Examining the affordance effect of shifting symbols on the virtual buttons of smartphones

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The concept of on-screen affordance suggests that the visual properties of digital objects can affect how users perceive their function and operation. This study aimed to investigate the on-screen affordance of virtual buttons on smartphones and examine whether the visual properties of virtual buttons, such as symbol position, would affect users' entry performance on smartphones. To this end, the study has designed a shifting symbol that suggests where to tap on virtual buttons, thereby helping users tap the button center. This study adopted a two-way within-subject design: 2 (symbol position: static mode vs. dynamic mode) × 26 (key position: 26 alphabetic keys). The dependent variables were four indices for entry accuracy and speed. In the serial tapping task, 30 university students tapped on the soft keyboard using their right thumb. The result revealed that adjusting the symbol position on virtual buttons could alter participants' tapping direction without understanding the shifting symbol's operation. This study also proved that the shifting symbol could reduce input offsets without consuming more time. These findings demonstrated that symbol positions on virtual buttons could afford the possible clicking action and tapping direction for users regarding the affordance of virtual buttons.

Keywords: touchscreen; mobile device; graphical user interface; visual cue

1 Introduction

Mobile devices provide more and more apps and have become one of the necessary tools in life. Most mobile devices employ touchscreens as interfaces, which offer a natural and convenient means of human-machine interaction. Inexperienced or disabled users can easily use the touchscreen with less training (Ahearne et al., 2016; Sesto et al., 2012). The touchscreen interface that combines display and input can provide ergonomics benefits and design efficiency (Orphanides & Nam, 2017). For instance, the visual elements, such as button size and spacing, can be easily adjusted for personal needs (Colle & Hiszem, 2004). While touchscreens possess the advantages mentioned above, they also have certain limitations, such as poor precision, finger occlusion, absence of tactile input, and the "fat finger" problem (Benko & Wigdor, 2010; Boring et al., 2012; Holz & Baudisch, 2010; Orphanides & Nam, 2017; Siek et al., 2005). Moreover, smartphone apps (e.g., mobile games, soft keyboard) use many little buttons, which will cause users to miss these buttons. Therefore, the present study aimed to investigate the on-screen affordance of virtual buttons on smartphones and examine whether the visual properties of virtual buttons would affect users' entry performance on smartphones.

1.1 On-screen affordance

The concept of affordances inspires designers to create products that offer intuitively understandable actions during human-product interactions (You & Chen, 2007). The theory of affordances, proposed by Gibson in 1979, emphasizes the importance of environmental information that provides how people interact with the environment and objects (Gibson, 2014). Norman introduced the concept of "perceived affordances" in the field of design, referring to the relationship between the properties of an object and the user's abilities, which determines how the user can effectively utilize the object (Norman, 2013). According to Kim and Lee (2023), on-screen affordance is applicable in a digital environment with its distinct material properties and rules. Thus, when designing touchscreen interfaces, it is necessary to consider users' affordance perception, including visual elements and operating actions.

The on-screen affordance indicates that the visual properties of digital objects can influence how their function and operation are perceived (Kim & Lee, 2023). A previous study investigated the impact of specific visual properties on on-screen object manipulation (Kim & Lee, 2023). The study identified the correspondence between an on-screen object and a touch gesture, such as the horizontal visual flow corresponding with the gesture “slide.” The response time for a slide gesture was faster on a horizontal visual flow than a vertical visual flow. Therefore, the gestural effect of on-screen affordance was confirmed. Additionally, previous studies have found some evidence related to the on-screen affordance of virtual buttons. In one study, notable visual cues were incorporated into button icons (Huang & Chen, 2010). In the absence of visual cues, most participants tended to tap the center of icons. However, when significant visual cues were present, the participants tended to tap on the visual cues instead. In another study, five label positions were tested on smartphone buttons (Chen & Kuo, 2019). The result showed that when the label was situated in a different location on the button, participants tended to tap on the label rather than the button center. Therefore, they have demonstrated that some visual properties of virtual buttons could influence users' perception and tapping directions on touchscreens.

1.2 Influential factors on touchscreens

Previous studies have found some factors which affect the tapping behavior on touchscreens, such as button size, button position, hand gestures, etc. The effect of button size on touchscreens has been examined in previous studies (Chang & Jung, 2019; Colle & Hiszem, 2004; Parhi et al., 2006; Park & Han, 2010b; Tao et al., 2018; Xiong & Muraki, 2014). These studies have shown that the larger the button, the better user's entry performance. Chang and Jung (2019) further regarded the button size as a combination of the width and height of the button. As the width or height of the button increased, the entry duration and error rate gradually decreased, and users' satisfaction gradually increased. Xiong and Muraki (2014) used electromyography (EMG) to record the electrical-potential activity of the right thumb and forearm muscles. When tapping on the smaller button, the thumb suffered from fatigue rapidly, and the electrical-potential activity of the first dorsal interosseous (FDI) also increased significantly.

In addition, button shapes and the type of tapping tasks would influence the optimal button size. Tao et al. (2018) proved that there was an interaction between button size and button shape. When tapping the larger buttons (i.e., 22.5mm and larger), the three button shapes (square, horizontal, and vertical rectangles) had similar entry speeds. However, the entry speed of the square button would be better than those of other button shapes when tapping the smaller buttons. Parhi et al. (2006) also found that the type of tapping tasks affected the optimal button size. The optimal button size of multi-target tapping tasks (such as numeric and text entry) was slightly larger than that of single-target tapping tasks (such as activating checkboxes). When users tapped many target buttons in a multi-target tapping task, they would trade off entry accuracy against entry speed. As a result, large buttons were needed to maintain accuracy in multi-target tapping tasks. Therefore, the user interface on smartphones should avoid adopting little buttons to provide a good user experience.

The hand gestures would significantly affect the entry performance on smartphones (Azenkot & Zhai, 2012). Users could use different hand gestures to tap on the touchscreen when using the mobile device, such as the thumb and index finger. Smartphone users usually prefer the thumb-based input method, but the entry accuracy and speed are not as good as the finger-based Input method (Kim & Jo, 2015). It is partly due to the physiological structure and visual occlusion that affect the interaction between the thumb and the touchscreen. To hold the smartphone stably, the thumb is fixed at the bottom-right or bottom-left corner of the device, thus reducing the mobility of the thumb. In particular, a larger touchscreen would produce more comfortless areas to tap for the thumb (Xiong & Muraki, 2016).

Previous studies have also examined the effect of button positions on the tapping behavior. Park and Han (2010b) found that the buttons in the central region had shorter entry duration and higher satisfaction scores than those in other regions when tapping the touchscreen with the right thumb. They also found that the buttons in the left region had fewer errors than those in other regions because the buttons in the left region were less hidden by the right hand. Chang et al. (2017) found that the buttons near the initial positions of the thumbs had significantly shorter entry duration and lower discomfort ratings. The peripheral buttons far away from the initial position of the thumb required a large thumb joint displacement and great effort to tap. Trudeau, Young, et al. (2012) assumed that poor motor performance was related to reaching the limit of the moving range of the thumb. For instance, the buttons at the top-left and bottom-right corners of the touchscreen were the furthest and closest positions from the base of the thumb, respectively. These buttons would cause excessive flexion or extension of the thumb and require greater control to move the thumb, resulting in longer entry duration. However, Lee et al. (2019) found that the thumb has better entry performance when moving from the top-right corner to the bottom-left corner of the touchscreen (adduction-abduction movement). Therefore, the button position would determine the distance and direction of the finger movement and affect users' tapping behavior on smartphones. Finally, the factors that influenced tapping behavior on touchscreens in the aforementioned studies are summarized in Table 1.

Table 1. The summary of the factors that influence tapping behavior on touchscreens.

Factor	Property	Effects
Button size	Large button > Small button	Higher entry accuracy Higher entry speed Higher satisfaction

		Less fatigue
Button position	Central region > Other regions	Higher entry speed Higher satisfaction
	Initial position > Peripheral position	Higher entry speed Less discomfort
	Left region > Right region	Higher entry accuracy
Hand gesture	Index finger > Thumb	Higher entry accuracy Higher entry speed
Button shape	Square small button > Rectangle small button	Higher entry speed
Task type	Single-target tapping > Multi-target tapping	Higher entry accuracy

Note: ">" denotes "superior to".

1.3 Research questions

The present study would expand earlier studies by investigating whether other visual properties of virtual buttons, such as symbols that constantly change positions, could influence users' tapping directions on smartphones. Moreover, the present study also explored whether it was valid to adjust the visual properties of virtual buttons, such as symbol position, to change users' tapping directions and improve entry performance. Therefore, this study has designed a shifting symbol that can suggest where to tap on the button to make the user's tapping position closer to the button center. This design concept of shifting symbols comes from the idea that users want to tap the button center to increase the hit rate. However, none of them considers the fact that many factors cause the input offsets. The input offset means that the actual tapping position is different from the intended position. The input offsets are affected by some factors, such as hand gestures (Azenkot & Zhai, 2012), button size (Jung & Im, 2015; Park & Han, 2010a; Sheik-Nainar, 2010), button position (Kim et al., 2014; Lee et al., 2019; Park & Han, 2010a), and noticeable visual cues (Chen & Kuo, 2019; Huang & Chen, 2010). Therefore, if the input offsets are considered in the button design, the usability of buttons can be improved.

According to previous studies (Chen & Kuo, 2019; Huang & Chen, 2010), noticeable visual cues can draw users' attention resulting in a change in their tapping positions on touchscreens. This study would use the shifting symbol on virtual buttons as noticeable visual cues and the familiar QWERTY soft keyboard as the test interface. The alphabetic symbol on each key was used as the shifting symbol. The experimental system could record the input offset of users' every keystroke and use the average offset value of each key to adjust the position of the alphabetic symbol on each key. Based on the users' recent tapping data, the shifting symbol could immediately update its position (see Section 2.2 Research design). This study expected that a shifting symbol could attract users to tap towards the button center of little buttons, which could reduce input offsets and enhance entry accuracy. Furthermore, if tapping towards shifting symbols was the intuitive action, it wouldn't take more time to improve the entry accuracy of little buttons. Therefore, this study proposed three hypotheses as follows.

- Hypothesis 1. The symbols that constantly change positions would influence users' tapping directions to change X offset and Y offset.
- Hypothesis 2. The shifting symbol could efficiently improve the entry accuracy of keys to reduce the X offset, Y offset, and error rate.

- Hypothesis 3. The shifting symbol wouldn’t reduce the entry speed of keys to increase the entry duration.

2 Method

2.1 Participants

Thirty university students (14 males and 16 females) participated in this experiment, with a mean age of 22.7 years (SD = 2.07). They had normal or corrected-to-normal vision. No one claimed that their hands had any disease. They had used the smartphone or tablet for at least 5 years (Mean = 7.53 years, SD = 1.55). The average thumb length of participants was 100.10 mm (SD = 8.44), and the average thumb width was 15.03 mm (SD = 1.41). When using mobile devices, the participants adopted three gestures to tap on the soft keyboard: using both thumbs (20 participants), using one index finger (one participant), and using one thumb (nine participants).

2.2 Research design

This study adopted a two-way within-subject design: 2 (symbol position: static mode vs. dynamic mode) × 26 (key position: 26 alphabetic keys). Symbol position and key position were independent variables. First, symbol position was a within-subject variable, including static or dynamic mode. In static mode, the position of the alphabetic symbol on each key is in the key center. In dynamic mode, the position of the alphabetic symbol on each key is adjusted immediately based on participants’ prior tapping habit. In order to ascertain the participants' prior tapping habits for each key, the experimental system would calculate the average tapping position of the latest five keystrokes on each key (Figure 1a). The mirror axes for each key are defined as the horizontal and vertical axes passing through its center, which are then used to determine the mirror position of the average tapping position for each key. This mirror position is subsequently used as the new center position for the corresponding alphabetic symbol (Figure 1b). For example, the coordinates of the center position of the “s” key are (77, 141); the average tapping position of the latest five keystrokes on the “s” key is (80, 146), which is offset by three pixels to the right (X offset = 3) and five pixels upward (Y offset = 5) from the key center. In this case, the center position of the alphabetic symbol on the key is adjusted to (74, 136). However, the moving range of the alphabetic symbol is bounded by the border of the key. Second, key position is also a within-subject variable. The relative spatial positions of 26 alphabetic keys are the same as those on the QWERTY keyboard.

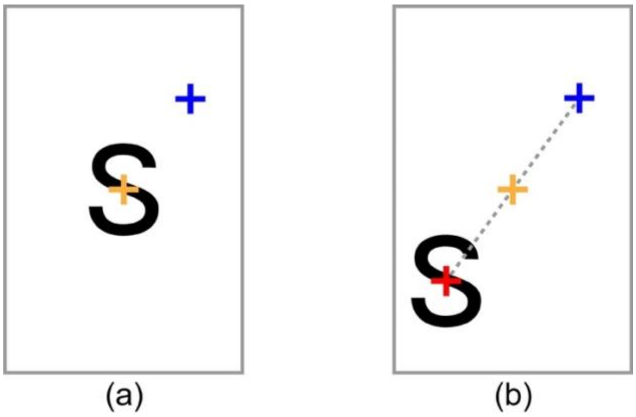

Figure 1. Method of adjusting the symbol position in dynamic mode (yellow cross: the key center; blue cross: the average tapping position; and red cross: the mirror position).

Four indicators were used as dependent variables: X offset, Y offset, error rate, and entry duration. In the serial tapping task, participants were instructed to tap the target keys on the soft keyboard. The X offset and Y offset are the horizontal and vertical distance between the user's touch location and the center of the target key, respectively. The error rate is the ratio of the failure at tapping the target keys. The above three indicators reflect the entry accuracy. In addition, entry duration is the time to tap each target key, which reflects the entry speed.

2.3 Apparatus and materials

Participants would use an Apple iPhone 6s (dimensions: 138.3 × 67.1 × 7.1 mm; weight: 143.0 g; LCD: 105 × 59 mm) to perform the serial tapping task. The logical resolution of the touchscreen on iPhone 6s is 375 × 667 pixels, with the CSS pixel ratio being two. Participants would use the SONY VAIO notebook (model: SVP132A1CP, 13-inch widescreen LCD) to fill in the questionnaires online. A 150-mm-long sliding caliper (with a resolution of 0.01 mm) was used to measure the thumb.

An experimental system can run the serial tapping task and record participants' tapping data. The interface of the experimental system is divided into two areas: the upper area displays the experimental parameter setting, and the lower area is a QWERTY soft keyboard (Figure 2a). The rectangular keys on the keyboard are colored grey and measure 7.5 x 4.9 mm. They are spaced apart by 0.9 mm from left to right and 1.1 mm from top to bottom. The lowercase letters on the keys are printed in the Kannada Sangam MN font and are colored white. The font size of the letters is 15.52 pixels. The interface of the soft keyboard involves two modes: a static-mode keyboard (Figure 2b) and a dynamic-mode keyboard (Figure 2c).

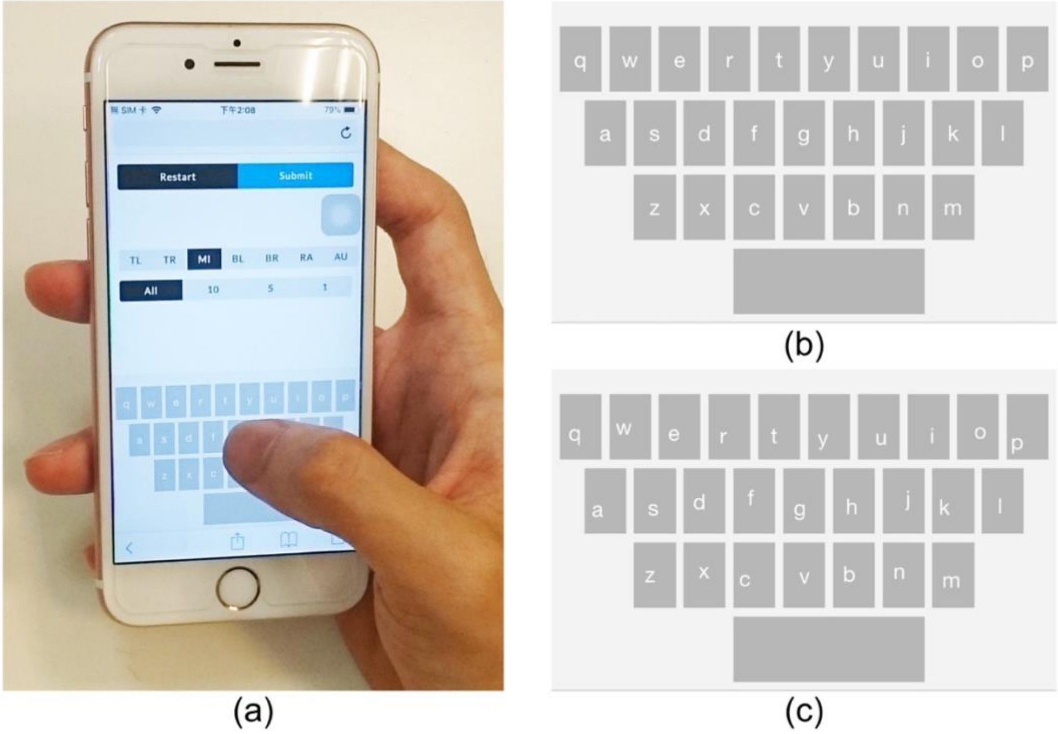

Figure 2. The Interface of two soft keyboards: (a) the experimental system; (b) the static-mode keyboard; (c) the dynamic-mode keyboard (the symbol position is adjusted based on a participant's data).

2.4 Procedure

After the participants entered the laboratory, the experimenter asked them to read the consent form and provide their background information and the mobile device experience. Then, the experimenter used the sliding caliper to measure the length and width of the participants' thumbs. The thumb was measured with reference to the methods of Xiong and Muraki (2016) and Turner et al. (2016). In the serial tapping task, the participants were instructed to hold the smartphone in a portrait manner with their right hand and tap on the soft keyboard with their right thumb. There was one round of practice before the formal experiment.

In the serial tapping task, participants were instructed to tap the target keys continuously. The experimental system randomly designated three keys as target keys. The original alphabetic symbols on these target keys were replaced with red target symbols "A," "B," and "C" (Figure 3a) or blue target symbols "1," "2," and "3" (Figure 3b). Successive presentations of two target symbols continued until the end of each round, during which participants were instructed to tap the target keys in either alphabetical or numerical order. When participants completed tapping the target key "B" or "2", the system randomly designated another three target keys (Figure 3b). When participants completed tapping each target key, the original alphabetic symbol on the target key reappeared. Whether in static or dynamic mode, the target symbol still retained the original position of the alphabetic symbol. If participants failed to tap the target key, a red alert was displayed on the keyboard.

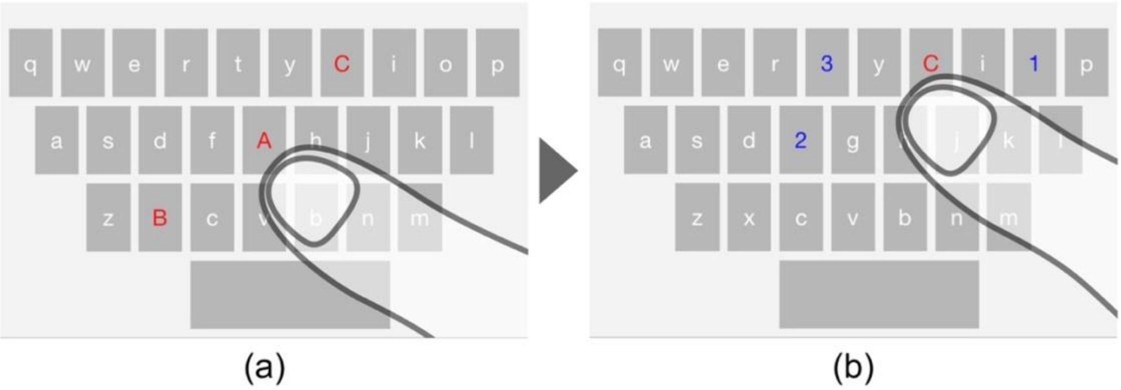

Figure 3. The process in the serial tapping task.

There were eight rounds in the formal experiment. Four rounds were in static mode and four rounds were in dynamic mode. To control the sequencing effect, this study used a counterbalanced (ABBA) design for these two modes. Each key was randomly tapped eight times in each round, resulting in 208 keystrokes per round. The participants could rest for a moment between each round. Moreover, the experimenter did not inform the participants that the position of alphabetic symbols on the key might change but rather allowed them to discover it actively during the task. After the formal experiment, the participants filled in the Chinese revised version of the System Usability Scale (SUS) (Bangor et al., 2008; Brooke, 1996) to evaluate the usability of the dynamic-mode keyboard. The experiment took 30 minutes.

2.5 Data collection and analysis

To understand whether the symbol and key positions affected the entry performance, this study collected four indices of the 26 alphabetic keys in static and dynamic modes. The experimental system collected 32 pieces of data for each key in either static or dynamic modes. The grey area of each key was the touchable area of each key. A tapping position outside the touchable area of each key was considered a tapping error. Therefore, the tapping error data was eliminated from the analyses for entry duration, X offset, and Y offset. A 2 (symbol position) × 26 (key position) repeated-measures ANOVA was applied to the X offset, Y offset, error rate, and entry duration. The significance level (α) was .05. When the data violated the assumption of sphericity, Greenhouse-Geisser correction was applied.

3 Result

Table 1 lists the means (M) and standard deviations (SD) of the X offset, Y offset, error rate, and entry duration. To clearly show the relationship between the indices and the key position, Table 1 presents the data in order of the spatial positions of keys on the QWERTY keyboard rather than in alphabetical order. This study also used the heat maps to mark the overall changes of the X offset, Y offset, error rate, and entry duration in different key positions in static and dynamic modes (Figure 4).

Table 2. Mean and SD values of the four indices.

	X Offset (pixels)				Y Offset (pixels)				Error Rate (%)				Entry Duration (msec.)			
	Static		Dynamic		Static		Dynamic		Static		Dynamic		Static		Dynamic	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Q	1.92	3.76	1.70	2.71	4.75	4.67	4.28	4.35	5.00	4.15	4.06	3.40	657	107	651	95
W	2.03	2.55	1.36*	1.74	4.21	5.27	3.70	4.24	4.38	4.54	5.21	5.28	614	88	626	84
E	0.49	2.13	0.72	1.73	3.51	6.01	3.49	4.41	3.65	4.50	3.75	4.22	561	89	577	71
R	0.74	2.62	0.76	1.61	3.34	6.05	3.12	5.17	5.10	3.89	5.00	3.81	531	79	539	58
T	1.08	2.44	1.00	1.71	2.92	5.91	2.66	4.91	6.15	4.68	6.35	5.09	521	73	526	68
Y	2.33	2.12	1.42*	1.78	3.37	5.91	2.75	4.67	6.67	6.18	5.94	5.15	523	80	541	90
U	3.03	1.99	1.87*	1.87	3.89	5.44	3.21	4.28	5.94	4.29	6.35	5.02	539	72	543	83
I	2.71	2.55	1.49*	1.82	4.03	4.94	3.26	3.94	5.31	4.87	4.79	4.32	560	101	562	77
O	0.36	3.13	0.58	2.37	3.56	5.13	2.98	4.28	6.25	5.19	4.58	4.84	597	89	598	86
P	3.60	4.63	3.26	3.64	3.90	5.14	3.30	4.46	4.58	3.91	5.73	4.50	610	101	615	93
A	-0.08	2.81	0.10	2.34	4.35	4.02	3.84	3.88	3.96	4.01	3.54	3.83	607	99	622	87
S	1.19	2.98	0.85	1.90	3.75	4.46	2.61	3.71	5.42	4.92	3.65	5.32	579	88	577	61
D	0.98	2.32	0.43	1.67	2.80	4.86	2.16	3.74	3.85	4.16	4.38	3.90	545	70	535	68
F	1.36	2.30	0.74*	1.79	2.42	5.20	1.86	4.23	3.33	3.48	5.00	4.90	521	79	523	65
G	1.89	2.04	1.22*	1.58	2.24	5.63	1.70	4.36	3.23	4.14	3.02	3.80	516	67	530	83
H	1.92	1.98	1.52	1.68	2.20	5.29	1.63	4.11	4.38	3.63	5.42	5.50	534	81	538	81
J	2.17	2.21	1.36*	1.88	2.38	4.91	1.92	3.95	5.94	5.28	6.56	5.77	548	84	555	85
K	1.23	2.66	0.82	2.31	2.50	4.92	2.00	3.86	5.31	4.35	6.56	5.99	602	85	613	94
L	2.59	3.55	2.81	2.91	1.85	5.05	1.74	3.96	13.02	10.86	13.13	12.07	616	101	625	79
Z	-1.22	2.84	-0.67	2.49	2.63	4.67	1.88	3.78	6.46	5.12	6.04	4.85	581	83	589	75
X	0.85	2.58	0.46	1.70	2.17	5.29	1.85	3.93	4.27	4.14	3.23	3.23	563	67	567	70
C	1.08	2.20	0.63	1.70	2.53	5.56	1.61	3.95	3.23	3.33	3.85	4.32	545	80	550	70

V	1.04	2.24	0.75	1.41	1.95	5.53	1.48	4.35	3.85	4.32	3.02	3.53	547	69	556	78
B	1.12	2.27	1.10	1.85	1.18	5.22	1.46	4.08	3.75	2.89	4.90	5.10	570	88	564	71
N	0.77	2.47	0.54	1.68	1.22	5.15	1.30	4.05	3.75	3.80	3.65	3.49	605	80	604	76
M	2.78	2.45	2.01*	2.43	1.17	4.94	1.21	3.89	5.63	5.47	7.19	6.26	637	67	644	80

*Note: * The testing of simple main effect shows that the value here is significantly smaller than that in static mode (p < .05).*

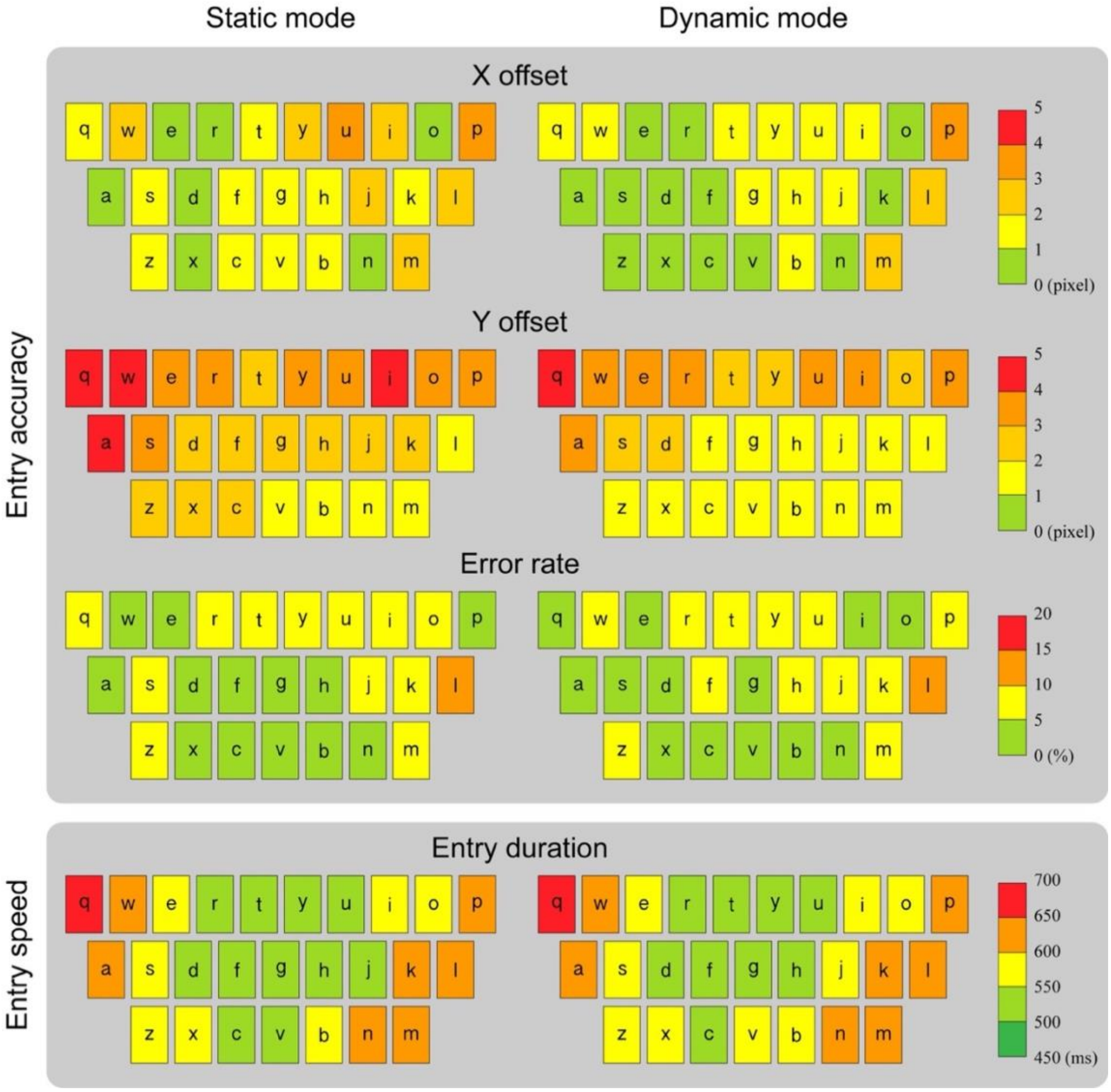

Figure 4. Heat maps for the four indices in static or dynamic modes (left column: static mode; right column: dynamic mode).

3.1 X offset

The main effect of the symbol-position variable was statistically significant [F $_{(1, 29)}$ = 10.78, MSE = 4.44, p = .003, η^2 = .271]. X offset in dynamic mode (M = 1.11, SD = 2.22) was significantly smaller than that in static mode (M = 1.46, SD = 2.87). The main effect of the key-position variable was also statistically significant [F $_{(3.279, 95.082)}$ = 6.47, MSE = 59.07, p < .001, η^2 = .182]. There was also a statistically significant interaction between the symbol-position and key-position variables [F $_{(11.187, 324.415)}$ = 2.48, MSE = 2.64, p = .005, η^2 = .079]. Further testing of the simple main effect showed that X offset of eight keys

(FGIJMUWY keys) in dynamic mode was significantly smaller than that in static mode (all p values < .05).

3.2 Y offset

The main effect of the symbol-position variable was statistically significant [$F_{(1, 29)} = 4.46$, MSE = 18.11, p = .043, $\eta^2 = .133$]. Y offset in dynamic mode (M = 2.42, SD = 4.28) was significantly smaller than that in static mode (M = 2.88, SD = 5.31). The main effect of the key-position variable was also statistically significant [$F_{(4.882, 141.579)} = 7.25$, MSE = 37.14, p < .001, $\eta^2 = .200$]. However, there was no statistically significant interaction between these variables [$F_{(11.718, 339.820)} = 1.24$, MSE = 2.63, p = .255, $\eta^2 = .041$].

3.3 Error rate

There was no statistically significant main effect of the symbol-position variable [$F_{(1, 29)} = .18$, MSE = 20.37, p = .677, $\eta^2 = .006$]. The error rate in dynamic mode (M = 5.19, SD = 5.46) wasn't significantly higher than that in static mode (M = 5.09, SD = 5.12)。The main effect of the key-position variable was statistically significant [$F_{(6.551, 189.979)} = 8.52$, MSE = 99.43, p < .001, $\eta^2 = .227$]. However, there was no statistically significant interaction between these variables [$F_{(25, 725)} = .89$, MSE = 14.78, p = .615, $\eta^2 = .030$].

3.4 Entry duration

There was no statistically significant main effect of the symbol-position variable [$F_{(1, 29)} = 1.77$, *MSE* = 6369, *p* = .194, $\eta^2 = .058$]. The entry duration in dynamic mode (*M* = 576, *SD* = 86) wasn't significantly higher than that in static mode (*M* = 570, *SD* = 91)。The main effect of the key-position variable was statistically significant [$F_{(9.506, 275.680)} = 39.71$, *MSE* = 5998, *p* < .001, $\eta^2 = .58$]. However, there was no statistically significant interaction between these variables [$F_{(25, 725)} = .54$, *MSE* = 1306, *p* = .968, $\eta^2 = .018$].

3.5 SUS score

The System Usability Scale (SUS) composes 10 items. Participants used 1 point (strongly disagree) to 5 points (strongly agree) to express the level of agreement with each item. Table 2 lists the means (*M*) and standard deviations (*SD*) of the rating score of each item. The SUS score was calculated based on the rating score data, ranging between 0 and 100. The result showed that the SUS score was 62 points for the dynamic-mode keyboard.

Table 3. SUS score for the dynamic-mode keyboard.

SUS item	*Mean*	*SD*
S1. I think that I would like to use this keyboard frequently.	2.93	1.08
S2. I found the keyboard unnecessarily complex.	2.70	1.06
S3. I thought the keyboard was easy to use.	3.27	1.01
S4. I think that I would need the support of a technical person to be able to use this keyboard.	1.73	0.78
S5. I found that the various functions in this keyboard were well integrated.	2.93	0.94
S6. I thought that there was too much inconsistency in this keyboard.	3.20	1.13
S7. I would imagine that most people would learn to use this keyboard very quickly.	3.63	1.03
S8. I found the keyboard very awkward to use.	2.47	1.04
S9. I felt very confident using the keyboard.	4.00	0.91

S10. I needed to learn a lot of things before I could get going with this keyboard.	1.87	0.94

4 Discussion

4.1 The effect of symbol positions

The present study investigated whether symbols that constantly change position could alter users' tapping directions on smartphones. The shifting symbol was a symbol that constantly changed its position based on the user's recent tapping data. The result showed that X offset and Y offset in dynamic mode differed from those in static mode. The shifting symbol could significantly change the values of X offset and Y offset, which confirmed Hypothesis 1 of this study. Therefore, the shifting symbol as a noticeable visual cue could draw users' attention resulting in a change in their tapping behavior on touchscreens, which was consistent with the results in the previous studies (Chen & Kuo, 2019; Huang & Chen, 2010). Moreover, this finding proved that the visual properties of virtual buttons could influence users' tapping directions on smartphones, which supported the assumption of the on-screen affordance (Kim & Lee, 2023).

This study also explored whether it was valid to adjust the symbol position to improve users' entry accuracy on smartphones. Improving the entry accuracy of little buttons was not easily accomplished as the thumb was several times larger than the little buttons, making it inherently difficult to locate the touchpoint precisely on touchscreens. However, this study demonstrated that the shifting symbol could significantly improve both X offset and Y offset. The shifting symbol could reduce X offset from 1.46 pixels to 1.11 pixels and Y offset from 2.88 pixels to 2.42 pixels. The improvement is 24% for X offset and 16% for Y offset. This result was consistent with the guiding effect of noticeable visual cues found in previous studies (Chen & Kuo, 2019; Huang & Chen, 2010). Nonetheless, the error rates in static and dynamic modes were approximately 5%, without significant improvement. Therefore, the shifting symbol could partially improve users’ entry accuracy on smartphones, which partly confirmed Hypothesis 2 of this study.

In terms of entry speed, the participants took an average of 576 msec to tap each key in dynamic mode, which was not significantly different from that in static mode. This result demonstrated that tapping towards shifting symbols didn’t reduce the entry speed to improve the entry accuracy of little buttons, which confirmed Hypothesis 3 of this study. Therefore, the preference to tap towards the symbols on little buttons seems a natural and intuitive response. The participants were still attracted and guided by the shifting symbol, despite their lack of understanding regarding the movement and underlying mechanisms behind it. Thus, the shifting symbol can guide users' clicking action immediately and effortlessly, exhibiting the characteristic of affordances (Still et al., 2014).

Finally, participants evaluated the usability of the dynamic-mode keyboard using the System Usability Scale (Table 2). The SUS score ranges from 0 to 100, with higher scores indicating better usability. The results revealed that the dynamic-mode keyboard received a SUS score of 62 points. According to the interpretation of SUS scores, products that receive scores below 70 points may require further adjustments to improve usability (Bangor et al., 2008). Therefore, the shifting symbol still has room for improvement. This study further investigated the scores of ten SUS items to comprehend the advantages and disadvantages of the shifting symbol. The scores of five SUS items (S3, S4, S7, S9, and

S10) showed that the participants could learn and use the dynamic-mode keyboard effortlessly. This result demonstrated that tapping towards shifting symbols was easy and intuitive. However, the scores of two SUS items (S2 and S6) showed that the shifting symbol would make the keyboard interface more complicated and inconsistent. Therefore, it is essential to adjust the style of the shifting symbol for practical application.

4.2 The effect of key positions

Previous studies have proved the effect of button positions on the touchscreen, so this study intended to examine whether button positions would moderate the effect of shifting symbols. The result of this study showed that there was a significant interaction between the symbol-position and key-position variables for X Offset. The shifting symbol could significantly improve eight keys with horizontal input offsets, such as the “F,” “G,” “I,” “J,” “M,” “U,” “W,” and “Y” keys (Figure 5). Most of these keys were near the initial positions of the thumbs and had lower discomfort ratings (Chang et al., 2017). Therefore, participants could adjust their tapping position on these keys horizontally and effortlessly. However, there was no significant interaction between the two independent variables for Y Offset. This result means that the shifting symbol could reduce the vertical input offsets regardless of key positions, which indicates that the vertical movement of the thumb seems to be less restricted than horizontal movement. Additionally, there were also no significant interactions between these independent variables for the error rate and entry duration. Therefore, these findings suggest that while the shifting symbol can guide users' clicking action, the effectiveness of shifting symbols still depends on the physiological characteristic of the thumb.

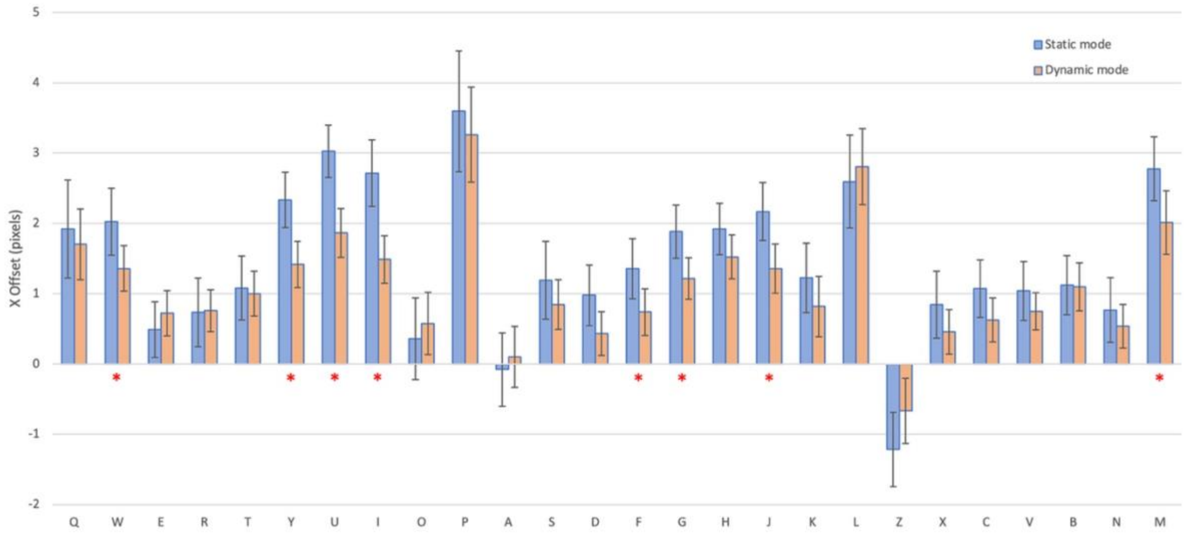

Figure 5. The interaction between the symbol-position and key-position variables for X Offset (denotes the significant different values between two modes).*

Additionally, the entry accuracy was significantly affected by the key position. Whether in static or dynamic mode, the right keys on the soft keyboard exhibited higher X offsets and error rates than the left keys. As tapping the right keys required inward thumb movement and involved larger displacements of the thumb joint, users would experience more discomfort (Chang et al., 2017; Trudeau, Udtamadilok, et al., 2012). Additionally, Y offsets of the upper and left keys were higher than those of the lower-right keys. When the user adopted an oblique touch gesture with their thumb to tap the upper and left keys, the large contact area between the thumb and the touchscreen made it difficult to pinpoint the intended touchpoint (Park & Han, 2010a; Xiong & Muraki, 2014). Although the entry performance of participants in dynamic mode had a similar pattern to that in static mode, the offset distance tended to decrease gradually, as shown in the enlarged green zone for X offset and enlarged yellow zone for Y offset in Figure 4. Finally, the entry speed was also significantly affected by the key position. Whether in static or dynamic mode, the keys on the left or right side of the soft keyboard exhibited longer entry durations than the keys in the middle, which was consistent with previous studies (Chang et al., 2017; Chang & Jung, 2019; Park & Han, 2010b).

4.3 Limitations and future directions

The results of this experiment, particularly the error rate, did not completely meet the expectations of this study. Two potential causes could explain this: visual saliency of cues and interference of borders. First, the symbol position was adjusted based on the participants' tapping habits in dynamic mode. Consequently, the change in the symbol position was not as distinct as that observed in the previous study (Chen & Kuo, 2019), where the labels were placed in the four corners of a button. Therefore, the shifting symbol was easily ignored by the participants, particularly participants with high entry accuracy. Following the interview, we also discovered that some participants did not observe any alterations to symbol positions in dynamic mode during the experiment. Future studies can provide additional instructions that clarify the mechanics of shifting symbols to participants before the experiment.

Second, based on their prior experience, the participants viewed the border of each key as an indicator of its touchable area, leading them to tap within the key border. However, in dynamic mode, the position of key borders remained the same even when the position of alphabetic symbols on the keys was altered, causing participants to encounter a conflict between the key borders and the alphabetic symbols. As a result, the guidance strength of alphabetic symbols was weakened. While key borders might diminish the visual guidance provided by alphabetic symbols, input offsets could still be reduced in dynamic mode. This result indicated that the shifting symbol had the potential to prompt participants to adjust their tapping movements. Future studies can enhance the intensity of visual guidance by modifying the virtual buttons, for instance, by eliminating button borders.

5 Conclusions

This study investigated the on-screen affordance of virtual buttons on smartphones and examined whether modifying the visual properties of virtual buttons is a valid approach to improve entry performance by altering users' tapping behavior. For this purpose, the study has designed a shifting symbol that suggests where users should tap on the button, helping users to tap the button center. The results revealed that adjusting the symbol position on virtual buttons could alter participants' tapping direction on smartphones. This study also demonstrated that a shifting symbol with offset correction could effectively reduce input offsets by adjusting the participants' tapping direction. The participants tended to tap towards the shifting symbol on little buttons, even when they were not aware of its intended function. These findings indicated that symbol positions on virtual buttons could afford the possible clicking action and tapping direction for users regarding the affordance of virtual buttons. Consequently, this study offers valuable insights into the design of virtual buttons by taking into account an understanding of the visual properties that influence clicking actions.

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