INTERNATIONAL JOURNAL OF HUMAN–COMPUTER INTERACTION, *21*(1), 91–108

Left-Handed Scrolling for Pen-Based Devices

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The effectiveness of interaction with mobile devices can be impacted by handedness; however, support for handedness in the interface is rarely provided. The goal of this article is to demonstrate that handedness is a significant interface consideration that should not be overlooked. Four studies were conducted to explore left-handed user interaction with right- or left-aligned scrollbars on personal digital assistants. Analysis of the data shows that left-handed users are able to select targets significantly faster using a left-aligned scrollbar when compared to a right-aligned scrollbar. User feedback also indicated that a left-aligned scrollbar was preferred by left-handed users and provided more natural interaction.

1. INTRODUCTION

Over the past decade, mobile computing has seen significant technological advances, which have led to widespread acceptance with increased ubiquity. Handheld computing is positioned to facilitate and augment many facets of our daily lives. Even with the growing prevalence of these devices, key design considerations have not been fully examined. Instead, standard desktop metaphors and interaction techniques are often applied directly to mobile devices (e.g., scrollbars). This approach allows users to apply their desktop computing skills directly to mobile devices but does not take into account device differences or contexts of use. We

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We thank the Natural Sciences and Engineering Research Council (NSERC) and Dalhousie University for supporting this research. Thanks also to members of the EDGE Lab for their assistance.

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hypothesize that widget placement is an important consideration when using direct input on a mobile device, particularly for left-handed users.

Despite the symmetric look of most mobile devices, closer examination reveals a design that is biased against users who are left-handed. For example, the stylus holder on most handheld computers is on the right-hand side and many side-panel buttons or thumbwheels are on the left side, both of which facilitate easy access for right-handed users. Even software widgets (which could easily provide a higher degree of flexibility) such as scrollbars are not appropriately designed for left-handed users. Given that more than 10% of the population is estimated to be left-handed (McManus, 2002), a significant number of potential users worldwide are being ignored with current designs.

As is the case with most desktop software, scrollbars on handheld computers are right-aligned. For right-handed users, this is ideal. It allows them to manipulate the scrollbar while keeping their hand outside the boundary of the handheld computer. Left-handed users, however, are forced to reach across the screen to manipulate the right-aligned scrollbar, use the stylus in their nondominant hand, or modify their grip on the stylus. Given that desktop software uses an indirect input method (i.e., a mouse), position of the scrollbar is typically not a factor; but the direct input methods used by some mobile devices cause problems. As a left-handed user reaches across the screen, a large portion of it is likely to be obscured by their hand. Because scrolling tasks often involve monitoring information as it is presented, this can be a significant problem.

Although the issue of appropriately designed widgets for left- and right-handed users seems obvious, most commercial software does not take handedness into consideration, even though software modifications should be fairly straightforward. As a result, interfaces and interaction styles have been designed primarily for right-handed users whereas left-handed users are forced to adapt. The overall goal of this research is to demonstrate the benefits of providing widgets (specifically scrollbars) that are appropriately placed given the handedness of the user.

In this article we examine scrollbar positioning on handheld computers for use by left-handed individuals. Related research is presented, followed by a description of four coordinated studies conducted to examine this issue. Finally, the results of each study are presented, and a discussion consolidates the findings.

2. RELATED LITERATURE

There is a general consensus that statically assigning handedness to an application is not advised even though right-handedness is generally assumed (Hancock & Booth, 2004; Harrison, Fishkin, Gujar, Mochon, & Want, 1998; Kurtenbach, Fitzmaurice, Baudel, & Buxton, 1997). Interfaces designed for a specific handedness often put users of the opposite handedness at a distinct disadvantage (Hancock & Booth, 2004; Kurtenbach et al., 1997).

Previous research has shown that handedness plays an important role in general aiming (Flowers, 1976), pen-based pointing tasks (Kabbash, MacKenzie, & Buxton, 1993), and the speed in selecting items from menus (Hancock & Booth, 2004). Performance differences have been shown between left- and right-handed users executing visually controlled aiming tasks using their nondominant hand (Flowers, 1976). However, the difference was found to be insignificant between dominant and nondominant hands for rough pointing tasks that do not require precise action (Kabbash et al., 1993). As the width of the target being acquired becomes smaller the dominant hand gains an advantage over the nondominant hand (Kabbash et al., 1993). Therefore, selecting a small target (such as a scrollbar) using the nondominant hand is more difficult than selecting the same target with the dominant hand.

Hancock and Booth (2004) found that the relative position of a target compared to the user's current cursor or stylus position, and the user's handedness both had a significant effect on which targets the user could select quickly. It is interesting that they found that the patterns for left-handed and right-handed users were mirrored. They also commented on screen occlusion and the fact that it can significantly impact the amount of time required to acquire a target when using a direct input device. However, this impact has not been fully quantified.

A number of projects have taken the importance of handedness into consideration in the design of their applications (Harrison et al., 1998; Kurtenbach et al., 1997; Raghunath & Narayanaswami, 2002). T3, a prototype graphical user interface for a two-dimensional drawing application, provides users with an adaptable interface depending on handedness (Kurtenbach et al., 1997). Artists interact with the system using a puck in their nondominant hand and a stylus in their dominant hand. Using relative position of the puck and stylus, the system can infer the artist's handedness and then place interface components such as pop-up palettes and anchor points appropriately.

Despite some emphasis on handedness in the research literature, relatively few commercial systems take handedness into consideration. Lefty 2.0 (2004) is a simple tool for Palm OS (Palm, Inc., Sunnyvale, CA) that adds a "Lefty" preference option. Although the program falls short of implementing a left-aligned interface, the author does provide suggestions for how to construct "Lefty-aware" applications. These suggestions include functions for mirroring the interface or swapping the position of two objects. One of the new features of Pocket PC 2002 (Microsoft, Redmond, WA) is improved left-handed user support. However, this is limited to alternate shape processing for text input. Windows Mobile 2003 Second Edition (Microsoft, Redmond, WA) introduced both left- and right-handed landscape modes (Lee, 2004), with the only difference between left and right landscape mode being a 180° rotation of the screen so that the personal digital assistant's (PDA's) navigation buttons are located on the other side (Lee, 2004).

Harrison et al. (1998) explored annotation of digital documents on a handheld computer. They found that it is more appropriate to make annotations on the side nearest the dominant hand. They observed that the user's nondominant hand was the one that typically held the device, whereas the dominant hand was used to annotate the document. The handedness of the user was determined via pressure sensitive pads placed on the back of the device. If the device sensed pressure on its left side (from the nondominant hand), it would allow for annotation on the right-hand side, and vice versa.

Raghunath and Narayanaswami (2002) considered handedness in their design of a wearable "wristwatch" style computer. To allow the user to scroll through data displayed on their device, they employ a roller wheel, located on the top-right corner of the watch. This position, they claim, is usable for both left- and right-handed users. Right-handed users grip the bottom of the device with their thumb and move the roller wheel vertically along the right edge with their index finger; left-handed users grip the bottom with their thumb from the opposite side and move it horizontally along the top edge.

3. RESEARCH OBJECTIVES

The main goal of this research was to demonstrate the importance of considering handedness for the design of interaction styles, particularly for mobile devices. We observed left-handed users interacting with both left- and right-aligned scrollbars as an example of an interaction style that is significantly impacted by handedness.

We employed a rich methodological approach to fully appreciate the scope of the problem from a variety of perspectives. In particular, we examined the movements that comprise a scrolling action, the act of scrolling using a variety of realistic tasks, the impact of a controlled lab environment versus a casual environment, and natural usage of scrollbars in everyday activities and contexts.

4. METHOD

Four coordinated studies were conducted to explore the impact of left- versus right-aligned scrollbars for left-handed users of small, mobile devices. Each study examined the research question with a different methodology, varying the amount of control and realism.

Study 1 was a controlled lab experiment that gathered detailed scrolling data to determine which scroll components are impacted by scrollbar location (i.e., scrollbar acquisition, main scrolling, and final corrective adjustments). Study 2 (lab experiment) and Study 3 (field experiment) both utilized realistic and representative tasks to understand the impact of scrollbar location. Study 2 was conducted in a controlled lab environment, whereas Study 3 was conducted in a more casual environment in an attempt to explore the impact of environmental setting. Study 4 was a weeklong field study to gather more in-depth qualitative data on longer term, ad hoc usage.

4.1. Participants

Twenty-eight individuals (13 male, 15 female) participated across the four studies. Studies 1, 2, and 3 each utilized 8 participants, and Study 4 utilized 4 participants (no participant took part in more than one study). Participants were recruited from staff and students at Dalhousie University and ranged in age from 18 to 54. All participants were frequent computer users, and 11 had experience using a handheld computer.

All participants identified themselves as being left-handed (by which they mean they perform the majority of their daily activities with their left hand and write using their left hand). To support the detailed qualitative analyses in Study 4, the handedness of the 4 participants was assessed using the Chapman and Chapman questionnaire (Chapman & Chapman, 1987). Prior research (Reiss, Reiss, & Freye, 1998) has shown that self-reporting of handedness is useful, but when dealing with specific handedness issues it is often advisable to administer a more precise test. The results of the Chapman and Chapman analysis revealed that 2 participants were left-handed and 2 were ambilateral, bordering on the side of left-handed. Both ambilateral participants found it more natural to use the stylus with their left hand than their right, comparing it to a pen which they both use in their left hand.

4.2. Settings

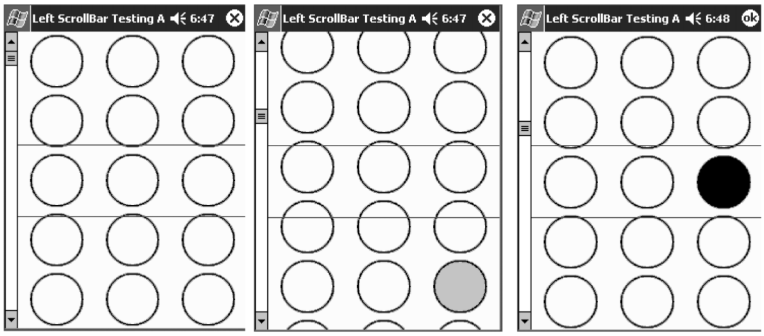
Studies 1 and 2 took place in a controlled setting—a usability laboratory. The laboratory contained an adjustable chair and a small square table. In these studies, a video camera was mounted on a tripod to the right of the participant's head to record interactions with the PDA. Study 3 was conducted in a realistic setting—the atrium of a university building. The atrium is a central social area, with a small coffee shop and leather sofas. This space is often busy, but the general noise and distraction level was similar across sessions. Study 4 was conducted in variable situations, depending on the locations visited by the participant throughout the week. All studies used an Hewlett-Packard iPAQ h4100 Pocket PC (Hewlett-Packard, Palo Alto, CA).

4.3. Experimental Conditions

All four studies explored two conditions, a left- and a right-aligned scrollbar. Conditions were counterbalanced between participants.

4.4. Tasks

Framing selection task. Study 1 utilized an isolated scrolling task modeled after Hinckley, Cutrell, Bathiche, and Muss's (2002) reciprocal framing task. This task involved users placing a target within an area marked on the screen. The testing software consisted of a 3-wide × 40-high grid of evenly spaced circles, 1.15 cm in diameter. The small screen limited the display to a grid of 15 circles (3 × 5; Figure 1a). Vertical scrolling was required to view the remaining circles. Two red lines were drawn above and below the center row of circles in the display to indicate the frame region where the target circle should be placed (Figure 1a). In each trial, one circle was filled in gray to indicate that it was the target circle (Figure 1b).



(a) (b) (c)

FIGURE 1 Framing selection task: (a) starting position—the horizontal red lines depict the target selection area, (b) target on screen but not within the selection area, and (c) target has been selected.

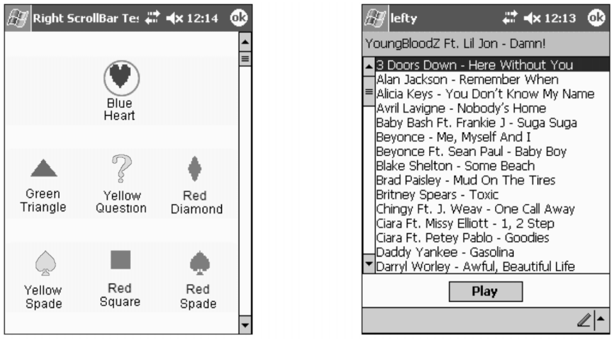
At the beginning of each trial, a start button was displayed. Participants were required to click on the Start button to reveal the grid of circles. Once the user scrolled the target to the center area of the screen, the target turned black to indicate that it was now in the correct position (see Figure 1c).

Icon selection task. Studies 2 and 3 each utilized a set of two realistic tasks: selecting an icon from a grid of icons and selecting an item from a list. The icon selection task was intended to simulate the situation where users need to actively search multiple screens of icons. Basic colored shapes were used with textual descriptions to ensure the distinctiveness of individual icons.

The software for the icon selection task consisted of a 3-wide × 20-high grid of evenly spaced icons, approximately 1.2 cm in diameter. The icon set consisted of eight different symbols utilizing seven possible colors. For example, Red Square and Blue Spade were two icons used in the task. The size of the screen restricted the number icons that could be displayed at once to a grid of nine icons (3 × 3). To view the remaining icons, the user was required to scroll vertically. The first row of the display consisted of a "reference target" icon in the center, circled in red (Figure 2a). The goal of the task was to scroll through the grid and find the matching target icon and then scroll back up and tap the original reference target.

List selection task. The list selection task was similar to the icon selection task except that participants were required to locate and select a song title in an alphabetically sorted list of song titles. This was intended to simulate skimming through an ordered list.

The software for the list selection task displayed 60 song titles (with a maximum of 40 characters) sorted alphabetically. The size of the screen restricted the number of songs that could be displayed at once to 15 (Figure 2b). Vertical scrolling was re-



(a) (b)

FIGURE 2 Starting screens for (a) icon selection task and (b) list selection task.

quired to view the remaining song titles. Once again, the user was presented with a reference target (a song title) at the top of the screen, separate from the list. The goal of the task was to locate the song title in the ordered list, select it, and then scroll back up to the top and tap the Play button. The list of songs and associated artists was compiled from the Billboard[1] listings.

Food diary task. Study 4 utilized a multilevel selection task with a hierarchical list of successively refined items. The participants were neither restricted nor required to make specific selections; they themselves determined when and where to use the software and which items they selected. It was therefore important that the task be compelling enough to encourage use. A food diary was chosen as the task, as nutrition is an important aspect of people's lives. It was hoped that the food diary would provide users with implicit motivation to encourage their use of the software.

The food diary consisted of an alphabetically sorted hierarchical food list.[2] The first level represented general food groupings (e.g., Beverages, Baked Products, Fruits and Fruit Juices). To select a food item, the user first clicked a Start button (Figure 3a) and then navigated to the appropriate food listing. Each subsequent selection (Figure 3b, c) in the list further refined the user's choice until they were presented with the food product they were looking for (Figure 3d). Once the user had selected the final food product, a calorie count was presented at the top of the screen (Figure 3d). To make another selection, the user clicked the Next button, which saved the previous selection and reset the list.

[1]Billboard Singles Chart— Billboard Top 100 Songs—Billboard Top 100 Singles. Retrieved March 25, 2005 from http://www.billboard.com/bb/charts/hot100.jsp

[2]Processed from Health Canada. Retrieved March 25, 2005, http://www.hc-sc.gc.ca/food-aliment/ns-sc/nr-rn/surveillance/cnf-fcen/e_index.html

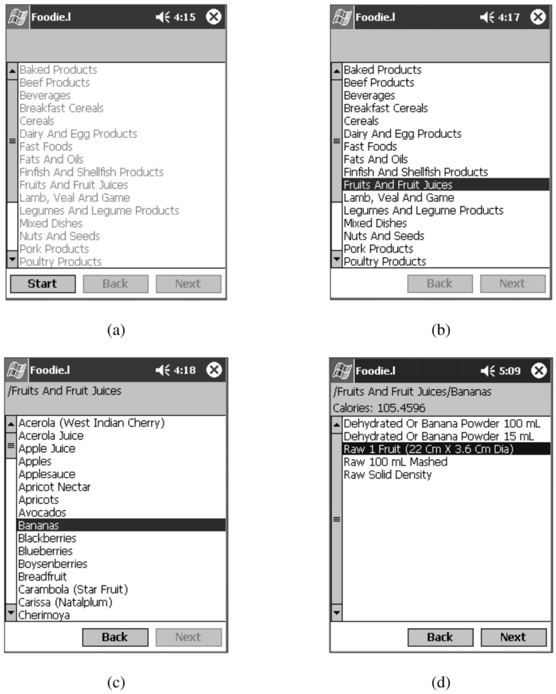


FIGURE 3 Process of selecting a food item: (a) start screen, (b/c) navigating the list, and (d) final food selection.

Task software. All applications were written in C# using the .NET Compact Framework windowing toolkit (Microsoft, Redmond, WA). Appropriate functionality of the scroll list class was overridden to allow programmatic selection of the scrollbar side. For each task, two versions of the software were created: one with the scrollbar on the left side of the screen and one with the scrollbar on the right side of the screen. The applications also recorded timing data.

4.5. Procedures

At the beginning of each study, participants were asked to fill out a background questionnaire. The details of their particular experiment were then explained to them, and they were given an introduction to the hardware and software they would be using.

Study 1 required each participant to complete two conditions (left- and right-aligned scrollbars) each comprising 75 framing selection tasks. Condition order was counterbalanced between participants. Studies 2 and 3 required each participant to complete two conditions (left- and right-aligned scrollbars) for both the icon selection and list selection tasks. Each condition comprised 45 selection tasks. Condition order was counterbalanced within selection tasks.

For Studies 1, 2, and 3, the ordering of the selection tasks was randomly determined prior to each study and the ordering was consistent across all participants. Prior to each condition, 10 practice selection tasks were administered to familiarize participants with the software and the condition's requirements. A postcondition questionnaire was administered at the end of each condition. Following the final condition, a postexperiment questionnaire was administered.

The procedure for Study 4 varied significantly from the other three studies. Participants were not required to perform a set number of selection tasks but were provided with the food dairy application to use when appropriate. They were told that as they ate during the day they should use the food diary software to record the foods they were eating. Participants were required to complete two 3-day conditions (left- and right-aligned scrollbars) spanning 6 days. Conditions were counterbalanced between participants.

To ensure the participants in Study 4 were familiar with the handheld computer and the food diary software, they were given an initial practice session during which they were instructed to find and select given food items. Upon successful completion of the practice session, participants were given an information packet explaining each experimental condition. In addition, they were provided with a paper calendar highlighting their condition schedule and a postcondition questionnaire. After the schedule was explained, participants were instructed that they would need to complete the postcondition questionnaire following their first condition (ending on Day 3) and return following the 6th day. When they returned, a second postcondition questionnaire was given along with a semistructured interview.

4.6. Data Collection and Analyses

Data logging and questionnaires were used in all four studies. Study 4 also administered a semistructured interview. Pertinent data were aggregated from all sources to construct a general understanding of how participants interacted with left- and right-aligned scrollbars and their performance on the selection tasks.

Data logging was used to capture all participant interactions and selections. In particular, detailed timing data were gathered for the scrolling tasks in Studies 1, 2, and 3. All scroll time data were analyzed using repeated measures analyses of variance.

Data logging was also utilized in Study 4 to collect timing data as well as general activity information. Given the small sample size and relatively open nature of this study, it was not practical to perform quantitative analyses on the data logs. Instead, the logs were used to gain a general sense of the participants' software usage over the week of the study.

Background questionnaires collected handedness information and computer and handheld computer usage history. Postcondition questionnaires in Studies 1, 2, and 3 gathered information on participants' comfort level, fatigue, perceived speed and accuracy, and whether their hand obscured the screen. Postcondition questionnaires for Study 4 gathered ease of use and scrollbar preference. Postcondition questionnaire data from Studies 1, 2, and 3 were used to compare left and right-aligned scrollbar usage using Wilcoxon signed-ranks analyses. Other preference data were analyzed using chi-squared tests.

The semistructured interview in Study 4 probed participants on their experiences during the two experimental conditions. These interviews were transcribed, and pertinent results were extracted.

5. RESULTS

5.1. Scroll Times

Study 1. Overall timing data for the task as a whole as well as the time to perform each subtask were gathered: acquire the scrollbar, scroll to bring the target into the center region (for the first time), and make small final targeting adjustments, if necessary (Table 1).

For the Task Time, participants were significantly faster when using the left-aligned scrollbar than the right-aligned scrollbar, $F(1, 6) = 29.12$, $p = .003$, partial $\eta^2 = .785$.

For the Scrollbar Acquisition Time, participants acquired the left-aligned scrollbar significantly faster than the right-aligned scrollbar, $F(1, 6) = 13.66$, $p = .01$, partial $\eta^2 = .695$. However, an interaction effect was also found for which condition participants performed first, $F(1, 6) = 26.24$, $p = .002$, partial $\eta^2 = .814$. Further analyses revealed that participants who used the right-aligned scrollbar first were significantly faster acquiring the left-aligned scrollbar in their subsequent tasks, $F(1, 3) = 66.05$, $p = .004$, partial $\eta^2 = .957$. In contrast, no significant differences were found for scrollbar acquisition times for participants who used the left-aligned scrollbar first, $F(1, 3) = 0.72$, $p = .458$, partial $\eta^2 = .194$.

For the Scroll Time, participants scrolled significantly faster using the left-aligned scrollbar than the right-aligned scrollbar, $F(1, 6) = 17.50$, $p = .006$, partial $\eta^2 = .745$.

For the Adjustment Time, no significant differences were found for scrollbar location, $F(1, 6) = 3.16$, $p = .126$, partial $\eta^2 = .345$. We also examined the average number of adjustments made when trying to position the target circle, and no significant difference was found for scrollbar location, $F(1, 6) = 2.31$, $p = .180$, partial $\eta^2 = .278$.

Studies 2 and 3. Studies 2 and 3 used the same tasks and data-logging techniques. Therefore, the timing data from both studies were combined, with study as a between-subjects factor. No significant difference was found based on which

Table 1: Timing Data for Study 1

	Framing Selection Task									
	TT		*SAT*		*ST*		*AT*		*#Adj*	
	M[a]	*SD*	*M*[a]	*SD*	*M*[a]	*SD*	*M*[a]	*SD*	*M*	*SD*
Left	3663	864	730	195	1862	1030	1070	336	1.55	0.49
Right	4413	860	832	244	2241	896	1341	537	2.19	1.29
Difference	750*		102*		379*		271		0.64	

Note. TT = task time; SAT = scrollbar acquisition time; ST = scroll time; AT = adjustment time; #Adj = number of adjustments.

[a]Measured in msec.

*$p \leq .01$.

study the participants performed, across all of the analyses. The timing data gathered included the time to select the target and the time to scroll back to the top after the item was selected for both the icon and list selection tasks (Table 2).

For the Target Acquisition Time in the icon selection task, participants acquired the target significantly faster with the left-aligned scrollbar than with the right-aligned scrollbar, $F(1, 12) = 27.05$, $p < .001$, partial $\eta^2 = .693$. A significant interaction effect was also found for which condition participants performed first, $F(1, 12) = 12.21$, $p = .004$, partial $\eta^2 = .504$, with participants being 665 msec faster on average when using the left scroll first and 3,389 msec faster on average when using the right scroll first. Further analyses revealed a significant difference between scrollbar location when participants used the right-aligned scrollbar first, $F(1, 6) = 26.08$, $p = .002$, partial $\eta^2 = .813$, but not when they used the left-aligned scrollbar first, $F(1, 6) = 2.64$, $p = .155$, partial $\eta^2 = .306$. The Return Time (the time to scroll back to the top after selecting the target icon) was significantly faster using the left-aligned scrollbar than the right-aligned scrollbar, $F(1, 12) = 17.48$, $p = .001$, partial $\eta^2 = .593$.

For the Target Acquisition Time in the list selection task, participants acquired the target significantly faster with the left-aligned scrollbar than with the right-aligned scrollbar, $F(1, 12) = 53.82$, $p < .001$, partial $\eta^2 = .818$. A significant interaction effect was also found for which condition participants performed first, $F(1, 12) = 16.96$, $p = .001$, partial $\eta^2 = .586$. Further analyses revealed that in both cases, participants performed significantly faster using the left-aligned scrollbar; however, the difference was greater when participants used the right-aligned scrollbar first (1,431 msec, partial $\eta^2 = .868$) versus the left-aligned scrollbar first (402 msec, partial $\eta^2 = .718$). The Return Time was significantly faster using the left-aligned scrollbar than the right-aligned scrollbar, $F(1, 12) = 27.84$, $p < .001$, partial $\eta^2 = .699$.

4.2. Questionnaire Data

Participants rated both the left- and right-aligned scrollbars on a Likert scale for several qualities: comfort, fatigue, perceived speed and accuracy, and screen obscurement. In all cases, a rating of 5 was positive, whereas a rating of 1 was

Table 2: Timing Data for Studies 2 and 3 for the Icon Selection Task and the List Selection Task

	Icon Selection Task				*List Selection Task*			
	TAT		*RT*		*TAT*		*RT*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Left	7,956	2,681	2,525	2,769	3,948	992	1,610	285
Right	9,983	3,300	2,894	2,685	4,865	1,251	1,930	393
Difference	2,027*		369*		917*		320*	

Note. TAT = target acquisition time; RT = return time.
*$p \leq .002$

negative. Participants in Studies 2 and 3 completed the questionnaire for both tasks they performed; therefore, the data for these two tasks were averaged for each participant.

Table 3 presents the descriptive statistics for each quality assessed. Wilcoxon signed-ranks tests revealed that the left-aligned scrollbar was considered significantly more comfortable, less tiring, faster, more accurate, and less obscuring of the screen than the right-aligned scrollbar ($p < .001$).

Participants were asked whether they felt that they held the stylus differently depending on where the scrollbar was located. Twenty of 24 participants indicated that they did hold the stylus differently, $\chi^2(1, N = 24) = 10.67$, $p = .001$.

Participants were also asked to rate their overall preference for scrollbar position on a scale of 1 (*strongly prefer left*) to 5 (*strongly prefer right*). Twenty-one of 24 participants indicated a strong preference for the scrollbar being on the left-hand side, 2 indicated a slight preference for the scrollbar on the left, and the remaining participant did not have a location preference, $\chi^2(2, N = 24) = 31.75$, $p < .001$.

4.3. Field Study Results

Participants in Study 4 interacted with each scrollbar condition for 3 days. Given that participants were free to select whichever foods they wanted, there was a wide selection of foods chosen. Each participant made 20 to 45 food selections for each condition (left $M = 30.5$, right $M = 28.25$).

All participants indicated that using the right-aligned scrollbar was more difficult and less natural than using the left-aligned scrollbar. For example, 1 participant explained that he "would normally use [the stylus] like a pen … definitely more natural on the left-hand side."

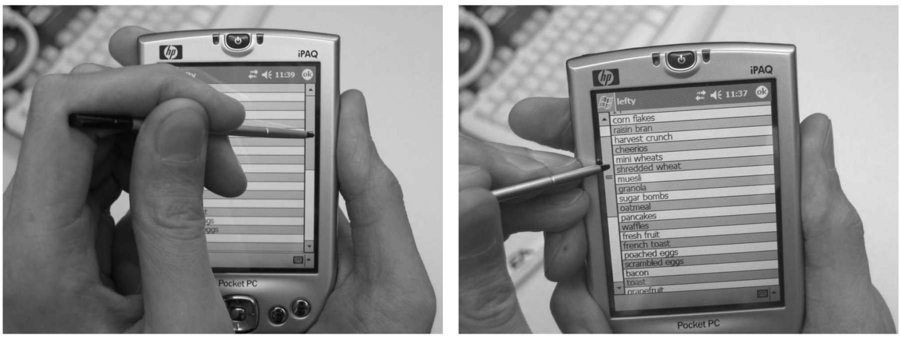
Table 3: Questionnaire Results With Wilcoxon Signed-Ranks Analyses ($n = 24$)

	M	*SD*	*Z*	*p*
Comfort				
Left	4.19	.60	–4.126	.000
Right	2.25	.71		
Tiring				
Left	4.35	.58	–3.948	.000
Right	2.83	1.01		
Perceived Speed				
Left	4.40	.53	–3.955	.000
Right	3.06	.85		
Perceived Accuracy				
Left	4.25	.79	–4.300	.000
Right	2.75	.78		
Obscured Screen				
Left	5.00	.00	–4.328	.000
Right	1.69	.69		

Note. Each item was rated for both the left and right-aligned scrollbars on a scale from 1 to 5 where a rating of 5 was positive and a rating of 1 was negative.

All participants also reported that when they used the right-aligned scrollbar, reaching across the screen to interact with the scrollbar obscured the screen (Figure 4a). One participant specifically explained that to scroll on the right side she had to reach across the screen, covering the entire screen. This meant that she couldn't really see anything, so she would have to iteratively scroll, take her hand away, and scroll some more to see where she was. With the left scrollbar she could see the list at all times. None of the participants reported obstruction problems when using the left-aligned software (Figure 4b).

To compensate for having the screen obstructed by their hand when using the right-aligned scrollbar, participants adapted their hand placement or stylus grip. Two of the 4 participants reported that they changed the position of their hand while holding the stylus over the course of the study. One arched his hand over the screen, extending the stylus (Figure 5a). The other extended the stylus up from the



(a) (b)

FIGURE 4 Left-handed person using (a) a right-aligned scrollbar and (b) a left-aligned scrollbar.

(a) (b)

FIGURE 5 Corrective hand positioning of left-handed users using a right-aligned scrollbar: (a) hand arching over the top of device and (b) stylus extending up from the bottom.

bottom of the device (Figure 5b). "I am totally changing the way I hold [the stylus] and the way I am putting my hand to use it. Whereas with the left-hand side it was just like I wouldn't even need to think about doing anything different."

Both participants who adapted their hand placement found it unnatural and awkward. The other two participants preferred to keep their hand in a more natural position. All participants compared the stylus to a pen and indicated that their idea of how to use a pen affected how they used the stylus. "Normally I hold it more naturally like a pen."

Position of the scrollbar did impact stylus use. When using the left-aligned scrollbar, all participants held the stylus as they would a pen, gripping it close to the tip. When using the right-aligned scrollbar, 3 of the 4 participants adapted their grip, holding the stylus farther back, similar to a pointer. None of the participants who adapted their grip felt that it was natural. The remaining participant (the one who did not adapt her grip) indicated that she preferred to use the stylus as she would a pen (more naturally), despite the disadvantages associated with this.

One participant commented that in reaching across the screen to use the right-aligned scrollbar his hand would often touch the screen and select an unwanted food item. "My pinky finger would actually touch the [screen]."

Two of the 4 participants (one ambilateral) indicated they had considered using the stylus in their right hand, but they found this too awkward. The other ambilateral participant (the one who indicated that the stylus was like a pen) noted that because she would never use a pen in her right hand, the idea of using the stylus in her right hand had never crossed her mind.

6. DISCUSSION

The results from this research clearly demonstrate the significant advantage of providing left-aligned scrollbars for left-handed users. Benefits were noted in scroll time performance, user preferences, and perceived ergonomic and performance benefits.

6.1. Faster Scrolling

Examination of the time to perform scrolling tasks across the three experiments (Studies 1, 2 and 3) consistently revealed that left-aligned scrollbars are significantly faster than right-aligned scrollbars for left-handed users. In addition, this result was comparable across the three different tasks we explored in both a controlled and an informal environment.

The timing differences are likely a result of the ergonomic difficulties reported in the questionnaires and field study results. All 28 participants strongly agreed that use of the right-aligned scrollbar caused the display to be occluded. This occlusion makes it difficult to visually scan content while scrolling. Therefore, tasks that require a visual scan should benefit more from the left-aligned scrollbar. This hypothesis was supported in Studies 2 and 3 with larger effect sizes for the acquire-target portion of the task (which required finding a particular target) than the return portion of the task (which only required scrolling back to the top).

Study 1 further investigated how left-aligned scrollbars impact scroll times by examining the individual components involved in a scrolling action. The results indicated that the left-aligned scrollbar was significantly faster for the scrollbar-acquisition phase and the main scrolling phase but not for the final-adjustments phase.

6.2. Order Effect

It was interesting to note that for several of the measures, there was a significant interaction effect due to the condition that was performed first. This effect was likely caused by participants' actions becoming more efficient as they became familiar with the experimental tasks. However, the left-aligned scrollbar was found to be faster overall. As a result, when participants used the left-aligned scrollbar first, their subsequent interactions with the right-aligned scrollbar likely improved because of the order effect, resulting in minimal or no significant differences. In contrast, when participants used the right-aligned scrollbar first, the order effect, combined with the fact that the left-aligned scrollbar was faster, caused participants' subsequent interactions with the left-aligned scrollbar to be significantly faster.

6.3. Natural Interactions

The results of Study 4 revealed that natural interactions are important to users and that left-aligned scrollbars are more natural for left-handed people. First, participants indicated that they perceived a direct mapping between the stylus and a pen and therefore they would be more inclined to use the stylus in their dominant hand. Two of the participants in Study 4 indicated that they had considered using their nondominant hand with the right-aligned software; however, they chose not to because they felt it would be awkward. In addition, Kabbash et al. (1993) suggest that providing a wider scrollbar should improve selection using the nondominant hand. Although using the nondominant hand solves the problem of screen occlusion, it makes the interaction less natural, particularly because of the relationship participants expressed between the pen and the stylus. Wider scrollbars would require a larger proportion of screen space, which is difficult to justify on small devices.

It is generally accepted that users should not have to adapt to using the computer; it should adapt to them. The specification of handedness could be automated (Harrison et al., 1998) or user controlled and would ensure a more natural interaction on handheld devices for left-handed users.

6.4. Smart Widgets Placement

Scrollbars (although the focus of these studies) are not the only on-screen widget for mobile devices that, inappropriately placed, can impact user performance given the user's handedness. Any application requiring on-screen input (i.e., hyperlinks, buttons, text entry forms, context menus, etc.) should make the placement of their input widget dynamic based on handedness. For example, it is common for applications to left align their drop-down menu or submenus. This works well for readability as English is read left to right but is inefficient given right-handedness. Left-handed users receive the benefit of not having to reach across the screen to select the drop-down bar, where right-handed users have to occlude their screen to make the interaction. This is a good example of how a desktop interface style does not appropriately map to a handheld and direct input.

In the case where handedness can not be determined or is not defined by the user, widgets should assume a neutral placement providing an equal benefit to either handedness. Widgets such as context menus could pop up directly above or below the mouse cursor rather than to the left or right (depending on handedness) so as to be useful to both left- and right-handed users. Because placing widgets in this manner will result in a less than optimal experience for all users it is important to discover the handedness of the user whenever possible.

6.5. Task

Left- and right-handed scrolling was examined across four different tasks. This examination provides us with insights into the general mechanics of scrolling (Framing Selection Tasks), a sense of its impact on realistic (albeit simple) tasks (Icon and List Selection Tasks), scrolling that does not require visually scanning for a target (returning to the top in the Icon and List Selection Task), and general usage information when users choose the degree of usage (Food Diary Task). The consistency of our results across all of these dimensions provides external validity to the results and provides compelling evidence that the scope of the problem is broad.

6.6. Environment

Studies 2 and 3 both examined the same tasks in different environments. Overall, no significant differences were found between the results from these two studies, suggesting that the scrolling problem is more of a fundamental motor control and occlusion problem and is impacted very little by environment distraction and comfort.

7. CONCLUSION

The results of our studies provide support for the intuitive notion that handedness is an important factor to consider in the design of handheld devices. Left-handed user performance was significantly enhanced when scrollbars were left aligned; the participants claimed overwhelmingly that they preferred the left-aligned scrollbar and found the interaction to be more natural. Looking closer at the practical significance of the results reveals that the time to perform a scrolling action is increased roughly 20 to 25% when left-handed users were forced to use a right-aligned scrollbar. In our tasks, this translated to a 1- to 2-sec increase in time per task. Although for infrequent movements this time is short, given the small screen available on most mobile devices means that scrolling will be a common action, and a 1- to 2-sec increase in every action can add up to be a significant amount of time.

Even if we disregard the time implications of left-aligned scrollbars, users' preferences should matter. Our results overwhelmingly demonstrate that left-aligned scrollbars are more comfortable, are less tiring, and obscure the screen less. Although left-handed users will likely adapt to yet another right-handed device in a right-handed world, maybe designers who recognize, appreciate, and support these differences will win loyalty from this community of users, which will be reflected in the products they choose to purchase. Given the malleability of software, there is no good reason why widget position cannot be a user preference.

Scrollbar position, although only one minor component of overall mobile device design, is representative of a larger problem. Metaphors from desktop systems are often automatically applied to new platforms without regard for the resulting implications. Metaphors used in desktop systems are assumed to extend well to mobile environments; clearly there are cases in which this is not true. To avoid situations like this in the future, it is important to identify other design elements that may suffer interaction problems similar to the scrollbar problems identified in this article.

Mobile devices, although popular and becoming more pervasive within our society, are inherently difficult to use effectively. As interface designers, we should attempt to make the devices as natural for use as possible. A user's handedness is only one piece of information that designers can leverage to provide a better experience; however, as this study has identified, it is an important one.

Ongoing work in this area is examining whether the occlusion problem observed in this study carries over to other devices such as a tablet PC. These devices require direct input but offer a much larger screen than PDAs. The larger screen should reduce occlusion but may increase the effects of fatigue. The correlation between screen size and direct input devices and the problems observed in this study are currently unknown.

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