Investigating Activity Zones on Smartphones

An Empirical Study with Older Adults

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***Abstract*— This paper investigates and extends existing knowledge on older adults' (65+) gestural interaction with smartphones. Specifically, it looks at the effect touch targets location has on older adults' performance of tap and swipe gestures. Two separate experiments, each with 40 participants, showed older adults' performance for tap is best toward the center, right edge, and bottom right corner of the smartphone's display. For horizontal swipe participants' performance is better with targets toward the bottom half of the display, while for vertical swipe performance is better with targets toward the right half of the display.**

Keywords*— *Activity zone, Older adults, Accessibility, Inclusive design, Tap, Swipe, Gestures, Smartphones

I. Introduction

The population is aging at an unprecedented rate [1]. By 2040, 21.7% of the population of the United States (US), and 28.2% of the population of the European Union (EU) is expected to be 65+ [2]. Simultaneously, civilization is rapidly evolving towards a fully digital world, where the pervasiveness of smartphones can no longer be ignored. In 2012, smartphones accounted for 44% of the mobile phone market share in the EU, and nearly 42% in the US [3]. This trend is also apparent among older adults, whose smartphone ownership nearly doubled from 2012-13 [4]. In 2011, the fastest growing smartphone market group was people aged 55-64, which is the next generation of older adults. Given the proliferation of mobile phone applications targeted at older adults [5, 6, 7] it is pertinent to further investigate touchscreen interaction performance for older adult users with a view to design to accommodate for those users' needs and characteristics.

Activity zones on mobile devices have been extensively researched for young adult users [8-10], but to our knowledge no investigation has been done in this area with older adults. The same situation exists with respect to gesture orientation. Several authors have noted the lack of consideration for older adults' specific needs and expectations [11-13], with authors [14-16, 30] raising concerns regarding the discoverability and affordances of touchscreen gestures. A previous study [17] confirmed that gesture discoverability on smartphones can be an issue for older adults. The same study also found that tap and swipe were the most discoverable and easily performed gestures for older adults. Another study [18] showed that older adults' performance is best with targets larger than 14mm for tap gestures and larger than 17.5mm for swipe gestures, with spacing between adjacent targets not having a significant influence on performance. This research further investigates activity zones to identify i) the regions on a smartphone's, which afford best performances for the tap and swipe gesture, and ii) the impact of gesture orientation on older adults' acquisition of tap and swipe targets. Two research questions guided the research: Which target onscreen locations allow older adults the best interaction performance? and Does orientation influence interaction performance of swipe gestures?.

II. Related Work

A. Implications of the Aging Process for Technology Use

It is well accepted that several psychomotor, cognitive, and sensory declines unfold with the aging process [12]. Cognitive changes are often associated with slower processing of visual information [19], a reduced working memory capacity [19, 20], and an increased difficulty in learning new concepts and processes [19]. Physical changes may include reductions in visual acuity [19, 20], ability to coordinate movement [19], touch sensitivity [21], and manual dexterity [22]. The reduced ability to learn new concepts and processes together with reduced touch sensitivity and manual dexterity are changes of particular relevance to interaction with smartphones, and in particular gestural interaction. The alterations that occur to the sensory, cognitive, and motor systems as a result of aging [12, 19, 20, 23] may cause many products to be less adequate or even unusable for older adults. However, ageing changes do not necessarily imply the inability of older people to use technology, but rather that specific design considerations must be taken into account to create products that are inclusive of this user population [11-13]. However, most products still do not consider older adults' specific needs and characteristics [11, 13], and focus mainly on younger and more technologically proficient user populations. Arguably, design adaptations that account for older adults' needs and characteristics will also positively impact the quality of interaction for other users.

B. Older Adults and Gestural Interaction with Touchscreens

Given the proliferation of smartphones, it is important to understand how older adults use this technology. Touchscreen interfaces have been said to provide an easy to learn and quick to use form of interaction [24, 25], even for populations such as

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older adults [24, 26, 27] who might not be technologically proficient [28]. A study with Japanese seniors showed attitudes toward computers improved significantly for a group using a touchscreen compared to a group using a traditional keyboard [29]. Still, a number of issues have been raised regarding the usability of gestural interfaces [14, 16, 30], such as lack of cues or affordances [15], generating gesture discoverability issues [14, 16, 30]. Since touchscreen interfaces do not inherently show what gestures they support, the range of available actions is obscured [14, 16, 30].

Several studies have investigated interaction differences between indirect input devices (e.g. mouse or keyboard) versus direct input devices (e.g. touchscreen or light pen). Rogers et al. [31] compared a rotary encoder input device (indirect) and a touchscreen (direct) with both younger and older users, finding that the touchscreen was better for discrete pointing and selection or ballistic movement tasks, while the indirect device was preferable for more repetitive tasks. The individual variability between older adults' performance in the touchscreen condition was high, meaning that in a large population more users might have difficulty using the touchscreen device than the rotary encoder [31]. Contrastingly, Fisk et al. [23] found that the use of a light pen (direct) significantly reduced age-related differences in a target acquisition task, and provided better results for novel use situations. Murata and Iwase [32] found no age-related difference in target acquisition times on a touch surface, but also observed that in the case of the indirect input device (a mouse), older adults were significantly slower [32].

Research efforts have explored older adults' performance with larger-sized (15''-17'') touchscreens, including gestures [27, 33], touch target sizes, and spacing between targets. Two studies [27, 33] asked participants to perform a gesture by retracing an arrow displayed on the screen with their finger and found that older adults were slower but not less accurate than their younger counterparts, and therefore capable of interacting with both mobile [27] and fixed touchscreen devices [33]. Motti et al. [38] reviewed interaction for older adults using touchscreen devices and identified a number of studies covering the topic. These studies do not answer the gesture discoverability issues mentioned above, still they show older adults are physically capable of performing gestures regardless of cognitive and psychomotor age-related changes. Jin et al. [34] evaluated touch target sizes for older adults on a 17'' touchscreen tablet fixed on a stand, presented to the participants at a 45° angle, and considering six different target sizes for both adjacent and non-adjacent targets, as well as five spacing sizes for adjacent targets. In 2010 [35], an exploratory study of a touch-based interface for older adults investigated gesture appropriateness for older adults and revealed that gestures such as tap and flick were easily understood and performed, while drag was confusing and harder to perform.

C. *Previous Studies on Activity Zones*

Dan Saffer defined smartphone activity zones in a blog article in 2011 [36], after which studies followed to study them. Parhi et al. [9] carried out a study with 20 younger adults in order to evaluate thumb-use and the performance of both discrete and serial tap gestures. They found that participants were most accurate with targets placed toward the center of the device, and less accurate toward the left edge and bottom right corner of the device. Contrastingly, Perry and Hourcade [10] found that participants were more accurate in acquiring targets on the edge of the screen, while being quicker and more comfortable with targets toward the center of the screen. More recently, [8] found that participants were most accurate in acquiring tap targets in the center and toward the right and bottom edges of the screen. Most studies so far were conducted with younger adults, and therefore cannot provide guidance in designing for an older population. Hwan et al. [39] studied target sizes, spacing, and location in smartphone use by older adults, but only the tap gesture was analyzed. Until this point, we are unaware of research evaluating activity zones for older adults, or specifically investigating the effect of swipe gesture orientation on swipe activity zones.

III. Study Overview

This research consisted of two experiments each addressing one research question. Each experiment used a testing tool that resembled a game.

A. *Participants*

40 older adults took part in this study, 18 female and 22 male, aged 65 to 95 (mean = 75.25). Inclusion criteria were age (65+) and availability to participate. Participants should also show no visible signs of dementia and have minimum to no experience with smartphones. All participants were recruited from retirement homes and daycare centers within the city of Porto, Portugal. None of the participants owned a touchscreen smartphone at the time of the study, nor prior to it, indicating their minimal to non-existent experience with smartphones.

B. *Procedures and Apparatus*

Test sessions were conducted in the daycare center or retirement home from which the participants had been recruited. Before starting a session with a participant, the facilitator presented herself, the goal of the study, explained the objectives of the study, and obtained informed consent. All participants agreed to take part in the study and were informed that no data would be collected that would allow for their identification. The facilitator explained the task to be completed with each test tool at the beginning of the session. Then, for each testing tool, participants would first view a tutorial on how to execute the test (i.e. play the game). Next, a short trial would take place in which no data was collected to give participants an opportunity to learn how to use the tool before the actual data was collected, thus avoiding biases related to learning issues. Lastly, participants performed the actual tasks using the testing tools.

The experiments were performed on an HTC Desire measuring 63mm x 123.9mm, with a 480px x 800px display, at 252 PPI. Data was logged on the smartphone itself.

C. *Testing Tools*

Target sizes for the tap and swipe gesture testing tools were determined based on a previous study [18] which found that the smallest acceptable target sizes for good performance were

10.5mm for tap and 14mm for swipe. Using these sizes, the authors created a grid for the tap (Fig. 1) and the swipe experiment (Fig. 2 and Fig. 3). The grids had 28 and 22 positions for the tap and swipe experiment, respectively.

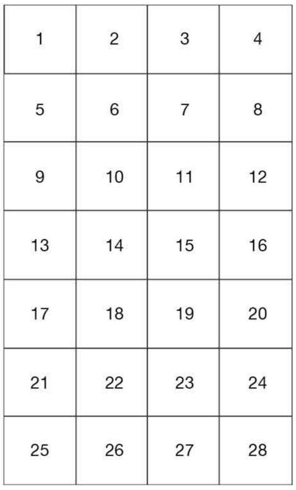

Fig. 1. Tap activity zones for experiment

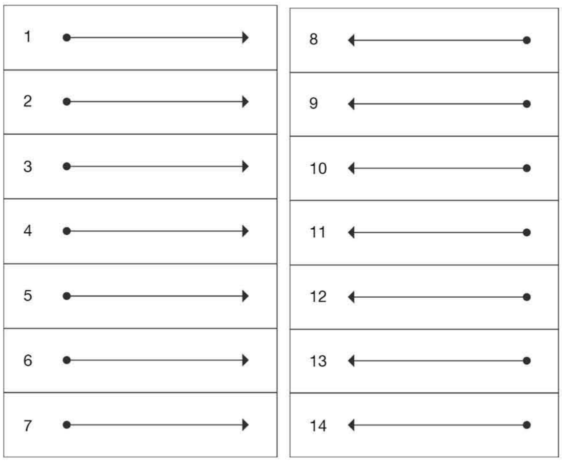

Fig. 2. Swipe activity zones (left-to-right and right-to-left) for experiment

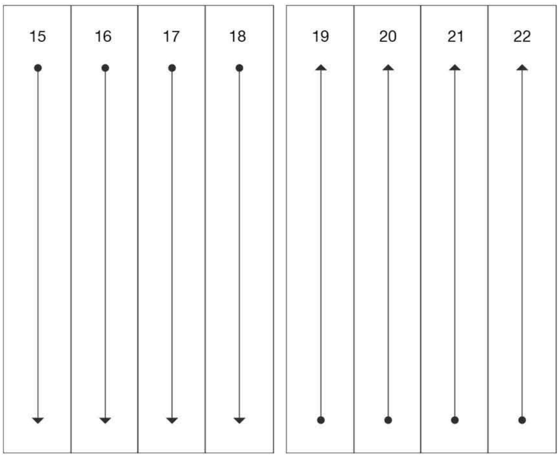

Fig. 3. Swipe activity zones (top to bottom and bottom to top) for experiment

1) Testing Tool for Tap Activity Zones

The test designed to investigate tap activity zones mimicked a 'Whack-A-Mole' game (Fig. 4) and required participants to smash a mole by performing a tap gesture. The mole randomly appeared at one of the 28 locations defined (Fig. 1). A single target would appear alone at a single time, and the following one would only appear if the current target had been correctly acquired, or if participants had missed it more than three times.

Fig. 4. Screenshot of tap activity zones experiment test tool

2) Testing Tool for Swipe Activity Zones

For the swipe activity zones experiment, participants were required to drag an animal from its initial position toward a destination target on the opposite side of the screen (Fig. 5). In order to do so, participants were not allowed to cross the barriers, as only the animal with the red target directly opposite to it was meant to be moved; this was intended to guarantee that all swipe gestures were strictly horizontal or vertical.

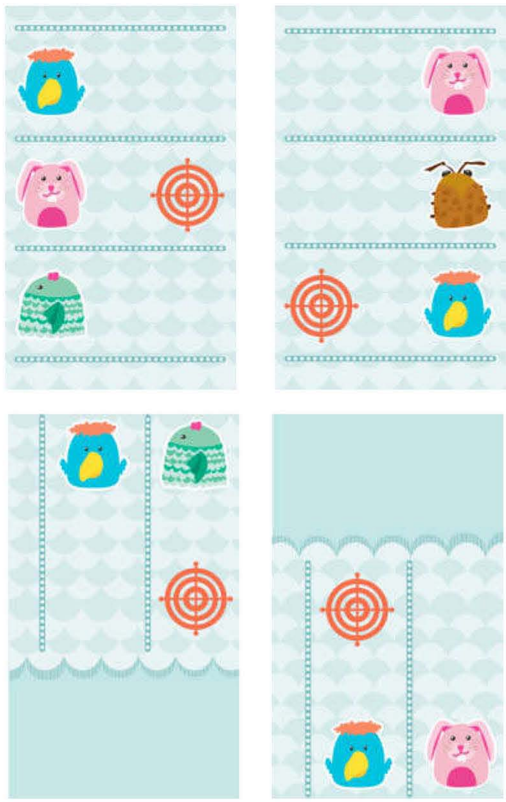

Fig. 5. Screenshots of swipe activity zones experiment test tool

Each draggable item appeared randomly at one of the 11 locations seen in Fig. 2 and Fig. 3, where the gesture orientation could be one of four: left-to-right, right-to-left, top-to-bottom, or bottom-to-top. Unlike the tap experiment, participants only progressed from one target to the next when they successfully dragged the correct animal from its initial position to the target destination. All participants had to complete the task and there were no maximum number of attempts to complete the task.

IV. Study Results

3360 taps and 2640 swipes were collected by this study. 3360 taps (28 grid positions x 3 repetitions x 40 participants) and 2640 swipes (((4 grid vertical positions x 2 gesture orientations) + (7 horizontal grid positions x 2 gesture orientations)) x 3 repetitions) x 40 participants. Per test, each position was tapped and swiped a total of three times per participant, which allowed us to collect 28 * 3 = 84 taps and 22 * 3 = 66 swipes, per participant.

A within-subject design was used, for which three variables were logged: accuracy, task completion time, and touch offsets. Accuracy was defined as the number of times a target was missed before correctly acquired, so, if a participant tried to hit a target twice but only managed to do so on the third try, accuracy would be 0.33% = 1 (accurate hit) / 3 (tries). Task completion time consisted of the average amount of time participants took to complete a task. Touch offsets were measured as the distance between a target's center point and participants' actual touches.

In order to conveniently interpret the results presented here it is important to mention 85% of the participants used their right hand for interaction, while only 15% used their left hand. Overall, 67.5% of participants held the smartphone with their left hand, while 15% held it with their right, another 15% placed the device on a table, and the remaining 2.5% held the smartphone in both hands. Regarding the fingers that participants used for interaction, 75% of participants used only their index finger, 12.5% of participants used their index finger and thumb interchangeably, and 5% used their thumbs. The remaining 7.5% equally (2.5% each group) used either their middle and index fingers, their middle, index, and thumb, or their ring, index, and thumb fingers.

A. *Tap Targets and Accuracy According to Activity Zones*

Mean accuracy rates were determined for each of the 28 grid locations defined (Fig. 1). The following heat map (Fig. 6) visually presents the accuracy rates obtained for each location, where darker areas represent those where participants achieved greater precision. Table I shows the actual accuracy rates. Mean accuracy rates were over 80% for all target locations, with position 22 reaching the highest precision (97.5%). Overall, participants were most accurate toward the center, right edge, and bottom right corner of the display.

A repeated measures ANOVA with Greenhouse-Geisser correction revealed that accuracy was significantly affected by tap target locations ($F(12.522, 488.376) = 3.709$, $P < 0.001$). These results were unexpected, as most participants interacted with their index fingers and therefore a more even distribution of mean accuracy rates was expected across all locations.

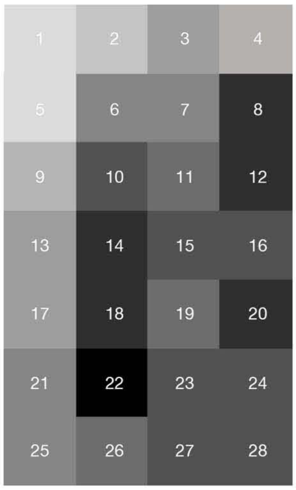

Fig. 6. Mean accuracy rates according to tap target locations

TABLE I. Tap Target vs. Grid Locations Mean Accuracy Rates

Grid locations	Mean Accuracy		Grid locations	Mean Accuracy
1	80.00%		15	92.36%
2	82.08%		16	93.19%
3	87.36%		17	87.78%
4	84.72%		18	94.58%
5	81.67%		19	91.94%
6	89.92%		20	94.58%
7	89.58%		21	89.58%
8	94.72%		22	97.50%
9	89.17%		23	93.75%
10	93.06%		24	93.19%
11	90.69%		25	89.03%
12	94.03%		26	91.11%
13	87.78%		27	93.75%
14	94.86%		28	93.75%
Grand Total			90.56%	

B. *Tap Targets and Touch Offsets According to Activity Zones*

The authors also analyzed the offset between target positions and participants' actual touch positions for each grid location. To determine offsets, all distances were measured in pixels and converted to mm by obtaining a pixel to mm ratio based on the dimensions of the screen used for the evaluation. Table II shows that with the exception of the first grid position where offsets were shifted to the top and right, touches systematically offset to the right and bottom of targets' center points. Overall, mean offsets on the x-axis amounted to 2.56mm, and to 2.27mm on the y-axis. The heat map in Fig. 7 provides an overview of mean touch offsets for each grid location. The darker the area, the more deviation exists between the target's center and participants' touches. Targets toward the top, left, and bottom edges of the screen present larger offsets. A repeated measures ANOVA with Greenhouse-Geisser correction revealed that target locations did have a significant effect on touch offsets ($F(10.474, 408.467) = 4.114$, $P < 0.001$). This means that offsets were significantly influenced by target positions.

TABLE II. X-AXIS AND Y-AXIS VS. TARGET LOCATIONS MEAN OFFSETS

Grid locations	Mean offsets x-axis	Mean offsets y-axis
1	4.51mm	5.36mm
2	3.58mm	3.96mm
3	2.43mm	4.14mm
4	2.08mm	3.73mm
5	4.07mm	3.40mm
6	2.34mm	3.14mm
7	2.43mm	2.69mm
8	2.04mm	2.21mm
9	3.39mm	2.11mm
10	2.55mm	2.80mm
11	2.73mm	3.02mm
12	2.22mm	3.03mm
13	3.30mm	2.93mm
14	2.25mm	2.31mm
15	2.49mm	2.81mm
16	2.44mm	2.36mm
17	3.11mm	3.28mm
18	2.38mm	2.00mm
19	2.37mm	3.24mm
20	2.26mm	2.58mm
21	3.19mm	2.82mm
22	2.25mm	1.87mm
23	2.06mm	1.90mm
24	2.15mm	2.99mm
25	3.25mm	3.21mm
26	2.86mm	2.96mm
27	2.50mm	3.65mm
28	1.79mm	2.52mm
	Grand Total offsets x-axis	2.68mm
	Grand Total offsets y-axis	2.97mm

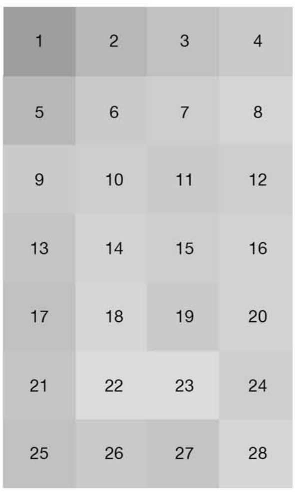

Fig. 7. Mean offsets according to grid locations

C. *Swipe Targets and Accuracy According to Activity Zones*

Table III presents a summary of accuracy rates according to target locations and gesture orientation. Results show that accuracy is higher towards the bottom portion of the screen. Left-to-right swipes mean accuracy was higher for targets toward the bottom half of the screen. Accuracy for positions 1, 2, and 3 were 90.26%, 86.76%, and 88.71%, respectively, while for positions 4, 5, and 7, mean accuracy was 92.21%, 91.60%, and 91.49%, respectively. Accuracy for the right-to-left orientation was also higher toward the bottom portion of the screen, where for locations 8 and 9, mean accuracy was 89.03% and 88.89%, respectively, while locations such as 11, 12, and 13 reached levels of 90.99%, 90.61%, and 92.28%.

For the vertical swipe conditions in the top-to-bottom direction, results show participants were most accurate toward the right edge of the screen. Location 18 reached an accuracy rate over 93%, while locations 15, 16, and 17 showed mean accuracies of 89.55%, 88.58%, and 89.48%, respectively. Participants were also most accurate toward the right half of the screen in the bottom-to-top orientation. Mean accuracy for location 21 was 93.67%, while for locations 19, 20, and 21, accuracy levels were of 87.47%, 87.88%, and 89.37% respectively.

TABLE III. GRID LOCATION VS. SWIPE ORIENTATION MEAN ACCURACY

Grid location	**Mean Accuracy left-to-right swipe**
1	90.26%
2	86.76%
3	88.71%
4	92.21%
5	91.60%
6	89.91%
7	91.49%
Grand Total	90.13%

Grid location	**Mean Accuracy top-to-bottom swipe**
15	89.55%
16	88.58%
17	89.48%
18	93.24%
Grand Total	90.20%

Grid location	**Mean Accuracy right-to-left swipe**
8	89.03%
9	88.89%
10	90.22%
11	90.99%
12	90.61%
13	92.28%
14	90.12%
Grand Total	90.31%

Grid location	**Mean Accuracy bottom-to-top swipe**
19	87.47%
20	87.88%
21	93.67%
22	89.37%
Grand Total	89.58%

A repeated measures ANOVA revealed that the effect of target locations on mean accuracy rates was not significant on the left-to-right condition ($F(6, 234) = 1.166$, $P = 0.325$), nor on the right-to-left condition ($F(6, 234) = 0.457$, $P = 0.840$). Similarly, in none of the vertical conditions did target locations significantly influence accuracy for top-to-bottom ($F(3, 117) = 1.414$, $P = 0.242$) or bottom-to-top conditions ($F(3, 117) = 1.966$, $P = 0.123$). A further repeated measures ANOVA with Greenhouse-Geisser correction revealed that gesture orientation did not affect mean accuracy rates. While no statistical significance was found, results seem to indicate that participants were more accurate in the left-to-right and top-to-bottom conditions. Regarding horizontal orientation, accuracy was higher for targets toward the bottom portion of the screen, while for the vertical conditions participants were more accurate toward the right half of the screen.

D. Swipe Targets and Touch Offsets According to Activity Zones

Table IV provides detailed results of the touch offsets for each target location and respective gesture orientation.

TABLE IV. GRID LOCATION VS. SWIPE ORIENTATION MEAN OFFSETS

Left-to-right swipe			
Grid location	Mean offset x axis	Mean offset y axis	Mean offset x&y
1	2.12mm	3.76mm	2.94mm
2	2.32mm	3.48mm	2.90mm
3	2.34mm	3.30mm	2.82mm
4	2.43mm	3.07mm	2.75mm
5	2.11mm	3.19mm	2.65mm
6	2.15mm	3.10mm	2.62mm
7	2.17mm	3.35mm	2.76mm
Grand Total	2.23mm	3.32mm	2.78mm
Top-to-bottom swipe			
Grid location	Mean offset x axis	Mean offset y axis	Mean offset x&y
15	3.41mm	2.25mm	2.83mm
16	3.18mm	2.42mm	2.80mm
17	2.64mm	2.31mm	2.48mm
18	2.91mm	2.29mm	2.60mm
Grand Total	3.04mm	2.32mm	2.68mm
Right-to-left swipe			
Grid location	Mean offset x axis	Mean offset y axis	Mean offset x&y
8	4.39mm	2.95mm	3.67mm
9	4.02mm	3.22mm	3.62mm
10	4.14mm	2.79mm	3.47mm
11	4.60mm	2.96mm	3.78mm
12	4.37mm	2.73mm	3.55mm
13	4.31mm	2.52mm	3.41mm
14	4.37mm	2.94mm	3.65mm
Grand Total	4.31mm	2.87mm	3.59mm
Bottom-to-top swipe			
Grid location	Mean offset x axis	Mean offset y axis	Mean offset x&y
19	3.03mm	4.27mm	3.65mm
20	3.05mm	4.40mm	3.72mm
21	2.32mm	3.95mm	3.13mm
22	2.30mm	3.94mm	3.12mm
Grand Total	2.68mm	4.14mm	3.41mm

For the left-to-right swipe orientation, offsets along the y-axis, were generally larger than those for the x-axis, although offsets along the x-axis were also registered. This means that participants generally touched the screen to the right and bottom of targets' center coordinates. Also, offsets were larger for targets located toward the top portion of the screen, where mean offsets for positions 1 and 2 were 2.90 and 2.94mm respectively, and for positions 5, 6, and 7, values were 2.65, 2.62 and 2.76mm respectively. These findings are consistent with the previously discussed results in which participants were most accurate toward the bottom portion of the screen.

For the right-to-left swipe orientation, and contrary to the previous condition, larger offsets were registered along the x-axis. Also, offsets were larger at the center, top, and bottom edges of the screen. The locations with the lowest offset were those between the center and top, and the center and bottom edges. The mean registered accuracy rates of locations 8, 9, 11, and 14 were 3.67, 3.62, 3.78 and 3.65mm respectively. The accuracy rates of locations 10, 11, and 13 were lower at 3.47, 3.55, and 3.41mm respectively. These findings concur with those regarding accuracy rates, where participants were most accurate for locations 11, 12, and 13. Overall touch offsets tend to be larger for the right-to-left condition than for left-to-right.

For the top-to-bottom swipe orientation, larger offsets were registered along the x-axis than on the y-axis. Additionally, offsets were smaller for targets located toward the right edge of the display which is consistent with the results regarding mean accuracy measures. Overall, mean offsets for locations 17 and 18 were 2.48 and 2.60mm, while for locations 15 and 16 these values were higher at 2.83 and 2.80mm respectively.

Considering the bottom-to-top orientation, data shows offsets along the y-axis tend to be larger than those along the x-axis. Additionally, larger offsets occurred toward the left side of the screen. This is consistent with the previously discussed accuracy rates in which participants were more precise toward the right edge of the display. The location with the lowest average offset was 22 (3.12mm offset), and the one with the highest average offset was location 20 (3.72mm offset).

Results indicate that offsets are larger for the right-to-left and bottom-to-top swipe conditions, which is consistent with the previously discussed results regarding mean accuracy rates. Furthermore, in the left-to-right condition, participants' y-axis offsets were larger, meaning that they touched the screen further to the right of targets. In the right-to-left condition, participants touched the screen further to the bottom of the targets. A similar shift happened for targets in the top-to-bottom condition, in which participants generally touched the screen towards the bottom of a target. As for the bottom-to-top orientation, participants performed a touch further to the right of the target. Considering most participants were right-handed, this is consistent with the angle in which an index finger approaches a touchscreen.

A repeated measures ANOVA conducted to assess the influence of target locations on touch offsets showed for the left-to-right condition, a significant effect for the y-axis ($F(6, 234) = 2.177$, $P < 0.05$), however no significant effect was found on touch offsets along the x-axis ($F(6, 234) = 1.435$, $P = 0.202$). For the right-to-left orientation, a significant effect of target locations on touch offsets was found for the y-axis ($F(6, 234) = 2.756$, $P < 0.02$), but again no significance was found for the x-axis ($F(6, 234) = 1.100$, $P = 0.363$). When considering the vertical swipe conditions, a significant influence of target locations on touch offsets was found for the top-to-bottom condition, along the x-axis ($F(3, 117) = 4.756$, $P < 0.01$), but not on the y-axis ($F(3, 117) = 0.298$, $P = 0.827$). For the bottom-to-top condition, a significant effect was found along the x-axis ($F(3, 117) = 6.899$, $P < 0.001$), but not on the y-axis ($F(3, 117) = 2.067$, $P = 0.108$).

V. DISCUSSION AND FUTURE WORK

This research found that target locations did influence participants' overall performance for both tap and swipe gestures. Results for tap suggested that tap targets are more easily acquired when placed toward the center, right edge, and bottom right corner of the display. Even though most participants used their index fingers for interaction, targets located at the top-left corner, as well as at the left and top edges of the screen, had lower accuracy rates and higher average offsets. Additionally, and as stated above, 85% of the participants interacted with their right-hand and therefore the results cannot be generalized for left-handed older adults.

Results of this study are consistent with the findings of:

- Parhi et al. [9], who investigated one-handed thumb interaction with younger and found targets placed near the left edge and bottom-right-corner of the display were more difficult to acquire and targets placed toward the center of the display offered the best performance.
- Park et al. [37], who carried out a study with 30 younger adults and defined pressing convenience regions as those placed toward the center of the display as opposed to the edges of the device.
- Henze et al. [8], who found that targets placed near the border of the smartphones were generally more difficult to hit than those placed toward the center.

However, the findings of this research contrast with those of Perry and Hourcade (2008), who found participants (college students) were more accurate at tapping targets near the edges of the screen and quicker and more comfortable tapping targets toward the center of the device.

The intersection of all three independent variables recorded in the swipe experiment showed that for horizontal swipes, participants' performance was best for swipe targets placed within the bottom half of the display. In regards to the vertical swipe condition, findings revealed participants perform best with swipe targets located in the right half of the display. However, it would be interesting to conduct this study with a group of younger adults, in order to assess differences or similarities regarding activity zones for swipe gestures.

Results also showed offset values of 2.23 x 3.32mm for the left-to-right orientation, 4.31 x 2.87mm for right-to-left, 3.04 x 2.32mm to top-to-bottom swipes, and finally 2.68 x 4.14mm for the bottom-to-top orientation. Additionally, y-axis offsets were significant for the horizontal swipe conditions, while x-axis offsets were significant for vertical swipes. The large offsets registered may offer an opportunity for further research. For swipe targets placed in locations where lower accuracy rates were registered (the top and right halves of the screen), it could be beneficial to shift their center coordinates according to the mean offsets found for the x and y axes, or to enlarge the invisible touchable areas surrounding the targets by the identified offset measures. For example, considering a left-to-right horizontal swipe target placed at the top edge of the display where mean accuracy rates were lower, it could be beneficial to enlarge the target's touchable area by 2.23mm to the right and 3.32mm to the bottom. To assess the of such adaptations was out of the scope of this paper, but it would be interesting to appropriately investigate and determine them. Moreover, since we did not control which fingers or hand participants used to interact, future research is needed regarding particular forms of interaction. This could mean investigating right-handed versus left-handed input, and thumb versus index finger input modes, as these conditions could significantly influence the results.

A few other aspects deserve being discussed in regards to this study and the extent of the application of its findings. For example, participants' gender distribution was uneven in both phases of the research. However, given the nature of the experiments performed in this research, gender should not have a significant effect on the results. Participants had very little proficiency with technology, so it is possible that if this research were to be conducted in different cultural and socio-economic conditions, results would be different. Furthermore, 85% of participants were right-handed. This might have influenced the results, and limits their applicability for left-handed users. Results showed that in the top-to-bottom condition, participants generally touched the screen towards the bottom of a target and that in the bottom-to-top orientation, participants performed a touch further to the right of the target. Considering most participants were right-handed, this is consistent with the angle in which an index finger approaches a touchscreen, but it is not possible to determine the extent of this interference.

VI. Conclusions

This work builds upon existing knowledge to contribute to a better understanding of the suitability of current smartphone gestures for older adults, particularly regarding activity zones. This research found for activity zones and gesture orientation that:

- Older adults were most accurate toward the center, right-edges, and bottom-right edges of the screen.
- Mean offsets shifted to the right and bottom of the target's centre points and were larger for grid locations where accuracy was lower – that is, the left and bottom edges of the screen.
- Older adults' performance was most accurate when performing horizontal swipe gestures toward the bottom half of the screen, both in left-to-right and right-to-left swipes.
- Older adults' performance was most accurate in performing vertical swipe gestures toward the right half of the screen, both in top-to-bottom and bottom-to-top swipes.
- Gesture orientation significantly impacts touch offsets, which indicates that for targets placed in more hard-to-reach locations it may be beneficial to adjust their locations.
- The targets' location did have a significant effect on older adults' performance of tap, but not swipe.

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