Comparing Pointing Techniques for Grasping Hands on Tablets

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ABSTRACT

With the recent success of tablet devices a new device type became available for mobile interaction. Just as for mobile phones, touch is the dominant way people interact with tablets. In contrast to the much smaller phones a firm grip with both hands is needed to securely hold tablet devices. While a large body of work has investigated touch interaction on smaller devices, is little empirical research has been carried out on touch-based pointing while holding the device with both hands. To understand touch-based interactions using tablet devices, we conducted an experiment to compare four pointing techniques on both the front and back of the devices while it was held in landscape format. We compare direct touch with the following alternatives for selecting targets, indirect pointing on a virtual touchpad, an inverse cursor, and a miniature interaction area. While direct touch is 35% faster than the fastest alternative, only 74% of the touchscreen and 64% of a back-of-device can be reached by each hand. We show that among the indirect pointing techniques, the miniaturized interaction area is significantly faster and received the best subjective ratings. We conclude that a miniaturized interaction area is a viable alternative to direct touch especially on the backside of tablet devices.

Author Keywords
Tablet; pointing; touch; direct; indirect; grasp.

ACM Classification Keywords
H.5.2. User Interfaces: Ergonomics.

INTRODUCTION
Over the last decade, touchscreens have arguably become the most common way to interact with computing devices. A large body of work has investigated how mobile devices with touchscreens are used in daily life and, in particular, developed novel interaction techniques for them. As direct manipulation is the dominant interaction paradigm for touch devices, investigating pointing techniques received major attention. Previous work has focused either on the interaction with mobile phones that can easily be held in

one hand (leaving the other hand free to interact) or on interaction with a much larger stationary touch display.

With the commercial success of tablet computers a third category of touch screen devices has become widely used. While tablets are small enough to be used "on the go" they are often too large to be held comfortably with one hand.

Indeed one of the most common ways to hold the device is using a two-handed grip (particularly if used in landscape format). Grasp-based pointing on tablets can cause ergonomic problems. Due to the large size of tablets, the thumbs and fingers are sometimes unable to reach the center of the display, while the device is being held [12, 21]. Therefore, direct touch, which is the most common pointing technique for touchscreens, may be not the most appropriated one for tablet devices.

The technology company Apple filed a patent on back-of-device interaction in 2006 [9]; and Wigdor et al. [20] demonstrated in 2007 how back-of-device interaction when using a tablet-sized device solves the *fat-finger* problem [16]. Since the release of the Motorola CHARM in 2010 and the Sony Playstation Vita in 2012, mobile devices with a touch-sensitive back are commercially available. It can be expected that touchpads will soon be embedded in the back of many devices. Users' performance when pointing through back-of-device interaction on tablet has not been study in-depth, and consequently, corresponding design guidelines are not available. Thus, we consider both, pointing on touchscreens as well as on touchpads built in the back of the device.

Pointing performance with grasping hands is constrained by parameters, such as reachability and joint flexion of the pointing digit. To understand touch-based interaction using tablet devices, we conduct an experiment that compares four pointing techniques on the front and on the backside of tablet devices while the device is being held in landscape format. We compare direct touch with selecting targets using a touchpad, an inverse cursor, and a miniature interaction area.

The contribution of this paper is threefold: (1) Describing the area that is easily accessible using direct touch while the tablet is held in landscape format based on empirical data. (2) Comparing four pointing techniques on both sides of tablet devices to show which technique is the best alternative to direct touch. (3) Proposing a combination of direct touch on the front and a miniature representation of

the tablet's interaction area on the back that makes the whole screen accessible.

In the following sections we first provide an overview about previous work on pointing techniques. Afterwards, a description of the conducted study and its results is given. Finally, we discuss our findings and conclude the paper with a summary and an outlook on future work.

RELATED WORK

This paper aims to increase our understanding of pointing on tablets. The aim is to overcome the current limitations caused by occlusion and limited target accessibility in the center of the device. Research with respect to pointing on tablet devices is rare. Thus we present here works on pointing with hand-held devices in general, which includes mobile phones. We identified four categories of pointing techniques: direct and relative pointing, remote direct pointing, and inverse direct pointing, which are presented in the following sections.

Direct pointing

Direct pointing is known to be very immediate and intuitive as touching the desired target corresponds directly to the way people interact in the physical world. In contrast to the physical world however, virtual targets are often very small. This can result in a phenomenon known as the *fat-finger-problem* [16], which means that the finger that touches the target is occluding it, thereby decreasing precision. *LucidTouch* [20] is a tablet-sized device that enables back-of-device interaction; and thus the fingers can select targets from the back side without occluding the content that is displayed on the front. *LucidTouch* uses a camera mounted at the rear of the device, which results in a rather bulky prototype. The concept of back-of-device interaction has been improved by Baudisch and Cheng: *NanoTouch* [1] uses a back-mounted touchpad instead of a camera and thus, enables back-of-device interactions even with very small devices.

If a user holds the device while pointing, the hand has to solve multiple tasks, meaning that direct pointing becomes more challenging due to the hands bio-mechanics. Thus, in addition to occlusion, a second problem of direct touch is the accessibility of targets that are further away or very close. The center of the tablet is hard to reach if the device is held in landscape format with both hands [12, 21]. For one-handed pointing on mobile phones it was found that the thumb performance varies with its posture. Poorest pointing performances results from excessive thumb flexion. When tapping on targets closest to the base of the thumb in the bottom right corner of the screen the performance is low. The highest performance is achieved when the thumb is in a rested posture, neither significantly flexed nor fully extended [17]. De Luca et al. [5] showed that back-of-device pointing without visual feedback has a too low accuracy to be considered a valuable input method for authentication. Finally, Buschek et al. developed a model to improve text entry on the back of the device but did not compare direct touch with other pointing techniques [2].

Inverse direct pointing

Roudeau *et al.* [14] introduced *MagStick*, which is a thumb interaction technique for target acquisition on mobile devices with small touch-screens. The technique addresses screen accessibility as well as target selection accuracy and occlusion. The user controls a cursor through an inverse drag motion and thus can select a target without occluding it with the thumb. While *MagStick* enables to access a larger area than the thumb can reach via direct touch, Roudeau *et al.* found that it is slower.

Kim *et al.* [10] proposed an expandable cursor called *Large Touch* that also moves inversely to the user's finger. In contrast to *MagStick*, the cursor moves a larger distance than the thumb that slides across the touchscreen. Thereby, *Large Touch* enables to reach locations that are further away from the thumb. Also in contrast to Roudaut *et al.* [14], Kim *et al.* found no difference in target selection time between the inverse cursor technique (*Large Touch*) and the common direct touch technique in a conducted study [10].

Miniature interaction area

ThumbSpace [8] introduced one-handed thumb interaction for small targets that are spread out wide on mobile phones' screens. The problem addressed is similar to the problem of pointing on targets that are hard to reach due to the size of a tablet. The approach taken is to shrink the screen into a small screen that is defined by drawing it with the thumb. This ensures that the thumb can reach all targets. Thus, *ThumbSpace* improves accuracy for selecting targets that are out of thumb reach, but it is slower than target selections with direct touch. A similar concept was proposed by Kim et al. [10] who presented *Sliding-screen* to address the limited target accessibility on phone touchscreens. A drag from the edge of the screen towards its center dynamically shrinks the interaction area, meaning that a tap can easily reach targets on the smaller display that may have been too far away on the interaction area before it was shrunk. Like *ThumbSpace*, this technique was found to be slower than direct touch for one-handed target selections with mobile phones.

The *ARC-Pad* [11] links the touchscreen of a phone to a large display in a one-to-one mapping. It enables to use the phone's touchscreen to be used as both an absolute and a relative touchpad for large displays. *ARC-Pad* combined absolute and relative cursor positioning. Tapping on the *ARC-Pad* causes the cursor to jump to the corresponding location on the screen, providing rapid movement across large distances. For fine position control, users can use a relative cursor control technique.

Relative pointing

Relative pointing is often used for remote-selections, such as mouse and touchpads that are built in laptops. Forlines *et*

al. [6] compared direct touch versus mouse input for unimanual and bimanual tasks on tabletop displays. Analyses of quantitative performance and subjective preference indicate that users may be better off using a mouse for unimanual input and their fingers for bimanual input when working on a large, horizontal display. Cockburn *et al.* [4] compared performance in touch selections on a touchscreen that was horizontally placed on a table in front of the user. They found that direct touch is faster than relative pointing (tap is faster than drag) using the finger. The error rate is high for small targets and further increases using direct pointing methods for target acquisitions over longer distances.

Hasan et al. compared relative pointing with direct touch for back-of-device interaction [7]. They found that relative pointing is faster and more accurate on the back of the device.

A comparison of *ARC-Pad* [11], which was described above, with relative pointing showed that ARC-Pad is faster than relative pointing. Moreover, relative pointing was more accurate. Thus, the *ARC-Pad* was, just like direct touch usually is, namely faster but less accurate than relative pointing.

Summary
Previous work developed and compared pointing techniques for tabletop displays [4, 6], for mobile phones' touchscreens [8, 10, 11, 14], and for the backside of phones [7]. Tablets are, however, a third device type that has almost been entirely neglected. Their size/weight requires a certain grip that not only affects pointing performance but also makes parts of the screen inaccessible using direct touch. In the following sections we reduce this research gap through a controlled experiment. Four target pointing techniques, which represent the four categories discussed above, are compared. We consider front- as well as back-of-tablet interaction using both the dominant and the non-dominant hand. The aim is to provide a fundamental understanding of pointing on tablets with grasping hands.

POINTING TECHNIQUES
Previous work proposed the following four categories of touch-based pointing techniques: direct pointing, inverse direct pointing, relative pointing, and remote direct pointing. In our experiment, we evaluate four pointing techniques (see Figure 1); and each of them represents one of the categories. Direct pointing is represented through *direct touch* (1). The *inverse cursor* (2) stands for the direct inverse pointing techniques. The *touchPad* (3) allows relative pointing; and the *miniature area* (4) enables direct remote pointing using a miniaturized display that represented the entire interaction area of the tablet.

(1) Direct touch
Direct touch is the common pointing technique for touchscreen interactions. The digit is directly touching the
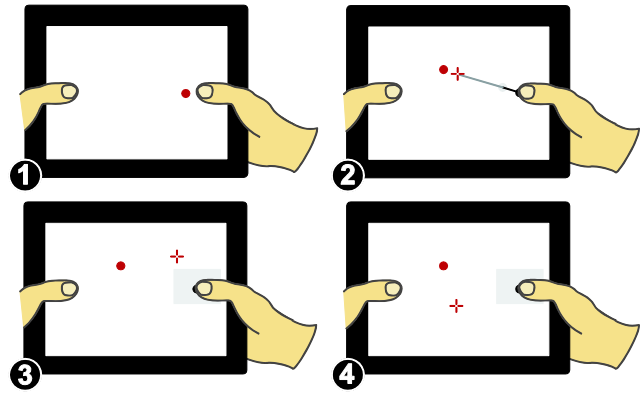
Figure 1. This paper investigates pointing techniques that are performed without losing the tablet grip: (1) direct touch (2) inverse cursor (3) touchPad (4) miniature area.

location where a target is displayed. If the direct touch is performed with the hands that hold a tablet in a symmetric bimanual grip, the thumb can execute direct touch on the front of the device and a finger does it on the back side. Direct touch is known to cause occlusion problems with touchscreens. This problem is addressed through back-of-device pointing proposed by Wigdor *et al.* [20]. Moreover, direct touch can make it difficult to access the center of tablets that are held with both hands [12, 21].

(2) Inverse cursor
The inverse cursor technique refers to *MagStick* [14] and *Large Touch* [10], which were developed for one-handed phone interactions. Similar to both approaches, the *inverse cursor* is controlled by setting an initial anchor point through a touch; and a drag gesture from that initial touch point pulls a cursor in the opposite direction. While the distance the cursor is moved using *MagStick* is similar to the length of the drag gesture; *Large Touch* translates the drag gesture to a larger cursor movement to overcome accessibility problems in one-handed phone interaction. The amount of movement of the *inverse cursor* is adaptive to allow for the entire interaction area to be always accessible when interacting with the hand that grasps the device. The cursor motion depends on the position of the start of the drag gesture. As the cursor movement is defined by an inverse digit movement, dragging the digit to the very outer touchscreen boarder will move the cursor to the touchscreen's very outer opposite edge. This ensures that every screen position is accessible.

(3) TouchPad
The *touchPad* technique is a virtual reference to physical touchpads that are commonly built in laptop computers. Researchers found that there are many ways to hold a tablet device [13, 19]; and Cheng *et al.* [3] proposed placing GUI components (such as virtual keyboards) where people grasp a tablet. Accordingly, our *touchPad* appears after an initial touch. A drag gesture on the *touchPad* moves a cursor relatively. For target acquisition using the *touchPad*, several drag gestures may be required to point on a target. Thus, a release cannot be used to confirm a target acquisition to

finish the selection. We have chosen a tap gesture as confirmation for target selection. *TouchPad* is the only relative pointing technique in our experiment. Relative pointing is known to be slower but more precise than absolute pointing techniques, such as direct touch [4, 7].

(4) Miniature area
The principle of our *miniature area* is to provide a miniature representation of the entire screen that is accessible using the grasping hand. The approach is inspired by *ThumbSpace* [8], the *Sliding-screen* [10], and the *ARC-Pad* [11]. While the *ARC-Pad* uses a mobile phone as a physical one-to-one representation of a large display; our *miniature area* is a virtual miniature one-to-one representation of the tablet's interaction area. Unlike *ThumbSpace* and *Sliding-screen*, which require defining the interaction area size with a drag gesture; *miniature area* does not require an extra interaction step to size the interaction area. The miniature display representation is pre-defined in size and is dynamically placed through a touch gesture. That is similar to the adaptive placement of the *touchPad* and ensures that the *miniature area* is always well accessible aiming for faster interaction. Unlike the *touchPad* that requires a tap gesture to confirm a target selection process, the *miniature area* in more immediate. Target acquisition is realized through touching the *miniature area* at the position that is mapped to the corresponding target position on the tablet's display. The position on the large screen that a touch on the *miniature area* is referring to is visualized through a cursor. Drag gestures allow for moving a cursor. A touch release confirms the target acquisition and ends the selection process.

EXPERIMENT
To provide foundational knowledge about grasp-based pointing on tablets, and to help designers to understand the human factors, we compared four pointing techniques in a controlled experiment. We evaluate the pointing techniques to determine their performance as well as perceived effort and usability. Performance provides insights in target accessibility and selection time. Effort and usability help understanding which pointing technique is preferred for what reason.

Design
Our study had a 4x2x2x3 within subject design with the independent variables *pointing technique* (direct touch, inverse cursor, touchPad, miniature area), *hand* (right, left), *device side* (front-, back-of-device), and *target size* (5, 7, 10mm). The targets were arranged in a 10x7 grid that was equally distributed over the touchscreen, excluding 2 positions of "start" buttons at the vertical center of both most left and right outer x-positions. One target per size appeared per target position in each condition. Thus, 204 targets had to be selected (or rejected if not accessible) per condition, resulting in 3264 targets per participant. The dependent variables were *target selection time, selection*

effectiveness, *perceived effort*, and *usability*. Touch events (for each *pointing technique*, *hand*, *device side*, *target size, and target position*) were recorded in logfiles. Perceived effort (for each *pointing technique* and each *device side*) was measured using the SMEQ scale, because it is known to be very sensitive with small sample sizes [15]. The usability of each pointing technique was recorded using the AttrakDiff questionnaire.

Participants
We recruited 14 right-handed participants (6 females) with different academic backgrounds, such as computer science, history of art, and media design. The participants had an average age of 29.6 years (SD=4.3).

Apparatus
A tablet sandwich was used to present the experimental task and to record logfiles. It consisted of two tablet devices glued with their rear sides together and connected via Bluetooth. This allowed for sensing touch events on the back of the apparatus and to update the GUI of the device at the front accordingly. The resolution of the screen was 1280x742 pixels (without bottom menu bar) with a size of 21.7cm x 13.6cm.

Procedure
For each pointing technique, we asked the participants to select targets that appeared after pressing a "start" button as fast and precise as possible. During the tasks, the participants were holding the apparatus in landscape format with two hands in a symmetric grip. Each pointing technique was used on both device sides using one hand after the other. If a target by any reason was perceived to be not easily selectable, the participants were asked to press a "cancel" button. We randomized the order of the 16 conditions. Each participant was asked to perform the tasks using each condition after a short training phase. After completing a condition, the participants filled the SMEQ and the AttrakDiff questionnaires. The experiment was split into two sessions. Each session lasted between 1.5 and 2 hours. When all conditions were completed, a demographic questionnaire was filled.

RESULTS
Our results contain effectiveness (measured as percentage of targets that could successfully be selected), efficiency (measured as task completion time), selection time per target position, number of attempts to select a target, perceived effort, and usability.

Effectiveness
Effectiveness represents the target accessibility for the different pointing techniques. If the participants were not able to select a target, for instance because they could not reach it, they could skip that task with a "cancel" button. The cancelled selection tasks per pointing technique are presented in Table 1.

pointing technique	direct touch	inverse cursor	touchPad	mini. area
	Front of the device			
right hand	50.95%	0.00%	0.00%	0.00%
left hand	51.65%	0.00%	0.00%	0.00%
	Back of the device			
right hand	52.71%	0.00%	0.00%	0.09%
left hand	54.34%	0.17%	0.04%	1.57%

Table 1. Cancelled selections tasks per pointing technique.

While the target accessibility for *inverse cursor, touchPad*, and *miniature area* was 100% on the front side and above 98% on the back of the device. Pointing with direct touch was cancelled in more than half of the cases. As it is expected, targets that are further away from the grasping hand are not reachable via direct touch. The target positions that were accessible in at least 90% of the attempts cover 37% of the front sided interaction area for each hand as well as 34% of the back of the tablet using the left hand and 30% using the right hand, as shown in Figure 2.
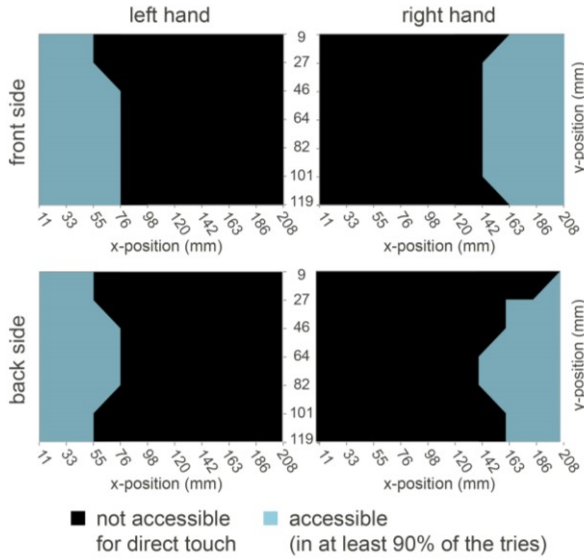
Figure 2. Locations of the targets that are accessible using direct touch.

Efficiency

Efficiency is measured as *target selection time* for the targets that were successfully selected. The selection tasks that were cancelled are not considered in this analysis. We removed 528 of the 45.696 tasks that were more than three standard deviations from the mean and took longer than 8.644s [18]. The average selection times (Mean) and the standard deviations (SD) are presented in Table 2.

A Kolmogorov-Smirnov-Test shows that our data is normally distributed. Mauchly's test indicated that the assumption of sphericity has been violated for the interaction effects *technique * hand* (p<.001).

	pointing technique			
	direct touch	inverse cursor	touchPad	mini. area
Mean	1.28s	2.93s	2.53s	1.97s
SD	0.74s	1.29s	0.92s	0.87s
	device side		hand	
	front	back	left	right
Mean	2.06s	2.57s	2.40s	2.22s
SD	1.06s	1.17s	1.15s	1.13s
	target size			
	5mm		7mm	10mm
Mean	2.51s		2.30s	2.13s
SD	1.24s		1.13s	1.03s

Table 2. Mean and SD for target selection time in seconds.

Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity for the respective tests. There was a significant main effect of *pointing technique* on the task completion time ($F_{3,36}$=124.24, p<.001). Bonferroni corrected pair-wise t-tests revealed significant differences between the four *pointing techniques* (p=.007 for *inverse cursor* vs. *touchPad* and p<.001 for all other comparisons, see Figure 3). Similarly, *hand* ($F_{1,12}$=20.77, p=.001), *device side* ($F_{1,12}$=60.64, p<.001, Figure 4), and *target size* ($F_{2,24}$=167.80, p<.001) had a significant effect on the task completion time. Bonferroni corrected pair-wise t-tests revealed significant differences between the three *target sizes* (p<.001, see Figure 5). We found interaction effects for *technique * device side* ($F_{3,36}$=10.33, p<.001), *hand * device side* ($F_{1,12}$=6.88, p=.022, Figure 6), and *technique * target size* ($F_{6,72}$=21.22, p<.001). In contrast, there were neither significant interaction effects for *technique * hand* ($F_{1.27,15.19}$=0.76, p=.43), *hand * target size* ($F_{2,24}$=0.15, I=.87), nor for *device side * target size* ($F_{2,24}$=2.98, p=.07).
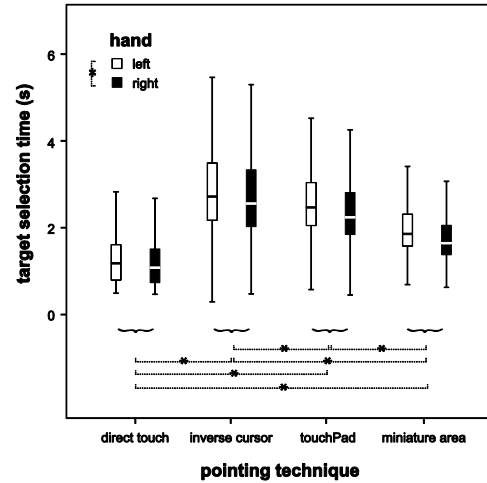
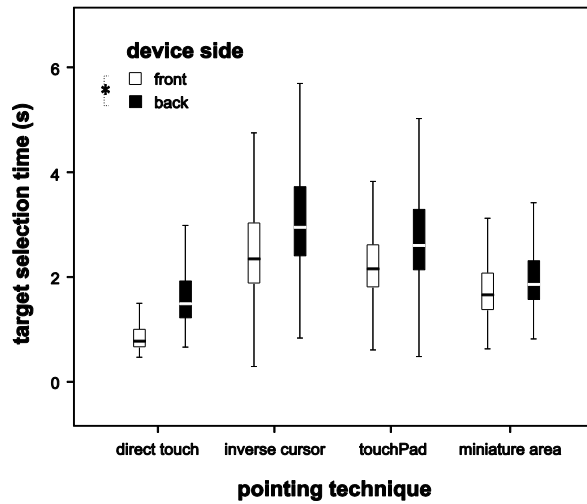**Figure 3. Selection times over pointing technique per hand and sign. differences (*).**

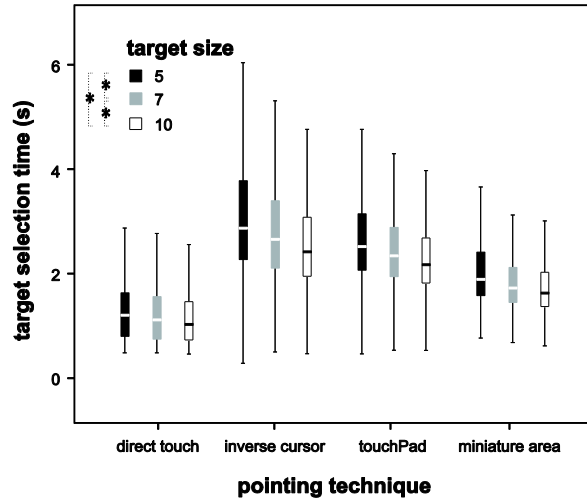**Figure 4. Selection times over pointing techniques per device side.**

Figure 5. Selection times over pointing techniques per target size.
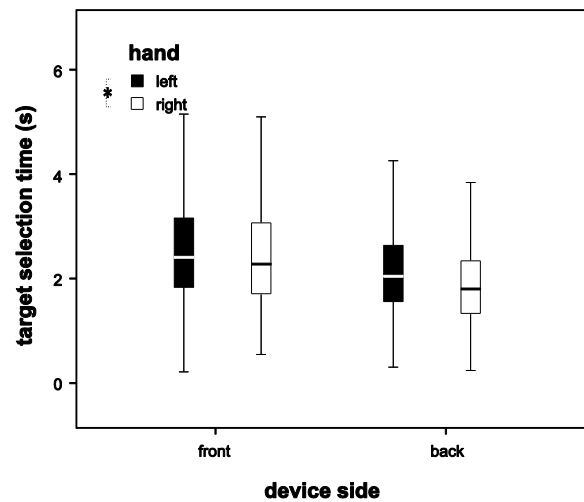

Figure 6. Selection times over device side per hand.

Selection time per target position

Selection time for each *target position* was calculated if the target was at least successfully selected in at least 90% of the attempts. Otherwise the target position was identified to be not accessible. The median time needed to select a target at a certain position is presented in Figure 7. *Direct touch* just allows for accessing targets that are located close to the hand that is selecting it. The other three techniques allow accessing the entire interaction area on both, the front and the back of the device. As shown in Figure 3; the *inverse cursor* has the lowest performance. Selection time increases the further the target is from the selecting hand for the *inverse cursor* and the *touchPad* technique. The *miniature area* results in an almost constant time across the screen and also in the highest selection performance over the entire interaction area on both device sides.
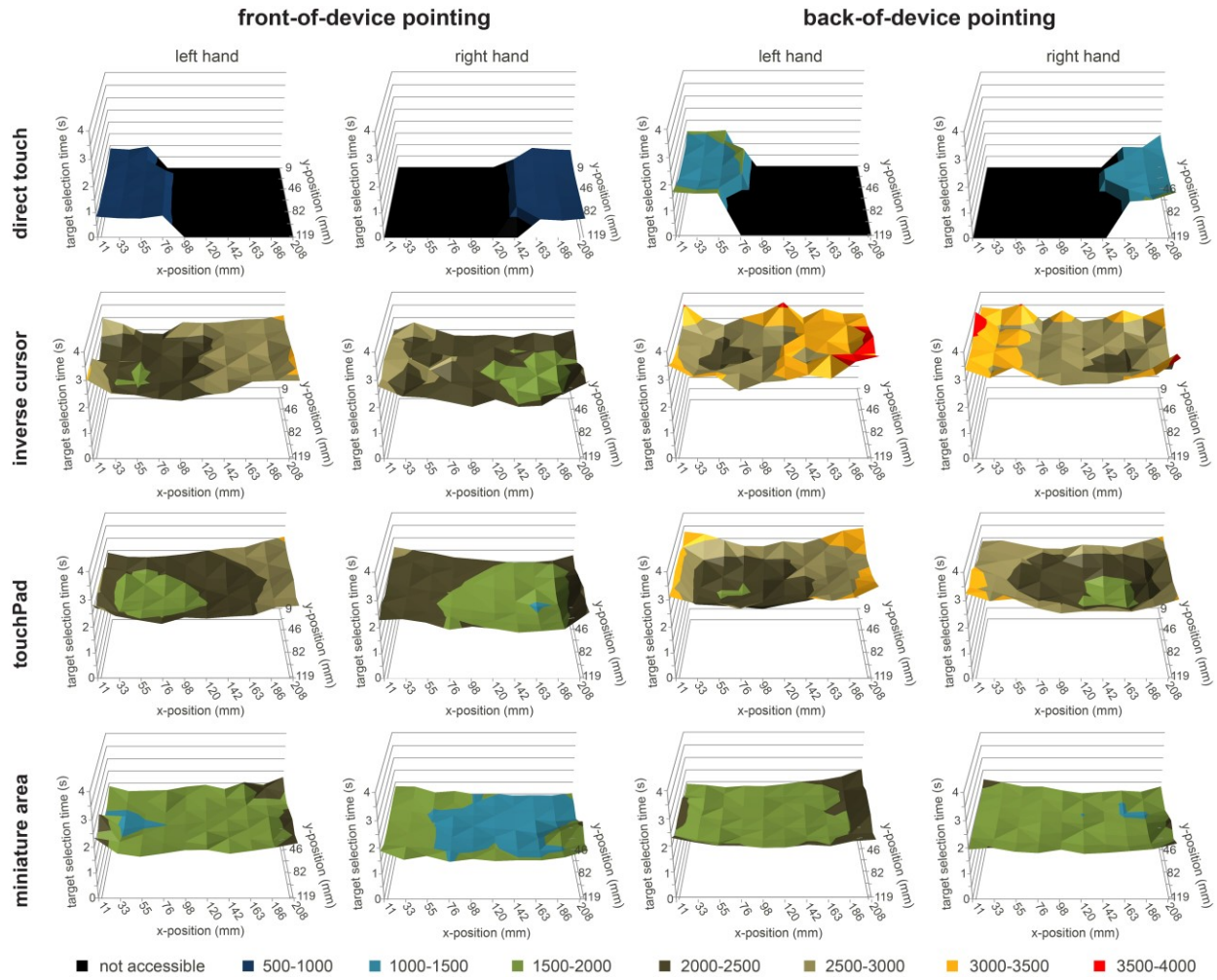
Number of attempts per target selection

We counted how many attempts participants needed to successfully select a target. The numbers of attempts are given by the number of touch downs/releases. Cancelled attempts were ignored for this calculation. We removed all tasks that were more than three standard deviations from the mean and took more than 10.4 attempts [18]. The average number of attempts (Mean) and the standard deviations (SD) for each *pointing technique, device side, hand,* and *target size* are presented in Table 3.

Again, a Kolmogorov-Smirnov-Test shows that our data is normally distributed, and Mauchly's test indicated that the assumption of sphericity has been violated for the main effect technique ($p<.001$) as well as for the interaction effects *technique * hand* ($p<.001$), and *technique * device side* ($p=.001$).Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity for the respective tests.

	Pointing technique			
	direct touch	inverse cursor	touchPad	mini. area
Mean	1.2	1.2	3.1	1.1
SD	0.6	0.6	1.1	0.4
	device side		hand	
	front	back	left	right
Mean	1.7	1.7	1.7	1.7
SD	1.2	1.2	1.2	1.2
	target size			
	5mm	7mm	10mm	
Mean	1.8	1.7	1.7	
SD	1.2	1.2	1.1	

Table 3. Mean and SD for number of attempts to select a target.

front-of-device pointing   back-of-device pointing

left hand   right hand   left hand   right hand

■ not accessible ■ 500-1000 ■ 1000-1500 ■ 1500-2000 ■ 2000-2500 ■ 2500-3000 ■ 3000-3500 ■ 3500-4000

Figure 7. Target selection time (median) for each target position at the front and the back of a tablet (counted in mm from the top left). If the target could not be selected in 90% of the attempts in a certain position, this position is labelled as not accessible.

There was a significant main effect of the *pointing technique* on the number of attempts participants needed to select a target ($F_{1.07,12.87}$=175.89, *p*<.001. Bonferroni corrected pair-wise t-tests revealed significant differences between *inverse cursor* and *touchPad* (*p*<.001), *direct touch* and *touchPad* (*p*<.001), *direct touch* and *miniature area* (*p*=.002), as well as *touchPad* and *miniature area* (*p*<.001), see Figure 8. There were no significant main effects for *hand* ($F_{1,12}$=0.001, *p*=.97) or *device side* ($F_{1,12}$=0.03, *p*=.87). *Target size* ($F_{2,24}$=33.17, *p*<.001) had a significant effect on the number of attempts. Bonferroni corrected pair-wise t-tests revealed significant differences between all *target sizes* (*p*=.047 for 5mm vs. 7mm, *p*<.001 for 5mm vs. 10mm, and *p*=.001 for 7mm vs. 10mm). We found significant interaction effects *for technique * target size* ($F_{6,72}$=11.14, *p*<.001) and *device side * target size* ($F_{2,24}$=8.93, *p*<.001). There were neither significant interaction effects for *technique * hand* ($F_{1.53,18.35}$=0.52, *p*=.07), *technique * device side* ($F_{1.91,22.89}$=2.73, *p*=.09, Figure 9), *hand * device side* ($F_{1,12}$=0.13, *p*=0.91), nor for *hand * target size* ($F_{2,24}$=0.26, *p*=.97).
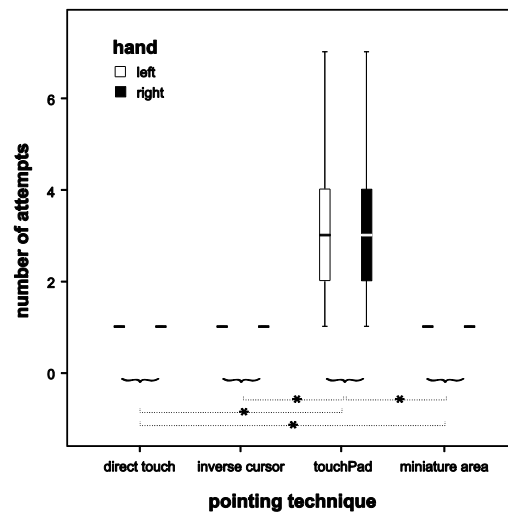
Figure 8. Number of attempts over pointing technique per hand and sign. differences (*).
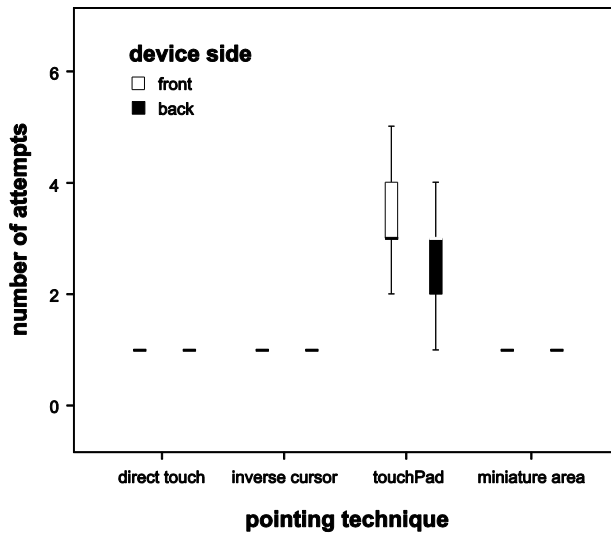
Figure 9. Number of attempts over pointing techniques per device side.

Perceived effort

The perceived effort was measured using the SMEG on a scale from 0 (no effort) to 220 (high effort). The average perceived effort (Mean) and the standard deviations (SD) as well as the according effort description are presented in Table 4.

Pointing techniques	direct touch	inverse cursor	touchPad	miniature area
Mean	81.3	104.8	54.9	49.2
SD	14.0	14.0	14.0	14.0
Description	fairly hard	pretty hard	a bit hard	a bit hard
Device side	front		back	
Mean	65.3		79.8	
SD	10.8		10.8	
Description	fairly hard		fairly hard	

Table 4. Perceived effort with Mean, SD, and description.

A repeated measure ANOVA yielded a significant different perceived effort for *pointing technique* ($F_{3,80}$=7.2, *p*<.001). For *device side* it was shown that interacting on the front was perceived significantly easier ($F_{1,92}$=7.9, *p*=.006). Moreover, we found an interaction effect for *pointing technique * device side* ($F_{3,81}$=3.1, *p*=.030).

While Bonferroni-corrected pairwise comparisons (see Figure 10) showed that the *inverse cursor* technique was perceived to be significantly harder than the *touchPad* (*p*=.021) as well as than the *miniature area* (*p*<.001), no significant difference was found between *direct touch* and any other technique (*direct touch* vs. *inverse cursor*: *p*=1.000, *direct touch* vs. *touchPad*: *p*=.221, and *direct touch* vs. *miniature area*: *p*=.336). Furthermore, we found no significant difference between the *touchPad* and the *miniature area* (*p*=1.000).
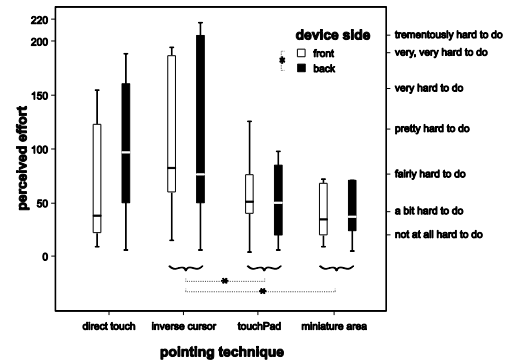

Figure 10. Perceived effort over pointing techn. per device side.

Usability

The four sub-scales of the AttrakDiff questionnaire, which describe usability, are pragmatic qualities, the hedonic quality of identification, the hedonic quality of stimulation, and global attractiveness. All four scales have as minimum 1 and as maximum 7, while high values refer to high qualities. The average usability qualities (Mean) and the standard deviations (SD) are presented in Table 5.

Pointing techniques	direct touch	inverse cursor	touchPad	miniature area
Pragmatic quality				
Mean	4.8	3.9	5.2	5.2
SD	0.2	0.4	0.2	0.3
Hedonic quality: Identification				
Mean	4.1	4.2	4.4	4.7
SD	0.2	0.2	0.2	0.2
Hedonic quality: Stimulation				
Mean	4.4	4.2	4.4	4.4
SD	0.3	0.3	0.3	0.3
Attractiveness				
Mean	4.6	3.8	4.9	5.2
SD	0.3	0.3	0.2	0.3
Device side	front		back	
Pragmatic quality				
Mean	5.0		4.6	
SD	0.2		0.3	
Hedonic quality: Identification				
Mean	4.3		4.4	
SD	0.2		0.2	
Hedonic quality: Stimulation				
Mean	4.1		4.5	
SD	0.3		0.2	
Attractiveness				
Mean	4.9		4.4	
SD	0.2		0.3	

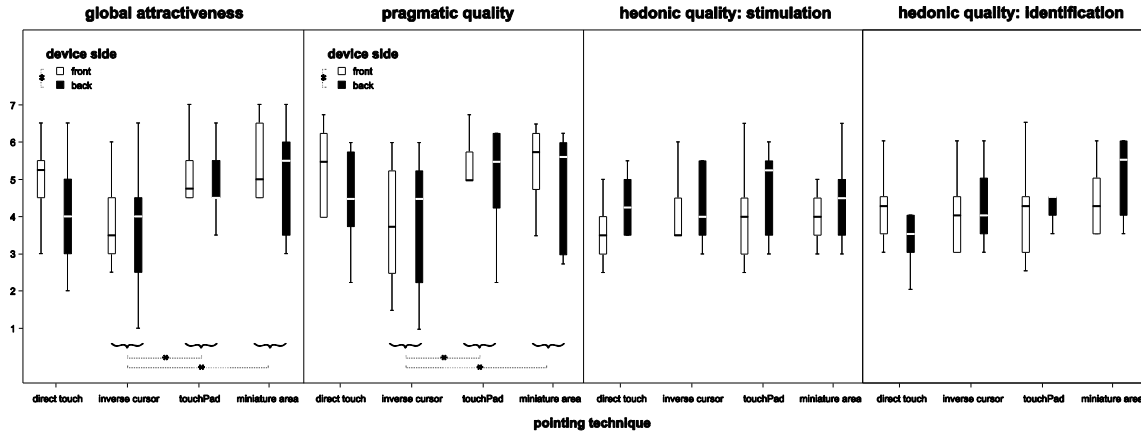**Table 5. Mean values and SD for the AttrakDiff sub-scales.**

Figure 11: Usability scales: global attractiveness, pragmatic quality, hedonic quality stimulation, hedonic quality identification to rate the four pointing techniques from 1=low rating to 7=high rating.

A MANOVA yielded significantly different ratings per *pointing technique* for the global attractiveness and the pragmatic qualities (global attractiveness: $F_{3,114}$=9.2, p<.001, pragmatic quality: $F_{3,114}$=10.2, p<.001). Both hedonic qualities, identification and stimulation were not rated differently (identification: $F_{3,114}$=2.5, p=.071, stimulation: $F_{3,144}$=1.8, p=.155). Moreover, the attractiveness and the pragmatic qualities were rated significantly different for both, pointing on the front and the back of the device (global attractiveness: $F_{1,10}$=6.7, p=.023, pragmatic quality: $F_{1,10}$=8.9, p=.011). Again, the hedonic qualities were not rated differently for both device sides (identification: $F_{3,114}$=1.4, p=.517, stimulation: $F_{3,144}$=4.5, p=.054). No interaction effect was found between the *pointing techniques* and *device side* (global attractiveness: $F_{3,114}$=1.3, p=.291, pragmatic quality: $F_{3,114}$=1.4, p=.268, stimulation: $F_{3,144}$=2.2, p=.103, identification: $F_{3,114}$=2.0, p=.128).

For attractiveness, Bonferroni-corrected pairwise comparisons (see Figure 11) showed that the *inverse cursor* technique received significantly lower ratings than the *miniature area* (p=.003) and the *touchPad* (p=.006). According pragmatic qualities, Bonferroni corrected post-hoc tests showed again that the *inverse cursor* was rated worse than the *miniature area* (p<.001) as well as than the *touchPad* (p=.002).

Comments
During the experiment, participants gave additional comments about their experience with the different pointing techniques. Four participants appreciated that targets were not occluded when interacting on the back of the device. Targets are always occluded when pointing via *direct touch* on the front side but also through the other three techniques if the targets were located on bottom positions where the thumb is rested while holding the device. One participant mentioned that a tap was sometimes misinterpreted as a drag using the *touchPad*.

DISCUSSION
Analyzing the collected data, we found that only 37% of the front and 32% of the back of tablets is accessible using *direct touch* with one hand. Even with two hands, only 74% of the front and 64% of the back. While *direct touch* is the fastest pointing technique, we found that it is only usable for areas at the screen's border. Among the other pointing technique, the *miniature area* is 28.4% faster than the *touchPad* and 48.7% faster than the *inverse cursor*. In contrast to the other techniques, the target selection time varies little across the screen using the *miniature area*. Looking at the subjective measures of all four techniques, using the *miniature area* resulted in the lowest perceived effort and the highest score on all sub-scales of the AttrakDiff questionnaire even in comparison with *direct touch*.

Our results are in line with Odell et al. [12] as well as with Wolf et al. [21] who found that the center areas of tablet touchscreens and for back-of-device interaction are not accessible with *direct touch*. Moreover, we have shown that *direct touch* on the back of the device results in the same problem. While Kim et al. [10] found that their inverse cursor *Large Touch* is as fast as *direct touch* when pointing on mobile phones, our results are contradictory to these but in line with those of Roudaut *et al.* [14] who found that *direct touch* is faster than the *inverse cursor* technique using mobile phones. The miniature areas *ThumbSpace* [8] and *Sliding-screen* [10] implemented for mobile phones were slower than direct touch, which is in line with our findings using the *miniature area* on the front as well as on the back of tablet devices. Moreover, our *miniature area* is (similar to the *ARC-Pad*) faster than relative pointing, which is represented through the *touchPad* technique in our study. While Hasan *et al.* [7] found that relative pointing performs better than direct touch for one-handed back-of-phone interaction in terms of target selection time as well as accuracy, we found like Cockburn *et al.* [4] that *direct touch* is faster than relative pointing, using our *touchPad* on

both the front as well as the back of a tablet. In contrast to the findings of Cockburn *et al.* [4] our findings do not show an increase in the number of attempts for small targets.

In light of our results, designers of applications for tablet devices currently have two options when arranging interactive controls in a landscape UI. They can either use the whole screen while forcing the user to choose another grip or they can arrange all interactive controls on the 37% on the front and 32% on the back of tablets near each vertical screen's border. An indirect pointing technique such as the *miniature area* could offer a third option and make the whole screen easily accessible. As all indirect techniques we considered are slower than *direct touch*, we propose a combination of a *miniature area* with *direct touch*. As the *miniature area* performs equally well on the front as on the back a viable option is to combine direct touch on the front with the *miniature area* on the back. This approach has the advantage that a dedicated pointing technique is used on each device side which helps to avoid confusion of the user. Furthermore, the whole screen becomes easily accessible and thus usable for designers.

CONCLUSION AND FUTURE WORK
In this paper, we investigated pointing on tablet devices. We compared four pointing techniques while participants held the device with both hands in landscape format. For this setup, we showed that only 74% on the front and 64% on the back of tablets can be easily reached using *direct touch*. Among the three alternatives, the *miniature area*, a virtual miniature one-to-one representation of the tablet's interaction area, is the fastest option. As this *miniature area* received the best subjective ratings, even compared to direct touch, we propose to combine direct touch on the front of tablet devices with the *miniature area* on the back. This combination would make the whole screen accessible and avoid mixing interaction techniques.

The conducted study focuses on one of the most common ways to hold tablet devices and as participants were comfortably seated the setup mimics the typical usage context. Future work should nonetheless investigate if the results hold true for other postures and situations. Furthermore, the screen size of the used device was 10.1"; and future work should investigate additional screen sizes. The fraction of the screen that is easily accessible will become even smaller for larger screens. It would be interesting to investigate if our results can be transferred to much larger tabletops where interaction is not restricted by hand size but by arm length.

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