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A Study of Pointing Performance of Elderly Users on Smartphones

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The number of global smartphone users is rapidly increasing. However, the proportion of elderly persons using smartphones is lower than that of other age groups because they feel it is difficult to use touch screens. There have only been a few studies about usability and elderly smartphone users or designs for them. Based on this background, we studied the pointing action of elderly users, which is a basic skill required to use touch screens on smartphones. We reviewed previous works to determine specific research methods and categorized them into three groups: (a) effect of target size and spacing on touch screen pointing performance, (b) effect of age on pointing performance, and (c) feedback of touch screens. To investigate the touch screen pointing performance of elderly, we conducted two experiments. In the first experiment, 3 target sizes (5 mm, 8 mm, and 12 mm) and 2 target spacings (1 mm, 3 mm) were evaluated. Adding to that, we analyzed whether touch screen pointing performance is dependent on the location of the target. In the second experiment, 3 types of feedback (auditory, tactile, and audiotactile) were evaluated. The results show that (a) pointing performance of elderly was significantly influenced by size, spacing, and location of target, and (b) the performance was higher in audiotactile feedback condition. We expected that these results can contribute to the design of smartphone applications for elderly users.

1. INTRODUCTION

The International Data Corporation (IDC; 2011) reported that sales of cellular phones in the first quarter of 2011 were about 420 million, and of this number, 100 million were smartphones. This is an 85% increase compared to last year, and the number of smartphone users will continue to increase rapidly. However, the utilization rate decreases with age and the elderly make up only 11% of smartphone users (A. Smith, 2011). Considering the proportion of the elderly population, the elderly have considerably lower access to smartphones than other age groups.

The touch screen interface is a major reason why there are so few elderly users. Direct pointing on a touch screen is intuitive to be sure, but at the same time it requires more exact pointing skills than hardware buttons. Research is needed to improve smartphones for elderly users that takes into account their physical condition. Smartphones have improved the computing capacity of users by enabling information searches via the Internet and the installation of applications that meet the users' needs. By making smartphones more accessible for the elderly, the elderly could also benefit from smartphone use as well. Furthermore, because touch screens are used in diverse settings such as kiosks, Automatic Teller Machines (ATMs), digital cameras, and so on, it is important to know how to help the elderly feel comfortable with using touch screens.

According to Henze, Rukzio, and Boll (2011), a touch screen and a few physical buttons is the dominant format for smartphones since the iPhone was introduced. Touch screens allow various controls by direct touch or gestures on a screen, so it is thought to be an intuitive method for novices from a human–computer interaction perspective. However, careful representation and control of information is necessary because of the limited space of touch screens. Researchers have studied and suggested the optimum level and layout of information through the evaluation of different target sizes and spacings (Colle & Hiszem, 2004; Jin, Plocher, & Kiff, 2007; Park & Han, 2010; Schedlbauer, 2007). Given that touch screens lack tactile feedback compared to physical buttons, visual, sound, and vibration feedback have also been studied. (Lee & Zhai, 2009). Vibration feedback was demonstrated to improve pointing performance on physical keyboards in previous studies (Hoggan, Brewster, & Johnston, 2008).

Regardless of previous attempts to better the touch screen experiences, the studies that targeted the elderly are few, even though the requirements for elderly users are different due to their declining cognitive abilities. We do not know yet what features should be provided to suit the elderly's cognitive skills or how to provide these features. Previous research suggested that other feedback types are appropriate for the elderly (Thornbury & Mistretta, 1981). In this article, the results show that the sensitivity of elderly users to tactile feedback was lower than that of children. Thus, research on proper feedback types for the elderly should be conducted.

Our study investigates smartphone touch screen behavior of elderly users. In particular, we studied target size, target spacing, and location of targets. In addition, we investigated the effect of feedback types on performance. To archive the research

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goal, two experiments were conducted. The first experiment evaluated the influence of target size, target spacing, and location on pointing performance. The second experiment evaluated the influence of feedback types. The questionnaire for subjective measures was adapted from previous studies and was asked right after each experiment. Proper target size, target spacing, and feedback were then analyzed using both objective and subjective data.

2. LITERATURE REVIEW

2.1. Factors Influencing Touch Screen Pointing Performance

The size and interkey spacing of pointing targets are known important factors that affect touch screen use. Colle and Hiszem (2004) conducted research on performance and preference by size and interkey spacing of numeral buttons on a 12.1-in. kiosk screen and proposed proper size and spacing. Twenty university students (18–22 years of age) participated and carried out one-, four-, or 10-number input tasks. The button sizes included four levels (10, 15, 20, and 25 mm) and spacing included two levels (1 and 3 mm). Task completion time, errors, and preferences were recorded for each layout. Results showed that except for one-number inputs, button size had significant effects on input performance at four- and 10-number inputs. Task completion time and errors decreased as button size increased to 20 mm. However, there was no significant difference in the 20 mm and 25 mm size targets and task completion time, errors, and preferences were not affected by interkey spacing. Participants preferred 20 and 25 mm buttons more than 10 and 15 mm buttons, but there was no difference in interkey spacing. Analysis of gender demonstrated that there were no differences in performance and preference based on gender.

In 2007 Schedlbauer researched proper key size and interkey spacing by comparing trackballs and touch screens (stylus input, direct finger input) in a mobile context. Participants were 22 to 57 years of age. There were seven men and one woman. In this study, participants performed nine-character (e.g., N 173 01 937, S 130 37 915) input tasks. Independent variables were button size (10, 15 mm) and interkey spacing (1.5, 4.5 mm). The ranking for the fastest task completion time was stylus, finger, and trackball. When using a trackball, participants made very few errors. They made the most errors when using their finger. Participants made almost the same number of errors using 15 mm size buttons with all three input methods. Interkey spacing did not affect pointing performance, similar to Colle and Hiszem (2004).

Sun, Plocher, and Qu (2007) investigated the effect of button size, spacing between buttons, button/icon types, and glove wearing (wearing vs. not wearing) on touch screen performance. This study showed that spacing between button and glove wearing did not affect performance, whereas button size did have a significant effect. Sears and Shneiderman (1991) researched performance, error rates, and user preferences using three types of devices—touch screen, touch screen with stabilization, and mouse. The main task in this experiment was to select a rectangular target of 1, 4, 16, and 32 pixels. Results showed that there was no difference in performance between the devices. However, error rates were reduced significantly for small targets when using a touch screen with stabilization. Rogers, Fisk, McLaughlin, and Park (2005) researched the performance of touch screen tasks depending on the button size, movement distance, direction, and type of movement. This study also analyzed the age of the user. The results demonstrated that performance was influenced by the age of the user and the task characteristics.

2.2. Effect of Age on Pointing Performance

Given the decreased physical abilities of elderly persons, there is a lot of research about this in many different fields. Especially, studies on pointing performance in particular have been conducted based on various devices.

Teeken et al. (1996) studied the effects of sex and age on the pointing actions of 141 participants ranging in age from 20 to 70 years old. Two experiments were conducted. The first was pointing to the right side of a target and then moving to left side. The second was continuously pointing to two targets for 15 s. Movement time, holding time, and errors were recorded. Results showed that movement time increased by the age of the participant. In the first experiment, the completion time of male was faster than female; however, there was no difference in second experiment. Moreover, age had an effect on the number of errors, whereas gender did not.

Hertzum and Hornbæk (2010) researched the difference of pointing behavior between mouse and touch pad users of different ages. Three groups (young: 12–14, adult: 25–33, elderly: 61–69) performed a pointing task experiment to investigate the effect of age on using these devices. With these pointing methods it was possible to assess the effects of eight movement directions. The measured variables were time and error rate at 6 px; 21 px size; and a 70 px, 175 px, 350 px spacing. The task completion time of young and adult groups was shorter than the elderly group, but the error rate was higher. This is similar to a study by Walker, Philbin, and Fisk (1997) that found a difference in strategy between adult and elderly users. Elderly users made more submovements and had longer task completion times. Moreover, the mouse was faster and more accurate than the touch screen and all participants preferred the mouse.

Murata and Iwase (2005) compared the usability of a touch screen interface by young, middle-aged, and older adults. Performance was measured by taking into consideration pointing time and target location. Results showed that there was no significant difference on pointing time between these groups. Moreover, performance was high when the pointing target was located in the center among nine target locations.

Zhou et al. (2012) presented a comprehensive literature review to investigate whether, and if so why, older adults accept handheld computers and how to design elderly-friendly handheld computers. As for input method, they recommended a 0.6 to 0.8 cm size key area and 5.6 to 7.5 mm interkey spacing. Beyond that, many researchers studied pointing behavior of the elderly with various devices such as mouse, touch pad, and trackball and verified that their performance is lower than other younger adults (Hsu, Chung Huang, Hui Tsuang, & Sheng Sun, 1999; M. W. Smith, Sharit, & Czaja, 1999; Walker et al., 1997).

Jin et al. (2007) proposed a design recommendation for the optimal button size and spacing of a touch screen interface for older adults. This was based on a user experiment that consisted of measuring reaction time, accuracy, and user preferences. Hence, button size, spacing, and manual dexterity were studied. The results showed that accuracy increased as the size of the buttons increased. The larger buttons were also preferred by the users. On the other hand, spacing showed no effect on response speed; however, accuracy and preference were low. Last, manual dexterity showed no significant effect on performance; however, it had a significant effect on the reaction time and accuracy of selecting target buttons.

Beyond the aforementioned research, there are many studies on the size of buttons and spacing between buttons on various devices (Forlines, Wigdor, Shen, & Balakrishnan, 2007; Henze et al., 2011; Park & Han, 2010; Taveira & Choi, 2009). However, the participants of most studies were 20 to 50 years of age. Moreover, relatively more complex tasks such as sentence or number input tasks were given to younger adults, whereas simple tasks such as pointing at a target were given to the older participants. These simple pointing tasks required less work, and thus the effect of cognitive ability on pointing performance was minimized.

In short, we conclude that the present state of research about elderly users of on mobile devices is inadequate. Thus, we selected the elderly as our target population to reflect the increasing smartphone adoption rates of the elderly and their diminishing physical ability.

2.3. Feedback of Touch Screens

Because touch screens offers information and control on one screen, this can be considered a very intuitive device. However, Lee and Zhai (2009) pointed out that the lack of tactile feedback is one of the major weaknesses of touch screens compared to physical buttons. Thus, mobile devices having touch screens provide visual, sound, and tactile feedback when a touch event occurs, and there are many studies about the effects of feedback on touch screen use.

Lee and Zhai (2009) evaluated touch screens (impact sensing, capacitive sensing) and physical keyboards using an input task of a given sentence. They evaluated the effect of sound, vibration, and sound–vibration feedback. The results showed that when sound and vibration feedback were given, task completion time and the number of errors significantly decreased. Similarly, Hoggan et al. (2008) conducted a comparative study on physical keyboards, nonfeedback touch screens, and tactile feedback touch screens to investigate the effects of vibration feedback. Twelve adults between 18 to 38 years of age participated in the experiment. Task completion time, the number of errors, and subjective measure with NASA-TLX were measured at nonmovement and movement status. The results showed that input performance on tactile feedback touch screens approached physical keyboard levels and there were no significant differences in movement status. It also showed that vibration feedback could significantly decrease workload level versus nonfeedback touch screens. Thus, tactile feedback is an important factor not only for improving pointing performance on touch screens but also for decreasing workload.

Altinsoy and Merchel (2009) investigated the difference of haptic and auditory feedback on touch screens. The experiment considered unimodal and multimodal environments for auditory and tactile feedback. Execution time, error rate, and subjective quality of the overall feedback were measured by dialing-numbers tasks with no feedback, auditory, audiotactile, and tactile feedback. The results show that tactile feedback had a positive effect on the quality and error rate compared to no feedback. Also, auditory and tactile feedback had high scores in subjective satisfaction compared to no feedback. Therefore, multimodal designs had a synergistic effect on touch screen feedback.

Previous studies verified that providing sound and tactile feedback are useful methods for supplementing the touch screen's lack of tactile feedback. However, participants in previous studies were mainly 20 to 40 years of age. Holzinger, Searle, and Nischelwitzer (2007) proved that the tactile sensitivity of the elderly is lower than that of children. Thus, it is possible that appropriate feedback types could differ between elderly and younger adults. Therefore, various feedback types (auditory, tactile, and audiotactile) were evaluated by elderly users to determine the best feedback type.

3. METHOD

3.1. Apparatus

In this study, we developed a program for evaluating pointing performance with various size targets, target spacing, and feedback types on smartphone devices. Eclipse Java EE IDE (Indigo version) and Android SDK were used for programming. Size and spacing of target were arranged by XML code.

The background color used in the program was black based on the icon arrangement of current smartphones. The color of buttons was white considering the brightness contrast and the visual ability of elderly users. Targets were presented in red considering the low perception ability of elderly users to blue and yellow. The size and spacing of targets in the program were as shown in Table 1.

The size and spacing of target were selected by considering objects in 4.3-in. smartphone keyboards, icons, and based on

TABLE 1
Target Size and Interkey Spacing

Size		Interkey Spacing	
5mm	Button size of QWERTY keyboard or Checkbox in system control panel	1 mm	An interkey spacing between QWERTY keyboard keys
8mm	Icon size in 4.3 in Android smartphone	3 mm	A interkey spacing between icons on an iPhone
12mm	According to Hertzum and Hornbæk (2010), the pointing time and errors were decreased at 12 mm target size.		Similar level to result of Jin et al. (2007)

previous work. Thus, in this research, we evaluated six layouts for the first experiment with no additional feedback except for visual feedback.

Because the level of sound and vibration feedback could affect the evaluation, they needed to be defined precisely. Sound feedback of 70 dB was used based on results of Gjoderum et al. (2009) study that suggested the proper level for elderly persons is 70 dB. Because this study sought to investigate only the effect of tactile feedback, we used default intensity level of vibration. The duration of vibration feedback was 300 ms 1-beat vibration based on Hoggan et al. (2008). All participants reported that the vibration feedback provided by the device was enough to be recognized. We did not include visual feedback as a dependent variable because visual sense was the basic feedback for the overall experimental task.

3.2. Participants

Twenty-two elderly subjects (older than 65) participated in our experiments. There were nine male and 13 female participants. Participants had generally good health and were able to recognize 5 mm size buttons and hear 70 dB sound feedback. Hertzum and Hornbæk (2010) limited participants to those who did not have information technology (IT) educational experience because they compared mouse and touchpad. However, in this study, we did not limit the participants by IT experience because the mouse was not evaluated. However, participants who owned a smartphone were not included to minimize the effect of past experience.

3.3. Subjective Evaluation

In addition to objective data collected during the experiment, subjective data from a questionnaire were collected. To develop the subjective evaluation questionnaire, we reviewed previous studies on pointing behavior (Table 2).

Previous studies mainly used ISO 9241 and NASA-TLX for subjective evaluation. The ISO 9241 is considered a more specific method for input devices compared to NASA-TLX. Thus, we developed the subjective evaluation questionnaire based on ISO 9241. Among the ISO 9241 items, fatigue of finger, wrist, and arm was not significant in the previous comparative studies on devices. Thus, these items were not included in this study. Adding to that, we did include additional measurements, such as suitability, to reflect various dimensions. Items used were as shown in Table 3.

3.4. Task

The main task in our experiments consisted of simple pointing at randomly presented targets. Target arrangement was similar to Douglas, Kirkpatrick, and MacKenzie (1999) with nine buttons arranged at 45° intervals with a red target among them (Figure 1). The pointing sequence was to the center target

TABLE 2
Reference and Assessment Items of Previous Study

Research	Reference	Assessment Items
Hertzum and Hornbæk (2010)	ISO 9241	Ease of use; level of difficulty; mental effort; physical effort; fatigue of finger, wrist, arm, shoulder, and neck
Douglas et al. (1999)	ISO 9241	Required level of mental and physical effort; smoothness of action; ease of use; speed; fatigue of finger, wrist, arm, shoulder, and neck; overall convenience and satisfaction
Hoggan et al. (2008)	NASA-TLX	Mental, physical, temporal demands; poor performance; effort; frustration; overall workload
Brewster, Chohan, and Brown (2007)	NASA-TLX	

TABLE 3
Items of Subjective Measurement in This Study

	Measurement	Definition
Experiment 1	Suitability	The quality of having the properties that are right for a specific purpose
	Ease of use	The property of a product or thing that a user can operate without having to overcome a steep learning curve.
	Mental effort	A cognitive load and fatigue during performance testing
	Physical effort	Muscle load and fatigue during performance testing
Experiment 2	Recognizability	The ease with which feedback signal can be discriminated
	Usability	An effectiveness of the interaction between humans and computer systems
	Satisfaction	An overall attitude toward the system

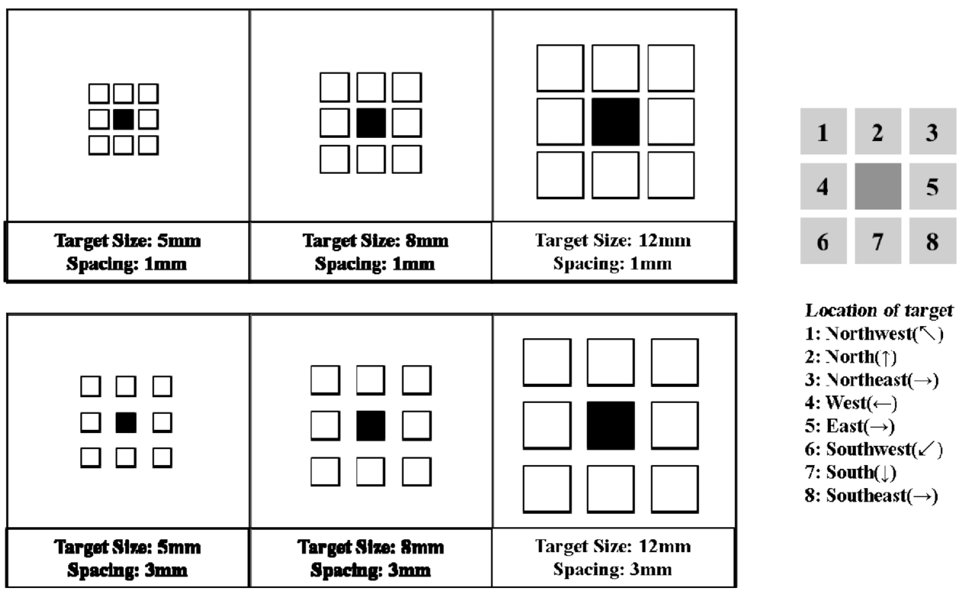

FIG. 1. Layout types used in the experiment.

then to the peripheral target. Targets were presented randomly to avoid participants from predicting the location of the target object. Each trial began when participants touched the center target. Then a red light was turned on among one of the peripheral targets. When the subject touched the red-colored peripheral target, the trial was completed. Performance measures included (a) task completion time (the time between touching the center target and touching the peripheral target) and (b) number of error (number of events that touching the outside area of target object).

3.5. Procedure

The experiment was divided into two experiments. To minimize the interaction effect between the two experiments, we had a 1-day interval period after the first experiment.

The first experiment was designed to investigate the effect of target size and spacing on touch screen pointing performance. Participants performed pointing tasks that consisted of six layouts for the first experiment. Thus, three size targets (5 mm, 8 mm, and 12 mm) and two target spacings (1 mm and 3 mm) were evaluated, which were repeated three times for each combination. Each combination consisted of eight trials, which included eight target locations that surrounded the center target object. After the experiment, participants filled out subjective assessment questionnaires about each layout type.

The second experiment was conducted to investigate the effect of feedback types on touch screen pointing performance. In the second experiment, four feedback types (no feedback, auditory, tactile, audiotactile) were evaluated and analyzed. Feedback was provided when the touched area was not included in the target object. To avoid fatigue and diminished performance due to long experiment times, we used only the most difficult touch screen layout in the second experiment. To select the most difficult layout, Fitts' Law Index was calculated for six layouts, and as a result, a layout with 5 mm size targets with 3 mm spacing was selected. In the second experiment, four additional feedback types (no feedback, auditory, tactile, and audiotactile) were randomly provided and also repeated three times for each feedback.

The overall experiment was administered individually for each participant. After a briefing about the experiment, participants filled out a background survey. Then participants had a training session for an average of 5 min. In each experiment, participants completed pointing tasks with randomly selected layouts. Participants could not proceed until the correct target had been selected. They could not predict the next target because the ordering of targets was randomized. The overall procedure of each experiment is shown in Figure 2.

4. RESULTS

4.1. Descriptive Statistics

Seniors older than 65 were the target subjects of our experiments. Twenty-two seniors participated—nine men and thirteen women. The average age of the participants was 70.55, ranging from 65 to 79, with higher average age of women than men as shown in Table 4. Six participants (27.27%) had previously taken computer classes, and another eight had experience using computers for an average of 8 years. Thirteen (59.09%) answered that they had used a touch-screen interface such as an ATM. Thirteen participants had no other experiences a touch screen interface other than an ATM. Overall, most of the participants had used or experienced IT devices and touch-screen interfaces but had not used mobile touch screen interfaces.

4.2. Experiment 1

In Experiment 1, we analyzed how the size and spacing between targets affect pointing performance. Pointing performance is measured by the time taken to complete the pointing task and the number of errors during the task. The results from our suggested layout are presented in Table 5.

It took the longest time when the target size was 5 mm and the spacing between targets was 1 mm. This arrangement also had the most errors. The layout with the best performance—the shortest completion time and the fewest errors—was when the target size was 12 mm and spacing was 1 mm. In sum, participants performed their tasks better as the targets got larger and the target spacing widened (Figure 3).

Drawing on these basic statistics, we conducted a repeated analysis of variance (ANOVA). The test is done (a) to find out

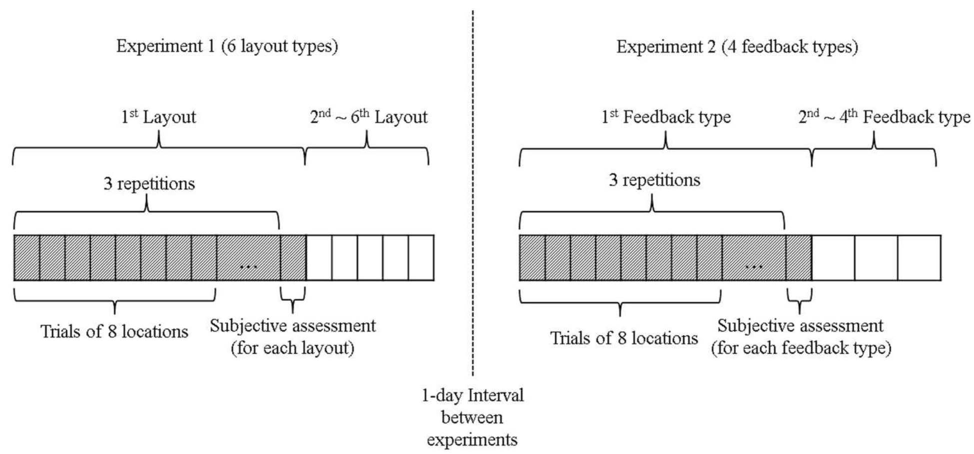

FIG. 2. Overall procedure of experiment.

TABLE 4
Descriptive Statistics of Participants

	Male	Female	Total
Gender	9	13	22
	Average = 69.11	Average = 71.54	Average = 70.55 (years)
	(*SD* = 1.197)	(*SD* = 0.996)	(*SD* = 3.713)
Computer education experience	Yes = 6	No = 16	
Computer usage experience	Yes = 8	No = 14	Average = 8.375 (years)
Touchscreen usage experience	Yes = 13	No = 9	Used place: ATM

TABLE 5
Results of the Task Completion Time and the Number of Errors

Target	Spacing: 1 mm	Spacing: 3 mm
Size		
5 mm	T = 40.811 (*SD* = 16.977)	T = 30.969 (*SD* = 15.795)
	E = 22.39 (*SD* = 15.444)	E = 18.68 (*SD* = 18.228)
8 mm	T = 17.543 (*SD* = 7.737)	T = 14.214 (*SD* = 3.459)
	E = 3.35 (*SD* = 3.952)	E = 1.56 (*SD* = 1.898)
12 mm	T = 12.206 (*SD* = 3.137)	T = 12.266 (*SD* = 2.599)
	E = 0.24 (*SD* = 0.583)	E = 0.39 (*SD* = 0.782)

Note. T = task completion time (msec); E = no. of errors.

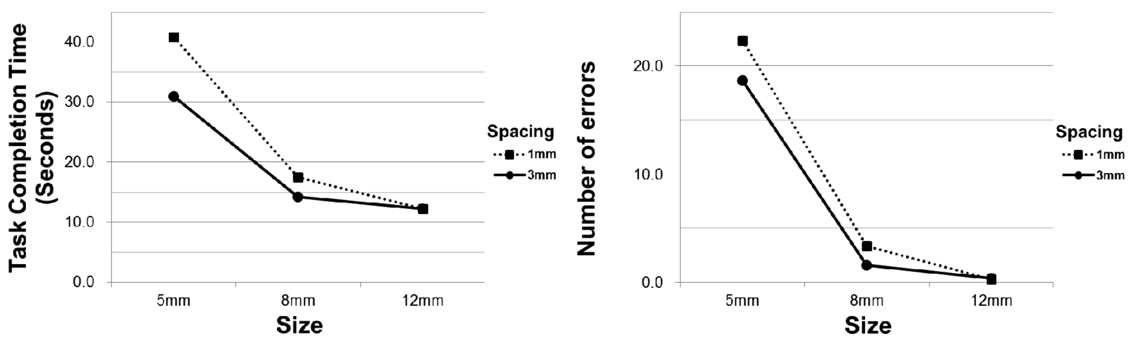

FIG. 3. Results of the task completion time and the number of errors.

if target size and spacing is significantly related to pointing task performance (task completion time and the number of errors), (b) to see whether there is a learning effect as the number of trials accumulates, and (c) to investigate whether a significant relationship exists between the direction of pointing and pointing performance.

Post hoc analyses were performed when pointing performances differed significantly depending on different target sizes, spacing, the number of trials, and the location of target in order to clarify on what level the performances differed. The ANOVA results of target size and spacing, the number of trials, and characteristics of participants are shown in Table 6. We measured the characteristics of participants with their level of computer related knowledge and experience using computers and touch-screen interfaces.

As shown, there were significant differences in task completion time related to target sizes, spacing, number of trials, and gender. An interaction effect between target size and intertarget spacing is present, and between target size and number of trials. Meanwhile, the error frequency rate decreased as target size grew larger and target spacing got wider. Moreover, size and spacing (p = .002) and size and trials (p < .000) had an interaction effect on task completion time. The interaction between size and spacing showed that task completion time with 3 mm spacing was greater than 1 mm spacing if the target size was 12 mm.

The ANOVA of the interaction effect between Size × Spacing (p = .002) and Size × Trial (p < .000) turned out to be significant on task completion time. Of interest, it took a longer time for participants to complete the task when the key size was 12 mm and spacing was 3 mm than when spacing was 1 mm for the same target size. We concluded that when target size reaches a certain level, the average distance between keys also widens for participants to point across the keys. Thus, when the target spacing is added to the distance, it results in longer task completion times. Thus, a layout with narrow target spacing will produce better performance, given a certain level of target size.

A learning effect was found given that performance improves as the number of trials increase. As in Figure 4, it can be seen that completion time and error frequency decrease over repetitive trials. The analysis revealed that task completion time is significantly decreased across the trials (p < .000), but it was not significant for error frequency (p = .237).

The post hoc analysis was conducted to more specifically examine the results of the ANOVA (Table 7). In other words, it was performed to determine whether the significant difference was caused by factor levels on the task completion time and the number of errors.

TABLE 6
Analysis of Variance Results

Dependent Variables	Factors	*df*	*F*	*p*	Significance
Task completion time	Size[b]	1.330	72.523	.000***	Y
	Spacing[c]	1	40.943	.000***	Y
	Trial[a]	2	15.327	.000***	Y
	Size × Spacing[b]	1.234	10.605	.002**	Y
	Size × Trial[b]	2.096	10.778	.000***	Y
	Spacing × Trial[a]	2	1.808	.177	N
	Size × Spacing × Trial[b]	1.995	1.371	.265	N
	Gender[c]	1	5.991	.024*	Y
	Computer education[c]	1	0.330	.572	N
	Computer experience[c]	1	0.008	.929	N
	Touchscreen experience[c]	1	3.483	.077	N
No. of errors	Size[b]	1.029	46.303	.000***	Y
	Spacing[c]	1	6.960	.015*	Y
	Trial[a]	2	1.491	.237	N
	Size × Spacing[b]	1.053	1.856	.187	N
	Size × Trial[b]	2.017	2.319	.110	N
	Spacing × Trial[a]	2	0.136	.873	N
	Size × Spacing × Trial[b]	1.967	0.537	.585	N
	Gender[c]	1	1.777	.198	N
	Computer education[c]	1	0.135	.717	N
	Computer experience[c]	1	0.001	.976	N
	Touchscreen experience[c]	1	3.266	.086	N

[a]Mauchly's Test of Sphericity was satisfied, so *F* value of Sphericity assumption in test of within-subjects effects is used. [b]Mauchly's Test of Sphericity was not satisfied, so *F* value of Greenhouse-Geisser in Test of Within-Subjects Effects is used. [c]*F* value of Wilks's lambda in multivariate test of significance is used.

$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

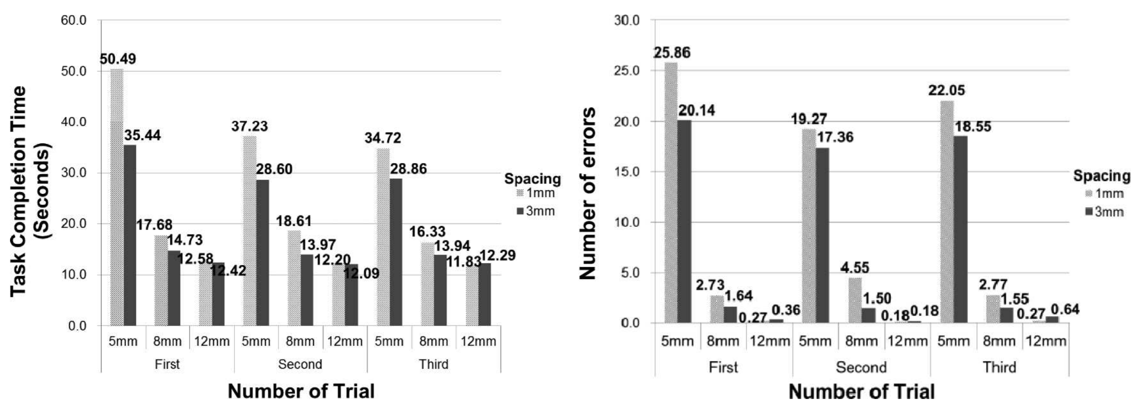

FIG. 4. The task completion time and the number of errors by number of trial.

As shown in Table 7, task completion times were significantly different in all the target sizes. Thus, the target size is an important factor in pointing performance. In the first trial, the task completion time was longer than the other two trials. This may be due to the lack of touch screen experience and unfamiliarity of the experimental task. Just like the task completion time, error frequency was significantly different in all target sizes.

In addition, this study analyzed the location of targets associated with the pointing movement, which could have significant effects on pointing performance. To analyze the effect of target location, we performed the ANOVA (Table 8). As a result, there

TABLE 7
Post Hoc Analysis Results of Size and Trial

Dependent Variables	Factors		Average	Standard Error
Task completion time(s)	Size	5 mm	35.890^{a}	2.359
		8 mm	15.879^{b}	1.063
		12 mm	12.236^{c}	0.570
	Trial	First	23.892^{a}	1.051
		Second	20.449^{b}	1.126
		Third	19.663^{b}	0.914
No. of errors (times)	Size	5 mm	20.538^{a}	2.865
		8 mm	2.455^{b}	0.455
		12 mm	0.318^{c}	0.092

Note. The mean difference is significant level (α) at the .05 level.
For each variable, values with different alphabet superscripts are significantly different at P < 0.05.

TABLE 8
Analysis of Variance Results of Target Location

Dependent Variables	Factors	*df*	*F*	*p*	Significance
Task completion time	Location^{a}	7	2.858	.042*	O
No. of errors	Location^{a}	7	4.261	.009**	O

$^{*}p < .05$. $^{**}p < .01$.
For each variable, values with different alphabet superscripts are significantly different at P < 0.05.

TABLE 9
Post Hoc Analysis Results of the Target Location

Dependent Variables	Factors	Average	Standard Error
Task completion time(s)	Location 1 (NW)	1.926^{a,b}	0.236
	Location 2 (N)	1.471^{a,c,e}	0.106
	Location 3 (NE)	1.774^{b,d}	0.185
	Location 4 (W)	1.566^{a,d,f}	0.120
	Location 5 (E)	1.443^{c,d}	0.085
	Location 6 (SW)	1.609^{a,d,f}	0.117
	Location 7 (S)	1.652^{b,e,f}	0.106
	Location 8 (SE)	1.801^{b,f}	0.138
No. of errors (times)	Location 1 (NW)	0.922^{a,b}	0.204
	Location 2 (N)	0.533^{b,c}	0.096
	Location 3 (NE)	0.740^{a,d}	0.163
	Location 4 (W)	0.530^{c,e,d,f}	0.118
	Location 5 (E)	0.477^{c,d,e}	0.084
	Location 6 (SW)	0.679^{a,b}	0.104
	Location 7 (S)	0.576^{a,b,e}	0.084
	Location 8 (SE)	0.699^{a,b,f}	0.095

Note. The mean difference is significant level (α) at the .05 level. Multiple comparisons mediated by least significant difference. N = North; W = West; E = East; S = South; NW = Northwest; NE = Northeast; SW = Southwest; SE = Southeast.
For each variable, values with different alphabet superscripts are significantly different at P < 0.05.

are significant differences in task completion time and number of errors over target location. The task completion time and the number of errors were significantly different by the target location.

Figure 5 shows that completion time and error frequency differed by target location. For target location, the task completion time (11.56 s) and the number of errors (5.53) for targets located at 1(NW) were the highest. On the other hands, targets located at 5(E) had the lowest pointing performance by task completion time (8.66 s) and the number of errors (2.86). These results indicate that pointing at target location 5 is a more natural motion than pointing at target location 1. However, because of all participants in our experiment are right-handed, these results may be affected by the participant's primary hand. To identify the difference by the level of target location, we performed the post hoc analysis (Table 9).

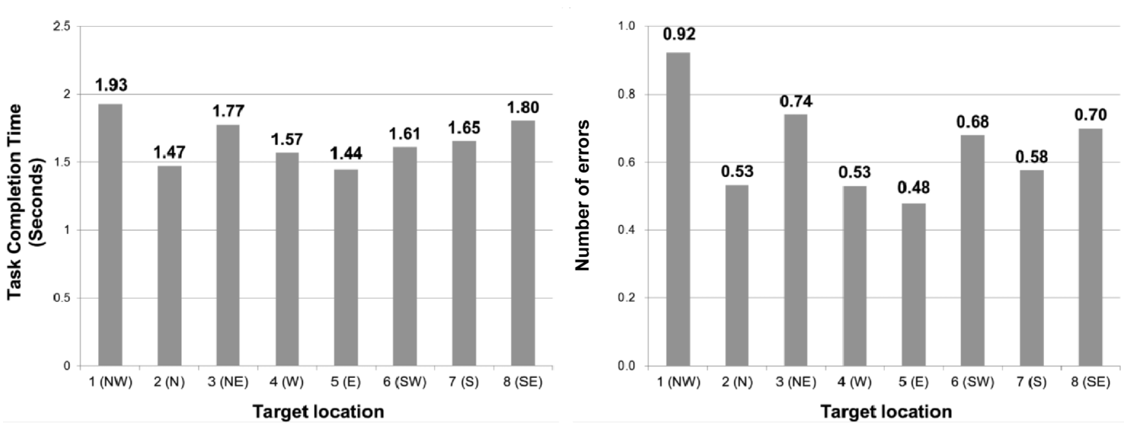

FIG. 5. The task completion time and the number of errors by target location. *Note.* N = North; W = West; E = East; S = South; NW = Northwest; NE = Northeast; SW = Southwest; SE = Southeast.

TABLE 10
Results of Subjective Evaluation

Layout		Average (*SD*)				
Size	Spacing	Suitability of Size	Suitability of Spacing	Ease of Use	Mental Effort	Physical Effort
5 mm	1 mm	1.68 (0.839)	1.91 (0.684)	1.86 (0.640)	1.82 (0.733)	4.59 (1.054)
	3 mm		3.55 (0.739)	2.41 (0.908)	1.95 (0.999)	4.55 (1.101)
8 mm	1 mm	3.77 (1.020)	3.09 (0.868)	3.73 (1.032)	2.95 (0.999)	4.82 (0.501)
	3 mm		4.23 (0.685)	4.32 (0.894)	3.50 (0.964)	4.41 (1.297)
12 mm	1 mm	4.91 (0.426)	3.27 (0.883)	4.82 (0.501)	3.68 (1.287)	4.77 (0.612)
	3 mm		4.59 (0.590)	5.00 (0.000)	4.32 (0.995)	4.77 (0.612)

TABLE 11
Analysis of Variance Results of Subjective Evaluation

Dependent Variables	Factors	*df*	*F*	*p*	Significance
Suitability of size	Size[a]	2	94.902	.000***	Y
Suitability of spacing	Spacing[b]	1	129.255	.000***	Y
Ease of use	Size[a]	2	131.428	.000***	Y
	Spacing[b]	1	32.406	.000***	Y
Mental effort	Size[a]	2	47.305	.000***	Y
	Spacing[b]	1	18.768	.000***	Y
Physical effort	Size[a]	2	0.955	.393	N
	Spacing[b]	1	3.241	.086	N

[a]Mauchly's Test of Sphericity was satisfied, so *F* value of Sphericity assumption in test of within-subjects effects is used. [b]*F* value of Wilks's lambda in multivariate test of significance is used.
***$p < .001$.

In post hoc analysis of pointing performance and location, location 1(NW) and location 5(E), location 2(N) and location 3(NE), and location 5(E) and location 8(SE) were significantly different in terms of task completion time and the number of errors. Pointing performance improved on target locations such as location 2(N) and location 5(E), whereas the target locations located diagonally from the center showed low performance. That is, participants could move quickly and easily when pointing from bottom to top and from left to right. On the other hand, diagonal pointing could lower speed and accuracy.

In addition, we performed a subjective evaluation of about six layouts right after each experiment. Through the survey questionnaire, we measured suitability of size and spacing, ease of use, mental effort, and physical effort. Table 10 shows the results of this subjective evaluation on each layout. The subjective evaluation shows that suitability of size was highest for 12 mm targets Moreover, 12 mm size and 3mm spacing was the highest for the suitability of spacing as well as ease of use and mental effort. Overall, elderly users preferred the layout with 12 mm size and 3 mm spacing. Suitability generally increased when target size and spacing increased. This is because pointing was improved by size and spacing. Table 11 shows the ANOVA results of the subjective evaluation.

There were significant differences in suitability of size, suitability of spacing, ease of use, and mental effort by target size and spacing. However, physical effort was not affected by target size or target spacing. There were no significant differences in physical effort by layout type. Results of post hoc analysis of subjective evaluation are shown in Table 12.

In the post hoc analysis results, there are significant differences among all sizes for suitability of size, ease of use, and mental effort. The results indicate that elderly users preferred a big target size over a small one.

4.3. Experiment 2

Pointing performance and the feedback type were analyzed to investigate whether there were significant differences. The feedback types for the second experiment were as follows: (a) no feedback (visual feedback was present by default), (b) auditory, (c) tactile, and (d) audiotactile. The results of each feedback types are shown in Figure 6.

TABLE 12
Post Hoc Analysis Results of Subjective Evaluation

Dependent Variables	Factors		Average	Standard Error
Suitability of size	Size	5 mm	1.682[c]	0.179
		8 mm	3.773[b]	0.218
		12 mm	4.909[a]	0.091
Ease of use	Size	5 mm	2.136[c]	0.140
		8 mm	4.023[b]	0.182
		12 mm	4.909[a]	0.053
Mental effort	Size	5 mm	1.886[c]	0.174
		8 mm	3.227[b]	0.185
		12 mm	4.000[a]	0.221

Note. The mean difference is significant level (α) at the .05 level. Multiple comparisons mediated by least significant difference.

As shown in Figure 6, the task completion time was the highest with tactile feedback and was the lowest in audiotactile feedback. On the other hand, the number of errors was the lowest in audiotactile feedback and was the highest when there was no additional feedback (visual only). On the whole, pointing performance was more effective when audiotacitle feedback was provided.

We conducted an ANOVA to analyze differences by feedback types. The results are shown in Table 13. Task completion time and error frequency significantly differed by the feedback type. Also, an interaction effect between feedback type and number of trials was found on task completion time. Table 14 shows the results of the post hoc analysis.

In the post hoc analysis of task completion time, no feedback and audiotactile, auditory and tactile, auditory and audiotactile, and tactile and audiotactile showed significant differences. In terms of error frequency, a significant difference was found between no feedback and audiotactile, auditory and tactile, and tactile and audiotactile. As a result, we concluded that the audiotactile feedback could improve the pointing performance of elderly users more than no feedback or tactile feedback.

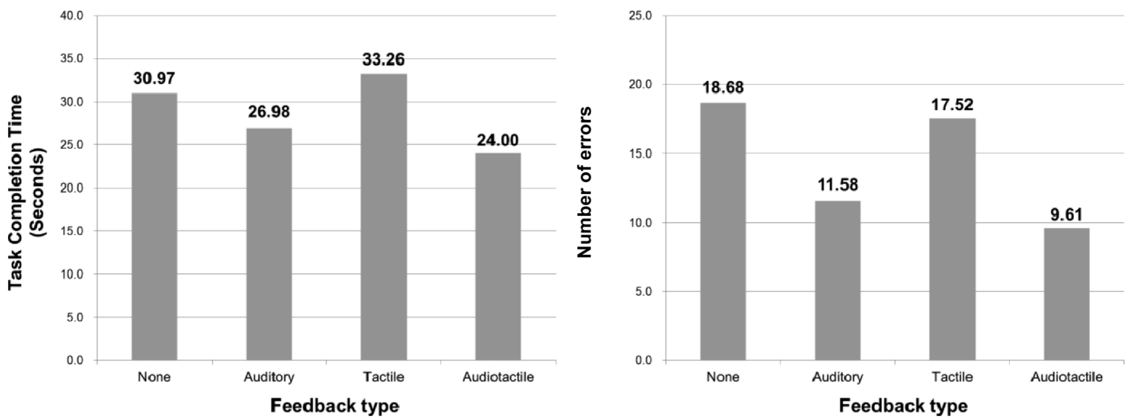

FIG. 6. The task completion time and the number of errors by feedback type.

TABLE 13
Analysis of Variance Results of Feedback Type

Dependent Variables	Factors	*df*	*F*	*p*	Significance
Task completion time	Feedback[b]	2.279	4.766	.010*	Y
	Trial[a]	2	0.864	.429	N
	Feedback × Trial[a]	6	3.309	.005**	Y
No. of errors	Feedback[b]	1.775	5.172	.013*	Y
	Trial[b]	1.542	0.806	.426	N
	Feedback × Trial[b]	3.838	1.409	.240	N

[a]Mauchly's Test of Sphericity was satisfied, so *F* value of Sphericity assumption in test of within-subjects effects is used. [b]Mauchly's Test of Sphericity was not satisfied, so *F* value of Greenhouse-Geisser in test of within-subjects effects is used.

$^{*}p < .05$. $^{**}p < .01$.

TABLE 14
Post Hoc Analysis Results of Feedback Type

Dependent Variables	Factors		Average	Standard Error
Task completion time(s)	Feedback type	None[a,b]	30.969	2.901
		Auditory[b]	26.979	1.235
		Tactile[a]	33.262	3.055
		Audiotactile[c]	23.998	1.299
No. of errors (times)	Feedback type	None[a,b]	18.682	3.401
		Auditory[b,c]	11.576	1.160
		Tactile[a]	17.515	2.404
		Audiotactile[c]	9.606	0.995

Note. The mean difference is significant level (α) at the .05 level. Multiple comparisons mediated by least significant difference.

For each variable, values with different alphabet superscripts are significantly different at $P < 0.05$.

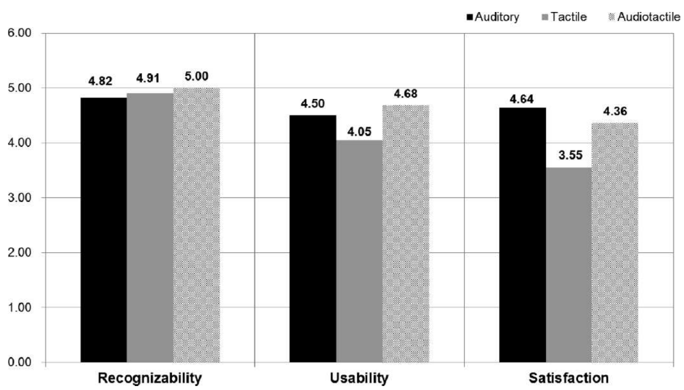

FIG. 7. Results of subjective evaluation of feedback type.

We also conducted a subjective evaluation of the degree of satisfaction (5-point Likert scale = 1 [*strongly disagree*] to 5 [*strongly agree*]) with feedback types. The subjective evaluation results of feedback types are shown in Figure 7.

Respondents preferred audiotactile feedback in terms of recognizability and usability. In contrast, they preferred auditory feedback in terms of overall satisfaction. To analyze statistical significance, an ANOVA and post hoc analysis were performed for the subjective evaluation of feedback types (Table 15 and 16).

In the ANOVA results, in terms of the usability and satisfaction, except for the recognizability, there were significant differences by the feedback types. Recognizability showed no differences among three types of feedback. In the post hoc analysis, results of usability, there was a difference between tactile feedback and other types (auditory and audiotactile). This result was consistent with the results for satisfaction. The results show that elderly users do not prefer tactile feedback in terms of usability and satisfaction.

Overall, when both audio and tactile feedbacks are present, pointing performance was significantly improved. However, elderly users do not generally prefer tactile feedback, such as vibration. In other words, the multimodal feedback could be effective for pointing performance, whereas the tactile feedback could have an adverse effect. Notably, tactile feedback requires more careful consideration because tactile feedback can cause physical fatigue or damage.

5. DISCUSSION

5.1. General Discussion

Through this study, we investigated the influence of target size, spacing, and location on elderly users' pointing performance on small touch screens. We also examined the

TABLE 15
Analysis of Variance Results of Subjective Evaluation of Feedback Type

Dependent Variables	Factors	*df*	*F*	*p*	Significance
Recognizability	Feedback[b]	1.236	1.000	.376	N
Usability	Feedback[a]	2	2.364	.003**	Y
Satisfaction	Feedback[b]	1.542	9.769	.001**	Y

[a]Mauchly's Test of Sphericity was satisfied, so *F* value of Sphericity assumption in test of within-subjects effects is used. [b]Mauchly's Test of Sphericity was not satisfied, so *F* value of Greenhouse-Geisser in test of within-subjects effects is used.

$^{**}p < .01$.

TABLE 16
Post Hoc Analysis Results of Subjective Evaluation of Feedback Type

Dependent Variable	Factors		Average	Standard Error
Usability	Feedback type	Auditory[b]	4.500	0.183
		Tactile[c]	4.045	0.167
		Audiotactile[a,b]	4.682	0.102
Satisfaction	Feedback type	Auditory[a,b]	4.636	0.168
		Tactile[c]	3.545	0.235
		Audiotactile[b]	4.367	0.203

Note. The mean difference is significant level (α) at the .05 level. Multiple comparisons mediated by least significant difference.

For each variable, values with different alphabet superscripts are significantly different at $P < 0.05$.

effect of additional feedback types on touch screen pointing performance.

Based on Experiment 1, we learned that elderly users' pointing performance on small touch screen devices was affected by target size, spacing between targets, and location of targets. Overall, pointing performance is increased as target size grows larger and spacing between targets gets wider. Of interest, the effect of spacing was not seen in large target size layouts. In the small and medium target size layouts, pointing performance is higher with wide target spacing. However, in the large target layouts, target spacing does not affect pointing performance. Pointing performance was slightly higher in narrow target spacing layouts rather than in wider spacing. The experiment showed that when target size reaches to a certain size, this size plus the spacing between the targets increases the task completion. Given that, the layout with narrow target spacing will produce better performance, having a certain level of key size.

Subjective evaluation showed results consistent with the results of the experiments. Participants reported that pointing was easier in terms of suitability, ease of use, and mental effort as the target size and spacing were increased. It is remarkable that subjective physical effort was not affected by target layout, but suitability, ease of use, and subjective mental effort were affected by target layout. This means that elderly users perceived difficulties coming from cognitive factors rather than physical effort. Consequently, to increase smartphone usage among elderly users, a familiar user interface and an environment consisting of simple tasks with an adequate layout are necessary, rather than the development of a totally different device.

Through the additional analysis of Experiment 1, we examined the effect of target location on pointing performance. We found that pointing performance improved when target location is in the upper and right direction from the center point. Pointing performance on diagonally located targets was lower. Based on this result, designers could consider a layout with a right/upper-side arrangement for frequently used buttons. However, the higher performance on right-sided target locations could be related to the participant's primary hand. Because this study recruited only right-handed people to avoid the effect of primary handedness, further study about the effect of one's primary hand on pointing performance is needed.

In Experiment 2, we investigated the effect of additional feedback types on pointing performance. As a result, we found that tactile feedback is inappropriate for elderly users because it did not improve pointing performance. Furthermore, it could distract participants from their pointing tasks and lower efficiency with an increasing subjective workload. Specifically, tactile feedback could cause users to lose a stable grip of the smartphone. This could be critical to elderly users because they have less physical strength. In contrast, with auditory feedback, overall pointing performance slightly improved. Adding to that, performance was increased significantly when the feedback provided by a combination of auditory and tactile feedback. This result indicates that multisensory feedback is a more effective solution than unisensory feedback for the elderly. Furthermore, in their subjective evaluation, respondents reported the lowest score to tactile feedback in terms of satisfaction and usability, whereas they reported that audio tactile feedback was similar to, or better than, auditory feedback. This means that with audio tactile feedback, auditory feedback could mitigate the negative effect of tactile feedback rather than increasing cognitive effort.

5.2. Limitations and Future Work

This study has some limitations that should be considered in further studies. The target population of this study was homogeneous in terms of age and related ability. Because our study focused on elderly users' mobile touch screen pointing performance, we limited our target population to elderly subjects. Further studies of a diverse population could deepen our understanding about human performance on touch screen interfaces with a wider perspective. Second, our priority was on the performance of elderly users. The aesthetic side of design was not the focus of this study. The performance of elderly users can be improved by adjusting the button size and spacing, but it can result in inhibiting the capability of designers and their preferences. Although previous studies have suggested the correlation between aesthetics and usability, it should be studied again from the perspective of elderly users to determine whether the same result will be replicated. Third, our study used simple tasks for basic research about elderly users' pointing performance on mobile touch screens. Further study is necessary to reflect the real use of smartphones, using tasks that are more diverse and difficult.

5.3. Conclusion

This study investigated the mobile touch screen pointing performance of elderly users. The results show significant effects of target spacing on pointing performance. It is a different result from the study by Colle and Hiszem (2004), which concluded that interkey spacing was not related to pointing performance on kiosk touch screens. The result of our study means that, unlike the static/large touch screen environment such as kiosks, on small/mobile touch screens, the combination of button size and spacing is important. In addition, it suggests that previous studies about input device and human performance should be reviewed consistent with advances in technology. In addition, previous studies concluded that tactile feedback was necessary because current mobile touch screens do not provide physical feedback (Hoggan et al., 2008; Lee & Zhai, 2009). However, our study shows that tactile feedback alone should be cautiously considered. This is especially the case when it is provided to elderly users in a multimodal format.

The results of this study can contribute to the design of mobile touch screen devices, application button layout of graphical user interfaces and feedback types. Because smartphones have to include information and an input controller in the same display, current smartphones include too much information relative to their touch screen space. As a result, the size of some touch objects or letters often gets smaller. In this respect, QWERTY keyboards are not appropriate for small mobile touch screens. This kind of input method could hinder smartphone use by the elderly. Therefore, designers and developers should provide an option to adjust button size or design the buttons that could be easily used by as many people as possible. We also recommend the development of a new input method with the least number of hardware buttons possible and that can be utilized in various ways. Adapting gesture-based interaction or a voice command function are other possible solutions to the problem of limited physical space relative to a large amount of information and objects.

Given the increasing use of mobile devices and, in particular, smartphones, this study is timely and pertinent. The use of smartphones by older citizens brings into sharp focus the need to bridge the gap between our aging population and advances in information technology. We expect that through further study about how people interact with their electronic devices, more people will be able to enjoy the benefits of technology.

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