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Human Factors: The Journal of the Human Factors and Ergonomics Society 2005 47: 271
DOI: 10.1518/0018720054679452

SPECIAL SECTION

Touch a Screen or Turn a Knob: Choosing the Best Device for the Job

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Input devices enable users to interact with systems. In two experiments, we assessed whether and how task demands and user age influenced task performance for a direct input device (touch screen) and an indirect input device (rotary encoder). In Experiment 1, 40 younger (18–28 years) and 40 middle-aged to older adults (51–65 years) performed tasks using controls such as sliders, up/down buttons, list boxes, and text boxes while using a system. The optimal input device to facilitate performance was dependent on the task being performed and the age of the user. In Experiment 2, touch screen use was assessed for 20 younger (19–23 years) and 20 older adults (51–70 years). Task demands were manipulated through button size, movement distance, direction, and type of movement. Performance was moderated by the age of the user and by task demands. Actual or potential applications of this research include guidance for the optimal selection of input devices for different user populations and task characteristics.

INTRODUCTION

A successful human-system interaction depends on the human's ability to communicate with the system – to direct it to perform an action, to request a piece of information, and so on. Such communication occurs through use of an input device such as a keyboard, button, knob, mouse, touch screen, or voice activation. The present research focused on variables that could influence input device use. For example, does the optimality of an input device depend on the task being performed? Is performance with a given input device influenced by the age of the user?

Recognition that one input device might be better relative to another device for a particular task is certainly not new. In fact, new input devices often are developed in an attempt to compensate for the limitations of existing devices. However, a systematic analysis of the interactions among task demands, user capabilities, and input device characteristics is lacking.

Input devices may be categorized as *direct devices* and *indirect devices.* A direct input device is one for which no translation is required between the activity performed by the person and the action of the device; examples include a touch screen, a light pen, or voice activation. Indirect devices, however, require a translation between the activity of the person and the action of the device. For example, a mouse moves in one dimension on the desktop and the cursor on the screen moves in a different dimension; moreover, depending on the settings of the mouse, a 1-inch movement of the mouse might result in a 3-inch movement of the cursor. Other examples of indirect devices include trackballs, joysticks, and rotary encoders.

The input device categories of direct and indirect have advantages and disadvantages, as summarized in Table 1. Generally, direct devices are best for discrete, pointing, and ballistic types of tasks. Indirect devices yield better performance for precision tasks or repetitive tasks. However, these generalizations are based on studies in which devices were compared for tasks in isolation (for reviews, see Greenstein, 1997; Greenstein & Arnaut, 1987). Whether these studies

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TABLE 1: Input Device Comparisons

Device	Advantages	Disadvantages
Direct Devices		
Examples: touch screen, light pen, voice recognition	Direct hand-eye coordination No need to memorize commands Minimal training High user acceptance Requires less space Long, ballistic movements accomplished quickly Better for pointing tasks	Arm fatigue Limited resolution Difficulty with precision Slow entry Finger or arm may obscure screen Inadvertent activation No inherent feedback
Indirect Devices		
Examples: rotary encoder, mouse, joystick, trackball	Can adjust control-display ratio More precise Gives tactile feedback Experienced users prefer it for long periods of use	Requires translation between rotary and linear movement Requires translation between hand and screen Requires learning time Movement time between controls is lengthy

Note. Data from Department of Defense Military Standard 1472D (1989), Greenstein (1997), and Greenstein and Arnaut (1987).

predict input device superiority and apply to the variety of tasks that must be performed in a complex system are empirical questions.

An additional research question is whether the pattern of advantages and disadvantages for input device categories will generalize across user groups differing in age. As people age, motor behaviors change such that older adults, compared with younger adults, take longer to make similar movements, and their ability to maintain continuous movement declines, coordination is disrupted, and movements are more variable (for a review, see Vercruyssen, 1997). In addition, older adults have more “noise” in their movement control system (Walker, Philbin, & Fisk, 1997), less effective perceptual feedback (Walker et al.), reduced working memory capacity (Zacks, Hasher, & Li, 2000), and declines in spatial ability (Salthouse, 1992). All of these characteristics associated with older age could conceivably influence use of input devices.

Some studies have directly examined older adults’ use of input devices. When using a mouse, older adults tend to make more errors and are slower than younger adults (Charness, Kelley, Bosman, & Mottram, 2001; Smith, Sharit, & Czaja, 1999; Walker et al., 1997), even if they are experienced mouse users (Walker, Millians, & Worden, 1996). However, few researchers have compared older adults’ performance across different input devices. One notable exception is a recent study by Charness, Holley, Feddon, and Jastrzembski (2004) in which performance using a mouse and a light pen was compared across young, middle-aged, and older adult age groups. They found that using a light pen reduced age-related differences for a menu target acquisition task. They suggested that direct devices might be generally better for older adults because they reduce the need for a translation from the activity of the user to the action of the device. However, additional assessments for a range of tasks are required to determine if the benefits of a direct device are general or specific to certain tasks.

OVERVIEW OF EXPERIMENTS

The purpose of the present research was to assess, comparatively, input device use for younger and older adults. The first experiment contrasted a direct device (a touch screen) and an indirect device (a rotary encoder). Performance for the two devices was assessed within the context of using a system; comparisons were made for a variety of tasks – some predicted to be performed better with the direct device, and others predicted to be performed better with the indirect device. We compared the performance of younger adults and adults over age 50 across tasks to determine if the age of the user interacted with use of each input device.

The second experiment focused solely on touch screen usage. Given the increased prevalence of touch screen interfaces and the potential performance issues found in Experiment 1, we conducted the second study to provide more detailed performance characteristics. We systematically manipulated the size of the target area, the distance of the movement required, the direction of the movement, and the type of movement (tapping or sliding). These comparisons enabled us to assess in more depth the task parameters that influence touch screen performance for younger and older adults.

EXPERIMENT 1: INPUT DEVICE USE IN CONTEXT

This experiment assessed performance differences for a direct versus an indirect input device as a function of the characteristics of the task being performed (i.e., the type of control) and the age of the participant. Rather than assess performance for the different task types in isolation, we assessed performance in the context of interacting with a system. Younger and older adults completed activities on the Entertainment System Simulator using either a direct touch screen device or an indirect rotary encoder device. Performance was assessed on tasks that would be expected either to be better for the direct device (i.e., ballistic, pointing, and discrete tasks) or to be performed better using the indirect device (i.e., precision and repetitive tasks).

EXPERIMENT 1: METHOD

Participants

Forty younger adults (18–28 years) and 40 middle-aged to older adults (51–65; hereafter referred to as *older*) participated in this experiment. The age range of the older group was chosen to be representative of the "older worker." Younger adults received course credit, and older adults were compensated $10/hr for their participation. Screening requirements were as follows: (a) corrected visual acuity of at least 20/40 (far and near vision); (b) hearing ability sufficient to respond to task-relevant sounds presented via a Visual Basic program; and (c) trimmed fingernails that would not interfere with the touch screen (participants were told prior to coming in to ensure that their fingernails were trimmed).

Upon their arrival, participants were assigned to either the touch screen or the rotary encoder condition. Standard ability tests were administered to evaluate whether the participant groups differed; these data are presented in Table 2, along with the demographic and health data for each group. The only significant difference for the young adults was that simple reaction time (RT) was faster for the rotary encoder group; there were no group differences for the older adults. We tested handedness to ensure that the assignment of left-handed participants was balanced across device conditions. Participants were instructed to use their preferred hand. Overall age differences ($p < .05$) were as follows: Older adults performed better on the vocabulary test and had more years of education; younger adults performed better on Digit Symbol Substitution, Reverse Digit Span, simple RT, and choice RT. These differences are consistent with those typically reported in the literature (e.g., Rogers, Hertzog, & Fisk, 2000). There were no age differences in self-reported health.

Materials

Input devices. The touch screen was a Data-Lux LMV10 capacitive touch screen, which required a bare finger to be in contact with the screen. The unit was approximately 11.5 inches across and 8 inches high (29.2 × 20.3 cm). The active, touch-sensitive screen was approximately 10.4 inches (26.4 cm) in diagonal. The monitor was securely attached to the desk, so it did not move when touched. The rotary encoder consisted of a black plastic outer casing about 3.25 × 1.5 × 1 inches (8.2 × 3.8 × 2.5 cm). A push button and rotary knob were located on the top face of the box. Participants held the device in one hand and controlled the knob with the other.

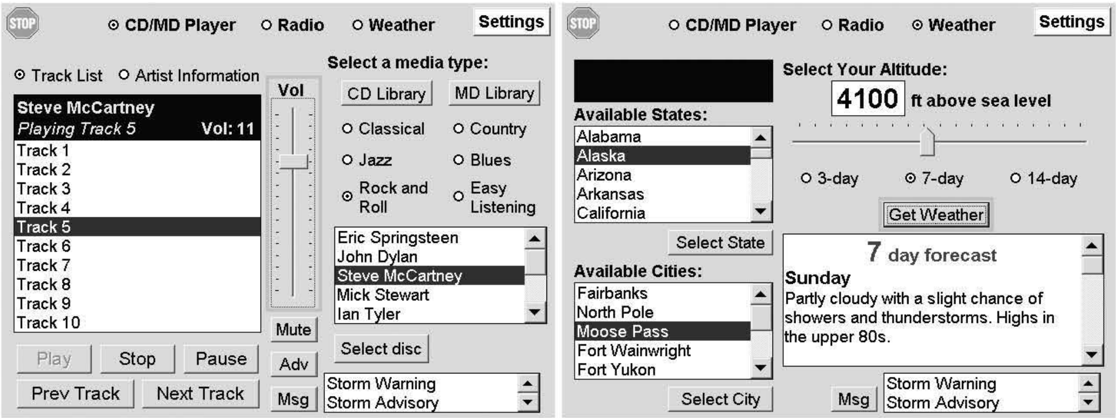
Entertainment System Simulator. The interface used in this experiment was a simulation of an entertainment system created using Microsoft Visual Basic 6.0 (see Figure 1 for screen examples). The simulator was sized to fit on the touch screen display, which was 640 pixels wide by 480 pixels tall. All text was sized to be 14 points

TABLE 2: Demographic and Ability Data for Participants in Experiment 1

	Touch Screen		Rotary Encoder		
	M	*SD*	*M*	*SD*	*t* Value*
	Younger Adults				
Males/females	12M/8F	—	10M/10F	—	—
Age	19.55	1.23	20.35	2.87	—
Education[a]	2.70	0.47	2.80	0.52	0.64
Health[b]	3.84	0.83	4.00	0.82	0.59
Digit Symbol Substitution[c]	71.65	8.41	69.50	11.10	0.51
Reverse Digit Span[d]	8.20	2.04	9.00	2.88	–0.66
Vocabulary[e]	31.35	3.03	30.35	5.32	–0.66
Simple reaction time[f]	276.59	43.43	316.14	65.47	2.14*
Choice reaction time[g]	326.37	52.06	347.47	80.79	0.91
Handedness[h]	1.15	0.37	1.05	0.22	–1.04
	Older Adults				
Males/females	6M/14F	—	8M/12F	—	—
Age	58.68	4.68	58.25	4.39	—
Education[a]	4.00	1.81	3.65	1.39	–0.69
Health[b]	3.60	0.94	3.50	0.95	–0.34
Digit Symbol Substitution[c]	60.30	9.90	57.00	13.46	–0.08
Reverse Digit Span[d]	7.50	2.48	7.30	2.96	–0.38
Vocabulary[e]	35.00	3.48	33.45	5.07	–0.03
Simple Reaction Time[f]	396.72	179.08	349.27	85.25	–1.07
Choice Reaction Time[g]	411.91	81.89	397.47	86.61	–0.54
Handedness[h]	1.05	0.22	1.05	0.23	0.04

[a] Range: 1 = less than high school, 2 = high school, 3 = some college, 4 = bachelor's degree. [b] Self-rating: 1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent. [c] Perceptual speed (Wechsler, 1997). [d] Memory span (Wechsler, 1997). [e] Verbal ability (Shipley, 1940). [f] Simple RT: time to press one key, in ms (locally developed). [g] Choice RT: time to select respond to one of two keys, in ms (locally developed). [h] Edinburgh handedness inventory (Oldfield, 1971): 1 = right, 2 = left.

*$p < .05$.



● CD/MD Player ○ Radio ○ Weather

● Track List ○ Artist Information

Steve McCartney
Playing Track 5 Vol: 11

Select a media type: ● Rock and Roll

Selected: Steve McCartney

○ CD/MD Player ○ Radio ● Weather

Available States: Alaska

Available Cities: Moose Pass

Select Your Altitude: 4100 ft above sea level

○ 3-day ● 7-day ○ 14-day

7 day forecast

Sunday
Partly cloudy with a slight chance of showers and thunderstorms. Highs in the upper 80s.

Figure 1. Sample screens from the Entertainment System Simulator used in Experiment 1, showing the screens for the CD player and weather information. Notice the variety of controls, including sliders, up/down buttons, text boxes, and list boxes.

or larger (equivalent to approximately 4.9 mm). The three primary functions of the Entertainment System Simulator were a compact disc player, an AM/FM radio, and a weather information station. In addition, the system had three subscreens that governed advanced audio controls (e.g., setting treble level), user settings (e.g., date and time), and a message center. The simulator was designed to include a variety of controls that are typically found in human-computer interfaces. (Additional details of the program are available in Rogers et al., 2002.)

Display configuration. The participant workstation consisted of two monitors. A 17-inch (43.2-cm) video graphics array (VGA) monitor was used to display the steps of the activities to be performed on the simulator. This monitor was centered in the workstation at eye level, approximately 18 inches (45.7 cm) from the participant. The touch screen was used to display the simulator. It was centered below the other monitor, approximately 16 inches (40.6 cm) from the participant.

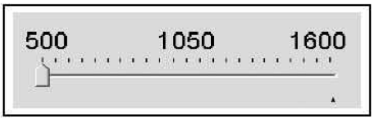
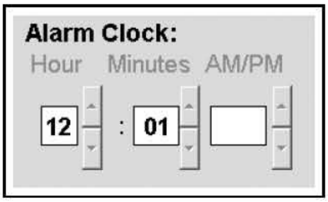
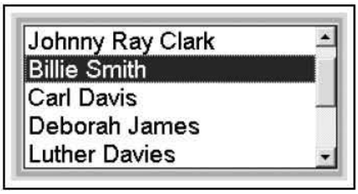
Simulator activities. The participants in the touch screen and rotary encoder conditions performed the same activities with the simulator. Each activity required traversing a maximum depth of two screens. For example, setting the treble on the radio required selecting the main radio screen and then selecting the advanced settings screen. Each activity required five to seven steps, and participants were instructed to follow the step-by-step instructions that were presented via a PowerPoint presentation on the monitor above the simulator screen. The instructions were presented in this manner to minimize the participants' memory load. Participants were asked to select a red stop sign at the upper left corner of the screen to indicate when they had completed an activity. The experimenter then advanced the slide show to the next task.

Simulator controls. To assess performance for different task characteristics, we selected different system controls to compare across the input devices. Controls used included sliders, up/down buttons, text boxes, list boxes, and drop-down list boxes (see Table 3). Controls were selected that would be expected to favor either the direct touch screen device or the indirect rotary encoder device. Thus we compared the following tasks: (a) ballistic task – moving a slider a long distance (more than 40 mm); (b) discrete task – selecting an up/down button a few times (fewer than 20); (c) pointing tasks – selecting an item from a list box or drop-down list box (in which scrolling was not required; the ballistic, discrete, and pointing tasks were all predicted to yield better performance when using a touch screen); (d) precision tasks – moving a slider a short distance (less than 20 mm), scrolling within text box and list boxes, and scrolling to select from a drop-down list box; and (e) repetitive task – selecting an up/down button multiple times (more than 80). The precision and repetitive tasks were predicted to be performed better with the rotary encoder. The tasks and predictions are presented in Table 4.

Navigation. Navigation with the rotary encoder involved two actions: (a) turning the rotary encoder, which moved an orange "highlight" (a box) clockwise around the various active controls (see Rogers et al., 2002, for the selection order); and (b) pressing the selector button to engage in transactions with the highlighted object, which turned the selector box yellow. When the selector box was yellow and the selector button pressed, movement of the rotary encoder knob constrained item selection to within that control. Pushing the button on the rotary encoder again turned the selector box orange, and navigation proceeded as usual. In the touch screen condition, in which participants selected the control directly, the orange selector box appeared around the control that was selected as feedback that the screen registered the touch.

Data collection. Whenever an event took place (e.g., tap on screen or rotation of encoder) an event log recorded participant number, experimental information such as condition and age group, name of item selected, amount of time that item was selected, the amount of time elapsed between the previous selection and the current selection, and a timestamp of the milliseconds elapsed since the task began. The program collected three aspects of completion time: (a) the amount of time between uses of a control (movement time); (b) the amount of time an actual control was active – that is, how long a finger was on a control in the touch screen condition or how long a button was held down in the encoder condition (button time); and (c) total time (i.e., the sum of all individual

TABLE 3: Control Descriptions and Examples

Control	Description	Example From Simulator
Slider	Allows selection of values by moving an indicator on a scale.	
Up/down button	Operates by moving an increment each time either the up arrow or the down arrow is selected.	
Text box	Contains text; additional text may be reached by selecting the up/down arrows at either end of the scroll bar or by moving the scroll bar itself.	14 day forecast Sunday Partly cloudy with a slight chance of showers and thunderstorms. Highs in the upper 80s.
List box	Available options are listed in a box; additional options may be reached by selecting the up/down arrows at either end of the scroll bar or by moving the scroll bar itself.	
Drop-down list box	Displays a currently selected list item. When clicked, a list of other potential items "drops down," from which another selection can be made. After selection of another item, the dropped-down list disappears.	

button times and movement times for a given task).

Procedure

Participants first completed the vision and hearing screening tests and then the simple and choice RT tasks. They then completed the handedness questionnaire, the input device experience questionnaire, and the ability tests. Participants were then given three practice activities on the Entertainment System Simulator, during which they were instructed how to perform on different controls. Experimenters read the instructions and allowed participants to ask questions. The practice activities were comparable to those performed in the experiment and provided exposure to each of the different controls.

TABLE 4: Control Task Descriptions, Predictions, and Summary of Results for Experiment 1

Control Task	Description	Prediction	Younger Adults	Older Adults
Long slider	Ballistic	TS < RE	TS < RE ($p < .01$)	No difference ($p = .90$)
List box, without scrolling	Pointing	TS < RE	No difference ($p = .25$)	No difference ($p = .81$)
Drop-down list box, without scrolling	Pointing	TS < RE	TS < RE ($p < .01$)	TS < RE ($p < .01$)
Short up/down Button	Discrete	TS < RE	TS < RE ($p < .02$)	No difference ($p = .19$)
Short slider	Precision	RE < TS	No difference ($p = .22$)	No difference ($p = .17$)
Text box, with scrolling	Precision	RE < TS	No difference ($p = .54$)	No difference ($p = .35$)
List box, with scrolling	Precision	RE < TS	No difference ($p = .96$)	No difference ($p = .35$)
Drop-down list box, with scrolling	Precision	RE < TS	TS < RE ($p < .01$)	No difference ($p = .43$)
Long up/down button	Repetitive	RE < TS	RE < TS ($p < .01$)	RE < TS ($p < .01$)

Note. RE = rotary encoder, TS = touch screen; TS < RE refers to faster performance for the touch screen; RE < TS refers to faster performance for the rotary encoder. In all cases younger adults were significantly faster than older adults; *p* values are for the planned device comparison conducted for each age group.

There were 60 activities; they were first randomly ordered, then grouped into 10 groups of 6. The presentation order of the activity groups was counterbalanced across participants using a partial Latin square. There was a short break after each activity, and participants were encouraged to rest for 5 min after every 20 activities. The study lasted approximately 2 hr for younger adults and 3 hr for older adults.

Design

Age was a between-participants grouping variable, and input device was a between-participants variable. The control task type was manipulated within participants. The primary dependent variable was time spent using a control.

EXPERIMENT 1: RESULTS

Data Analysis

Errors in the tasks were minimal, so the focus of the analyses was on the movement time data (i.e., time spent using a control). To assess the predictions in Table 4, we conducted Age (younger, older) × Input Device (touch screen, rotary encoder) analyses of variance (ANOVAs) for the different controls. We also conducted a planned comparison of the two devices for each group. The analyses are organized according to whether the touch screen or the rotary encoder was expected to yield superior performance. Table 4 presents a summary of the main findings with the *p* values for the planned comparisons. Table 5 presents the means and standard deviations for each task control by input device and age group.

Touch Screen Hypothesized Superior

Long slider. The long slider tasks required a ballistic type of movement for which the direct touch screen device was presumed to be better suited. Young adults were faster than older adults, $F(1, 76) = 32.75, p < .001, \eta_p^2 = .30$, but neither the main effect of input device ($p = .15$) nor the interaction was significant ($p = .23$). However, the planned comparison for the younger adults did reveal a faster response for the touch screen relative to the rotary encoder. Older adults' performance did not differ across devices.

List box without scrolling. Selecting an item from a list box was a relatively simple pointing task, presumably suited to the characteristics of a touch screen. The younger participants were faster than the older participants, $F(1, 76) =$

TABLE 5: Means and Standard Deviations (in seconds) for each Control Task, Input Device, and Age Group

	Younger Adults				Older Adults			
	Touch Screen		Rotary Encoder		Touch Screen		Rotary Encoder	
Control Task	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Long slider	4.72	1.95	6.21	1.02	8.62	4.07	8.75	1.97
List box, without scrolling	2.68	0.69	2.38	0.91	3.86	1.68	3.74	1.55
Drop-down list box, without scrolling	1.39	0.24	2.87	1.26	2.15	0.51	4.59	2.36
Short up/down button	3.08	1.39	4.68	2.55	8.81	5.78	6.85	3.32
Short slider	2.55	0.74	2.78	0.40	6.27	4.89	4.70	1.34
Text box, with scrolling	5.66	1.84	6.12	1.13	8.57	2.30	9.06	2.70
List box, with scrolling	4.74	1.58	4.30	1.38	6.74	2.63	6.67	2.32
Drop-down list box, with scrolling	3.38	0.48	4.30	1.00	5.39	2.65	5.97	1.98
Long up/down button	25.68	11.76	12.24	2.73	42.40	15.55	15.42	5.86

Note. Control tasks at the top of the table were predicted to be faster with the touch screen whereas those in the bottom of the table were predicted to be faster with the rotary encoder.

19.77, $p < .001$, $\eta_p^2 = .21$. Neither the main effect of device ($p = .46$) nor the age by device interaction was significant ($p = .76$), nor were there differences for the planned comparisons. Hence for both age groups, an item from a list box could be selected equally quickly with the direct or the indirect device.

Drop-down list box without scrolling. When operating a drop-down box that did not require scrolling, younger participants were faster than older participants, $F(1, 76) = 16.47$, $p < .001$, $\eta_p^2 = .18$. There was an effect of device, $F(1, 76) = 41.33$, $p < .001$, $\eta_p^2 = .35$, in which performance with the touch screen was faster than with the encoder; this effect did not interact with age ($p = .12$). The planned comparisons revealed a significant benefit of the touch screen for both age groups; hence the task of selecting an option from a drop-down box was performed more quickly with the direct device.

Short up/down button. Moving an up/down button a short distance was a discrete task that might also be well suited to a touch screen. Younger adults performed better than did older adults overall, $F(1, 76) = 23.65$, $p < .001$, $\eta_p^2 = .24$. Although there was no significant difference between devices ($p = .82$), there was a significant interaction between age and input device, $F(1, 76) = 4.81$, $p < .03$, $\eta_p^2 = .06$; younger adults were faster with the touch screen, but older adults were faster with the rotary encoder. The planned comparison revealed that the device difference favoring the touch screen was significant for the younger adults; for the older adults, the device difference was in the opposite direction, favoring the rotary encoder, but the difference was not statistically significant, perhaps because of the high variability in the touch screen condition.

Summary. For the four tasks predicted to yield better performance for the touch screen, the pattern was generally as expected for the young adults: Three of the tasks followed the prediction, and for one task there was no device difference. However, for the older adults, only one of the pointing tasks yielded performance in the expected direction; for the other pointing task and for the ballistic task the device difference was not significant, and for the discrete task the pattern was in the opposite direction, albeit not significantly.

Rotary Encoder Hypothesized Superior

Short slider. The short slider was a precision task; hence the rotary encoder would be expected to yield faster performance. An Age × Device ANOVA revealed that younger adults were faster than older adults, $F(1, 76) = 24.05$, $p < .001$, $\eta_p^2 = .24$, but there was not an effect of device ($p = .25$), nor was there a significant interaction ($p = .12$). Neither of the planned comparisons yielded a significant difference.

Thus for both age groups performance was comparable for the two devices.

Text box with scrolling. The requirement to scroll when selecting from a text box is also a precision task. Again, the younger participants were faster than the older participants, $F(1, 75) = 39.71$, $p < .001$, $\eta_p^2 = .34$. However, the main effect of device ($p = .31$), the age by device interaction ($p = .97$), and the planned comparisons were all nonsignificant. Thus younger and older adults could scroll within a text box equally well with either device.

List box with scrolling. A similar pattern was observed for scrolling within a list box. The younger participants were faster than the older participants, $F(1, 76) = 23.05$, $p < .001$, $\eta_p^2 = .23$. However, the main effect of device ($p = .60$), the age by device interaction ($p = .66$), and the planned comparisons were all nonsignificant, indicating that scrolling within a list box did not differ across devices.

Drop-down list box with scrolling. When operating a drop-down box that required scrolling, younger participants were faster than older participants, $F(1, 76) = 22.18$, $p < .001$, $\eta_p^2 = .23$. Contrary to prediction, the rotary encoder tended to be slower to use than the touch screen, $F(1, 76) = 3.75$, $p = .056$, $\eta_p^2 = .05$. Although there was no interaction of age group by device ($p = .67$), the planned comparison showed a significant benefit for the touch screen for the younger adults but no device difference for the older adults.

Long up/down button. The task of moving an up/down button a long distance was the type of repetitive movement that might be well suited to the rotary encoder input device. Younger adults were significantly faster overall, $F(1, 75) = 18.34$, $p < .001$, $\eta_p^2 = .20$, and those in rotary encoder condition were faster overall than the touch screen condition, $F(1, 75) = 75.76$, $p < .001$, $\eta_p^2 = .50$. The interaction between age and input device also reached significance, $F(1, 75) = 8.50$, $p < .005$, $\eta_p^2 = .10$. The benefit of the rotary encoder was larger for the older adults but was significant for young adults as well.

Summary. For the five tasks expected to yield better performance for the indirect rotary encoder device, the pattern was mixed. For the younger adults, there were no device differences for three of the tasks, the touch screen was better for one of the precision tasks, and the rotary encoder was better for the repetitive task. For the older adults, only the repetitive task yielded a device difference, and it was in the expected direction; however, for the other tasks, performance for the touch screen was as good as with the rotary encoder, contrary to what would be predicted from the general literature.

EXPERIMENT 1: DISCUSSION

These data illustrate that one cannot simply conclude that a particular input device is always better than another. It is critical to consider the task requirements and user age to determine the optimal input device. For the younger adults, when differences existed between the input devices, those differences generally corresponded to predictions based on task demands. For ballistic movements such as moving a slider a long distance, pointing tasks such as selecting an item from a drop-down list, or discrete tasks such as manipulating up/down buttons a short distance, the touch screen was significantly faster to use than the rotary encoder. For a repetitive task such as selecting an up/down button many consecutive times, the rotary encoder was superior. For the remaining tasks there were no significant performance differences for the two input devices. Thus for younger adults, the optimal input device can be largely determined by the nature of the task demands.

For older adults, the pattern was not quite as clear. For selection from a drop-down list box, the touch screen yielded better performance, as predicted. However, for the up/down buttons, regardless of the number of selections, older adults performed better with the rotary encoder, although the difference was significant only for the long up/down buttons (see Tables 4 and 5). For many of the task categories, there were no significant differences between the two input devices; however, this finding may be qualified by the high variability observed for the touch screen condition. For more than half of the tasks, the standard deviations were substantially higher in the touch screen condition than in the rotary encoder condition, even in cases where the means did not differ. These data indicate that for older adults, there are likely to be more individual differences in the degree to which a touch screen can be used quickly and accurately and there is likely to be less variability for the rotary encoder. It should also be noted that the older adults in this study had a mean age of 58.45 years, and the age-related differences in input device use may be exacerbated for older adults.

Selecting an Input Device

The selection of the optimal input device for a particular system can be informed by an analysis of the controls that are prevalently used in the interface. For example, if the system requires repetitive tasks such as using up/down buttons to move through a long list, then the optimal choice would be a rotary encoder for both age groups. If the system contains pointing tasks within drop-down list boxes, the touch screen would be preferable for younger and older adults. This result is similar to the Charness et al. (2004) finding that a light pen (a direct device) was better than an indirect device (a mouse) for younger but especially for older adults performing a menu target acquisition task, which is basically a pointing task. Beyond these specific examples, the decision is less clear. For other controls, the touch screen was better or at least not worse than the encoder was. However, for the older adults, the touch screen also tended to be more variable, which may not be preferable for a system that will be used by a wide range of individuals. Thus the absence of a device difference might lead a designer to select an indirect device for systems that will be used by older people.

Selecting Task Controls

During the design process, decisions may dictate that a particular input device must be used (e.g., because of cost considerations or system configuration requirements). The results of the present experiment provide the following guidance for such a situation. First, if a rotary encoder is to be used, then the selection of the specific controls to be used for the interface is less constrained. Younger and older participants were able to use the encoder, and this input device seemed compatible with slider controls, up/down buttons, and various scrolling tasks. Based on the present data, the only control to be avoided (or at least used infrequently) if a rotary encoder is used would be a drop-down list box.

If a touch screen must be used, the selection of controls should be more specific. For example, use of text boxes and list boxes would be appropriate, regardless of scrolling needs. However, up/down buttons may be generally difficult to use, especially for older adults. Moreover, because of larger individual performance differences associated with the touch screen, there are likely to be more individuals (especially older adults) who will have difficulties using a touch screen as an input device.

EXPERIMENT 2: TOUCH SCREEN ASSESSMENT

Experiment 1 indicated that performance using a touch screen tended to be more variable relative to performance using a rotary encoder, especially for older adults. There was also evidence in Experiment 1 that for certain controls touch screens yielded faster response times as compared with the rotary encoder, although this tended to be more evident for younger adults. The purpose of the second experiment was to explore further the variables that influence performance with a touch screen for younger and older adults.

Given the prevalence of touch screen interfaces (Fritz, 2000) and the fact that in some instances input device selection is constrained to a touch screen type of input device, it is important to determine the optimal button size, button placement, movement distance, and direction of movement for these devices. To provide guidance, we manipulated the following variables: size of buttons, direction of the movement, distance of the movement, type of movement, and precision of movement. We tested younger and older adults to determine if the task parameters influenced the performance of both age groups in a similar manner. The present study examined Fitts' law (Fitts, 1954) within a new set of task parameters.

EXPERIMENT 2: METHOD

Participants

Twenty younger adults (19–23 years) participated and received course credit. Twenty older adults (51–70 years) were recruited from the community and received $10/hr for their participation. Participant screening and testing was the same as in Experiment 1; details are presented in Table 6. The age-related ability differences are consistent with Experiment 1 and the general literature (e.g., Rogers et al., 2000). With respect to touch screen experience, usage rates were low for both age groups, ranging between one and three times in the last 3 months.

Materials

Input device and tasks. The touch screen and configuration were the same as used in Experiment 1. Participants were tested on four distinct tasks on the touch screen: (a) unstacked buttons, (b) stacked buttons, (c) horizontal scroll bars, and (d) vertical scroll bars.

The unstacked button task consisted of a start button below nine white buttons (three rows of three) of the same size (see Figure 2). The layout of the button matrix remained fixed throughout the experiment. When contact with the start button was made, one of the nine buttons above it changed from white to black after a random delay ranging from 250 to 750 ms. The participant then released the start button and touched the black button as quickly as possible. Participants were given audio feedback when they successfully touched the highlighted button. There were 45 trials per block (each button was a target five times); participants completed five blocks with an enforced 1-min break between blocks. The size of the buttons varied between blocks of trials (11, 13, 16, 18, and 21 mm). The order of button size presentation was counterbalanced across participants. Movement distance was determined as a function of the distance from the start button to the nearest corner of a given button and did not vary with button size.

The stacked button task was nearly identical, except that there was no space between the buttons in each column to simulate stacked buttons (see Figure 2). There were disabled buttons at the top and bottom of each column, and these were never targets. There were 45 trials per block (each button was a target five times) and five blocks. The size of the buttons varied between blocks (11, 13, 16, 18, 21 mm), but the distance from the start button to the nearest corner of any particular button was constant between blocks. The order of button size presentation was counterbalanced across participants.

For the horizontal and vertical scroll bar tasks there were three scroll bars on the screen (see Figure 2). The participant pressed a button to activate the trial, and a black rectangle appeared (on the right of the horizontal scroll bars and on the bottom of the vertical scroll bars). Participants dragged the position indicator as quickly as possible past the black rectangle (left to right for the horizontal condition, and down to up for the vertical one), at which point that scroll bar would become inactive and another one active. Participants were given audio feedback when they scrolled to the end of the scroll bar. There were five blocks of 15 trials, with each scroll bar being activated five times per

TABLE 6: Demographic and Ability Data for Participants in Experiment 2

	Younger Adults		Older Adults		
	M	*SD*	*M*	*SD*	*t* Value*
Males/females	8M/12F	—	7M/13F	—	—
Age	20.78	2.46	61.70	5.36	—
Education (years)	13.31	1.13	14.88	2.34	2.58*
Health[a]	4.00	0.77	3.35	0.88	–2.44*
Digit Symbol Substitution[b]	77.67	12.43	52.63	18.22	–4.90*
Reverse Digit Span[c]	8.06	3.49	8.89	9.25	0.37
Vocabulary[d]	29.33	4.23	34.05	5.99	2.78*
Handedness[e]	1.06	0.24	1.06	0.24	0.97
Touch screen use last 3 months[f]	2.58	2.12	2.90	1.21	0.57

[a] Self-rating: 1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent. [b] Perceptual speed (Wechsler, 1997). [c] Memory span (Wechsler, 1997). [d] Verbal ability (Shipley, 1940). [e] Edinburgh handedness inventory (Oldfield, 1971): 1 = right, 2 = left. [f] Scaled from 1 to 8: 1 = never, 8 = daily, most of the day.

*$p < .05$.

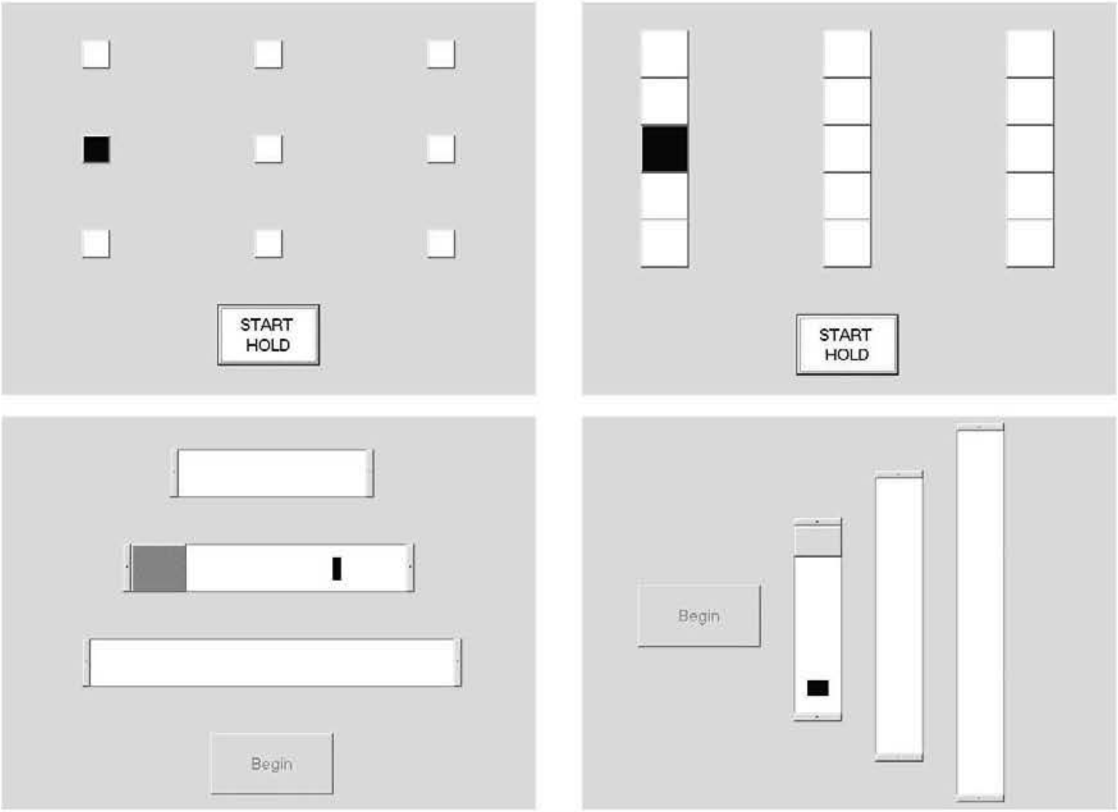


Figure 2. Examples of the button and scroll bar tasks used in Experiment 2. The top displays depict the unstacked (left) and the stacked (right) button tasks. The bottom displays depict the horizontal (left) and vertical (right) scroll bar tasks. Note that the sizes of the buttons and the width and length of the scroll bars were manipulated, as described in the text.

block. Each trial consisted of three scroll bars with lengths of 68, 102, or 136 mm. Scroll bar width was 11, 13, 16, 18, or 21 mm and varied between blocks.

Procedure

Participants provided informed consent and completed demographics and health forms as well as ability, vision, and handedness tests. They were then seated at a touch screen station and instructed to adjust the tilt of the screen to their preference. They were told to use the index finger of their dominant hand and not to rest that arm on anything while performing the tasks. All participants completed tasks in the same order: unstacked, stacked, horizontal scroll bar, vertical scroll bar. There were enforced 5-min breaks between tasks. After completing the tasks, participants completed a touch screen experience questionnaire and were debriefed.

Design

Age was a between-participants grouping variable. All other variables were manipulated within participant as repeated measures. The primary dependent variable was movement time.

EXPERIMENT 2: RESULTS

Errors in the tasks were minimal and are captured in the movement time data as a slower response. The focus of the analyses was on movement time, defined as the time it took the participant to touch a target button after releasing the start hold button for the button tasks and the time required to slide the bar past the target point for the scroll bar tasks.

Unstacked Versus Stacked Buttons

Overall analysis. A combined ANOVA was conducted to compare directly the unstacked versus the stacked buttons as a function of the other variables. The design of the analysis was Age (younger, older) × Button Type (unstacked, stacked) × Size (11, 13, 16, 18, or 21 mm) × location (left top, left middle, left bottom, center top, center middle, center bottom, right top, right middle, right bottom).

The overall main effect of button type was significant in that participants were faster to respond to the stacked buttons, relative to the unstacked buttons, $F(1, 38) = 21.22$, $p < .001$, $\eta_p^2 = .36$. Button type did not interact with any other variable (size, location, or age). Based on previous movement control findings (e.g., Walker, Meyer, & Smelcer, 1993; Walker et al., 1997), the stacked button superiority is not unexpected, given differences in movement phases. The initial ballistic submovement would be similar between the two conditions. The difference would occur in the intermediate submovements. Less intermediate submovement verification time would be required in the stacked condition because intermediate aiming need be less "precise" because of the overall figure/ground pattern created by the stacked condition. Hence these data are consistent with the overall mouse movement model put forward by Walker et al. (1993). Although this aspect of the data is consistent with expectations, an overall practice effect cannot be completely ruled out (given that the unstacked condition was presented first). However, an interaction with age would be expected if it were simply a practice effect, because older adults typically improve more (e.g., Charness et al., 2004).

Not surprisingly, younger adults' movement time was faster than older adults', as indexed by the main effect of age, $F(1, 38) = 26.88$, $p < .001$, $\eta_p^2 = .41$. Movement time was also slower for the smaller buttons, $F(4, 152) = 29.24$, $p < .001$, $\eta_p^2 = .44$, and this effect interacted with age, $F(4, 152) = 3.86$, $p < .005$, $\eta_p^2 = .09$. As is evident from Table 7, decreasing button sizes slowed older adults more than it did younger adults.

There was a significant main effect of button location, $F(4, 152) = 29.24$, $p < .001$, $\eta_p^2 = .44$, and this effect did not interact with button size ($p = .61$), age ($p = .28$), or Button Size × Age ($p = .80$). An interesting pattern emerged when we investigated movement time as a function of the location of the buttons. Table 8 represents the mean movement times as a function of the location of the button. The italicized numbers highlight the faster times. For both younger and older adults, movement to the buttons in the center column was fastest. This pattern suggests that location is an additional parameter (along with size and distance) to be considered in the placement of buttons for an interface using a touch screen input device. Statistical comparisons (two-tailed t tests, $p < .05$) indicated the following for younger adults: Movement times were faster to the center top button than to buttons that required shorter movements, such as the left middle, right middle, and right bottom buttons; there was also no difference between moving to the center top and left bottom buttons. For the older adults, movement times were faster to the center top button than to the left middle ($p = .07$) and right middle buttons. There was no difference between moving to the center top button and moving to either the left bottom or the right bottom buttons, both of which were closer. These results are not consistent with the prediction that would

TABLE 7: Means and Standard Deviations (in ms) as a Function of Button Size for Younger and Older Adults

	Younger Adults		Older Adults	
Button Size	*M*	*SD*	*M*	*SD*
11 mm	511.63	124.34	815.48	249.09
13 mm	426.89	105.41	608.68	210.76
16 mm	392.11	76.65	568.93	148.03
18 mm	368.35	87.27	544.94	174.16
21 mm	379.32	95.12	490.69	133.87

Note. The means are averaged across button location and button type.

TABLE 8: Means and Standard Deviations as Function of Button Location

Younger Adults			Older Adults		
Mean Movement Time (ms)					
444	***399***	441	652	***584***	649
428	***379***	440	645	***557***	600
404	***351***	431	628	***527***	587
Standard Deviation of Movement Time (ms)					
96	74	83	170	171	159
91	84	98	175	142	144
85	87	112	190	177	158

Note. The means and standard deviations are presented in the locations that correspond to their display locations (three columns of three). The bold italicized numbers represent the fastest times for each age group. These means are averaged across button size and button type.

be made by Fitts' law (1954) alone, because the top button is farther away than the lower and middle buttons; however, such inconsistencies are not unexpected (e.g., see Welford, 1976, for a review).

The standard deviation data are also presented in Table 8. The older adults were more variable for all of the button locations.

Index of difficulty. Fitts' law states that the speed of a movement is related to the distance of the movement and the size of the target (Fitts, 1954). Fitts' law is instantiated as the following equation: $movement\ time = a + b \log_2(2D/W)$, in which D = distance, W = width, and a and b are task constants. The index of difficulty is $\log_2 (2D/W)$.

Figure 3 represents the slope of the line relating movement time to task difficulty for younger and older adults for the stacked and unstacked buttons. For both younger and older adults, the slowing of movements as a function of the task difficulty increased for the stacked condition, for which more precision of movement was required relative to the unstacked button condition (i.e., the slopes were higher for the stacked condition). This difference probably reflects time for movement planning. Variability was higher for the unstacked condition, as evidenced by the dispersion of the data points. These movements can be more ballistic in nature, requiring less planning (the additional planning for the stacked condition reduces the variance) but also increasing the slope as task difficulty increases. Note also the higher variability for the older adults: The dispersion of individuals within the older adult group increased as a function of the index of difficulty for the task. Thus as movements required more distance, or the size of the target became smaller, older adults became more variable in their movement times.

Scroll Bar Tasks

For the scroll bar tasks, a combined ANOVA was conducted to compare directly the horizontal and vertical tasks. The design of the analysis was Age (younger, older) × Orientation (horizontal, vertical) × Size (11, 13, 16, 18, or 21 mm) × Length (68, 102, or 136 mm). The only significant main effect was for length, $F(2, 76) = 79.47$, $p < .001$, $\eta_p^2 = .68$, because the movement times were faster for the shorter scroll bar lengths. However, the effect was not strictly linear but was significantly quadratic as well ($p < .01$). Moreover, the pattern of performance differed for the horizontal and vertical scroll bars, with a significant orientation by length interaction, $F(2, 76) = 27.75$, $p < .001$, $\eta_p^2 = .42$. Table 9 provides these data separately for the two age groups, but it is clear that the patterns were very similar for the younger and older adults. For both age groups, the movement times for the horizontal tasks were virtually the same for the 68 and 102 mm lengths and substantially slower for the 136 mm length. Also for both age groups, for the vertical tasks there was a more linear increase in movement time from the 68 to the 102 to the 136 mm lengths.

As an additional follow-up to the orientation by length interaction, we analyzed each scroll bar length separately. The orientation effect was significant for all three lengths (all *p*s <.01), but the direction of the effect was not consistent, hence the interaction. Moving a scroll bar in a horizontal direction was faster than in a vertical direction for the shorter lengths (68 and 102 mm), but for the 136-mm task, movement in a vertical direction was faster than in a horizontal direction.

Note that there was not an overall main effect of age ($p = .12$), nor did age interact with any of the other effects (all *p*s > .23). Table 9 shows that the younger adults did tend to be faster, but the age-related differences were relatively small in most cases (less than 50 ms).

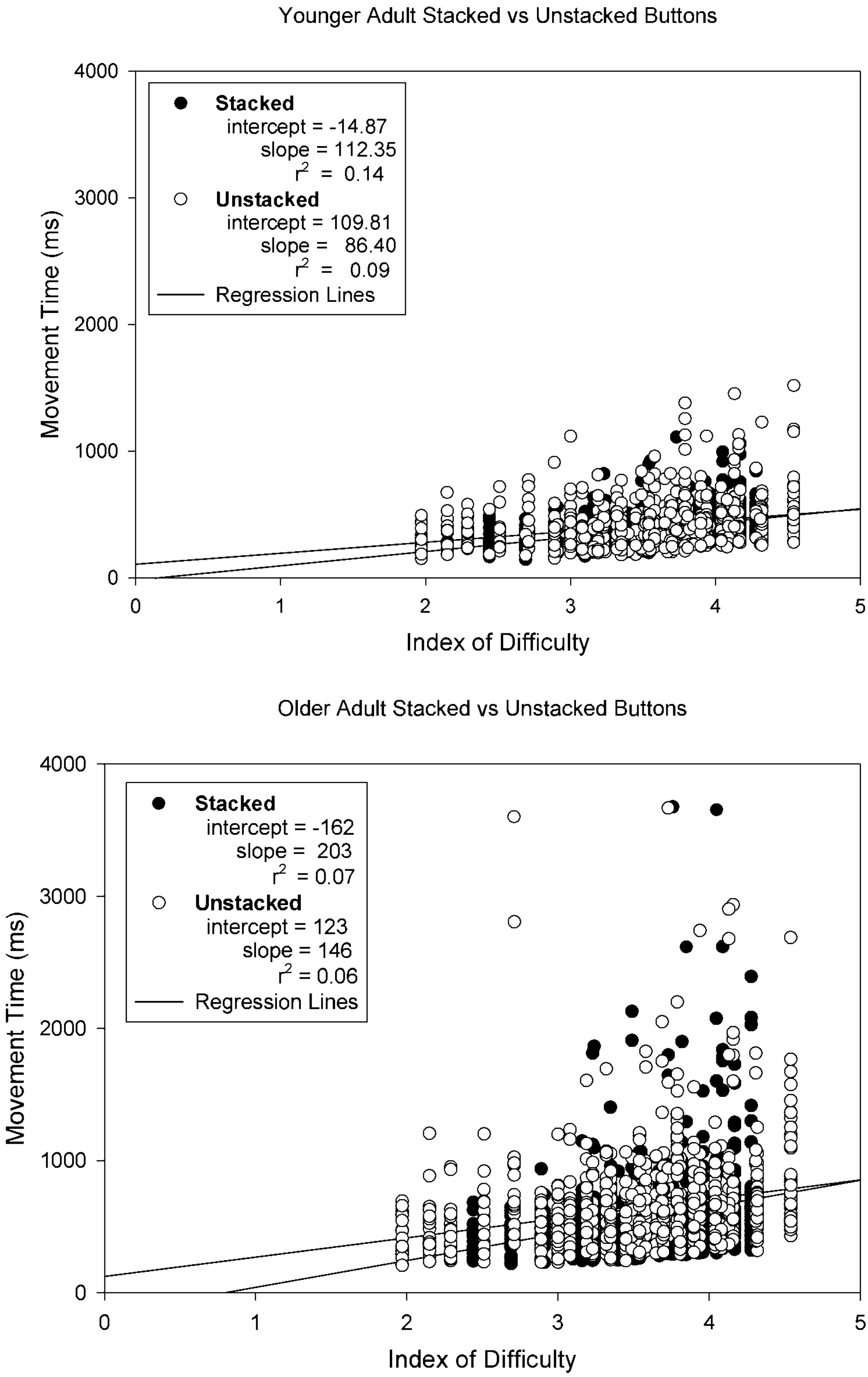


Figure 3. Movement time as a function of task difficulty for younger (top) and older (bottom) adults for the unstacked and stacked buttons. The index of difficulty is $\log_2(2D/W)$, in which D is distance to the target and W is the target width.

TABLE 9: Means and Standard Deviations (in ms) for Horizontal and Vertical Scroll Bar Movement Times

Length of Scroll Bar	Younger Adults				Older Adults			
	Horizontal		Vertical		Horizontal		Vertical	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
68 mm	109.31	41.51	166.49	65.61	143.82	82.45	182.00	69.62
102 mm	106.12	29.36	188.49	63.62	144.74	90.34	231.76	90.72
136 mm	327.12	123.86	247.23	89.14	437.39	353.15	290.26	89.00

Note. These means are averaged across scroll bar widths.

Where the difference was largest for the longest horizontal scroll bar, performance was also quite variable. Thus age-related differences in these tasks are generally quite small, but it is important to note that the standard deviations were generally higher for older adults, as observed in Experiment 1 for the touch screen condition.

There were also no differences in movement time for the different scroll bar widths ($p = .62$). Although narrower scroll bars might require extra time planning of the movement, once the participant had a finger on the scroll bar, width did not influence the movement time to the designated location.

EXPERIMENT 2: DISCUSSION

The results of this study suggest that many variables affect movement time when using a touch screen input device. Fitts' law indicates that the size of the target (i.e., the button) and the distance of the movement will influence performance, and this was true for both younger and older adults, although the slope of the function was larger for older adults. We also observed that the specific location of the button influenced movement time. Both younger and older adults were fastest moving up in a straight line than to either side (even if the distance up was longer than the distance to the side). This finding represents a boundary condition that must be placed on Fitts' law (see also Friedlander, Schlueter, & Mantei, 1998; MacKenzie & Buxton, 1992). When possible, interfaces should be designed to require straight up-down movements rather than diagonal movements.

Another task parameter that influenced performance for both age groups was the precision required of the task. In the stacked condition, in which target buttons were embedded within other buttons, the slope of the function relating movement time to task difficulty (slope = 112 ms for younger and 202 ms for older adults) was larger than the slope of that function for the unstacked condition (slope = 86 ms for younger and 146 ms for older adults), in which the buttons were free standing. Such a finding is not inconsistent with our previous discussion concerning the main effect superiority of the stacked condition compared with the unstacked condition. The increased slope for the stacked condition relative to the unstacked condition would be expected if, as final submovement accuracy verification took place, there was less contrast around the absolute target location, as would be the case in the stacked condition. The fact that older adults showed an increased effect of relative movement time (as the slope represents) as demands for movement precision increased and target contrast decreased is completely consistent with Walker et al. (1997). Certainly this finding speaks to the generality of this and other age-related movement time data, especially when considering input device effects. This finding also has important implications for display design: As precision is required and target items are closely located to nontarget items, movements are going to be slowed, and this was especially true for older adults.

We also observed that for both younger and older adults, efficiency of scrolling was differentially dependent on whether the scrolling was in the horizontal direction or in the vertical direction. For shorter scrolling tasks, horizontal scrolling was faster; however, for longer scrolling tasks, vertical scrolling yielded better performance. This pattern provides direct guidance for display design – namely, if movements are short, horizontal scroll bars will yield superior performance; if movements must be longer, then a vertical scroll bar would be better. However, it is important to note that we tested only ballistic movements that were left to right in the horizontal direction and up to down in the vertical direction. The horizontal and vertical patterns might differ for right-to-left or down-to-up movements.

Another consistent finding in these data is that older adults' movement times tended to be much more variable than younger adults'. For participants 51 to 70 years of age, control of a touch screen interface varied a great deal between individuals. It was not the case that the variability was attributable to the wide range of ages in the older group. The performance of the middle-aged (51–60 years) and the older (61–70 years) adults overlapped almost completely. It was simply the case that as a whole, the older adults were more variable than were the younger adults in their ability to use a touch screen to make discrete movements.

The finding of no age difference for the scroll bar tasks is consistent with previous data. For example, Walker et al. (1997) found that younger and older adults were equally good at producing a forceful movement when precise accuracy was not required. The ballistic nature of the scroll bar tasks may have enabled the older adults to make faster movements and hence not differ from the younger group.

CONCLUSIONS

An important design conclusion, reinforced by the present research, is that it is inappropriate to suggest one input device as always a best choice. The present data suggest that one must consider task requirements and user age group when specifying input device selection. The current study also provides data to help with the design process when faced with preselected input device decisions (when the choice of the input device is constrained but the task or display control characteristics are not severely constrained). If one is faced with the requirement to use a direct input device such as a touch screen, the present data provide guidance for choosing optimal display control characteristics (e.g., short up/down buttons). Similarly, the data specify what display controls will work best with an indirect device such as the rotary encoder (seen with increasing frequency as desktop computer input devices and in automobiles). Although the age of the user must always be considered in the overall design process, the present data help isolate cases in which age will not interact with the input device, given specified task characteristics and display control selection.

Overall, the data from the present research enhance the generalizations concerning advantages and disadvantages of categories of input devices. Also, the data from the second experiment extend current knowledge of movement time characteristics, at least for touch screen types of devices. Those data point to the generality of the body of data allowing movement time estimations. However, the present data help point to design trade-offs that must be made (e.g., closely spaced controls can aid overall movement time but can slow precision movements).

Will the present data allow the designer a simplistic decision-making task concerning input device selection? Certainly the data will not provide a specific answer for each design-related question. However, the current study does what worthwhile laboratory studies should do – it helps to identify and to constrain the acceptable solution space for the designer. The data point out the unique interrelatedness that can exist among input device, display characteristics, and user populations.

ACKNOWLEDGMENTS

This research was supported in part by a grant from the National Institutes of Health (National Institute on Aging), Grant P01 AG17211, under the auspices of the Center for Research and Education on Aging and Technology Enhancement (CREATE), and by contributions from Deere & Company. We thank Jerry Duncan and Bruce Newendorp for their support and advice on this research. We also thank Neil Charness for his insights on the design of Experiment 2 and Chao-Chung Lin and Justin Whittle for their assistance with the execution of the experiments.

Portions of this research were presented at the Ninth Cognitive Aging Conference in Atlanta, Georgia (April 2002); the Human Factors

and Ergonomics Society 47th Annual Meeting in Baltimore, Maryland (October 2002), with proceedings (Pak, McLaughlin, Lin, Rogers, & Fisk, 2002); and the Fourth International Conference on Gerontechnology in Miami, Florida (November 2002).

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Date received: May 19, 2003
Date accepted: May 25, 2004