Does Proprioception Guide Back-of-Device Pointing as Well as Vision?

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Abstract

We present research that investigates the amount of guidance required by users for precise back-of-device interaction. We explore how pointing effectiveness is influenced by the presence or absence of visual guidance feedback. Participants were asked to select targets displayed on an iPad device, by touching and releasing them from underneath the device. Another iPad was used to detect finger positions from the rear. Results showed that participants were able to select targets as accurately without visual feedback of finger position as they were with it. Additionally, no significant increase in workload was identified when visual feedback was removed. Our results show that users do not require complex techniques to visualize finger position on the rear of device. Visual feedback does not affect any performance parameters, such as effectiveness, perceived performance, and the number of trials needed to select a target. We also outline the implications of our findings and our future work to fully investigate the effect of visual guidance feedback.

Keywords

Ergonomic; occlusion; back-of-device; feedback.

ACM Classification Keywords

H.5.2 [Information inter-faces and presentation]: User Interfaces - Ergonomics; Haptic I/O.

General Terms

Design, human factors, performance.

Introduction

The shrinking physical size of portable devices, coupled with their complementary increase in functionality, and the fat-finger-problem [8], has led to an increase in the amount of research focused on around and back-of-device interaction [1,3,7,11]. Many promising techniques have emerged during the last few years. Examples include Lucid Touch [11], Nano Touch [1], Hoverflow [3], and the iPhone sandwich [7], which allows multitouch sensing simultaneously on both the front and rear of the device. Small touchscreen, pocket-sized devices, such as smartphones, dominate both the mobile market and research into mobile HCI. While the popularity of pad-sized devices (such as the iPad) has grown enormously, the research community has only recently shown interest in this class of device.

The anatomy of the human hand defines how we grasp and hold objects and devices. When standing, pad-devices are held in both hands with the thumb on the user-facing (front) side and the four fingers on the rear-side (back) of the device (cf. figure 1). The need to continue to grasp the device means that only one hand is fully available for interaction, as the grasping hand is occupied in stabilizing the device. The ability to interact with the rear of the device however, allows both hands to hold the device, and allows all digits to be used for interaction (the thumbs on the front, and fingers with their greater reach on the rear). However, with such an approach, the fingers behind the device are occluded and interaction must be performed without the continuous visual feedback to the user. This may impede the performance of back-of-device finger gestures, increasing both time and errors. Previous research relating to the back-of-device interactions focused on illustrating the position of fingers interacting
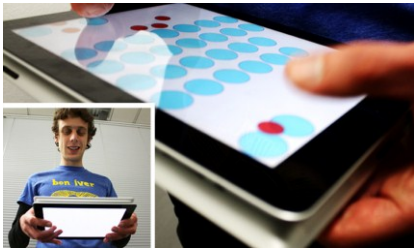

figure 1. Interactive prototype that displays targets (blue circles) on the front screen. The fingers that are touching on the back screen are visualized as red circles on the front screen.

with the rear of the device via the visual display [1,7,11].

However, is such visual feedback necessary? Actually nobody has bothered to find out if it is necessary or not. In our daily lives, we often use physical tools and devices without the need to visually monitor how our hands are interacting with them. For example, when looking through a viewfinder to take a photograph or interacting with controls on a car steering column (such as indicators or headlamps), users only require haptic feedback for their successful completion.

Our work aims to determine if and how visual guidance feedback affects users' perceived and objective pointing performance during back-of-device interaction. We want to verify if proprioception - the haptic system's ability to monitor the position and orientation of our limbs in 3D space [5] - can compensate for the lack of visual feedback. Proprioception refers to the understanding of our own body position, without the need to see it, e.g. reading a book whilst drinking tea. We can still locate the cup, pick up the cup, drink the tea and replace the cup without needing to look at it.

Related work

In this section we discuss three areas: existing approaches to back-of-device feedback and investigations of gesture feasibility while holding devices, and a brief overview of why proprioception might work for guiding occluded gestures.

Visualizing back-of-device gestures
Back-of-device interactions address the problem of obstructing visual content on the screen during interaction and the so-called *fat-finger problem* [8]

when selecting small targets. Significant work has been carried out in this area, but it assumes that some form of visual feedback of back-of-device interaction is required. LucidTouch [11] and Nano Touch [1] display a pseudo see-through representation of the user's complete hand and fingers on the visual display to represent back-of-device hovering [11] and touching [1]. RearType [6] places a physical keyboard on the back of a tablet but presents a visual representation on the display, visually highlighting the keys as they are pressed.

Gesture ergonomics while grasping devices
In addition to the work undertaken on visually representing the location of the fingers in back-of-device interaction, consideration has also been given to the types of interaction and gestures users can and would perform while holding mobile devices. Wolf *et al.* [13] developed a taxonomy that presents a generic set of feasible finger gestures while holding objects. The only gestures within this taxonomy that are still feasible while grasping an object are tabbing or dragging. Wobbrock *et al.* [12] carried out a Fitts' law study to investigate performance of the index finger and the thumb on the front and the back of a PDA size device. The results indicated good performance for the index finger on the front and the back of the device and an overall diminished performance for the thumb.

Approaches for understanding feedback
Feedforward theory [4] describes human's ability to execute movements without any sensory feedback because of existing motor knowledge. We can draw on this theory to explain the performance of back-of-device pointing, such as when configuring the controls on a digital camera whilst looking through the

viewfinder. While looking through the viewfinder, users receive no visual feedback about the positions of their fingers and do not need to pay attention to their finger trajectory. Applying feedforward theory for automated trajectories to back-of-device interaction suggests that users would not require feedback or target guidance if the action relies on existing motor knowledge.

The Sensorimotor Adaption Model [9] is based on information of multiple sensory modalities that serve to monitor physical movement. For instance, vision and proprioception both provide information about hand movements. Vision had been thought to dominate this process [10], but studies, such as [9] have shown that the sensory motor system weights modalities based on their information quality. If a modality loses information, such as poor lighting reducing vision, proprioceptive information is given more weighting, becoming the dominant feedback control modality. Taking Sensorimotor Adaption Theory as inspiration, we propose that proprioception can serve as internal feedback modality and replaces visual system feedback without affecting the use of back-of-device interactions, such as pointing.

Resulting approach
A lot of research has been done on back-of-device interaction techniques and gesture ergonomics while holding mobile devices. Usually rich feedback is provided to the users to support their actions. But so far none has investigated if users actually need visual guidance feedback for occluded interactions. The Feedforward theory [4] and the Sensorimotor Adaption Model [9] suggest that visual guidance is not necessary in this instance and have motivated us to explore how much feedback occluded gestures actually need.
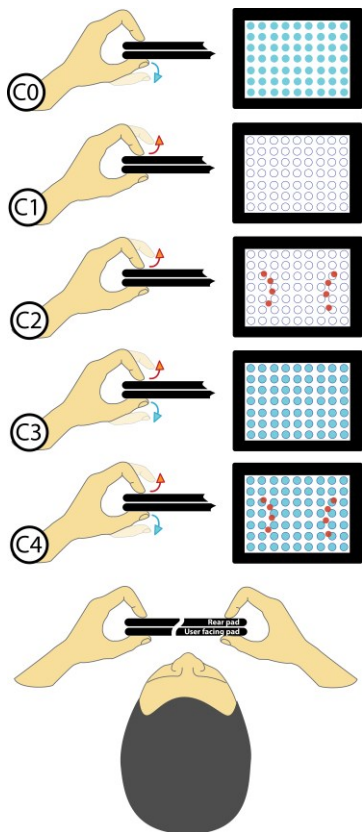
figure 2 Interactions: participants were asked to select targets by touching and releasing them on different sides of the device. Front only: C0 🔵, back only: C1&C2 ⭕, or both front & back C3&C4 🔵. Red circles (🔴) on the front screen provide feedback about the finger positions at the device's rear in conditions C2 and C4.

Experiment

Design

The interaction techniques that we will investigate are body movement-based. We apply theories of humans' motor feedback [4,9] onto feedback design for movement-based human-computer interaction. To investigate users' motor-feedback requirements, we rely on Feedforward theory [4] and the Theory of Sensorimotor Adaption [9] and formulate the following hypothesis: proprioception can serve as the internal feedback modality for accurate pointing and replace visual system feedback without affecting the use of back-of-device interactions.

To determine the impact of visual feedback on the performance of back-of-device interaction, we designed a quantitative experimental study. We focused on effectiveness and efficiency, which are competitive strategies that limit each other's result's quality. Saving the efficiency parameter time (i.e. solving a task under time pressure) usually decreases effectiveness. Therefore our study aimed to simulate natural device usage through self-paced tasks that focus on task performance rather than completion time.

Ten participants, six female and four male, aged between 24 and 64 years old, took part in the study. The experimental prototype consisted of two iPad devices glued together back-to-back to allow sensing touch events from the front (with the thumb) and the rear (with the fingers) while holding the device (see Figure 1 and inspired by [7]) The participants were asked to interact with the prototype in five different ways (conditions C0 to C4 – cf. figure 2). They had to select 15mm sized targets shown on the top iPad screen.

	front 🔵	back ⭕	front&back 🔵
feedback 🔴		C2	C4
no feedback	C0	C1	C3

Table 1. Feedback & interaction technique for each condition.

Participants were asked to delete blue circular targets on the front screen using three interaction techniques: a common *front touch release* technique (C0: 🔵), *back touch release* where fingers are occluded by the device (C1 & C2: ⭕), and *front and back touch release* similar to pinching (C3 & C4: 🔵). As the user must touch the rear iPad to hold the device (as is the case with any back-of-device interaction), employing touch-down events for the activation would lead to unintentional deletions. Therefore, touch-up events was chosen as the activation (and thus deletion) command. This is also the standard technique for selection on devices such as the iPad.

In two of the five conditions participants were provided visual feedback on the front screen about finger touch positions on the rear screen (back only: C2 ⭕) and front and back: C4 🔵). When users' fingers touched the prototype's rear, red circles (🔴) appeared on the front screen at the positions corresponding to where the fingers were set at the back of the device. The positions of the red circles were updated as the fingers moved.

Two other conditions (back only:C1 ⭕, and front and back: C3 🔵) did not provide any visual feedback of back touches, and therefore users would not be able to readjust their finger positions on the rear by seeing where the fingers were and if the fingers were on a target. The fifth condition, C0, acted as a control for
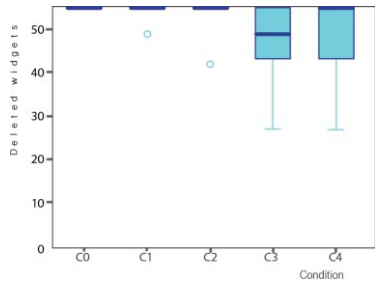
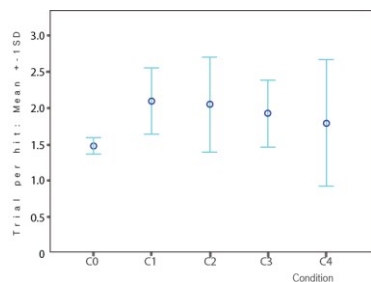**figure 3** Effectiveness: number of deleted targets for each condition.

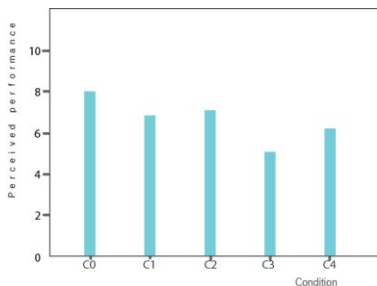**figure 4** Number of trials required to delete targets for each condition.

figure 5 Perceived performance (NASA TLX subscale) for each condition.

conventional pad based interaction. Here, the rear iPad was dormant and performed no role.

Red colored circles (⬤) were used to represent finger positions so as to distinguish them from the blue targets (⬤ ◯ ◯). Users could select a target by touching the rear of the device using proprioception. A red circle would appear at the touch position which moved with the finger as the finger slid along the device. When the red circle was moved to the same position as a blue target, and the user released their finger touch (touch-up) the blue circle was deleted (cf. figure 2, C2: ◯ & C4: ◯).

Participants' interactions were recorded whilst the tasks were being completed. To capture the task performance, we measured the progress of task completion by using the number of successful deleted circles out of all circles (56). However, we did not focus on efficiency in terms of how long users took to complete the tasks; we measured how the tasks were completed as descriptive measurements of number of trials needed to delete a single circle. The subjective performance was measured though NASA TLX [2] after the tasks had been completed.

Results
User performance was determined as the number of targets successfully selected during the tasks for each condition (effectiveness) as well as the number of trials that were needed to select a target successfully (efficiency). The perceived performance was also measured.

Although a repeated measure ANOVA showed a significant omnibus test for effectiveness

($F_{(1.72, 15.51)} = 7.7$, $p = .006$, *part. eta²* $= .461$), Sidak-corrected pairwise comparisons yielded no significant results. (cf. figure 3). Regarding the number of trials (cf. figure 4) no significant results were observed, $F_{(1.65, 11.54)} = 1.7$, $p = .229$, *part. eta²* $= .193$.

For the perceived performance (cf. figure 5) again a significant omnibus test was shown, $F_{(4,36)} = 6.6$, $p < .001$, *part. eta²* $= .422$. But Sidak-corrected pairwise comparisons indicated significant differences only between C0 vs. C3 ($p = .005$) and C2 vs. C3 ($p = .032$) and not for C1 vs. C2 ($p = .820$) and C3. vs. C4 ($p = .619$).

Our results show that the provision of visual feedback had no significant effect on either quantitative or subjective perceived performance.

Discussion
Our hypothesis proposes that proprioception will overcome the lack of visual feedback in back-of-device interaction as explained by the Sensorimotor Adaption Model (SAM) [9]. The removal of visual feedback did not lead to significant quantitative or qualitative degradation in performance. Given the hypothesis; having non-significant results indicate that visual feedback may not be necessary. Thus the visualization of finger position might be redundant for proprioceptive feedback. These findings are promising because they support back-of-device interactions without occluding a screen, and may also allow interacting with screen-less devices.

In this initial study we focused on comparing the effectiveness of back-of-device both with and without visual feedback of finger positions. To solve a task as

complete as possible (that means being effective) usually increases the required time. Our results show that users' effectiveness for proprioception guided back-of-device pointing is promising and visual feedback may not be necessary for back-of-device interactions. Complex techniques to determine hovering of back-of-device fingers (rather than touching) aren't necessary and further work is needed to identify interaction techniques that rely more on proprioception than visual guidance. A follow-up study may be conducted with a stimulus-response structure for investigating performance according to a visual representation of occluded gestures for different target sizes, as well as for dragging gestures.

Based on the presented results, occluded gestures, whose proprioceptive guided performance did not diminish with the absence of visual guidance, open up a new design space for interacting with all types of handheld objects. The cognitive ability of users to use motor knowledge rather than visual guidance provides a great opportunity for ubiquitous interaction wherever humans are and with whatever they hold in their hands.

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