# Differences in Pointing Task Performance Between Preschool Children and Adults Using Mice

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Several experiments by psychologists and human factors researchers have shown that when young children execute pointing tasks, they perform at levels below older children and adults. However, these experiments have not provided user interface designers with an understanding of the severity or the nature of the difficulties young children have when using input devices. To address this need, we conducted a study to gain a better understanding of 4 and 5 year-old children's use of mice. We compared the performance of thirteen 4 year-olds, thirteen 5 year-olds and thirteen young adults in point-and-click tasks. Plots of the paths taken by the participants show severe differences between adults' and preschool children's ability to control the mouse. We were not surprised then to find age had a significant effect on accuracy, target reentry, and efficiency. We also found that target size had a significant effect on accuracy and target reentry. Measuring movement time at four different times (first entering target, last entering target, pressing button, releasing button) yielded the result that Fitts' law models children well only up to the time they first enter the target. Overall, we found that the difference between the performance of children and adults was large enough to warrant user interface interactions designed specifically for preschool children. The results additionally suggest that children need the most help once they get close to targets.

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## 1. INTRODUCTION

"It's too small!" said one of the five year-olds using the software our team developed. She was having difficulty clicking on one of the icons. Her classmates in a kindergarten class were having similar problems with other icons. While we had not observed these problems in children aged seven and older, the kindergarteners were clearly in need of larger icons. They did not have difficulty with the size of the icons because of vision problems. Recognizing what the icons represented was not the problem either. The problem was that we had designed icons too small for them to select with a mouse comfortably given their still developing motor skills. After increasing the size of the icons, the problem went away.

In the past, designers of children's software have seldom used empirical evidence on young children's motor skills to influence their interface designs. Instead, they have relied on their experience, design partnerships, and on testing to ensure that their designs are appropriate.

While these are all important elements in the creation of good designs, empirical data on children's abilities with input devices can help avoid lengthier testing and offer valuable insights to researchers and designers. Some researchers have conducted studies to assess these abilities. However, these studies have been mainly aimed at comparing input devices, not at learning about the severity and nature of children's difficulties using them. This article provides a thorough literature review of studies on children's motor skills and proficiency with input devices, and presents the results of a study we conducted to learn about the abilities of four and five year-old children with mice. Our aim in conducting the study was to better understand the severity and nature of the difficulties children belonging to these age groups have when using mice.

## 2. LITERATURE REVIEW

### 2.1 Information Processing Speed in Children

As children grow older, they improve the rate at which they can process information. Thomas [1980] provides a summary of the research in this area. In the past few years, Kail [1991] has proposed a model for this improvement in terms of reaction time (shorter reaction times equal faster information processing speeds). Equation (1) illustrates Kail's model:

$$RTchild = (1 + be^{-c.age})\, RTadult \tag{1}$$

where for a particular task, *RTchild* is the predicted reaction time for children, *RTadult* is the measured reaction time for adults, *b* and *c* are empirically derived constants, and *age* is the age of the children. The ideal population used for determining *RTadult* is undergraduate students (eighteen to twenty-two years-old), as information processing rates are known to decline as adults age. Other researchers [Fry and Hale 1996; Miller and Vernon 1997] have evaluated Kail's model and found it to fit their experimental data. Figure 1 shows a plot of Kail's model with *RTadult* equal to 1, and the values for *b* and *c* reported in Kail [1991] ($b = 5.16$, $c = 0.21$). The values of these constants are still being evaluated, as

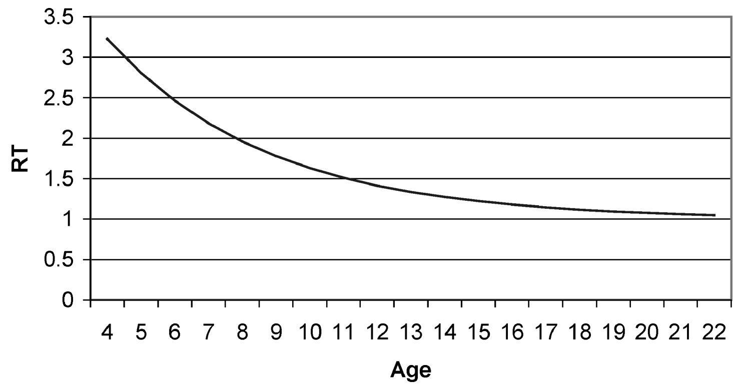


Fig. 1. Plot of Kail's model with $RTadult = 1$, and the values for $b$ and $c$ reported in Kail [1991] ($b = 5.16, c = 0.21$).

both Miller and Vernon [1997] and Kail and Park [1992] have conducted further studies for this purpose.

Kail's exponential curve indicates information processing speed increases more rapidly in young children than it does in older children. This means that young children will show greater improvements in their performance in information processing tasks between grade levels than older children. It also means that the variability in information processing speed between children the same age will be greater at younger ages (e.g. the differences in performance between two 12 year-olds are likely to be smaller than those between two 4 year-olds).

While Kail reports children can greatly increase their performance in information processing tasks through practice, the same is true for adults [Kail 1991]. Kail believes there are no differences in the improvement children and adults can make through practice, and therefore practice does not have an impact on his model. He conducted a study that confirms his hypothesis [Kail 1986].

Card, Moran and Newell's model of human performance [Card et al. 1983], widely cited in the Human-Computer Interaction (HCI) field, explains the relevance of Kail's model to children's motor skills. This model of human performance shows that the human motor system depends on processed information from the perceptual system. Research has shown that pointing movements, such as those needed to operate input devices, are made up of a distance covering phase and a homing phase. Movement in the homing phase is not continuous, but a series of micro-movements followed by micro-corrections [Meyer et al. 1990]. People with quicker information processing rates will be able to make more micro-corrections in the same amount of time, which translate into smoother motion and better performance. Thomas, in his review, also mentions how information processing rates have an impact on children's movements [Thomas 1980]. Based on these models, young children's performance in pointing movements, such as those performed with input devices, should be below that of older children and adults.

### 2.2 Fitts' Law

Fitts' law, a model that predicts pointing movement time based on target size and distance to target, was developed in the early 1950s by Paul M. Fitts, an experimental psychologist. Fitts' law models one-dimensional horizontal pointing movements.

The equation that defines Fitts' law has undergone improvements since its inception [MacKenzie 1992; Welford 1968]. This is the form in which it was recently published as part of the ISO 9241 standard [Douglas et al. 1999; International Organization for Standardization 2000]:

$$MT = a + b\ log_2(A/W + 1) \tag{2}$$

where *MT* is movement time, *A* is target amplitude (i.e. distance to target), *W* is the width of the target, and $a$ and $b$ are empirically determined constants. The rough meaning of the equation is that smaller targets that are further away take longer to point at.

Other equations associated to Fitts' law are (3) and (4):

$$ID = log_2(A/W + 1) \tag{3}$$

$$IP = ID/MT \tag{4}$$

where *ID* is the index of difficulty, and *IP* is the index of performance. The index of difficulty expresses the difficulty of the pointing task (the same *ID* may be obtained through different combinations of *A* and *W*). The index of performance expresses the quality of the performance of participants' pointing under the experimental conditions. It can be used to compare the performances of different groups of people under the same conditions (e.g. children vs. adults), or of people executing tasks under different conditions (e.g. using a mouse vs. a joystick). Sometimes the constant $b$ is used to express concepts similar to *IP* as it corresponds to the slope of the function tying *ID* to *MT* ($1/b$ is the same as *IP* when $a$ is 0).

### 2.3 Fitts' Law Applied to Children

Psychology researchers have been studying how Fitts' law relates to children for almost 30 years. Through studies, they have shown that Fitts' law appropriately models children's pointing movements and confirmed that young children have a lower performance in these tasks than older children and adults [Kerr 1975; Salmoni and McIlwain 1979; Sugden 1980; Wallace et al. 1978]. They have also found that younger children show a greater variability in their performance [Kerr 1975; Salmoni and McIlwain 1979]. Both of these observations agree with Kail's model. Schellekens et al. [1984], and Salmoni [1983] have also confirmed the existence of a distance-covering phase and a homing phase in children's pointing movements. In addition, Schellekens et al. [1984] found differences in performance between young children and older children and adults in the homing phase, suggesting information processing speeds contribute to the difference. Also of note are Kerr's findings of no gender differences, and no

Table I. Empirically Derived Data from Four Psychology Studies of Children's Performance in Fitts' Law Tasks

| Study | Age | Empirically Derived Data |
|---|---|---|
| Kerr [1975] | 5 | $a = 564$ (msec), $b = 139$ (msec/bit) |
| | 7 | $a = 227$ (msec), $b = 123$ (msec/bit) |
| | 9 | $a = 142$ (msec), $b = 108$ (msec/bit) |
| Wallace et al. [1978] | 4, 5 | $b = 97.25$ (msec/bit) |
| | Adult | $b = 43$ (msec/bit) |
| Salmoni and McIlwain [1979] | 1st grade | $b = 137.9$ (msec/bit) |
| | 5th grade | $b = 99.0$ (msec/bit) |
| | 9th grade | $b = 95.6$ (msec/bit) |
| | University | $b = 110.1$ (msec/bit) |
| Sugden [1980] | 6 | $IP = 5.43$ (bits/sec) |
| $ID = 5.585$ | 8 | $IP = 6.37$ (bits/sec) |
| | 10 | $IP = 7.53$ (bits/sec) |
| | 12 | $IP = 8.44$ (bits/sec) |

correlation between the skeletal age[1] of children (assessed by X-rays) and their performance [Kerr 1975].

Table I shows a summary of empirically obtained data from these studies. Since the data sets are so small, and the age of the adults in the studies is unknown, it is difficult to make any assertions as to whether they fit Kail's exponential curve.

### 2.4 Fitts' Law Applied to Input Devices

While Fitts' law was developed for one-dimensional tasks, it has been applied successfully to two-dimensional tasks, including selecting items on a computer screen with an input device. Experiments by various researchers have shown very high correlation coefficients, as summarized by MacKenzie [1992].

When applying Fitts' law's equation (2) to pointing tasks on a computer, its components map to useful information. The constant $a$ is usually associated with the action taken to select the target, such as clicking a mouse button. Depending on the setup of the experiment, it may also be associated with reaction time. The constant $b$, on the other hand, is associated with the difficulty of using the particular input device for the type of task being performed. *IP* is also used for this purpose [MacKenzie 1992].

In the HCI field, Fitts' law has been primarily used to evaluate and compare input devices. The first to use Fitts' law for this purpose were Card et al. [1978]. In their study, they compared the performance of a mouse, an isometric joystick, step keys, and text keys on the selection of text on a computer screen. They found the mouse provided better performance than the other devices. This influenced the selection of the mouse as an input device for the Xerox Star, which in turn influenced choices for future personal computers.

Scott MacKenzie has been one of the most active HCI researchers with regards to Fitts' law since the early 1990s. Perhaps his most important

[1]Skeletal age is a measure of how closely the skeleton approaches its final size and shape; it has been associated with athletic ability in pre-adolescents [Kerr 1975].

contribution is the proposal of the equation in the ISO 9241 standard (equation 2) [MacKenzie 1991]. He also made a significant contribution by studying how Fitts' law applies to two-dimensional tasks involving rectangular targets [MacKenzie and Buxton 1992]. He found that in such cases, the smaller of the rectangle's width and height should be used as the target width in Fitts' law (or alternatively a measure of width based on the approach angle). Accot and Zhai [2003] later refined this two-dimensional model. MacKenzie [1992] also proposed that HCI researchers follow Welford's advice [Welford 1968] in using effective target width ($W_e$) for Fitts' law calculations based on the normal distribution of the coordinates of study participants' selections of targets.

Since conducting Fitts' law studies became the accepted way of evaluating input devices, the International Standards Organization (ISO) now provides specifications on how to carry out these studies in the ISO 9241 Part 9 standard [Douglas et al. 1999; International Organization for Standardization 2000]. The specifications include equation (2) and MacKenzie's proposal of following Welford's advice on using effective width in equations (2), (3) and (4).

## 2.5 Children and Input Devices

Many researchers have looked at children's use of input devices in the last decade [Crook 1992; Inkpen 2001; Joiner et al. 1998; Jones 1991; King and Alloway 1993; Strommen et al. 1996]. They have found high correlations between study data and Fitts' model [Inkpen 2001; Jones 1991]. They have also observed how children's performance with input devices increases with age [Crook 1992; Joiner et al. 1998; Jones 1991; King and Alloway 1993], and how younger children show a higher variability in their performance [Joiner et al. 1998; Jones 1991]. Both of these findings are compatible with Kail's predictions. Some researchers have also questioned the usefulness of Fitts' law when it comes to children because children may not be capable of expert performance and efficiency may not be as important to children as it is to adults [Joiner et al. 1998; Strommen et al. 1996].

Jones [1991] has been the only one to study children as young as six years old in their Fitts' law performance with computer input devices. He conducted a study with six, eight and ten year-old children comparing the use of mouse, joystick and trackball input devices in continuous (going back and forth between targets) and discrete (one target at a time) tasks.

The study's tasks involved clicking on square and rectangular targets all at the same distance, at four fixed angles (up, down, left and right). When users missed a target, they had to repeat the task. They also had to repeat the task if they did not enter the square or rectangle through the side facing the original position of the cursor (this was an unusual requirement).

The study found children improved their performance with age, confirming the observations in the psychology studies and Kail's model's predictions. Table II summarizes the results for the continuous task with square targets. The ratios between the performances at each age are similar to those found in the psychology studies and to those predicted by Kail's model (see Table III).

Table II. Empirically Derived Constant *b* for Six, Eight, and Ten Year-Olds from Jones' Study for a Continuous Task with Square Targets Averaged over All Input Devices Used [Jones 1991]

| Age | Fitts' Constant *b* (msec/bit) |
|---|---|
| 6 | 735 |
| 8 | 578 |
| 10 | 510 |

Table III. Comparison of Improvement in Performance with Age Between Jones' Fitts' Law Study (with Input Devices), Two Psychology Studies, and Predictions from Kail's Model

| | Improvement in Performance Between Ages | | |
|---|---|---|---|
| Source | 6 and 10 | 6 and 8 | 8 and 10 |
| Jones [1991] | 44% | 27% | 13% |
| Salmoni & McIlwain [1979] | 39% | n/a | n/a |
| Sugden [1980] | 39% | 17% | 18% |
| Kail [1991] | 51% | 26% | 20% |

Jones' data also showed that younger children had more variability in their performance, as the standard deviation of children's movement time was consistently higher for younger children. This coincides with the observations of Kerr [1975], and Salmoni and McIlwain [1979], and the predictions of Kail's model.

As the study was conducted before MacKenzie showed how Fitts' law works with rectangular targets, Jones took the "depth" of the rectangle with respect to the user's original location to be the width of the target. Of the four combinations used in the study, two had a width at least three times larger than the height. Such ratios will reduce the ability of the width to be reliable when used in Fitts' law according to Accot and Zhai [2003]. This experimental setup made Jones incorrectly conclude that Fitts' law did not apply to children when rectangular targets were involved. As far as comparing input devices, Jones did not find any of the devices to be clearly better than the others.

Another researcher who examined children and input devices was Kori Inkpen. Inkpen [2001] conducted a study comparing drag-and-drop versus point-and-click techniques with nine to thirteen year-old children using mice. While it was not the main goal of her study, Inkpen applied Fitts' law to her participants' use of the mouse. She found that the children's performance was comparable to those summarized by MacKenzie [1992]. She did not look at differences in performance between ages.

Joiner et al. [1998] conducted two studies comparing children's pointing and dragging. In the second study, children between the ages of five and twelve performed pointing and dragging tasks. The results indicated that children's performance increased with age as the variability in their performance decreased, again in agreement with Kail's model. Joiner et al. questioned the application of Fitts' law to children because according to them children are not capable of expert or errorless performance. Joiner et al. did not provide empirical evidence to validate this claim.

King and Alloway [1992, 1993] conducted two studies comparing children's use of mouse, keyboard and joystick input devices while using an application designed for children. While the researchers did not use Fitts' law, they did keep track of time to complete the given task. King and Alloway's participants in the studies were four to eight years old. Children's performance improved with age, but the variability of performance within an age group was not reported. Confirming Kerr's [1975] findings, no gender effects were found.

Crook [1992] conducted a study to find out if young children could use graphical user interfaces. His study concentrated on whether children could manipulate the tools usually found in such interfaces using a mouse. The participants were children aged three to eight years old, plus three teachers with no computer experience, and twelve adult expert users. In a point-and-click task, Crook reported a clear improvement with age (the numeric value of the variability of performance within an age group was not reported). But overall, the children did fairly well, with second and third graders achieving similar performance to two of the teachers. Given the small sample of teachers though, this finding may not be significant. The third teacher performed significantly better than the other two, at a level comparable to the expert users. Since we do not know the age of the two poorly performing teachers, there is a possibility this discrepancy could be due to their age.

Strommen et al. [1996] studied three year-old children's use of mouse, trackball and joystick input devices. The study's task involved moving a cursor to click on targets appearing on different parts of the screen. The results showed gender differences, as boys were able to click on more targets than girls. This may be due to boys being more motivated towards this goal-oriented task than girls. The inconsistency with other studies on gender difference could also be explained by the fact that this study looked at younger children [Kerr 1975; King and Alloway 1992; King and Alloway 1993].

While the joystick was the quickest device to use (with a slight advantage over the mouse), children entered and left the target more times when using the joystick than when using the mouse or the trackball. The result of the joystick being faster may be due to the fact that children often pressed the joystick's button before getting to a target, and as soon as the cursor touched the target, it would count as a click on the target. The authors did not clarify whether this was possible with the other devices, but they did say that children only showed this behavior when using joysticks. This type of button behavior is non-standard and should be avoided in future studies.

Instead of recommending the joystick, Strommen et al. recommend the use of the trackball, which the three year-olds found the easiest to use during the first session of the study, and had the least amount of target reentry. They also argue that the result of the joystick being quickest shows that speed (and by extension, *IP* in Fitts' model) does not necessarily equal ease of use when it comes to young children. They furthermore add that while efficiency may be a goal for adult users, this may not be the case with three year-olds, for whom play might be more important, even in what appear to be goal-oriented tasks.

## 3. STUDY

### 3.1 Motivation

The reviewed studies provide some trends in the evolution of children's abilities with input devices and some specific advice (e.g. point-and-click vs. drag-and-drop). However, they do not give designers an understanding of the severity or the nature of the difficulties children have in pointing tasks. More importantly, they do not address whether these differences in performance justify interactions designed specifically for young children. In order to address this need, we conducted a study comparing the performance of 4 and 5 year-olds with adults in the use of mice for pointing tasks. We decided to study preschoolers because that is where we expected to find the largest differences between age groups (according to Kail's model), and by extension, where data from a study would be most useful. We decided on the mouse as an input device because it is the device children are most likely to use on a computer.

### 3.2 Research Questions

In order to obtain a better understanding of children's pointing abilities, we needed to learn how age impacts children's difficulty and efficiency in using mice in point-and-click tasks. The research questions we sought to answer through the study are the following:

- What is the nature of the difference between preschool children and adults in the use of mice to point-and-click?
- Do age, target size, or distance to target have a significant effect on accuracy (whether the participant presses and releases the mouse button inside the target), or target reentry? What are the accuracy and target reentry rates for each combination of factors that do have a significant effect?
- Does Fitts' law model children's use of mice correctly when first entering the target, last entering the target, pressing the mouse button, or releasing the mouse button?
- Does age have a significant effect on efficiency?

By answering these questions, we expected to learn whether preschool children require user interfaces designed for their age group. We additionally expected to obtain insights into strategies interaction designers may adopt to address young children's needs.

### 3.3 Participants

Thirteen four year-old children (6 girls and 7 boys, average age 4 years and 5 months), thirteen five year-old children (6 girls and 7 boys, average age 5 years and 6 months), and thirteen 19–22 year-old adults (6 women, 7 men, average age 20 years and 6 months) participated in the study. All participants were right-handed.

The children were a racially and ethnically diverse group from a local preschool located on the campus of the University of Maryland. The children had access to one computer in each of their classrooms. None of the children required instruction on how to use a mouse. Parents of the four year-olds reported that eleven children used computers less than 1 hour a week, while two used computers between 1 and 5 hours a week. Parents of the five year-olds reported that four children used computers less than 1 hour a week, eight used computers between 1 and 5 hours a week, and one used computers between 5 and 10 hours a week.

The adults were a similarly diverse group of undergraduate and graduate students from the University of Maryland. We decided to include adults in our study because we believe data on children's performance is more valuable when compared with adult performance tested under the same conditions. Just like the ratio of adult performance using different input devices (e.g. using mice vs. trackballs) holds across different experimental conditions [MacKenzie 1992], we expect that the ratio of adult to child performance with the same input device will also hold across experimental conditions. We only recruited adults in the ages of 18–22 because this adult age group should provide us with data on peak adult performance, as adult performance decreases with age [Kail 1991]. Of the adults, one reported using computers between 0 and 5 hours a week, one reported using computers between 6 and 10 hours a week, three reported using computers between 11 and 20 hours a week, and eight reported using computers more than 20 hours a week.

### 3.4 Materials

We used a Pentium III 650 MHz laptop with 128 MB RAM running Microsoft Windows 98 at a resolution of $1024 \times 768$ pixels. As an input device, we used a Logitech USB Optical Mouse. We used a regular sized mouse because we found no empirical evidence in the literature pointing to children performing better with smaller mice. Crook [1992] mentions anecdotal evidence of no apparent difference in performance by preschoolers using smaller versus regular sized mice.

The mouse moved the screen cursor approximately 18 pixels for every millimeter of physical mouse motion (similar to what we obtained using the "medium" speed setting in Windows with no acceleration). We connected the laptop to a 21" monitor, yielding a control-display ratio of 0.15 (e.g. for every 0.15 inches the mouse moved, the cursor moved 1 inch). The reason why we decided against using acceleration is that it is possibly part of the solution to the problems children have with pointing devices. Rather than studying a solution, we chose to better diagnose the problem avoiding the use of strategies that could make children's use of mice more difficult to analyze.

Tasks consisted of moving a cursor from a home area towards a target, and clicking on the target. The targets were red circles and always appeared to the right of the cursor's starting location in the home area. Tasks ended as soon as participants clicked, regardless of whether this occurred inside or outside the target circle. To start a new task, a researcher initiated a 1.5 second animation of a yellow square from the top of the screen towards a black square representing the participant's home area. When the yellow square covered the black

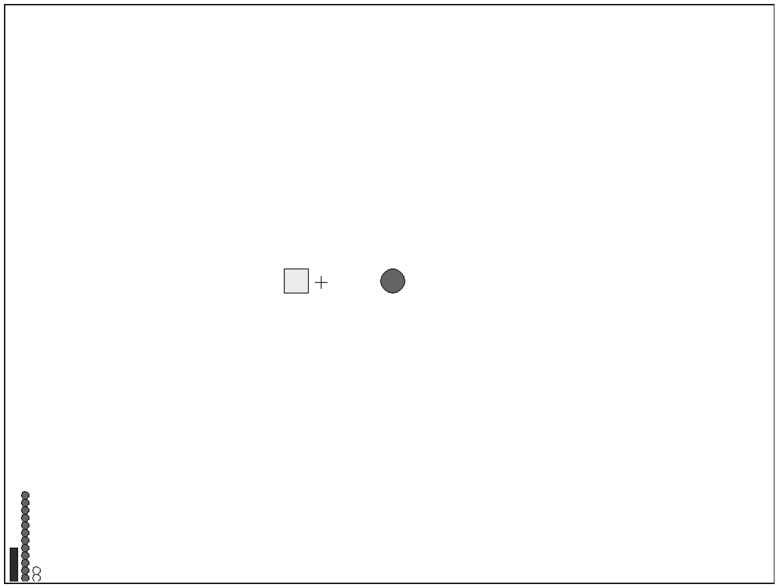

Fig. 2. Screenshot of study software showing the yellow square representing the home area, the crosshair cursor, the target circle, and information on elapsed time and number of hits and misses on the bottom left.

square, a crosshair appeared in the middle of the yellow square. At this point, participants were allowed to move the mouse (moving earlier would cause the yellow square to restart its animation). Recording of elapsed time did not start until participants moved the crosshair.

To provide feedback to participants, on the bottom left of the screen, a blue bar showed the cumulative elapsed time, a pile of red circles showed the number of hits, and a pile of white circles showed the number of misses. Figure 2 shows a screenshot of the study software.

In designing the experiment, we decided against having tasks one immediately after the other for three reasons:

1. Children have difficulty clicking when using mice
2. We were not interested in measuring how quickly children would react to having a target appear somewhere else on the screen
3. We wanted our participants to have a chance to move the mouse to a comfortable position.

We implemented the animation of the yellow square to avoid any mouse motion before the start of a task. We decided researchers should initiate the yellow square animation because of the difficulty young children have in clicking the mouse, and because we did not want them to be distracted by having to press something on the keyboard. With this setup, participants were still the ones initiating the task (by moving the mouse), yet we made sure that before initiating the task, the participants had not moved the mouse, knew where they had to click, and had the chance to move the mouse to a comfortable position.

Table IV. Size of Targets in Pixels and Millimeters, and Equivalent Physical Mouse Motion also in Millimeters

| Screen (pixels) | Screen (mm) | Physical Mouse Motion (mm) |
|---|---|---|
| 16 | 5.9 | 0.9 |
| 32 | 11.9 | 1.8 |
| 64 | 23.7 | 3.6 |

We decided to present targets at only one angle because determining the differences in performance by angle of approach was not one of our goals, and past research has not found large differences in performance at different angles of approach when using mice (e.g. MacKenzie and Buxton [1992] found diagonal motion took 4% longer than horizontal or vertical motion).

### 3.5 Procedure

The study was conducted in quiet rooms, one at the pre-school, and another at our lab. The room the children used was set up with chairs and a table of appropriate height for the children. During the study, participants sat down on a chair in front of a table that had the 21″ monitor and the optical mouse on it. A researcher sat to the right of the table, holding the laptop.

Before the study started, a researcher explained to each participant that they had to click on red circles as quickly and as accurately as possible. The participants then proceeded to work on five practice tasks to make sure they understood how they had to proceed, and how to interpret what was shown on the screen.

Participants completed 5 blocks of 9 tasks each for a total of 45 tasks. They were encouraged to position the mouse comfortably between tasks. Participants took between 5 and 15 minutes to complete all tasks. This amount of time proved to be about right for the preschool children, as it would have been difficult to keep some of them interested in the study software much longer. The length of the study also minimized interruptions to the children's school day. Keeping the study short also ensured that we would measure performance not tainted by extensive practicing. Such practicing could have made our child participants into "experts", something the children we are trying to help with this research are not.

### 3.6 Design

The target circles participants clicked on had one of three diameters (16, 32, or 64 pixels) and their centers appeared at one of three distances (128, 256, or 512 pixels). See Table IV for further information on target size. The combinations between sizes and distances yielded the 9 tasks that made up a block. The study software presented these 9 tasks in random order, and repeated the same order for every block of testing. The independent variables were: age level (between-subjects), target size (within-subjects), distance to target (within-subjects), and block number (within-subjects). The dependent variables measured were: accuracy, target reentry, target reentry during click (number of times target was reentered between the time the participant pressed and released the mouse button), and movement time (when first entering target, when last entering target, when pressing the mouse button, and when releasing the mouse button).

In measuring accuracy and target reentry, we heeded the advice of Strommen et al. [1996] that when evaluating children's performance with input devices we should not concentrate only on how quickly they can complete tasks. However, we also wanted to learn how Fitts' law applied to 4 and 5 year-old children, and that is why we also measured movement time.

### 3.7 Results

3.7.1 *Observations and Path Plots.* In observing both children and adults complete the study's tasks, we noticed some clear differences. Adults were quicker and had better control of the mice. Children showed difficulty in the tasks once they got close to the targets. To gain a more intuitive understanding of the differences between the age groups, we plotted paths taken by participants. Figure 3 shows the paths taken by all participants in each age group for a particular task.

The top of Figure 3 shows the smooth paths taken by adults. The narrow band of activity between the starting point and the target suggests an accurate distance-covering phase. The lack of paths over part of the target shows high accuracy and control during the homing phase. The paths taken by 4 and 5 year-olds show a completely different picture. They are all over the screen and they look jagged, rather than smooth. In addition, there is a halo of activity around the target that is not present in the paths taken by adults. These observations suggest lesser control by children in both the distance-covering and homing phases.

To look at the differences more closely, Figure 4 shows plots of typical paths taken by an adult, a 5 year-old, and a 4 year-old to click on a target. The path taken by the adult shows greater control of the input device and the type of motion expected in Fitts' law tasks. Notice the smooth adjustment in the homing phase after the distance-covering phase was a bit short. The paths taken by children on the other hand, show that the worst control problems occurred once they got close to the target. While the distance-covering phases were not particularly accurate, the homing phases show hesitation and difficulty before children pressed the mouse button.

Besides exposing some of the differences between adults and children, the path plots also show some differences between 4 and 5 year-olds. As expected, all the differences we pointed out between children and adults appear more acute for 4 year-olds. This is consistent with the theory that slower information processing speeds cause younger children to adjust mouse motion less frequently. Beyond any numerical results in this paper, Figure 3 makes it clear that there are major differences between adults' and children's use of mice.

3.7.2 *Accuracy and Target Reentry.* In order to verify the differences we observed through path plots and learn additional facts from the study, we analyzed accuracy and target reentry data. Through repeated measures ANOVAs, we found that target size and age level had a significant effect on accuracy,

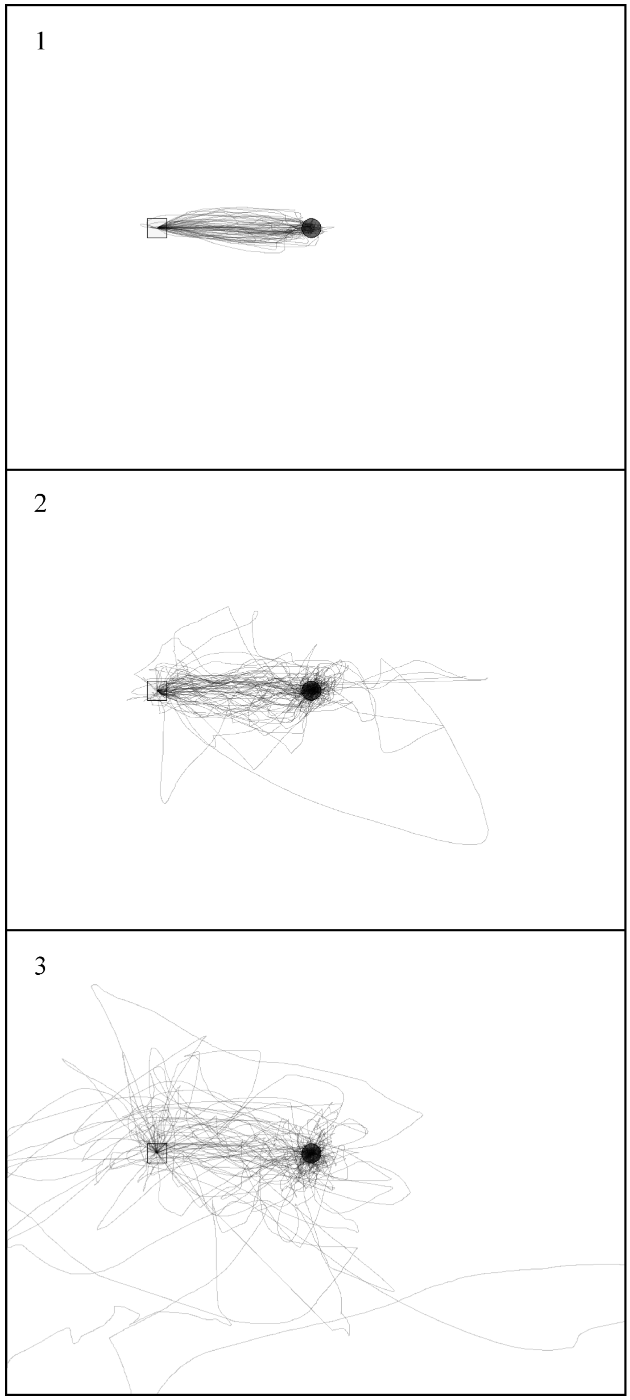


Fig. 3. Paths taken by participants to click on a 32 pixel target at a distance of 256 pixels. (1) Paths taken by all adult participants. (2) Paths taken by all 5 year-old participants. (3) Paths taken by all 4 year-old participants.

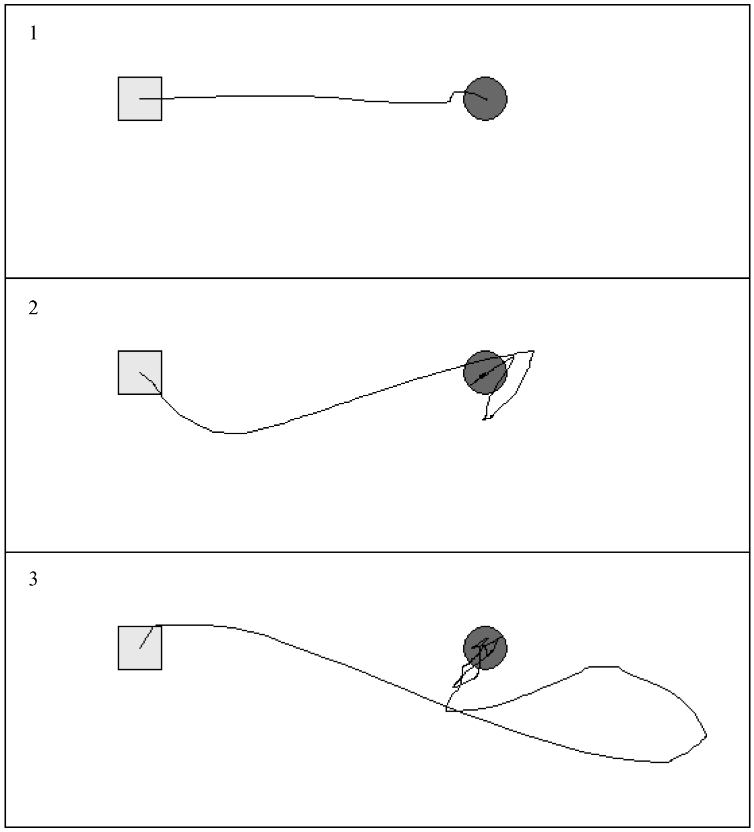


Fig. 4. Plots of three participants' mouse motion towards a 32 pixel circular target 256 pixels away from the home position. Participant in (1) was a 21 year-old female. Participant in (2) was a 5 year 8 month old female. Participant in (3) was a 4 year 6 month old female.

target reentry, and target reentry during click (see Table V), while distance to target and block number did not. Because of this, we decided to analyze accuracy, target reentry, and target reentry during click performance for every age group at each target size through repeated measures ANOVAs.

Table VI shows the results of our analysis, including significant differences according to Dunnett's T3 test for age differences (this test does not assume equal variances) and pairwise comparisons using Bonferroni's correction for target size differences. In addition, Figure 5, Figure 6, and Figure 7 illustrate the results from Table VI. As expected, the data shows clear improvements in performance with age and with larger target sizes. The standard deviation of performance also shows an overall decrease with age and the size of the targets, meaning that participants were more consistent as they aged and as targets got larger.

Figure 5 provides the interesting insight that to achieve the same level of accuracy as adults at 16 pixels, 5 year-olds require 32 pixels, and 4 year-olds 64 pixels. Even at these increased sizes, the children will have a greater amount of target reentry and target reentry during click (see Table VI). This stark

Table V. Result of Repeated Measures ANOVAs, Looking at Significant Differences Based on Target Size, Age Level, Distance to Target (Amplitude), and Block Number

| Independent Variable | Dependent Variable | F Statistic | p Value |
|---|---|---|---|
| Target size (MANOVA Wilks' Lambda) | accuracy | $F(2, 35) = 34.9$ | $p < 0.001$ |
| | target reentry | $F(2, 35) = 28.4$ | $p < 0.001$ |
| | target reentry during click | $F(2, 35) = 24.2$ | $p < 0.001$ |
| Age level (between subjects ANOVA) | accuracy | $F(2, 36) = 20.7$ | $p < 0.001$ |
| | target reentry | $F(2, 36) = 14.3$ | $p < 0.001$ |
| | target reentry during click | $F(2, 36) = 27.0$ | $p < 0.001$ |
| Distance (MANOVA Wilks' Lambda) | accuracy | $F(2, 35) = 0.16$ | $p = 0.854$ |
| | target reentry | $F(2, 35) = 0.48$ | $p = 0.621$ |
| | target reentry during click | $F(2, 35) = 0.19$ | $p = 0.830$ |
| Block number (MANOVA Wilks' Lambda) | accuracy | $F(2, 35) = 1.26$ | $p = 0.305$ |
| | target reentry | $F(2, 35) = 1.97$ | $p = 0.122$ |
| | target reentry during click | $F(2, 35) = 0.92$ | $p = 0.462$ |

Table VI. Accuracy, Target Reentry, and Target Reentry During Click for Each Age Group and Target Size. The Significant Differences for Age Were Obtained through Dunnett's T3 Test. The Significant Differences for Target Size Were Obtained through Pairwise Comparisons Using Bonferroni's Correction

| Measurement | Target Size | Age | Mean | Standard Deviation | Significant Differences (Age) | Significant Differences (Target Size) |
|---|---|---|---|---|---|---|
| Accuracy (percentage) | 16 | 4 yr | 43 | 24 | 5*, adult*** | 32***, 64*** |
| | | 5 yr | 74 | 25 | 4* | 64* |
| | | adult | 90 | 12 | 4*** | |
| | 32 | 4 yr | 77 | 11 | 5**, adult*** | 16***, 64** |
| | | 5 yr | 91 | 7.5 | 4** | 64* |
| | | adult | 96 | 5.8 | 4*** | |
| | 64 | 4 yr | 90 | 12 | | 16***, 32** |
| | | 5 yr | 97 | 5.2 | | 16*, 32* |
| | | adult | 99 | 2.5 | | |
| Target reentry | 16 | 4 yr | 1.63 | 1.25 | adult* | 64* |
| | | 5 yr | 1.38 | 0.64 | adult*** | 32*, 64*** |
| | | adult | 0.38 | 0.20 | 4*, 5*** | 32**, 64** |
| | 32 | 4 yr | 1.11 | 0.65 | adult*** | 64* |
| | | 5 yr | 0.92 | 0.27 | adult*** | 16*, 64*** |
| | | adult | 0.14 | 0.08 | 4***, 5*** | 16** |
| | 64 | 4 yr | 0.63 | 0.39 | adult** | 16*, 32* |
| | | 5 yr | 0.39 | 0.15 | adult*** | 16***, 32*** |
| | | adult | 0.11 | 0.09 | 4**, 5*** | 16** |
| Target reentry during click | 16 | 4 yr | 1.12 | 0.66 | 5**, adult*** | 32**, 64*** |
| | | 5 yr | 0.26 | 0.25 | 4** | 64* |
| | | adult | 0.12 | 0.18 | 4*** | |
| | 32 | 4 yr | 0.39 | 0.30 | 5*, adult** | 16** |
| | | 5 yr | 0.13 | 0.16 | 4* | |
| | | adult | 0.03 | 0.08 | 4** | |
| | 64 | 4 yr | 0.15 | 0.26 | | 16*** |
| | | 5 yr | 0.03 | 0.11 | | 16* |
| | | adult | 0.01 | 0.03 | | |

$^{*} = p < 0.05$, $^{**} = p < 0.01$, $^{***} = p < 0.001$.

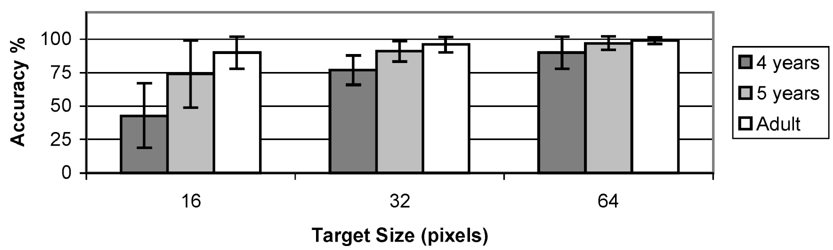


Fig. 5. Average accuracy for participants clicking on targets by target size and age level. Error bars are two standard deviations long.

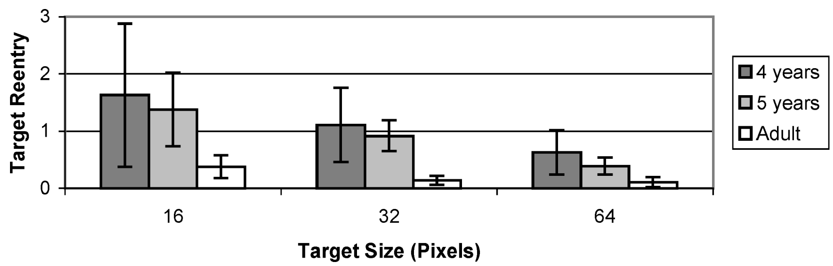


Fig. 6. Average number of times participants reentered target (not counting the first time they entered a target) by target size and age level. Error bars are two standard deviations long.

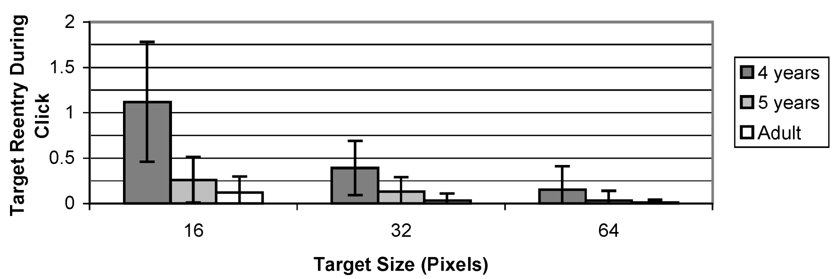


Fig. 7. Average number of times participants entered a target while pressing the mouse button during a click by target size and age level. Error bars are two standard deviations long.

difference in abilities provides evidence of the need to take into account children's pointing abilities when designing software for them.

These numbers also confirm our earlier observations of children having greater difficulty than adults in the homing phase. These differences are clear in that for every target size, there were significant differences between adults and children of both ages in target reentry rates.

Given our experimental conditions, 64 pixel targets offered significant advantages over 32 pixel targets for both 4 and 5 year-olds in terms of accuracy and target reentry. For adults on the other hand, there were no advantages in going from 32 to 64 pixel targets. While these advantages will be relevant for users under conditions similar to the participants in this study, pixel sizes will not be as relevant to users using different control-display ratios, or display sizes. However, Table VI may still help provide estimates of appropriate target

Table VII. Fitts' Law Correlation Coefficient and Constants $a$ and $b$ for Movement Time (msec) on First Entering and Last Entering the Target

| | First Entry | | | Last Entry | | |
|---|---|---|---|---|---|---|
| Age | $R^2$ | $a$ | $b$ | $R^2$ | $a$ | $b$ |
| 4 years | 0.94 | 386.4 | 447.6 | 0.82 | 379.3 | 711.9 |
| 5 years | 0.96 | 167.0 | 280.1 | 0.85 | −31.13 | 483.1 |
| Adult | 0.91 | −43.13 | 151.5 | 0.97 | −34.81 | 169.1 |

sizes for users under conditions other than those in this study. This could be accomplished by finding a target size under which adults have a similar performance in terms of accuracy and target reentry to the one they had with 16 pixels in this study. Designers could then infer what would be appropriate target sizes for preschool children by considering the ratios between the target sizes used in this study. While these estimates will not provide an optimal size, they can provide designers with a better starting point than just knowing that targets for children should be bigger.

3.7.3 *Movement Time and Fitts' Law.* We also analyzed the data from the study using Fitts' Law. Before conducting calculations, we removed extreme outliers[2] using box plots, both in terms of movement time for all four different types of movement time recorded, and location of click for movement time to press and release the mouse button. The reason for removing outliers was that sometimes participants would get distracted during a task, or would accidentally click where they did not mean to click. The number of extreme outliers for the four movement times was below 4% (first entry 3.0%, last entry 3.5%, press 3.4%, and release 3.6%). After removing extreme outliers, we performed a linear regression with movement time as the Y variable and Fitts' *ID*, see Equation (3), as the X variable. Given the small number of times participants repeated each combination of target size and distance, we aggregated time for all users in an age group (by calculating the average time of completion per combination of target size and distance). We performed the regression for the four movement times for which we collected data. For the press and release regressions we calculated the index of difficulty using both $W_e$ (adjusted width as specified in Section 2.4, producing $ID_e$) and the actual width of the target (producing *ID*) as recommended in Zhai [2002]. We calculated $W_e$ on a per-age-group basis. Table VII, Table VIII, and Table IX show correlation coefficients ($R^2$) and Fitts' law constants $a$ and $b$ (obtained from the regression, meant to calculate movement time in milliseconds). Figure 8, Figure 9, Figure 10, and Figure 11 show the regression lines together with the data points for each of the times we measured, using *ID* instead of $ID_e$.

The data shows, as expected, very strong correlations for adults for all movement times and all methods of calculating the index of difficulty. Children, on the other hand, show very strong correlations on first entering the target, but

[2]Extreme outliers are data points more than three interquartile ranges above the third quartile, or more than three interquartile ranges below the first quartile. An interquartile range is the distance between the first and third quartile [Tukey 1977].

Table VIII. Fitts' Law Correlation Coefficient and Constants $a$ and $b$ for Movement Time (msec) on Pressing the Mouse Button

| | Press | | | | | |
|---|---|---|---|---|---|---|
| | $ID_e$ | | | $ID$ | | |
| Age | $R^2$ | $a$ | $b$ | $R^2$ | $a$ | $b$ |
| 4 years | 0.58 | 1564 | 687.3 | 0.78 | 1572 | 638.4 |
| 5 years | 0.69 | 530.0 | 559.2 | 0.81 | 851.4 | 490.7 |
| Adult | 0.92 | 136.2 | 185.0 | 0.97 | 195.1 | 175.4 |

Table IX. Fitts' Law Correlation Coefficient and Constants $a$ and $b$ for Movement Time (msec) on Releasing the Mouse Button

| | Release | | | | | |
|---|---|---|---|---|---|---|
| | $ID_e$ | | | $ID$ | | |
| Age | $R^2$ | $a$ | $b$ | $R^2$ | $a$ | $b$ |
| 4 years | 0.44 | 2018 | 686.2 | 0.79 | 1819 | 648.5 |
| 5 years | 0.50 | 1140 | 464.0 | 0.82 | 1105 | 490.0 |
| Adult | 0.92 | 263.0 | 180.0 | 0.97 | 310.0 | 176.0 |

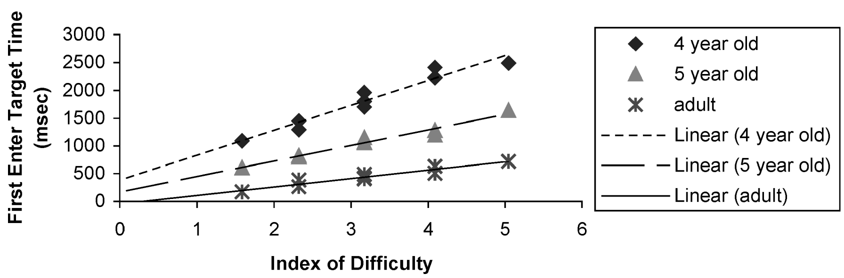


Fig. 8. Plot of time to first enter target versus index of difficulty for 4, 5 year-olds, and adults, including regression lines. Data points show the average time of completion for each combination of target size and distance for each age-group.

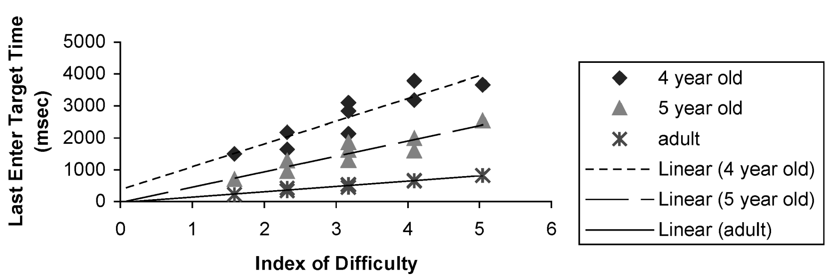


Fig. 9. Plot of time of last entering target versus index of difficulty for 4, 5 year-olds, and adults, including regression lines. Data points show the average time of completion for each combination of target size and distance for each age-group.

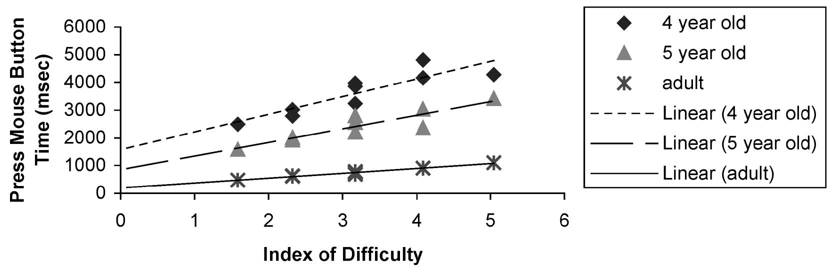


Fig. 10. Plot of time to press mouse button versus index of difficulty for 4, 5 year-olds, and adults, including regression lines. Data points show the average time of completion for each combination of target size and distance for each age-group.

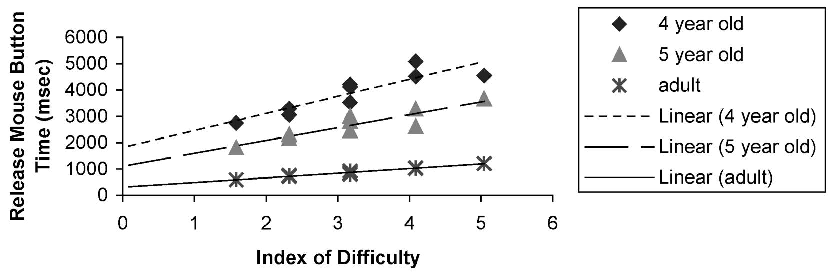


Fig. 11. Plot of time to release mouse button versus index of difficulty for 4, 5 year-olds, and adults, including regression lines. Data points show the average time of completion for each combination of target size and distance for each age-group.

not afterwards. This may be due to the fact that while adults followed a move to the target with an immediate click (as evidenced by small target reentry numbers), children had a tendency to hover over the target once they got to it, to make sure they would click inside. The number of times they reentered targets is evidence of this behavior. The path plots also illustrated this issue. Hence, for children, the task stopped being a Fitts' law task after they arrived at the target. Figure 12 sheds more light onto this issue by showing the composition of movement time for the three age groups. It shows the greater proportion of time it took for children to press the mouse button after they got to the target.

Comparing correlation coefficients derived through the use of $ID_e$ and $ID$, we found much higher correlation coefficients when using $ID$. While MacKenzie [1992] bases the reason for using $ID_e$ on information theory, the practical reason for adjusting the width of the targets is the idea that if participants are less accurate than expected, they likely performed the tasks too quickly (so the target width is adjusted to be bigger), while if they are more accurate than expected, they completed the tasks too slowly (so the target width is adjusted to be smaller). This may sometimes be true for adults, although it did not help in this study, because it does not seem to fit what 4 and 5 year-olds did. When clicking on small targets, the children's low accuracy may have caused $W_e$ to be larger than the real size of the targets even though children were not clicking on these targets "quicker" than they should as evidenced by the fact that they reentered these targets significantly more often than they did larger targets.

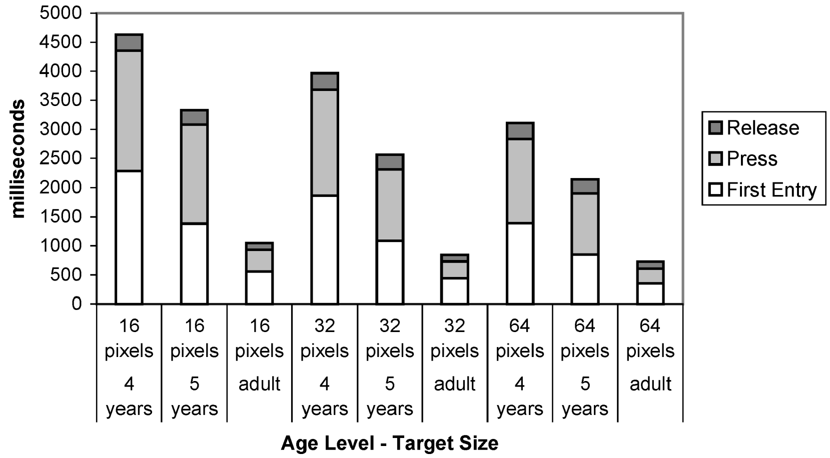


Fig. 12. Average movement time for the three age levels at each target size decomposed by the time it took to first reach the target, the time it took to press the mouse button, and the time it took to release it.

Figure 13 illustrates this by showing representative paths a 4 year-old participant took to click on a 64 pixel target versus a 16 pixel target. When clicking on the 64 pixel target, the participant showed less hesitation yet managed to be accurate. In comparison, when clicking on the 16 pixel target, the participant hesitated more therefore taking more time, yet did not manage to click inside the target. Another possible reason for the problems with $ID_e$ is that it was calculated based on $W_e$ obtained not individually, but on a per age group basis. Given the variability between the performances of children the same age, this could have also affected the usefulness of $ID_e$. An additional reason could be that the targets may have been too small for children to be appropriately modeled by Fitts' law. This is analogous to adults having trouble with very small targets on touch screens [Albinsson and Zhai 2003]. Regardless of the reason, the lower correlation coefficients suggest that in the future, researchers conducting similar studies with children should use both *ID* and $ID_e$ and share and compare the outcomes.

In order to compare the efficiency with which children and adults completed tasks we used Fitts' index of performance (*IP*). While we used *IP* to compare performances within our study, we recommend those seeking to compare performances in this study with those of other studies to use the regression coefficients found on Table VII, Table VIII, and Table IX as they do not depend on the average *ID* (see Zhai [2002] for more information). Table X shows *IP* calculated based on the time participants first entered the target (this is when correlations with Fitts' law were highest, as shown in Table VII, Table VIII and Table IX). The data shows a significant increase in performance with age and a decrease in the coefficient of variance (i.e. the standard deviation divided by the mean). The coefficient of variance tells us, for example, that a 4 year-old whose performance is one standard deviation greater than the mean would perform 30% better than the average child his/her

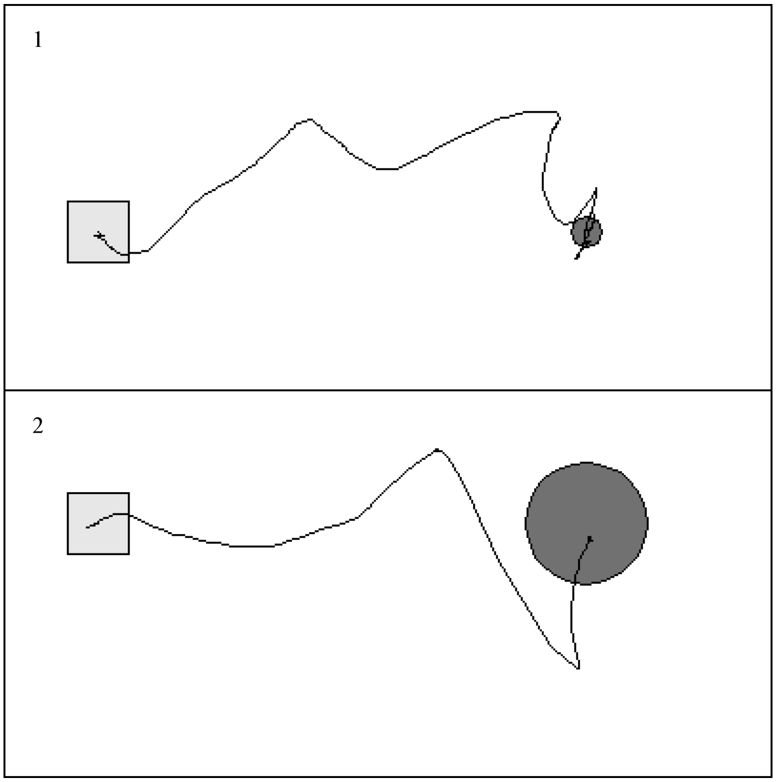


Fig. 13. Mouse paths by a 4 year 3 month old male; (1) when clicking on a 16 pixel target 256 pixels away; and (2) when clicking on a 64 pixel target 256 pixels away.

Table X. Fitts' Index of Performance (*IP*), in Bits per Second, Based on Movement Time to First Enter the Target. Significant Differences Reported According to Pairwise Comparisons Using Bonferroni's Correction

| Age | Mean | Standard Deviation | Coefficient of Variance | Significant Differences |
|---|---|---|---|---|
| 4 years | 1.95 | 0.59 | 0.30 | 5**, adult*** |
| 5 years | 3.24 | 0.60 | 0.19 | 4**, adult*** |
| Adult | 7.80 | 1.08 | 0.14 | 4***, 5*** |

* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

age. On the other hand, an adult with a performance one standard deviation greater than the mean would perform 14% percent better than the average adult. This confirms that variability in performance decreases as children get older.

3.7.4 *Gender Effects.* While we did not design the study to measure gender differences, we still performed ANOVAs to check for significant differences based on gender. The analyses showed that preschool boys on average performed better than girls in terms of accuracy, target reentry, and Fitts' *IP*. We only found significant differences in 5 year-olds though. The differences were in *IP* based on time to first enter target ($p < 0.05$, means: females = 2.84, males = 3.57), and target reentry during click ($p < 0.05$, means: females = 0.21, males = 0.079). Due to the small number of participants in the study, this result should only be taken as a suggestion of possible differences rather than a clear conclusion.

## 4. DISCUSSION

### 4.1 Relevance of Results

Some researchers have questioned the value of conducting studies like the one presented in this paper. In spite of their objections, we believe the results we presented are relevant to the design of graphical user interfaces in children's software.

As mentioned earlier, Strommen et al. [1996] criticized the use of speed, and by extension Fitts' law, when assessing ease of use by children. In spite of their concern, we believe Fitts' law can provide valuable information when used in conjunction with other statistics such as accuracy and target reentry. In particular, it can provide designers with helpful guidelines to ensure children do not have frustrating experiences trying to click on visual targets that take too long to click on. For example, using an input device that moves very slowly could prove highly accurate and have low rates of target reentry and at the same time be frustrating.

Gillan et al. [1990] expressed skepticism about using results from studies like the one presented in this paper to influence the design of graphical user interfaces. They suggested that having participants click on targets may not yield all the information needed to predict more complex interactions such as point-and-drag and the use of menus. This is likely true for applications designed for adults, but does not necessarily apply to applications designed for children. While further studies on children's use of input devices could be conducted, including Fitts' law for dragging tasks, and steering law tasks [Accot and Zhai 1997] for the use of menus and similar tasks, these are not likely to be necessary as such interactions are not common in young children's software. Designers have used simple interactions in young children's software because complex interactions are difficult for children due to their still developing abilities [Strommen 1993]. These simple interactions provide a good match for the type of tasks participants completed in this study. In particular, simple point-and-click interfaces are quite common in software designed for young children (some examples are Benford et al. [2000], Druin et al. [2001], Hourcade et al. [2002a, 2002b]).

As mentioned earlier, Joiner et al. [1998] have questioned the application of Fitts' law to children because they are not capable of expert, errorless performance. Their argument contradicts the studies reviewed in this paper that have successfully applied Fitts' law to children. Our data clarifies the issue, and proves both sides correct by showing very high correlations with Fitts' law up to the point when children first entered targets (see Table VII), and lower correlations afterwards (see Table VIII and Table IX). This suggests that while Fitts' law applies to children, it does not model children as well as adults when clicking on targets.

While Crook [1992] did not argue against studies like the one presented in this paper, his study suggests that young children can actually manage to complete tasks similar to those necessary to use software designed for adults. However, the fact that they can complete the tasks does not mean that they find the tasks easy. The evidence reviewed and presented in this paper clearly shows that children have more difficulty using input devices in their younger years. Experiencing difficult tasks can create frustration, which in turn can make children turn away from potentially enriching educational and creative software [Druin 2002a]. Moreover, we believe children deserve to use software that is designed for their unique abilities. Software should not have to be more difficult to use because children are the users.

## 4.2 Implications of Results

4.2.1 *Severity and Nature of Children's Difficulties.* The study presented in this paper helps to answer the question of the severity and nature of children's difficulties in point-and-click tasks. The evidence shows differences between the children and adults in this study were large enough to warrant interactions designed specifically for preschool children. Not only were children slower, but more importantly, they were significantly less accurate, and had significantly less control over the mouse than adults did. For example, target reentry rates showed clear differences in terms of control. The path plots in Section 3.7.1 further illustrate this issue.

The results also suggest that children have the most difficulty during the homing phase. Several pieces of evidence suggest this is true:

- During the study we observed children having greater difficulty once they got close to the target, especially with targets smaller than 64 pixels.
- The path plots in Figure 4 show typical paths in which children hovered around the target before clicking on it.
- Distance to target had no significant effect on accuracy or target reentry, while target size did, suggesting that the homing phase is responsible for differences in these values.
- Children had low accuracy and high target reentry rates.
- Children spent a greater proportion of time than adults hovering over the target as evidenced by Figure 12.
- Fitts' Law modeled children's tasks well only up to the time they first entered the target.

4.2.2 *Possible Solutions.* Taken together, these elements suggest that preschool children do require interfaces that take into account their developmental needs. In addition, the results suggest designers should concentrate on providing solutions to assist children during the homing phase (i.e. once they get close to the targets).

One way to help is to size visual targets in such a way that children may have accuracy and target reentry rates that will not cause frustration. The advantage of concentrating on target size is that it affects both speed and accuracy. Distance to target, on the other hand, affects only speed and depends on the cursor's initial location.

The downside of increasing the size of visual targets is that they can occupy valuable screen space children could use for authoring, accessing more options, or pursuing other activities. This may not be as problematic as it seems because children's cognitive abilities, needed to decipher the complexity of graphical user interfaces, also improve with age [Thomas 1980]. One way to reduce complexity is to reduce the number of actions available to a user [Shneiderman 1998]. This means that while a ten year-old may be able to work with an interface that has 25 actions available through icons, this interface may be too complex for a five year-old to visually process and use in an effective manner. Thus, young children who can effectively use a lesser number of icons are the same ones who need larger icons.

An alternative to point-and-click interfaces with large icons was proposed by Strommen [1993]. His proposal is to "hop" between the options in a user interface. This can be accomplished with input devices, such as game pads, that have directional buttons, plus an additional button to make selections. Users press the directional buttons to highlight an option of their choice, and then press the selection button to activate it. Using this technique, children could be assured of always being on a valid option, instead of having a cursor miss an icon when pointing-and-clicking. While this technique may not work for every application and may not be appropriate for use with the mouse and other input devices, it is worth considering, especially if the users are very young (e.g. three years old).

Using input devices other than regular sized mice may also help children perform better during the homing phase. Smaller mice will fit children's hands better and may provide some advantages. According to Strommen et al. [1996], young children may benefit from using trackballs due to low target reentry rates. In addition, children may benefit from other input devices, such as tablets, that have not been thoroughly studied with children.

Another option is to slow down mouse motion by using operating system settings. While doing this will increase accuracy and reduce target reentry, it will also increase movement time. If children want to use software with targets that are too small for them, parents or teachers could make use of this operating system setting. Sanders and McCormick [1993] provide a summary of research on how to optimize control-display ratios.

An alternative to simply slowing down mouse motion is to use acceleration. Acceleration could provide speed during the distance-covering phase, and accuracy during the homing phase. There is a possibility though that the difference in speeds could cause some confusion. Extra sensitivity during the distance-covering phase could also bring about additional problems, such as overshooting the target, due to children's control issues.

Expanding targets may also prove helpful to children in the homing phase. Zhai et al. [2003] showed that expanding targets by a factor of two after users covered 90% of the distance to the target increased the speed with which adults managed to complete point-and-click tasks. They also found that if users could predict expansion (i.e. if targets expanded consistently), they had higher error rates as tasks became more difficult, surpassing the error rates for the same tasks without expansion. Since accuracy is likely to be more important to children than speed, this calls into question the viability of expanding targets in children's user interfaces.

Area cursors have been suggested for older adults [Worden et al. 1997] and have also been applied in children's software such as KidPad [Hourcade et al. 2002]. Area cursors make the active area around a cursor larger than the one pixel occupied by the cursor's hotspot. This means, for example, that a user need not be directly on top of an icon in order to interact with it. This approach can have an effect similar to making targets larger. The problem is that if targets are next to each other, area cursors will not be of much help.

Another interesting idea suggested by our data is to use a crossing interface, such as those studied by Accot and Zhai [2002]. In these interfaces, instead of clicking on an option to select it, users cross it either by moving or dragging a pointing device. The advantage of such an interface is that it could save time (as shown in Figure 12) and better match Fitts' law (according to Table VII). In addition, it could help children in situations such as those found by 4 year-olds trying to click on 16 pixel targets, where they had very low accuracy rates, yet they reentered the target several times (see Table VI). The trouble with crossing interfaces is that there are very few examples of its use in software for adults, let alone software for children. In addition, the path plots suggest children may cross many items before crossing their target.

After selecting appropriate options to help children have a comfortable experience using software, a further challenge for designers posed by children's motor skills is that these skills change as children age. An interface designed to take into account the motor skills of nine year-olds will not work well with four year-olds. This is an additional reason, besides the cognitive limitations mentioned by others [Druin 2002b; Strommen 1993], not to design interfaces that will fit all children (so-called "K-12", or "all ages" interfaces).

The number of different age groups to design for is likely to depend on the application at hand. However, the evidence summarized in this paper points to children making greater improvements in their abilities in their early years, as Kail's model predicts. This means that designers should pay greater attention to the needs for age-specialized interfaces when their target audience is younger. For example, the differences between three and four year-old children are more likely to prompt a need for different interfaces than the differences between eleven and twelve year-old children.

The need for different interfaces does not mean that separate applications should be built for each age group. One option is to design for the lowest common denominator. Designers have to be careful when establishing the lowest common denominator due to the high variability in children's performance when they are younger. For example, in this study, while the average 5 year-old has a 74% accuracy rate with 16 pixel targets, a 5 year-old performing one standard deviation below the mean will have an accuracy rate of 49% (see Table VI).

While designing for the lowest common denominator is easy to implement, it can also limit the availability of options for older, or more skilled children. In spite of this limitation, it may be an appropriate solution for simple applications that do not have extra functionality available for older children.

Another option is to design software that can be configured to different skill levels. Windows, for example, allows users to set its icons to be larger (twice the width), and to adjust mouse speed and acceleration. Such options are more difficult to implement, but they may better accommodate more users. These options could also be combined with providing more functionality to more advanced users. In this way, an interface could both adapt to users' motor and cognitive abilities. For example, younger or less experienced users could start using software with fewer options and larger visual targets, and later move on to accessing more options with smaller visual targets. Interfaces for older children could involve many interactions that require reading, typing and spelling skills, while those for younger children could be based on pointing-and-clicking on a small number of appropriately sized icons with meaningful visual designs. This is in tune with Shneiderman's [1998] recommendation of providing novices with a small number of actions and simpler interfaces.

A similar outcome could be achieved by allowing users to take different paths through an application. The paths could be designed to fit different age groups. While children could use the path designed for their age group they would be free to easily explore the paths and interfaces designed for other age groups. An example is SearchKids, [Druin et al. 2001; Hourcade et al. 2002b] an application where children can retrieve the contents of a digital library through different interfaces that can be accessed by navigating through a zoomable environment.

The solutions discussed above were considered as they relate to children. Some of them may additionally prove useful for another population with lower information processing speeds: older adults. In considering the above mentioned solutions for this other population, designers should take into account the additional challenges of designing for older adults including poor vision, memory loss, hearing problems, and other cognitive and sensory issues [Gregor et al. 2002; Hanson 2001].

## 5. FUTURE WORK

More studies need to be conducted to gain a better understanding of the evolution of children's performance with input devices. Of particular interest is whether this evolution follows an exponential curve as proposed by Kail. These studies may also be used to find at what age children reach performances similar enough to adults so that specialized interaction designs are not justified. A natural next step would be to conduct studies with children of other ages, in particular elementary school children. It would be helpful if future studies include eighteen to twenty-two year-old adults as participants in order to better compare results across studies. Additionally, more attention needs to be paid to gender differences.

Similar studies also need to be conducted to learn more about the amount of on-screen options and overall complexity children can manage at different ages.

Guidelines from these studies and others, combined with information on input device performance could provide powerful building blocks for the construction of age appropriate user interfaces. Other populations, such as older adults, could be studied as well.

Other possible research directions include the investigation of various techniques to help children interact with visual items on graphical user interfaces. These include the use of acceleration, crossing interfaces, expanding targets, and area cursors. In addition, it would be valuable to learn how children are affected by the use of different input devices, such as smaller mice, tablets, and trackballs. In particular, we would like to learn how path plots differ when these devices are used.

## 6. CONCLUSION

We empirically evaluated the severity of the differences between preschool children and adults in the use of mice in point-and-click tasks. The significantly lower performance of the preschoolers in terms of accuracy, target reentry and time means that user interface designers should use strategies to accommodate young users. The results also point at children having the most difficulty during the homing phase, as they approach the target. The path plots, together with accuracy and target reentry rates, the time spent by children hovering over targets, and the fact that Fitts' law applies only up to the first time they enter the target all support this claim.

Given our findings, we surveyed possible solutions to children's difficulties. In considering solutions, designers should particularly make certain that user interfaces are appropriate for the youngest children they intend to support and should consider designing alternative interfaces for different age groups. In doing so, they should take into account the greater variability in performance children show at younger ages.

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