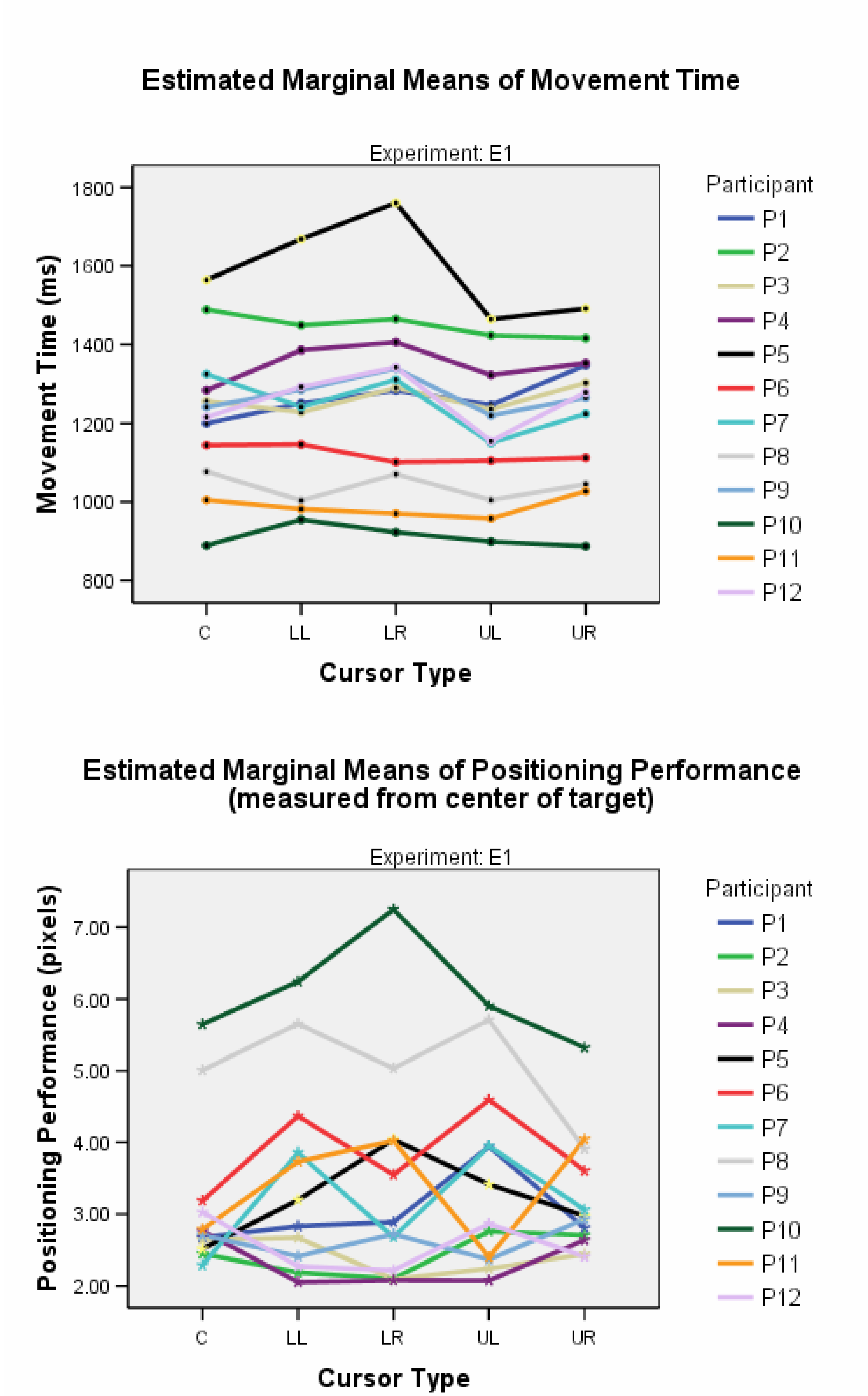


Figure 5.5 Two grouped scatter charts, the top based on movement time (speed) and the bottom on positioning performance (accuracy), show each cursor type's performance tested in E1.

cursor type outperforming all directional cursors. The results from this study did not provide the same results found by Po et al. (2005).

5.3.3 Hypothesis 3

Hypothesis 3 was an extension of the research work done by Po et al. and addressed the research question as to whether there is one orientation-neutral cursor design that performs better than the others. Experiment three (E3) was designed to test six orientation-neutral cursors (⊙ ○ × ⊗ + ⊕) including the circle cursor (○) used in Po et al's study. As stated previously, this hypothesis was formalized to test the following statements:

> NULL: The augmented circle cursor (⊙) will not yield the best performance (as defined above) when compared to other orientation-neutral cursors (○ × ⊗ + ⊕).

> ALTERNATIVE The augmented circle cursor (⊙) will yield the best performance when compared to other orientation-neutral cursors (○ × ⊗ + ⊕).

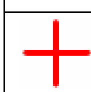
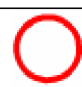
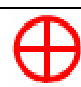
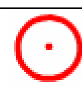
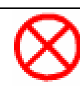
The ANOVA applied to the data recorded in experiment three (E3) observed significant main effects for cursor type and participant. Consistent with previous results, they suggest that some cursor types are better than others [Movement time: $F(5, 55) = 2.547$, $p = 0.038$; positioning performance: $F(5, 55) = 2.450$, $p = 0.045$]

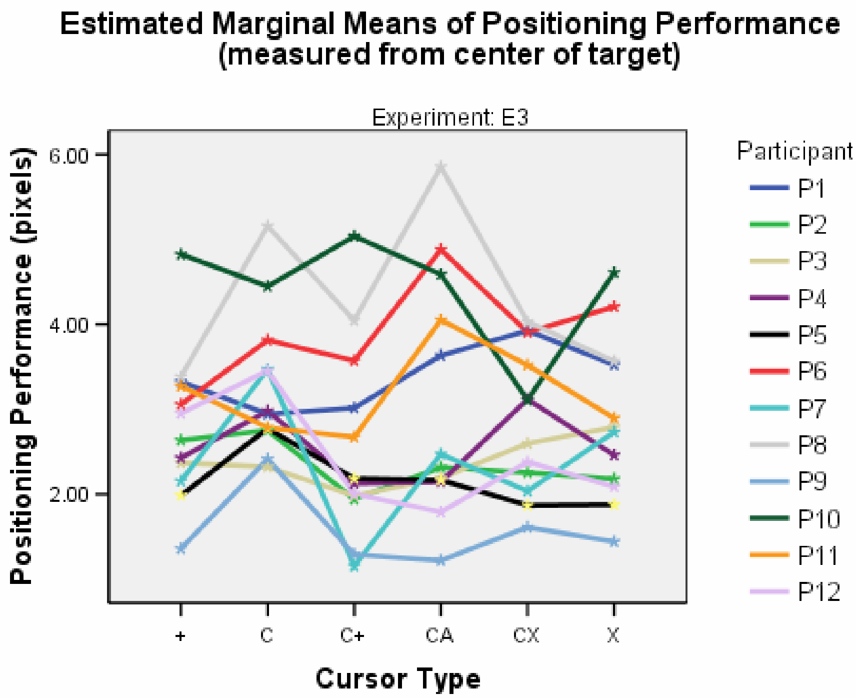
and that some participants show better performances than others [Movement time: $F(11, 62.646) = 67.380$, $p < 0.001$; positioning performance: $F(11, 50.709) = 16.766$, $p < 0.001$]. Two two-way ANOVAs between cursor type and participant, testing movement time and positioning performance, returned results that showed a significant two-way interaction between cursor type and participant [Movement time: $F(55, 385) = 5.943$, $p < 0.001$; positioning performance: $F(55, 385) = 2.141$, $p < 0.001$].

These results indicated that the selected orientation-neutral cursor presented to the participants during a trial had impact on the performance of how accurately the center of the highlighted target was clicked and the length of the time of a trial. Therefore, the null hypothesis was rejected in favor of the alternative hypothesis. However, in order to find out whether the augmented circle cursor yields the best performance when compared to the other five orientation-neutral cursors, the data was subjected to a "paired contrast" test. This test revealed that augmented circle cursor did not outperform all others. In fact, with respect to movement time performance the test produced three different results. The cursor's performance compared to the plain circle (C) cursor was the worst (mean difference = 73.677, $p < 0.001$), the "same" (showing no statistical significance with $p > 0.05$) for the "+" and "X" shaped cursors (+: mean difference = -6.000, $p = 0.701$; X: mean difference = -7.948, $p = 0.611$), and better in contrast to the cursor with an "+" (C+) or "X" (CX) inside the circle (C+: mean difference = -44.934, $p = 0.004$; CX: mean difference = -39.219, $p = 0.012$). The results of the "paired contrast" with respect to positioning performance were similar in that the results were not clearly favoring the augmented circle (CA) cursor. Combined with the results discussed above, Figure 5.6 illustrates that the augmented circle cursor (CA, see Table 5.2) did not provide overall performance improvements for both movement time and positioning performance for any of the 12 participants.

Even though these results confirmed what was believed to be true, different orientation-neutral cursors do not show the same performance, the results did not show that the augmented circle (CA) cursor outperformed all others. The ensuing result was that experiments E5 and E6 were not conducted.

Table 5.2 Orientation-neutral cursor types

Orientation-Neutral Cursor Types					
+	**C**	**C+**	**CA**	**CX**	**X**
					



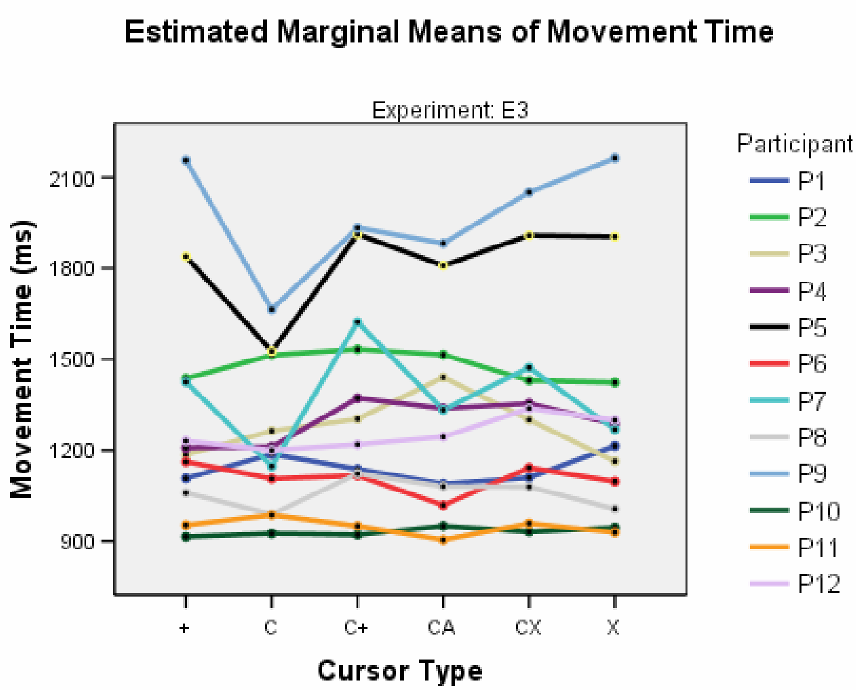


Figure 5.6 Experiment 3: Two grouped scatter charts, the top chart based on positioning performance and the bottom chart based on movement time, show each cursor type's performance.

5.3.4 Hypothesis 4

Hypothesis 4 was an extension of Po et al’s (2005) study and focused on the research question as to whether the best performing orientation-neutral cursor would also yield best results when compared to the four directional cursors used in experiment one (E1). As stated previously, this hypothesis was formalized to test the following statements:

NULL: The best performing orientation-neutral cursor will not yield better performance when compared to the four directional cursors (↖ ↗ ↙ ↘).

ALTERNATIVE: The best performing orientation-neutral cursor will yield better performance when compared to the four directional cursors.

Since the results of E3 and E4 did not reveal one true orientation-neutral cursor type that clearly outperformed any others, E5 and E6 were never conducted. Thus, this two hypothesis statements were not tested.

5.3.5 Hypothesis 5

Hypothesis 5 extended Po et al’s research to investigate the research question, determining whether the same results will be obtained using the same experimental setup, and replacing all target menu circles with squares. As stated previously, this hypothesis was formalized to test the following statements:

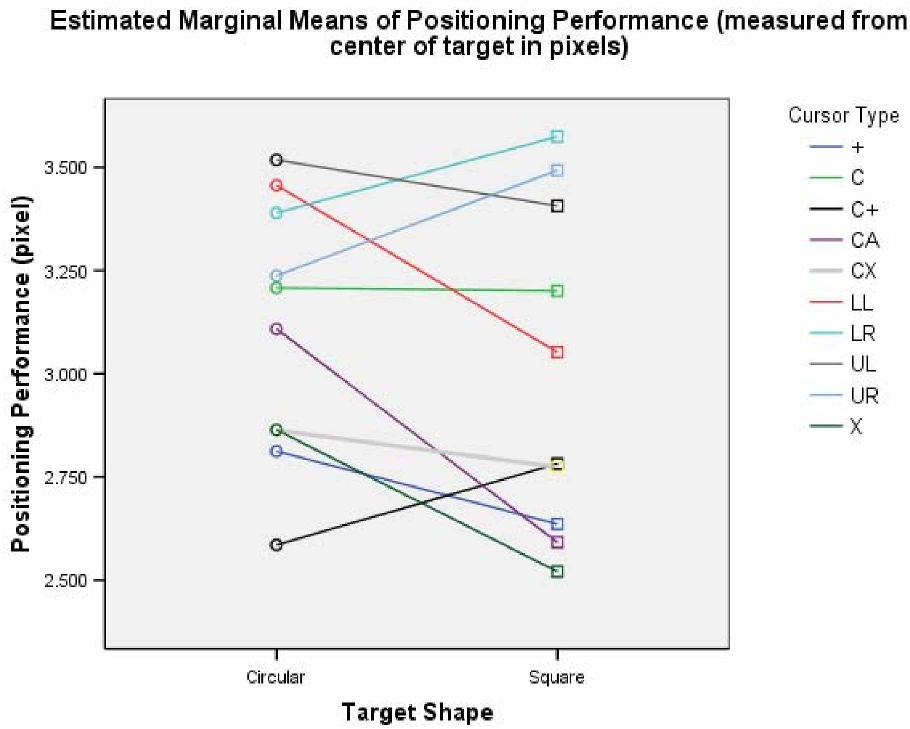
NULL: Changing all target shapes from circles to squares will have no significant effect on the results.

ALTERNATIVE: Changing all target shapes from circles to squares will have significant effect on the results**.**

Experiments two (E2) and four (E4) were designed to test these statements by replacing all target menu circles with squares. Consistent with previous hypotheses, the ANOVA revealed main effects for participant [Movement time: $F(11, 10.662) = 10.466$, $p < 0.001$; positioning performance: $F(11, 14.027) = 24.715$, $p = 0.000$] and cursor type [Movement time: $F(9, 3.554) = 10.413$, $p = 0.026$; positioning performance: $F(9, 12.431) = 4.991$, $p = 0.005$]. The two-way ANOVA found a significant interaction between target shape and participant [Movement time: $F(11, 99.690) = 7.445$, $p < 0.001$; positioning performance: $F(11, 102.435) = 2.005$, $p = 0.035$]. An additional three-way ANOVA between participant, target shape, and cursor type creating the most realistic experiment conditions, also indicated statistical significance for both dependent variables [Positioning performance: $F(99, 6096) = 2.114$, $p = 0.000$; movement time: $F(99, 6096) = 10.457$, $p = 0.000$]. Thus, the null hypothesis was rejected in favor of the alternative hypothesis. However, further analysis was required in order to determine whether a square target shape showed improved movement time and positioning performances when compared to a circle target.

Graphing the two-way interaction between target shape and cursor type, illustrated in Figures 5.7 and 5.8, provided details with respect to. Investigating the two-way interaction between target shape and cursor type shown in Figure 5.7 indicates that neither target shape appeared to be unanimously better when tested by the ten different cursor types. In respect to positioning performance (graph on the top in Figure 5.7) more than half of the cursor types produced improved performances (they were more accurate aiming toward the target's center). When analyzing the movement performance (elapsed time of a trial displayed in bottom graph in Figure 5.7) the advantage of a squared target appeared to be less important. From the graphs, only two cursor types (C+ and CX) seemed to show mentionable improvements when the target was a square rather than a circle. On the other hand, exploring the two-way interaction between participant and target shape, shown in Figure 5.8, pointed out that square targets had different impact on all participants. Both graphs visualize these observations. While for some participants (e.g., P9) the target shape affected movement times positively (see chart on the top in Figure 5.8), the charts did not illustrate a clear trend that one particular target shape showed consistent improvements in movement time and positioning performance across all participants.

The statistics testing this hypothesis showed that target shape matters but the square target was not unanimously better for all participants. Square targets work better for some but not for all participants.



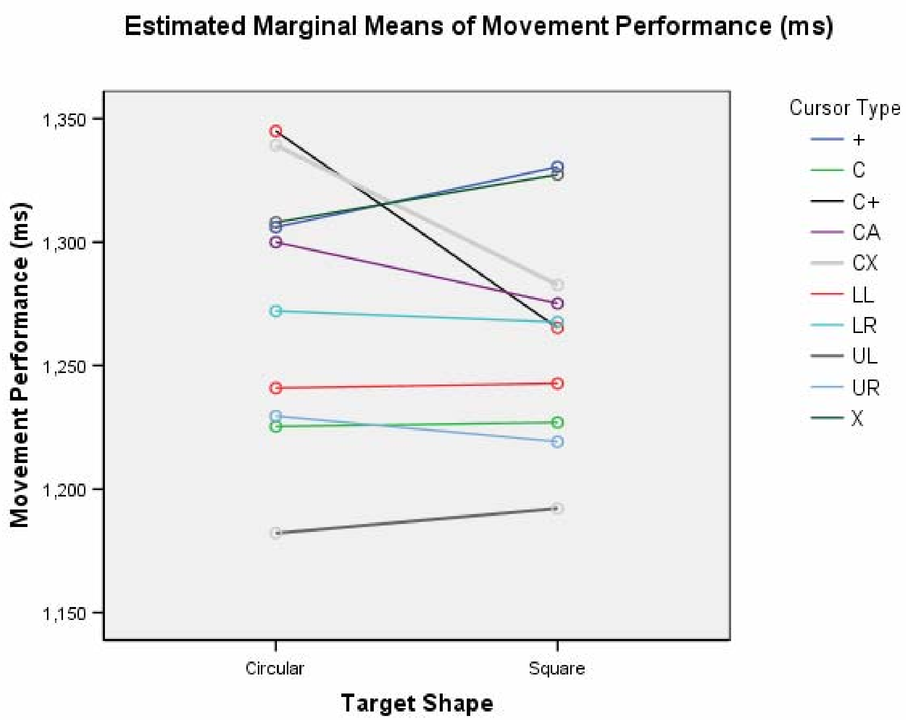
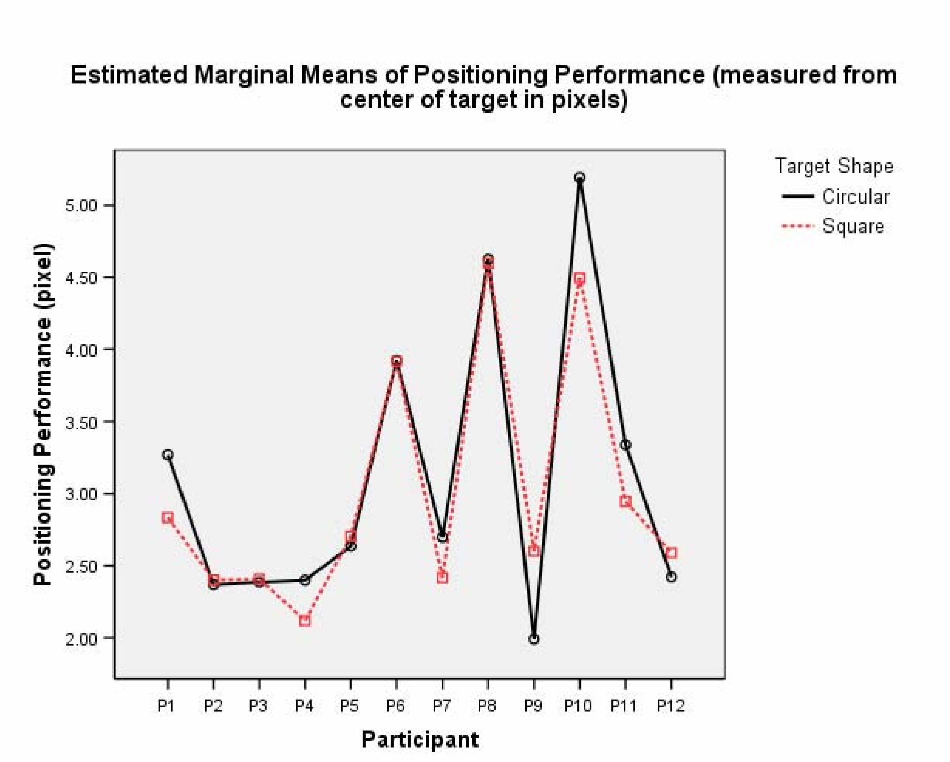


Figure 5.7 Two-way interaction between target shape and cursor type based on positioning performance (graph on the top) and movement time (graph on the bottom).



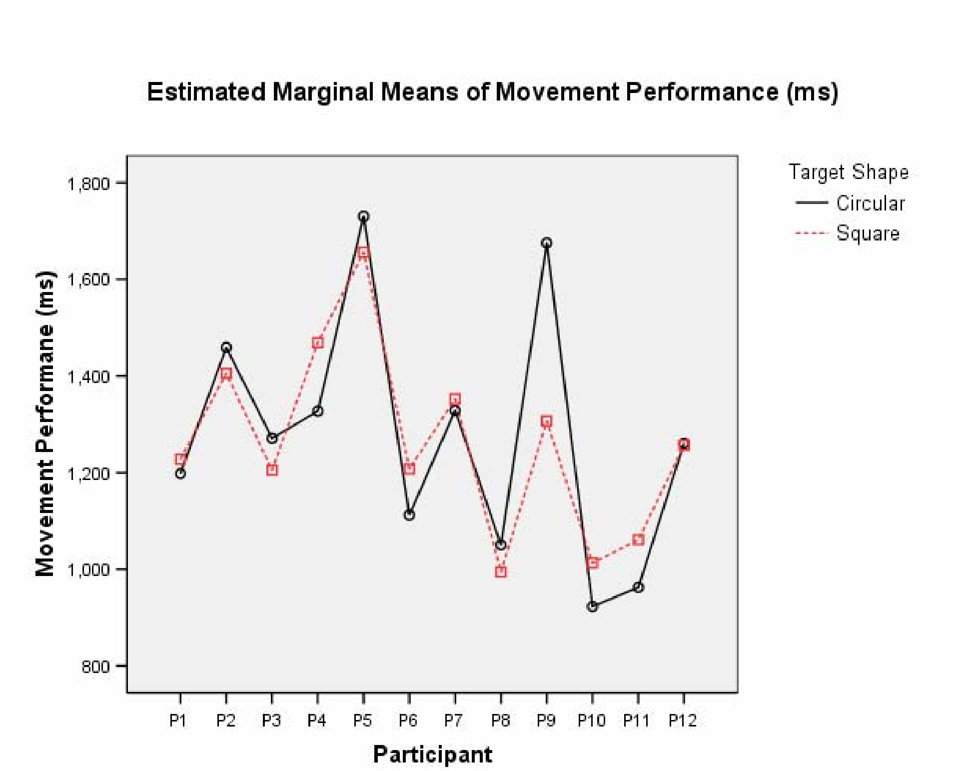


Figure 5.8 Two-way interaction between participant and target shape based on positioning performance (graph on the top) and movement time (graph on the bottom).

5.3.6 Overall User Study Results

Analysis of the data gathered during the experiments conducted throughout this study suggested that there seems to be a relationship between movement time and positioning performance for each cursor type. A shorter mean movement time (faster) reflected a less accurate mean positioning performance and vice versa. Trials that were executed faster were not as accurate when aiming towards the center of the highlighted target. The graphs illustrated in Figure 5.9 were taken from experiment one (E1) but are representative of observations made throughout the entire study. The graph to the left displays all cursor types based on mean movement performance and the graph on the right shows the same cursor types measured by mean positioning performance. When a participant took more time to move the selected cursor type to the highlighted target (movement time), it resulted in a higher degree of accuracy when clicking the center of the highlighted target (positioning performance). While the mean movement performance (speed) for the arrow pointing in the upper left (UL) corner of the screen was better than any of the other four cursor types it ranked lowest in regards to mean positioning performance (accuracy). In contrast, the circle shaped cursor (C) demonstrated a slower mean movement performance but resulted in an improved mean positioning performance value.

Analyzing the data collected from all conducted experiments (E1-E4) from one dimension (speed or accuracy) only, provides valuable information in regards to which cursor type was the fastest or most accurate for each participant. Table 5.3 illustrates these results that are separated into orientation-neutral and directional cursors. For each participant (P1-P12) a check mark indicates which cursor type performed best in each dimension. For example, participant one (P1), using the orientation-neutral cursors, achieved fastest results with the augmented circle (CA) shaped cursor, while the "+" shaped cursor was most accurate. On the other hand, comparing the directional arrows, the arrow pointing in the upper left (UL) was fastest and the arrow pointing in the lower left (LL) was most accurate. Across all 12 participants, when orientation-neutral cursors were tested, for 7 out of 12 participants the plain circle (C) cursor was fastest, while the circle with the cross hair inside (C+) was most accurate for 4 out of 12 participants. In contrast, comparing all directional cursors, the results indicated that the arrow pointing to the upper left (UL) of the screen was fastest for 11 out of 12 participants and the arrow pointing to the lower left (LL) of the screen provided most accurate characteristics for 4 out of 12 participants. However, compared to the LR and UR arrows, the performance advantage as to how precisely a target was clicked in its center was minimal.

The overall conclusions of this study and suggestions for future work are included in Chapter 6.

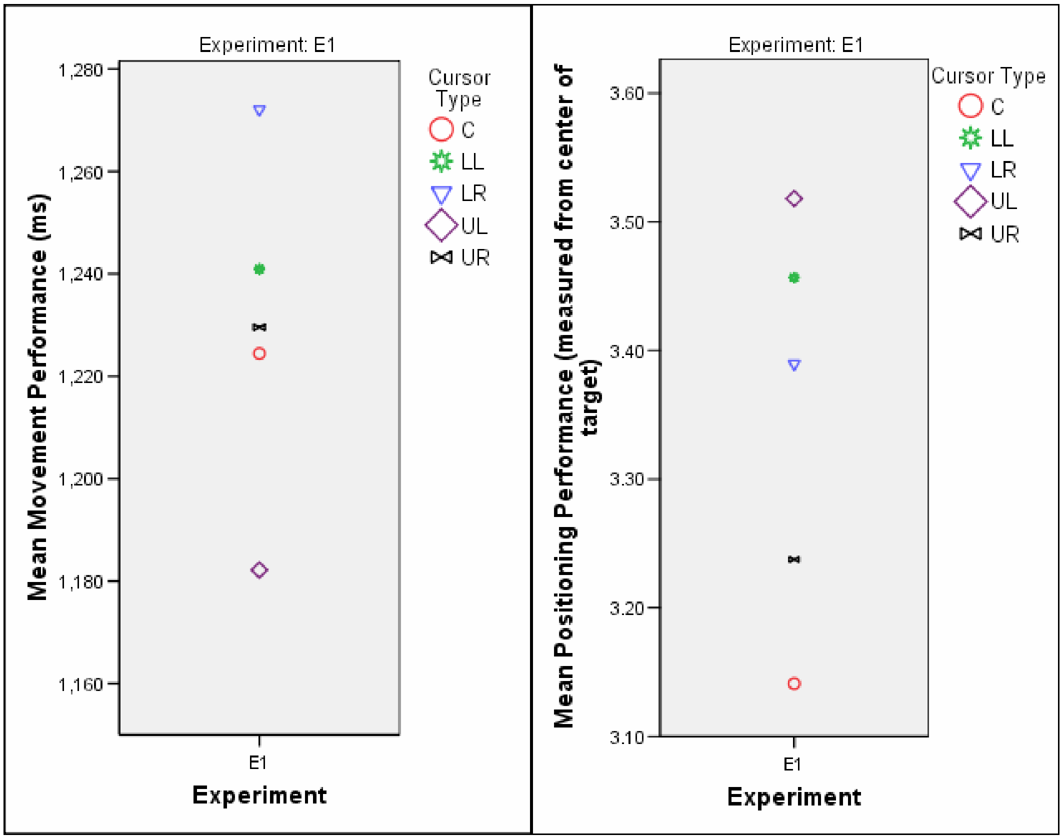


Figure 5.9 Side-by-side comparisons of Movement time and Positioning Performance shown on data gathered and recorded from E1 across all 12 participants.

Table 5.3 Cursor type performance measured in each dimension (speed and accuracy) across all experiments

Cursor Type		*Orientation-Neutral*						*Directional*			
		+	C	C+	CA	CX	X	LL	LR	UL	UR
P1	*speed*				√					√	
	accuracy	√						√			
P2	*speed*					√				√	
	accuracy			√				√			
P3	*speed*		√							√	
	accuracy			√					√		
P4	*speed*		√							√	
	accuracy			√				√			
P5	*speed*		√								√
	accuracy						√	√			
P6	*speed*				√					√	
	accuracy	√									√
P7	*speed*		√							√	
	accuracy			√					√		
P8	*speed*		√							√	
	accuracy	√									√
P9	*speed*		√							√	
	accuracy				√					√	
P10	*speed*		√							√	
	accuracy					√					√
P11	*speed*			√						√	
	accuracy						√			√	
P12	*speed*			√						√	
	accuracy						√		√		

CHAPTER 6 CONCLUSIONS AND FUTURE WORK

The findings stated in Chapter 5 lead to the conclusions outlined in this chapter. Also included are suggestions of future work that will expand on existing research in this area, including this study.

6.1 Conclusions

The research described in this thesis involved conducting four experiments in a tightly controlled test environment in order to compare the movement time and positioning performance of different cursor designs to targets presented on the screen. The experiment was divided into two parts: (1) An experiment (E1) that replicated the mouse-input portion of a research study conducted by Po et al. (2005), and (2) three additional experiments (E2-E4) that extended Po et al's study comparing the performance of six orientation-neutral cursors and different target shapes.

This study did not produce the same results as Po et al. All statistical tests performed on the data gathered revealed significances between the independent variables measured (cursor type and target). In other words, no one particular cursor shape showed improved performances with any of the eight targets positioned on the circular menu.

These differences could be explained due to the high complexity of the tested independent variables – cursor type and participant. ANOVA tests applied on the data found numerous significant two-way interactions as well as a few significant three-way interactions. Additional "paired contrast" tests compared the performance of two cursor types with each other.

The overall conclusion from this study is that there is no one cursor of those tested that performed best for everyone. Navigating a mouse cursor on a graphical user interface (GUI) with respect to movement time and positioning performance depends greatly on the individual. A cursor type that works well for one person might be difficult to use by someone else. The same observation can be applied to the effectiveness of different target shapes.

Additionally, the results gathered in Table 5.4 conclude that when only one dimension (speed or accuracy) is considered, one cursor type seems to stand out with respect to speed (plain circle (C) cursor – orientation-neutral cursor and UL arrow – directional cursor) and accuracy (Circle with "+" inside (C+) – orientation-neutral cursor and LL arrow – directional cursor). However, further thorough studies need to be completed in this area. Only scientifically based experiments may show whether one cursor type clearly outperforms all others in each category, orientation-neutral and directional cursors.

It is important to recognize two levels of significance: (1) statistical significance and (2) practical significance. "Statistical significance simply means that we reject the null hypothesis [upon an agreed level of significance,]. . . however, in practice the difference between the two means may be relatively small to the point of having no real engineering significance." (Anonymous, n.d.-a) While from the standpoint of the scientist it is of great importance to find out which cursor shape with respect to which target location under specific conditions might be most efficient, these results impact only a fraction of daily computer users. For example, a “paired contrast” between two directional cursor types (LL arrow and LR arrow) in this study found a statistical significance ($p = 0.002$) with a mean difference of 0.52245 pixel. As a reminder, 1 pixel = 0.01042 inch, thus, 0.52245 pixel = 0.00544 inch = 0.13823 mm, which is approximately the width of an average human hair. This clearly illustrates that this result showed statistical significance but has no practical significance for general web browsing using a mouse on a computer’s GUI.

Finally, it seems common sense that different applications require different cursor types. Three examples that might explain the proper usage of cursors in different programs: (1) With a computer aided design (CAD) application it might be important that a GUI uses a cursor design that supports precise cursor movements without consideration of speed; (2) A video game that requires quick and accurate responses from its user would benefit from a cursor design statistically proven to be simultaneously accurate and fast; and finally, (3) when performing regular web browsing on a computer a cursor allowing quick movements on the GUI without high-precision should be considered since accuracy is usually not the main focus when clicking buttons or text entry fields.

6.2. Future Work

The results of this study did not identify one specific cursor type that performed best under the tested experiment conditions. Therefore, further study and research would be appropriate expanding on the results of this study.

This study instructed all participants to emphasize each trial's execution on both speed and accuracy equally when moving the cursor from the center to the highlighted target. Another study could, testing the same cursor types used in this experiment, develop an experimental design that measures and analyzes data on one dimension only, movement time (speed) or positioning performance (accuracy). During a trial the participant would be instructed to either to move the cursor as fast or as precisely as possible from the center to the highlighted target. It would be of interest to this research community to know whether one cursor type could be identified that performs clearly better than all other cursor types when speed or accuracy is important.

In the design of this study all ten cursor designs were of identical measurement (32 x 32 pixels) and all nine targets had the same size (60 x 60 pixels). Further study on this topic might be warranted by conducting a similar experiment using different sizes of cursors and targets and determining comparison of measurements in movement time and positioning performance. This additional study might vary even further by using a smaller design of the cursor with a larger designed target and vice versa and also incorporate randomly selected sizes of cursors and targets during the same trial study and determining variances in measurements of movement time and positioning performance.

Two orientation-neutral cursors used in this study showed an “x” (⊗) or “+” (⊕) within a circle. A similar study might change each cursor design and reduce the size of the “x” and “+” within the circle to a smaller version in the circle’s center. Thus, these modified cursors might not block the view as much and possibly result in more precise navigation. It might be of further interest if such redesigned cursors compared with the cursors used in this research study would show significant variances in movement time and positioning performance.

During this study the selected colors for cursor designs, targets, and background followed closely the original experimental design from Po et al. (2005). Figure 6.1 shows a snapshot of Experiment 4, representing the color scheme used for all experiments in this user study (the black background is omitted for better visibility of the colors used for targets and cursor). Future research work might use different colors for cursors and targets on a different colored background. It might be of further interest to this research community to see if the change of colors results in significant differences in movement time and positioning performance.

All cursor designs used in this user study were opaque, thus, blocking the view of the target when the cursor was moved from the center target to the highlighted target. Further study using a transparent cursor design that would permit the user to see what was under the cursor while navigating to the highlighted target. Analyzing these results might yield more significant differences in movement time and positioning performance.

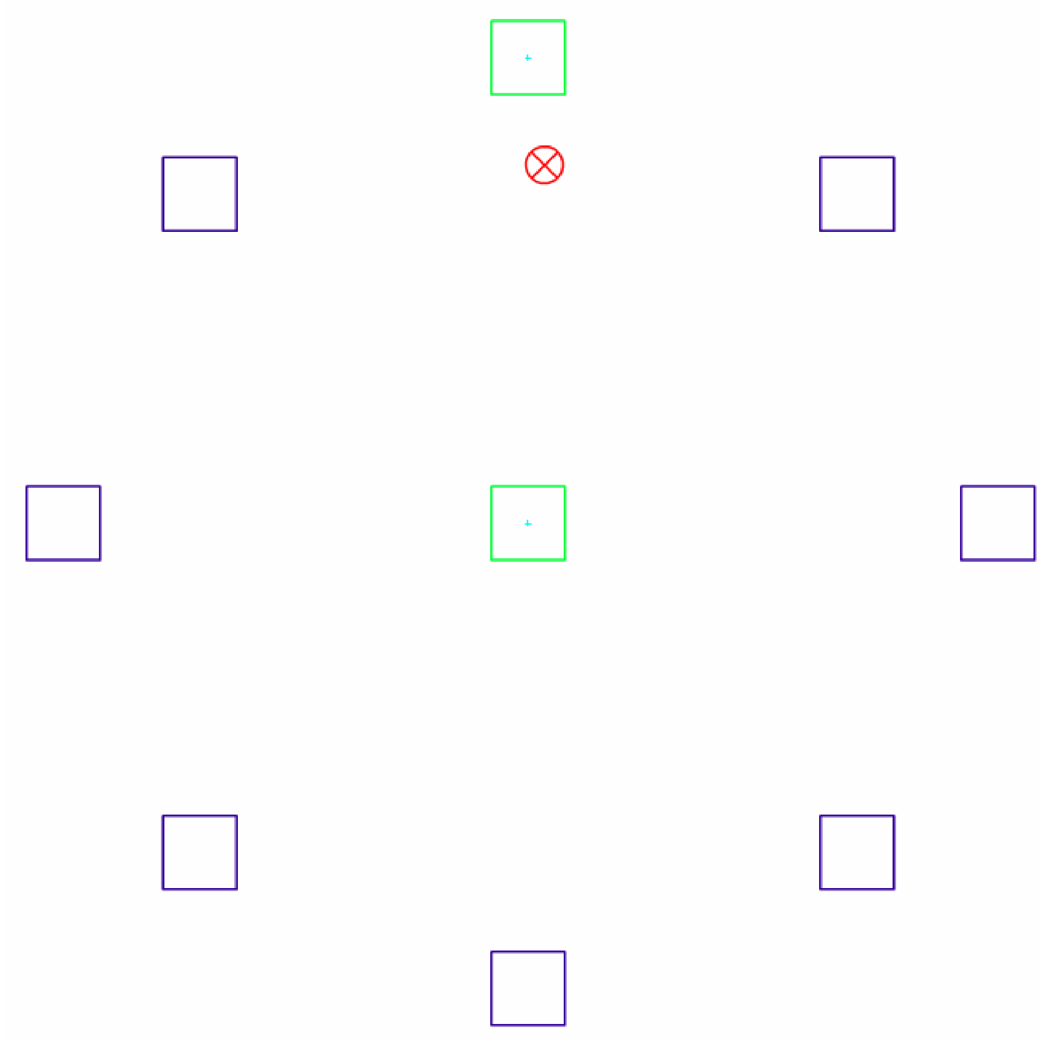


Figure 6.1 Color scheme used in this experimental design following closely the colors used in the original study from Po et al. (2005).

REFERENCES

Anonymous (n.d.-a) NIST/SEMATECH e-Handbook of Statistical Methods, Retrieved February 17, 2007 from http://www.itl.nist.gov/div898/handbook/

Anonymous (n.d.-b) Unit Conversion. Retrieved October 27, 2006, from http://www.unitconversion.org/unit_converter/typography.html

Callahan, J., Hopkins, D., Weiser, M., and Shneiderman, B. (1988). An empirical comparison of pie vs. linear menus. *Proceedings CHI 1988,* ACM Press, 95-100.

Fitts, P. M., and Seeger, C. M. S-R compatibility: Spatial characteristics of stimulus and response codes. *Journal of Experimental Psychology 46,* APA (1954), 199–210.

Flashguru (2002, May). Flash MX Event Model (Movieclips and buttons listen automatically). Retrieved November 22, 2006, from http://www.flashguru.co.uk/flash-mx-event-model/#more-490

Haahr, Mads (1999, June). Introduction to randomness and random numbers. (Background). Retrieved November 1, 2006, from http://www.random.org/essay.html

Lippa, Y., and Adam, J. J. An explanation of orthogonal S-R compatibility effects that vary with hand or response position: The end-state comfort hypothesis. *Perception and Psychophysics 63(1),* Psychonomic Society (2001), 156-174.

Martin, D. W. (2004). *Doing Psychology Experiments* (6th ed., 150-173). California: Wadsworth/Thomson Learning.

Mathematica® (Version 5.0) [Computer Software and built-in Help]

Phillips, J. G., Meehan, J. W., and Triggs, T. J. (2003). Effects of cursor orientation and required precision on positioning movements on computer screens. *International Journal of HCI 15*(3)*,* Lawrence Erlbaum, 379-389.

Po, B. A., Fisher, B. D., and Booth, K. S. (2005). Comparing cursor orientations for mouse, pointer, and pen interaction. *Proceedings CHI 2005,* ACM Press, 291-300.

Weisstein, Eric W. (n.d.). "Random Number" From *MathWorld*--A Wolfram Web Resource. Retrieved November 1, 2006, from http://mathworld.wolfram.com/RandomNumber.html