Exploring User-Defined Back-Of-Device Gestures for Mobile Devices

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ABSTRACT
Many studies have highlighted the advantages of expanding the input space of mobile devices by utilizing the back of the device. We extend this work by performing an elicitation study to explore users' mapping of gestures to smartphone commands and identify their criteria for using back-of-device gestures. Using the data collected from our study, we present elicited gestures and highlight common user motivations, both of which inform the design of back-of-device gestures for mobile interaction.

Author Keywords
Smartphones; back-of-device interaction; gestures, eyes-free interaction; mobile; hybrid input

ACM Classification Keywords
H.5.2. User Interfaces: Input devices and strategies, Interaction Styles, Miscellaneous

INTRODUCTION
With the lowering cost and increased versatility of mobile devices, people are becoming more inclined to purchase and use smartphones. Today, smartphones are used for various purposes such as reading, navigating maps, taking pictures, or playing games. Physical keyboards have disappeared in favor of larger screens, and the majority of mobile devices are controlled primarily by interacting with their display. While this form of input is popular, the diversified use of mobile devices has spurred interest in additional input modes such as mid-air [23, 35, 3] and motion gestures [24, 9, 18, 11, 17, 16].

Studies have shown that one-handed interaction with hand-held devices is the preferred mode of operation for many users [10]. With interactive tasks performed by one hand, users can free their other hand for other tasks, such as carrying shopping bags or holding a bus handle [33]. In one-handed interaction, the thumb of the phone gripping hand becomes the main channel of input—other auxiliary fingers are seldom used. This presents several problems in one-handed mobile interaction techniques, especially considering the recent increase of form factors in mobile devices. While gripping the device with one hand, that hand's thumb often cannot reach the entirity of the screen. This is known as the *limited thumb reachability* problem [5]. Other issues encountered in one-handed thumb based interaction are:

- *Fat finger problem* [4]: error prone target acquisition on small screens attributed to wide surface area of thumb.
- *Occlusion problem* [29]: wide surface area of thumb blocking the view of a large percentage of a small screen.

To address the limited thumb reachability problem in smartphones, recent large screen mobile phones are equipped with features that can shift the entire screen [2] or shrink the entire screen to bring difficult to reach areas closer to the user's thumb [22]. Although these solutions address the limited thumb reachability issue, they reduce the input gesture space for the user to enable one-handed operation. This increases both the fat finger and occlusion problems as the effective touch-space becomes smaller.

Alternatively, to address the thumb reachibility problem, the device's input space can be increased by facilitating interaction with the back of the device using the otherwise unused fingers of the phone-gripping hand [Figure 1]. Back-of-the-device gestures provide an alternative one-handed solution to the limited thumb reachability problem by enabling the user to interact with previously unreachable areas of the screen by using one of two methods:

1. Directly mapping unreachable areas on the front touchscreen to areas that are reachable using the (longer) index finger on the the back of the device.
2. Remapping unreachable areas on the front touchscreen to reachable areas on the back of the device.

Since the effective screen size remains the same, the problems of increasing occlusion and wrong target acquisition, as in in [2] and [22], can be avoided.

Many research studies have been conducted to utilize the back of mobile or handheld devices as a possible input space [33, 4, 25, 27, 28, 7, 6]. Some of the proposed methods of utilizing the back-of-device as input space are:

- Applying additional hardware [12, 33]
- Using the existing rear-facing camera [32, 1]
- Using the existing internal sensors [19]

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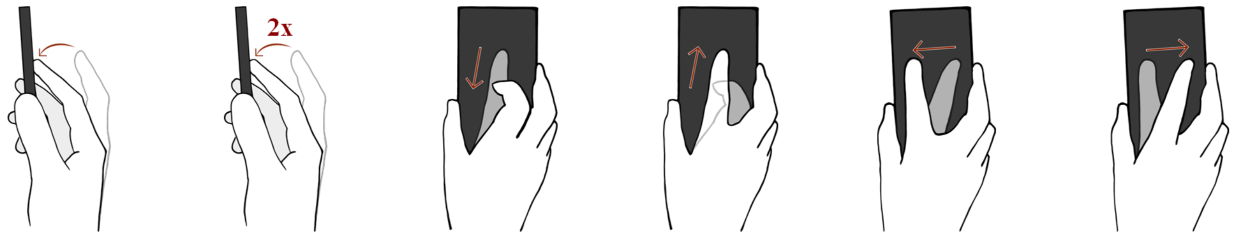

Figure 1. Example back-of-device gestures performed by using otherwise unused fingers of the phone-gripping hand.

Up until now, all research on possible back-of-device interaction for mobile devices has focused on designer-defined gesture sets; there have been no explorations of user-defined gesture sets. This is critical because research has shown that user-defined gestures are easier to learn and recall [30], easier to perform [15], and more appropriate than designer-defined gestures [15].

Elicitation studies [31] are a well-established methodology for advising the design of user-defined surface [15] and motion [20] gesture sets as well as multimodal systems [13]. This approach consists of presenting participants with a system action or task (i.e. the *referent*) and requesting them to suggest a gesture to be used as a trigger (i.e. the *sign*). A consensus gesture set can be defined if there is sufficient agreement among participants' gestures [31]. Elicitation studies are particularly appropriate for informing the design of new technology since the methodology does not require that the system be implemented to determine the user's needs and desires [14].

Thus, in this paper we conduct and present the results of a elicitation study [14] which examines back-of-device gestures for mobile devices. Our work offers the following contributions:

1. Understanding the user's mental model and their criteria for creating possible back-of-device gestures.
2. Identifying a set of back-of-the device gestures elicited from end users for common smartphone interactions.
3. Providing guidance to smartphone designers for incorporating back-of-device interaction.

METHOD

We elicited user-defined gestures for back-of-device interaction by conducting interactive, one-on-one interviews with 15 volunteers. In each interview, we asked the participant to create a one-handed back-of-device gesture, while thinking aloud, for each of twenty-three tasks. Table 1 shows the complete list of tasks. Each task was accompanied by a visual reference (either an image or a short video) displayed on the phone's screen using custom software that showed the effect of performing the task. Once the participant was satisfied with his or her gesture, he or she was instructed to perform the gesture. The tasks were common to smart phones, and chosen for their frequency of use and ease of understanding. A video camera was used to record the participant's hand performing

Category	Sub-Category	Task Name
Navigation	System-Phone	Next
		Previous
		Go To Home Screen
	Application	Next
		Previous
		Pan Left
		Pan Right
		Pan Up
		Pan Down
		Zoom In
		Zoom Out
Action	System-Phone	Answer Call
		Hang-up Call
		Ignore Call
		Mute Microphone
		Switch to speaker-phone
		Lock Phone
		Act on Selection
	Application	Take Selfie
		Copy
		Cut
		Paste
		Open Context Menu

Table 1. The list of tasks presented to participants, grouped by category.

gestures on the back of the device. Interviews lasted 30-45 minutes in length.

Because the primary aim of our study was the elicitation of user-defined gestures, our focus was not to distract or affect user performance with recognizer or sensor technology. Therefore, we didn't support any gesture recognition during the elicitation study. Instead, the participants were encouraged to focus on gesture design and performance while assuming that the smartphone was acting like a *magic brick* [20] capable of tracking and detecting any kind of gesture they designed. This methodology was adopted in order to reduce the likelihood that participants would limit their proposed gestures based on their understanding of current technology and gesture recognition techniques.

Apparatus and Participants

The study was performed using a LG Nexus 4 smartphone running Android 5.0.1. Custom code was developed in Java using the Android SDK [8] to help present the tasks in the study. Fifteen participants aged 19-33 (Mean = 23.73, S.D. = 3.95, 6 females, 1 left handed) were recruited using a departmental email list and compensated with a $10 Amazon gift card. All participants owned smartphones.

RESULTS

Our results consist of elicited gestures, agreement scores for given tasks, subjective ratings for each gesture, and qualitative observations. Each observed gesture was coded by two different researchers to ensure consistent labeling. The qualitative observations were extracted from the participants' feedback from the conducted interview sessions.

Gestures Designed by Users

The participants tended to design gestures heuristically and intuitively. The designed gestures were heavily influenced by *legacy bias*, *concern for accidental input*, and *ease of performance*.

Legacy Bias

Participants were noticeably influenced by previous interaction experiences. For example, for map navigation tasks including *Pan(left/right/up/down)* and *Zoom(in/out)*, most users mimicked the gestures they were already applying on the front touchscreen of smartphones/tablets. The participant identified those gestures as more appropriate and natural.

> *"To pan the map down, I'd like to slide my finger from down to up because this is the same gesture when I'm doing map navigation in front screen. [P8]."*

Some participants mimicked keyboard shortcut key patterns by creating 'C' and 'V' gestures for *Copy* and *Paste*. Additionally, some participants created gestures that were influenced by popular applications. For example, some gestures created for *Answer/Hang-up/Ignore Call* were inspired by *Tinder* [26], where swiping in one direction or the other is synonymous with acceptance or rejection.

Concern for Accidental Input

Some of the participants designed gestures to be resistant to accidental triggering. For instance, users suggested double tap or rhythmic taps on the back of the device for some selection/action tasks. These participants indicated that they believed that while a single tap can sometimes occur by accident, actions like double tap or rhythmic taps are less likely to be accidental.

Ease of Performance

We observed that participants carefully considered simplicity and ease-of-performance when designing gestures. As a result, many elicited gestures were short, memorable, and easy, such as *tap*, *double tap*, and *swipe*. Some of these gestures were location specific. For example, participant P1 used the gesture of one tap in the middle of the back of the device to mimic the action of taking a selfie, whereas he tapped once on the upper left corner to open an application. We observed that most of these simple gestures could be completed quickly.

Natural and Consistent Mappings

In general, analysis of the user-designed gestures showed that for the navigational tasks (e.g. *next item, previous item, up, down, left, right*), participants tended to apply gestures that were similar to their front touchscreen counterparts. Furthermore, for the tasks that are equivalent but opposite of each other, participants frequently designed similar gestures in opposite directions/orientations. For example, participants that chose swiping from left to right for viewing the previous screen also chose swiping in the opposite direction for navigating to the next screen. Similarly, some participants employed circular gestures in opposite directions for mimicking the opposite actions of *Mute* and *Switch to Speakerphone*.

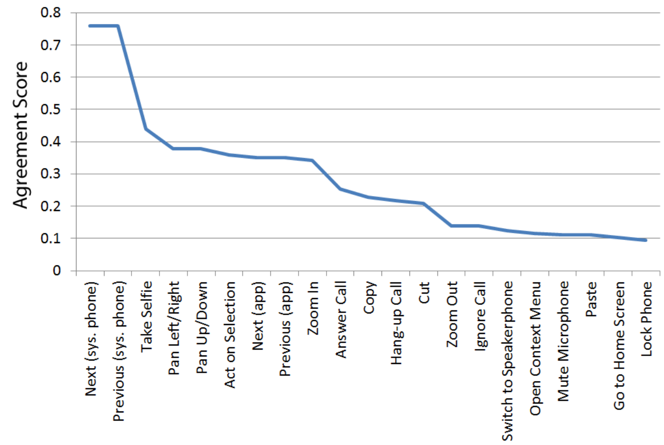

Figure 2. Agreement scores for each task sorted in descending order for back-of-device gestures.

Agreement Scores

As in Wobbrock et. al [30], we used an agreement score standard for each task to extract the degree of consensus among participants. The mathematical equation for calculating the agreement score is:

$$A_t = \sum_{P_i} \left(\frac{P_i}{P_t}\right)^2 \tag{1}$$

In Equation 1, t is a task in the set of all tasks T, P_t is the set of proposed gestures for task t, and P_i is a subset of identical gestures from P_t. The range for A is $[0, 1]$. For example, the task *Next (System-Phone)* has 4 groups of gestures from 15 participants: *single tap on left side of device with respect to user*, *swipe-left with respect to hand*, *swipe-left with respect to person*, and *thumb swipe-down with respect to side*. The size of these groups are 1, 2, 11, and 1 respectively. Therefore, the agreement score for this task is:

$$A_{Next_{SP}} = \left(\frac{11}{15}\right)^2 + \left(\frac{1}{15}\right)^2 + \left(\frac{1}{15}\right)^2 + \left(\frac{2}{15}\right)^2 = 0.76 \tag{2}$$

Agreement scores for the task and gesture set developed by our participants are illustrated in Figure 2. We found that only two tasks had significant consensus, garnering agreement scores of 0.76. These elicited gestures were *swipe-left* and *swipe-right*, and corresponded to pulling or pushing the content of the home screen to move it.

DISCUSSION

In this section, we summarize trends from our interviews and discuss notable findings from the elicitation study.

Concern for Accidental Input

A number of participants opted to design gestures that they felt were less likely to accidentally trigger an unwanted action on the phone. Participants reported a concern that normal handling—grasping, holding, bumping while in a pocket—would be misread by the phone as a back-of-device gesture. This is less of a concern for front touchscreens, as users generally avoid casual handling of the touchscreen. Furthermore, since back-of-device interaction lacks the front touchscreen's advantage of readily indicating the location of a target (e.g. by providing a visual target), the possibility of erroneously triggering location-specific gestures is higher. Consequently, determining whether contact with the back of the device is accidental or intended input is the subject of future research.

Moving Content vs. Moving Viewport

One reason for generally low agreement scores was a conflict between two approaches to movement (e.g. navigating a map) on a mobile phone. Roughly half of the participants chose to move the content, as if they were pulling or pushing the content with their finger, while the other half performed inverted gestures that moved the viewport instead. This conflict is likely due to participants' differing prior experiences with movement types across devices.

Phone Oriented and Localized Gestures

The vast majority of elicited gestures were phone-orientated, meaning swipes were made along the vertical and horizontal axes of the mobile phone. Although we observed that this appeared to result in slightly more awkward finger movement for the participants, participants remarked that these gestures were easy to use. We also observed that participants performed the same gestures, such as tap, on different places or in different orientations to perform different tasks. For example, for *Mute* and *Switch to Speakerphone*, some participants used clockwise/counterclockwise circles.

Novel Rhythmic Gestures

We observed a total of three rhythmic gestures performed by two participants. There were two occurrences of a *1-2 tap* and one occurrence of a *1-2-2 tap*. The *1-2 tap* was performed by first pressing the back of the device with an index finger, then bringing the middle finger down as well. The *1-2-2 tap* was identical to the *1-2 tap* except it added an additional two finger tap at the end with the index and middle fingers. While not elicited often, we believe rhythmic taps could give gesture designers more options and possibly address the concern for accidental gesture input, because of the added timing element to the gestures.

Challenges of New Tasks

Although most of the tasks considered in our study already had popular mappings to surface gestures, some common tasks did not have prominent corresponding gestures. For example, while editing selected text by *Copying*, *Cutting*, or *Pasting* is commonly done using a mobile device, there are no surface gestures mapped to those tasks. For these sets of tasks, participants usually had difficulty designing a back-of-device gesture. This caused the agreement scores to be low in comparison to the other tasks. However, participants frequently tried to create simple actions similar to those used with other computing devices—such as using a finger to draw a 'C' or 'V' on the back of the phone for doing copy or paste, which conforms to the "*ctrl*+C" and "*ctrl*+V" keyboard shortcuts.

LIMITATIONS AND FUTURE WORK

We believe that as in other elicitation studies, the primary limitation to our study lies in legacy bias [14, 21]. Since our gesture set was heavily influenced by users' previous interactions with devices, it is difficult to determine how optimal our elicited gestures are. Therefore, future research could explore a second elicitation study where legacy bias would be mitigated using techniques described by Morris et al. [14] and Ruiz and Vogel [21], and by studying other user demographics and cultures.

We also plan to implement recognizers for the user-defined back-of-device gesture set by customizing the off-the-shelf *Yotaphone 2* [34], which would then be examined in a user study. We believe that this will allow developers to revise and expand the user-defined back-of-the device gesture set, and will spur interest in exploring alternate use-cases for dual-touchscreen-enabled mobile devices.

CONCLUSION

In this paper, we conducted an elicitation study for back-of-device gestures. Notably, there was little consensus among participants regarding their chosen gestures, with only two tasks yielding high agreement scores. We observed that participants were noticeably influenced by legacy bias and showed a concern for accidentally triggering gestures. In addition, there was a split among participants regarding movement gestures, with some intending to move content and others wanting to move the viewport. Furthermore, users performed similar gestures on different locations of the phone to perform discrete tasks. The majority of gestures were orientated along the major axes of the device and a small number of gestures involved rhythmic taps. We believe that this work can inform the design of the next generation of mobile interaction.

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