Educational Technology Research Section

Formative Studies in the Development of a New Computer Pointing Device for Young Children

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Abstract

The present paper reports the results of two formative research studies conducted during the design process for a new, portable trackball-like computer input device for small children. In the first study, fifty three-year-old children used the new device with the controller ball exposed to different degrees. Results indicated that the more exposed ball led to more stable, transparent performance but that children in both conditions failed to support the device during use. In the second study, a new device with handles and other design changes was compared with the results from the first experiment. Results indicated that the children supported the device much more frequently, specifically by grasping the handles. Developmental differences between younger and older three-year-olds were observed in both studies. The findings are discussed in terms of what they suggest about the design of appropriate interfaces for young children, and how formative research on products in development can contribute valuable information to this new area of educational research.

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Introduction

Formative research, which is employed in the development of new educational products or teaching strategies, is typically thought of as a poor cousin of traditional experimental research in psychology. Traditional research is conducted to address issues that have theoretical implications; the findings are meant to advance knowledge in a particular area by providing results that test competing hypotheses, and are universally valid in their implications. Formative research, in contrast, is conducted to determine what makes a particular computer program or instructional method effective; the findings are often concretely related to the particular software or method being tested, resulting in little easily generalizable knowledge (Schauble, 1990). However, formative studies do have substantial pragmatic value, since they provide empirical data on the success or failure of new designs that can be highly informative (Hawkins & Kurland, 1987; Newman, 1990). The two studies reported here were conducted as part of the design process in the development of a new computer input device for small children. The results of these studies serve two purposes. First, they provide developmental data on children's performance using a particular computer input device; and, second, they are a useful case study of both the iterative nature of formative studies, and the trade-offs typically associated with conducting evaluative research in applied settings.

For almost a decade, the Interactive Technology Group at Children's Television Workshop (CTW) has been producing software for small children for a variety of different computer systems, including Nintendo (Children's Computer Workshop, 1983; Children's Television Workshop, 1988a; 1988b; 1989; 1990; Rice, 1987). CTW has also designed input devices specifically for small children, such as the Atari Kids Controller (Atari, 1983). Extensive formative research on such products in development is integral to the CTW design process, and has provided valuable insights into interactivity and its design for young learners (Strommen and Revelle, 1990). In addition, CTW has conducted basic research studies of young children's ability to use different input devices under various conditions (Razavi, Medoff, & Strommen, 1991; Revelle, Strommen, & Offerman, 1990; Revelle & Strommen, 1990), and has used this information to guide the design of its software products.

In 1988, CTW's Interactive Technologies group was asked to work with a design firm to develop an input device for a new home entertainment system. The new product, an interactive compact-disc system, would use the television as its mode of display. Adults were expected to control software through a thumb-operated joystick and remote control, but such a device was clearly beyond the capabilities of small children. Given that a significant number of software titles for the new system would be designed for preschoolers' use, an alternative input device specifically for young children was required. Two important constraints on the design of this new input device were given. First, the device had to allow young children to point to and select items from icon-based menus appearing on the television screen, as would a computer pointing device like a mouse, joystick, or trackball. Second, the device was to be used in a living room or other casual home environment, so a child had to be able to use it without the presence of a desk or table surface to support the device. Usage scenarios anticipated the child would be sitting on the floor, or on a sofa or chair, at an indeterminate distance from the television screen.

The first step was to consider existing device designs. A review of the properties of each indicated that of the different devices currently available each had distinct advantages and difficulties when considered in light of the design constraints described above.

Touch screen, touch pad, and lightpen

The results of CTW's own research and that of others (Cunningham, 1985; Avons, Beveridge, Hickman, & Hitch, 1983; Revelle, *et al.*, 1990) all had indicated that these devices were very easy for small children to use. They could not be considered as options here, however. The touch screen and light pen both required (1) expensive apparatus not easily adapted to televisions of differing sizes, and (2) a very close proximity to the television, since direct physical contact was necessary to select icons on the TV screen. The touch pad was rejected for several reasons. First, a recent study had raised serious questions about preschoolers' ability to coordinate the simultaneous use of a stylus on the pad with the need to press function buttons to register choices (Strommen, 1991). Second, the control-display gain of the device varies as a function of screen size; the fine-motor performance required to control such a device seemed beyond the ability of most young children (for a general discussion of this issue, see Arnault & Greenstein, 1986).

The mouse and joystick

The inadequacy of the above interfaces led to the consideration of the three most common input devices: the mouse, joystick, and trackball. Although the mouse has been shown to be easy for young children to use, it had to be rejected as a model because it requires a surface on which it can be moved. The joystick was a possible choice; handheld designs are available, so it need not be near the television or on a surface. It has, however, been uniformly shown to be among the hardest devices for small children to control (Revelle, *et al.*, 1990; Revelle and Strommen, 1990), and thus it was not considered as a serious option.

The trackball

The trackball design, like that of the mouse, allows for all aspects of the user's hand and arm movement (direction, speed, and distance) to be directly translated into onscreen cursor movement, a situation that allows for easy mapping of the actions taken on the input device into cursor movement on the screen (Buxton, 1986). CTW's research had shown it to be at least as easy for young children to use as a mouse (Revelle & Strommen, 1990), and a study of adult users had found it to be equal to the touch screen and touch pad in speed, with slightly higher accuracy (Whitfield, Ball, & Bird, 1983). A second appealing quality of the trackball was that the action of rolling a ball is familiar to children, and can serve as an easily grasped analogy for moving the cursor in a desired direction. Since analogies have been shown to be powerful influences on computer use (Allwood, 1986; Carroll & Rosson, 1989), this concrete similarity to a familiar activity was a major asset.

Conventional trackball designs had two serious drawbacks, however. First, they required that the device itself be stationary, located on a table or other surface that is usually very close to the screen and cursor. This design allows the ball to sit firmly in a solid base, so that it can be rolled in the desired direction. Second, the size of the typical trackball is small (usually about one to two inches in diameter) and only a fraction of the ball is exposed for contact with the user's fingers and hand. Such a design requires a high degree of fine-motor control. Typical adult use involves rolling the ball with the fingertips, but Revelle and Strommen (1990) had found that children tended to use their palms, thumbs, and other parts of their hands to roll the trackball. Although they were quite successful using these strategies, the presence of a stable, stationary base for the trackball appeared crucial to their effectiveness. What changes in this basic design could be made that would capitalize on its advantages, and remove the necessity of a desk-level base to support the controller ball?

Modifications to the design and the first study

The design process was governed by the principle that a well-designed input device should (a) provide the user with easy, accurate cursor control; and (b) encourage consistent, stable patterns of usage behavior. It was hypothesized that a single design change might achieve both of these goals: Enlarging the controller ball. A substantially larger controller ball could be designed to rest in a large, portable base that could easily sit on the floor or in a child's lap. The larger ball would also allow for a wide variety of both fine- and gross-motor actions to be used to move the ball, all of which would result in effective cursor movement. However, the use of a larger ball also raised more complex interface issues related to how the motion of the ball is translated into cursor motion on the screen. In conventional trackball use, the small ball only allows for a limited amount of ball rotation per finger stroke. This is not a hindrance, however. The trackball's translation of both speed and distance into cursor action results in effective, psychologically pleasing cursor movement—a series of short, quick strokes can swiftly move the cursor to its destination. Using the same software, however, a large trackball would allow a huge distance to be covered in a single stroke. Moreover, when the ball was rolled quickly the result would be a jarring and confusing change, as the cursor literally flew across the screen.

CTW's software engineer, Michael Artin, proposed an elegant solution to this problem in the form of a software modification. The heart of the change is a loop that checks the trackball and responds to any registered movement of the ball. The cycle takes place in a fraction of a second, so any sense of its length is imperceptible to the user. At the top of the cycle, the program checks the trackball for *any* movement, and if any occurs the program scrolls the screen or moves the cursor a *fixed amount* in the direction indicated: 8 pixels to the left or right, and 5 pixels up or down. Thus, a child spinning the trackball quickly and a child rolling the ball gently both obtained the same response from the cursor. The result is a decidedly non-linear relationship between ball movement and cursor movement, such that the cursor moves at essentially a fixed rate, regardless of the speed at which the child turns the ball.

Once the software changes were made, our next concern was how much of the ball should be exposed for use in cursor control. Conventional trackballs only expose a small portion (typically less than one quarter) of the controller ball's total size. Maintaining this exposure with the new device could be beneficial, for several reasons. First, exposing only a small portion of the ball keeps the surface of the device relatively flat, and encourages flat-fingered hand motions. Second, the relatively flat surface might encourage a more direct translation between the surface with the ball and the television screen, in a manner similar to a touch pad. Exposing a large portion of the ball, however, also posed potential advantages. The raised ball heightens the analogy to the physical act of rolling a ball, a distinct benefit for very young users. Second, the raised ball would also allow for more gross-motor actions by the user to be registered by the cursor, another benefit for younger users. The question of which level of ball exposure was optimal led to the first experiment. A prototype of the new device was created, with two different cases. One case exposed only the upper quarter of the ball, in a manner similar to conventional trackball design; the other exposed almost one half of the ball's surface (see Figure 1). By comparing two groups of three-year-old children using the devices, it was possible to determine which of the two ball exposures was best for young children.

Experiment 1

The two designs were evaluated on two levels: Ease of cursor control and ergonomic soundness of the design. Children's performance when moving the cursor and selecting objects was evaluated using quantitative measures of movement speed and placement accuracy; ergonomic soundness of the design was evaluated by assessing the stability and effectiveness of the physical behaviors children executed on the device to move the cursor on the TV screen. The best design should, first and foremost, allow children to move the cursor easily and accurately. Almost as important, however, the device's physical design should give rise to consistent usage styles, and should not have unexpected consequences for the different styles children adopt when using it.

Method

Participants

Fifty children, 25 boys and 25 girls between the ages of 33 and 47 months (M = 40.4 months), participated in the present study. They were drawn from several preschools and daycare centers in Manhattan, in New York City. The children ranged in SES from lower-middle to upper-middle class.

Materials

The prototypes in Figure 1 were used as the input devices in the present study. Each device weighed about three pounds. The case for the controller ball and buttons measured 11 inches from side to side, and 6.5 inches from front to rear. The controller ball in both devices measured 4.5 inches in diameter, and was made of thick, hollow plastic. Two rollers inside the case registered movements of

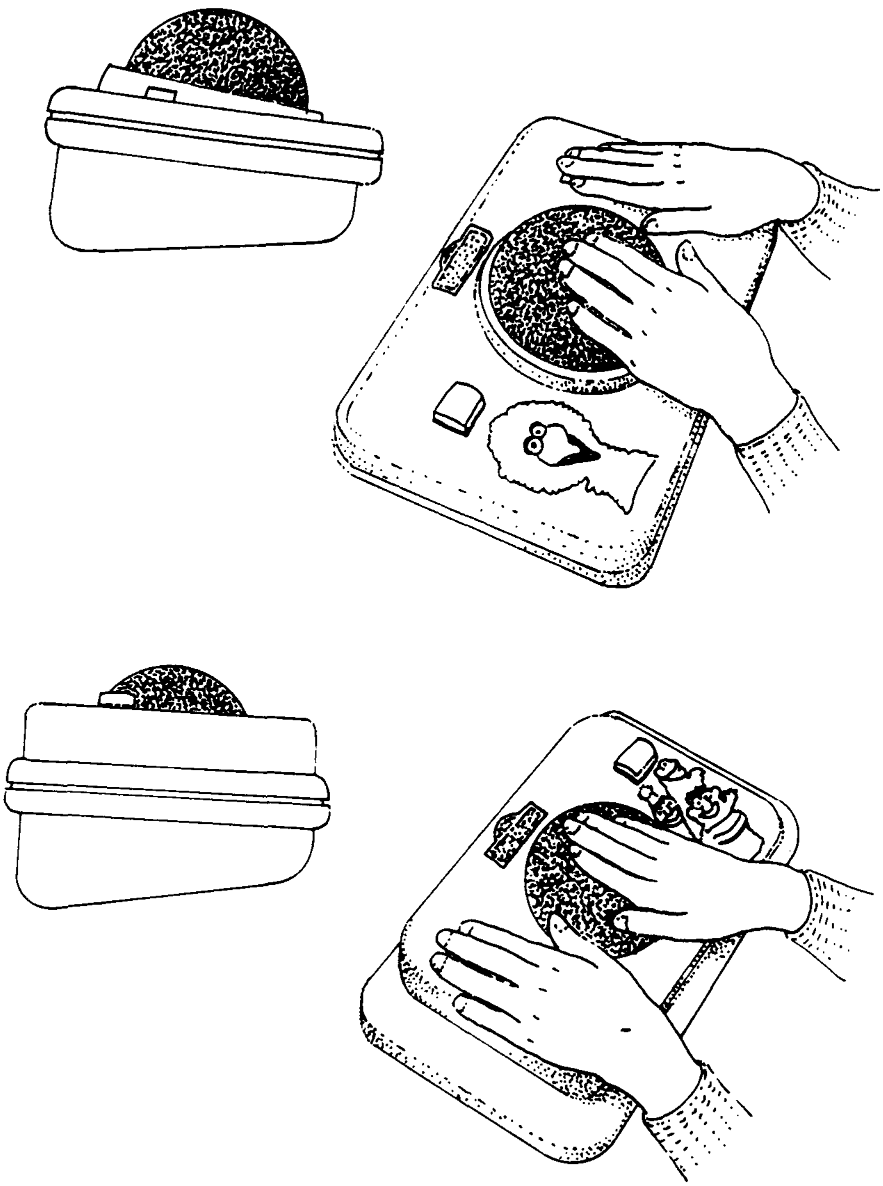

Figure 1. The two levels of large trackball exposure tested in Experiment 1. The low case (top) allows much more physical contact with the ball than the high case (bottom), and proved easier for young children to use.

the ball in terms of X and Y coordinates, which were translated into cursor movement via software. The buttons were two yellow rectangles, 1 × .75 inches in size, located on each side of the controller ball. Both buttons functioned in the same manner, and children could use either to register a selection. In the **low case condition**, the hole in the case through which the ball protruded was almost the diameter of the ball, and the ball extended out of the case a full 1.75 inches. In the **high case condition**, the hole in the case was less than 3.75 inches in diameter, and the ball extended out of the case merely half an inch.

The computer monitor screen measured 13 inches diagonally. The software used was a prototype of an actual software product, a two-screen wide graphic environment (640 × 200 pixels) depicting a cartoon version of the interior of Big Bird's home on *Sesame Street*. There were 13 objects in this environment, an average of 50–75 pixels apart, that responded to user action. The size and location of the objects on the screen were varied, and could not be altered for the experiment, so comparisons of children's performances with the different objects will not be considered in this study. All objects functioned the same way. When the cursor was placed on them, they were highlighted by a "sparkling" effect; when the button was pressed, the objects animated, and produced a sound effect (Big Bird talked, the radio played, etc.). The quality of these drawings was quite high, and children found them very appealing.

Procedure

The children were randomly assigned to two device groups, and each child used only one of the devices. The children were brought into a room where a Wang PC-280 AT compatible computer with a color VGA monitor, and a video camera were arranged. The children were tested while they were sitting on a sofa approximately six feet from the computer screen, or while sitting on the floor at about the same distance. The children were asked to name all the objects, and were then shown how to use the ball to move the cursor in two directions: left and right. The Researcher modeled rolling the ball with his/her fingertips, saying "Watch this! When I roll the ball toward me, the star moves toward me. When I roll the ball toward you, the star moves toward you. You try it!" After the children rolled the ball left and right, they were then asked to move the cursor in two directions for which they had not been instructed: "How should I roll this ball to make the star go up?" and "How should I roll this ball to make the star go down?" These questions served as an index of the child's intuitive grasp of the device's properties. If any of the children could not move the cursor in the requested directions, the Researcher modeled the correct movement for them, and asked them to repeat the actions. If the children could not do so, they did not participate in the study. Children who could move the cursor as required were next asked to "make the star touch Big Bird's TV," and the sparkling highlighting was pointed out to them, with the Researcher saying "When you see those sparkles, you can press a button and something will happen. You can press whichever button you want."

After the children were comfortable with the task, they performed a sequence of 13 trials in which they were asked to move the cursor (a bright green star) to an object on the screen (Big Bird, the radio, etc.) and press a button. Screen objects were kept in the same locations, and tested in the same order, for all children. Each trial was controlled through the computer keyboard such that only the target object was active on each trial. The objects were arranged in a path that satisfied two requirements. First, it required the child to move the cursor in all directions over the course of the session. Second, the most efficient line of movement between objects was always a straight line that did not cross the "hotspot" or active area of any other objects. At the end of each trial, the children could animate the objects as many times as they wanted, and the cursor remained on the object until the Researcher asked the child to move to the next object in the sequence. At the end of the trials, the children were allowed to select whatever objects they wanted during a free play session. The children's performance was videotaped for later analysis.

Results

Scoring and analysis

The children's performance with the two devices was assessed on two levels: ability to place the cursor and soundness of ergonomic design. The ability to place the cursor was measured using three variables. *Movement time* was assessed for each of the 13 objects clicked on, and was defined as the length of time between the child's first movement of the cursor on this trial to the first contact with the target object's hotspot. *Cursor overshoots* were defined as the number of extra times the child passed the cursor across the target object before successfully stopping on it and selecting it. This variable is an indication of accuracy of cursor placement. The *number of different objects highlighted* provides a measure of efficiency of placement, since following the ideal path between objects would result in no contact with others.

The soundness of the ergonomic design of the devices was assessed using three variables as well. *Style of ball use* was a descriptive measure scored according to what parts of children's hands and arms were used to roll the ball. *Consistency of handedness* of both ball use and button use was scored according to whether children used their left hand, right hand, or both hands during the trials. The last action that placed the cursor on the target object was the action scored for the ball, and the first successful button press on the target object was the button action scored. Exclusive left-handed use was scored as a -1; exclusive right-handed use was scored as a +1, and equal use of both hands was scored as a 0. These scores were averaged across the 13 trials to produce a summary value that ranged between -1 and +1, giving an index of hand preference during ball and button use. *Support of the device* during use (by holding onto it, leaning on it, etc.) was simply noted as present or absent during each trial as well.

Unless otherwise noted, all analyses were performed using 2 (device type) × 2 (sex) × 2 (age group) × 13 (object) ANOVAs. For purposes of analysis, a median split of the children's ages was used to create two age groups, those younger than 41 months and those older.

Understanding of cursor control

Only four children failed the directional pretest, where they were asked to move the cursor up and down; these same children did not benefit from the Researcher's modeling of the correct behavior either, and did not participate in the study. It is worth noting that these children were all very young (two were 36 months, one 37, and one 38 months).

Ability to place the cursor

Every child completed all 13 trials without difficulty. The ANOVA of the average number of different objects highlighted revealed a significant effect for age $F(1, 47) = 16.75$, $p < .0001$, and for object, $F(12, 470) = 11.26$, $p < .0001$. The age effect indicates that older children highlighted other objects significantly less often than younger children, M = 0.91 different objects for the older children vs. M = 1.44 for the younger group. The object effect appears to be due to the proximity of objects on the screen to one another; children were more likely to highlight different objects on the way to a target object where there were objects near to the path being traveled, indicating some deviations in their trajectories across the screen. ANOVA results for child movement time indicate significant effects only for age group $F(1, 47) = 18.62$, $p < .0001$, and object, $F(12, 470) = 15.22$, $p < .0001$. The age effect is due to the fact that younger children are significantly slower than older children, M = 11.78 seconds per trial for the young group vs. M = 6.88 seconds for the older group. The object effect simply reflects the unequal distances between the objects. The ANOVA for number of overshoots reveals a significant effect for age group, $F(1, 47) = 10.47$, $p < .002$, and for object, $F(12, 470) = 4.78$, $p < .0001$. The age difference reflects increased accuracy of placement with age. While the younger children overshot the target objects M = 1.37 times, older children overshot objects M = 0.68 times per trial. The difference between the objects appears to be related to the size and dimensions of the individual object hotspots. Small, or narrow, objects were more frequently overshot than larger, or wider, objects.

Ergonomic variables

Based on an initial review of the videotapes, children's use of the device was classified into two types: vigorous and delicate. Vigorous use was defined as use of the whole hand (thumb, fingers, and palm together) to produce hard, rolling strokes that spun the ball several rotations each. Delicate use was defined as using only the fingertips and thumbs, alone or in various combinations, to roll the ball in shorter, tighter, and more controlled movements. Inter-rater reliability for this classification scheme, using the percent agreement method, was 90%.

Overall, 36% of children in the low case condition and 32% of children in the high case condition employed hard rolling action at least once during the sessions. While ball exposure did not affect usage style, the high case did not prove to be effective in supporting vigorous action. For both case types, the amount of exposed ball surface influences how far the cursor will move with each roll of the ball. In the low case condition, a long roll moved the cursor a substantial distance across the two-screen wide environment. In the high case condition, however, the ball can only be rolled a small distance before the hand must be repositioned for a new movement, resulting in more limited cursor movement per each roll of the ball. In the high case condition, several children struggled to use both hands sequentially to keep the ball in constant motion, and several others adopted an unusual method of sliding the entire length of their arm across the ball to achieve the same goal. This behavior was not observed in the low case condition. An additional difficulty with the high case was that of the children who used vigorous rolling, several actually pinched their fingers in the edge of the case where the ball and case meet. No children pinched their fingers in the low case condition; the edge of the case was far from the upper area of the ball where children used their fingers.

High or low case also made a difference in handedness of device use. Children's average hand preference scores were analyzed using a 2 (device type) × 2 (sex) × 2 (age group) ANOVA design. For handedness of ball use, age was not a significant factor, and neither was sex; however, the high case produced more two-handed ball use than the low case (handedness M = .31 for the high case vs. M = .61 for the low case, $F(1, 47) = 2.97$, $p < .09$). For handedness of button use, the effect was even more substantial: While age and sex were again not significant factors, the high case resulted in significantly less consistency in which hand was used to press the buttons (M = 14), compared to the low case (M = .63), $F(1, 47) = 7.46$, $p < .009$.

Children's support of the device was scored in terms of whether they held onto the device while using it, and if so, whether they used one or both hands to do so. The results revealed a surprising and unforeseen problem: 80% of the children (75% for the low case and 85% for the high) supported the device on an average of less than two of the 13 trials. They used both their hands to roll the ball and press the buttons, but seldom used a free hand to stabilize the device during use. As a result, it frequently slid off the children's laps, or had to be repositioned; during use; 20% of the children actually dropped the device off their laps onto the floor at least once during use.

Discussion

The results of the comparison between the high and low case designs yielded several findings. First, the two designs did not differ in their effects on children's ability to move the cursor; both trackball-based designs allowed children to perform the desired task easily. Second, significant age-related changes in all three variables related to cursor control were observed. The direction of the mean performances clearly indicates that between the ages of three and four, children's performances increase in speed and accuracy. And although the response times for both age groups seem long in comparison with adult performances reported in other studies, they are actually comparable to the times observed in previous studies of young children's input device use (c.f., Revelle and Strommen, 1990). It appears that young children move the cursor more slowly, and tend to deviate its course during movement more often, resulting in longer movement times. The third finding of the present study is that case design had a notable effect on the consistency of handedness of ball and button use. Stable, consistent usage behavior was identified as a goal of the new design. The finding that the high case resulted in more variable motor performances, and caused problems especially for children who used vigorous action, suggests that the more exposed ball in the low case is the superior design overall, despite a lack of quantitative differences between it and the high case model.

As is often the case with formative research, however, unexpected negative consequences of the design led to modifications to be tested in a new study. In the present situation, the unexpected problem of child users failing to support the device during use meant that the basic design of the device had to be judged inadequate. The absence of a supporting surface for the device makes the user's support of it a critical issue. In examining the children's performances, several possible factors that contributed to children not supporting the device were hypothesized. First, the device was somewhat large for small children. The cumbersome shape and size of the device may have contributed to children's being unable to "hang on" to it during use. Second, children had complained that the device was "heavy" for them. The weight of the device may have contributed to its being unsteady on their laps, and to the children feeling as if they were unable to secure it or catch it if it fell. Third, the bottom of the device was smooth, causing it to slide around on rugs or on clothing fabric. Finally, while the outer case of the device had a distinct rim, no children grasped it like a handle; in fact, no handles existed on the device. In considering how to improve the device to encourage support, we made several structural changes based on the above hypotheses that were then tested in the second experiment.

Experiment 2

The goal of the present study was to determine if changes in the design of the case of the device would increase the number of children supporting it, and whether these changes would have any adverse effects on their ability to use the device. Based on the factors hypothesized to contribute to children's failure to support the device, several changes were made in the design of the device (see Figure 2). First, the device was made smaller and lighter. The horizontal width of the device remained unchanged, but the vertical width was shortened more

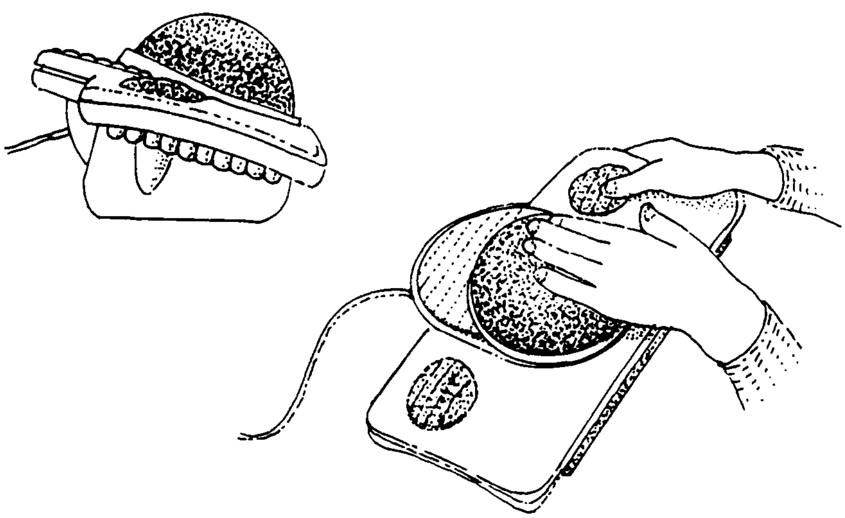

Figure 2. The modified large trackball device tested in Experiment 2. Note the curved sides and handles to encourage support during use.

than 15%, from 6.5 to 5.5 inches. Lighter plastics and a thinner wall were used in the new case as well, resulting in a substantial weight reduction from just over three to just over two pounds. Second, high-friction rubber strips were added to the bottom of the device to increase its traction on fabric and floors. Finally, the rim of the case was extended and molded into handles on the two sides of the device. All of these changes were intended to increase the stability of the device during use, and to encourage children to support it during use by holding onto it in some fashion. A new sample of children was then tested on the modified device to determine if our changes accomplished the goals that we intended.

Method

Participants

Twenty children from the same environments described in Experiment 1 participated in the present study; no child who participated in the first experiment was included in the second. There were equal numbers of males and females in the group, with a mean age of M = 44.33 months (range 39 to 47 months).

Procedure

The procedure was identical to that in Experiment 1. The only difference was the computer used—a Toshiba 5200 30386 laptop computer, with the same software and same color monitor that was used in Experiment 1, replaced the Wang PC-280.

Results

Scoring and analysis

The scoring and analysis were conducted in the same manner as outlined for Experiment 1. The data from Experiment 1 for the low case condition were compared to the data collected from the new design.

Ability to place the cursor

No children failed the directional pretest. All children completed all 13 trials without difficulty. ANOVA results of the average number of different objects highlighted reveals a significant main effect only for object, $F(12, 480) = 4.43$, $p < .0001$, and for the object by age group interaction, $F(12, 480) = 2.01$, $p < .03$. The interaction effect is apparently the result of the fact that for nine of the 13 objects, older children highlighted significantly fewer objects than younger children, while for the remaining four objects there were no significant age differences. Results for movement time indicate significant effects for age group, $F(1, 48) = 5.58$, $p < .02$, device type, $F(1, 48) = 22.06$, $p < .0001$, and object $F(12, 480) = 8.64$, $p < .0001$. The age effect is due to the fact that younger children are again significantly slower than older children, M = 9.31 seconds per trial for the young group vs. M = 4.94 seconds for the older group. The device effect reflects the fact that children were significantly faster with the new design than the original, M = 8.95 seconds with the first design vs. M = 3.23 for the new model. The object effect again appears to be related to the distance between the objects.

An ANOVA of the number of overshoots reveals no significant effects for any variable.

Ergonomic variables

The ways in which the children used their hands on the ball were similar to those observed in the first experiment, but with several notable differences. First, the new design produced a marked reduction in the use of vigorous rolling; only a single child (5% of the sample) rolled the ball vigorously during the trials. The majority of children employed the more delicate finger and thumb control also observed in the first study. This drop in gross-motor behavior appears to be due to the increased tendency of children to support the device with one hand grasping a handle during use (see below). In Experiment 1, children tended to use one hand on the ball and the other on a button. Because one hand was continuously on the ball, it could be rolled frequently and with some vigor. The current design leads children to grasp the handle with one hand, and use the other to both roll the ball *and* press the button. Because the free hand must now serve two functions, rather than simply roll the ball, the ability to roll the ball in a continuous, vigorous manner is greatly reduced.

The effects of the new design on handedness were examined by submitting the children's average hand preference scores to a 2 (age group) × 2 (device type) × 2 (sex) ANOVA. The results indicate that the mean handedness score for ball use of the new design (M = .55) is not significantly different from the low case design in Experiment 1. A significant difference in consistency of handedness for button use was found only for age group, $F(1, 48) = 6.30$, $p < .02$, $M = 0.81$ for younger children, but $M = 0.44$ for older children. No difference between the two designs was obtained.

Significantly more children supported the new device, 65% vs. an average 22% for the previous study, χ^2 (1, n = 70) = 8.64, $p < .001$. The modal support method involved grasping the left handle with the left hand, and using the right hand to both roll the ball and press the buttons. With our few consistently left-handed children, this pattern was simply reversed: left-handers grasped the right handle with their right hand and used the left to roll the ball and press the buttons. For those children who did not support the device, the high-friction strips added to the bottom made a big difference. The device rode securely on their laps, and no children in the present study dropped the device during use.

Discussion

The results of Experiment 2 indicate that the design changes meant to encourage children to support the device were successful in doing so. The addition of the handles, in particular, had a powerful effect on how children held the device during use. The simple presence of the handles caused them to be used—a striking finding when considered in light of the fact that the "wings" on the case of the first device designs were very similar to the handles on the new design. The presence of a special graspable edge under the wing appeared to make the difference. This finding supports the observations of Norman (1988), who contended that certain physical structures, such as doorknobs or buttons, "afford" or imply that certain types of action can be performed on them, based on cultural norms and conventions. Many children's toys have handles, and including handle structures on either edge of the device appears to access children's familiar seheme for holding something.

In addition, children's performance when using the device becomes more consistent across users, with a notable decline in the rough, vigorous rolling action observed in Experiment 1. Children tended to hold the device using a "one hand on a handle, one on the ball or button" style, in contrast to the more variable two-handed and one-handed styles noted in the first experiment. Holding a handle of the device in order to support it thus appeared to have the beneficial, secondary effect of preventing children from executing the rough rolling noted in the first experiment. This result illustrates the important, indirect (and frequently unanticipated) effects that design changes meant to address one dimension of the product's use can have on others—in this case, for the better.

General Discussion

Both studies reported here illustrate the role of formative research as a tool in the product design process. The goal of formative research is not just to evaluate whether a product in development has achieved its goals, but also to identify unanticipated consequences of the product's design that may need to be modified. The first experiment, for example, clearly indicated that children could use both versions of the new device to control cursor motion, but also revealed problems with the high case that ruled it out as the best design. The first experiment also revealed, however, that children were not supporting either version of the device during use—a critical problem. Observations made in the first study led to the isolation of a set of properties of the device that were hypothesized to discourage support, and these features were modified for a new study. The second experiment assessed these changes against the original design. The results clearly indicated that these changes, especially the adding of handles, prompted children to support the device during use.

In closing, it can be seen that formative research differs from traditional experimental work in significant ways. First and foremost, formative studies serve a different purpose than basic research. They are conducted to answer immediate questions with concrete implications, rather than to address theoretical issues. Formative studies thus must often be conducted using very limited finances and schedules, constraints that have a significant impact on their design and execution. In the present paper, for example, the results of the second study were compared with the data from the first rather than with a new, independent sample of children using the original design. This is not considered an ideal experimental design, but it is the best that could be done given the resources available in the production schedule for the new device.

The pragmatic, evaluative nature of formative studies also means that unlike basic research, which is carefully designed to answer a narrow theoretical question, formative studies are much broader in focus. Formative studies attempt to evaluate the product in question in an open-ended manner, so that spontaneous problems and successes can be documented and scrutinized. Formative studies are thus often much more observational and eclectic in their design than traditional studies (Savenye, 1992).

Formative studies thus bridge a significant gap between the product development process and the theoretical literature. These studies provide useful information about the success or failure of a given product design, and the effect of different modifications on it. They do not, however, attempt to explain either why a given design is effective or whether the reasons for a design's success reflect on a particular psychological theory. Nonetheless, the results of such applied studies provide empirical grist for the theoretical mill, just as theoretical studies inform the design of new products in the first place. Yet, formative studies often remain unpublished, because they are viewed as "lacking in rigor" by traditional standards. Hopefully, the results of the two studies included here demonstrate that a lack of "rigor" does not mean a lack of informative content. A closer relationship between the two types of research can only lead to the more profitable linking of theory and practice in the field of educational technology—a linkage that is long overdue. ■

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