September 27, 2012
University of Duisburg-Essen

Page navigation in touch based interfaces

An empiric study of swipe gestures and buttons considering motoric factors, perception and affordances

Interactive Systems Group
Bachelor thesis

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Statement of authorship

This bachelor thesis is the result of my own work. Material from the published or unpublished work of others, which is referred to in the dissertation, is credited to the author in the text.

Duisburg, September 26, 2012

Abstract

This thesis focusses on page navigation in touch based interfaces (with emphasis on smartphones), comparing buttons and swipe gestures regarding their perceptual as well as their motoric aspects. Theories of affordances are explained and used as a theoretical foundation. With the help of an empiric field study by means of specially developed research applications on an Android handset which made use of the device's sensor package, data was gathered: Average execution times for swipe gestures and button presses were established. It was also found that these modes don't seem to differ regarding execution times on a motoric level. On a perceptual level, buttons were found to be understood faster, more consistent and to have smaller error rates than swipe gestures. Furthermore, the level of visibility needed to correctly understand buttons or swipes was examined and it seems as if even small cues are sufficient. Additionally, data about average swipe leghts, heights and similar parameters was gathered.

Zusammenfassung

Diese Bachelorarbeit behandelt Seitennavigation in touch-basierten Benutzeroberflächen (mit Fokus auf Smartphones). Verglichen werden hierfür Buttons und Wisch-Gesten (*Swipes*) hinsichtlich Wahrnehmungs- und motorischen Aspekten. Affordance-Theorien werden als theoretische Fundierung erklärt und herangezogen. Es wurde eine empirische Feldstudie unter Verwendung von selbstentwickelten Forschungs-Anwendungen an einem Android-Smartphone (unter Einbezug der Gerätesensoren) durchgeführt, mit deren Hilfe Daten gesammelt wurden. Gemessen wurden durchschnittliche Ausführungszeiten für das Aktivieren von Buttons sowie die Ausführung von Swipes, hierbei zeigte sich, dass diese sich motorisch nicht zu unterscheiden scheinen. Auf Wahrnehmungs-Ebene schienen Buttons allerdings hinsichtlich des Begreifens auf Nutzerseite sowie der Fehlerraten und der Konsistenz der Ausführungszeiten überlegen. Weiterhin wurde die Intensität der visuellen Anhaltspunkte für korrektes Erkennen des Navigationsmodus beim Nutzer untersucht, hierbei zeigte sich, dass schon kleine Anhaltspunkte ausreichend scheinen. Ergänzend wurden zusätzlich Durchschnittswerte über Swipes, z.B. hinsichtlich ihrer Höhe und Länge gemessen.

Keywords: Page navigation, swipe, button, execution time, touch based, affordance, perception, motorics, smartphone, touchscreen, interface

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1 Introduction and approach

Touch enabled devices, i.e. smartphones and tablets represent a huge market with an immense growth rate, as can be seen in various market statistics and projections, see e.g. Gartner (2012); IDC (2012); MobiThinking (2011). While of course it is difficult or even impossible to pinpoint this market's definite starting point, one might look towards the release of the first Apple iPhone in 2007 as the timeframe after which said market started to take off: It was the first device available and frequently bought which incorporated the features implied today if we talk about touch based devices: The focus on finger-friendly usage, apps, device sensors and a big touchscreen as the main mode of user interaction. Thus, it is safe to say that the market for touch based devices is a comparatively young one which is reflected on the scientific research on those devices – it too is emergent and growing, yet not nearly as well covered as research on older, more established areas, such as regarding home computers.

This thesis resides in one of the many growing subcategories of research on touch based devices, namely within the aspects encompassed by Human Computer Interaction (HCI) and as such, focusses on the usability of these devices. The primary topic is page navigation, since navigating between different views or pages is one of the most basic tasks on touch based devices. As means to execute these navigational changes, buttons and swipe gestures, both very widespread methods, are considered and examined. To this end, the concepts of *affordances* and their *perception* are used as the theoretical foundation for research questions and hypotheses. The instrument for conducting this research is a scientific Android application named VAP (**V**ariations in **A**ffordance **P**erception) which has been developed and used for a usability study in the context of the work on this thesis. This reflects the spirit within the theoretical constructs around affordances that user research should often be done *out there*, directly on the user itself and the (technological) artifact in question.

Preceding the execution of the VAP-study, there also has been a preliminary study, again with a specifically developed Android application which focussed on finding average times for the execution of swipe gestures and onscreen button pushing on a *motoric* level without the influence of perception.

1.1 Methodology (overview)

VAP gives users the tasks of navigating between different views of the application while the means to navigate, i.e. the navigational control mechanisms ((action-) buttons vs.

swipes) and the ease of perception for the respective control mechanism are systematically varied. Participant's completion times for the tasks are measured and the average motoric execution times found in the prelimiary study can then be subtracted from the completion times which yield the time differences that result from the variations in ease of perception. VAP and the preliminary study also incorporate all framing elements of a scientific study, i.e. they instruct the participant, retrieve demographic data, etc. The usability study with VAP has been conducted with the participation of 53 persons, the preliminary study had sample size of 17 persons.

1.2 Structure of this thesis

We will start by comprehensively introducing the concept of affordances, its theoretical framework, historic context and development, including a short overview of the directions in which current research seems to point. This introduction will be comparatively long and in relation maybe longer than usual for mainly practical theses which is due to the fact that affordances are an ambigous concept and the author felt it appropriate to try and revise some of this ambiguity before further utilizing aspects of the related theories.

We will then introduce the selected HCI elements, i.e. swipes and (action-) buttons where especially the swipe as the more ambiguous element will be explored in detail. The relations of these HCI elements with the concept of affordances will be explained. Following up will be a short working synopsis which will distill essential conclusions of the preceding chapters for the following study. This will conclude the theoretical part.

Subsequently, the empirical part of the thesis will start with an detailed walkthrough through the preliminary study, leading to VAP and its functions. We will then develop the scientific hypotheses and explain their foundations and the sample of the study as well as the statistical methods utilized will be described, followed by a report of the results.

Finally, the results will be discussed in relation to the hypotheses, limitations of the study will be considered and an outlook will be given. The thesis will be concluded by a short summary as well as a reflection on the utilization of a mobile application for scientific purposes.

2 State of the art

This chapter will first examine the development and current state of the concept of affordances. Subsequently, the chosen HCI-elements for this study and the reasoning behind their choosing will be explained and finally, a working definition (or rather: synopsis) suitable for the purpose of this study will be synthesized.

2.1 Affordance – a historical overview

Affordances (and the preceding concepts) have been devised, used and adopted in and across very different research areas – from psychology through computer science up to philosophy – over decades and are not as distinct as other scientific expressions, a fact that calls for a historic review.

2.1.1 Origins

The term *affordance* is often attributed to J.J.Gibson, which is correct insofar as that he coined the name (Gibson, 1977) and further defined it within his theory of an ecological approach to visual perception (Gibson, 1979). However, to comprehensively understand the approach, one has to go further back (we will revisit Gibson later on):

Uexküll and Kriszat (1934) were responsible for establishing the concept of *ecology* ("Umwelt") into the biological disciplines at the beginning of the 20th century. Of special interest here is the theory of *functional circles* ("Funktionskreise"): Every object in the world has certain properties like size, shape, color, etc. which are registered by organisms and trigger a subjective set of experiences: The perceptual cue. This cue in turn triggers an effector cue, i.e. a specific behaviour. The behaviour has an effect on the environment which leads to a different perception and the whole circle starts anew. Uexküll (1980) also introduces *colourings* ("Tönungen") of objects, which are individually percieved meanings of objects in the ecology of an organism[1].

Other early concepts preluding later affordance-centered theories can be found in Gestalt psychology. Noteworthy in this era is Kurt Lewin who, based on his military

[1]To illustrate his meaning, Uexküll famously uses the example of an old, gnarly oak: To a ranger, this tree will represent just a few cubic meters of wood while it might be a frightning view to a small child. To a fox living in the roots, the oak will be a safe haven and an ant won't even perceive the tree as a whole rather than the valleys and mountains of its bark. Thus, every perception, every *colouring* and every triggered behaviour will be different (Uexküll & Kriszat, 1934).

experience in World War 1, considers the perception of geographical topologies under different circumstances: In times of war, the perception shifts and the environment becomes *battle things* (“Gefechtsdinge”) which in turn reflects on behavioral aspects. A village might, for example, no longer be considered as a place to live and work but rather as a cluster of cover positions against enemy fire. Lewin calls this the *demand character* or *valence* (“Aufforderungscharakter”[2]) of objects (Lewin, 1917).

Another Gestalt psychologist working on demand characters was Kurt Koffka – he stated:

> To primitive man each thing says what it is and what he ought to do with it: A fruit says “Eat me”; water says “drink me”... (Koffka, 1935, p. 7)[3]

Like Lewin (and like Uexküll, albeit in a different research area), Koffka saw demand characters of objects as highly situative properties. An often used example to illustrate this is that of a postbox: A person who wants to mail a letter will be extremely attracted to the next postbox, however if he has posted the letter, postboxes will no longer have demand characters (until the person wants to mail another letter).

2.1.2 Gibson

As stated above, Gibson invented the term *affordance* (Gibson, 1977), however for him, affordance is not a stand-alone concept but rather just one key element within a much bigger construct: His theory of an ecological approach to visual perception. This fact is often overlooked or oversimplified when Gibson and his affordances are mentioned in HCI-related topics, lectures or discussions. From a more holistic perspective, one might however argue that the complete context does matter indeed in order to round out the understanding of Gibson’s concept and especially the later, meaning-wise evolutions of affordances.

Visual perception – direct or indirect?

> The baby ... feels it all as one great blooming, buzzing confusion.
>
> (James, 1890)

It might be heavily (over-)quoted, but James’ description still serves very well to describe the scientific way of thinking Gibson felt he had to challenge: The cognitive, (information-)processing-centered approach to visual perception. This movement started with Helmholtz (1855) who found the human eye to be technically insufficient for complete perception and thus concluded that higher-order cognitive functions, i.e. experiences, inferences, etc. have to play an important role in perception to supplement

[2]This term is actually sometimes used even today to describe/translate affordance in German.
[3]Later also quoted by Gibson (1979).

the raw visual data originating in the eye. This is called top-down processing (Gregory, 1970) and it represents an indirect model of visual perception: If we look at an object, it triggers a complex process of developing mental hypotheses, of, so to speak, guessing on a cognitive level based on past experiences in order to gather meaning from one's surroundings.

> This is a radical hypothesis, for it implies that the "values" and "meanings" of things in the environment can be directly perceived. (Gibson, 1979)

Gibson dismissed the indirect approach and focussed instead on direct perception, i.e. the assumption clearly stated in the quote above: That bottom-up processing and thus the relevance of direct visual input is necessary and sufficient to descern meaning, as shall be explained in detail below.

Gibson's background

Gibson's work around perception originates to a considerable degree in his work for the US Air Force during World War II: He was a member of multiple research units working on pilot training and selection programs. It was here where he discovered that the traditional, indirect model of perception and the approach of laboratory-based studies, especially concerning depth perception did not yield much results to actually help to train pilot skills – Gibson then decided to shift his focus and his studies to the world *out there* and not the one in the human head, a decision he pursued over the next decades.

Key points of Gibson's theory

Like his predecessors in spirit (see 2.1.1), Gibson believed an ecological foundation to be essential for visual perception:

> The size-levels emphasized by modern physics, the atomic and the cosmic, are inappropriate for the psychologist. We are concerned here with things at the ecological level ... because we all behave with respect to things we can look at and feel ... (Gibson, 1979)

To give a comprehensive overview over the theory of Ecological Perception would be impossible within this thesis, but in order to understand the framework in which affordances fit for Gibson, it will suffice to illustrate his main concepts:

Surfaces and Texture Gradients For Gibson, one of the most important features in perception are surfaces. In the real world (unlike in many laboratory studies), objects are perceived ecologically on or in conjunction with surfaces. These surfaces usually have textures (an obvious example is a paved street) which are important for perception (e.g. for size perception, see fig. 2.1a).

Optic Array The pattern of light which reaches the eye at a given moment, i.e. the sum of directly visible information about the layout of one's surroundings. An example for a pilot in flight would be the whole of fig. 2.1b (without the marked vectors).

Optic Flow Again, unlike in laboratory studies, in the real world perception is almost always associated with movement: An observer moves his eyes, his head, his position, etc. The (apparent) movement of objects due to movement of the observer is called the Optic Flow, which in turn causes changes in the Optic Array. Optic Flow patterns are related to specific movements (e.g. spreading flow vectors originating from the point of aim are specific to flight parallel to the ground, see fig. 2.1b).

Invariants During all movement and change in the Optic Array, there is information that stays constant (invariant). For example, the horizontal lines of the landing strip in fig. 2.1b will stay parallel during straight flight forward, as will the pattern (the vectors) of the Optical Flow itself.

Affordances

> The *Affordances* of the environment are what it *offers* the animal, what it *provides* or *furnishes* ... (Gibson, 1979, p. 127)

and

> The perceiving of an affordance is not a process of perceiving a value-free physical object to which meaning is somehow added in a way that no one has been able to agree upon; it is a process of perceiving a value–rich ecological object. (Gibson, 1979, p. 140)

Thus, affordances are action possibilities latent within the environment. To illustrate, a small, round(ish) object with certain red, yellow or green colors and a stem protruding from one end affords eating to a human – it is an apple.

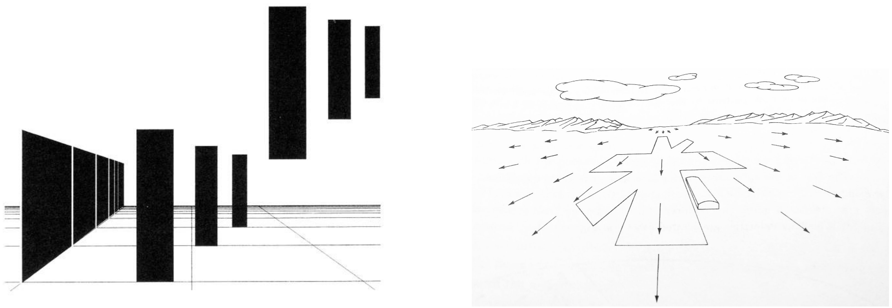
Crucial properties of affordances are:

- They "cut across the dichotomy of subjective-objective" (Gibson, 1979, p.129). Affordances don't have to be perceived in order to exist; An apple still has the affordance *edible*, even if viewed by an actor who has not seen an apple in his whole life and doesn't know it is edible: The *existence* of the affordance is not influenced by the actors knowledge, experience, his culture, values or goals. However, his ability to *perceive* the affordance might very well be.

- Consequently, an affordance can either exist or not exist, it is binary.

- Also consequently, affordances are invariant. They do not change with knowledge, value, etc. of actors. Gibson himself states that "invariant combinations of invariants ... specify the affordances" (Gibson, 1979, p. 140).

- Consistently to the the framework of bottom-up processing and direct perception: Affordances can, according to Gibson, be picked up “directly, without an excessive amount of learning” (Gibson, 1979, p. 143).



(a) Textured Gradients. From Guski (1996)

(b) Optical Flow during flight. From Gibson (1979, p. 124)

Figure 2.1: Illustrations of Gibson’s concepts

2.1.3 Norman

We now turn towards HCI and (interaction) design: Donald Norman can be considered a definite authority in these fields and, fittingly, he was the one who picked up Gibson’s work and introduced the concept of affordances into HCI. However, as mentioned before, there are fundamental differences in both approaches.

Norman states that “. . . affordance refers to the perceived and actual properties . . . ” (Norman, 1988, p. 7) and that “affordances result from . . . past knowledge and experience” (Norman, 1988, p. 219). These quotes clearly demonstrate differences between Gibson and Norman: The possibility of false affordances, i.e. action possibilities percieved by an actor that the object in question does not posess, as well as the statement that affordances are direct results from individual experiences, contradict Gibson. Coming from a HCI point of view, the explanation for these contradictions is obvious: In designing products, it is highly relevant not to confuse the possible user, not to make the product ambivalent and not to create easily perceptible false possibilities for actions. Norman also includes ease of use/ease of usage discovery in his concept: “. . . affordances and constraints . . . lets a user determine readily the proper cause of action” (Norman, 1988). Again, value judgement of usages is understandable from the designer’s perspective, however it is nothing Gibson has ever associated with affordances.

Development

Norman recognized that his ambigous description and usage of the word affordance has led to confusion and imprecise application of the term in the HCI community and has been trying to clarify his meaning (Norman, 1999). His main approach here was the change of wording to "perceived affordances" (Norman, 1998, 1999). He states that "the designer cares more about what actions the user perceives to be possible than what is true" (Norman, 1999), a sentiment that reiterates his functional approach of reducing Gibson's big theorem to the smaller subset of HCI/interaction design.

Moreover, he reinforces the importance of his concept of constraints and conventions and its differentiation from affordances: There are physical constraints (e.g. the physical size of a display), logical constraints (e.g. content that doesn't fit on a display but is clearly, logically reachable though scrolling) and cultural constraints. The latter are of special interest to us: They are basically conventions, i.e. learned rules, shared by groups like the scrollbar on the right side of a display and its behavior (Norman, 1999). To formulate it like Gibson might have: The perception of an affordance can be moderated by cultural constraints. Hence, constraints and conventions are less fundamental and more specific than affordances.

To illustrate: An onscreen-cursor might change its shape when guided over different fields, buttons, etc. in order clarify what actions are possible. These shapes are (cultural) conventions. However, the user is still free to click anywhere on the screen, completely independent from the current cursor-shape. Changing the underlying affordance *click–able* would require more drastic measures like locking the mouse buttons when the cursor is not over interactive sections of the screen.

This distinction as well as conventions/constraints are obviously highly relevant to HCI and will be reconsidered later on.

2.1.4 Gaver

William Gaver, who was a scholar of Don Norman, also considered affordances as relevant concepts for HCI and design[4]. However, unlike Norman and unlike in a lot of other references to affordances in HCI, Gaver explicitly heeds Gibsons' original meaning and context of the term, attempts to systematically break it down to HCI purposes and to build an appropriate framework (Gaver, 1991).

To begin with, Gaver puts the ecological approach within a HCI context:

> In focussing on everyday perception and action, the ecological perspective may offer a more succinct approach to the design of artifacts that suggest relevant and desirable actions in an immediate way. (Gaver, 1991, p. 79)

He then delves into affordances themselves which he consideres the "epitome of the ecological approach" (Gaver, 1991). Here, he makes a fundamental distinction which is often overlooked when the term affordance is used in HCI-contexts: Perceptual information vs. affordances, that is: Affordances are action possibilities independent *on*

[4]As a sidenote: Gaver even states that "Gibson's writings had the effect of leading me into human-computer interaction. Up to that point, I had turned up my nose at the field" (Gaver, 2008).

an existential level from the informations available/perceptible about them, like Gibson stated. Going from there, he develops a model for applying affordances in HCI and design, see fig. 2.2.

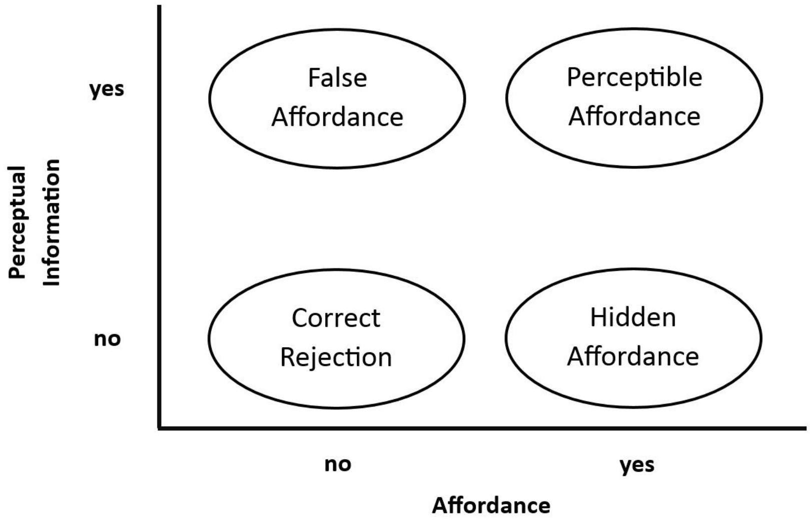


Figure 2.2: Gaver's model of affordances according to Gaver (1991).

Perceptible Affordance: An affordance is existent and *can* be perceived, e.g. a door that *can* be opened, is visible, has a door handle, etc.

Hidden Affordance: An affordance is existent but *can not* be perceived, e.g. a secret doorway that however *could* still be opened.

Correct Rejection: There is no affordance present and there is no perceptual information that suggests one, e.g. a wall that is solid and doesn't *look like* a door.

False Affordance: There is no affordance present, however there is perceptual information that suggests one, e.g. lines on a solid wall that *seem like* there is an open-able door[5].

With this framework, Gaver separates concepts like usability, ease of use and ease of usage discovery from the general term *affordance*, which is a distinction that e.g. Norman did not employ, at least not in the beginning and even later on not as sharply defined within a model as Gaver did (see 2.1.3). Gaver's model is thus more consistent with Gibson's original work, yet at the same time more focussed on its utilization in pracitcal, design-oriented applications rather than Gibson's more abstract and broader theoretical model: "... considering affordances explicitly in design may help suggest ways to improve the usability of new artifacts" (Gaver, 1991).

[5]Note: The designation *Dalse Affordance* seems imprecise because there is no affordance involved – it is the perceptible information that is suggesting a false affordance.

Gaver also includes other application-centered points in his analysis which include:

- Learning, culture and experience which have an influence on the perception of affordances. Like Gibson, he consideres these points as moderators rather than existential factors for affordances (Gaver, 1991).
- Exploring and sequence of affordances which are necessary for real-world complex design applications: One affordance can lead to another (e.g. grasping a door handle can lead to pushing it down and then opening the door through tactile information (Gaver, 1991, p. 82). Thus, exploration, an important concept in HCI is introduced into affordances. This is, again, compatible to Gibson in that it applies one of his more general principles to concrete design: Gibson implies sequence/combination, e.g. through his already mentioned definition of affordances as "invariant combinations of invariants" (Gibson, 1979, p. 140) which in turn implies that there can be higher order (combinations of) invariants.
- Product design and HCI include more than visual aspects. Interaction with artifacts also include the other senses like feeling and hearing. Feeling is especially relevant, since most Human-Machine-Interaction includes tactile manipulation. Gibson's focus on visual perception is extended through Gaver to include the other senses as well (Gaver, 1991).

2.1.5 Current development

> I just couldn't take it anymore. "I put an affordance there", a participant would say... Affordances this, affordances that.... Yikes! What had I unleashed upon the world? (Norman, 1999)

There surely still is a lot of confusion around the concept of affordances both in academic circles (see e.g. the literature survey in McGrenere and Ho (2000)) as well as in the not-necessarily-academic HCI and design community (which is referred to by Norman's quote above), however there is a lot of work that encorporates or details affordance and progress is being made, so it seems consensus that the general idea has appeal for HCI and design. We will try to illuminate some tendencies in an overview:

- To round out the previous sections, it needs to be recapitulated and emphasized once more that while Norman's original manner of expression was ambiguous, later on his and Gaver's understandings of affordances – while still not exactly the same – seem at least to point in the same directions, namely the importance in the distinction between action possibilities and their (possibility or ease of) being perceived.
- The importance of this distinction seems to be spreading, see e.g. McGrenere and Ho (2000); Lintern (2000).

- The distinction also implies, that the dimension *perception* of an affordance can be already viewed as a gradient (ease of perception). However, to better serve within a real-world HCI and design context, the binary concept of the affordance itself (the dimension *action possibility*) might be better extended into a gradient one, too: For design, it is not oly relevant *if* an action can be performed, but *how easy* it can be performed, too. See McGrenere and Ho (2000); Warren (1995)[6]. This distinction can also be viewed as one between usability (ease of perception) and usefulness (ease of use of an affordance).

- Past interface/interaction/industrial design often seems to be lacking in human factors and cohesive conceptual models. Ecological perception and consequently, affordances, could take this role and provide much-needed models (Lintern, 2000; Norman, 1992; Smets, 2010).

- There is of course also critique regarding ecological perception and affordances. A lot of it has to do with the disregard of inferential cognitive processes, e.g. Fodor and Pylyshyn (1981). This can be viewed as more important for academic, comprehensive purpose rather than output-driven design and HCI. However, it would be prudent to at least consider these criticisms as well as the immense leaps in neurosciences since Gibson – this is done e.g. in Ruecker (2003).

- In further critique, May (2010) holds that direct perception and "good" HCI design in the sense that the user sees *through* the interface rather than sees the interface itself might not always be even desirable; Safety-critical applications might require actors to cross-check and to monitor the system with which they interact themselves, too.[7] Hornecker (2012), based on empirical studies with tangible interfaces, critizises lack of depth behind the term affordance and argues that users are able to interpret and combine affordances in phsysical objects endlessly which limits the use of the concept in design. Furthermore, she points out that too inviting affordances or thight mappings might discourage reflection and learning in users.

[6]Warren (1995) e.g. uses stairs as example and as object in studys. Stairs obviously afford climb-ability and he tries to measure this affordance itself. He develops a ratio, $\pi = R/L$, where R is the height of a stair-step and L is the climber's leg length. Consequently, π can be used to describe how easy the affordance climb-ability can be performed. Note also that it represents a ratio between an actor and his environment, a concept that fits Gibson's notion of actors as reference frames for affordances (see 2.1.2) well. This train of thought is also highly fascinating because, if continued, it could provice a way to attach other branches of science, from ergonomics to other human-centered concepts in architecture like Le Corbusier's Modulor (Le Corbusier, 1953) or similar approaches into HCI and design in a structured, systematic way.

[7]One could argue that, while obviously true, this does not necessarily contradict ecological perception and affordances but rather calls for different affordances than in a consumer-oriented device like a smartphone.

2.2 Chosen HCI-elements

Up to this point, we have laid the theoretical, research-oriented groundwork for the current study. However, to complete these groundworks, we also need to thoroughly examine the actual elements which will be tested in VAP and preVAP which will be the subject of this section. The two chosen basic HCI-elements are:

The (Action-) Button A basic (action-) button to initialize an action like a page-turn, activated by a tap with a single finger.

The Swipe A translational, gestural movement (finger down, movement, finger up), often used to change to a different view.

Both are present in all three currently or probably prospectively most widespread (IDC, 2012) mobile device operating systems, for buttons see Microsoft Corp. (2012c); Apple Inc. (2012b); Google Inc. (2012c), for swipe gestures see Microsoft Corp. (2012b); Apple Inc. (2012a); Google Inc. (2012b).

The following sections will explain the elements and the further reasoning behind their choosing in detail.

2.2.1 (Action-) button

An (action-) button is one of the most basic control structures available in HCI. The attribute *action* has been added up to this point to illustrate which kind of buttons (there are action buttons, radio buttons, etc.) are adressed. From here on out, we will omit it because the current section clarifies this point.

Cooper, Reimann, and Cronin (2007) list the button's main characteristics as follows:

- A button posesses the affordance *press-ability*.
- A button is an imperative control: It initiates an immediate action.
- Buttons are usually rectangular (sometimes oval).
- They usually have a simulated 3d-appearance (raised by default, indented while activated and held).
- The corresponding action is initiated as soon as the user pushes and releases the button.

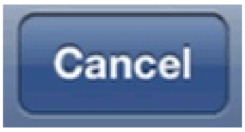
The button as a concept is an old one: It has been taken from its very roots (e.g. wall switches) over into the digital form where it has been used for a long time and by a lot of people, especially as a staple within WIMP-interfaces[8]. This is done either in

[8]Windows, Icons, Menus and Pointer – the most widespread UI-concept for traditional desktop-computers.

physical form in conjunction with a computer (keyboards, mice, etc.) or in completely digital form (onscreen-buttons).

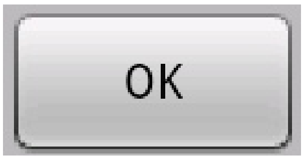
The WIMP-paradigms themselves don't all translate into touch-based interfaces (Anthes, 2008), but the button is one of the exceptions: It is still in widespread use, see fig. 2.3 and its core functionality has not changed. It is however noteworthy that the metaphor of *pushable* in the sense of pseudo-3D, shadowing, etc. seems to to erode, see the visual style of Buttons in Windows Phone (fig. 2.3b) and in the latest Android-Versions as compared to previous versions (fig. 2.3d). This tendency can also be viewed in other related sectors, for example in the upcoming Microsoft Windows 8 operating systems where the design language (which is also used in WindowsPhone and is codenamed *Metro*) moves towards a flattened, simplified look (see e.g. (Microsoft Corp., 2012a)).

To formulate it in a Gibsonian way: Classical buttons are defined by a specific set of surfaces and textured gradients like shape and shadowing. They furthermore possess invariants like the fact that the button shape stays the same while its texture changes in a specific way if pressed. Modern buttons (in the sense of more flattened ones, as explained above) still possess several of these characteristics like the general shape, yet they tend to be stripped of others like a lot of (textured) gradients.

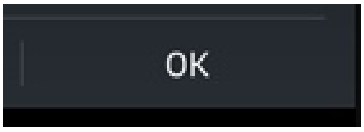


(a) Button in iOS

(b) Button in Windows Phone



(c) Button in Android, earlier



(d) Button in Android, later

Figure 2.3: Buttons in different mobile operating systems

The reasoning behind choosing buttons as test elements is focussed primarily on their importance: Like in traditional WIMP-interfaces (and, like in the physical world), buttons tend to control important actions and are one of the most integral parts of the HCI in touch based interfaces. This makes it a valuable object of study. Furthermore, it is safe to say that the button is an established concept (e.g. Norman (2002)) and thus one where cultural constraints and conventions are involved in that most people would know the basic concept of a button and would be able to perceive its affordance. Furthermore, if one follows Gibson's way of thinking, the recent change in button design (classical vs. flattened) might/should have an influence on the perceptability of their underlying affordances – which is one of the things this study attempts to clarify.

2.2.2 Swipe gesture

Unlike the button, swipe (sometimes also called *flick*) gestures are concepts that are less well covered in HCI literature, less well established and thus warrant a more in-depth inspection.

Origins

Gesture-based navigation is not as new a concept as one might instinctively think. In fact, it has been around for a long time and can be traced back to general ideas of measuring different dimensions (position, force, sheer, ...) in touchscreens (Herot & Weinzapfel, 1978), while the idea of natural gestures including prototype systems and the reference to a flick gesture for movement of onscreen elements also came up very early (Minsky, 1984). Feature and gesture rich systems have been proposed and developed as early as Krueger, Gionfriddo, and Hinrichsen (1985)[9]. A comprehensive overview of (multi) touch and gesture development including further references can be found in Buxton (2012).

Variety in swiping

The idea of swiping/flicking in HCI has been advanced in multiple contexts. These range from flicking with a digital pen for scrolling purposes (Aliakseyeu, Irani, Lucero, & Subramanian, 2008), three dimensional swiping gestures for dismissing objects and navigation (LaViola (1999), see also modern gaming systems like the Microsoft Kinect) to task-specific flicks for web-browser navigation (Moyle & Cockburn, 2003). It has also been introduced into major operating systems, for example in the form of navigational Pen Flicks in Microsoft Windows since Windows Vista (Microsoft Corp., n.d.) and Apple OS X as multi-touch gestures, again for navigational purposes (Apple Inc., 2011).

Not only do these concepts differ regarding their purpose, they also use different underlying logic: A swipe or flick gesture can be viewed either as controlling the *view* or controlling the *canvas*. The former means that the user *grabs* the frame or view around the onscreen content and *pushes* it, so that e.g. in a swipe from left to right, the view moves to the right which means that the displayed content actually moves to the left. Controlling the canvas in contrast means that the user *grabs* the displayed content itself and directly manipulates it, so that by swiping from left to right, the displayed content follows the swipe and moves to the right, too.

Both concepts have a long history in personal computing in general. To start with WIMP again: The famous Xerox Star for example used the canvas metaphor (Smith, Irby, Kimball, Verplank, & Harslem, 1989), while later on, most systems shifted to moving the view: The biggest names in the industry, i.e. Windows, OS X and Linux all move the view for navigating on system level. However, the canvas metaphor is still

[9] A video demonstration that shows this system and its features can be viewed on MediaArtTube (2008).

in use, for example in a lot of PDF-viewers – the Adobe Acrobat Reader e.g. actually uses an icon and corresponding cursor in the form of a grabbing hand to illustrate the possibility of moving the canvas.

Unfortunately, there is not a lot of research in this area in general and even less on the translation and distinction between WIMP and touch-based paradigms. One of the few studies that fit the profile would be Johnson (1995) who evaluates the difference between view- and canvas-based strategies in touch-based interfaces. He finds that the canvas metaphor seems to be the most intuitive and preferred method. If we leave academic research for a moment and look at the current situation, we seem to find Johnson's findings to be reflected in the real world: Smartphones and tablets use the canvas-metaphor (more below), while WIMP-interfaces rely on view. Further trends can be observed in the upcoming Microsoft Windows 8 operating system: It will use view-based metaphors within its traditional, WIMP-oriented part. However, it also has a completely different mode intended for touch-focussed use, where the canvas-metaphor is in place. Another current example is Apple's *natural scrolling* introduced in the OS X version Lion – here, the canvas metaphor is introduced, but again, only in a touch based setting, namely for use with a touchpad while other modes (scroll bars, mouse wheels, etc.) still work the other way round. The feature is controversial, see e.g. Berne (2011) and one might argue that this is further evidence for the tendency Johnson postulated because a touchpad is different from a touchscreen in that it does not have the same degree of direct manipulation – it sits on a level between WIMP and completely touch-based interfaces.

Current swiping

It is important to note that much of the work cited above and in general in this area is well within the realms of academics, i.e. theoretical and/or incorporating prototypes or demonstration systems. There is hardly any research oriented towards widespread, consumer-based handheld devices which is, quite self-explanatorily due to the fact that these devices that are a technically capable of performing fluid touch-based interaction and actually include it have only been available for a very short period of time. This section will thus be rather an attempt of a synopsis of the current state in swiping mechanisms by way of observation rather than based on academic research.

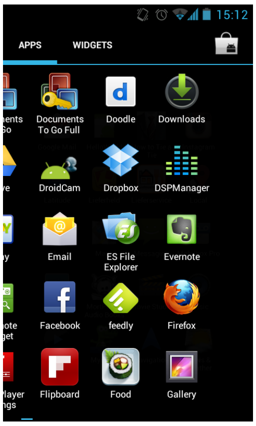
There seems to exist a general rise in the use of swipe gestures (see above), which also translates into the mobile world: Examples include WebOS where the swipe played an important role to switch between so called cards (representing applications), MeeGo where the swipe was very prominently used for multitasking, i.e. swiping into and out of applications or the BlackBerry OS (on the PlayBook tablet) for general navigation. We will focus now on the three major mobile touch-based operating systems:

1. iOS most prominently utilizes swipes for navigating between homescreens. Swipes are, e.g. also used to navigate between pictures (in fullscreen-mode). For an example (here as a multitouch-gesture to swipe between apps) see fig. 2.4a.

2. Android also uses swipes for navigating between homescreens. The navigation within the so-called app drawer (where all installed applications are represented) is also done primarily via swipe gestures. Like in iOS, navigation when viewing pictures is also done by swiping. A swipe within the app drawer is shown in fig. 2.4b.

3. Windows Phone, unlike iOS and Android does not use horizontal swiping to navigate between homescreens, in fact, it has only one homescreen (called Start Screen) which represents all installed applications and is scrolled through vertically. However, the swipe is heavily utilized within applications or aggregations of applications (called hubs) to navigate between different views. Picture navigation is similar to iOS and Android. The people-hub is shown as an example in fig. 2.4c.

(a) Swiping in iOS. From Tofel (2012).



(b) Swiping in Android.

(c) Swiping in Windows Phone. From Orantia (2010)

Figure 2.4: Swiping in different mobile operating systems

To sum up: All major mobile, touch-based operating systems seem to favour horizontal swipes as ways to navigate between related screens or views while incorporating the canvas metaphor – which is the perspective towards swipes we will use from now.

Note: The list above is not a comprehensive one. Swipe gestures are used in considerably more ways than stated. To name just two examples: Revealing delete-functions (iOS) and permanently closing applications while multi-tasking (Android). These are, however, isolated applications of swiping and not used commonly throughout the different operating systems. There are also vertical swiping movements, e.g. to reveal notifications (iOS and Android) or to unlock the device (Windows Phone). These swipes however are generally not used for swiping into other views, i.e. for navigational purposes between pages. The list focusses on the most often used, basic functionality of horizontal swipes which are present in all three operating systems and which are consistent to a considerable degree with the past usages of swipes as touched on in 2.2.2.

Perception of ***swipe-ability***

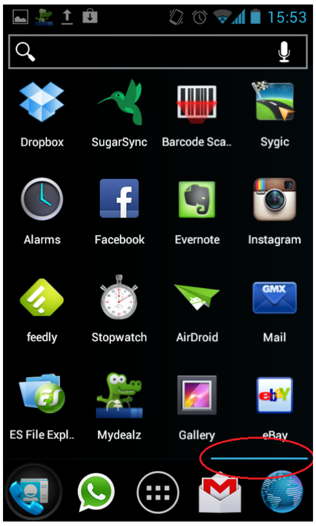
As demonstrated in the previous sections, swipe gestures are by no means as commonly used in personal computing as buttons. Also unlike buttons, they don't have a perfectly clear mapping to real-world-objects[10]. The third and obvious property of swipes is that they are inherently invisible.

The bottom line is that swipes have just gained momentum in touch-based interfaces and are only moderately conventionalized and understood by users (Nielsen, 2011). Hence, all three big mobile operating systems often include visual cues that are intended to help users see the swipe-ability. These cues can are usually persistent, subtle cues that do not exlicitly state *swipe* but rather hint at the possibility. Android (see fig. 2.5c, cue highlighted in red) and iOS (see fig. 2.5a, cue highlighted in red) use similar concepts: Small geometrical elements that visualize swipe-ability and often the current position within a swipe-able structure at the same time. They come in different shapes, but their functionality stays the same. Windows Phone takes a different approach and hints *there is more* by way of cutting of content that indicates continuation on currently invisible parts of the canvas (see fig 2.5b. Note that this is a still screen, not a screenshot during a transition between screens). It also has to be mentioned that there are variations of these indicators in all operating systems and that there are situations with no visual cues too (e.g. within gallery applications, as shown in fig. 2.5d for iOS – the same principle applies in the other systems as well). It can however been said that in most situations where a swipe as a navigational measure is critical and there are no other considerations in place (like the desire to view photos unobstructed), there usually are subtle visual cues implemented that follow the same principles.

[10] One might, for example, view a swipe as having parallels to turning pages in a book (See Demibooks (2010) or multiple ebook-reader apps, e.g. iBook where the swipe is accompanied visually by a page-turn animation). However, this analogy is not as solid as with the button: Swipes are by no means always accompanied by such visual cues.

(a) Cues in iOS.From Howlett (2011).

(b) Cues in Windows Phone. From Auer (2010).



(c) Cues in Android.

(d) No visual cues. From Apple Inc. (n.d.)

Figure 2.5: Swiping: Visual cues in different mobile operating systems

Reasons for choosing swipes

The reasons for choosing swipe gestures are on the one hand very similar to the reasoning behind buttons: They are a very important, basic element in touch-based interfaces. On the other hand, swipes have, presumably, as to the reasoning above, a lot less foundation within cultural constraints and conventions which should enable a lot less people to perceive their affordance or at least do slow down the perception significantly. This makes swipes an obvious und sensible choice for comparisons.

2.3 Working synopsis

The fact that there is no comprehensive, widespread scientific definition of affordances makes this section a necessity. It is not called *working definition* because we most certainly will not try to create one in a bachelor's thesis. Instead, we will try to compile a task-focussed, compact *synopsis* based on 2.1 which in turn will be used later on to base the study upon.

1. Every touch enabled device has the affordance *touch-able*. The designers have given the device the action possibility of interacting by touching.
2. Tapping a button is, however, an affordance in itself, it is the specific action possibility of pushing on a visually defined onscreen area with one finger. There are touch-enabled devices conceivable which do not posess this possibility, it is thus an affordance in its own right.
3. Swiping is also an affordance in its own right by way of the same reasoning as for buttons.

Going from there, we have to clarify that we are (for this study) not interested primarily in these affordances *per se* but rather in their *perception*. We heed the aforementioned distiction between affordances and their perception and will orient ourselves on Gaver's model (again, see fig. 2.2). Our interest is the usability, not the underlying usefulness of an affordance[11]. To this end, we will also include constraints and especially cultural conventions in our considerations, since these might have an influence on the perception of affordances.

This concludes the theoretical part, following up are the empirical sections.

[11]VAP will however collect some data that goes beyond perception which will be discussed briefly later.

3 The present study

In this study, the two HCI elements *buttons* and *swipes* will be varied regarding their perceptability: There will be the conditions *visibility high* (vis. high) and *visibility low* (vis. low) for buttons and swipes respectively. It will then be measured how easy users pick up and correctly react to these conditions. The time they need to do that will be used as the means of operationalization because time is a central factor in this aspect of HCI: How well, i.e. how fast can a user successfully interact with the machine? The differences between the conditions and between buttons and swipes in general will be analyzed.

The study can be viewed in Gibson's spirit in that it is an attempt, to go *out there* and to directly study what users do, how they do it and how well they perceive different navigational models. It is not a laboratory study but field research. Smartphones and tablets are devices built to be used mobile and ubiquitous and as such, they can and should be examined alike. This is also in accordance with Don Norman: "…and the only way to find out what people do is to go out and watch them – not in the laboratories, not in the usability testing rooms, but in their normal environment" (Norman, 1999).

Preceding the main study, there has been a prelimiary one which established average, baseline motoric values for executing swipes and button presses. This was done in order to subtract these average values from the times found later in the main study, so that the results there include as few motoric components as possible but are rather focussed on the perceptual differences.

To begin with, we will now look at the used device, give a short overview over the preliminary study and the respective app and then look in depth at VAP, followed by a list and explanation of this study's hypotheses. Subsequently, the sample will be described, the statistical methods explained and the results will be reported.

3.1 Used device

For both the preliminary and the main study, a Samsung GT-I9100 Galaxy SII (SGSII) smartphone was used as the test plattform. One – rather basic – reason for this decision was the fact that it is the author's smartphone and was thus available to him at all times. However, it was not just availability and convenience but also the fact that the SGSII is one of the most popular Android devices (Android being the most widespread mobile operating system at the time of writing (IDC, 2012)) and its screen size and display resolution are also very common (Open Signal Maps, 2012)[1]. Display-wise it also falls under Google's most common criteria *normal and hdpi*. These generalized criteria describe specific ranges of device displays and *normal and hdpi* is by far the most widespread, accounting for 55.3% of all devices tracked at the time of writing. The latest figures and more about Googles generalized criteria can be found in Google Inc. (2012a). The SGSII is therefore a suitable basis for mobile usability studies regarding smartphones.

Technical data of the used SGSII (excerpt):

- Screen size: 4.3 inch
- Screen resolution: 480*800px (218ppi)
- 1,2Ghz Dual Core CPU
- 1GB RAM
- Custom ROM with Google's latest Android version (*Jelly Bean*), meaning no manufacturer-specific skin or other UI-alterations

For controlled and comparable device-specific settings, the used SGSII has been switched to full backlight, airplane- as well as silent-mode for all participants. This is done automatically in VAP and the app for the preliminary study.

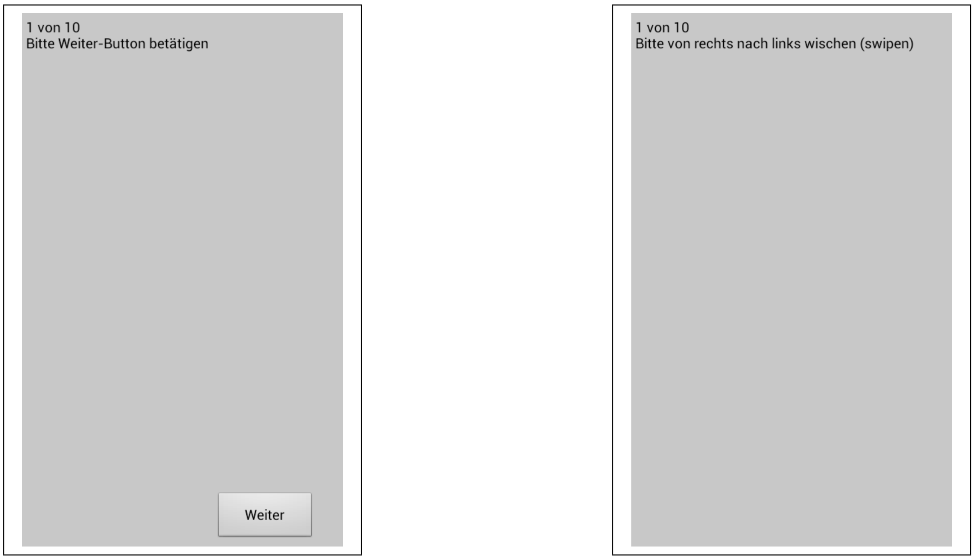
3.2 PreVAP: Prelimiary study

Since VAP was intended to reserarch differences in affordance *perception*, non-perceptual elements should be eliminated. The main factor here is undoubtedly motorics: Every button press or swipe gesture obviously does not only consist of perception but also of a significant motoric part that executes the action. For these motoric actions, average execution times had to be established which was the preliminary study's task. The application (called *preVAP*) for this preliminary study is very similar to VAP (see 3.3) which is why this section will be brief:

After a start screen which included a briefing, instructions and the declaration of consent, participants were asked to navigate through 10 pages using buttons (see fig. 3.1a) and 10 pages using swipes (see fig. 3.1b). Before each condition, the method for navigating was introduced and explained on a separate screen. Half of the participants got the swipe condition first, the other half the button condition. The execution times were tracked via timestamps for each successful navigational steps, subtracting out animation

[1]This source does list the SGSII as the most common device but it does not explicitly rank display resolutions which is why the author contacted Open Signal Maps (OSM) directly and got confirmation that 480x800 was indeed the most common resolution tracked. This can be seen as very valid data since OSM's sample size is over 650 000.

time and insuccessful navigational attempts (e.g. a swipe backwards or the like). The screens within each condition were similar, except for an iterating counter to show the participants their progress. This structure was chosen to eliminate learning processes and yield acurate, real-world average times for the motoric execution of a swipe and a button press. The prelimiary test was then finished on an end screen including a debriefing.



(a) Button condition **(b)** Swipe condition

Figure 3.1: Preliminary study: Conditions

Furthermore, the same demographic information as well as additional data as in VAP was gathered and all data was logged in three logfiles, *PRETESTallTimes.txt*, *PRETESTsensorData.txt* and *PRETESTtouchPositions.txt* (the structure of which was the same as in the main study's logfiles, see 3.3 for further explanation).

3.3 VAP: Main study

Variations in **A**ffordance **P**erception or VAP was born from the general idea to put a modern, mobile, touch based device within a scientific context. It incorporates all parts of a traditional study, from the declaration of concent through the test and data gathering itself up to the debriefing. The following sections will explain VAP in detail.

3.3.1 Walkthrough

Start screen

VAPs Start Screen (see fig. 3.2a) includes two of the main formal cornerstones of scientific studys: The explanation of the study, including its purpose, its duration, data confidentiality and anonymity. Following that, there is the statement of agreement in which the participant gives his consent to take part in the study and to the scientific usage of the gathered data. The participant has to actively check a radio button in order to make the OK-Button with which he can continue to the next view appear.

Demographics screen

The demographics screen (see fig. 3.2b) collects all necessary demographic information about the participant:

1. Sex of the participant. Answers: male / female.

2. The participant's age. Answer: Number.

3. Does the participant own or use a smartphone or tablet regularly (more than once a day)? Answers: Yes / No.

4. Which smartphone or tablet does the participant own or use? Answers (multiple possible): iOS / Android / WindowsPhone / Other.

5. Where is the participant now? Answers (multiple possible): In company (more than the participant and the examiner) / only the participant and the examiner present / Indoors / Outdoors.

6. Is the participant left- or right handed? Answers: Left handed / Right handed.

All questions except for "Which smartphone or tablet does the participant own or use" are obligatory and if the user tries to continue without answering them, he will receive a short popup message (called ToastMessage in Android) asking him to answer everything.

Finish screen part one

The finish part one screen (see fig. 3.4a) rounds up part one of the study and informs the participant that he will now continue to part two where he will get to read a short text, split into multiple screens and that it will be his task to navigate to the next screen respectively.

Buttons, visibility low

The buttons, visibility low screen (see fig. 3.3a) presents the user with a button-based navigation. The style of the buttons is very restrained, only thin, grey lines separate the buttons from the background and one another. The body of the buttons has the same color as the background. This is based on the more recent Android buttons and Windows Phones style (see 2.2.1).

Buttons, visibility high

The buttons, visibility high screen (see fig. 3.3b) also presents the user with a button-based navigation. However, these buttons are more traditional, i.e. in pseudo-3d with gradient color and perceived depth. (see 2.2.1).

Swipe, visibility low

The swipe, visibility low screen (see fig. 3.3c) bases its navigation on swipes. It utilizes the aforementioned concept of small, visual cues in form of button indicators to suggest swipe-ability (see 2.2.2).

Swipe, visibility high

The swipe, visibility high screen (see fig. 3.3d) also bases its navigation on swipes. However, here, *swipe-ability* is not only suggested but explicitly declared by an explanatory pictogram in conjunction with written instructions ("Swipe from right to left to continue"). The pictogram is taken from Wroblewski (2010) (an attempt to standardize symbols for touch gestures). The additional textual instruction is consistent with Norman (1998) who explicitly advises designers to describe desired actions in words, too.

The finger movement threshold for successful execution of a swipe has been set to match the values Google itself uses for swipe-able interfaces[2]. A comparison with iOS and WindowsPhone was not possible because unlike Android, they are closed source, so Android's threshold has been used.

End Screen

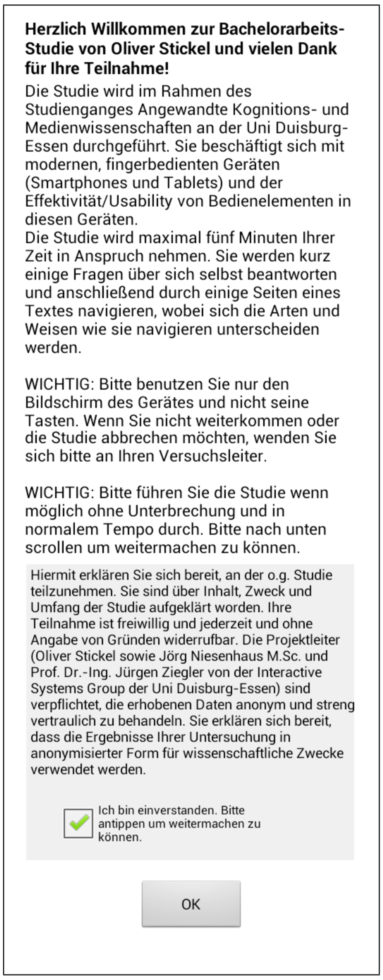
The end screen (see fig. 3.4c) thanks the test person for his participation and includes a debriefing. It also explains which text was displayed. It includes a finish-button which completes and quits the study.

Intermediate screen

The intermediate screen (see fig. 3.4b) is called after each HCI-element test screen in order to equalize the process and give the participant time to adjust after/before each new mode of navigation.

[2]A constant of 25dp multiplied by the variable of the current display's scale factor. A dp is short for DIP, which is a density-independet pixel (relative to a physical pixel on a default screen with 160ppi) The scale factor is calculated from the display's pixel density and, in our case, equals the most common value, namely 1 for the SGSII used in the study. More information about scale factors can be found in Google Inc. (2012b).

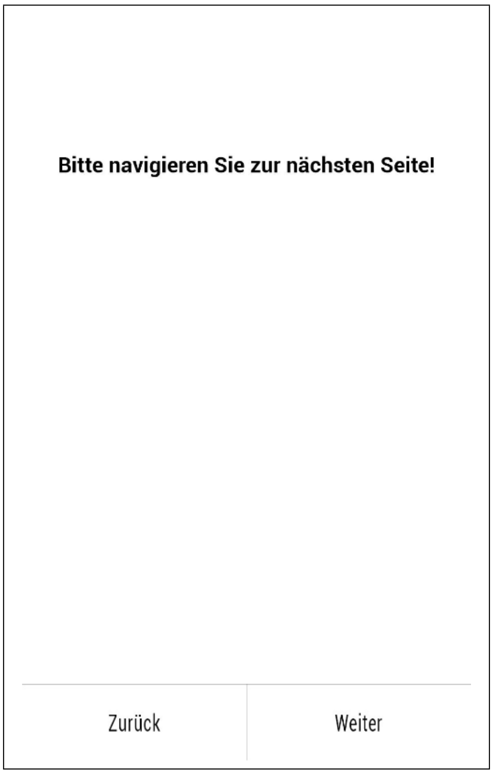
VAP-Screenshots



(a) Start screen

(b) Demographics screen

Figure 3.2: VAP: Start- and demographics screen



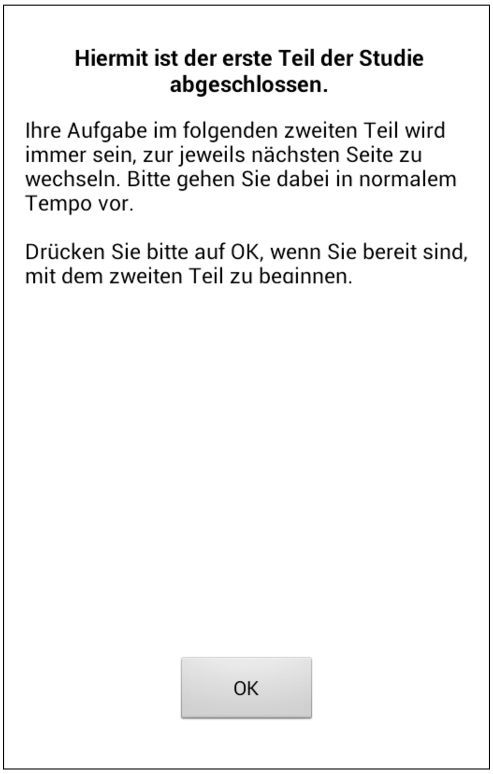
(a) Buttons, vis. low

(b) Buttons, vis. high

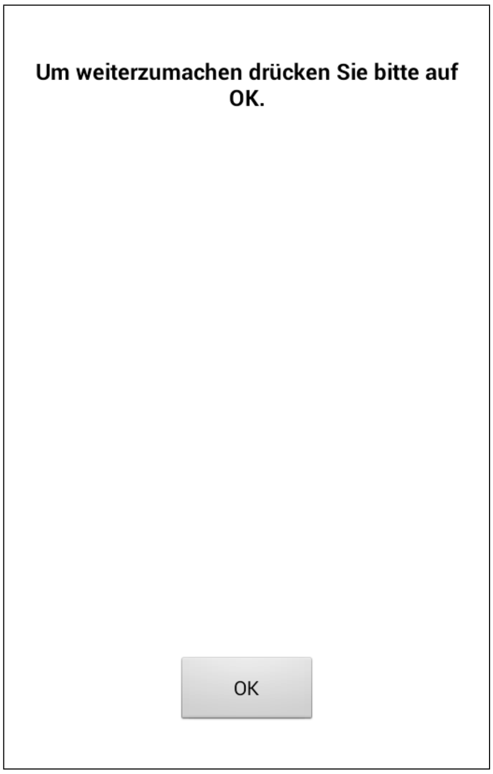
(c) Swipe, vis. low

(d) Swipe, vis. high

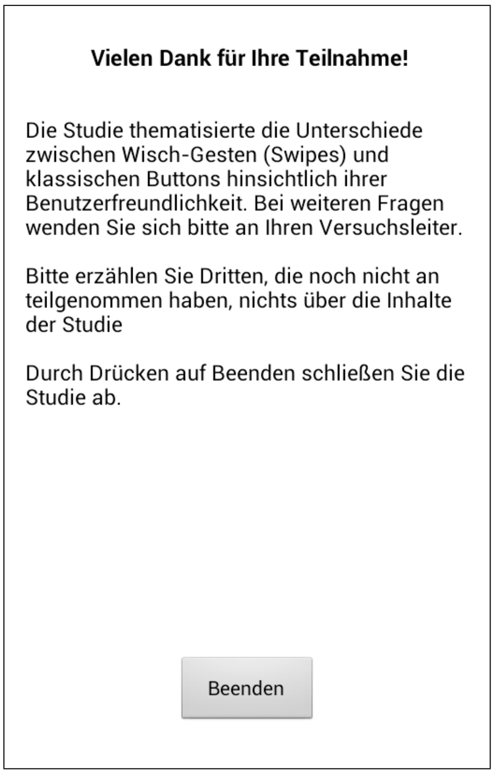
Figure 3.3: VAP: HCI-Elements screens



(a) "Finish part one" screen



(b) General Intermediate Screen



(c) Endscreen

Figure 3.4: VAP: Intermediate screens and end screen

3.3.2 Order/Variations

The basic order of VAP's screens is:

1. Start screen
2. Demographics screen
3. Finish part one screen
4. Test screens for HCI elements, alternating with the intermediate screen
5. End Screen

As mentioned above, the visibility of the HCI elements is varied in this study. In order to gain balanced results without learning effects or similar and to be able to compare these variations, the test screens for the HCI elements have to be varied regarding their order too:

Condition 1:

1. Button, vis. low
2. Swipe, vis. high
3. Button, vis. high
4. Swipe, vis. low

Condition 2:

1. Button, vis. high
2. Swipe, vis. low
3. Button, vis. low
4. Swipe, vis. high

During its start, VAP loads its own logfile, determines the condition of the previous participant and sets the current condition to the other one respectively in order to get similar numbers of participants in conditions one and two.

3.3.3 Main data

VAP (as well as preVAP) writes the collected data into three logfiles. This section will cover the main logfile, for the additional ones see 3.3.5. The main logfile is called *VAPallTimes.txt* and is saved to File.DirRootExternal which is the Android designation for the root folder of the mounted external storage device (e.g. the SD-card in the device). If there is no external storage present, a corresponding warning message is displayed. Each participant gets one line in the allTimes-logfile, a linebreak is entered after each participant's dataset. This is an exemplary set for one participant (breaks are due to available space on paper, there is actually no linebreak in this set):

```
1: 0, 23, 1, 1000, 1001, 1, 1345208571350, 1345208571674,
   1345208580446, 1345208580628, 1345208587246, 1345208587432,
   1345208587974, 1345208588161, 1345208588946, 1345208589136,
   1345208589725, 1345208589929, 1345208590599, 1345208590692,
   1345208591432, 1345208591631, 1345208592300, 1345208592479,
   1345208593028, 1345208593210, 1345208593892, 1345208593974,
   1345208595046, BACKBUTTON: 7,
```

The first number represents the condition (see 3.3.2). The next six numbers represent the answers to the demographic questions. Explained sequentially:

1. Sex: 0 is male, 1 is female.
2. Age: Not encoded, directly represents the age.
3. Has or uses smartphone/tablet: 0 is no, 1 is yes.
4. Which Operating System: Four digits ABCD where A,B,C,D can be either 0 (no) or 1 (yes). A is iOS, B is Android, C is Windows Phone and D is other.
5. Current location: Four digits ABCD where A,B,C,D can be either 0 (no) or 1 (yes). A is in company with more people than the examiner, B in company only with the examiner, C is indoor and D is outdoor.
6. Left or right handed: 0 is left handed, 1 is right handed.

To translate our example: The participant was in condition 1, is male, 23 years old, owns/uses a smartphone or tablet regularly, the device has iOS as operating system and at the time of participation, he was in company with more people than the examiner and outdoors. The participant is right handed.

The next values all represent timestamps[3]. They always follow the same repeating pattern: A screen change initialization, triggered whenever the method to change to the next screen is called (i.e. when the user hits the corresponding button or executes a swipe), sets a timestamp. After that, the screen change is executed and animated. When the animation is finished, a second timestamp is set. Bottom line: If we subtract an end of animation timestamp from its following screen change initialization timestamp, we get the amount of time the participant actually spent on the corresponding, completely drawn screen.

The first time stamp is written when VAP is started and can also be used as the unique, yet anonymous identifier for this participant. This stamp is a screen change

[3]The number of miliseconds since January 1, 1970, to be precise (as returned by the used date method).

initialization timestamp. The last screen has no end of animation timestamp because the app exits here which is done on the system level without in-app animation.

Lastly, there is the *BACKBUTTON:* part: This is included because on the Button vis. low and Button vis. high pages, there is a back-button, yet this button is nonfunctional (it has been left in VAP because a complete navigation usually consists of forward and back buttons and this pattern was not to be broken in order not to confuse the participants). Furthermore, users can try to swipe backwards (from the right to the left), which is also nonfunctional. To see how many users would want to navigate back, this counter has been implemented. It displays the index of the screen(s) where the user has tried to navigate backwards (in this case, on index 7 which is Button, vis. high for condition 1).

3.3.4 Technical details

It would not be sensible to go through VAP code-wise in detail since the application does not contain much in the way of technical, informatic innovation and the source code is attached to the thesis. However, there are some details that should be explained:

- VAP was developed using Basic4android (B4A), see Anywhere Software (n.d.), a Rapid Application Development IDE. As such, the source code is in the VBA-like language used by B4A.

- VAP permanently saves data gathered about a participant only when he uses the finish-button on the end screen of the app so that anonymous abort is possible up to the last second.

- VAP is tailored to the author's Samsung Galaxy SII. This especially concerns the display resolution: The application will only look right if used on devices with 480x800 pixels. The decision has been made partly due to technical reasons (concerning the touch focus rights of views in Android) in order to be able to collect additional data (see 3.3.5) and partly due to the fact that Android devices span a huge range of resolutions and OS versions. This does not only just result in a lot of additional work to make an application broadly usable, it is also difficult to do without at least a few different test handset (which the author does not have access to). For the purpose of this thesis, it has been decided to develop for and support primarily the device on which the study is carried out.

- The basis for VAP's sliding panels layout are the code examples from Uziel (2011); Stipp (2011). They have been used only as the very basis for navigational panels. The examples have been modified, heavily expanded and all of VAP's specific functions (like time measurement, content, file in- and outputs, etc.) were implemented by the author. *Note:* Google itself provides a nice, pre-built sliding panels layout class (called ViewPager) which is also represented in B4A. The reason for not choosing this class is that the ViewPager makes restricting swipe-ability impossible without deeper, more basic interventions into the code/system.

- If a participant aborts the study, VAP writes an line containing "ABORTED" into the logfile in order to determine dropout-rates later in the statistical analysis.

3.3.5 Additional data

Touch-based devices have the ability to register a myriad of different data – from orientation through GPS location up to barometric pressure – which could make them a very powerful scientific tool. In this spirit, VAP also records some data related to the topic of this thesis, namely touch coordinates and device sensor informations (ambient volume and light). This data will not be looked upon in depth, but will rather be used partly to help interpreting the data from VAPallTimes.txt and partly to help proof the point that mobile devices can be very versatile scientific instruments. It could however of course be used further in later studies or publications.

Touch coordinates

It must be said in advance that Android's touch-focus management makes it difficult to globally record all touches because (on a normal, developer-level without deeper interventions), it is only possible to gather data from the object which currently has the touch focus. This means that every single onscreen element (buttons, panels, labels, ...) would need its own listener which would certainly possible but rather elaborate and blowing up the code quite a bit. To circumvent this while gathering at least a segment of the theoretically collectable data, VAP's HCI element test screens consist only of one panel (plus the overlying buttons in case of the button screens). This makes it comparatively hassle-free to record all incoming touches on these panels which is done in the secondary logfile, named *VAPtouchPositions.txt* (also in File.DirRootExternal). Again, every participant has its own line in the file. An exemplary entry looks like this:

```
1, 1343930984660: 5: 397, 562, 150, 678, 8: 221, 685, 221, 685,
    9: 321, 637, 111, 654,
```

The first number represents the condition (1 or 2). The second, long number is, again, the initial time of VAP's start. It is the same number as the one in the VAPallTimes.txt logfile and could be used to map the touch data to the other informations about the participant if need be. The following entries are all in the form "index: X down, Y down, X up, Y up". The index represents the screen on which the touch input occurred and the X and Y values represent the coordinates of the touch (down is where the finger started to touch and up is where it was lifted from the screen).

Note: When interpreting these values, it is important to be aware of the fact that Android treats the *upper left corner* of the screen as the axes' origin.

A minimal entry in VAPtouchPositions.txt consists of two sets of coordinates, namely on screens 5 and 9. These are swipe, vis. low and swipe, vis. high where the participant of course has to touch the panel to swipe to the next screen. If the logfile has more entries, this means that the participant has (falsely) tried to tap, swipe or otherwise interact with the screens on other positions or unsuccessfully on the correct ones. So, to interpret our example: Apart from the needed swipes in screens 5 and 9 (which were successful on the first tries), there was apparently a tap (tap because X down and X up / Y down and Y up are identical) on screen 8, an intermediate screen, which could not have yielded any results. Data like this can be used to calculate general error rates or other helpful informations. To give just a few examples:

- To check for false affordances: Participants might for example be already used to the concept of swipes and try to navigate by swiping even in views that are not swipe-able. In VAP, it is of course very much intentional that not every screen is swipe-able, however inferences about the prevalence of swipe-awareness could be drawn.
- If a lot of taps occur around the areas of buttons, these buttons are obviously misplaced or missized. The touch informations can help to spot this.
- If a lot of participants need multiple attemts to successfully execute a swipe, the touch data can be consulted to analyze. The participant's swipes might for example be shorter than the defined sensitivity in the app. In this case, the swipe affordance would need to be adapted to the user's constraints/conventions (which could e.g. be learned from other applications that include swipes with different sensitivities).
- One might look at the touch data in comparison to other data, e.g. if a participant is left or right handed. Does it make a difference if left handed persons have to swipe from right to left in comparison to right handed persons?

Sensor informations

VAP also logs the current level of ambient sound and ambient light. This is done in the tertiary logfile *VAPsensorData.txt* (again, in File.DirRootExternal and again with one line per participant). An exemplary entry:

```
2, 1344694747908: 0, 1766, 106, 106, 106, 106, 101, 106, 106,
   111, 111, 106, 0, 282, 254, 262, 327, 327, 405, 319, 319,
   544, 304, 304,
```

Like in the other logfiles, the first number represents the condition, the second large number is the initial timestamp (which again could be used to map the information from this logfile to the data from the other logs).

Following up is a zero which is due to the listener initializations and should be ignored. The next 11 numbers represent the light sensor values whenever the participant navigates to the next screen, so that the first light value can be interpreted as the lighting conditions for the start screen, the second one for the demographics screen and so on. In the exemplary log, the lighting conditions for screen one seem to have been much brighter than for the other screens.

Note: The light sensor measures in discrete steps which have a certain range so that a series of the same values is not unusual. This goes back to the sensor's intended function, which is primarlily to adjust the backlight depending on ambient lighting condition – if the sensor were too sensitive, backlight flickering would occur which is why there is a certain amount of tolerance involved[4]. The units of the lighting values are lux.

This data can be used (in conjunction with the data from VAPallTimes.txt) in order to check if the location (indoor/outdoor) and the light have an influence on the times participants need to navigate. Lighting is a potential confunding variable because displays on smartphones and tablets are usually harder to read in bright light due to the fact that these devices use backlights which have to compete against the incoming bright light. Leaving the realm of usability for a moment, just as a suggestion for further work with multiple devices: Data like this could also be used to analyze how different types of displays (LCD, OLED, etc. which usually vary regarding their readability in bright light) fare in comparison to each other.

The 11 values following the next zero (which should be ignored too) are the ambient sound levels (again, corresponding to the timestamps/screens of VAP). Like light, ambient noise is a potential confunding variable because sounds can be distracting to the participants. This data should however be handled with extra care and only be consulted in case of ambiguity, because it is not completely reliable: If, for example, wind directly hits the microphone of the device, it of course registers a rather high noise level which might not be perceived by the participant as such. The participant also could very easily cover the microphone with his hand which could muffle the registered sound levels.

Unfortunately, there is no clear documentation of the sound level's unit (see Google Inc. (2012b)). A logical assumption would be that it is the range of the (device specific) microphone, mapped to the domain of an integer (which is what the called Android method returns). As such, there is no clear unit and the data should only be used for relative comparisons where 0 = silent and 32767 = maximum sound level (see Stackoverflow (2010)).

[4]Determining the exact thresholds is not viable because they are manufacturer-, device- and ROM-specific and not very important for our concerns.

3.4 Hypotheses

This section will illuminate the main research questions and hypotheses which will be attempted to be answered with the help of VAP. It will be brief because the rationale behind the hypotheses has already been explained comprehensively in 2.

3.4.1 Research question – preVAP

Besides measuring motoric times, preVAP also has other scientific potential: Buttons require only two onscreen actions: Touch down and touch up at the same coordinates. Swipes on the other hand require three: Touch down, lateral movement over a certain threshold, touch up. This makes buttons an intuitive candidate for faster execution times, however there are other factors to consider:

Users might hold a smartphone in very different ways[5]. This can result in hugely varying distances from the starting poing of the executing digit to a coordinate-specific target like a button. A swipe gesture on the other hand can be executed anywhere on the screen. If we take Fitts' Law (Fitts, 1954; Fitts & Peterson, 1964) into account, the distance to the target is an important factor for execution times. The other main factor in Fitts' Law is the target size: A button has a specific size while a swipe gestures' target can be the whole screen which is usually significantly larger than a button. The question here is how the aforementioned additional necessary movement for a swipe gesture influences the execution time in comparison to the distance and size factors. There is not enough research in this area to formulate a specific hypothesis which is why this topic will be approached exploratorily.

Research question: Are onscreen buttons or swipe gestures faster regarding their motoric execution times?

3.4.2 Hypothesis 1 – Buttons vs. swipes in general

As explained in 2.2.1 as well as 2.2.2, swipe gestures are presumably much less established (there is less cultural conventions) than buttons, so for this, perception-oriented hypothesis, unlike for the motoric execution times, there is evidence suggesting a directed hypothesis:

Hypothesis 1: Within button screens, users will perceive the affordances faster, meaning the completion time will be faster than on swipe screens.

[5]There is hardly any research concerning this topic, but some factors are obvious, e.g. different device orientations and the dominant hand of the user (left/right, see also (Seidman, Siegel, Sah, & Bowyer, 2012)). Other factors might depend on individual preference and anatomy, e.g. if the user holds the device with one hand and interacts with the thumb of the same hand or if he uses the other hand to interact. The user might also hold the device with both hands and interact with both thumbs.

3.4.3 Hypothesis 2 – Cultural Conventions

To phrase it like Norman might have: It can be assumed that people who own or regularly use touch based devices form a subgroup by learning the device-related cultural constraints and conventions. In short: People learn about their devices which probably reflects on their speed in picking up the affordances in VAP, i.e. in their completion times. This consideration can be further subdivided since the affordance of a button is such an old and well established one (see 2.2.1) and should thus be perceivable more evenly thoughout the participants compared to swipes.

Hypothesis 2a: People who own or regularly use touch based devices will be faster to complete VAP's test screens than others.

Hypothesis 2b: Completion times for swipe screens will differ between participants who have or use a touch based device regularly and people who don't.

Hypothesis 2c: Completion times for button screens will differ less between participants who have or use a touch based device regularly and people who don't.

3.4.4 Hypothesis 3 – Button conditions

As stated in 2.2.1, there seems to be a trend to make buttons more visually restrained, yet classical HCI wisdom holds that onscreen buttons should follow their physical models, i.e. incorporate pseudo-3d, drop shadows, etc. to be more easily perceptible and more effective (again, see 2.2.1).

Hypothesis 3: Perception of the affordances, meaning completion times for visually restrained buttons (VAP-screen: buttons, vis. low) will be slower than those for classical buttons (VAP-screen: buttons, vis. high).

3.4.5 Hypothesis 4 – Swipe conditions

As mentioned multiple times, the cultural conventions of swipes are presumably not very distinct which seems to vindicate visual cues to advertise the existence of the swipe affordance. Here, a bold visual cue, supplemented by text should result in better performance than a smaller, more restrained one (Norman (1998)).

Hypothesis 4: Completion times for small swipe cues (VAP-screen: swipe, vis. low) will be slower than those for big cues (VAP-screen: swipe, vis. high).

3.5 Sample description: Preliminary study

In all, data from N=17 participants could be used for analysis. The participants were recruited by word of mouth and social networks. Subsequently, every participant took the survey on the author's Samsung Galaxy SII under the observation of the author. The dropout rate amounted to 0 participants. There was no financial or other incentive and there were no inclusion or exclusion criteria (other than that the participants had to be of legal age due to ethical reasons).

9 (42.9%) of the participants were male, 8 (38.1%) female. The average age was M=24.88 (SD=2.20, $Range$=22 – 30). 8 (38.1%) of the participants owned or used a smartphone regularly, 9 (42.9%) did not. Of the former group, 4 (19%) had/used iOS, 4 (19%) Android, 0 (0%) Windows Phone and 0 (0%) another operating system.

At the time of the study, 7 (41.2%) of the participants were indoor, 10 (58.8%) outdoor. 1 (5.9%) were only in company with the examiner, 16 (94.1%) in company of more people.

3.6 Sample description: Main study

In all, data from N=53 participants could be used for analysis. Three single data points (timestamps) from different participants were excluded from the statistical analysis because they were considerd as runaway data. These decisions were made under careful consideration of the supplemental data (comparison to the other results of the participant, ambient sound, light levels and touch data). The participants were recruited by word of mouth and social networks. Subsequently, every participant took the survey on the author's Samsung Galaxy SII under the observation of the author. The dropout rate amounted to 0 participants. There was no financial or other incentive and there were no inclusion or exclusion criteria (other than that the participants had to be of legal age due to ethical reasons).

35 (66%) of the participants were male, 18 (34%) female. The average age was M=33.42 (SD=13.16, $Range$=20 – 63). 29 (54.7%) of the participants owned or used a smartphone regularly, 24 (45.3%) did not. Of the former group of participants, 6 (11.3%) had/used iOS, 21 (39.6%) Android, 1 (1.9%) Windows Phone and 6 (11.3%) another operating system.

At the time of the study, 35 (66%) of the participants were indoor, 18 (34%) outdoor. 16 (30.2%) were only in company with the examiner, 37 (69.8%) in company of more people.

Note: There was a small bug in VAP as well as preVAP which corrupted the question for the participant's dominant hand so that apparently, each participant was right handed (which is not true). This data subset can not be used for analysis.

3.7 Statistical methods

Statistical analysis was conducted with Microsoft Excel 2013 (public preview) for basic, mainly descriptive tasks and IBM SPSS 20 for more complex statistic analysis. The main technique used for comparison of mean times was the T-test for paired samples since most measurements basically have the same dependent variable (execution time) and each participant took part in each condition. Where appropriate, the T-test for independent samples was used. Tests were two-sided, except where stated otherwise.

3.8 Results

We will now report the gathered results in detail as well as the output from the statistical analysis. It is important to note that all time data referring to the main study has been adjusted by the motoric times found in the preliminary study, e.g.: If a participant needed x miliseconds to complete a screen and the average motoric execution time for a button press was y miliseconds, the adjusted time is $x - y$ miliseconds. All times in this section are given in miliseconds. All data from the main study reported and analyzed here is *adjusted data*. The original data can be found on the enclosed CD (in the form of the original logfiles as well as in an easier comprehensible and readable Excel sheet).

3.8.1 Research question – preVAP

preVAP had 10 screens for each condition. After a descriptive analysis, regarding the progression of execution times, the first three screens were omitted from the analysis because of possible learning effects. It was also found that the last screen (screen 10) in each condition had a longer execution time than the previous screens. It is presumed that this gradient is due to the fact that there was a counter on each screen and when this counter reached 10/10, participants expected something to happen or at least payed more attention to the counter than on previous pages. Thus, screen 10 was also omitted. The data was consequently recoded into two variables (Button and Swipe) so that we have 102 data points per variable even if the N itself was 17.

Average motoric execution time for a button press was M=893.41ms (SD=482.79, *Range*=158ms – 2639ms).

Average motoric execution time for a swipe gesture was M=927.23 (SD=531.50, *Range*= 284ms – 3194ms).

The difference between swipe and button times for the motoric preliminary study is not significant ($T(101)$=.62, p=.54).

Note: This is a cursory report, focussing only on the mean execution times because these times are necessary for the main study. However, the preVAP data yields more potential for analysis in future considerations.

3.8.2 Hypothesis 1 – Buttons vs. swipes in general

The results are reported in table 3.1. M_{CT} is short for "Mean completion time".

Table 3.1: Buttons vs. swipes

	M_{CT}	*SD*	*Range*
Button, vis. low	1779.25	1536.29	292.59 – 7774.59
Swipe, vis. low	3301.79	3866.19	244.77 – 18860.77
Button, vis. high	1537.47	995.08	39.59 – 4755.59
Swipe, vis. high	3284.32	2937.29	242.77 – 13162.77
Both button screens	1662.71	1062.79	209.09 – 4660.09
Both swipe screens	3284.90	2897.15	243.77 – 14030.27

The difference between the mean completion times in button and swipe screens is significant ($T(49)=4.89$, $p<.001$).

3.8.3 Hypothesis 2 – Cultural Conventions

Participants who owned or used a touch based device completed a test screen in VAP (calculated from all button and swipe screens) in M=2068.21 (*SD*=1584.64, *Range*=39.59 – 13162.77). People who did not own or use a touch based device needed M=3057.30 (*SD*=2194.65, *Range*=192.59 – 18860.77).

Since the corresponding hypothesis was directed, a significance level of $\alpha=.10$ was used. The difference in completion times is significant ($T(51)=1.09$, $p=.06$).

The subdivided results are reported in table 3.2. "Owned or used touch based device regularly" is abbreviated as "TBD yes" and "Did not own or use touch based device regularly" as "TBD no". M_{CT} is the denomination for "Mean completion time".

Table 3.2: Completion times and differences, subdivided

	M_{CT} **swipe**	*SD*	*Range*	M_{CT} **button**	*SD*	*Range*
TBD no	4293.57	3412.76	721.27 – 14030.27	1907.34	1327.10	519.59 – 4660.09
TBD yes	2484.91	2153.66	243.77 – 7763.77	1445.26	714.02	209.09 – 2903.59

There is no significant difference for button screens between TBD yes and TBD no ($T(34.35)=1.52$, $p=.137$).

There is a significant difference for swipe screens between TBD yes and TBD no ($T(50)=2.331$, $p<.05$).

3.8.4 Hypothesis 3 – Button conditions

Completion times for visually restrained button screens (button, vis. low) averaged M=1787.94 (SD=1523.90, $Range$=292.59 – 7774.59). For the classical button condition (button, vis. high), M was 1537.47 (SD=995.08, $Range$=39.59 – 4755.59).

The difference is not significant ($T(50)$=1.23, p=.22).

3.8.5 Hypothesis 4 – Swipe conditions

Completion times for screens with small swipe clues (swipe, vis. low) averaged M=3301,79ms (SD=3866.19, $Range$=244.77 – 18860.77). For the screens with bigger cues (swipe, vis. high), M was 3268.00 (SD=2963.52, $Range$=242.77 – 13162.77).

The difference is not significant ($T(51)$=.065, p=.95)

3.8.6 Additional measurements

This section will report snippets of additional results from the studies which are valuable but not covered in the hypotheses.

Anatomy of a swipe

For this analysis, all touch coordinates of *successful* swipe gestures from the preliminary study and the main study have been consolidated which yielded 276 usable data points. The results are given in Table 3.3 and visualized in chart 3.5. Measurements are given in dp (which in this case are the same as pixel on the 480x800px display of the SGSII). Again, touch data is reported as well as displayed in accordance with the standard Android way, i.e. in a coordinate system with its origin in the upper left corner.

Table 3.3: Anatomy of a swipe gesture

	M	***SD***	***Range***
Finger down: X-value	405.21	46.60	248 – 471
Finger down: Y-value	477.99	91.76	309 – 750
Finger up: X-value	118.05	71.53	1 – 278
Finger up: Y-value	526.94	94.20	306 – 742
Length	286.63	95.35	64 – 464
ΔY-height	59.89	43.78	0 – 159

Note: Due to the implementation of VAP and its sliding panels, there was some false data regarding the x-coordinates of swipe gestures. This happened if the users attempted multiple swipes in very fast succession while the animation methods were not completely finished. The data set has been thoroughly looked over and traceable errors, mainly negative values have been deleted, but there may still be a (small) amout

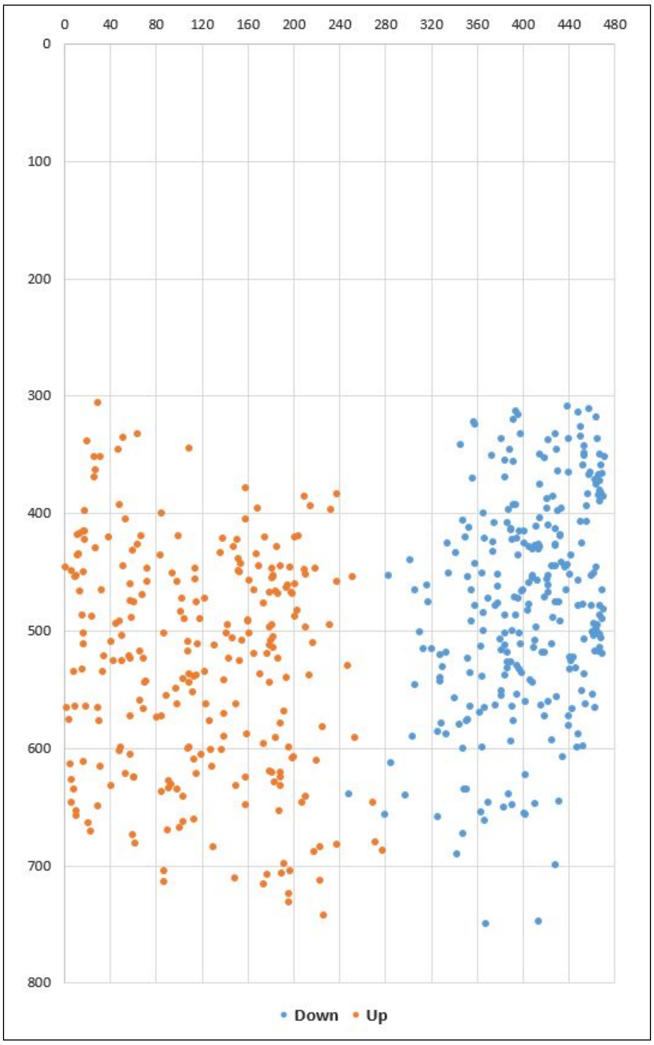


Figure 3.5: Anatomy of a swipe: visualized

of unknown errors. To further check the x-values, the dataset has exploratorily been stripped of *all* possible candidates for errors (i.e. participants who needed multiple swipes to complete a screen), yet the results did not differ from the ones above more than statistically was to be expected which lead to the decision to report the results as they were. This error possibility *only* concerns x-values, the y-values are completely accurate.

Error rates

On the swipe test screens, 20 participants produced 69 error inputs. 29 of those errors were attempts to tap, 40 were insuccessful swipe gestures.

On the button test screens, 13 participants produced 20 error inputs. 2 of those errors were insuccessful taps, 18 were attempted swipe gestures.

For all participants in total, VAPs test pages would have needed a minimum of 212 touches to complete (52 participants * 4 touches per participant). In total, 89 errors occured which amounts to a total error rate of 41.98%.

4 Discussion, Limitations and Outlook

4.1 Demographic data

This section will discuss aspects of the demographic data. It only refers to the main study in order to avoid errors because some participants were in the preliminary as well as the main study.

The fact that there were more participants who did own or use a touch based device on a regular basis than who did not does not reflect on projections regarding greater populations (Statista, 2012; GfK, 2012). It can be presumed that this is due to the fact that the study was conducted primarily around the university and especially the faculty of engineering as well as the IT department. However, statistically speaking, the even distribution of users and non-users works well for analysis. For further, bigger studies it might however be prudent to aim for a broader sample spectrum.

Additionally, concerning device posession/usage distribution, some cursory, exploratory analysis was done and it was found that the average age of users who posess/use touch based devices was 32.79 (which is close to (BVDW e.V.Google Inc., 2011) who find an average age of 35) while that of users who don't was 34.17.

Regarding operating system distribution, the results were consistent to market analyses and projections: We found that 6 participants owned or used an iOS device while 21 owned or used Android. Windows Phone (1) and other OS (6) were not prominently featured. This distribution pattern is consistent to IDC (2012) which supports the validity of our sample.

During VAP's development, the issue of the dominant hand came up: A person who is right handed has to execute a different move over a different distance to hit the same UI element as a left handed person. This might influence performance and it would have been interesting to be able to report related data, especially concerning comparisons between buttons and gestures because while the former have fixed positions, gestures are more location–agnostic. Unfortunately, due to the bug explained in 3.6 we can't discuss this question here, yet the area remains a viable option for further work.

4.2 PreVAP: Preliminary study

During the conception of this thesis as well as the test phase, there have been a lot of conversations, discussions and opinions about which navigation method would be faster:

Swipes or buttons. We can now come to an answer to this question, namely that in terms of statistics, neither is faster or slower on a motoric level. On average, button presses were faster, but only by just under 34ms and not in a statistically significant manner. This is especially interesting because there is hardly any (published) scientific work on this topic and classical models like Fitt's Law are not easily adaptable to gestures on a touchscreen which made predictions for this research question impossible. As a sidenote: Not a single person involved in any kind of discussion or debriefing talks during the study (including the author) predicted this outcome. Everyone had a more or less sound prediction as to which mode would be faster, taking into consideration motorics, perception, Fitt's Law and other factors. Studies like preVAP, spread over a range of device form factors and with greater consideration of biological and motoric facts could be used to upgrade models like Fitt's Law for touch based devices for more accurate predictions in the future.

PreVAP's results could also serve in HCI modelling: GOMS (KLM-Level) comes to mind. While there is a lot of data to model mouse clicks, keystrokes and similar, touch-related mean data is quite rare at this point. The preVAP results could help to remedy this lack, at least for devices that are comparable in size and technical specifications.

Another impulse for future work originates in the somewhat surprising result and, again, the thinness of scientific publications in the area: The comparison between buttons and swipes is important because it is basic. Building from there, more complex gestures could and should be analyzed and compared with their non-gesture, or maybe not even touch-based counterparts – Motoric data would be an important foundation for these considerations. The upcoming Windows 8 comes to mind as an excellent area of study: It incorporates a hybrid approach: The completely touch and gesture centered UI formerly called Metro as well as a complete embrace of classical WIMP paradigm. Both environments can be used for a lot of very similar (if not the same) tasks, yet use highly different approaches. One might argue that this duality (or clash thereof) represents a certain zeitgeist which most definately warrants scientific consideration. Analyses here could utilize a similar approach as was taken in this thesis (the preliminary study as well as the main study).

4.3 VAP: Main study

We will now discuss the results from the main study, starting with the comparisons between conditions and finishing with those within conditions.

4.3.1 Between conditions

The main study indicated that button navigation is significantly faster than swipe navigation concerning perceptive aspects. Thus, **hypothesis 1** can be accepted. This is consistent to the reasoning from 2.2.1 and 2.2.2: Buttons are a well established concept which makes their affordance readily perceptible while swipe gestures are comparatively new (Nielsen, 2011) which lets people correctly pick up their affordance slower. This should be considered in conjunction with other factors:

For one, there are the error rates: Participants made far more errors on swipe screens than on button screens (69 : 20) and looked at even closer, only 2 of the errors on button screens were tap errors and 18 were attempted swipes (which might have been encouraged by VAPs very mixed navigational modality which of course does not occur in real-life applications). This means that almost every single button press was successful while on the swipe pages, there were 29 attempts to tap something (the background, the display border, ...) and 40 insuccessful swipe attempts. Error rates will be discussed further in 4.4.

The second important factor would be consistency: Looking at the data, it can be observed that button press times seem to fluctuate much more than swipe times which can be seen in the varying standard deviation but becomes more distinct to the naked eye if visualized, see chart 4.2. In this graph, all times from the main study are represented: The button times are blue, the swipe times orange. The y-axis are the times in miliseconds, while the x-axis is two-tiered, to the left (1 – 53) are the *visibility low* conditions, to the right (53 – 106) are the *visibility high* ones. This representation lets us perceive easily the profile of each button and time condition. It is obvious that the button times are much more uniform than those for swipes. To bring in a more qualitative factor: During the study, participants did never indicate any kind of lack regarding understanding during or wished to discuss the button pages after the test while the swipe pages often sparked a raised eyebrow or conversation (which ranged from "Swipes are of course more natural and efficient" to "I don't get all that swiping business". One participant even asked the examiner for help because he could not figure out the swipe, visibilty low condition[1]. These factors indicate a very wide range in ease of perception of the swipe affordance in people.

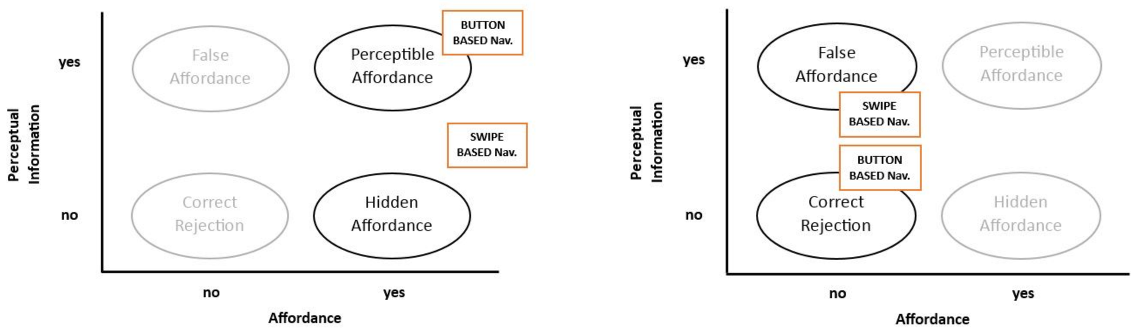
Yet, we have the preliminary study which suggests that swipe gestures are not *inherently* slower than button presses (see 4.2), pointing towards another reason for the difference we found – within our context of affordances, this reason would logically be perception. At this point, we can reference back to Norman's cultural conventions (Norman, 1999) as well as Gaver's multidimensional model including ease of perception (Gaver, 1991). From these basics as well as VAP's data, we might conclude that there is a cultural subgroup which knows how to press a button very well. The subgroup of people who know how to execute a swipe gesture very well is however smaller and less well spread through the population. On Gaver's model we might thus map buttons

[1]This is the highest timestamp in chart 4.2. For the careful observer: This data point has been excluded from the statistical analysis because it would have impacted the data disproportionately. It has however been included in the chart to help visualize the inconsistency in swipe times and also because – even if statistically problematic – data points like this one are relevant for HCI concerns which are not merely statistical.

(regarding only the y-axis and the right half of the figure for now) more towards *Perceptible Affordances* while swipes would be lower, more towards *Hidden Affordances*, see fig. 4.1a. The results regarding **Hypotheses 2a, b and c** further support the consideration of conventions: It was assumed that people who owned or used a touch based device regularly would complete a test screen in VAP faster than people who don't. This, and consequently hypothesis 2a could be confirmed. In a further breakdown, it was assumed that completion times for swipe screen will differ between people who have or use touch based devices regularly and people who don't while completion times for button screen will do so less or not at all. Both hypotheses (2b and 2c) could also be confirmed, again hinting at different cultural groups regarding buttons and swipes.

Future work should track this phenomen over time because presumably, swipe times will get more consistent as touch based devices become more widespread and their set of affordances will get easier to recognize for a broader population. A progression over longer timeframes would not only be interesting but could also be of use in other psychological disciplines, especially learning theories. Regarding this point it also has to be noted that such considerations naturally include more focus on higher cognitive aspects (especially relating to learning) than was necessary for this thesis and its segmented, results-oriented perspective, thus revealing the limits of a perception and affordance based, ecological approach.

Another interesting area, again possibly connected to learning would be ways not only to track performance but also to influence it, i.e. ways to educate and train people in gestures on touch based devices.



(a) Perception **(b)** Rejection

Figure 4.1: Gaver: Different Dimensions.

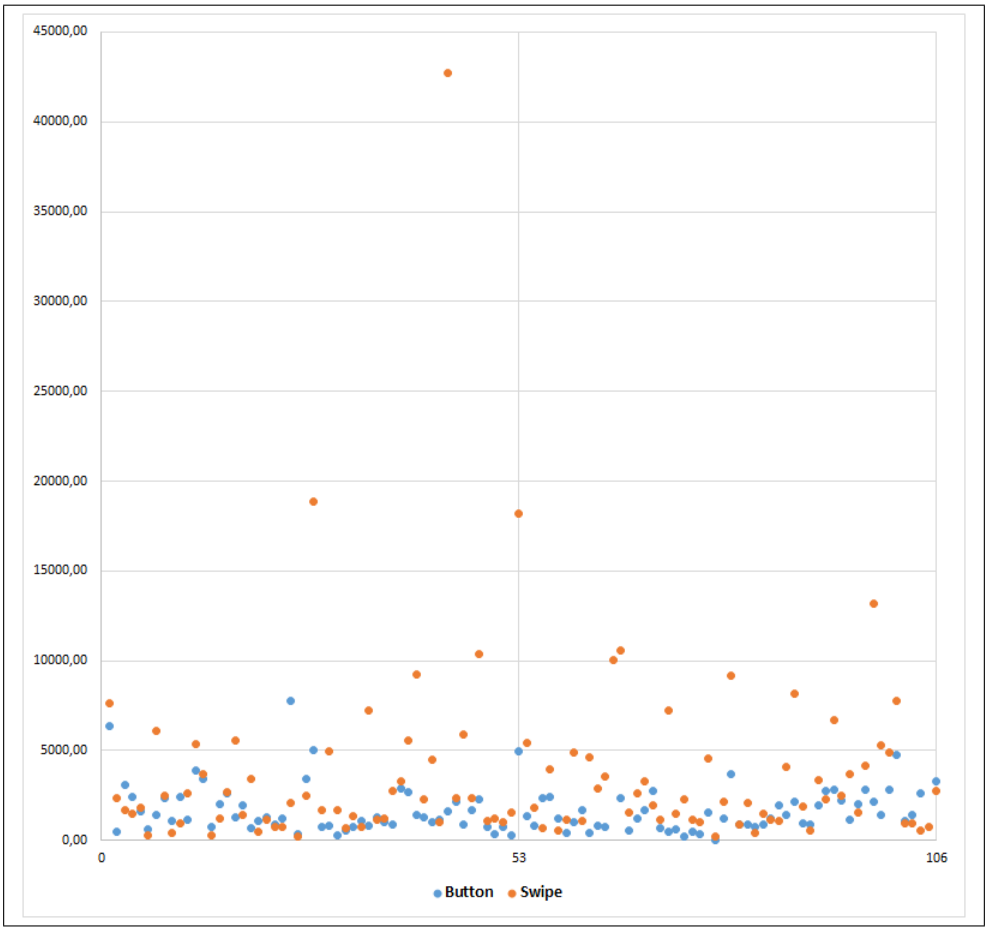


Figure 4.2: Touch times, visualized

4.3.2 Within conditions

Hypotheses 3 and 4 related to comparisons within the button and swipe screens: It was assumed that there would be a difference between completion times regarding the *visibility high* and *visibility low* conditions for buttons and swipes, respectively. The results indicate that this is not the case.

For the button screens, we have to take into consideration the design of VAP's buttons: The visibility low buttons were modelled similar to late Android buttons, i.e. as one solid border-to-border strip at the bottom of the screen where the right half was the forward and the left half the back button. All borders were very thin, the button area had no visual gradients and was the same color as the background. The visibility high buttons were styled classically with more prominent borders, gradient, pseudo-3d and especially: A smaller footprint. Taking Fitt's Law into consideration, it might be possible that the similarities between both conditions are simply due to the fact that the visibility high buttons were smaller than their counterparts. To completely understand the influence of visibility and textured gradients (see 2.1.2), it might be prudent to also study visually restrained buttons which are smaller (like utilized in Windows Phone), i.e. similar in size but not in gradient to classical buttons. For now at least it can be said that Android-like, visually restrained buttons seem to work similarly well as their classical counterparts.

Concerning swipe screens, the similarity between the visibility conditions might be due to the fact that even experienced smartphone-users take and need a moment to read the proffered instructions in the visibility high condition while less experienced users on the other hand might take longer to figure out the visibility low conditions, i.e. the more subtle clues hinting at swipe-ability. This levelling-theory can be backed through VAP's data: There was no significat difference between users who own or use use a touch based device regularly and users who don't regarding completion times in the swipe visibility high condition. Yet in the swipe visibility low condition, there was a significant difference ($T(25.88)=2.73$, $p=<.05$).

For practical application, the apparent similarity between the visibility conditions means that subtle clues seem to be sufficient for a wide spectrum of users which could save screen real estate for developers.

In the future, it might be sensible to study the effect of high and low visible cues in applications where more content is displayed, too. Usually in mobile application, there will be content of some nature displayed on the screen and the more subtle variety of clues hinting at swipe-ability will be displayed below or above this content while bigger clues will be displayed more prominently and thus possibly be easier and faster to pick up. This might influence performance, especially regarding less experienced users. However, since the principle stays the same as in VAP, it might very be that again, there will be a levelling effect.

4.4 Additional measurements

The additional data gathered in VAP and preVAP also yielded HCI related data worthy of further discussion.

Regarding the **anatomy of a swipe,** the average X- and Y-coordinates of the touch data in conjunction with their standard deviations could be used to specify two onscreen zones which should if possible be free of other UI elements (like buttons, text input boxes or similar) since these might confuse users or lead to false inputs. They should be treated as a designated areas primarily for displaying content.

The average swipe legth of 286.63dp is useful to work on thresholds for swipe distances. The default values used in Android (and VAP) as explained in 3.3.1 proved to be robust, a comparison to iOS and Windows Phone is not possible due to the closed nature of these operating systems.

Usually, in a complete application or a framework on the system level, there also needs to be a ΔY-thresold in order to enable the listeners to differentiate between the allowed vertical finger movement within a swipe gestures and the point at which vertical movement of the canvas, i.e. a scroll is called for. This was not necessary in VAP, but the found mean ΔY can be used to do so: On average, participants moved their finger 59.89dp in a vertical direction during a swipe. This, combined with the SD of 43.78 allows for for work on vertical thresholds.

All data relating to the anatomy of a swipe from this study is, however primarily useful for devices which are physically similar to a SGSII. Further work should detail other device form factors, taking into consideration size, display resolution etc. Especially the device size varies hugely between available touch based devices. It should be analyzed if e.g. swipe height, length and ΔY are correlated to these form factors or if they are constant (i.e. determined through physical limitations like finger length or the dominant hand). Similar studies should be carried out regarding button interactions, taking into acount different form factors as well as different operating systems.

Concerning **error rates**, it is noteworthy that there were hardly any insuccessful button presses (only 2 in total). This is again presumably due to the cultural factors already discussed in 4.3.1. However, it has to be said, that there were also 18 attempts to swipe on a button screen. This can be viewed as an indicator that certain persons (possibly tech-savy ones) expect swipe-able interface pages. As a consequence, developers should think about maybe enabling swiping as well in previously only button–based interfaces. This might also encourage exploratory learning in users who previously were not as familiar with gestures as with buttons. In terms of affordance, button-based navigations in touch based devices seem to posess a certain amount of what Gaver would call *False Affordance*, possibly due to the availability of swipe based navigation in other applications which users presumably learn and try even in applications which don't posess this affordance. On swipe screens, 29 attempts to tap were made which means that swipe-based navigation seems to have even bigger potential for false affordance. This is of course consistent to the already much-elaborated presumed cultural difference between buttons and swipes. Fig. 4.1b visualizes these tendencys (again, focussed on the y-axis, this time on the left half of the figure).

40 errors in total were due to insuccessful attempts at executing a swipe gesture. This last aspect, the insuccessful swipes cannot be mapped onto Gaver's model and serve well to show its limitations. It clearly relates to a factor already mentioned in 2.1.5: Ease of use (McGrenere & Ho, 2000; Warren, 1995). An affordance (in this case, swipe-ability) might be existant and perceivable, yet not usable in an easy manner. Regarding swipe gestures, this might be due to questionable finger movement thresholds or even factors not relating to software at all (e.g. the size of the device or even the display coating). Ease of use and especially the theoretical extension of an affordance framework regarding this dimension could represent future research areas.

The last factors which are to follow were not gathered in VAP or preVAP directly but rather observed in the course of the study. The first one concerns the **way people hold**

a device. Most participants seemed to prefer holding a smartphone with the same hand with which they initiated touches on the display by using their thumb but there were also quite a few who held the device in the non-dominant hand and initiated touches with the dominant one, usually with their index finger. A few participants employed a mixed mode. Very few people rested the device on a surface (usually a desk) in front of them and interacted with the index finger of the dominant hand. It would be interesting to see if and how these different strategies impact time-related performance. Additionally, it would be sensible to explore this question regarding different form factors due to the huge variation in size and weight between smaller smartphones and tablets. Studies analyzing this could not only use observation but also easily collect data from device's built-in sensors like the gyroscope.

Furthermore, it was observed that some participants instantly tried to switch VAP's default portrait **orientation** (which can't be changed) to landscape. This happened only at the beginning of the study, i.e. on the first screen, no participant tried to do so later on. It is assumed that this might be due to the fact that VAP's first page displays a rather large amount of text and participants might expect better readability in landscape orientation. It might also be due to general preference/motoric aspects when holding a device. Systematic studies if and when users try to change orientation might help to improve mobile HCI. And, just like in the current study, a lot of additional data could be gathered – angle thresholds for orientation switches come to mind as examples.

4.5 Final Words / A mobile app as a scientific instrument

Through preVAP we did not only get a tool for the main study but also the insight that buttons and swipe gestures don't seem to differ on a motoric level, as well as average button and swipe execution times on a motoric level which might prove useful for HCI modelling. VAP then provided us with a lot of information: Buttons' affordances seem to be picked up faster, more consistently and have smaller error rates than swipe affordances. All in all, buttons proved to be the better established concept, however, we also saw that swipe gestures seem to be established to a certain degree which will be a very interesting trend to follow over time. We also found information about modern, visually restrained buttons which seem to work as well as classical ones. Similarly, regarding swipes, our results indicated that visually restrained clues as to swipe-ability seem to be sufficient and work as well as bigger, more tutorial-like ones. Through sensor data, we found a lot of information regarding swipe lengths, heights and other *anatomic* data usable for the design and implementation of applications as well as more basic frameworks. For future research, we also generated some impulses which developed from and during the testing, especially regarding orientation and the way people hold their devices.

This thesis can, however, also be viewed from a less results-oriented perspective but rather from one regarding its methodology: The deployment of a mobile app in conjunction with the corresponding touch based device in a scientific context. To the author's best knowledge, this has been done sparsely at best – of course apps are used and developed in universities all the time but apps to replace classical ways of conducting studies seem to be very rare. This seems a pity because there is great potential in mobile applications: The possibilities of a veritable myriad of sensor data from location through front and back cameras, barometric sensors up to gyroscopes in one small, well documented package is quite unique at this point in time. While this of course applies closely to HCI-related question, it also has potential for other disciplines. To name just one example: A classical questionnaire will work perfectly fine on a PC and it will in most cases work just as well on a touch based device (in this case, a tablet would be appropriate) but on the latter, it will have the additional benefit of being able to gather potential confounding variables (like sound levels). To achieve this, a standard framework for studies on touch based devices (similar to suites like Soscisurvey or Limesurvey) would be conceivable. Such a suite could also piggyback HCI research questions (anatomic gesture data, orientation, ...) on every study which could benefit multiple scientific disciplines at once. Regarding piggybacking, it would also be possible to attach a set of HCI related questions to other apps and let them gather results. Bigger application developers in the economy would probably be unwilling to cooperate but there are a lot of university-related applications[2] where the developers might be interested in gathering additional data for scientific purposes.

Another distinct advantage of scientific studies on touch based devices is the ubiquity: If the topic of the study allows it, participants can be recruited virtually everywhere which is not only convenient but also reflects Gibson's spirit of *going out there* and carrying out tests directly on users in their natural environment. This ubiquity makes it sensible to keep the study concise and compact (VAP took e.g. under five minutes to complete) which also gets noticed positively by the participants: After completion, comments along the lines of "well, that was quick and painless" were very common and often led to discussions about the novelty as well as the convenience (for the researcher as well as the participant) of this kind of study[3].

All in all, preVAP's and VAP's results as well as the applied methodology speak for themselves and the author strongly believes that touch based devices have a place in science – as research objects and instruments.

[2]As an example: In fact, the IT-department of the University of Duisburg-Essen will release a campus app in a few weeks.

[3]Especially in conversation with other students working on theses or research projects and who, depending on their study design, sometimes had quite a few difficulties recruiting enough participants for their laboratory studies...

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