Chapter 2
Related Work

Research on interaction with tablets is rare compared to work that is done on interaction with mobile phones. Two major challenges in grasp-based tablet interaction are to consider the influence of the form factor and of the grasp on ergonomics in interaction design. Ergonomics in interactions design affects the gesture design, the accessibility of interaction areas, and pointing at targets that are hardly accessible through the common direct touch. As such, relevant works on *ergonomics in gesture design*, the definitions of *interaction areas*, and *pointing techniques* for tablets are presented in the following sections.

2.1 Ergonomics in Gesture Interaction with Grasping Hand

Designing gestures that are easy for the computer to recognize, as well as easy for the user to remember and perform, is difficult. While gesture interfaces often may be constrained through the possibilities of sensor technology (Bailly et al. 2012; Gustafson et al. 2010); a large body of work applied a user-centered design approach. A common approach in user-centered gesture design is to *enable the user to design gestures* for specific predefined commands (Bhandari and Lim 2008; Kray et al. 2010; Wobbrock et al. 2009). Whilst other researchers have investigated *ergonomics in gesture interaction* to better understand why certain gestures are easier to perform than others (Hoggan et al. 2013; Wobbrock et al. 2008), with a goal to develop design recommendations for easier performable gestures.

2.1.1 Gesture Design

Besides technology driven gesture design (Han 2007; Bailly et al. 2013), a common method in gesture design is to ask participants to design gestures or to select ones from given examples that they find being an appropriate fit to predefined commands.

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Bhandari and Lim (2008) asked participants to design gestures to common camera control and picture view tasks. They identified a collection of touch-based gestures, such as tap, drag, pressure and drawn circles and squares, as well as gestures that require moving the mobile phone, such as shaking the phone to start a slide show. Wobbrock et al. (2009) investigated user-defined gestures for tabletops by asking participants to propose gestures for a given task without providing any guidance on what those gestures should be. Kühnel et al. (2011) adapt the design methodology proposed by Wobbrock et al. (2009) for the development of a gesture-based user interface to a smart-home system. The authors show the adaptability of the approach described by Wobbrock et al. (2009) for three-dimensional gestures in the smart-home domain. Kray et al. (2010) conducted a study to identify user-defined gestures for connecting mobile phones, public displays, and tabletops, e.g. to synchronize devices or to download content from one to another. Wolf et al. (2011a) explored the development of mobile device gestures (touch gestures on a phone as well as device movements) to control a spatial auditory interface by asking users to propose and design gestures for given tasks. Results showed a set of 20 touch and motion gestures to control the auditory interface.

The sets of the user-defined gestures contain mainly commonly known touch gestures, such as tap and drag, some more symbolic gestures drawn on the touchscreen, such as a cross, as well as device movements, such as pointing with the device at objects or directions or tilting and rotating it. All gestures are quite simple and easy to perform. They are known from HCI, have analogies to inter-human communication, and are mostly deictic or symbolic gestures (Rime and Schiaratura 1991), such as pointing at content to select it or crossing out something to disconnect or delete it. Fewer gesture are iconic sighs, for instance, shaking a device to activate it refers to shaking somebody to wake him/her up.

The main focus of these works is rather an analysis about the gesture-functionality mapping than as if participants would have designed gestures that are ergonomic. All presented user-defined gesture sets mainly contain gestures that are commonly known from gesture-based human-computer interaction or from inter-human interaction. While the user-design gestures may be subconsciously chosen because they are easy to remember and easy to perform, the design decisions participants make during that approach is mostly hidden, and as such not evaluated. One may suggest that some participants chose gestures that they already know, because the majority of the chosen touch gestures are gestures that are listed in the Apple Design Guidelines (Apple Inc. 2013), as well as in those from Android (Android Developers Gesture Patterns 2013) and in the Windows UX Guidelines (Microsoft 2012).

2.1.2 Ergonomics in Gesture Execution

However, much research has been done in designing gesture interaction; work on ergonomics in that area has just recently begun to address diverse ergonomic aspects in gesture execution, such as muscular load, fatigue, performance, gesture execution time and gesture execution paths.

Tomatis et al. (2012) used electromyography (EMG) to investigate gesture ergonomics, in particular muscular load during tapping tasks. Lozano et al. (2011) obtained finger movement (angular excursions of the finger joints) information with a CyberGlove® 22 sensor system; and the data of finger movements followed the same trend as EMG and thus showed that more finger movements cause higher muscular load. They showed through considering EMG in addition to a data glove, that hand configuration affects ergonomics of multi-touch gestures.

Assuming ergonomic gestures lead to high performance, in particular short task solution times and few errors, Wobbrock et al. (2008) compared the performance of the index finger and the thumb for front- and back-of-phone interactions, and showed that with shorter interaction times, when using the thumb on the front screen, interaction has greater ergonomic values than e.g. interacting with the thumb on the rear of the phone.

Hoggan et al. (2013) investigated ergonomics for touch gestures that are executed with a "free" hand on a tablet. They found that rotation gestures with two touches are differently executed depending on their starting points. Parameters of a rotation gesture were systematically controlled in the experiment, such as rotation angle, rotation direction, distance between fingers, and position. Time and touch events were recorded; and the variations for each factor were controlled by giving instructions to the participants. The study shows that within-gesture parameters, such as the angle of the fingers (given as start and final position of the two touch points) influence the gesture execution time.

Wolf et al. (2012a) explored touch gesture parameters in gestures for back-of-device interaction with mobile phones. Gestures are often guided through visual feedback as it is usually provided through slider shapes and button positions. Wolf et al. asked participants to perform one-hand gestures on the back of mobile phones without providing guidance. They found that gesture trajectories differ depending on the location they are performed at, between the fingers that execute the gesture, and in regard to its direction. For example, a prototypical drag path performed with the index finger is significantly longer than one performed with the ring finger. Thus, a drag gesture for touchscreen gestures may require different thresholds for gesture classification than if the gesture is performed on a touchpad on the back of the device. Furthermore, grasp-based gestures are not performed with a free hand in contrast to typical gestures on mobile phones.

However, the act of grasping (i.e., prehension) has been widely studied (Jones and Lederman 2006; MacKenzie and Iberall 1994) to understand the hand's biomechanics and the way people grasp objects, gesture ergonomics of grasping hands is rarely investigated, and no work has been done in exploring gesture ergonomics while grasping tablets.

2.1.3 Summary

The grasp seriously constrains touch gesture execution on tablets because it limits the flexibility of the hand. Thus, ergonomic gestures are needed for that interaction scenario. The approach of user-defined gesture design shows what gestures are familiar and preferred by users than result in ergonomic gesture design. However, ergonomics are considered when existing gestures are evaluated in regards the specification of particular parameters; ergonomics has not been considered during the gesture design process so far.

Thus, considering ergonomics in the gesture design process for grasp-based interaction is a true research gap, which this dissertation will address in Chap. 3. In Chap. 4 it is presented how parameters of the ergonomic gestures are more specifically defined.

2.2 Interaction Areas

Reachable interaction areas for tablet devices are recommended in the user experience guidelines from Microsoft (2012). However, interaction areas for the most common ways to hold the device are proposed; for the two-handed tablet grip in landscape format (which this dissertation focuses on) it is recommended to readjust the grip for accessing the center of the device. Thus, no interaction areas for the symmetric bimanual grip (Fig. 1.1) are defined by Microsoft.

Odell and Chandrasekaran (2012) investigated the interaction areas of the symmetric two-handed grip and found that the center of the tablet is not reachable. Participants were asked to draw with finger paint on paper attached to a tablet's touchscreen sized 286 × 183 × 14 mm while holding it with two hands. No paint was drawn in the center of the tablet. Unfortunately Odell and Chandrasekaran provided no precise dimensions for the accessible touch areas. Thus, the existing guidelines for interaction areas are rather roughly defined.

However, research on tablet interaction areas is still limited to the touchscreens built in the front side of the device; using the back side of tablets for interaction is a promising direction to extend tablets' interaction areas. The technology company Apple filed a patent on back-of-device interaction in 2006 (Kerr et al. 2010); and Wigdor et al. (2007) demonstrated in 2007 how back-of-device interaction when using a tablet-sized device solves the *fat-finger problem* (Siek et al. 2005). Since the release of the Motorola CHARM in 2010 and the Sony 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. Previous research did not address back-of-device interaction areas on tablet devices and consequently, corresponding design guidelines are not available. Thus, the accessibility of interaction areas for grasp-based interaction with two-handed held tablets, including the front and the back of the device, are the second major research topic of this dissertation. This topic is addressed in Chap. 5.

2.3 Pointing Techniques

The limited accessibility of interaction areas on tablets indicates the problem of accessing items that are not located within these areas. That motivates research toward understanding of pointing on tablets. The aim is to overcome the current limitations caused by the limited target accessibility in the center of both sides of tablets. Research on pointing on tablet devices has to the author's best knowledge not been done and thus is a research gap. Thus, general works on pointing with hand-held devices is presented here, which includes mobile phones. Four categories of pointing techniques have been identified while researching relevant works on this topic: direct touch pointing, inverse direct pointing, remote direct pointing using a miniature interaction area, and relative pointing. These four categories are used as structure of the follow sections.

2.3.1 Direct Touch Pointing

Direct pointing is known to be very immediate and intuitive as touching the desired target refers to the way people interact in the physical world. In contrast to the physical world however, virtual targets are often very small. That causes the *fat-finger-problem* (Siek et al. 2005), which means that the finger that touches the target is occluding it, which decreases precision. *LucidTouch* (Wigdor et al. 2007) 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. Thus, the concept of back-of-device interaction has been improved by Baudisch and Cheng: *NanoTouch* (Baudisch and Cheng 2009) 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 and direct pointing becomes more challenging due to the hand's 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 (Odell and Chandrasekaran 2012). Moreover, for one-handed pointing on mobile phones it was found that the thumb performance varies with its posture. Poorest pointing performances result 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 (Trudeau et al. 2012).

2.3.2 Inverse Direct Pointing

Roudaut et al. (2008) 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 access to a larger area than the thumb can reach via direct touch, Roudeau et al. found that it is slower.

Kim et al. (2012) 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., 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.

2.3.3 Miniature Interaction Area

Karlson and Bederson (2007) introduced *ThumbSpace* that allows for one-handed thumb interaction for small targets that are spread out wide on mobile phones' screens, which is similar to the problem of pointing on targets that are, due to the size of a tablet, hard to reach. This problem was solved by shrinking the screen into a small screen that is defined by drawing it with the thumb. That 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. (2012) who presented *Sliding-screen* to address the limited target accessibility on phones' touchscreens. A drag from the edge of the screen towards the screen's center dynamically shrinks the interaction area. Then a tap can easily reach targets on the smaller display that may have been too far away on the interaction area before shrinking it. This technique was, like *ThumbSpace*, found to be slower than direct touch for one-handed target selections with mobile phones.

The *ARC-Pad* (McCallum and Irani 2009) links the touchscreen of a phone to a large display in a one-to-one mapping. It enables to use the phone's touchscreen as absolute and as 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.

2.3.4 Relative Pointing

Relative pointing is often used for remote-selections, such as mouse and touchpads that are built in laptops. Forlines et al. (2007) compared direct touch versus mouse input for unimanual and bimanual tasks on tabletop displays. Analyzes 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. (2012) 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. (2012) compared relative pointing with direct touch for back-of-device interaction. They found that relative pointing is faster and more accurate on the back of the device.

A comparison of *ARC-Pad* (McCallum and Irani 2009) 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, faster but less accurate than relative pointing.

2.3.5 Summary

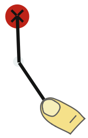
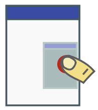
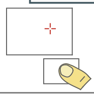
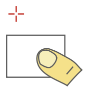
Previous work developed and compared pointing techniques for tabletop displays (Forlines et al. 2007; Cockburn et al. 2012), for mobile phone touchscreens (Karlson and Bederson 2007; Kim et al. 2012; Roudeau et al. 2008; McCallum and Irani 2009), and for the backside of phones (Hasan et al. 2012). Tablets are, however, a third device type that, except from this dissertation, has almost been neglected. Their size and weight requires a certain grip that not only affects pointing performance but also makes parts of the screen inaccessible using direct touch.

In pointing research with mobile phones, direct touch was in comparative studies always found to be the fastest technique; while it suffers from accuracy and occlusion as well as from constrained accessibility for targets that are further away. Other techniques are slower but allow for accessing target over larger distance.

In summary, no research was done in investigating direct touch pointing on tablets, neither on the touchscreen nor on the back of the device. Furthermore, the problem of reaching targets in the center of the device through investigating techniques beyond direct touch is a research gap. Identifying a pointing technique for targets out of reach is an important research topic for bimanual tablet interaction as the established direct touch technique fails.

In Chaps. 6 and 7 these research gaps are reduced through two controlled experiments, one on understanding biomechanics in pointing with direct touch and another in comparing four target pointing techniques, which represent the four categories discussed above. Both studies consider front- as well as back-of-tablet

Table 2.1 Comparison of the features of different pointing techniques (extension of Roudaut et al. 2008)

	Direct touch	Inverse cursor	Miniature area	Relative pointing (touchpad)
Example	Common touchscreens: 	*MagStick*: 	*ThumbSpace*:  *ARC-Pad*: 	Common mousepads: 
Target accessibility	Within the length of the digits	High	Everywhere	High
Occlusion	Everywhere	None	*ThumbSpace*: everywhere; *ARC-Pad*: none	None
Pointing accuracy	Coarse	Fine (if facilitated by magnetic cursor)	Less accurate than relative pointing	Fine
Target acquisition time	Fast	Slower than direct touch	Slower than direct touch (*ThumbSpace*; faster than relative pointing (*ARC-Pad*)	Slow

interaction. Chapter 6 provides a fundamental understanding of direct touch pointing on tablets with grasping hands. In Chap. 7 it is shown that indirect pointing techniques enable to reach targets that are not accessible through direct touch; and the usability of these techniques is discussed (Table 2.1).

2.4 Summary and Resulting Research Questions

This dissertation focuses on grasp-based interactions with tablets; and guidelines that support designing interactions with these devices are missing. Research gaps exist for instance in guidelines for touch gestures considering both, touchscreen gestures as well as back-of-device gestures. Furthermore, interaction areas have been investigated for tablet devices; but the information gained there are vague and again, the back of the device has not been addressed. Finally, research on pointing techniques for tablet devices is important, as the accessibility of the interaction areas are limited. As no previous work addressed this topic; this dissertation investigates the limits of direct touch for pointing at tablets as well as compares pointing techniques that are designed with the aim to reach targets that are not reachable with direct touch while grasping a tablet.

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