Investigating Pressure-based Interactions with Mobile Phones While Walking and Encumbered

Shimin Feng[1]
Graham Wilson[2]
Alex Ng[3]
Stephen Brewster[2]
Glasgow Interactive Systems Group
School of Computing Science
University of Glasgow
Glasgow, United Kingdom

[1] shiminf@dcs.gla.ac.uk
[2] {first.last}@glasgow.ac.uk
[3] a.ng.1@research.gla.ac.uk

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Abstract
In encumbered (e.g. carrying shopping bags) and walking situations, interacting with mobile phones is physically demanding and leads to poor input performance. This paper presents two user studies which investigate the effectiveness of using *pressure* as an alternative input modality to touch when using mobile phones while walking and encumbered. Force-sensing resistors (FSR) were placed around the edges of a mobile phone to provide multiple pressure points to execute onscreen spreading, pinching, rotating and dragging single handedly. Experimental results showed that it is possible that encumbrance had no significant effect on pressure-based targeting performance. Our preliminary findings show promise with using multi-digit pressure input to facilitate one-handed touchless interactions with handheld devices in multitasking encumbered contexts.

Author Keywords
Pressure-based input; Encumbrance; Walking; Mobile interaction; Fitts' Law.

ACM Classification Keywords
H.5.2. User Interfaces – Haptic I/O

Figure 1: A typical encumbrance scenario, making interaction with mobile phones physically challenging. Replacing touch input with pressure input by using sensors around the device facilitates one-handed interaction and reduces physical strains on the user.

Introduction

Mobile phones are used in many different contexts and one common situation is when users are walking and encumbered (i.e. carrying everyday objects such as shopping bags, packaging boxes, umbrellas etc. - see Figure 1). Previous work (e.g. [5,6,8]) which has examined the effects of encumbrance and mobility reported poor targeting performance with touchscreen mobile phones, especially for one-finger target selections [7]. Perhaps using direct touch on handheld devices is too physically challenging to maintain a reasonable level of performance, and therefore alternative input modalities could be more effective. We propose the use of pressure-based input with mobile phones during encumbered and walking situations for several reasons.

When users are carrying cumbersome objects, it can be physically taxing to adjust hand posture to interact in an efficient manner single handedly. Furthermore, the popularity of large mobile phones such as the Apple iPhone 6+ and Samsung Galaxy Note means that it can be difficult to access all areas of the touchscreen without using both hands to input. By replacing direct touch with pressure sensors around the device, hand posture does not need to be altered greatly and facilitates one-handed interactions, freeing up the non-interacting hand for other activities such as carrying bags and opening doors. In addition, bi-directional and multi-axis onscreen movements are possible when multiple sensors are deployed [13], therefore negating the need and physical strains on the user when selecting targets out of the thumbs optimal reach during one-handed input and when encumbered.

In this work, we show the walking and encumbrance context in Figure 1. The user did not hold or grasp an object in the hand. He/She carried a shopping bag in each hand, thus was only strained by the belt of the bag. The fingers of the hand were still flexible to articulate different amounts of pressure on the sensors attached around the device. One of the motivations for such an encumbrance situation is the real world application scenario. Image a girl carries a shopping bag in each hand on the street. Meanwhile, she needs the map navigation with the mobile phone. In such a circumstance, it is difficult for her to zoom or rotate on a map with a mobile device while walking and encumbered. The use of pressure input enables the one-handed zoom or rotation thus will be of great convenience in such encumbrance situations.

To investigate the effect of encumbrance and the performance of pressure input, and to test if multi-digit pressure input can provide one-handed input for interaction while walking and encumbered, we conducted two user studies, which collectively examined the accuracy and movement time (MT) of three main standard onscreen gesture types: (1) spreading & pinching (zooming in and out), and (2) rotating (in both directions), and (3) dragging. We measured accuracy (if the selected onscreen position was within the target area) by computing the number of accurate selections and the total number of effective selections for each participant and then calculated the mean accuracy. We also calculated the movement time (from the start to the end of the trial with the 750ms dwell time removed) for each participant and then computed the mean MT.

Figure 2: Experimental device: Samsung Galaxy S3 with 2 force-sensing resistors attached: one under the thumb and one under the middle finger.

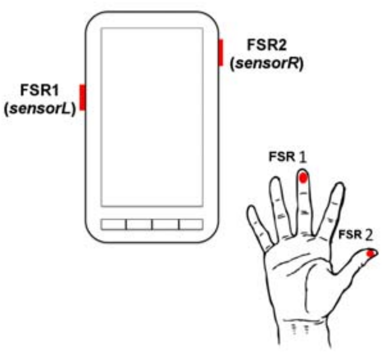

Figure 3: Top image illustrates the mobile phone for both studies, with one FSR attached to each side of the case. FSR1 was operated using the middle finger while FSR2 was used with the thumb. The position of the sensors were placed for right-handed users, but can be easily reversed for left-handers in future work.

Related Work

Earlier encumbered and mobile user studies have mainly evaluated how targeting performance on touchscreen mobile devices is affected. Ng *et al.* [5] found that tapping accuracy using the index finger on mobile phones decreased as much as 70% when users held a typical shopping bag in the dominant hand while walking. Later, Ng *et al.* [6] measured the impact encumbrance and mobility had on one- and two-handed input postures and found that there was no clear advantage of having an extra finger for targeting when both hands were carrying shopping bags. More recently, Ng *et al.* [7] examined four main touch-based gestures while users were carrying typical shopping bags and walking. Since touch-based interaction has shown to be problematic when users are encumbered and on the move, alternative pressure-based input may improve usability.

Several pressure-based interfaces have been proposed in recent years and have shown that input is highly accurate when pressing into [1,4], or tangentially across [2] the screen, but these interfaces tend to use only a single digit and control only a single axis at one time. Attaching multiple pressure sensors around the sides of a device provide several inputs from the gripping fingers. This setup allows for bi-directional control over one axis [9] or two axes simultaneously [13] while providing the benefit of leaving the screen completely visible. Wilson *et al.* [13] showed that multi-digit pressure input can provide similar performance to multi-touch during zooming and/or rotation when the user is sitting down. Walking negatively impacts control of pressure [10,11], but the use of a velocity-based control method mitigates these issues [12]. No research has yet to examine the usefulness of pressure-based input for encumbered and mobile contexts, thus, we carried out two user studies to investigate this.

Study 1

This section described the design and results from Study 1, which examined the use of pressure input to perform onscreen spreading & pinching (zooming in and out) and rotating (clockwise and anticlockwise) inputs.

Hardware

A Samsung Galaxy S3 mobile phone (~12.05px/mm) was used and placed inside a plastic phone case, which had flat sides to attach the sensors easily. Pressure input was provided by two Interlink Electronics FSR-400 force-sensing resistors (FSR) connected to an SAMH Engineering CS6-24 sensing module. The module communicated with the phone over Bluetooth and had a sampling rate of 30Hz. We attached the CS6-24 module to the back of the case and one FSR to each side (de-noted as sensorL and sensorR). SensorL was placed approximately halfway down the left side (operated by the middle finger) and sensorR was attached near the top of the right side (pressed by the thumb). This con-figuration was designed for right-handed users (Study 1 only recruited right-handed participants) but can be easily reversed for left-handed users in future studies. We used a pressure space of 5 Newtons (N) and the relationship of force to velocity is shown in Table 1. Figure 2 illustrates the hardware.

Input	Velocity
Spreading/Pinching	72 px/s (6 mm/s) per Newton
Rotating	22 deg/s per Newton

Table 1: Relationship between force and input velocity in pixels (px) and millimeters (mm) per second and per Newton applied.

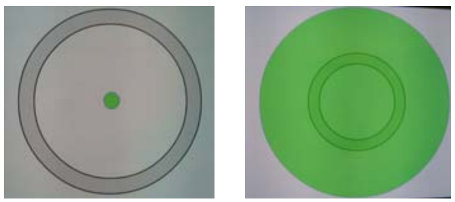

Figure 4: Zooming interface start positions - Zoom In/Spread (L) and Zoom Out/Pinch (R).

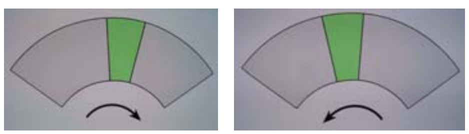

Figure 5: Rotation interface - Rotate Clockwise (L) and Anticlockwise (R).

Task

A set of Fitts' law style targeting tasks were developed to examine the effectiveness of using pressure-based input to perform the following four gestures/actions when walking and encumbered: 1) zooming in (*spreading*), 2) zooming out (*pinching*), 3) *rotating clockwise* and 4) *rotating anticlockwise,* as shown in Figure 4 and 5. The pressure controls are shown in Figure 3. For zooming, pressure controlled the expansion (zooming/spread) and contraction (zoom out/pinch) of a circle, which started at its smallest or largest size during zoom in and zoom out trials, respectively. For rotation, an arc of 110° was shown and pressure controlled the filling of the arc in red, from either the left (clockwise) or right (anticlockwise). The task was to move the outer edge of the circle, or the edge of the filled arc, to within the target boundaries. For spreading, a green control circle appeared at the center of the screen, with the target illustrated by a grey ring. SensorL was mapped to expand the control circle towards the target while sensorR was used to contract the control circle if the target area was exceeded. Pinching operated the same way as spreading, but the control circle was now greater than the target ring. There were three target widths (1.6, 3.2 and 4.8mm) and there target distances (8, 16 and 24mm), giving a total of nine target width/distance combinations. For rotating in both directions, an arc of 110° was shown at the top of the screen, where the target area was illustrated in green. SensorL and sensorR were used for clockwise and anticlockwise movements respectively. Applying pressure on the sensors filled the arc in transparent red. There were target widths (6^{o}, 12^{o}, 18^{o}) and three target distances (30^{o}, 60^{o}, 90^{o}), therefore nine unique target width/distance combinations. Each combination was presented 6 times during every condition, thus 54 trials for each of the 8 conditions, including Spreading (Unencumbered & Encumbered), Pinching (Unencumbered & Encumbered), Rotating Clockwise (Unencumbered & Encumbered) and Rotating Anticlockwise (Unencumbered & Encumbered). The user was walking in each condition.

At the start of each trial for both tasks, the screen displayed an alert, "Please remove fingers from the sensors" to ensure that the participants did not press the sensors accidentally. After a two-second delay, the interface was presented and participants were instructed to complete the trial as quickly and as accurately as possible. A target was selected using the Dwell technique (750ms).

Experimental Design

The same encumbrance scenario as [6,7,8] was used, therefore the participants held a 1.5kg shopping bag in each hand when performing the tasks. Using an established evaluation approach designed for encumbered and walking studies [8], participants walked around a predefined test route indoors and maintained their preferred walking during interaction (PWS&I) by following a human pacesetter.

There were eight conditions in total as each of the four input types was evaluated either unencumbered or carrying the bags. A within-subject design was used and twenty right-handed participants (15 males), aged between 18 to 39 years (Mean = 27, SD = 5.8) were recruited for Study 1. The conditions were counter-balanced by type of encumbrance and pseudo-randomised by input type as much as possible to reduce ordering and learning effects. The study took

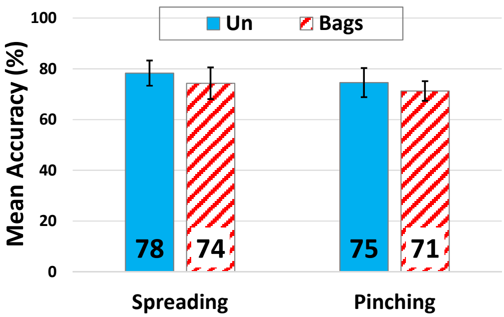

Figure 6: The overall mean accuracy (%) for pressure-based *spreading* and *pinching*. Error bars denote 95% CI.

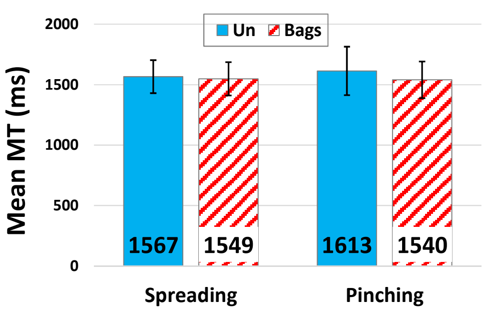

Figure 7. The mean movement time (ms) for pressure-based *spreading* and *pinching*. Error bars denote 95% CI.

approximately 60 minutes to complete and £6 was paid for taking part.

Results

A total of 8640 trials were recorded for the entire study. Potential outliers were removed (by following the method described by [3]) if the endpoint error was greater than two target widths from the center of the current target. Consequently, 116 trials (1.34%) were removed for the data analysis. In this work, we calculated the Cohen's *d* and presented the effect sizes in the results.

SPREADING AND PINCHING ACCURACY

The overall mean accuracy for pressure-based spreading and pinching is shown in Figure 6. The Wilcoxon test for spreading showed that encumbrance had no significant effect on targeting accuracy (p=0.09) with effect size *d*=0.3.

A Friedman test showed that target distance also had no effect on accuracy for spreading (χ^2 (2) = 5.49, p=0.06). However, target width had a significant effect on targeting accuracy (χ^2 (2) = 33.44, p < 0.01). Post hoc Wilcoxon comparisons showed that each pair of widths differed significantly from each other.

A Wilcoxon test showed that encumbrance had no effect on targeting accuracy when pinching (p=0.08) with effect size *d*=0.3. A Friedman test showed that target distance also had no significant effect on accuracy during pinches (χ^2 (2) = 3.69, p = 0.16). Target width had a significant effect on accuracy (χ^2 (2)=33.75, p<0.01) with post hoc pairwise comparisons showing that all widths had significantly different accuracy values.

SPREADING AND PINCHING MOVEMENT TIME

The mean movement times for pressure-based *spreading* and *pinching* are shown in Figure 7. Encumbrance had no effect on movement time when performing spreads (p = 0.97) with effect size *d*=0.1. Target distance had a significant effect on movement time (χ^2 (2)=30.9, p < 0.01): there were significant differences between all three target distances. A Friedman test showed that target width had a significant effect on target accuracy (χ^2 (2)=27.9, p < 0.01), with significant differences between each pair of target widths.

The results failed to show encumbrance had effect on movement time for pressure-based pinching (p = 0.13) with effect size *d*=0.2. Target distance did have a significant effect on time (χ^2 (2) = 17.1, p < 0.01), with *post hoc* pairwise comparisons showing significant differences between all three distances. Target width also had a significant effect on target accuracy (χ^2 (2) = 26.8, p < 0.01).The 1.6mm target width differed significantly from larger 3.2mm and 4.8mm targets.

ROTATING ACCURACY

The mean target accuracy for rotating clockwise (CW) and anticlockwise (AntiCW) is shown in Figure 8. Encumbrance had no significant effect on target accuracy when rotating CW (p = 0.13) with effect size *d*=0.3. Target distance also had no significant effect on target accuracy for CW rotations (χ^2 (2)=1.15, p = 0.56). However, target width had a significant effect on accuracy when rotating CW (χ^2 (2)=37.01, p < 0.01) with *post hoc* pairwise comparisons showing significant differences between all pairs of target widths.

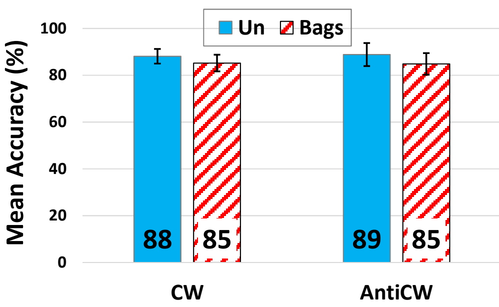

Figure 8: The overall mean accuracy (%) for pressure-based *rotating clockwise (CW)* and *anticlockwise (AntiCW)*. Error bars denote 95% CI.

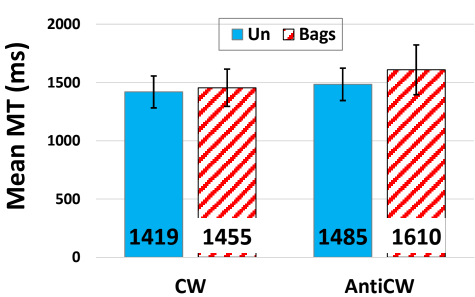

Figure 9. The mean movement time (ms) for pressure-based *rotating clockwise (CW)* and *anticlockwise (AntiCW)*. Error bars denote 95% CI.

The Wilcoxon test conducted for rotating AntiCW showed that encumbrance had a significant effect on targeting accuracy ($p = 0.03$), with accuracy being higher when unencumbered (88.8%) than when carrying the bags (84.8%). The effect size d=0.5. Target distance had no effect for target accuracy during AntiCW rotations ($\chi^2(2) = 0.21$, $p = 0.90$). Target width had a significant effect ($\chi^2(2) = 34.62$, $p < 0.01$): *post hoc* pairwise comparisons showed that all target widths differed significantly from each other.

ROTATING MOVEMENT TIME

The mean movement time for rotating CW and AntiCW is shown in Figure 9. Encumbrance had no effect on movement time when rotating CW ($p = 0.31$) with effect size d=0.1. Target distance had a significant effect on movement time during CW rotations ($\chi^2(2) = 32.7$, $p < 0.01$), with all target distances differing significantly from each other. Target width also had a significant effect on accuracy when rotating CW ($\chi^2(2) = 23.7$, $p < 0.01$): all target widths differed significantly from each other.

For rotating AntiCW, encumbrance had no significant effect on movement time ($p = 0.07$) with effect size d=0.3. Target distance did have a significant effect on time when rotating AntiCW ($\chi^2(2) = 38.1$, $p < 0.01$), with all target distances differing significantly from each other. Target width had a significant effect on movement time during AntiCW rotations ($\chi^2(2) = 33.6$, $p < 0.01$): all target width pairwise comparisons differed significantly.

Study 2

In this experiment, we continued our work in Study 1 by designing a pressure cursor for target selection. This interaction technique was compared with the Dragging in the touch-based gestures [7]. The interface was shown in Figure 10.

Hardware and Task

For Study 2, we used the same mobile device setup as Study 1. There were three target widths (5.0, 7.5 and 10.0mm), four target distances (24, 36, 48 and 96mm) and eight directions. The task was to move the cross cursor on the screen to the green target area. In this study, the user only needed to press one FSR sensor, that is, FSR2 in Figure 3, for speed control. The user controlled the two-dimensional movement of the cursor by rotating the phone [14]. The overall magnitude of speed at which the cursor moved was controlled by the amount of pressure applied to the sensor pressed by the thumb. The speed along each axis (x-axis and y-axis) on the screen was determined by the orientation and the overall speed. The pressure space was set to 5N and applying more pressure to the sensor made the cursor move faster and release from the sensor slowed the cursor down. To select the current onscreen position, the Dwell (750ms) technique was used to enable the user to select the target.

Experimental Design

The same encumbrance scenario as Study 1 was evaluated and participants walked around the same test route at their measured PWS&I. Eighteen right-handed participants (14 males) aged between 18 - 35 years (Mean = 23.78, SD = 5) were recruited from our institution. A within-subject design was used and there

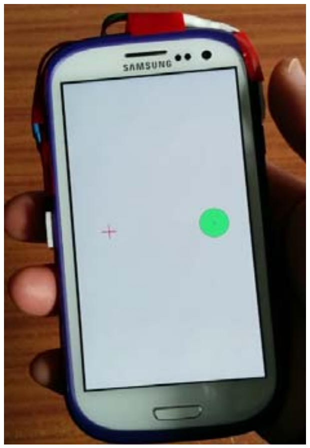

Figure 10. Pressure cursor interface. It shows the cursor (red cross) and the target (green area bounded by the circle). The task is to move the cursor into the target area by tilting the phone for direction and pressing the sensor for overall speed control.

were two conditions: performing the pressure-based pointing task either unencumbered or carrying a bag in each hand. The conditions were counter-balanced to reduce ordering effects.

Results
A total of 6480 trials were recorded for Study 2. Potential outliers were removed using the same method as Study 1 and as a result, 27 trials (0.42%, 11 for Unencumbered and 16 for Encumbered) were removed from the initial data analysis.

The overall mean accuracy and movement time for pressure-based targeting for both conditions are shown in Table 2. Early statistical analysis using Wilcoxon test showed that encumbrance had no significant effect on accuracy during pressure-based targeting ($p=0.10$) with effect size $d=0.5$. However, encumbrance had a significant effect on movement time ($p < 0.01$) with effect size $d=0.4$. The pressure cursor achieved a much higher accuracy but required more movement time than the touch-based Dragging gesture.

		Categories	
		Un.	*En.*
Dragging	Accuracy (%)	49.7%	47.7%
	MT (ms)	344	386
Pressure Cursor	Accuracy (%)	98.5%	97.0%
	MT (ms)	3334	3677

Table 2: Mean Accuracy and mean Movement Time: Unencumbered (Un.), Encumbered (En). Comparison of the touch-based Dragging and pressure cursor interaction

Discussion & Future Work
The results are promising: encumbrance had no negative effects on accuracy or movement time when pinching, spreading, rotating clockwise or targeting with the pressure cursor. Only accuracy when rotating anticlockwise was significantly worse when encumbered, and this difference was small in real terms, dropping from ~89% to ~85%. The difference in accuracy was less than 5% and movement time was no longer than 130ms across all three input types, with participants performing slightly worse when encumbered. This shows early promise in using pressure-based input for encumbered and walking situations. An interesting result is that encumbrance has a significant effect on targeting accuracy with rotating anticlockwise and not a significant effect with rotating CW. This result suggests that the weight in the hand had a larger influence on the thumb movement in comparison with the middle finger movement in this rotation circumstance. How the user carried the weight and the device can be seen in Figure 1 and Figure 3 respectively. While walking itself reduces precision of pressure input compared to when sitting [12], the results here show that pressure input can be carried out even when encumbered, with no effect on input. Velocity-based pressure input may be stable enough to absorb the unintended movements caused by walking [10,12] and encumbrance [5] to facilitate good performance. This is in contrast to touchscreen interaction, where encumbrance has been shown to severely impair tapping accuracy [5,6]. Moreover, in comparison with touch [7], the results suggest that one-handed multi-digit pressure input may be better suited to carrying out complex movement gestures such as zooming or rotation in encumbered scenarios, compared to traditional two-handed multitouch input.

The pressure cursor in Study 2 is a promising targeting technique for high accuracy in comparison with touch-based Dragging gesture. However, pressure-based targeting took a much longer movement time than touch, suggesting a speed vs. accuracy trade-off. Perhaps compromising input speed for accuracy during pressure input is worthwhile since an inaccurate touch selection could take even longer to recover and more frustrating for the user. The work here suggests pressure has the potential to improve usability in these physically demanding situations.

As multitouch can control concurrent zooming, rotation and translation, the future work will test pressure-based concurrent zooming and rotation, and all three inputs combined. This will require more than the two sensors used here, but previous research has shown concurrent control over multiple axes is possible [13].

Conclusions

This paper has shown that it is possible that encumbrance has no significant negative effects on accuracy and movement time when zooming, rotating or targeting with the pressure cursor on a mobile phone using multi-digit pressure input, which can provide one-handed input for interaction while walking and encumbered.

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